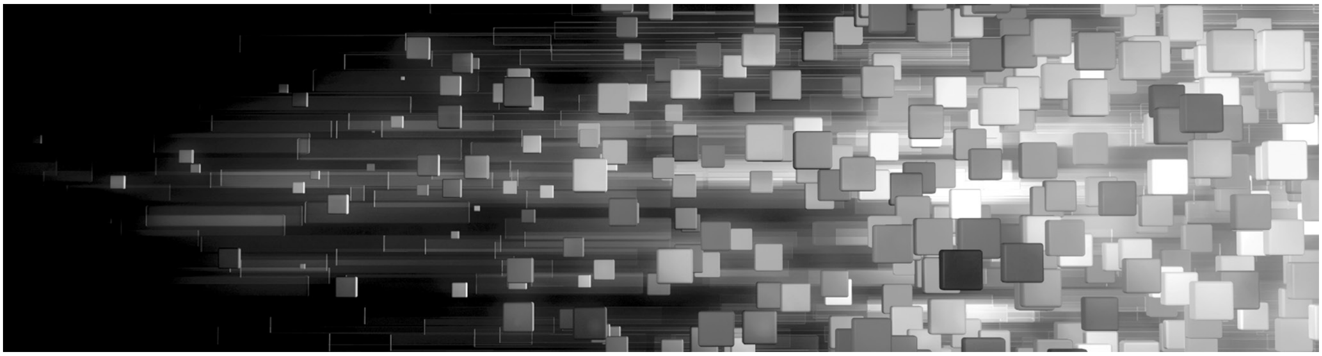
The SAGE Handbook of
Digital Technology Research



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The Historical Context

Paul Ceruzzi

INTRODUCTION

In the spring of 1942, the US National Defense Research Committee convened a meeting of high-level scientists and engineers to consider devices to aim and fire anti-aircraft guns. The German *Blitzkrieg* had made the matter urgent. The committee noticed that the proposed designs fell into two broad categories. One directed anti-aircraft fire by constructing a mechanical or electronic analog of the mathematical equations of fire-control, for example by machining a camshaft whose profile followed an equation of motion. The other solved the equations numerically – as with an ordinary adding machine, only with high-speed electrical pulses instead of mechanical counters. One member of the committee, Bell Telephone Laboratories mathematician George Stibitz, felt that the term 'pulse' was not quite right. He suggested another term, which he felt was more descriptive: 'digital' (Williams 1984: 310). The word referred to the method of counting on one's fingers, or, digits. It has since become the adjective that defines social, economic and political life in the twenty-first century.

It took more than just the coining of a term to create the digital age, but that age does have its origins in secret projects initiated during World War II. But why did those projects have such a far-reaching social impact? The answer has two parts.

The first is that calculating with pulses of electricity was far more than an expeditious way of solving an urgent wartime problem. As the digital technique was further developed, its creators realized that it tapped into fundamental properties of information, which gave the engineers a universal solvent that could dissolve any activity it touched. That property had been hinted at by theoretical mathematicians, going back at least to Alan Turing's mathematical papers of the 1930s; now these engineers saw its embodiment in electronics hardware.

The second part of the answer is that twenty years after the advent of the digital computing age, this universal solvent now dissolved the process of communications.

That began with a network created by the US Defense Department, which in turn unleashed a flood of social change, in which we currently live. Communicating with electricity had a long history going back to the Morse and Wheatstone telegraphs of the nineteenth century (Standage 1998). Although revolutionary, the impact of the telegraph and telephone paled in comparison to the impact of this combination of digital calculation and communication, a century later.

THE COMPUTER

Histories of computing nearly all begin with Charles Babbage, the Englishman who tried, and failed, to build an 'Analytical Engine' in the mid-nineteenth century (Randell 1975). Babbage's design was modern, even if its proposed implementation in gears was not. When we look at it today, however, we make assumptions that need to be challenged. What is a 'computer', and what does its invention have to do with the 'digital age'?

Computing represents a convergence of at least three operations that had already been mechanized. Babbage tried to build a machine that did all three, and the reasons for his failure are still debated (Spicer 2008: 76–77). Calculating is only one of the operations. Mechanical aids to calculation are found in antiquity, when cultures developed aids to counting such as pebbles (Latin calculi), counting boards (from which comes the term 'counter top'), and the abacus. In the seventeenth century, inventors devised ways to add numbers mechanically, in particular to automatically carry a digit from one column to the next. These mechanisms lay dormant until the nineteenth century, when advancing commerce created a demand that commercial manufacturers sought to fill. By 1900 mechanical calculators were marketed in Europe and in the United States, from companies such as Felt, Burroughs, Brunsviga of Germany, and Odhner of Sweden (later Russia).

Besides calculating, computers also store information. The steady increase of capacity in computers, smartphones and laptops, usually described by the shorthand phrase 'Moore's Law', is a major driver of the current social upheaval (Moore's Law will be revisited later). Mechanized storage began in the late nineteenth century, when the American inventor Herman Hollerith developed a method of storing information coded as holes punched into cards. Along with the card itself, Hollerith developed a suite of machines to sort, retrieve, count and perform simple calculations on data punched onto cards. Hollerith founded a company to market his invention, which later became the 'Computing-Tabulating-Recording' Company. In 1924 C-T-R was renamed the International Business Machines Corporation, today's IBM. A competitor, the Powers Accounting Machine Company, was acquired by the Remington Rand Corporation in 1927 and the two rivals dominated business accounting for the next four decades. Punched card technology persisted well into the early electronic computer age.

A third property of computers is the automatic execution of a sequence of operations: whether calculation, storage or routing of information. That was the problem faced by designers of anti-aircraft systems in the midst of World War II: how to get a machine to carry out a sequence of operations quickly and automatically to direct guns to hit fast-moving aircraft. Solving that problem required the use of electronic rather than mechanical components, which introduced a host of new engineering challenges. Prior to the war, the control of machinery had been addressed in a variety of ways. Babbage proposed using punched cards to control his Analytical Engine, an idea he borrowed from the looms invented by the Frenchman Joseph Marie Jacquard (1752–1834), who used cards to control the woven patterns. Whereas Hollerith used cards for storage, Jacquard used cards for control. But for decades, the control function of a Hollerith installation was carried out by *people*: human beings who carried decks of cards from one device to another, setting switches or plugging wires on the devices to perform specific operations, and collecting the results. Jacquard's punched cards were an inside-out version of a device that had been used to control machinery for centuries: a cylinder on which were mounted pegs that tripped levers as it rotated. These had been used in medieval clocks that executed complex movements at the sounding of each hour; they are also found in wind-up toys, and music boxes. Continuous control of many machines, including automobile engines, is effected by cams, which direct the movement of other parts of the machine in a precisely determined way.

COMMUNICATION

Calculation, storage, control: these attributes, when combined and implemented with electronic circuits, make a computer. To them we add one more: communication – the transfer of information by electricity across geographic distances. That attribute was lacking in the early electronic computers built around the time of World War II. It was a mission of the Defense Department's Advanced Research Projects Agency (ARPA), beginning in the 1960s, to reorient the digital computer to be a device for which communication was as important as its other attributes.

Like control, communication was present in early twentieth-century business environments in an ad hoc fashion. People carried decks of punched cards from one machine to another. The telegraph, a nineteenth-century invention, carried information to and from a business. Early adopters of the telegraph were railroads, whose rights-of-way became a natural corridor for the erection of telegraph wires. Railroad operators were proficient at using the Morse code and were proud of their ability to send and receive the dots and dashes accurately and quickly. Their counterparts in early aviation did the same, using the radio or 'wireless' telegraph. Among the many inventions credited to Thomas Edison was a device that printed stock prices on a 'ticker tape', so named because of the sound it made. Around 1914, Edward E. Kleinschmidt combined the keyboard and printing capabilities of a typewriter with the ability to transmit messages over wires (Anon. 1977). In 1928 the company he founded changed its name to the Teletype Corporation. The Teletype had few symbols other than the upper-case letters of the alphabet and the digits 0 through 9, but it provided the communications component to the information processing ensemble. It also entered our culture. Radio newscasters would have a Teletype chattering in the background as they read the news, implying that what they were reading was 'ripped from the wires'. Although it is not certain, legend has it that Jack Kerouac typed the manuscript of his Beat novel *On the Road* on a continuous roll of Teletype paper. Bill Gates and Paul Allen, the founders of Microsoft, marketed their software on rolls of Teletype tape. Among those few extra symbols on a Teletype keyboard was the '@' sign, which in 1972 was adopted as the marker dividing an addressee's e-mail name from the computer system the person was using. Thus to the Teletype we owe the symbol of the Internet age.

The telegraph and Teletype used codes and were precursors to the digital age. By contrast, the telephone, as demonstrated by Alexander Graham Bell in 1876, operated by inducing a continuous variation of current, based on the variations of the sound of a person's voice. In today's terms it was an 'analog' device, as the varying current was analogous to the variations in the sounds of speech. Like 'digital,' the term 'analog' did not come into common use until after World War II. During the first decades of electronic computing, there were debates over the two approaches, but analog devices faded into obscurity.

One could add other antecedents of telecommunications, such as radio, motion pictures, television, hi-fidelity music reproduction, the photocopier, photography, etc. Marshall McLuhan was only the most well-known of many observers who noted the relation of electronic communications to our culture and world-view (McLuhan 1962).

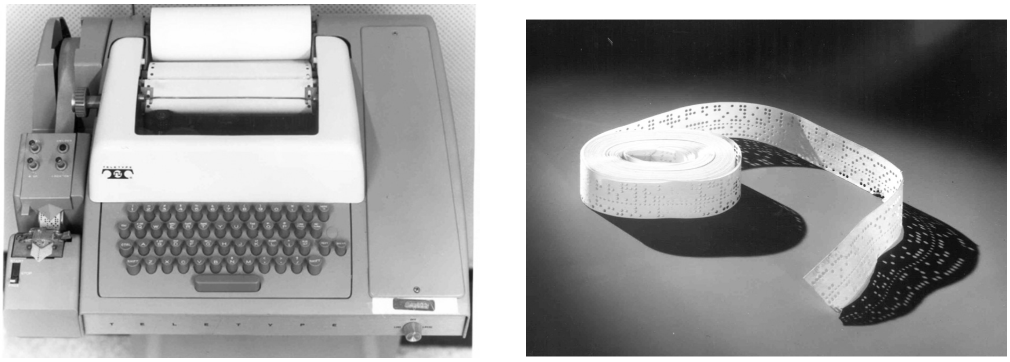


Figure 1.1 (Left) A Teletype Model 'ASR-33', a paper tape reader, which could store coded messages. Ray Tomlinson, a programmer at Bolt Beranek and Newman, says that he chose the '@' sign (Shift-p) to delimit e-mail addresses because it was the only preposition on the keyboard. (Right) Teletype tape containing a version of the BASIC programming language, developed by Bill Gates and Paul Allen, c. 1975 (source: Smithsonian Institution photo).

Others have observed the effects of telecommunications: for example, how the photocopier democratized the process of publishing or how cheap audio cassettes helped revolutionaries overthrow the Shah of Iran in 1979. As mentioned above, nearly all of these antecedents were dissolved and transformed by digital electronics, sadly too late for McLuhan to apply his insights.

DIGITAL ELECTRONIC COMPUTING

Before examining the convergence of communications and computing, we return to the 1930s and 1940s when electronic computing appeared. At the precise moment when the ensemble of data processing and communications equipment was functioning at its peak efficiency, the new paradigm of digital electronics emerged. We have already encountered one reason: a need for higher speeds to process information. That could be achieved by modifying another early twentieth-century invention: the vacuum tube, which had been developed for the radio and telephone. Substituting tubes for mechanical parts introduced a host of new problems, but with 'electronics,' the calculations could approach the speed of light. Solutions emerged simultaneously in several places in the mid-1930s, and continued during World War II at a faster pace, although under a curtain of secrecy that sometimes worked against the advantages of having funds and human resources made available.

The mechanical systems in place by the 1930s were out of balance. In a punched card installation, human beings had to make a plan for the work that was to be done, and then they had to carry out that plan by operating the machines (Heide 2009). For scientists or engineers, a person operating a calculator could perform arithmetic quite rapidly, but she (such persons typically were women) had to carry out one sequence if interim results were positive, another sequence if negative. The plan would have to be specified in detail in advance, and given to her on paper. Punched card machines likewise had stops built into their operation, signalling to the operator to proceed in a different direction depending on the state of the machine. The human beings who worked in some of these places had the job title 'computer': a definition that was still listed first in dictionaries published into the 1970s. This periodic intrusion of human judgment and action was not synchronized with the speeds and efficiencies of the mechanized parts of the systems.

THE DIGITAL CONCEPT

The many attempts to balance these aspects of computing between 1935 and 1950 make for a fascinating narrative. There were false starts. Some were room-sized arrangements of mechanisms that might have come from a Rube Goldberg cartoon. Others were modest experiments that could fit on a table-top. With the pressures of war, many attacked this problem with brute force. The following are a few representative examples.

In 1934, at Columbia University in New York, Wallace Eckert modified IBM equipment to perform calculations related to his astronomical research (Eckert 1940). He used punched cards for control as well as data storage, combining the methods of Jacquard and Hollerith. At the same time, Howard Aiken, a physics instructor at Harvard University, designed a machine that computed sequences directed by a long strip of perforated paper tape (Aiken 1964). Aiken's design came to fruition as the 'Automatic Sequence Controlled Calculator', unveiled at Harvard in 1944, after years of construction and financial support from the US Navy (Harvard University 1946).

Among those who turned towards electronics was J. V. Atanasoff, a professor at Iowa State College in Ames, Iowa, who was investigating ways to mechanize the solving of large systems of linear algebraic equations. These could be solved by a straightforward sequence of operations, or an *algorithm:* a recipe that, if followed, guaranteed a solution. But the solution of a large system required so many steps that it was impractical for human beings to carry them out. Atanasoff conceived of the idea of using vacuum tubes, and of the idea of using the binary system of arithmetic. In 1940, he proposed building such a machine to Iowa State College,which gave him a modest grant. He completed a prototype that worked, erratically, by 1942. That year Atanasoff left Iowa for the Washington DC region, where he was pressed into service working on urgent wartime problems for the US Navy. He never completed his machine.

The US Army supported a project to aid in the aiming accuracy of large artillery, which led to a machine called the ENIAC: 'Electronic Numerical Integrator and Computer', unveiled to the public in 1946 at the University of Pennsylvania. With its 18,000 vacuum tubes, the ENIAC was a huge step beyond anything done elsewhere. It was designed by John Mauchly and J. Presper Eckert (no relation to Wallace Eckert), and it used vacuum tubes for both storage and calculation. It did not appear *de novo*: Mauchly had visited J. V. Atansoff in Iowa for several days in 1941, where he realized that computing with vacuum tubes was feasible. The ENIAC was programmed by plugging the various elements of it in different configurations. Reprogramming it might require days, but once rewired it could calculate an answer in minutes. Historians are reluctant to call the ENIAC a computer, a term reserved for machines that can be more easily programmed, but the 'C' in the acronym stood for 'computer', a term deliberately chosen by Eckert and Mauchly to evoke the rooms of women operating calculating machines.

If the onset of war hindered Atanasoff's attempts to build a high-speed computer, it had the opposite effect in the UK, where at Bletchley Park, outside London, multiple copies of a device called the Colossus were in operation by 1944. Details remained a closely guarded secret into the 1970s. The Colossus was not a calculator but a machine that aided in the unscrambling of German coded messages. Given the dominance of text on the Internet today, one would assume that the Colossus would be heralded more, but secrecy prevented its taking a more prominent place in history. The Colossus employed vacuum tubes, using base-two circuits that had an ability to follow the rules of symbolic logic.

That simple concept, of designing circuits which had only two instead of 10 states as an ordinary calculator had, was the sword that cut the Gordian knot of complexity (Randell 1980). Because of the secrecy surrounding the Colossus, it is difficult to see how it contributed to this profound conceptual breakthrough. Atanasoff's choice of binary also pointed towards this breakthrough, but his project did not proceed to completion. However, two other efforts have been better documented, and a closer look at them may help us understand the significance of what happened.

In 1937 Konrad Zuse was a 27-year-old mechanical engineer working at the Henschel Aircraft Company in Berlin, where he was occupied with tedious calculations. He began work on a mechanical calculator to automate that process. In June of that year he made several remarkable entries in his diary:

> For about a year now I have been considering the concept of a mechanical brain … Discovery that there are elementary operations for which all arithmetic and thought processes can be solved … For every problem to be solved there must be a special purpose brain that solves it as fast as possible … (Zuse 1962: 44)

Zuse chose the binary system of arithmetic because, as a mechanical engineer, he recognized the advantages of switches or levers that could assume one of only two positions. As he began sketching out a design, he came upon an insight that is fundamental to the digital age that has followed. That was to recognize that the operations of calculation, storage, control and transmission of information, until that time traveling on separate avenues of development, were in fact one and the same. In particular the control function, which had not been mechanized as much as the others in 1937, could be reduced to a matter of (binary) arithmetic. That was the basis for his use of the terms 'mechanical brain' or 'thought processes', which must have sounded outrageous at the time. Zuse realized he could design mechanical devices that could be flexibly rearranged to solve a wide variety of problems: some requiring more calculation, others requiring more storage, each requiring varying degrees of control. In short, he conceived of a universal machine. Once he chose to base his design on the binary system, the rest seemed to flow naturally.

Zuse mentioned his discovery to one of his former mathematics professors, only to be told that what he claimed to have discovered had already been worked out by the famous Göttingen mathematician David Hilbert and his students (an earlier version of the concept had been devised by the Englishman George Boole). That was only partially true: Hilbert worked out a relationship between arithmetic and binary logic, but he did not extend that theory to a design of a computing machine (Reid 1970). The previous year, 1936, the Englishman Alan M. Turing (1912–1954) had done that, in a 36-page paper published in the *Proceedings of the London Mathematical Society* (Turing 1936). So while Zuse took the bold step of introducing theoretical mathematics into the design of a calculator, Turing took the opposite but equally bold step, of introducing the concept of a 'machine' into the pages of a theoretical mathematics journal.

Turing described a theoretical machine to address a mathematical problem. While his paper was admired by mathematicians, it was his construction of this 'machine' that placed Turing among the founders of the digital age (Petzold 2008). The term is in quotation marks because Turing built no hardware; he described a hypothetical device in his paper. One cannot simulate a Turing Machine on a modern computer, since a Turing Machine has a memory tape of unbounded capacity. No matter: the machine he described, and the method by which it was instructed to solve a problem, was the first theoretical description of the fundamental quality of a digital computer, namely that a properly constructed computer can be programmed to perform a limitless range of operations – the limitless 'apps' one finds on a modern smartphone. Turing formalized what Zuse, the engineer, had recognized. A computer, when loaded with a suitable program, becomes 'a special purpose brain', which does whatever the programmer wants it to do.

It took about 15 years before engineers could bring the hardware to a point where these theoretical properties could matter.

Before 1950 it was a major accomplishment to get a digital computer to operate without error for even a few hours. Nonetheless, Turing's insight was significant. By the late 1940s there was a vigorous debate among engineers and mathematicians about computer design, after the first machines began working. From those debates emerged a concept, known as the 'stored program principle', which extended Turing's ideas into the design of practical machinery. The concept is credited to the Hungarian mathematician John von Neumann (1903–1957), who worked closely with Eckert and Mauchly at the University of Pennsylvania (Aspray 1990), and whom Turing visited during the war. Modern computers store their instructions and the data on which those instructions operate, and any new data those instructions generate, in the same physical memory device. Computers do so for practical reasons, and for theoretical reasons: the two types of information are treated the same inside the machine because fundamentally they *are* the same.

Turing's abstract machine, after it had been realized in electronics in the 1950s, had uncanny parallels in other disciplines of knowledge. These are metaphorical, but they all seem to point in the same direction. The notion that a computer consisted of discrete components which moved through successive and discrete 'states' as those components processed binary ones and zeros, had its counterpart in Thomas Kuhn's radical view of the history of science, which for Kuhn did not proceed in smooth increments but rather successive finite states, which he called 'paradigms' (Kuhn 1962). Kuhn's idea was enormously influential on the social sciences, to the extent that the term 'paradigm' is almost forbidden as it has lost its explanatory power (the term's connection to computing permits its use in this chapter, however). Likewise the notion of a computer executing fixed programs from a 'Read-Only Memory' (ROM), which alter the contents of Random Access Memory (RAM), has an uncanny similarity to the mechanism of the Double Helix as discovered by Watson and Crick in 1953, in which information is transmitted one-way from a fixed DNA code to RNA (Crick 1970). The notion of high-level computer languages (described later), which are compiled by the computer into low-level sequences of bits that the computer executes, likewise suggests the theories of human language acquisition developed by MIT linguist Noam Chomsky in the post-war years (Chomsky 1957). The notion of coding information – any information, not just numbers – in binary form had unforeseen implications.

FIRE-CONTROL

We now return to fire-control, the topic of the secret meetings of the National Defense Research Committee that George Stibitz attended. The committee's chair was Vannevar Bush, a former professor at MIT, where he built an analog computer called the Differential Analyzer, and where he and his students explored a variety of mechanical and electronic devices. In 1938 Bush proposed building a 'Rapid Arithmetical Machine' that would use vacuum tubes. With his move to Washington in 1939, the priorities shifted. Work on the Rapid Arithmetical Machine continued at MIT, but a working system was never completed. Norbert Wiener, one of Bush's colleagues, analyzed the problem of tracking a target in the presence of noise and against an enemy pilot who is taking evasive action. Wiener's mathematics turned out to have an impact, not only on fire-control but also on the general question of the automatic control of machinery. He coined the term 'cybernetics' and later published a book under that title, which became another influential book of the era. Among the many insights found in that book is a discussion of 'Maxwell's Demon': a thought-experiment that purported to violate the Second Law of Thermodynamics. The 'demon' was a fictitious agent who could transfer heat from a cold to a warm body, a clear violation of the

Law. By introducing the notion of 'information' as a physical, not just an abstract quantity, Wiener showed why no violation of the Second Law could occur, and that 'information' was intimately linked to the physical world (Wiener 1961: 56). Thus Wiener, along with his MIT colleague Claude Shannon, laid the foundation for establishing information theory as a science on an equal basis with thermodynamics or physics.

It was out of this ferment of ideas that the theory of information processing emerged, with an articulation of what it meant to be 'digital'. It was also a time when fundamental questions were raised about the proper role of human beings who interacted with complex control machinery. Modern-day tablet computers or other digital devices do not bear a physical resemblance to the anti-aircraft computers of the 1940s, but questions of the human–machine 'interface', as it is now called, are of paramount importance, and those questions do go back to that era.

At the end of the war Vannevar Bush looked again at the world he helped bring into being. He wrote a provocative article for the *Atlantic Monthly*, 'As we may think', in which he warned that a glut of information would swamp science and learning if not controlled (Bush, 1945). He proposed a machine, the 'Memex,' which would address this issue. His description of Memex, and that article, had a direct link to the developers of the graphical computer interface and of the World Wide Web. Likewise, Norbert Wiener's *Cybernetics* did not articulate the digital world in detail, but the term was adopted in 1982 by the science fiction author William Gibson, who coined the term 'cyberspace' – a world of bits.

COMMERCIALIZATION

The ENIAC was a one-of-a-kind, wartime project. It would hardly be remembered, were it not for Eckert and Mauchly's next step. After completing the ENIAC, they sought to build and sell a version that would have commercial applications. That product, the UNIVAC, was conceived and marketed as suitable for any application one could program it for – hence the name, an acronym of 'Universal Automatic Computer'. Eckert designed it conservatively, making the UNIVAC surprisingly reliable. Eckert and Mauchly founded a company – another harbinger of the volatile Silicon Valley culture that followed – which was absorbed by Remington Rand in 1950. The UNIVAC made it clear that the electronic computer was going to replace the machines of an earlier era. That led to a decision by the IBM Corporation to enter the field with electronic computers of its own. By the mid-1950s IBM and Remington Rand were joined by other vendors, while advanced research on memory devices, circuits and, above all, programming was being carried out in US and British universities.

The process of turning an experimental, one-of-a-kind research project into reliable, marketable and useful products took most of the 1950s and 1960s to play out. Those were the decades of the 'mainframe', so-called because of the large metal frames on which circuits were mounted. IBM dominated the industry in both the United States and western Europe as well. Science fiction and popular culture showed the blinking lights of the control panels, but the true characteristic of the mainframe was the banks of spinning reels of magnetic tape, which stored the data and programs that initially came from punched cards. Because these systems were so expensive, a typical user was not allowed to interact directly with the computer – the decks of cards were compiled into batches that were fed into the machine, so the expensive investment was always kept busy. A distaste for batch operations drove computer enthusiasts in later decades to break away from this, at first through interactive terminals, later through personal computers.

Those decades also saw the arrival of 'software', unforeseen by the 1940s pioneers. Computers were harsh taskmasters, demanding to be programmed in binary arithmetic, but beginning in the 1950s researchers developed computer languages that allowed users to write software in more familiar forms. The most popular were COBOL, for business applications, and FORTRAN, for science. These were followed by a Babel of other languages aimed at more specific applications – a trend that continues to the present day, with modern Web applications programmed in Java, C++, Python, and others, many derived from a language called ‘C’ that was developed at Bell Labs in the 1960s. This was an unforeseen consequence of the stored program principle, although we now see it was implied in Zuse’s insight into the ‘brain’ he sought to build in the 1930s, and in Turing’s concept of a universal machine.

Computing technology advanced through the 1950s and 1960s as the devices became more reliable, and as users learned how to write software. The military played a role as well, adapting mainframe computers for air defense with the ‘SAGE’ system, and supporting very high-performance computers supplied by companies like Cray Research, for classified military research.

Some of the terms introduced at this time give us insight into the digital world that followed. The SAGE system, for example, was designed to operate in ‘real time’: processing data as fast as it was received by radars tracking enemy aircraft. That implies the entity of time, in the digital world, is no longer a proscenium on which the events of the world are played; it is a variable digital engineers can manipulate and control like any other. It also implies that computers may also deal with forms of time that are less than real: a notion once only found among science fiction writers. Also, in the late 1960s IBM introduced a system that had what it called ‘virtual’ memory: data were stored on relatively slow disks, but the user had the illusion that the data were in the faster but smaller core memory. The conservative IBM engineers did not realize it, but they highlighted the computer’s ability to blur any distinctions between real, virtual, or illusory.

Around 1960 the batch method of operations began to change. The transistor, invented in the late 1940s at Bell Laboratories, had a long gestation period, but by 1960 mainframe computers were taking advantage of the transistor’s reliability, small size, and low power consumption. More significant was the ability now to use transistors to develop a new class of small computers, inexpensive enough to be used in laboratories, industrial settings, and other places where mainframes were impractical. The primary supplier of these so-called minicomputers was the Digital Equipment Corporation (DEC), located in the suburbs of Boston. Minicomputers were impractical for home use, but they set in motion a trend that would bring computers into the home by the 1980s.

Descendants of the minicomputer, first introduced around 1960, are now the laptop computers and tablets in use today. The mainframe was still preferred for heavy duty computing, although its batch method of operation was under attack. Only a handful of people noticed when that attack was first mounted. It had the effect, as it played out, of adding that last crucial component to the digital revolution: the convergence of digital *communications* with the functions of information storage, calculation and control that took place two decades earlier. Once again a war, this time the Cold War, played a crucial role.

TELECOMMUNICATIONS, AGAIN

The convergence began in November, 1962 on a chartered train traveling from the Allegheny Mountains of Virginia to Washington, DC. The passengers were returning from a conference on ‘information system sciences’, sponsored by the US Air Force and held at a resort in the Warm Springs Valley. Thomas Jefferson had visited and written about these springs, but the conference attendees had little time to take the healing waters. A month earlier, the United States and Soviet Union had gone to the brink of nuclear war over the Soviet’s placement of missiles in Cuba. Poor communications, between the two superpowers and the White House, the Pentagon, and commanders of ships at sea, escalated the crisis. Among the conference attendees was J.C.R. Licklider, a psychologist who had just taken on a position at the US Defense Department's Advanced Research Projects Agency (ARPA). For Licklider, the conference had been a disappointment. None of the presenters had recognized the potential of computers to revolutionize military or civilian affairs. The long train ride gave him a chance to reflect on this potential, and then to do something about it.

Licklider was able to act because he had access to Defense Department funds and a free rein to spend them on projects as he saw fit. He also had a vision: he saw the computer as a revolutionary device that could be used to work in symbiosis – his favorite term – with human beings. Upon arrival in Washington, the passengers dispersed to their respective homes. Two days later, Professor Robert Fano of MIT proposed a project, based on discussions he had with Licklider on the train ride. That led to 'Project MAC': exploring 'machine-aided cognition', by allowing 'multiple-access' to a computer – a dual meaning of the acronym. Licklider arranged for the US Navy to fund the proposal with an initial contract of around $2.2 million (Licklider 1990).

To overcome the impracticality of allowing someone to use an expensive computer, the resource would be *time-shared*: it would spend a fraction of its time with each multiple user, who would not notice that the resource was being shared (note the interesting concept of time). The closest analogy is a grandmaster chess player playing simultaneous games with less capable players. Each user would have the *illusion* (another word they used deliberately) that he or she had a powerful computer at his or her personal beck and call. Time-sharing gave

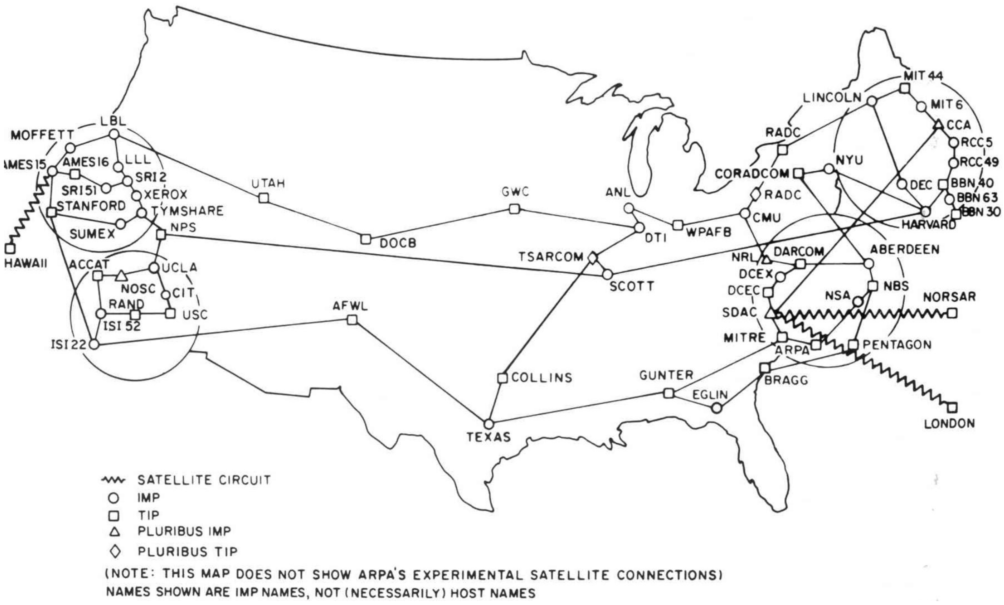


Figure 1.2 ARPANET, ca. 1974. Note the concentration of nodes on the two coasts of the US, with crucial satellite links to London and Norway, the latter for classified Cold War data transfers (source: DARPA).

way to more sophisticated forms of computer networking, but from these efforts came the notion of 'logging on' to a system (borrowed from ship's terminology), and entering a password to gain access (along with the first instances of cracking a password to gain unauthorized access).

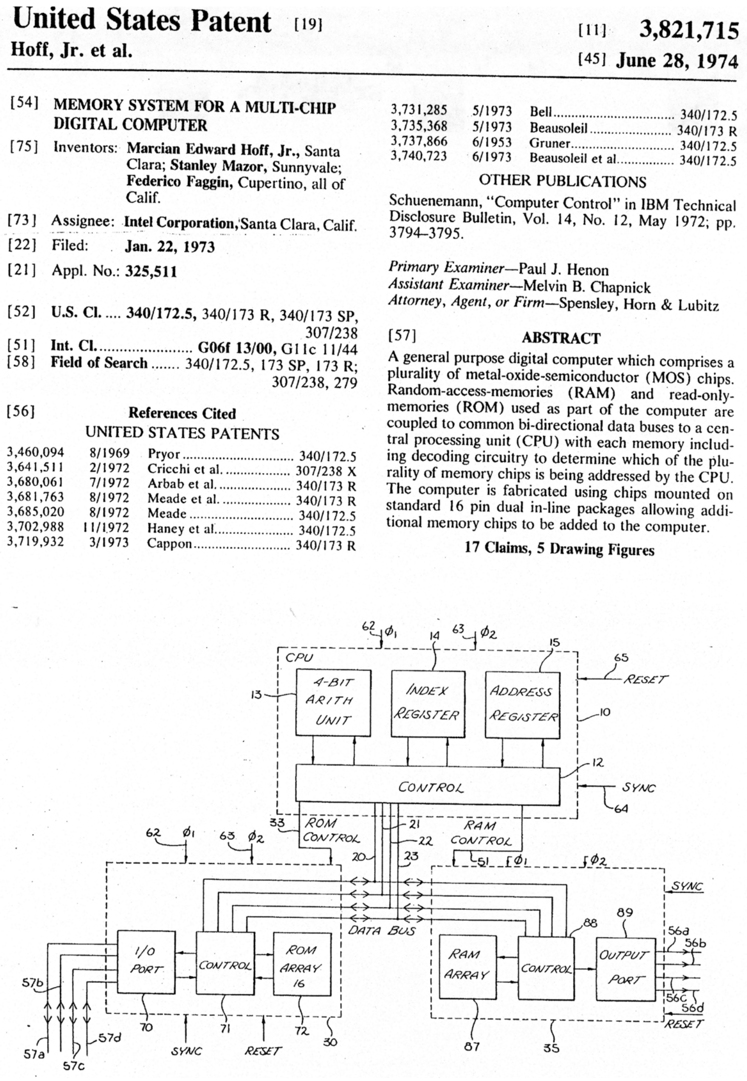
ARPA also began funding other research: to interact with a computer using graphics, and to network geographically scattered computers to one another. Time-sharing was the spark that set those other efforts in motion (Kita 2003). A crucial technical step came when ARPA managers learned of the concept of *packet switching*, conceived independently in the UK and US. The technique divided a data transfer into small chunks, called packets, which were separately addressed and sent to their destination, and which could travel over separate channels if necessary. That concept was contrary to all AT&T had developed over the decades, but it offered many advantages over classical methods of communication, and it is the technical backbone of the Internet to this day. The first computers of the 'ARPANET' were linked in 1969; by 1971 there were 15 computers on the network, and the next year it was demonstrated at a computer science conference. ARPANET was a military-sponsored network that lacked the social, political, and economic components which comprise the modern networked world. It did not even have e-mail at first, although that was added relatively quickly. It did demonstrate the feasibility of packet switching. The rules for addressing and routing packets, which ARPA called *protocols*, remain in use.

PERSONAL COMPUTING

The social component of today's digital world came from another arena: personal computing. This was unexpected and not understood by computer scientists and manufacturers. Personal computing was enormously disruptive, and led to the demise of many established computer companies. It also unleashed a torrent of personal creativity, without which innovations like the ARPANET would never have broken out of its military origins.

The transformation of digital electronics from room-sized ensembles of machinery to hand-held personal devices is a paradox. On the one hand it was the direct result of advances in solid-state electronics. As such it is an illustration of technological determinism: the driving of social change by technology. On the other hand, personal computing was driven by idealistic visions of the 1960s-era counterculture. By that measure, personal computing was the antithesis of technological determinism. Both views are correct. After ten years of transistor development, inventors in Texas and California devised a way of placing multiple transistors and other devices on a single chip of silicon. That led to circuits which could store ever-increasing amounts of data – the storage component of computing described earlier. In 1965 Gordon Moore, working at the California company where the chip was co-invented, noted that the storage capacity of the devices was doubling about every year or so. This became known as 'Moore's Law' – an empirical observation that has persisted into the twenty-first century. Soon after that, Moore co-founded the Intel Corporation, and at about the same time a local journalist christened the region south of San Francisco as 'Silicon Valley'. In 1971, another engineer at Intel, Marcian E. Hoff, led a team that placed all the basic circuits of a computer processor on a chip – another key component of computing – and created what was, next to the airplane, the greatest invention of the twentieth century: the microprocessor.

To the electrical engineers, the microprocessor was trivial: simply by looking at Moore's Law, it was easy to see that by the mid-1970s it would be possible to put on a single chip the same number of circuits that constituted the room-sized UNIVAC of



United States Patent [19]

Hoff, Jr. et al.

[11] **3,821,715**

[45] **June 28, 1974**

[54] **MEMORY SYSTEM FOR A MULTI-CHIP DIGITAL COMPUTER**

[75] Inventors: **Marcian Edward Hoff, Jr.,** Santa Clara; **Stanley Mazor,** Sunnyvale; **Federico Faggin,** Cupertino, all of Calif.

[73] Assignee: **Intel Corporation,** Santa Clara, Calif.

[22] Filed: **Jan. 22, 1973**

[21] Appl. No.: **325,511**

[52] **U.S. Cl.** .... **340/172.5,** 340/173 R, 340/173 SP, 307/238

[51] **Int. Cl.** **G06f 13/00,** G11c 11/44

[58] **Field of Search** .... 340/172.5, 173 SP, 173 R; 307/238, 279

[56] **References Cited**

UNITED STATES PATENTS

3,460,094	8/1969	Pryor	340/172.5
3,641,511	2/1972	Cricchi et al.	307/238 X
3,680,061	7/1972	Arbab et al.	340/173 R
3,681,763	8/1972	Meade et al.	340/173 R
3,685,020	8/1972	Meade	340/172.5
3,702,988	11/1972	Haney et al.	340/172.5
3,719,932	3/1973	Cappon	340/173 R
3,731,285	5/1973	Bell	340/172.5
3,735,368	5/1973	Beausoleil	340/173 R
3,737,866	6/1953	Gruner	340/172.5
3,740,723	6/1973	Beausoleil et al	340/172.5

OTHER PUBLICATIONS

Schuenemann, "Computer Control" in IBM Technical Disclosure Bulletin, Vol. 14, No. 12, May 1972; pp. 3794–3795.

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[57] **ABSTRACT**

A general purpose digital computer which comprises a plurality of metal-oxide-semiconductor (MOS) chips. Random-access-memories (RAM) and read-only-memories (ROM) used as part of the computer are coupled to common bi-directional data buses to a central processing unit (CPU) with each memory including decoding circuitry to determine which of the plurality of memory chips is being addressed by the CPU. The computer is fabricated using chips mounted on standard 16 pin dual in-line packages allowing additional memory chips to be added to the computer.

17 Claims, 5 Drawing Figures

Figure 1.3 Patent for the microprocessor, by Marcian 'Ted' Hoff et al., United States Patent and Trademark Office.

1950. In reality, the invention was anything but trivial. It was the result of careful design and an understanding of the properties of silicon. Intel recognized the power of this invention, but it marketed it to industrial customers and did not imagine that anyone would want to use it to build a computer for personal use. Hobbyists, ham radio operators, and others who were marginally connected to the semiconductor industry thought otherwise. A supplier of circuits for amateur rocket enthusiasts in Albuquerque, New Mexico, was one of the first to design a computer kit around an Intel microprocessor, and when the company, Micro Instrumentation and Telemetry Systems (MITS), announced their 'Altair' kit on the cover of the January 1975 issue of *Popular Electronics*, the floodgates opened.

The resulting flood was unanticipated by the engineers in Silicon Valley; it was a shock to the ARPA-funded researchers in Cambridge as well. In 1975, Project MAC was well underway on the MIT campus, with a multi-faceted approach towards using large computers. Elsewhere in Cambridge, the

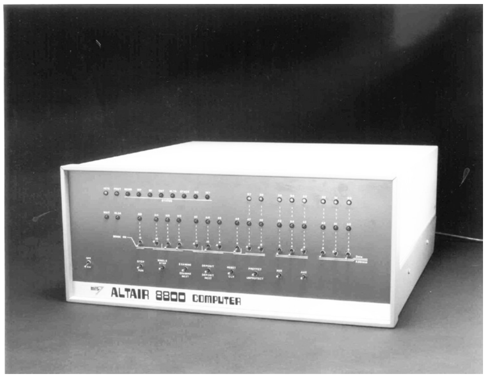

Figure 1.4 The Altair personal computer, the introduction of which on the cover of an issue of *Popular Electronics* in 1975 sparked the personal computer revolution (source: Smithsonian Institution photo).

research firm Bolt Beranek and Newman (BBN) was building the fledgling ARPANET (it was at BBN where the '@' sign was adapted for e-mail). Yet when Paul Allen, a young engineer working at a local electronics company, and Bill Gates, a Harvard undergraduate, saw the *Popular Electronics* article, they both left Cambridge and moved to Albuquerque, to found Microsoft, a company devoted to developing software for the Altair.

The people working on the two coasts at first ignored this phenomenon, but not for long. In Silicon Valley, young computer enthusiasts, many of them children of engineers working at local electronics or defense firms, designed and built personal systems of their own – including the Apple II, built by Steve Jobs and Steve Wozniak in 1977. Among the most fanatical promoters of personal computing were Stewart Brand, editor of the counterculture bible *The Whole Earth Catalog*, who believed that computers would fulfill the broken promise that LSD and other mind-altering drugs was supposed to yield (Turner 2006). The Apple was the best-known, and probably the best-designed, but it was one of literally dozens of competing personal systems, from all over the US and Europe, that used the microprocessor. MITS struggled, but Apple did well, and its financial success alerted those in Silicon Valley that microprocessors were suitable for more than just embedded or industrial uses.

While Bill Gates and Paul Allen saw the potential for personal computing, others in Massachusetts persisted with research on large mainframes, the power of which would be many times greater than anything one could own personally. Researchers at MIT were working on Artificial Intelligence and advanced programming languages, and they reasoned, correctly, that the small systems were ill-suited for those applications. Local companies were making large profits on minicomputers, and they regarded the personal computers as too weak to threaten their product line. Both groups failed to see how quickly the ever-increasing computer power described by Moore's Law, coupled with the enthusiasm and fanaticism of hobbyists, would find a way around the deficiencies of the early personal computers.

The IBM Corporation was also making profits on its line of mainframes. A small group within the company set out to develop a personal computer based around an Intel microprocessor. The IBM Personal Computer was announced in 1981. It did not have much memory capacity, and it was difficult to network, but in part because of the IBM name, it was a runaway success, penetrating the business world. One reason for the success of both the IBM PC and the Apple II was a wide range of software, which enabled owners of these systems to carry out financial calculations that were cumbersome to do on a mainframe using punched cards. These first programs, VisiCalc and Lotus 1-2-3, came from suppliers in Cambridge, Massachusetts; they were followed by software suppliers from all over the US, with Microsoft soon dominating the industry.

XEROX PARC

Apple's success dominated the news about Silicon Valley in the late 1970s, but equally profound innovations were happening quietly at a nearby laboratory set up by the Xerox

Corporation. The Xerox Palo Alto Research Center opened in 1970, when dissent against the US involvement in the war in Vietnam ended the freewheeling funding for computer research at the Defense Department. Xerox was able to hire many of the top scientists funded by ARPA, and from its laboratory there emerged innovations that defined the digital world: the Windows metaphor, the local area network, the laser printer, the seamless integration of graphics and text on a screen. Xerox engineers developed a computer with icons that the user selected with a mouse – a device invented at Stanford University by Douglas Engelbart, who was inspired by Vannevar Bush's 'As We May Think' article. Xerox was unable to translate those innovations into successful products, but an agreement with Apple's Steve Jobs led to the innovations finding their way to consumers via the Apple Macintosh computer, introduced in 1984, followed by software from Microsoft (Smith and Alexander 1988).

The visionary research at the Xerox lab was far removed from the world of hobbyists tinkering with primative personal computers as they existed in the late 1970s. Stewart Brand, editor of the counterculture bible the *Whole Earth Catalog*, stated that '"Telecommunicating" is our founding domain', but for Brand that was a hope more than a reality (Brand 1984: 139). The first personal computers were used for other things: games, spreadsheets and word processing, which were not practical or permissible on mainframes. One could link a personal computer to a local network over one's home telephone, but larger networks were impractical, as the rate structure of the US telephone system made long-distance links expensive. Commercial and hobby services addressed that problem by interconnecting local networks. The most successful was America Online (AOL), which grew out of a system to allow personal computer users to play games with one another. Hobbyists established local 'bulletin boards' on their home or business computers, exchanging messages with other boards late at night, when long-distance telephone rates were lower.

The social forces driving AOL and the bulletin boards were the ancestors of the forces driving Facebook, Twitter, and similar programs in the twenty-first century. As with the invention of the personal computer itself, these forces drove networking from the bottom up, while privileged military and academic agencies drove networking from the top down. The two eventually collided, with unexpected results. The growing awareness of the usefulness of networks placed demands on ARPA that, as a military agency, it was unwilling to meet. It responded by establishing a military-only network for internal use and spinning off the rest to the National Science Foundation (NSF). Around 1987 the NSF gave contracts to commercial suppliers to build a network for research and academic use. The NSF found itself unable to keep to its taxpayer-supported mission of restricting the network solely to research or non-commercial use. The dilemma was solved by a revision to the NSF's enabling legislation, signed in 1992, which relaxed the non-commercial restrictions. Within a few years the 'Internet', as it was now being called, was fully open to commercial use (Aspray and Ceruzzi 2008).

THE WORLD WIDE WEB

For many, the Internet is synonymous with a program that runs on it called the World Wide Web, a program developed in the early 1990s. The convoluted story outlined above explains the confusion: the ARPANET was led by military people who wondered at times whether even personal e-mail messages would be permitted over it. Companies like IBM marketed their own proprietary networks. Hobbyists ran networks from their homes. The Internet subsumed all of those, by virtue of its open protocols, lack of proprietary standards, and ability to interconnect existing networks of various designs. The Web, developed by Tim Berners-Lee and

Robert Cailliau at the European Council for Nuclear Research (CERN) near Geneva in 1990, continued this trend by allowing the sharing of diverse kinds of information seamlessly over the Internet (Berners-Lee 1999). Web software was, and remains, free.

The World Wide Web, overlaid on a commercialized but decentralized Internet, dissolved the tangle of incompatible formats, arcane programming languages and impenetrable jargon that were the hallmarks of digital electronics. It was not perfect: the Web had deficiencies that had to be addressed by a variety of approaches in the 1990s and after.

Berners-Lee introduced a program he called a *browser* to view Web pages, but it was a commercial browser from a company called Netscape that transformed the Web. The Netscape browser, introduced in 1994, integrated graphics and text, and the use of the mouse, which made Web 'surfing' painless. Netscape also developed a method of encrypting data, such as credit card numbers, and a more secure Hypertext Transfer Protocol was also developed. Those enabled commercial services like Amazon and eBay – both launched in 1995 and among the largest presences on the Web. Netscape introduced a way of tracking a person's Web session with a piece of data called a 'cookie', probably named after a character from the television program *Sesame Street*. Netscape's public offering of stock in August 1995 triggered an explosion of interest on Wall Street, with the subsequent bubble and its bursting dominating financial news for the rest of the decade.

Berners-Lee hoped that his software would allow people to post information on the Web as easily as they could access it. However, building Web pages required at least a rudimentary facility with programming, even in the simple HTML language. One response was the creation of an application called a 'Web log', soon shortened to *blog*. These began to appear in the mid-1990s and spread quickly. The breakthrough was that the blogger did not have to compile a program or otherwise drop down to HTML programming. The most successful blogs gained large followings and spanned the spectrum from celebrities, journalists and pundits to ordinary folks who had something to say. With the advent of social networking sites like Facebook, blogs lost some of their appeal, although they remain popular.

Another deficiency of the Web resulted from its most endearing feature: its ability to access information directly, whether it was on one's hard drive or on the other side of the planet. But how to navigate through it? As soon as this problem became evident, a number of indexing schemes appeared, variously called portals or search engines. Unlike private networks, which could charge for their built-in indexing schemes, these had to be supported by advertising, similar to the way commercial radio and television evolved in the United States. Some of them, like Yahoo!, combined human indexing with automated tools. The most successful has been Google, which ranks Web pages based on how often others link to them. Those who examine Google's financial success often point out that the opening screen of a Google search is clean, simple, and uncluttered, in contrast to Yahoo!'s or AOL's busy opening screens. The World War II human factors psychologists would have understood.

THE SMARTPHONE

In discussing the significance of what it means to be 'digital', this chapter has proposed that the digital approach has become a Universal Solvent, dissolving any technology that comes into its path. In the new millennium, this phenomenon once again appeared with a vengeance, as the lowly portable telephone, an analog device invented in the early 1970s, was transformed into a general purpose, mainframe, internetworked computer. It is called a 'smartphone', but making phone calls is the least of its capabilities. Young people prefer to use the device not to make calls, but to 'text': in other words, they use it as a portable Teletype. Smartphones incorporate Web access, satellite navigation using the Global Positioning System, on-board accelerometers descended from the US space program, maps, Yellow Pages, an encyclopedia, dictionaries in multiple languages, movies, playback of recorded music, generation of synthesized music, a radio, television, games, and photography. In other words, 'anything' in the sense that was described by Alan Turing.

Currently the dominant supplier of these phones is Apple, but like its Macintosh computer, Apple derived the basic ideas from elsewhere. Engineers had toyed with the idea for a long time as computers kept getting smaller, and had even introduced miniature versions of laptops, with tiny keyboards and displays. However, the human interface was a bottleneck – how to allow people to use computing power comfortably without a standard keyboard and video screen? In 1996 a Silicon Valley firm called Palm developed an ingenious device that replaced all the functions of paper organizers like the Filofax®, using a touch screen. A model introduced in 2002 by a Palm spin-off, Handspring, integrated a telephone. A few years later, Apple's iPhone carried this attention to human factors even farther, driven by the vision of the company's leader, Steven Jobs.

One could end this narrative with the adoption of these smartphones, recognizing that the digital world has evolved more since 2000 than in all the prior decades. The sudden rise of Facebook and Twitter defies understanding and will require a few years to sort out. The reader who has followed this narrative will see that the social forces behind Facebook are not new; they are only in a more accessible form. Early academic networks, for example, had forums where the topics of discussion ranged from the arcana of programming in the Unix operating system to what they openly categorized as 'sex, drugs, and rock and roll' (Salus 1995: 147). Likewise the chat rooms that fueled the growth of America Online were places where people could freely converse who otherwise had trouble socializing or who were engaged in behavior not sanctioned by their communities.

A glut of books, blogs, movies and television programs have appeared to explain what is happening. These analyses of a networked planet have an uncanny parallel to concepts that appeared at the dawn of this age, before the technologies had matured. Marshall McLuhan's 'global village', is getting a second look (McLuhan 1962). Stewart Brand's *Whole Earth Catalog*, inspired by the writings of Buckminster Fuller, likewise seems prescient (Brand 1980). Students of the Facebook phenomenon might want to take a look at the writings of the Jesuit philosopher Pierre Teilhard de Chardin, whose book *The Phenomenon of Man* (1955) introduced a concept of a 'noosphere' of global consciousness. Many, including the Catholic Church, thought his ideas a little too far-fetched, but perhaps he was only a few years ahead of his time.

The desire to use digital technology for social interaction, at the same time as its use as a weapon by the US military, is not a new story. Nor is the tension between a desire to make money, against a desire to share and promote a digital vision of Utopia. What has happened since the turn of the millennium is that the exponential increase in raw digital power, expressed in shorthand as Moore's Law, enabled and made practical the profound implication of the theories of information and computing first uncovered in the 1930s and 1940s. Unless Moore's Law comes to a sudden end – and there is only slight evidence that it will – the coming decades will only bring more astonishing fruits of the 'Digitization of the World Picture' (Dijksterhuis 1961).

REFERENCES

Aiken, Howard H. ([1937] 1964) 'Proposed automatic calculating machine', *Spectrum IEEE*, 1(8): 62–69.

Anon. (1977) 'Edward Kleinschmidt: Teletype inventor', *Datamation* (September): 272–273.

Aspray, W. (1990) *John von Neumann and the Origins of Modern Computing*. Cambridge, MA: MIT Press.

Aspray, William and Paul Ceruzzi (eds) (2008) *The Internet and American Business*. Cambridge, MA: MIT Press.

Berners-Lee, T. (1999) *Weaving the Web: The Original Design and Ultimate Destiny of the World Wide Web*. San Francisco, CA: HarperCollins.

Brand, S. (1980) *The Next Whole Earth Catalog: Access to Tools*. New York: Random House.

Brand, S. (ed.) (1984) *Whole Earth Software Catalog*. New York: Quantum Press/Doubleday.

Bush, V. (1945) 'As we may think', *The Atlantic Monthly*, 176.

Ceruzzi, P.E. (2003) *A History of Modern Computing* (2nd edn). Cambridge, MA: MIT Press.

Chomsky, N. (1957) *Syntactic Structures*. The Hague: Mouton.

Crick, F. (1970) 'Central dogma of molecular biology', *Nature*, 227 (August 8): 561–563.

Dijksterhuis, E.J. (1961) *The Mechanization of the World Picture*. Oxford: Clarendon Press.

Eckert, Wallace J. (1940) *Punched Card Methods in Scientific Computation*. New York: Thomas J. Watson Astronomical Computing Bureau.

Harvard University (1946) *A Manual of Operation for the Automatic Sequence Controlled Calculator*. Cambridge, MA: Harvard University Computation Laboratory.

Heide, L. (2009) *Punched-Card Systems in the Early Information Explosion, 1880–1945*. Baltimore, MD: Johns Hopkins University Press.

Kita, C. (2003) 'J.C.R. Licklider's vision for the IPTO', *IEEE Annals of the History of Computing*, 25(3): 62–77.

Kuhn, T.S. (1962) *The Structure of Scientific Revolutions* (2nd enlarged edn). Chicago, IL: University of Chicago Press.

Licklider, J.C.R. (1990) *In Memoriam: J.C.R. Licklider, 1915–1990*, Palo Alto, CA: Digital Equipment Corporation, Systems Research Center, Report # 61, August 7.

McLuhan, M. (1962) *The Gutenberg Galaxy: The Making of Typographic Man*. Toronto: University of Toronto Press.

Petzold, C. (2008) *The Annotated Turing*. Indianapolis, IN: Wiley.

Randell, Brian (ed.) (1975) *The Origins of Digital Computers: Selected Papers*. Berlin, Heidelberg, New York: Springer-Verlag.

Randell, B. (1980) 'The Colossus', in N. Metropolis, J. Howlett, and Gian-Carlo Rota (eds) *A History of Computing in the Twentieth Century*. New York: Academic Press.

Reid, C. (1970) *Hilbert*. New York: Springer-Verlag

Salus, P. (1995) *Casting the Net: From ARPANET to INTERNET and Beyond…* Reading, MA: Addison-Wesley.

Smith, Douglas and Robert Alexander (1988) *Fumbling the Future: How Xerox Invented, then Ignored, the First Personal Computer*. New York: William Morrow.

Spicer, Dag (2008) 'Computer History Museum Report', *IEEE Annals of the History of Computing*, 30(3): 76–77.

Standage, Tom (1998) *The Victorian Internet: The Remarkable Story of the Telegraph and the Nineteenth Century's On-Line Pioneers*. New York: Walker & Company.

Teilhard de Chardin, Pierre (1955) *The Phenomenon of Man* (English edition). New York: Harper.

Turing, Alan M. (1936) 'On computable numbers, with an application to the Entscheidungsproblem', *Proceedings of the London Mathematical Society* (2nd Series, vol. 42), 230–265.

Turner, Fred (2006) *From Counterculture to Cyberculture: Steward Brand, the Whole Earth Network, and the Rise of Digital Utopianism*. Chicago, IL: University of Chicago Press.

Wiener, Norbert ([1948] 1961) *Cybernetics: or Control and Communication in the Animal and the Machine*. Cambridge, MA: MIT Press.

Williams, Bernard O. (1984) 'Computing with electricity, 1935–1945'. PhD dissertation, Department of History, University of Kansas, Lawrence, Kansas.

Zuse, Konrad (1962) *Der Computer, Mein Lebenswerk*, Berlin: Springer-Verlag. (Translated into English as *The Computer – My Life* in 1993.)