UIC John Marshall Journal of Information Technology & Privacy Law

Volume 15
Issue 1 *Journal of Computer & Information Law - Fall 1996*

Article 3

Fall 1996

The Invention and Future of the Computer, 15 J. Marshall J. Computer & Info. L. 21 (1996)

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Recommended Citation
Lee Loevinger, The Invention and Future of the Computer, 15 J. Marshall J. Computer & Info. L. 21 (1996)

https://repository.law.uic.edu/jitpl/vol15/iss1/3

THE INVENTION AND FUTURE OF THE COMPUTER

by LEE LOEVINGER†

Like all great inventions, the modern computer is a product of numerous ideas and devices, conceived and developed by many individuals, over a long period of time. However, the combination of elements that is the essence of the modern computer is now known to be the conception of one man.

I. HISTORICAL MODES OF CALCULATING

The earliest known calculating device is the abacus, which probably originated in Babylonia between 4000 and 3000 B.C. during the primitive days of writing. The abacus was originally a board or slab sprinkled with sand or dust on which marks were made to keep track of numbers. Over time this system was modified into a board marked with lines and counters whose positions indicated numerical values, such as ones, tens, hundreds and so forth. This system probably grew out of the primitive habit of counting on fingers.[1] In a Roman version the board was grooved to facilitate moving the counters. This eventually evolved into a frame with counters strung on wires. Through the Middle Ages the abacus was used in Europe, Asia, and the Arab world. This device provided an efficient method of counting, adding and subtracting, but other mathematical calculations required special skills until the introduction of zero as a place holder. The introduction of the Hindu-Arabic notation of zero and of place values greatly facilitated calculation, and, thus, gradually replaced the abacus. However, Europeans continued to use the abacus as

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1. TOBIAS DANTZIG, NUMBER: THE LANGUAGE OF SCIENCE 1-13 (Doubleday, 4th ed. 1956).

late as the seventeenth century; people in the Middle East and Asia still use the device.

Historians traced the modern decimal number system to ancient Egyptian, Babylonian and Sumerian, and Chinese roots. However, major credit for this system belongs to Hindu-Arabic mathematicians between the eighth and the eleventh centuries A.D. "0" was first used as a placeholder number in the eighth or ninth century and appeared sporadically in Egyptian number systems at that time. The modern form of notation began with publication of a work entitled *Liber abaci* by Leonardo of Pisa in A.D. 1202.

Blaise Pascal (1623-1662), a precocious French mathematician who built a mechanical adding machine in 1642, constructed the first digital calculator. This device was essentially a mechanized abacus, able to add and subtract, in which toothed wheels replaced the counters and columns. Gottfried Leibniz (1646-1716), a German philosopher, jurist, and mathematician, who independently invented calculus about the same time as Sir Isaac Newton, constructed a mechanical calculating machine in 1673 that could also multiply, divide, and extract square roots. He gave a generalized treatment of positional number systems and in 1679 he perfected a binary system of numeration. Leibniz advocated this system, suggesting that "1" represented God and "0" a void—that rationale has not been accepted. However, the binary system, which uses only the two symbols of 0 and 1 in differing combinations to represent all numbers, has proved very useful both in providing a notation for expression of the logical forms later developed by George Boole and in permitting an adaptation of this system to electronic processing which utilizes only "on" and "off" states.

Charles Babbage (1791-1871), an English mathematician, constructed a mechanical calculator for mathematical tables around 1813. His machine could perform calculations up to eight decimals, and he designed another calculator capable of a twenty decimal capacity. Babbage drew up plans for an analytical engine that would perform any arithmetical operation, but the engine was never built. The design was forgotten until the discovery of Babbage's unpublished notebooks in the 1930's.

In 1847, George Boole (1815-1864), also an English mathematician, published *Mathematical Analysis of Logic* in which he argued that logic was a matter of mathematics rather than philosophy. In 1854, he expounded this idea further in *The Laws of Thought*, which demonstrated that symbols of quantity can be separated from those of operation. In "Boolean logic," a proposition is either true (1) or false (0) and is represented by the two symbols of binary notation. Propositions thus represented can be combined by conjunctions, disjunctions, and other logical relations. This Boolean algebra is basic to the design of digital computer circuits.

The United States census of 1890 was the occasion of an invention which became the foundation for International Business Machines Corporation (IBM). Herman Hollerith (1860-1919), the founder of IBM, invented punch card machines in 1886. These machines recorded data by punching small holes in cards that were then read by passing them through a device which made electrical contacts through the holes. Punch cards were first used in the 1890 census, and then they were widely adopted in both the United States and Europe. This invention was the basis for the formation and growth of IBM.

In 1937, English mathematician Alan Turing (1912-1954) published *On Computable Numbers*, proving that there are some mathematical problems that cannot be solved by an automatic machine. Turing conceived a *hypothetical* device, now known as the "Turing machine," which is a theoretical computer not limited by any fixed maximum amount of data storage nor susceptible to malfunctioning. The Turing machine performs functions according to an "algorithm," (that is, a well-defined specified sequence of operations) in a series of discrete steps by scanning an infinite tape divided into squares, each of which is blank or on which is printed one of a finite number of symbols. The machine can print, erase, or both, and can move the tape right or left. The output is determined from the symbols remaining after the machine has stopped. This is a mathematically idealized machine because of the machine's unlimited possible input, calculation space, and output. However, it would be impossible to construct such a machine. This concept constitutes what is known as the "Turing test," which is used to determine whether a problem may be solved by a computer through the use of an algorithm. Roger Penrose employed the Turing test in expounding on his thesis that no such thing as "artificial intelligence" exists.[2] Turing's ideas influenced the design of computers constructed in the 1940's and after.

II. CONCEPTION OF THE COMPUTER

In the late 1930's, the basic design of modern computers was conceived by a man whose contribution warrants a detailed account. John V. Atanasoff was born in 1903, the son of well-educated parents. His father was an electrical engineer and his mother a school teacher with a talent for mathematics. When he was nine, his father bought a slide rule, which fascinated the boy. The young Atanasoff worked with the

2. ROGER PENROSE, THE EMPEROR'S NEW MIND: CONCERNING COMPUTERS, MINDS, AND THE LAWS OF PHYSICS 5-11 (Oxford Univ. Press 1989); ROGER PENROSE, SHADOWS OF THE MIND: A SEARCH FOR THE MISSING SCIENCE OF CONSCIOUSNESS 12-16 (Oxford Univ. Press 1994).

slide rule until he understood the mathematical principles on which the rule operated. This led him to the study of logarithms, trigonometric functions, and, finally, a college textbook on algebra. He mastered all of these areas within a few months while still nine years old. At college, Atanasoff studied higher mathematics and electrical engineering; he graduated with a straight "A" average. He received a teaching fellowship at Iowa State, where he earned a master's degree in mathematics. He then enrolled at the University of Wisconsin where he was an instructor in mathematics while completing a Ph.D. in theoretical physics. His doctoral thesis involved extremely complicated mathematical problems which required hours of work on a mechanical calculator.

In 1930, Atanasoff returned to Iowa State as an assistant professor of mathematics and physics. He continued to work on subjects that required more efficient ways of solving complex mathematical problems. He was familiar with the Monroe calculator, a mechanical apparatus that can do addition, subtraction, multiplication, and division, and with IBM tabulators. These devices, together with analog devices, such as the slide rule and the "differential analyzer" (built by Vannevar Bush (1890-1974) at Massachusetts Institute of Technology (MIT)), were the best devices available in the mid-1930's for solving complex mathematical problems.

All of the calculating machines available at that time would have been readily understandable to Pascal, Leibniz, and Babbage. In reality those machines were little more than refined versions of the machines designed and constructed by those pioneering mathematicians. Atanasoff wanted to go beyond anything then known, and, therefore, concentrated on devising a new machine that would solve linear algebraic equations. He assumed that there would be no limit to the tasks this machine could perform.

After months of frustrating intellectual struggle, Atanasoff went for a long, solitary drive one evening, and stopped in a roadhouse for warmth and a bourbon. As he relaxed, his ideas began to flow and he came to several conclusions as to the methods he must adopt to construct this type of machine. The machine would have to be electronic—the mathematical operations would occur by changes in electrical charges rather than mechanical movements, and this would require control of electric charges by thermionic valves (now known as vacuum tubes), which had never previously been used in such an application. Electronics would be much faster than any mechanical processing. Electronics would also permit use of a digital, rather than an analog system. Digital mathematical computation is inherently accurate and precise and would be compatible with the binary on-off nature of electronics. The machine would use condensers (now called capacitors) for storing electric charges for memory with a regenerative (periodic readout and recharging) process to avoid memory losses from energy leakage. The system would compute by direct logical action (which turned out to be Boolean algebra). Atanasoff planned a machine which would solve sets of up to twenty-nine equations with twenty-nine unknowns, with each of thirty coefficients (including constants) having about fifteen decimal places. This was an extremely ambitious plan for 1937, going far beyond any machine then known.

Atanasoff immediately set to work constructing such a machine. He completed the plans for the computer by the end of 1938. In early 1939, he secured a grant to employ an assistant and construct the machine. By October 1939, Atanasoff and his assistant, Clifford Berry, had a small working model, which they referred to as a breadboard prototype. Construction of the full scale machine was well underway by late spring of 1940. Atanasoff and Berry also prepared a thirty-five page description of the theories and construction ideas involved.

III. DISCLOSURE OF THE INVENTION

In December 1940, Atanasoff attended a conference of the American Association for the Advancement of Science, where he heard a lecture by a young physics professor named John W. Mauchly. Mauchly had constructed a "harmonic analyzer" (a type of analog processor) to sift through large amounts of weather data. Atanasoff told Mauchly that he was building a computing machine, which was of great interest to Mauchly.

On January 15, 1941, the *Des Moines Tribune* ran a brief story on the Atanasoff computer. In June, Mauchly came to visit Atanasoff, stayed as a house guest for four days, and examined the computer.

Prior to Mauchly's visit, Atanasoff entered into an agreement with Iowa State college officials to patent the machine. However, in December 1941, the Japanese attacked Pearl Harbor and the United States declared war. The Navy gave Atanasoff a series of jobs in the Naval Ordnance Laboratory, where he remained with brief interruptions until 1952. The college officials abandoned the patent application. Consequently, the Atanasoff invention was never patented, and the design passed into the public domain. After 1952, Atanasoff founded his own engineering company, which he sold to Aerojet General in 1956. He became Vice-President of Aerojet, a position he held until 1961. Thereafter, he served as an executive and scientific consultant to several companies and received over thirty patents on a variety of inventions.

In 1957, he became a member of the Cosmos Club of Washington, D.C., which at the time was an exclusive men's club composed of distinguished scientists and other professionals. The qualifications that were presented to the Admissions Committee were only skills in mathematics and physics—the scientific colleagues sponsoring his admission did not consider his work on computers important enough to mention to the committee.

IV. JUDICIAL DETERMINATION OF PRIORITY

During World War II, Mauchly and J. Presper Eckert developed a computer for the Army which they completed in 1946. They called the computer the Electronic Numerical Integrator and Calculator ("ENIAC"). Although often referred to as the first general purpose electronic computer, the ENIAC was originally designed to calculate artillery firing tables. The ENIAC had to be manually wired to execute each program because the computer had no internal memory. The computer was 15,000 square feet in size, weighed thirty tons, and contained 6,000 switches and 17,468 vacuum tubes. The longest number it could handle contained ten digits. Mauchly and Eckert received patents on the ENIAC which they sold to Sperry Rand. Sperry Rand asserted these patents as a basis for collecting royalties from all firms engaged in producing or marketing any electronic computer.

One of these firms, Minneapolis Honeywell, resisted the royalty demands. In 1967, Honeywell sued Sperry Rand and Sperry Rand filed a countersuit. The Minnesota federal court consolidated the two cases for trial before Judge Earl R. Larson.[3] The actual trial of the case consumed over 135 trial days, running until March, 1972. Seventy-seven witnesses (including Atanasoff and Mauchly) gave testimony, and an additional eighty witnesses were presented through depositions. Honeywell introduced over 25,000 exhibits, and Sperry Rand introduced approximately 7,000. The trial transcript was 20,667 pages long, and the judge issued his 420 page decision on October 19, 1973.

Judge Larson stated in his Findings of Fact that:

> Eckert and Mauchly did not themselves first invent the automatic electronic digital computer, but instead derived that subject matter from one Dr. John Vincent Atanasoff. . . . Between 1937 and 1942, Atanasoff, then a professor of physics and mathematics at Iowa State College, Ames, Iowa, developed and built an automatic electronic digital computer for solving large systems of simultaneous linear algebraic equations. In December, 1939, Atanasoff completed and reduced to practice his basic conception in the form of an operating breadboard model of a computing machine. . . . The breadboard model established the soundness of the basic principles of design. . . .[4]

The judge also found that Mauchly had gone to Ames, Iowa, where

3. Honeywell Inc. v. Sperry Rand Corp. and Illinois Scientific Dev., Inc., 180 U.S.P.Q. 673 (D. Minn. 1974).

4. *Id.* at 694.

he was a house guest of Atanasoff for several days.[5] Atanasoff gave Mauchly a full explanation of the computer, and Mauchly read the manuscript prepared by Atanasoff which gave a comprehensive description of the Atanasoff invention.[6] As a result of these events, the invention claimed in the ENIAC patent was actually derived from the Atanasoff invention.[7] In short, Atanasoff was the inventor of the computer. Based on these and other detailed findings, Judge Larson concluded that the ENIAC patent was invalid and unenforceable.[8] Despite the millions of dollars that Sperry Rand had at stake in the validity of the patent, the company did not appeal the decision.

This decision should have been of widespread interest because the decision concerned one of the major inventions of the twentieth century. Unfortunately, the court issued the decision nine days after the resignation of Vice-President Agnew and one day before the Saturday Night Massacre, when President Nixon fired Archibald Cox, Elliott Richardson, and William Ruckelshouse. Consequently, news of the decision was lost in the tidal wave of news and comment about the Watergate affair. However, the case continued to be of interest to journalists and scholars. In 1984, the American Federation of Information Processing Societies induced Atanasoff to write and publish an account of the process that he used to conceive and construct the computer.[9]

V. PUBLIC RECOGNITION OF THE INVENTOR

In 1988, two books were published which related and analyzed the facts summarized above. One was by Arthur W. Burks and his wife,[10] both of whom are mathematicians and computer scientists. Arthur Burks was also one of the scientists who helped construct the ENIAC, and he was a collaborator with John von Neumann on their seminal paper on computer design.[11] With a thorough technical knowledge of the theory, construction, operation, and history of computers, the Burks wrote, "John Vincent Atanasoff initiated the computer revolution with his invention of the world's first electronic computer."[12]

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5. *Id.* at 695.

6. *Id.*

7. *Honeywell*, 180 U.S.P.Q. at 695.

8. *Id.* at 769.

9. John Vincent Atanasoff, *Advent of Electronic Digital Computing*, ANNALS HIST. COMP. 229 (1984).

10. ALICE R. BURKS & ARTHUR W. BURKS, THE FIRST ELECTRONIC COMPUTER: THE ATANASOFF STORY (Univ. of Mich. Press 1988).

11. *Id.* at 287.

12. *Id.* at 1.

The second book on the subject was by Clark R. Mollenhoff,[13] Washington Bureau Chief for the *Des Moines Register* in 1973, a Pulitzer Prize winning journalist, and a professor of journalism at Washington and Lee University. Using his skills as an experienced reporter, Mollenhoff investigated thoroughly and related in detail the story of Atanasoff's "development of those basic concepts of the automatic electronic digital computer that are present in virtually all modern computers today."[14] Mollenhoff also told of the spurious claims that previously denied Atanasoff credit for inventing and constructing "the world's first electronic digital computer," and the belated recognition of the computer as Atanasoff's invention not only by the court, but also by scientists,[15] and academic institutions.

The University of Wisconsin at Madison conferred an honorary Doctor of Science degree on Atanasoff on May 16, 1987. This honor is representative of numerous similar honors bestowed upon Atanasoff:[16]

> John Vincent Atanasoff . . . had the central insights that led to one of the most momentous inventions of the century, the electronic digital computer. His invention is transforming our world. It accelerates mathematical calculation beyond the dreams of our ancestors; it enhances our collective memory; it functions as a surrogate to human intelligence in applications so numerous that not even a computer can aggregate them all. . . .[17]

Finally, in 1990, President George Bush awarded Atanasoff the National Medal of Technology "for his invention of the electronic digital computer and for contributions toward the development of a technically trained United States workforce."[18]

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13. CLARK R. MOLLENHOFF, ATANASOFF: FORGOTTEN FATHER OF THE COMPUTER (Iowa State Univ. Press 1988).

14. *Id.* at xi.

15. Allan R. Mackintosh, *Afterword* to MOLLENHOFF, *supra* note 13, at 245; Allan R. Mackintosh, *Dr. Atanasoff's Computer: The men who for decades were credited with inventing the first electronic digital computers were not, in fact first. That honor belongs to a once forgotten physicist named John V. Atanasoff*, SCIENTIFIC AMERICAN, Aug. 1988, at 90-96. (Mackintosh was a professor of experimental solid state physics at the University of Copenhagen).

16. Dr. Atanasoff was awarded the Order of Cyril and Methodius, First Class, by the Bulgarian government, and elected a foreign member of the Bulgarian Academy of Sciences. He received honorary degrees from the University of Florida (D. Sci., 1974), Moravian College (D. Sci., 1981), Western Maryland College (Litt. D., 1984), Mount St. Mary's College (Doc. of Humane Letters, 1990). He received the U. S. Navy Distinguished Service Award in 1945, election to the Iowa Inventors Hall of Fame in 1978, Iowa State University Distinguished Achievement Citation in 1983, Computer Pioneer Medal, IEEE (Institute of Electrical and Electronic Engineers) in 1984, the Holley Medal, ASME (American Society of Mechanical Engineers) in 1985, and the Medal of Bulgaria in 1985.

17. MOLLENHOFF, *supra* note 13, at 241.

18. Brit Hume, *Financial Personal Computing*, WASH. POST, Nov. 26, 1990 at F17.

VI. DEVELOPMENT OF COMPUTER TECHNOLOGY

Following construction of the ENIAC, the basic design conceived by Atanasoff was rapidly elaborated into the modern version of the computer. Experts constructed the Electronic Discrete Variable Automatic Computer ("EDVAC") at the University of Pennsylvania on the basis of ideas first outlined in a paper by von Neumann at the Institute for Advanced Study at Princeton. The EDVAC was a computer in which the externally stored programs of the ENIAC were converted into internal instructions. These instructions were treated in the same manner as numerical data and stored in the computer's electronic memory, thus permitting modification of the computer programs. The EDVAC was not completed until 1950, but scientists completed a computer of similar design at Cambridge University in England in 1949.

In 1947, physicists at Bell Laboratories invented transistors. These semiconductor devices, which are used for amplifying, controlling, and generating electrical signals, performed the functions of vacuum tubes. Transistors underwent ten years of development before becoming commercially available, and by the late 1950's were incorporated into computers. As transistors were smaller, more reliable, and consumed less power than vacuum tubes, computers using transistors were smaller, more efficient, faster, and operated at a cooler temperature than their predecessors. Thus began the second generation of computers.

The third-generation of computers arrived in the late 1960's and 1970's when electronic components were further miniaturized due to the development of integrated circuits. These circuits were solid state devices which consisted of hundreds of transistors, diodes, and resistors on a single silicon chip. The fourth generation came in the 1980's when the development of very large scale integration ("VLSI") increased the density of computer chips, so that they contained thousands or hundreds of thousands of transistors per chip. By 1995, a single chip contained more than five million transistors, with the promise of a chip containing ten million transistors in the near future.

In the 1980's, the best computer memory chips could store four megabits, or four million bits of information. In the 1990's, the most advanced chips can store 256 megabits; scientists project that one gigabit, or one billion bits of information, will be the available capacity per chip before the end of this decade.[19] This is enough capacity to store more than ten times the complete works of William Shakespeare.

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19. Paul Blustein, *Billion-Bit Memory Chip Developed by NEC. Storage Capacity Seen as Needed for Next Century Multimedia.*, WASH. POST, Feb. 14, 1995, at C2.

VII. SCOPE OF COMPUTER APPLICATIONS

As a highly sophisticated mathematician, Atanasoff was well aware that his invention of a machine that employed binary mathematical language and Boolean algebraic logic and syntax was capable of varied applications well-beyond the solving of complex mathematical formulas.[20] However, neither Atanasoff nor his contemporaries could have anticipated the developments that resulted in the ubiquitous use and influence of computers in the last decade of this century. In 1945, Vannevar Bush, then science advisor to the President, speculated about "a future device for individual use . . . in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory."[21]

Advances in technology during the second half of the twentieth century transformed computers as much as technology changed aviation from the early airplane of the Wright brothers at Kitty Hawk, to what has been called the "ultimate ubiquity"[22] of jet planes circling the globe. The first use of vacuum tubes for computing occurred in the Atanasoff computer, however, vacuum tubes were superseded by transistors in the 1950's. Atanasoff's computer used capacitors for data storage. 1951 saw the introduction of magnetic tape. In the 1960's, magnetic disks, and later chips, were used in computers for memory. Modern technology has vastly increased the capacity, speed, reliability, flexibility, miniaturization, and convenience of computers, until they have achieved an ultimate ubiquity. Yet computers of the 1990's, and, so far as can be predicted, of the next century, are based on the combination of elements first conceived by Atanasoff—electronic, digital, binary, and Boolean.

In 1995, Nicholas Negroponte, Professor of Media Technology at MIT wrote:

> [C]omputing is not about computers any more. It is about living. . . . We have seen computers move out of giant air-conditioned rooms into closets, then onto desktops, and now into our laps and pockets. But this is not the end. . . . Like a force of nature, the digital age cannot be denied or stopped. . . . The information superhighway may be mostly hype today, but it is an understatement about tomorrow. It will exist beyond people's wildest predictions. . . . We are not waiting on any invention. It is here. It is now. It is almost genetic in its nature, in that each generation will become more digital than the preceding one.[23]

20. The statement regarding Atanasoff's awareness is based on personal discussion with Alice Atanasoff, his widow, and Atanasoff, *supra* note 9, at 258.

21. Vannevar Bush, *As We May Think*, ATLANTIC MONTHLY, July 1945, at 101.

22. AVIATION: THE ULTIMATE UBIQUITY, ENCYCLOPAEDIA BRITANNICA vol. 28, 801 (15th ed. 1993).

23. NICHOLAS NEGROPONTE, BEING DIGITAL 6, 229, 231 (Knopf 1995).

Corroboration is provided by a report stating the microprocessor is the heart of the present American economy and American industry now spends more on computers and related communications equipment than on all other capital equipment combined.[24] World wide penetration of personal computers is occurring faster than the penetration of telephones.[25] The World Wide Web, a part of the Internet computer system, is used by the Associated Press to collect and disseminate news, and the Internet is embraced daily by more media concerns, consumer product companies, and businesses of all types.[26]

VIII. THE ROAD AHEAD—THE COMPUTER FUTURE

The evolution of the computer from a massive, expensive, special purpose contrivance, to the ultimate ubiquity of desk top terminals and pocket calculators, was not solely the result of advancing technology. This evolution was also due in part to the development of general purpose software adaptable to a host of commonplace uses and to the marketing of relatively cheap personal computers (PC's). A principal actor in that process is a young man who was born in 1955, more than a decade after the invention of the computer. Bill Gates was a founder, and remains the chief executive, of Microsoft, which is the dominant software supplier to both computer hardware manufacturers and to individual computer users. He provides his views of the future role of the computer in society in a book appropriately entitled *The Road Ahead*,[27] which quickly climbed onto the best seller lists in the United States.

Gates wrote his first software program when he was thirteen-years-old. At that time, computers were still large, somewhat awkward machines, that were challenging to curious intellectual youngsters since they were uncommon and difficult to operate. The appearance of a microprocessor chip in 1972 stimulated Gates and his partner, Paul Allen, into thinking about the future of computers. They dreamed of the possibility that computers would be built around microprocessors, and of starting a company to write and supply software to such computers—hence the name "Microsoft."

Gates briefly sketches, "the beginning of the information age," mentioning several people who made early calculating devices, including Leibniz and Babbage. He fails to mention that Leibniz was probably the first to develop a binary system of numeration, which he correctly notes is "the alphabet of electronic computers." More significantly, he fails to

24. John Huey, *Waking Up to the New Economy*, FORTUNE, June 27, 1994, at 36.

25. Rich Karlgaard, *Bozo Explosion*, FORBES ASAP, Dec. 4, 1995, at 9.

26. John Markoff, *If the Medium Is the Message, the Message Is the Web*, N.Y. TIMES, Nov. 20, 1995, at 1.

27. BILL GATES, THE ROAD AHEAD (Viking Penguin, New York, 1995).

mention George Boole, whose system of symbolic logic is basic to the design of digital computer circuits. Further, he attributes development of the ENIAC to Mauchly and Eckert without mentioning the judicial determination of Atanasoff as the inventor. However, the compact disk encyclopedia published by Microsoft, *Encarta 95*, does mention Atanasoff, but without specifying details of the case related above.

Computers are unique in an aspect that Gates and other experts usually overlook. In the great panoply of technology in modern society, inventions with popular usage or a direct impact on the general public were conceived and designed primarily for utilitarian purposes. For example, these inventions range from the cotton gin and harvester, to the telegraph, telephone, electric light, airplane, automobile, radio, and television. In contrast, the computer—like the microscope, telescope, and other more exotic instruments—was conceived and designed for the purpose of advancing scientific research. This is significant at least in presenting the history of the computer. The computer's conception and reduction to practice, by Dr. Atanasoff, served as a means to solve complex equations in scientific research. Computer use, for many years, was almost exclusively for such purposes. Today, computer use continues in most areas of scientific research. Indeed, some problems are so complex that investigation is impossible without computers.[28] However, scientific research is not a primary area of Microsoft activity. Rather, Gates and Microsoft have directed their activities to the development of personal computers (PC's), and applications in programs such as word processors, games, spreadsheets, Internet connections, and other popular uses for the mass-market.

Microsoft initially wrote and supplied software for PC's without producing or selling hardware. This approach provided software to all hardware manufacturers on terms so economical that there was no incentive to choose another source. As a result, Microsoft is a major factor in computer development, since computer value depends on the quality and variety of application software available.

IBM was the dominant computer hardware manufacturer in 1980. IBM came to Microsoft to discuss building a personal computer. Microsoft provided a basic software system, which became known as a disk operating system (DOS). Microsoft provided the software system for a low one-time fee, which permitted IBM to use DOS on as many computers as it could sell. Microsoft's profits came from selling software to other companies which made machines compatible with IBM. Originally, IBM sold personal computers with a choice of three operating sys-

28. Donald H. Weingarten, *Quarks by Computer: Yearlong computations have helped to confirm the fundamental theory behind quarks - and, using its principles, even to identify a new particle*, SCIENTIFIC AMERICAN, Feb. 1996, at 116-20.

tems. The Microsoft system was the least expensive and it soon became the standard. This put Microsoft in the business of licensing a software platform for the computer industry. By 1995, Microsoft operating systems were used by more than nine-hundred different manufacturers. Furthermore, since Microsoft does not require others to get permission, prior to developing applications that are compatible with Microsoft systems, there are tens of thousands of commercially available software packages that run with Microsoft based machines . . . including some that are competitive with Microsoft applications.

Gates proclaims that Microsoft has been a leader in the PC era since the first introduction of PC's. This is now a little scary to Gates because there has never been a leader from one era who was also a leader in the next. *The Road Ahead* outlines Gates' vision of the future and his effort to defy history by becoming and remaining a leader in the coming era. Bill Gates' effort will consist of continuing to provide software.

One of the most interesting future possibilities is an appliance termed a "wallet PC." This would be about the same size as a conventional wallet, but would display messages and schedules, receive and send e-mail and faxes, monitor weather and stock reports, take notes, list appointments, contain digital photographs, and store digital cash that could be transferred to a store or other commercial enterprise or to another wallet PC. Such a device would obviously be subject to theft and abuse—the wallet PC would store "keys" to identify the owner in order to protect against these possibilities. These keys might be passwords that change from time to time or biometric measurements such as fingerprints or voiceprints. A wallet PC might also tell the bearer its exact geographical location, or give directions for routing on a real highway.

As a possible supplement to, or substitute for, a wallet PC, there may be computer kiosks located in office buildings, shopping malls, airports, and similar places. Anyone with appropriate identification may stop and secure computer services for any information sought, much as you would be able to use a drinking fountain or pay phone today.

A major part of Gates' vision concerns the so-called "information superhighway," which is not quite the right metaphor. That phrase suggests a linear path, whereas the future network Gates foresees is more comparable to a market where all participants may communicate with all others; deals, communications, flirtations, and all manner of transactions may take place directly between any two individuals or organizations. Today's Internet is not the information highway, although it is the beginning of one.

One of the problems requiring solution in the development of any future information network is devising a method of payment for information and communication. This includes software, which is a particular kind of information.

A technology that will be adopted in the near future is "digital simultaneous voice data" ("DSVD") which makes it possible to transmit both voice and documentary messages over a telephone line. A step beyond this is "integrated services digital network" ("ISDN") which transmits both voice and data, but at a much faster rate than is possible on current telephone lines. This technology has been available for a decade, but has not been installed because there is no demand for it until PC's become more commonplace. As the Internet gradually develops into a broader highway, fiber-optic cable will replace copper wires, due to greater bandwidth or information carrying capacity. Ordinary telephone lines can transmit about 64,000 bits of information per second. The long distance fiber-optic cable now being installed carries 1.7 billion bits of information per second. This is enough bandwidth for 25,000 simultaneous telephone conversations; and even more assuming use of data compression techniques.

Commercial enterprise has been the largest user of computer technology to date, and will surely continue to be a principal user. Gates predicts that in the next five years bandwidths available for communication in urban business areas will increase by a factor of one hundred. The ways that people collaborate and communicate will be less tied to location than at present. Wide use of DSVD and ISDN by businesses will provide more and improved product support services.

Viewing the economic scene more broadly, Gates predicts that the communications revolution will produce "friction-free capitalism." This means that the market will make completely informed decisions, thus ensuring efficient distribution of society's resources. This will occur because the electronic marketplace acts as ultimate go-between—the universal middleman—transmitting information between hosts of sellers and buyers economically and efficiently. Advertising will be written and sent to specific customers according to individual requirements, allowing potential buyers to interrogate a seller concerning details and quality and to bargain over price. In many products, mass customization will replace mass production. Installation of electronic filters that permit reception of only certain types of material in e-mail in-boxes may help reduce the plague of junk mail.

Classrooms, like corporations, will change to meet the flexible opportunities provided by new technological forces. Information may bring mass customization to classroom learning. This does not mean that computers will replace teachers. On the contrary, teachers themselves must learn to utilize the resources of computers and networks. Many people are cynical about the educational system because of that system's failure to produce results. Gates says that part of this cynicism is because many

PC's in schools today lack the capacity to respond fully to students' demands. He predicts that over time computers will be installed in every classroom in the world.

According to the *Statistical Abstract of the United States*, 97.5% of all United States schools now have microprocessors for student instruction, although not all classrooms have computers.[29] However, anecdotal evidence suggests that many teachers cannot fully utilize them, and few or none have the capacity or connections appropriate for a fully established information highway. The President recently announced a plan to put a computer in every public school classroom by the year 2000, which is predicted to cost two billion dollars.[30]

Gates' book is literate, colloquial, and easy to read despite the sometimes technical subject matter. The book contains little jargon, and the technical terms are explained. There is an admirably plain-language explanation of the advantages of binary digital language (pages 23-26). There is also the most lucid explanation I have seen of the inherently complex device of public key encryption (pages 107-11), which is certainly destined to be a matter of continuing concern for the indefinite future.

The Road Ahead presents a broader and more detailed vista of the future than any brief summary or review can depict. The book is significant and worth serious attention because the author is someone who has been as influential in determining the present status of information technology as any other living person. The text is consistently optimistic, to a degree that suggests a somewhat Panglossian view. However, Gates presents the book with an appropriate degree of modesty. In the Foreword, Gates writes that in ten years it may appear that "[w]hat I've said that turned out to be right will be considered obvious and what was wrong will be humorous."[31]

IX. THE SOCIAL IMPACT OF COMPUTERS

This author's hunch is that Bill Gates has overestimated the technical ability of the population. For all the care and skill that has gone into the production of the numerous excellent Microsoft programs, the company is still spending $600 million a year to maintain a staff of some 3,400 technical support personnel who answer questions from baffled

29. U.S. Bureau of the Census, *Statistical Abstract of the United States: 1995* (115th ed.), tbls. 258-259, at 169.

30. Bill McAllister, *Clinton Says Plan to Put Computer in Every Classroom Will Cost $2 Billion*, WASH. POST, Feb. 16, 1996, at A9.

31. GATES, *supra* note 27, at xiii.

users of company software virtually all day and night.[32] If the future of information technology really is much like that now envisioned by Gates—and I do not doubt that it may be—then the idea occurs to me that there are just two possible results. One possibility is that society will divide into a class of sophisticated technological aristocrats, who are able to cope with and afford all the complexities of advanced networks and mechanisms, and a much larger class of plebeians who still have trouble programming their VCRs.

The alternative possibility is that computers, or devices attached to networks to deliver information carried by broadband optical cables, will be constructed and programmed to operate by push-buttons, like today's television sets. Technically unsophisticated people do operate highly complex mechanisms, such as today's automobiles, radios, and television sets, without having any notion of the technology involved. On the other hand, there are many mechanism, like airplanes, which are no more complex but which cannot be operated by the ordinary person. Before World War II, some futurologists predicted that after the war helicopters would be common and few would find need for automobiles, as travel by air would be so common. I am assailed by the suspicion that Gates' predictions may be based upon a similar false optimism.

A more pessimistic view comes from academe. Eli Noam, Director of the Institute for Tele-Information at Columbia University, expressed concern that although the effect may be more subtle than the impact on industry, new communications technologies born of computers are likely to weaken the traditional institutions of higher learning, such as universities.[33] The fundamental reason is that computer networks as tools of inquiry are undermining the traditional flow of information. From the beginning of writing, as a means of recording information, to the present time, information has been stored in libraries, which have usually been housed under the institutional roof of a university. Scholars have come to the universities where they were instructed by professors. In recent years, the body of knowledge, especially in science and technical subjects, has grown exponentially and, correspondingly, the areas of expertise have necessarily evolved into constantly narrowing fields. However, as the information-induced pressures of specialization have increased, so have the means of communicating and disseminating information. People no longer have to go to a university either to consult a body of recorded knowledge in some specialized field or to learn the views of an eminent authority on a specific question. Electronic computer networks

32. Steve Lohr, *When Pointing and Clicking Fails to Click: More and More Questions, and Employees, at Computer Help Services*, N.Y. TIMES, Jan. 1, 1996, at 45.

33. Eli M. Noam, *Electronics and the Dim Future of the University*, 270 SCIENCE 247 (1995).

are beginning to create new scholarly communities which, in contemporary jargon, may be regarded as "virtual universities." As Noam puts it:

> The threats to universities may not appear overnight, but they will surely arrive. . . . Yet the fundamental forces at work cannot be ignored. They are the consequence of a reversal in the historic direction of information flow. In the past, people came to the information, which was stored at the university. In the future, the information will come to the people, wherever they are.[34]

There can be no confidence in predicting the ultimate impact of computers on higher education. Those who recall the touted advent of "educational television" (a term largely abandoned) are entitled to be skeptical about the prospect of any technology increasing the popular availability and dissemination of knowledge. Nevertheless, some significant cultural change is certainly occurring. As early as 1983, the late Ithiel de Sola Pool, an MIT professor of political science and an authority on the social impact of computers, proclaimed that electronic and digital technology are causing deregulation of communications facilities and that those are the "technologies of freedom."[35] As recently as 1995, the Rand Corporation, a think tank concerned with futurology, issued a report similarly concluding that universal access to Internet e-mail will foster the growth of democracy.[36]

The prolific prophets of futurism, Alvin and Heidi Toffler, declare that the first great wave of social change was the Agricultural Revolution.[37] The second wave was the Industrial Revolution. The Third Wave is the Information Revolution, which we are now encountering. The first wave was symbolized by the hoe; the second by the assembly line; and the third by the computer. "[D]igital networks are the heart of the Third Wave infrastructure."[38] The full effects of this will not be manifest until the twenty-first century, but we can foresee some of these effects now. Vice-President Al Gore said that he and Speaker Newt Gingrich believe that digital telecommunications and related technology will have an impact on the world "to the same extent that accompanied the invention of writing."[39]

Although the "invention of writing" does not seem altogether comparable, there is an historical analogy. In the fifteenth-century, Johannes Gutenberg invented movable type for printing which revolutionized pop-

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34. *Id.* at 249.

35. ITHIEL DE SOLA POOL, TECHNOLOGIES OF FREEDOM 3-6 (Harv. Univ. Press 1983).

36. Denis Caruso, *Digital Commerce: The Rand Corporation Salutes E-mail as the New Foundation of Democracy*, N.Y. TIMES, Dec. 4, 1995, at D5.

37. ALVIN TOFFLER & HEIDI TOFFLER, CREATING A NEW CIVILIZATION: THE POLITICS OF THE THIRD WAVE 19 (Turner Publ. 1995).

38. *Id.* at 74.

39. Gene Koprowski, *Interview: Al Gore*, FORBES ASAP, Dec. 4, 1995, at 134.

ular communication, education, and culture, and has been the foundation of our civilization since then. The Tofflers boldly assert that the computer and its digital language will create "a new civilization." That claim may be hyperbole. However, digital electronic technology is now becoming a universal medium of information recording, retrieving, reasoning, learning, and communicating. As the culture of the last half-millennium has been based on the fifteenth-century invention of Gutenberg, the culture of the twenty-first century will surely be based upon the twentieth century invention of John Atanasoff.