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book club synopsis

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The Innovators: How a Group of Hackers, Geniuses and Geeks Created the Digital Revolution

Walter Isaacson

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As the pace of the business world moves ever faster, innovation is more than just a buzzword: It is an absolute necessity in order for companies to continually perform. In *The Innovators,* Walter Isaacson looks to the past to examine the qualities and circumstances of the visionaries who shaped the world over the past 200 years. The insights he finds—that collaboration was key and ego often an undoing, among them—reveal a path forward for the business leaders of today.

About the author

Walter Isaacson is the award-winning author of books such as *Steve Jobs, The Wise Men: Six Friends and the World They Made, Einstein: His Life and Universe* and *Kissinger: The Biography.* He has numerous notable accomplishments in media, including serving as editor for *Time* magazine and as chairman and CEO of CNN. Isaacson is currently the CEO and president of the Aspen Institute and serves on the board of directors of United Airlines and the board of overseers of Harvard University.

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timeline:

the digital revolution: by the years

In reading this summary of Isaacson's work, use this timeline as a compass to navigate through history. It details the innovations of the past century and a half and highlights the people whose contributions were key to the digital age.

1843 Ada, Countess of Lovelace, publishes "Notes" on Babbage's Analytical Engine.

1935 Tommy Flowers pioneers use of vacuum tubes as on-off switches in circuits.

1937 Alan Turing publishes "On Computable Numbers," describing a universal computer.

1937 Claude Shannon describes how circuits of switches can perform tasks of Boolean algebra.

1937 Howard Aiken proposes construction of large digital computer and discovers parts of Babbage's Difference Engine at Harvard.

1937 John Vincent Atanasoff puts together concepts for an electronic computer during a long December night's drive.

1941 Konrad Zuse completes Z3, a fully functional electromechanical programmable digital computer.

1941 John Mauchly visits Atanasoff in Iowa, sees computer demonstrated.

1944 Harvard Mark I goes into operation.

1944 John von Neumann goes to Penn to work on ENIAC.

1945 Six women programmers of ENIAC are sent to Aberdeen for training.

1945 Vannevar Bush publishes "As We May Think," describing personal computer.

1947 Transistor invented at Bell Labs.

1952 Grace Hopper develops first computer compiler.

1954 Texas Instruments introduces silicon transistor and helps launch Regency radio.

1956 Shockley Semiconductor founded.

1957 Robert Noyce, Gordon Moore and others form Fairchild Semiconductor.

1958 Advanced Research Projects Agency (ARPA) announced.

1958 Jack Kilby demonstrates integrated circuit, or microchip.

1959 Noyce and Fairchild colleagues independently invent microchip.

1960 Paul Baran at RAND devises packet switching.

1961 President Kennedy proposes sending man to the moon.

1962 MIT hackers create Spacewar game.

1963 Engelbart and Bill English invent the mouse.

1965 Ted Nelson publishes first article about "hypertext."

1965 Moore's Law predicts microchips will double in power each year or so.

1966 Bob Taylor convinces ARPA chief Charles Herzfeld to fund ARPANET.

1968 Noyce and Moore form Intel, hire Andy Grove.

1968 Stewart Brand publishes first *Whole Earth Catalog*.

1969 First nodes of ARPANET installed.

1971 Intel 4004 microprocessor unveiled.

1971 Ray Tomlinson invents email.

1972 Nolan Bushnell creates Pong at Atari with Al Alcorn.

1973 Alan Kay helps to create the Alto at Xerox PARC.

1973 Community Memory shared terminal is set up at Leopold's Records, Berkeley.

1973 Vint Cerf and Bob Kahn complete TCP/IP protocols for the Internet.

1975 Altair personal computer from MITS appears.

1975 Paul Allen and Bill Gates write BASIC for Altair, form Microsoft.

1975 First meeting of Homebrew Computer Club.

1975 Steve Jobs and Steve Wozniak launch the Apple I.

1980 IBM commissions Microsoft to develop an operating system for PC.

1983 Microsoft announces Windows.

1983 Richard Stallman begins developing GNU, a free operating system.

1984 Apple introduces Macintosh.

1991 Linus Torvalds releases first version of Linux kernel.

1991 Tim Berners-Lee announces World Wide Web.

1993 Steve Case's AOL offers direct access to the Internet.

1994 Justin Hall launches Web log and directory.

1995 Ward Cunningham's Wiki Wiki Web goes online.

1997 IBM's Deep Blue beats Garry Kasparov in chess.

1998 Larry Page and Sergey Brin launch Google.

1999 Ev Williams launches Blogger.

2001 Jimmy Wales, with Larry Sanger, launches Wikipedia.

2011 IBM's computer Watson wins *Jeopardy!*

Introduction: How this book came to be

Walter Isaacson opens *The Innovators: How a Group of Hackers, Geniuses and Geeks Created the Digital Revolution* by stating, "The computer and the Internet are among the most important inventions of our era, but few people know who created them." While names like Thomas Edison, Alexander Graham Bell and Samuel Morse are familiar, those of digital-age innovators are not. Writes Isaacson: "Most of the innovations of the digital age were done collaboratively. … This is the story of these pioneers, hackers, inventors and entrepreneurs—who they were, how their minds worked and what made them so creative. It's also a narrative of how they collaborated and why their ability to work as teams made them even more creative."

Innovation as more than a buzzword: How does innovation happen in the real world? Isaacson explores this idea by answering several questions:

- How did the most imaginative innovators of our time turn disruptive ideas into realities?
- What can the key breakthroughs of the digital age—and the people who enabled them—teach us?
- What ingredients produced people's creative leaps?
- What skills proved most useful?
- How did the individuals who are profiled lead and collaborate?
- Why did some people succeed and others fail?

The digital revolution: The world we live in—where any individual can create, disseminate and access information anywhere—resulted from the combination of the computer and distributed networks. From the 21st century perspective, the Internet and the PC are intertwined, but that was not always the case. The Internet was originally developed to facilitate collaboration while personal computers focused on developing individual creativity. Networks and personal computers initially developed separately; the linking of the two did not begin until the late 1980s with the development of modems, online services and the Web.

Collaborative creativity: Too often we focus on the lone inventor and the question "who invented this?" That focus takes away from the tale of teamwork, which Isaacson says, "is actually more important in understanding how today's technology revolution was fashioned. … The protocols of the Internet were devised by peer collaboration, and the resulting system seemed to have embedded in its genetic code a propensity to facilitate such collaboration."

- People were able to create and share content because of the system of open networks, which was connected to computers controlled by individuals. That resulted in individuals controlling distribution of information rather than with gatekeepers, central authorities and institutions.
- Users repeatedly commandeered digital innovations to create communications and social networking tools.
- Attempts at Artificial Intelligence, where machines do all the thinking, have not brought about the changes that some anticipated. Instead Augmented Intelligence, with machines and people forming a partnership, appears promising.

The many guises of innovation: The key innovations of the digital age came in many forms, including:

- Physical devices, such as the computer and transistor and related processes, including programming, software and networking
- The development of new services, such as venture capital
- The creation of organizational structures for research and development, such as Bell Labs
- The invention of a corporate culture and management—the Intel Way—that was the antithesis of East Coast companies' hierarchical structure.

Connecting the arts and the sciences: "The truest creativity of the digital age came from those who were able to connect the arts and sciences," writes Isaacson. "'I always thought of myself as a humanities person as a kid, but I liked electronics,' Jobs told me when I embarked on his biography. 'Then I read something that one of my heroes, Edwin Land of Polaroid, said about the importance of people who could stand at the intersection of humanities and sciences, and I decided that's what I wanted to do.'"

"The people who were comfortable at this humanities-technology intersection helped to create the human-machine symbiosis that is at the core of this story," Isaacson emphasizes.

chapter one:

ada, countess of lovelace

The only legitimate child of the poet Lord Byron, Ada Lovelace inherited her father's romantic spirit, but was raised by her mother, who separated from the poet when Lovelace was just five weeks old (she never saw him again). Her mother tried to temper her romantic spirit by having her tutored in mathematics; Lovelace referred to that combination as her calling to "poetical science." Her love of poetry and math, says Isaacson, "primed her to see beauty in a computing machine."

Looking backwards Isaacson believes that "the advances of the Industrial Revolution … transformed the nineteenth century in much of the same way that the advances of the Digital Revolution … have transformed our own. At the heart of both eras were innovators who combined imagination and passion with wondrous technology, a mix that produced Ada's poetical science and what the 20th century poet Richard Brautigan would call 'machines of loving grace.'"

A short biography: In her schooling, Lovelace was tutored extensively in mathematics and had a strong interest in technology. At age 17, she met the science and math eminence Charles Babbage when he demonstrated a model portion of his Difference Engine at a weekly salon. The mechanical contraption, which could calculate a sequence of numbers and showed how the pattern could suddenly change based on his coded instructions drove Lovelace further into mathematics. She later befriended Mary Somerville, one of Britain's few noted female mathematicians and scientists, who served as her mentor and encouraged her interest in applied science.

“Ada’s ability to appreciate the beauty of mathematics is a gift that eludes many people,” writes Isaacson. “She realized that math was a lovely language, one that describes the harmonies of the universe and can be poetic at times.”

Charles Babbage and his engines: A mathematician, philosopher, inventor and mechanical engineer, Babbage sought ways to mechanize mathematical calculations by breaking them down into steps. Following his invention of the Difference Engine, Babbage began working on the Analytical Engine—a general-purpose computer able to carry out a variety of different operations based on programming instructions given to it. This machine could perform a task, then switch to another, and even instruct itself to switch tasks. In imagining this machine, he drew upon Joseph-Marie Jacquard’s automated loom, which used cards with holes punched in them to control the process of creating complicated patterns such as brocade. The British government had no interest in funding Babbage’s machine, but Lovelace appreciated the concept and saw that its potential might include not just numbers but any symbolic notations, including musical and artistic ones.

Lady Lovelace’s notes: Babbage presented his ideas to a group of Italian scientists in 1842. Notes from the presentation were circulated and translated by Lovelace. In addition, she created a section called “Notes by the Translator,” which ended up twice the length of the original. Writes Isaacson, “her ‘Notes’ became more famous than the article and were destined to make her an iconic figure in the history of computing.” In the notes, Lovelace envisioned the modern computer—a general-purpose machine rather than one that performed a specific arithmetic task. The point emerged that the machine was not limited to math and numbers. It could store, manipulate, process and act upon anything that could be expressed in symbols, including words and music. This insight, writes Isaacson, “would become the core concept of the digital age: any piece of content, data or information—music, text, pictures, numbers, symbols, sounds, video—could be expressed in digital form and manipulated by machines.”

The first programmer: Lovelace figured out in step-by-step details the working of what is now called a computer program or algorithm and showed exactly how the algorithm would be fed into the computer: a numbered list of coding instructions. "It was mainly on the basis of this … that Ada has been accorded by her fans the accolade of 'the world's first computer programmer,'" writes Isaacson.

Can machines think? She also contemplated whether machines could think and believed the answer was no: "The Analytical Engine has no pretensions whatever to originate anything," she wrote. "'It can do whatever we know how to order it to perform. It can follow analysis; but it has no power of anticipating any analytical relations or truths." *Scientific Memory* published Lovelace's translation and "Notes" in September 1843; however, Babbage's machines were never funded nor built.

Isaacson believes that Lovelace's contribution was both "profound" and "inspirational" since she was "able to glimpse a future in which machines would become partners of the human imagination, weaving tapestries as beautiful as those from Jacquard's loom. Her appreciation for poetical science led her to celebrate a proposed calculating machine that was dismissed by the scientific establishment of her day, and she perceived how the processing power of such a device could be used on any form of information. Thus did Ada, Countess of Lovelace, help sow the seeds for a digital age that would blossom 100 years later.

chapter two:

the computer

Charles Babbage's paper envisioning a sophisticated computer appeared in 1837, but it was 100 years later that the technological advances needed to build one were achieved. There were incremental steps along the way: for example, at the U.S. Census Bureau, Herman Hollerith automated the tabulation of the 1890 census by creating a mechanized tabulator, using electrical circuits to process information and punch cards. With this invention the census data was available a year after its collection in contrast to the eight years previously required. Hollerith founded what would later become the International Business Machines Corporation (IBM).

Innovation, when viewed through this lens, is thus seen as the accumulation of hundreds of small advances, such as counters and punch-card readers. In Isaacson's view of history, however, this incremental approach is not sufficient. "The birth of the computer age required some larger imaginative leaps from creative visionaries," writes Isaacson.

The modern computing era: By 1937 "new approaches, technologies, and theories began to emerge," writes Isaacson. "The result would be the triumph of four properties, somewhat interrelated, that would define modern computing."

- **Digital:** The computer revolution would be based on digital, not analog, computers.
- **Binary:** The digital system that modern computers adopted would be binary, using just 0's and 1's, rather than all 10 digits of the decimal system.

- **Electronic:** The British engineer Tommy Flowers pioneered the use of vacuum tubes as on-off switches in electronic switches in the mid-1930s. "By using electronic components such as vacuum tubes and later transistors and microchips, computers could operate thousands of times faster than machines that had moving electromechanical switches," says Isaacson.
- **General purpose:** Machines would ultimately have the ability to be programmed, reprogrammed and even program themselves for a variety of purposes.

Alan Turing: A 24-year-old British mathematician Alan Turing published an essay in 1937 proposing the concept of a Logical Computing Machine, which could "be used to compute any computable sequence." While the essay attracted little attention at the time, his Logical Computing Machine came to be referred to as the Turing Machine and his name, says Isaacson, "became indelibly stamped on one of the most important concepts of the digital age."

Collaboration at Bell Labs: AT&T ran a research facility that served as a haven for turning ideas into inventions. At this facility, theorists mixed with hands-on engineers, mechanics and other problem solvers. Notes Isaacson: "This made Bell Labs an archetype of one of the most important underpinnings of digital-age innovation—what the Harvard science historian Peter Galison has called a 'trading zone.' When these disparate practitioners and theoreticians came together, they learned how to find a common parlance to trade ideas and exchange information."

Claude Shannon: In 1937, an MIT graduate student turned in a master's thesis that *Scientific American* later referred to as "the Magna Carta of the Information Age." In the essay, "A Symbolic Analysis of Relay and Switching Circuits," Claude Shannon, who became familiar with the telephone system's circuits during a summer break working at Bell Labs, suggested that it was possible to design a circuit containing relays and logic gates that could perform, step by step, a sequence of logical tasks. His demonstration of how complex mathematical operations could be performed by means of relay circuits "became the basic concept underlying all digital computers," notes Isaacson.

George Stibitz: Drawing upon Shannon's idea, in 1939, mathematician George Stibitz created the Complex Number Calculator with more than 400 relays, each of which could open and shut 20 times per second. The computer was not programmable but demonstrated the potential of a circuit of relays to do binary math, process information, and handle logical procedures.

Howard Aiken: In 1937, Howard Aiken, a Harvard physics doctoral student who had discovered a demonstration model of Babbage's Difference Engine in an attic, convinced his Harvard superiors and IBM executives to fund a modern version of Babbage's digital machine. By 1941, IBM was constructing the machine—the Mark I—to Aiken's specifications. With the advent of World War II, Aiken joined the Navy and convinced the Navy to take over the machine. The Harvard Mark I borrowed many of Charles Babbage's ideas, but it was also fully automatic since programs and data, using paper tape, could be entered without human intervention.

Konrad Zuse: In 1937, this German engineer completed the prototype for a binary mechanical calculator, the Z1, capable of reading instructions from a punched tape. By 1941, Konrad Zuse's Z3, employing electromechanical relays for the arithmetic and the memory and control units, became the first fully working all-purpose, programmable digital computer.

John Vincent Atanasoff and John Mauchly: Lone inventor John Vincent Atanasoff built a calculating device in his Iowa basement that used vacuum tubes. "Atanasoff deserves the distinction of being the pioneer who conceived the first partly electronic digital computer," notes Isaacson. Atanasoff's computer, however, was never fully functional and the patents he drew up were never filed. His invention would have been relegated to the dustbins of history except that in June 1941, Pennsylvania physicist John Mauchly visited him. When Mauchly saw the partly built machine, he added these insights to those he had been collecting over the years and quickly moved ahead with his plans to build his own computer. Later a protracted legal war broke out, one of many patent wars of the digital era. Isaacson notes: "'A new idea comes suddenly and in a rather intuitive way,' Einstein once said, 'but intuition is nothing but the outcome of earlier intellectual experience.'" Mauchly, unlike Atanasoff, was able to collaborate with a team with varied talents. "As a result … he and his team would go down in history as the inventors of the first electronic general-purpose computer."

ENIAC: After America's entry into World War II, Mauchly and his chief engineer, J. Presper Eckert, were asked to work on the tables needed to speed up the production of firing tables. Mauchly requested War Department funding for a digital electronic computer, using circuits with vacuum tubes that could solve differential equations and perform other mathematical tasks. This became ENIAC, the Electronic Numerical Integrator and Computer. Although ENIAC was designed primarily for handling differential equations (that would be key to calculating missile trajectories), Mauchly also noted that it could have a "programming device," enabling it to do other tasks.

Bletchley Park: At the end of 1943, on the grounds of a redbrick Victorian manor in Bletchley, 54 miles west of London, another electronic computer was secretly built. British codebreakers, including Turing, were working to break the German Enigma code. This code-breaking computer known as Colossus was the first all-electronic, partially programmable computer. By November 1945 the British had a fully electronic and digital computer capable of some conditional branching. It was a machine geared for code breaking, however, and unlike ENIAC, could not be instructed to perform all computational tasks.

So, who invented the computer? The ideal computer is a machine that is electronic, general purpose and programmable. Concludes Isaacson, "Mauchly and Eckert should be at the top of the list of people who deserve credit for inventing the computer, not because the ideas were all their own but because they had the ability to draw ideas from multiple sources, add their own innovations, execute their vision by building a competent team, and have the most influence on the course of subsequent developments. Ultimately, however, he insists, “the main lesson to draw from the birth of computers is that innovation is usually a group effort, involving collaboration between visionaries and engineers, and that creativity comes from drawing on many sources. Only in storybooks do inventions come like a thunderbolt, or a light bulb popping out of the head of a lone individual in a basement or garret or garage.”

chapter three:

programming

The machines built during WWII were initially thought of as specialists in a particular task—solving mathematical equations or deciphering codes—rather being generalists. Alan Turing proposed: "We do not need to have an infinity of machines doing different jobs. A single one will suffice." They needed the programs that would enable them to perform, seamlessly and quickly, logical operations involving data and symbols. The next step in the computer's development, however, involved storing programs inside the machine's electronic memory rather than relying on the earlier laborious process that involved replugging by hand external cables.

Grace Hopper: While men led the development of the computer's hardware, women, such as naval officer Grace Hopper, specialized in the early programming. Hopper's skill lay in translating scientific problems into mathematical equations and then into ordinary English. In 1944, Howard Aiken asked Hopper to write what became the world's first computer programming manual. Among the programming practices that she perfected at Harvard were:

- The subroutine: Chunks of code for specific tasks that are stored once but can be called upon when needed at different points in the main program.
- The concept of a compiler: It facilitated writing the same program for multiple machines by creating a process for translating source code into the machine language used by different computer processes.
- The terms "bug" and "debugging": One night the Mark II gave out and the cause was found to be a smashed moth in

> one of the electromechanical relays. The moth was pasted into a logbook with the entry "Panel F (moth) in relay. First actual case of bug being found." Fixing glitches became referred to as "debugging the machine."

The women of ENIAC: While ENIAC was originally conceived to perform a set of calculations repeatedly, by 1945 the machine was needed for many other types of calculations, which required it to be reprogrammed often. A group of women were assigned to examine the blueprints of ENIAC and figure out how to program it. They created diagrams and charts for the configuration of cables and switches and recording the sequences, doing what would be regarded as programming for the first general-purpose computer.

Stored programs: As they worked on developing ENIAC, John Mauchly and J. Presper Eckert recognized that a good way to make computers easily reprogrammable would be to store the program inside the computer's memory rather than load them in every time. Having this "stored-program" architecture would ensure that a computer's task could be changed instantly, but it would also require a large memory capacity.

John von Neumann: The Hungarian-born mathematician, who at one point had mentored Alan Turing undertook understanding the potential of high-speed computers. He became convinced that the only solution was to build a computer that worked at electronic speeds and could store and modify programs in an internal memory. In 1944, he visited the University of Pennsylvania, which, writes Isaacson, "kicked into orbit the thinking about stored-program computers." Serving as a consultant to the ENIAC team, von Neumann pushed the idea that the computer program should be stored in the same memory as its data, so that the program could be easily modified as it was running. He was especially good at devising the fundamentals of computer programming and the rigorous logic and precise expression that were needed to create the instruction set. He grasped that by commingling data and programming instructions in the same stored memory, the memory could be erasable (what is now referred to as read-write memory). The stored program instructions could be changed any time a program was running and the computer could modify its own program based on the results it was getting.

"One of von Neumann's great strengths," writes Isaacson, "was his talent—questioning, listening, gently floating tentative proposals, articulating, and collating—for being an impresario of such a collaborative creative process."

Patent wars: In 1945, von Neumann, as he returned to his base in Los Alamos, Nevada, prepared a "draft report" describing the new computer Electronic Discrete Variable Automatic Calculator (EDVAC) that the University of Pennsylvania, utilizing the "von Neumann" architecture, was developing. This was an extremely useful document and guided the development of subsequent computers. But it rankled Eckert and Mauchly: They had tried to patent many of the concepts behind ENIAC and EDVAC, but the distribution of von Neumann's report put those concepts into the public domain.

"These patent disputes were the forerunner of a major issue of the digital era," notes Isaacson. "Should intellectual property be shared freely and placed whenever possible into the public domain and open-source commons? That course, largely followed by the developers of the Internet and the Web, can spur innovation through the rapid dissemination and crowd-sourced improvement of ideas. Or should intellectual property rights be protected and inventors allowed to profit from their proprietary ideas and innovations? That path, largely followed in the computer hardware, electronics, and semiconductor industries, can provide the financial incentives and capital investment that encourages innovation and rewards risks."

UNIVAC: At the end of March 1946, Mauchly and Eckert left the University of Pennsylvania, formed their own company and pioneered turning computing from an academic to a commercial enterprise. Among its machines: UNIVAC, which achieved celebrity status on election night 1952 when it predicted with 100-to-1 certainty that Dwight Eisenhower would beat Adlai Stevenson for the U.S. presidency.

Among the people that Mauchly hired was Hopper, who had in 1952 created the world's first workable compiler. The device translated symbolic mathematical code into machine language, helping nonprogrammers write programs and she had also helped develop the open-source method of innovation by sending out the initial versions of the compiler to people. Observes Isaacson: "Her instinct that programming should be machine-independent was a reflection of her preference for collegiality; even machines, she felt, should work well together. It also showed her early understanding of a defining fact of the computer age: that hardware would become commoditized and that programming would be where the true value resided."

Turing's take: Can machines think? While he thought about the development of stored-program computers, Turing also began to wonder if a machine, which could modify its own program based on the information it processed, could be involved in a form of learning. Could that lead to artificial intelligence? "Turing's unsettling notion that machines might someday be able to think like humans provoked furious objections at the time (1947)—as it has ever since," writes Isaacson.

In October 1950 Turing published his second seminal work, "Computing Machinery and Intelligence" in which he devised what has become known as the Turing Test: posing questions to a human and machine and then trying to determine from their answers which one is the human. In cognitive science, notes Isaacson, "the Turing test and the objections to it remain to this day the most debated topic."

chapter four:

the transistor

The initial computers, which relied upon large, expensive vacuum tubes that consumed a lot of power, could only be afforded by corporations, research universities and the military. “The true birth of the digital age, the era in which electronic devices became embedded in every aspect of our lives,” writes Isaacson, began on December 16, 1947 when two Bell Labs scientists, Walter Brattain and John Bardeen, “put together a tiny contraption they had concocted from some strips of gold foil, a child of semiconducting material, and a bent paper clip. When wiggled just right, it could amplify an electric current and switch it on and off.” This contraption—known as the transistor—“became to the digital age what the steam engine was to the Industrial Revolution.”

Transistors and the later innovations that permitted millions of them to be etched onto tiny microchips meant that the processing power could be installed into rocket ship nose cones, laptop computers, calculators, music players and mobile devices. Proclaims Isaacson of the device: “It came from the partnership of a theorist and an experimentalist working side by side, in a symbiotic relationship, bouncing theories and results back-and-forth in real time. It also came from embedding them in an environment where they could walk down a long corridor and bump into experts who could manipulate the impurities in germanium, or be in a study group populated by people who understood the quantum-mechanical explanations of surface states, or sit in a cafeteria with engineers who knew all the tricks for transmitting signals over long distances.”

Return to Bell Labs: In 1936 Bell Labs' new director, Mervin Kelly, decided that it should focus on basic science and theoretical science rather than traditional practical engineering, believing that innovation belonged in an industrial organization. "The key to innovation—at Bell Labs and in the digital age in general—was in realizing that there was no conflict between nurturing individual geniuses and promoting collaborative teamwork," writes Isaacson.

Replacing vacuum tubes at Bell: When physicist William Shockley came to Bell Labs in 1936, he was asked to figure out how to replace vacuum tubes with a more stable, solid and cheap device. Shockley believed the solution could be found in solid material such as silicon rather than filaments in a bulb. He was paired with Walter Brattain, an adroit experimenter making ingenious devices with semiconducting compounds such as copper oxide. John Bardeen, an expert in quantum theory, also joined them. Because space was at a premium, Bardeen sat in Brattain's lab. Observes Isaacson: "It was a smart move that showed, once again, the creative energy generated by physical proximity."

The transistor: In November 1947, Brattain, working with Bardeen, "found a nice slab or silicon, put a tiny drop of water on it, coated a piece of wire with wax to insulate it, and jabbed the wire through the water drop and into the silicon," writes Isaacson. "It was able to amplify a current, at least slightly. From this 'point-contact' contraction, the transistor was born." Over the next month they developed further iterations, and on December 23, 1947, when Shockley convened a demonstration, Bell Lab executives could hear for themselves the actual amplification of a human voice using a simple solid-state device.

Transistor radios: While Bell Labs was an innovation incubator, it was not good at capitalizing on its inventions. As part of a regulated monopoly, it licensed its patents to other companies, offering the transistor for $25,000 to any company that wanted to produce them. Pat Haggerty of Dallas-based Texas Instruments jumped on the opportunity and lured Bell Labs chemical researcher Gordon Teal to work on it. Haggerty insisted that his engineers brainstorm devices that would be affordable, appeal to consumers and spawn a new market. He came up with the idea of a small pocket radio and worked with a small Indianapolis company that built TV antenna boosters to create the Regency TR-1. The Regency radio, which used four transistors and was the size of a pack of index cards, came on the market in November 1954 for $49.95. Within a year, consumers had snapped up 100,000. IBM chief Thomas Watson Jr. bought 100 Regency radios, gave them to his top executives and told them to get to work using them in computers.

The transistor radio, concludes Isaacson, "became the first major example of a defining theme of the digital age: technology making devices personal." The radio traditionally sat in the living room with the family huddled around it; the transistor radio let the user listen anyplace and anytime. "The seeds were planted for a shift in perception of electronic technology, especially among the young. It would no longer be the province only of big corporations and the military. It could also empower individuality, personal freedom, creativity, and even a bit of rebellious spirit."

The process of innovation happens in stages: In the case of the transistor, Shockley, Bardeen and Brattain's invention came first, followed by their production with engineers like Gordon Teal leading the way. Finally, and equally important, came new markets conjured up by entrepreneurs such as Haggerty.

Palo Alto, California: After leaving Bell Labs, Shockley founded Shockley Semiconductor in 1955 in Palo Alto, California, where he had grown up and his aging mother lived. A valley known for its orchards and Stanford University, Palo Alto doubled in size during the 1950s, partially due to the defense industry's boom in the area. Companies making electrical measuring instruments and other technological devices developed along with them, and in 1953, Stanford's dean of engineering created an industrial park on undeveloped university land, enabling tech companies to acquire property inexpensively and build offices.

The Shockley rebels: Among the semiconductor engineers whom Shockley recruited to join his company was Iowan Robert Noyce, a charismatic 28-year-old with an MIT doctorate who had been working as a research manager at Philadelphia's Philco. The soft-spoken chemist Gordon Moore, who would become one of Silicon Valley's most revered figures, was another key hire.

But Shockley had a prickly personality that alienated many people over the years. "In his pursuit of the four-layer diode, he was secretive, rigid, authoritarian and paranoid," forming private teams and refusing to share information with Noyce, Moore and others, writes Isaacson. Winning the Nobel Prize in 1956 made things worse as Shockley insisted that his name be listed as co-author on all articles and most patent applications coming out of the firm. Ultimately eight of his employees, including Noyce and Moore, rebelled and decided to form their own company—an unusual step for the time. Shockley Semiconductor never recovered from the defection of the "traitorous eight," as the rebels were known, and six years later Shockley gave up and joined Stanford's faculty.

Fairchild Semiconductor: The eight "rebels" approached inventor, playboy and entrepreneur Sherman Fairchild, owner of Fairchild Camera and Instrument and the largest single stockholder of IBM, for funding for their new tech company. He put up $1.5 million with an option to buy the company if it was successful for $3 million. The circumstances for the founding were fortuitous: Not only were transistor radios growing in popularity, but on October 4, 1957—three days after Fairchild Semiconductor was formed—the Russians launched the Sputnik satellite, setting off the U.S.-Russian space race.

Concludes Isaacson: "The civilian space program, along with the military program to build ballistic missiles, propelled the demand for both computers and transistors. It also helped assure that the development of these two technologies became linked. Because computers had to be made small enough to fit into a rocket's nose cone, it was imperative to find ways to cram hundreds and then thousands of transistors into tiny devices."

chapter five:

the microchip

As the use of the transistor increased, so did what one Bell Lab executive described as "the tyranny of numbers." The more components in a circuit, the more connections were required. A system of 10,000 components, for example, could require 100,000 or more little wire links on the circuit boards that were often soldered by hand. This situation provided, says Isaacson, "a recipe for an innovation. The need to solve this growing problem coincided with hundreds of small advances in ways to manufacture semiconductors." The result—an integrated circuit known as a microchip—came about independently at Texas Instruments and Fairchild Seminconductor.

Jack Kilby: In 1958, after he joined Texas Instruments, Jack Kilby experimented with what else might be done with silicon. He came up with what became known as the "'monolithic idea': you could make all of these components in one monolithic piece of silicon, thus eliminating the need to solder together different components on a circuit board," writes Isaacson. What he had come up with was a "solid circuit," the first integrated circuit.

Robert Noyce's approach: Robert Noyce and his colleagues at Fairchild were working on how to fix the problem of their transistors not working very well. Experimenting with the "planar process," a flat plane of oxide that sat on top of the silicon, Noyce realized that it could eliminate the wires that stuck out of the transistor's layers by printing little copper lines on top of the oxide layer. These printed copper lines, connecting the regions of a transistor, could also be used to connect two or more transistors. "Noyce had come up with the concept of a microchip independent of (and a few months later than) Kilby," writes Isaacson, "and they had gotten there in different ways. Kilby was trying to solve the problem of how to overcome the tyranny of numbers by creating circuits with many components that didn't have to be soldered together. Noyce was mainly motivated by trying to figure out all the neat tricks that could come from [the] planar process. There was one other, more practical difference. Noyce's version didn't have a messy spider's nest of wires protruding from it."

Protecting discoveries: The patent application filed by Texas Instruments in February 1959 for Kilby's idea of an integrated circuit made the application sweeping and broad. Noyce and his Fairchild team filed a competing application in July 1959 focusing specifically on what was special about his version, emphasizing that the planar process permitted a printed circuit method "for making electrical connections to the various semiconductor regions" and to "make unitary structure more compact and more easily fabricated." As with the computer, the patent wars took years to resolve. By the time Noyce prevailed in November 1969, the legal proceedings were essentially irrelevant; the market had exploded and the companies had hammered out their own agreements. In 1966, each company granted that the other had some intellectual property rights to the microchip and agreed to cross-license to each other whatever rights they had. Other companies would have to make licensing deals with both companies.

Microchips blast off: The demand for the microchip came from several sectors, including:

- The military: In 1962 the Strategic Air Command designed the land-based Minuteman II, which required 2,000 microchips alone for its onboard guidance system. Texas Instruments became the principal supplier, and by 1965, seven Minutemen were being built weekly and the Navy was also buying microchips for its submarine-launched missile, the Polaris.
- The U.S. civilian space program: Fairchild landed the contract, for example, to build 75 Apollo Guidance Computers, which contained 5,000 microchips apiece.

- Consumer devices: Hearing aids, which needed to be very small and had a built-in market, were the first consumer devices to use microchips although demand was limited, while Texas Instruments' Pat Haggerty used them to create a handheld pocket calculator.

Smaller, cheaper, faster, more powerful: This became the pattern for electronic devices. Observes Isaacson: "This was especially true—and important—because two industries were growing up simultaneously: the computer and the microchip. 'The synergy between a new component and a new application generated an explosive growth for both,' Noyce later wrote." And it was also "a key lesson for innovation: Understand which industries are symbiotic so that you can capitalize on how they will spur each other on."

Moore's Law: In an essay titled "Cramming More Components Onto Integrated Circuits," published in 1965, Gordon Moore predicted that "Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobile, and personal portable communications equipment." Another pronouncement of his made him famous: "The complexity for minimum components costs has increased at a rate of roughly a factor of two per year," he noted. "There is no reason to believe it will not remain nearly constant for at least two years." Known as Moore's Law, this became a goal for the industry and a self-fulfilling prophecy. Noyce decided that setting a low price would incentivize device makers to incorporate microchips into their new products. Low price therefore stimulated demand, which in turn led to high-volume production and economies of scale.

Arthur Rock and venture capital: Wealthy families such as the Vanderbilts and Rockefellers had been the backbone of venture capital and private equity investing in new companies for most of the 20th century. After World War II these families institutionalized the business of "adventure capital," forming such companies as the Rockefeller family's Venrock Associates.

East Coast investment banker Arthur Rock was the businessman who brought Shockley's rebels and Fairchild together and took a stake in the deal as well. Deciding that he could raise money and do deals without a corporate patron, he moved to San Francisco. Two early bets—Teledyne and Scientific Data System—had paid off, so he was quickly able to sign up investors when Noyce and Moore came looking for money to fund their new company, Integrated Electronics Corp (Intel).

The Intel way: The flattening of the traditional hierarchical structure had already begun at other companies, but the new digital culture really took shape at Intel. Noyce and Moore were unpretentious, nonauthoritarian, averse to confrontation and uninterested in the trappings of power. They were great partners—except that they needed a tough manager to enforce some discipline. Andy Grove, director of engineering and a pioneer of the metal-oxide semiconductor, became the necessary third key player in creating Intel's culture.

- Grove, influenced by Peter Drucker's *The Practice of Management*, realized that effective management came from the right combination of an outside person, an inside person and a person of action: Noyce was the outside face; Moore, the inside, while Grove was the man of action.
- Intel was a culture of meritocracy: it functioned without a chain of command that empowered employees to be entrepreneurial.
- Noyce believed that the more open and unstructured a workplace, the faster new ideas would be sparked, disseminated, refined and applied. For example, he worked among the other employees at a small gray aluminum desk.
- Business units performed as their own small and agile companies and were not dependent upon bosses to make decisions.
- Group meetings were encouraged where everyone was treated as an equal.

- Grove imposed the discipline, holding people accountable for their sloppiness and maintaining that failure had its consequences.
- Grove, who also worked in an exposed cubicle, added an overlay of what he called "constructive confrontation." Recalled one employee: "Andy was the guy who made sure the trains all ran on time. … He had very strong views about what you should do and what you shouldn't do and he was very direct about that."

"Despite their different styles," writes Isaacson, "there was one thing that Noyce and Moore and Grove shared: an unwavering goal of making sure that innovation, experimentation, and entrepreneurship flourished at Intel."

The invention of the microprocessor: One problem Intel employees encountered was the demand from clients for specific microchips to perform specific tasks. In the case of the Japanese company Busicom, Intel took an order in 1969 for 12 special-purpose microchips and agreed on a price. Ted Hoff, who was assigned to work on chip design, realized that the company probably couldn't produce the chips at the negotiated price. Noyce encouraged him to think about how to simplify the design. Writes Isaacson: "Hoff proposed that Intel design a single logic chip that could perform almost all of the tasks Busicom wanted. 'I know that this can be done,' he said. … 'It can be made to emulate a computer.'"

In renegotiating the price with Busicom, Intel made a critical decision and retained the rights to the new chip in order to license it to other companies for purposes other than making a calculator. Noyce "realized a chip that could be programmed to perform any logical function would become a standard component in electronic devices." This new type of chip, replacing custom chips, could be made in bulk with the price continually declining. "It would also usher in a more subtle shift in the electronics industry," writes Isaacson. "The importance of hardware engineers … began to be supplanted by a new breed, software engineers, whose job it was to program a set of instructions into the system."

The Intel 4004: The microprocessor made its debut in November 1971, and microprocessors quickly started showing up in thousands of products including traffic lights, car brakes, coffeemakers, refrigerators, elevators and medical devices. Their foremost success, however was making smaller computers possible.

Concludes Isaacson: "The microprocessor spawned hundreds of new companies making hardware and software for personal computers. Intel not only developed the leading-edge chips; it also created the culture that inspired venture-funded startups to transform the economy and uproot the apricot orchards of Santa Clara Valley, the 40-mile stretch of flat land from south San Francisco through Palo Alto to San Jose."

chapter six:

video games

The evolution of microchips led to devices becoming smaller and more powerful. But there was another impetus driving the computer revolution: the belief that computers weren't merely for number crunching but could and should be fun for people to use. Two cultures came together in the creation of video games: hard-core hackers, who believed in "the hands-on imperative" and enjoyed pranks, programming tricks, toys and games; and rebel entrepreneurs, who wanted to break into the amusement games industry. Writes Isaacson: "Thus was born the video game, which turned out to be not merely an amusing sideshow but an integral part of the lineage that led to today's personal computer. It also helped to propagate the idea that computers should interact with people in real time, have intuitive interfaces, and feature delightful graphic displays."

Steve Russell and Spacewar: The geeky student organization at MIT known as the Tech Model Railroad Club spawned the hacker subculture and the seminal video game Spacewar. Intricate pranks at MIT, such as putting a live cow on a dorm roof, were referred to as hacks, and connoted both technical virtuosity and playfulness. "'We at TMRC use the term hacker only in its original meaning, someone who applies ingenuity to create a clever result, called a hack,' the club proclaimed. 'The essence of a hack is that it is done quickly and is usually inelegant.'"

In September 1961, the Digital Equipment Corporation (DEC) gave the prototype of its PDP-1 computer to MIT and a group of hackers decided they wanted create a real computer video game for it. Their best programmer, Steve Russell, began working on a space-war game and, when the basics were completed, he put his program tape in the box that held other PDP-1 programs. His friends began to make improvements, resulting in an open-source collaboration. The game soon spread to other computer centers and its popularity led DEC to ship the game preloaded into its computers, and programmers created new versions for other systems. "Spacewar highlighted three aspects of the hacker culture that became themes of the digital age," writes Isaacson: (1) It was created collaboratively, (2) it was free and open-source software, and (3) it was based on the belief that computers should be personal and interactive.

Nolan Bushnell and Atari: Computer science student Nolan Bushnell was a Spacewar fanatic but also an amusement park enthusiast, having worked in one to help pay for his college education. At the University of Utah he had access to a PDP-1 computer and "realized you could make a whole lot of quarters if you could put a computer with a game in an arcade." After college he kept searching for a way to turn a computer into an arcade video game: "Then I had a great epiphany," he recalled. "Why not do it all with hardware?" Bushnell designed circuits to perform each of the tasks that the computer program would have done, which made it cheaper. And then he made it simpler, turning Spacewar into a fun game featuring one user-controlled spaceship fighting two simple saucers that the hardware generated. He sold the game—Computer Space—to a company that was working on its own computer game. Computer Space made its debut in the fall of 1971 at the Dutch Goose Bar in Menlo Park, California, and 1,500 units were eventually sold.

Bushnell was one of those innovators who turned an invention into an industry. Computer Space acquired a cult following—not in bars but in student hangouts. "Arcade games, once the domain of pinball companies based in Chicago," writes Isaacson, "would soon be transformed by engineers based in Silicon Valley." For his next video game Bushnell decided to go out on his own and launched his new venture, Atari, on June 27, 1972.

Pong: At a trade show, Bushnell saw a primitive Magnavox console for playing games on home television sets and was intrigued by one of the offerings, a version of Ping Pong. He asked Al Acorn, his engineer, to think about this idea and create his own game. Acorn turned the monotonous blip bouncing between paddles into something amusing, then created a scoreboard—and the right "thonk" sound from the sync generator to make the experience appealing. His game—Pong—didn't use a microprocessor or computer code, relying on the hardware with the type of digital logic design used by TV engineers. But it was fun and simple to figure out to play. "Consciously or not, Atari had hit upon one of the most important engineering challenges of the computer age: creating user interfaces that were radically simple and intuitive," observes Isaacson.

Atari had a hit: While the average machine made $10 a day, Pong was taking in $40. Bushnell then decided to manufacture the game on his own, bootstrapping the whole operation. He ultimately opened a production facility in an abandoned roller-skating rink near the company's Santa Clara office, where he produced the game for just over $300 and sold it for $1200. Pong's success led to a lawsuit from Magnavox over the home-television game that Bushnell had seen at a trade show. Bushnell, rather than fighting, agreed to pay a relatively low fee of $700,000 for perpetual rights to make the game on the condition that Magnavox enforce his patents and demand a percentage royalty from other companies that wanted to make similar games. These stipulations helped put Atari at a competitive advantage.

The Atari culture: Bushnell's company workforce enjoyed beer bashes and pot-smoking parties on Friday nights, no fixed hours and no dress code. The company developed its own culture that drew from the hippie movement and would help define Silicon Valley: Authority should be questioned, hierarchies should be circumvented, noncomformity should be admired and creativity should be nurtured.

Reflecting on the rise of the video game, Isaacson notes "innovation requires having at least three things: a great idea, the engineering talent to execute it, and the business savvy (plus deal-making moxie) to turn it into a successful product." It was Bushnell, at age 29, who had the genius to put it together.

chapter seven:

the internet

The Internet was built through the collaboration of three groups: the military, universities and private corporations. In 1950, Congress created the National Science Foundation. Writes Isaacson: “The creation of a triangular relationship among government, industry, and academia was, in its own way, one of the significant innovations that helped produce the technological revolution of the late twentieth century. The Defense Department and National Science Foundation soon became the prime funders of much of America’s basic research, spending as much as private industry during the 1950s through the 1980s.”

Vannevar Bush’s Triangle: Vannevar Bush had a foot in three camps: He was dean of the MIT School of Engineering, founder of the electronics company Raytheon and the United States’ top military science administrator during World War II. His 1945 report, “Science, The Endless Frontier,” advocated government funding of basic research in partnership with universities and industry. Bush also maintained that World War II had made it “clear beyond all doubt” that understanding the fundamentals of basic science in nuclear physics, lasers, computer science and radar “is absolutely essential to national security” and America’s economic security depended upon basic scientific knowledge.

While Bell Labs had existed before World War II, hybrid research centers sprung up after the war funded government contracts and encouragement. Among them were the RAND Corporation, which was designed to provide research and development to the U.S. Air Force; the Stanford Research Institute and its offshoot, the Augmentation Research Center; Xerox PARC; Lincoln Laboratory, which was a military-funded research center affiliated with MIT; and Bolt, Beranek and Newman (BBN), a Cambridge-based R&D company founded by MIT engineers and a few Harvard colleagues.

J.C.R. Licklider and computer time-sharing: At MIT, J.C.R. Licklider, in collaboration with A.I. pioneer John McCarthy, helped to develop systems for computer time-sharing in the 1950s. Researchers traditionally submitted punch cards or tape to the computer's officers and then waited hours or days for the results to come back. Researchers found this "batch-processing" frustrating since a tiny mistake often resulted in having to resubmit cards for another run. Time-sharing gave researchers a more direct human-computer partnership (symbiosis) since multiple terminals could be hooked up to the same mainframe; users could type in commands directly and get a response quickly.

SAGE and human-computer interaction: MIT's Lincoln Laboratory computers were being developed for an air defense system—the Semi-Automatic Ground Environment (SAGE)—that would provide an early warning of an enemy attack and coordinate a response. SAGE had 23 tracking centers across America that were connected by long-distance phone lines and could disseminate information on up to 400 fast-moving planes at once. Notes Isaacson: "To do so required powerful interactive computers, networks that could transmit vast amounts of information, and displays that could present this information in an easy-to-understand graphical fashion." Licklider was asked to help design the human-machine interfaces that users saw on the screen. He began to think about partnerships beyond SAGE and talking about people interacting on friendly digital consoles.

Licklider explained: "The hope is that, in not too many years, human brains and computing machines will be coupled together very tightly … and that the resulting partnership will think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today."

The Intergalactic Computer Network: In 1962, Licklider moved to the Defense Department's Advance Research Projects Agency

(ARPA), which funded basic research at universities and corporate institutes. He headed up the new Information Processing Techniques Office (IPTO), which focused on information processing and psychological factors in military decision-making. By 1963, Licklider returned to his vision of time-sharing, real-time interactivity and interfaces that fostered man-machine symbiosis as "the Intergalactic Computer Network." He sent a memo to "members and affiliates" of that dream network: "Consider the situation in which several different centers are netted together. … Is it not desirable, or even necessary for all the centers to agree upon some language or, at least, upon some conventions for asking such questions as 'What language do you speak?'"

Bob Taylor and Larry Roberts: Bob Taylor and Larry Roberts worked together at IPTO. Taylor was concerned that the universities and research centers with ARPA contracts wanted the latest computers with the most capabilities, which was wasteful and duplicative. The solution needed was to build a data network to connect research centers, which would prevent researchers who had to do both data mining and graphics from having to travel between sites to use the required computer or asked IPTO to provide their site with an additional computer. It would also allow researchers at different locations to learn about their colleagues work easily. Larry Roberts, who was working at Lincoln Laboratory, was recruited to come to Washington to be the agency's chief scientist and run the project.

ARPANET: In 1967, ARPA came up with a network plan: It would design and give member sites a standardized minicomputer that would do the routing between the sites. The big research computer at each site would be used to establish a connection with its ARPA-supplied routing minicomputer. This procedure would relieve the host site's mainframe of most of the burden and ARPA would have the power to standardize the network. Furthermore, the routing of data would be completely distributed rather than controlled by a few big hubs

Packet switching: How was the data going to be sent through the proposed network? The phone system relies on circuit switching: A set of switches creates a dedicated circuit for signals to go back and forth during the conversation and the connection remains open throughout. In packet switching, messages are broken down into bite-size units of the same size (packets) that are given address headings saying where they should go. The messages wend their way through the system node to node, using whatever links are available at that point. "It's like breaking a long letter into dozens of postcards, each numbered and addressed to the same place," explained Vint Cerf, one of the Internet's pioneers. "Each may take different routes to get to the destination, and then they're reassembled."

A distributed network: In 1960, engineer Paul Baran described the packet-switched network as a fishnet, maintaining that the network should not be centralized nor decentralized but rather distributed: Every node should have equal power to switch and route data. Writes Isaacson: "This would become the defining trait of the Internet, the ingrained attribute that would allow it to empower individuals and make it resistant to centralized control."

Was the Internet's development nuke-related? There were many causes for the development of the Internet, including concerns about the vulnerability of communications if there was a nuclear attack. ARPA director Stephen Lukasik recalls that there was pressure from Congress in the 1960s only to fund projects directly relevant to a military mission. What turned the tide, says Lukasik, "was this idea that packet switching would be more survivable, more robust under damage to a network. … In a strategic situation—meaning a nuclear attack—the president could still communicate to the missile fields."

Developing ARPANET through collaboration: ARPANET represented an interesting conjunction of military and academic interests: It was funded by the Department of Defense but designed by academics. Even after ARPANET morphed into the Internet in the 1980s, it served both a military and civilian purpose. "This interplay of military and academic motives became ingrained in the Internet," concludes

Isaacson. “These academic researchers of the late 1960s, many of whom associated with the antiwar counterculture, created a system that resisted centralized command. It would route around any damage from a nuclear attack but also around any attempt to impose control.”

The ARPANET has landed, October 1969: In 1968, Larry Rogers selected BBN to build the mini-computers destined for the four research centers—UCLA, Stanford Research Institute (SRI), University of Utah and the University of California at Santa Barbara—that would serve as the routers or Interface Message Processors (IMPs) of ARPANET. BBN proposed an improvement that increased the network’s reliability: In passing a packet from one IMP to the next, the sending IMP would store the message until it got an acknowledgement from the receiving IMP and would resend the message if the acknowledgement didn’t come fast enough. BBN’s suggestion, key to the network’s reliability, is another example of the design being improved by collective creativity.

The challenge still remained as to how the big “host” computers would connect to the standardized IMPS at each site. In April 1967, UCLA’s Stephen Crocker mailed a “Request for Comment” to colleagues who were pondering the issue. “That culture of open processes was essential in enabling the Internet to grow and evolve as spectacularly as it has,” recalled Crocker. “The RFC process pioneered open-source development of software, protocols, and content,” says Isaacson. “Even more broadly, it became the standard for collaboration in the digital age.” On October 29, 1969, the ARPANET link was made when a terminal at UCLA connected through the network to a terminal 354 miles away at SRI in Palo Alto.

The Internet: Within a few years of ARPANET’s launch, similar packet-switched networks existed around the country. In 1973, ARPA’s Robert Kahn decided it was time to patch all these together, to create an “internetwork” (later shortened to “internet”). Kahn and colleague Vint Cerf decided a common protocol was needed to stitch the network together so that each computer had the same method and template for addressing its packets. Their paper "A Protocol for Packet Network Interconnection" (1974) laid out the directions for the Internet. Internet Protocol (IP) specified how to put the packet's destination in its header and how it would move through networks to get there, while a higher-level Transmission Control Protocol (TCP) instructed how to put the packets back together in the correct order, checked to see if any were missing, and requested transmission of lost information.

In 2014, Cerf reflected: "New things keep piling onto the Internet. It has scaled up a million times over. Not many things can do that without breaking. And yet these old protocols we created are doing just fine.'"

Networked creativity: Who deserves the credit for inventing the Internet? As Isaacson sees it, the Internet was built partly by the government and by private firms, but mostly its creation lies with a loosely knit cohort of hackers and peers who shared their creative ideas. It was built with the belief that power should be distributed rather than centralized and that authoritarian diktats should be circumvented.

chapter eight:

the personal computer

For the Internet to reach its full potential, it had to reach beyond the community of researchers in academia and military institutions. It wasn't until the 1980s that the gates of the early civilian counterparts to ARPANET were fully opened and the '90s that ordinary people gained access. But there was another critical limitation: People had to have hands-on access to computers. "The digital age could not become truly transformational until computers became truly personal," writes Isaacson.

"As We May Think": Vannevar Bush conceived of a personal computer in a 1945 article, "As We May Think" in *The Atlantic*: "Consider a future device for individual use, which is a sort of mechanized private file and library … it may be consulted with exceeding speed and flexibility." Bush talked about a "direct entry" device such as a keyboard and predicted hypertext links, file sharing and other ways of collaborating.

Yet early computers remained in the realm of institutions rather than individuals. By the early 1970s companies such as DEC produced minicomputers (the size of a small refrigerator) but DEC's leadership dismissed the idea of computers belonging to individuals: "I can't see any reason that anyone would want a computer of his own'" said DEC's president Ken Olsen in 1974.

The cultural brew: Social forces, along with the technological development of the microprocessor, led to the creation of the personal computer. This cultural mix included:

- Engineers who migrated to the area to work at defense contractors, such as Westinghouse and Lockheed

- An entrepreneurial startup culture exemplified by Intel and Atari
- Hackers who moved West from MIT bringing a craving for hands-on computers
- A subculture of "wireheads" and hard-core hobbyists who liked to hack into the Bell System's phone lines or large corporations' time-shared computers
- Idealists and community organizers in San Francisco and Berkeley who wanted to "co-opt technological advances for progressive purposes"
- Three countercultural strands: the hippies who came out of the Bay Area's beat generation; the New Left activists who initiated Berkeley's Free Speech Movement and other antiwar protests; and the Whole Earth communalists, who believed in controlling their own tools, sharing resources, and resisting conformity and centralized authority

Initially the hippie and antiwar movements were wary of computers, notes Isaacson, but by the early 1970s, when the possibility of personal computers arose, attitudes began to change. "Computers went from being dismissed as a tool of bureaucratic control to being embraced as a symbol of individual expression and liberation," John Markoff wrote in his history of the period, What the Dormouse Said.

Stewart Brand: In 1967, Stewart Brand came out with the Whole Earth Catalog, which combined the sensibilities of the back-to-the land counterculture with the goal of technological empowerment. On the first page of the first edition he proclaimed: "A realm of intimate, personal power is developing—power to the individual to conduct his own education, find his inspiration, shape his own environment, and share his adventure with whoever is interested. Tools that aid this process are sought and promoted by the Whole Earth Catalog."

Douglas Engelbart, the mouse and NLS: An engineer, Douglas Engelbart believed in Bush's vision that people would have their own terminals where they could manipulate, store, and share information, calling this "augmented intelligence." In 1962, with funding from ARPA and NASA, he founded the Augmentation Research Center at SRI.

Engelbart looked for the simplest way for a user to point to and select something on a screen, examining such on-screen cursors as light pens, joysticks, trackballs, and trackpads. He remembered the planimeter, which utilized two perpendicular wheels to calculate the area of a space by being rolled in each direction. He drafted a sketch of the idea, which ultimately became the device known as the "mouse."

In the next six years, Engelbart came up with a full-fledged augmentation system that he called "'oNLine System (NLS). NLS, writes Isaacson, "included many other advances that led to the personal computer revolution: on-screen graphics, multiple windows on a screen, digital publishing, blog-like journals, wiki-like collaborations, document sharing, email, instant messaging, hypertext linking, Skype-like videoconferencing, and the formatting of documents."

Alan Kay and Xerox PARC: In 1971, computer scientist Alan Kay, who had an interest in computer graphics and natural user interfaces, was hired by Bob Taylor to work at Xerox PARC in Palo Alto. At his formal interview, when he was asked what he hoped his greatest achievement would be, Kay replied "A personal computer," which he went on to describe. Kay called his computer a Dynabook and thought of it as a tool for creativity rather than a piece of equipment in networked terminals for collaboration. He first pitched an "interim" machine to Xerox's bosses that would be the size of a carry-on suitcase and have a small graphical display screen. This computer, the Xerox Alto, was controlled by a keyboard and mouse, and was simple, friendly, and intuitive to use.

Two thousand Altos were produced and used in Xerox offices and affiliated institutions, but they never reached the consumer market. "The company wasn't equipped to handle an innovation," recalled Kay. Furthermore, when the Alto was demonstrated to Xerox's male executives, "The men thought it was beneath them to know how to type," said Bob Taylor. "It was something the secretaries did. So they didn't take the Alto seriously, thinking that only women would like it."

The community organizers: In San Francisco, community organizers such as antiwar protester and electrical engineer Lee Felsenstein believed that the best way to wrest power from big institutions was to create new types of communications: networked computers which "would bring the locus of power down to the people." Felsenstein learned about the mainframe computer of the nonprofit Resource One and—along with Judy Milhon, one of the first female hackers, and systems programmer Efrem Lipkin—decided to use this computer as a public electronic bulletin board. In August 1973, they set up a terminal with a link via a phone line to the mainframe at a Berkeley record store for what they called Community Memory.

Writes Isaacson: "Felsenstein had seized on a seminal idea: Public access to computer networks would allow people to form communities of interest in a do-it-yourself way." The creators also decided to let users come up with their own uses for the system, whether it was poetry or seeking chess partners. Community Memory became the forerunner to Internet bulletin board systems.

The Homebrew Computer Club: Felsenstein also met with other computer enthusiasts at potluck dinners and in early 1975 circulated a flyer advertising a new club: "Are you building your own computer? Terminal? TV typerwriter? I/O device? Or some other digital black-box magic? If so, you might like to come to a gathering of people of likeminded interests." The first meeting of the Homebrew Computer Club was held on March 5, 1975, in a Menlo Park garage.

Ed Roberts and the Altair: Serial entrepreneur Ed Roberts in Albuquerque, New Mexico, had launched a company that made do-it-yourself kits that tracked toy rockets for model rocket enthusiasts, and then one that made do-it-yourself calculator kits. Fascinated by computers, he decided that his company MITS could make a do-it-yourself kit for a rudimentary computer for under $400. With 256 bytes of memory, no keyboard or input device, and dependent on toggling a row of switches to input data or instructions, "the machine that Roberts and his motley crew built … wasn't a technological triumph, [but] it was what hobbyists had been yearning for. There was a pent-up demand for a computer that they could make and own, just like a ham radio."

Roberts was also lucky that he knew Les Solomon, the technical editor of *Popular Electronics*. The magazine's January 1975 issue proclaimed "the era of the computer in every home—a favorite topic among science-fiction writers—has arrived!" The Altair 8800, which got its name from the star that Star Trek's spaceship Enterprise was visiting on the TV the night that the article went to print, was an immediate hit. "'To my mind," Bill Gates later said, "the Altair is the first thing that deserves to be called a personal computer."

The debut: The Altair was the centerpiece at the first meeting of the Homebrew Computer Club. It wasn't much to look at—switches and lights—but as 30 people gathered around, they sensed that a new age was dawning. "That may have been the moment at which the personal computer became a convivial technology," recalled Felsenstein. Within weeks members were writing programs for it. Writes Isaacson: "The members of the Homebrew Club had found a computer they could take home and make do all sorts of beautiful things, including, as Ada Lovelace had predicted, rendering music."

Concludes Isaacson: "As a result, electronics club hobbyists, in league with the Whole Earth hippies and homebrew hackers, launched a new industry, personal computers, that would drive economic growth and transform how we live and work. In a power-to-the people move, computers were wrested from the sole control of corporations and the military and placed into the hands of individuals, making them tools for personal enrichment, productivity, and creativity."

chapter nine:

software

Various models of software development emerged for the personal computer. Writes Isaacson: "Each model had its advantages, each had its incentives for creativity, and each had its prophets and disciples." Among them were:

- The Microsoft approach of Bill Gates and Paul Allen, in which the operating system was unbundled from the hardware
- The Apple approach of Steve Jobs and Steve Wozniak, in which the hardware and operating system were tightly bundled
- Free and open-source approaches such as that developed by Richard Stallman and Linus Torvalds, which allowed the software to be modified by any user

These models coexisted, along with various combinations of open and closed, bundled and unbundled, proprietary and free, notes Isaacson. "Windows and Mac, UNIX and Linux, iOS and Android: a variety of approaches competed over the decades, spurring each other on—and providing a check against any one model becoming so dominant that it stifled innovation."

Paul Allen and Bill Gates: Gates and Allen became friends in the computer room of Seattle's Lakeside Private School, which had a General Electric Mark II time-sharing computer system. For Gates, notes Isaacson, "the computer terminal became to him what a toy compass had been to the young Einstein: a mesmerizing object that animated his deepest and most passionate curiosities." Gates loved its logical rigor: "When you use a computer, you can't make fuzzy statements. You make only precise statements." While still in middle school, Gates learned BASIC (Beginners All-Purpose Symbolic Instruction Code) and produced programs that played tic-tac-toe and converted numbers from one mathematical base to another.

The Lakeside Programming Group: In the fall of 1968, Gates, who was entering eighth grade, and Allen formed the Lakeside Programming Group. Shortly afterwards one of the Lakeside mothers, who was a partner at the Computer Center Corporation (C-Cubed), offered the group the opportunity to test-drive the company's new DEC PDP-10 and see what they could do to make it crash. (C-Cubed had a deal with DEC that it would not make lease payments until it had been debugged and stable.) "I became hard core," recalled Gates. "It was day and night." Two rules were established: Whenever the machine crashed, the users had to describe what they had done and they couldn't do the same trick again until they were asked to. The group's mentor at C-Cubed was Steve Russell, who earlier at MIT had created the video game Spacewar. Working with the computer, Gates and Allen learned the importance of the computer's operating system, mastering assembly code and underlying commands, reading assembler manuals, becoming experts in the complexities of an operating system.

After the project ended, Gates and Allen became involved over the next few years in other projects, including writing a payroll program for one company that would produce paychecks with correct deductions and taxes, a class scheduling program for their high school, a traffic tabulator that analyzed traffic patterns, and helping to program the electrical grid management system of the Bonneville Power Administration.

Gates at Harvard: After Gates arrived at Harvard, he convinced Allen, who had dropped out of Washington State University, to move to the Boston area and take a job at Honeywell. Gates remained at Harvard—but just barely; by his sophomore year he decided that he would not go to the lectures for any course in which he was enrolled but would audit lectures of courses he was not taking. One outcome of his self-created schedule was meeting the big, boisterous and gregarious Steve Ballmer. "Gates's haphazard life at Harvard was suddenly upended in December 1974," writes Isaacson, "when Allen arrived at his Currier House room with the new issue of *Popular Electronics* featuring the Altair on the cover. Allen's rallying cry, 'Hey, this thing is happening without us,' jolted Gates into action."

Allen and Gates spent the next eight weeks in a code-writing frenzy. Writes Isaacson: "they wanted to shift the balance in the emerging industry so that the hardware would become an interchangeable commodity, while those who created the operating system and application software would capture most of the profits. Years later, Gates reflected: "That was the most important idea I ever had."

Basic for the Altair: Gates and Allen decided to write an interpreter for the programming language BASIC that would run the Altair's Intel 8080 microprocessor. This would enable hobbyists to create their own programs for the Altair. "It would become the first commercial, native high-level programming language for a microprocessor," says Isaacson. "And it would launch the personal computer software industry." Gates and Allen wrote a letter to MITS, the fledgling company that made the Altair, saying that they had created a program (they actually hadn't yet) and after they succeeded, Allen flew down to Albuquerque to demonstrate it. Of the demo, reports Isaacson: "Roberts had been watching quietly. He had taken his failing company further into debt on the wild surmise that he could create a computer that a home hobbyist could use and afford. Now he was watching as history was being made."

Roberts agreed to license the BASIC interpreter for inclusion on all Altair machines, and Allen returned to Cambridge. Allen returned to Albuquerque to become director of software for MITS; Gates ultimately dropped out of Harvard two semesters shy of graduating. He would get an honorary degree in June 2007.

Micro-Soft: The deal for Micro-Soft BASIC to license the software to MITS for 10 years and to be bundled with each Altair for $30 in royalty per copy was significant. Gates and Allen retained the ownership of the software with MITS having the rights to license it. MITS would make its "best efforts" to sublicense the software to other computer makers, splitting the revenues with Gates and Allen.

This set a precedent for other licensing deals. Said Gates: "We were able to make sure our software worked on many types of machines. That allowed us and not the hardware makers to define the market."

The innovator's personality: Gates, from Isaacson's point-of-view, exemplifies the innovator's personality. "An innovator is probably a fanatic, somebody who loves what they do, works day and night, may ignore normal things to some degree and therefore be viewed as a bit unbalanced," Gates observed about himself in an interview. "Certainly in my teens and 20s, I fit that model." Observes Isaacson: "Gates's intensity paid off. It allowed Microsoft to meet software deadlines that seemed insane, beat other competitors to the market for each new product, and charge such a low price that computer manufacturers rarely thought of writing or controlling their own software."

Software wants to be free: Roberts sent the Altair on a road show in 1975 to publicize it. At a Homebrew Computer Club meeting the software was shared, which infuriated Gates who was there. He responded in an "Open Letter to Hobbyists" that would initiate the war over the protection of intellectual property in the PC age. Gates pointed out that the feedback from those using BASIC was positive but most of the "users" never bought BASIC—less than 10 percent of all Altair owners had bought it—and the royalties that he and Allen received amounted what worked out as less than $2/hour. "Why is this?" he asked. "As the majority of hobbyists must be aware, most of you steal your software. Hardware must be paid for, but software is something to share. Who cares if the people who worked on it get paid? … What hobbyist can put 3 man-years into programming, finding all bugs, documenting his product and distribute for free? … The facts is, no one besides us has invested a lot of money in hobby software," he asserted.

"By resisting the hacker ethos that anything could be copied should be free," writes Isaacson, "Gates helped ensure the growth of the new industry." At the same time the widespread pirating of the software also helped the company. "By spreading so fast, Microsoft BASIC became a standard, and other computer makers had to license it."

Steve Wozniak and Steve Jobs: In 1971 young hardware engineer Steve Wozniak "Woz," along with his friend Steve Jobs created a Blue Box, a gadget that emitted just the right tone chirps to fool the Bell telephone system and make free long-distance phone calls. Wozniak built the device but Jobs had the idea to sell it, which they briefly did. "If it hadn't been for the Blue Boxes, there wouldn't have been an Apple," Jobs later reflected. "Woz and I learned how to work together."

In 1974, after dropping out of Reed College, Jobs went to work at Atari under the creative video entrepreneurs Nolan Bushnell and Al Acorn. Jobs later said that he learned at Atari that interfaces needed to be friendly and intuitive and that devices should not need manuals. Wozniak attended the first Homebrew Computer Club meeting and observed the Altair computer. What intrigued him, however, was the spec sheet for a new Intel microprocessor. He had been designing a terminal with a video monitor and a keyboard (a "dumb" terminal that would connect via a phone line to a time-shared computer elsewhere). Wozniak had his "aha" moment: He could use a microprocessor to put some of the computing power into his computer terminal.

Apple: On June 29, 1975, Wozniak tapped a few keys on his keyboard, the signal was processed by a microprocessor and letters appeared on the screen—the first time a keyboard and monitor had been integrated with a personal computer designed for hobbyists. While Wozniak wanted to give away his design to the computer club, Jobs didn't. "His desire to package and sell an easy-to-use computer—and his instinct for how to do it—changed the realm of personal computers just as much as Wozniak's clever circuit design did," says Isaacson. "Indeed, Wozniak would have been relegated to minor mentions in the Homebrew newsletter had Jobs not insisted that they create a company to commercialize it."

Jobs called chip makers such as Intel to get free samples and approached Paul Terrell, owner of The Byte Shop, a small chain of computer stores. Terrell ordered 50 computers of what became known as the Apple I but insisted that the computers be fully assembled. This was another step in the PC's evolution: computers were no longer just for hobbyists. In planning the Apple II, Jobs studied the Cuisinart and decided that this PC should be like an appliance: fit together with a sleek case, no assembly required and everything—the power supply, the keyboard, the software and monitor—would be tightly integrated. It went on sale in June 1977 for $1,298, and within three years 100,000 had been sold. With the Apple II and later computers, Apple pioneered the practice of creating machines that users were not supposed to open and fool around with. With the Apple II, Jobs also established the doctrine that his company's hardware would be integrated with its operating system software.

"The integrated model did not become standard practice," notes Isaacson. "The launch of the Apple II woke up the big computer companies, most notably IBM, and prompted an alternative to emerge. IBM—more specifically as it was outmaneuvered by Bill Gates—would embrace an approach in which the personal computer's hardware and its operating system were made by different companies. As a result, software would become king, and except at Apple, most computer hardware would become a commodity."

Dan Bricklin and VisiCalc: For personal computers to be more than toys, they had to be useful: There needed to be application software that could put the computer's processing power to work to perform a specific chore. Software engineer Dan Bricklin conceived the first financial spreadsheet program, VisiCalc. Bricklin and his collaborators had the sense to make VisiCalc a product, not just a program. Because it was written initially for the Apple II, Visicalc ramped up the computer's sales. "Thus did VisiCalc not only stimulate the market for personal computers," says Isaacson, "but it helped to create an entire new profit-driven industry, that of publishing proprietary application software."

The IBM operating system: In 1980, an IBM team, which was in the process of creating its own personal computer, met with Gates. First they talked about licensing programming language, both current and future. But then the team realized that it needed an operating system, the software program that handles the basic instructions that other software uses, including data storage, memory allocation and software application interaction. Gates realized that one operating system, most likely the one chosen by IBM, would end up being the standard operating system that the PC would use.

Microsoft didn't have an operating system but knew of a struggling local Seattle company that did. The company went and bought the software for a "pittance," writes Isaacson, acquiring "software that, after they spruced it up, would allow it to dominate the software industry for more than three decades." Then came the masterstroke: While Microsoft had bought the DOS software outright "for whatever usage," Gates did not make the same arrangement with IBM. In the deal that was struck in November 1980, IBM's license to use the operating system, which was called PC-DOS, would be nonexclusive. Microsoft could license the same operating system to other PC makers under the name MS-DOS. Microsoft would keep control of the source code. IBM couldn't modify or evolve the software into something that became proprietary to its machines.

The IBM PC made its debut August 1981 for $1565, but Gates and Allen weren't invited as the company thought of Microsoft as a vendor. "Gates got the last laugh," writes Isaacson. "Thanks to the deal he made, Microsoft was able to turn the IBM PC and its clones into interchangeable commodities that would be reduced to competing on price and doomed to having tiny profit margins."

The Graphical User Interface (GUI): While at Xerox PARC, Jobs had seen GUI, which featured a desktop metaphor with windows, cute icons for documents and folders as well as a trash can, and a mouse-controlled cursor that made the icons easy to click. Jobs was determined to incorporate the interface ideas into a simple, inexpensive PC. He pushed for the design to be incorporated into the mass-market affordable Macintosh (1984). In a memorable PC moment—which would be echoed in later Apple releases—Jobs unveiled the Macintosh, walking across a dark stage, pulling the new computer out of a cloth bag, as the theme song from Chariots of Fire played and the word MACINTOSH scrolled horizontally across a screen.

Of Jobs's borrowing Xerox PARC's ideas, Isaacson says: "Conception is just the first step. What really matters is execution. Jobs and his team took Xerox's ideas, improved them, implemented them, and marketed them."

Windows: Until the appearance of the Macintosh, Jobs and Gates had a good relationship. Apple had a deal with Microsoft to write new versions of its software for the Mac and at a meeting Jobs shared with Gates his plans. In the 1981 contract, Microsoft agreed that it would not produce for a period of time for any company other than Apple any software "that utilizes a mouse or tracking ball" or point-and-click graphical interfaces. The prohibition would last until the end of 1983 (as it turned out, the Mac didn't ship until January 1984). Microsoft, however, secretly began designing a new operating system to replace DOS in September 1981 and based it on the desktop metaphor with windows, icons, mouse and printer. Jobs was livid over what had happened and remained resentful for the rest of his life. Windows eventually dominated in the PC market.

"The primary reason for Microsoft's success," maintains Isaacson, "was that it was willing and eager to license its operating system to any hardware maker. Apple, by contrast, opted for an integrated approach. Its hardware came only with its software and vice versa. Jobs was an artist, a perfectionist, and thus a control freak who wanted to be in charge of the user experience from beginning to end. Apple's approach led to more beautiful products, a higher profit margin, and a more sublime user experience. Microsoft's approach led to a wider choice of hardware. It also turned out to be a better path for gaining market share."

Richard Stallman and the free and open-source software movements: Yet another approach to the creation of software emerged in late 1983 that has continued through to the present. Richard Stallman, who had been at MIT but left to avoid any patent issues, decided to develop an operating system similar to and compatible with UNIX, which was the standard for most universities and hackers. He called his operating system GNU. When he proposed the operating system, Stallman proclaimed "I consider that the Golden Rule requires that if I like a program I must share it with other people who like it.

Software sellers want to divide the users and conquer them, making each user agree not to share with others. I refuse to break solidarity with other users in this way. … Once GNU is written, everyone will be able to obtain good system software free, just like air.”

Stallman wrote the initial components for the GNU operating system, including a text editor and compiler. What it lacked, however, was the central module, the “kernel”, which manages the request from software programs and turns them into instructions for the computer’s central processing unit. He also came up with a GNU General Public License, giving people rights to run, copy, modify, and distribute the program.

Linus Torvalds: In 1991, Finland’s Linus Torvalds created his own computer program, Linux, which contained 10,000 lines of code. He decided to share it with the hope that others would improve it. “His release of his Linux kernel led to a tsunami of peer-to-peer volunteer collaboration that became a model of the share production that propelled digital-age innovation,” writes Isaacson. A year after its release, Linux had improvements such as a Windows-like graphical interface and tools to facilitate the networking of computers.

“The combination of GNU and Linux created an operating system that has been ported to more hardware platforms, ranging from the world’s ten biggest supercomputers to embedded systems in mobile phones, than any other operating system,” concludes Isaacson. “Linux is subversive,” wrote Eric Raymond in *The Cathedral and the Bazaar*, a history of the open-source movement. “Who would have thought that a world-class operating system could coalesce as if by magic out of part-time hacking by several thousand developers scattered all over the planet, connected by the tenuous strands of the Internet.” Linux became a model as well for commons-based peer productions, such as Mozilla’s Firefox browser and Wikipedia.

chapter ten:

online

While the Internet and the personal computer both were developed in the 1970s, they operated on separate tracks for more than a decade. This was partially because of the different users' mindset: while some loved the joy of networking, others saw the PC as a machine to enjoy on their own. A more tangible reason, however, was that the ARPANET and other private networks were not accessible to the majority of computer users. Writes Isaacson: "For almost fifteen years, beginning in the early 1970s, the growth of the Internet and the boom in home computers proceeded in parallel. They didn't intertwine until the late 1980s, when it became possible for ordinary people at home or in the office to dial up and go online. This would launch a new phase of the Digital Revolution … computers would augment human intelligence by being tools both for personal creativity and for collaborating."

Email and bulletin boards: Over the years, the desire to communicate, collaborate and form community has led to the creation of "killer apps." ARPANET got its first—email—in 1972. Users of big central computers had been able to use a program to send messages to others sharing the same computer. In late 1971, Ray Tomlinson, an MIT engineer working at BBN, created a hack that allowed messages to be sent to folders on other mainframes. The most ingenious part of his file transfer program was to use the @ sign on his keyboard to create the addressing system (username@hostname).

Email became the main method for collaborating, with a 1973 study finding that email accounted for 75 percent of the ARPANET's traffic. Virtual communities also sprouted, growing out of email chains that became known as mailing lists. By February 1978, the first computer Bulletin Board System allowed hackers, hobbyists and self-appointed "sysops" (system operators) to set up their own online forums, and in 1979 another innovation appeared: a threaded message-and-reply discussion forum called "Usenet" with the categories of postings on it called "newsgroups."

Modems: The average PC user, however, could not access the developing virtual communities. The modem, which could modulate and demodulate an analog signal (such as that carried by a telephone circuit) in order to transmit and receive digital information, finally enabled users to hook up. The modem was slow in coming because of AT&T's near monopoly of the phone system and its willingness to go to court to fight early modems that were developed, and the technology was expensive. But in 1975, the Federal Communications Commission opened the way for consumers to attach electronic devices to the network, and in 1981 the Hayes Smartmodem, which could be plugged directly into a phone line and connected to a computer, came on the market.

The WELL: Visionary Stewart Brand helped to conjure up the prototypic online community: The WELL (Whole Earth 'Lectronic Link). Working with physician and epidemiologist Larry Brilliant, who had used a conferencing system to bring medical expertise to far-flung communities as well as to organize missions when problems arose, Brand proposed creating an online community where people could discuss whatever they wanted. He insisted that participants could not be totally anonymous; They could use a handle or pseudonym but had to sign up with their real names so other members knew who they were. "Like the Internet itself, The WELL became a system designed by its users," notes Isaacson. "There was minimal hierarchy or control, so it evolved in a collaborative way."

William Ferdinand von Meister and The Source: In 1978, serial entrepreneur William Ferdinand von Meister, whose nine startups in 10 years included a bulk telephone routing system for businesses and a service called Infocast that sent information through computers by piggybacking digital data on FM radio signals, created The Source. His creation was the first consumer-oriented online service, using telephone lines to link home computers into a network. The Source also focused on creating community with its forums, chat rooms and private file-sharing area. Unfortunately, von Meister was not able to manage it effectively, and The Source was later sold to *Reader's Digest* and then to CompuServe. Yet von Meister was undaunted by his missteps: "His ilk made forgiving failure a feature of the Internet Age," says Isaacson. "Through his serial failures, he helped to define the archetype of the Internet entrepreneur and, in the process, invent the online business."

Von Meister's next companies Control Video Corporation (CVC) and GameLine, which allowed Atari users to download video games for purchase or rent, found customers. He began to bundle GameLine with some of the information services that had been in The Source. Among the early investors of the service was investment bank Hambrecht & Quist's Dan Case, whose younger brother Steve also became involved.

Q-link: Early in his career Steve Case had worked for Procter & Gamble and learned a valuable trick: Launch a new product by giving it away. The company floundered but an interesting triumvirate controlled it: the undisciplined idea generator von Meister, the strategic Case and the rough-edged manager Jim Kimsey. In 1984, CBS, Sears, and IBM formed a computer network service called Prodigy. Commodore computers then came to CVC and asked the company, which was renamed Quantum, to create an online service for it. The result was Q-Link, which included news, games, soap opera updates and most importantly, an area with active bulletin boards and live chat rooms. Within two months Q-Link had 10,000 members but Quantum's management realized that success depended on branching out to other computer makers.

America Online: In 1987, Apple's customer service department struck a deal with Quantum for AppleLink. Case then made a similar deal with Tandy but also realized that these separate private-label services could not connect with one another. Moreover the computer makers were dictating Quantum's products and marketing. Then Apple pulled the plug, deciding that it didn't like a third-party using the Apple brand name. Case and Kimsey decided to combine the users of the three services into one integrated service with its own brand name and an unbundled software approach that worked on all computer platforms: America Online.

“AOL, as it became known, was like going online with training wheels. It was unintimidating and easy to use,” notes Isaacson. “Case applied the two lessons he had learned at Proctor & Gamble: make the product simple and launch it with free samples. America was carpet-bombed with software disks offering two months of free service.” Moreover “members,” not customers, were greeted when they signed on with the messages “‘Welcome!’” and “‘You’ve got mail!’” that made the service feel friendly.

Al Gore and the eternal September: AOL and other online services developed independently of the Internet, functioning as walled gardens that coddled their users who were not able to access the Internet directly. When access opened up, it transformed the Internet by producing a flood of new users, and importantly, “began to connect the strands of the Digital Revolution in the way that Bush, Licklider and Engelbart had envisioned. Computer and communications and repositories of digital information were woven together at the fingertips of every individual.” In September 1993, AOL allowed its members access to the newsgroups and bulletin boards of the Internet. Veteran “netizens” referred to this phenomenon as the Eternal September, as a never-ending flow of newbies flooded in.

This opening-up of the Internet was not happenstance but rather the result of a carefully crafted, bipartisan policy led by Tennessee’s Senator Al Gore Jr. Gore had looked into technological developments in a congressional study in 1986, then held hearings that led to the High Performance Computing Act (1991) and the Scientific and Advanced Technology Act (1992). After his 1992 election as vice president, Gore pushed the National Information Infrastructure Act (1993) which made the Internet widely available to the general public and moved it into the commercial sphere, which allowed for both private and government investment.

"It's useful to reflect on what led to the Eternal September of 1993," writes Isaacson. "Over the course of more than three decades, the federal government, working with private industry and research universities had designed and built a massive infrastructure project, like the interstate highway system but vastly more complex, and then threw it open to ordinary citizens and commercial enterprises. It was funded primarily by public dollars, but it paid off thousands of times over by seeding a new economy and an era of economic growth."

chapter eleven:

the web

Ordinary computer users needed some form of a guide to navigate around the Internet: "it was a murky jungle with no maps … that could intimidate all but the most intrepid pathfinders," writes Isaacson. Tools were needed that enabled posting and finding content.

Tim Berners-Lee: Unlike many of the digital age pioneers Tim Berners-Lee, whose parents were computer scientists, grew up in a household where computers were integral. So, from an early age, he pondered what computers could—and couldn't—do. He was also fascinated by a Victorian-era almanac called *Enquire Within Upon Everything*. By the time Berners-Lee graduated from Oxford University, he was convinced that new ideas occur when a lot of random notions churn together until they coalesce. Berners-Lee took a consulting job at CERN, the mammoth supercollider and particle physics lab near Geneva. He needed to find a way to catalog the connections among the thousands of researchers, their projects and their computer system. To do so, he created a computer program named Enquire. He then had another idea: "Suppose all the information stored on computers everywhere were linked. There would be a single global information space. A web of information would form."

How could people brainstorm together when miles apart? He came up with a simple maneuver that made connections: hypertext (a word of phrase that is coded so that when clicked it sends the reader of another document or piece of content). There would be no central node and no command hub: If an individual knew the web address of a document, it could be linked to another document. Berners-Lee developed the Remote Procedure Call, a protocol permitting a program running on one computer to call up a subroutine on another computer. He then created standards for naming documents, what is known today as Uniform Resource Locators—the URLs that are in use today.

“By the end of 1990 he had created a suite of tools that allowed his network to come to life,” writes Isaacson: “a Hypertext Transfer Protocol (HTTP) to allow hypertext to be exchanged online, a Hypertext Markup Language (HTML) for creating pages, a rudimentary browser to serve as the application software that retrieved and displayed information, and server software that could respond to requests from the network.” Berners-Lee also resisted the attempts by CERN’s administrators to patent his ideas, insisting that the Web protocols be made available freely, shared openly and put perpetually into the public domain.

Marc Andreessen and Mosaic: To move around the Web, people needed a piece of software on their own computers that became known as a browser. Berners-Lee had written one but it was just for NeXT computers so others began exploring alternatives. By October 1993, the Web had grown from 50 Web servers to more than 500, spurred by Marc Andreessen’s creation of Mosaic, the first easy-to-install Web browser with graphic capabilities, at the National Center for Supercomputing Applications (NCSA) at the University of Illinois. Andreessen’s attention to user feedback also contributed to Mosaic’s success; he continually gathered suggestions and complaints from Internet newsgroups and then released updated versions.

Should content be free?: Berners-Lee’s vision of a browser and Andreessen’s didn’t dovetail, as Andreessen focused more on display features and less a collaborative tool. “I was disappointed that Marc didn’t put editing tools in Mosaic,” said Berners-Lee. “If there had been more of an attitude of using the Web as a collaborative medium rather than a publishing medium, then I think it would be much more powerful today.” A concept of two-way links, requiring the approval of both the creator and the recipient, also didn’t take hold. Had it done so, says Isaacson, “it would have been possible to meter the use of links and allow small automatic payments to accrue to those who produced the content that was used. … The entire business of publishing and journalism and blogging would have turned out differently. Producers of digital content could have been compensated in an easy, frictionless manner permitting a variety of revenue models, including ones that did not depend on being wholly beholden solely to advertisers. Instead the Web became a realm where aggregators could make more money than content producers."

The idea that content should be free took hold among media moguls, but the concept was not a sustainable business model. While the number of websites exploded exponentially, advertising stayed flat. "Consumers had been conditioned to believe that content should be free," writes Isaacson. "It took two decades to start trying to put that genie back in the bottle." As micropayments have emerged in the past few years, Andreessen, today a prominent venture capitalist, has been enthusiastic about their potential. "'If I had a time machine and could go back to 1993,' Andreessen has said, 'one thing I'd do for sure would be to build in Bitcoin or some similar form of cryptocurrency.'"

Justin Hall and how Web logs became blogs: Swarthmore College student Justin Hall created a website in 1994 titled Justin's Links From the Underground that users could find on the Web. Not only was his website the precursor for Web directories such as Yahoo, Lycos and Excite, but it also provided a running Web log of his activities, random thoughts, musings, and intimate encounters. He became the "founding scamp of blogging," says Isaacson. "The recipe for his and many future blogs: stay casual, get personal, be provocative."

That summer Hall interned in San Francisco at HotWired.com, which was part of Wired magazine, and he, along with others, argued that the website, in contrast to the paper edition, should be filled with user-generated material. His point of view differed from that of magazine editor Lou Rossetto, whose outlook "was shared by many other print-world editors [and] ended up shaping the evolution of the Web. It became primarily a platform for publishing content rather than for creating virtual communities." Hall felt differently and became the "Johnny Appleseed of Web logging." He posted on his website an offer to teach people HTML, and in the summer of 1996 traveled across America by bus, visiting whomever offered to put him up for a night or two in exchange for lessons. The social phenomenon—weblogs—humanized the Internet and spread quickly, and a few years later the phrase "blog" was commonly used to refer to this writing process. "'By publishing ourselves on the web, we reject the role of passive media marketing recipient," declared Hall. By 2014 there were 847 million blogs worldwide.

Ev Williams and Blogger: The right tools were needed for blogging to take off. "Creating user simplicity is one of the keys to successful innovation," notes Isaacson. "For blogging to become a whole new medium that could transform publishing and democratize public discourse, someone had to make it easy, as easy as 'Type in this box and then press this button.' Enter Ev Williams."

In 1999, Williams, along with Meg Hourihan, launched Pyra Labs, which offered a suite of Web-based applications that let teams share project plans, to-do lists, and create documents together. What Williams and Hourihan didn't have was a way to share their ideas, so they began posting on a little internal website called Stuff. Williams also had a personal website, and he posted his notes and comments to his homepage. But the process was laborious, as he had to type each item and update using HTML code. He wrote a simple software script that automatically converted his posts into the proper format. Williams launched his product, Blogger, and by the end of 2000 it had 100,000 accounts. Eventually the partnership between Williams and Hourihan unraveled; the company ran out of money, and by 2002, following the launch of Blogger Pro, was bought by Google.

"Williams's simple little product helped to democratize publishing," writes Isaacson. "'Push-button publishing for the people' was his mantra." But what began for publishing eventually became a social tool, and "the blogosphere evolved into being a community rather than merely a collection of soap-boxes." Williams went on to become a serial entrepreneur, later co-founding Twitter, and Medium, a publishing site designed to promote collaboration and sharing.

Ward Cunningham and Wikis: Although Tim Berners-Lee had envisioned the Web as a collaboration tool, innovations such as the Mosaic browser had turned Web surfers into passive consumers. In 1995, the collaborative tool wiki, which allowed users to modify Web pages by clicking and typing directly onto the pages through wiki software, was invented.

Ward Cunningham at Tektronix needed a way to track projects so he modified a software product named HyperCard, which let people create their own hyperlinked cards and documents on their PCs. His modification enabled people to make the cards and links through a black box on each card in which you could type a tile or word or phrase. Cunningham then developed an Internet version of his HyperText program, which let users edit and contribute to a Web program. He called the software and the program WikiWikiWeb, which allowed anyone to edit and contribute without a password and was available for anyone to modify and use. Soon there were scores of wiki sites as well as open-source improvements to his software, but for several years they were known only within the software engineer community.

Jimmy Wales and Wikipedia: "Before the rise of search engines, among the hottest Internet services were Web directories, which featured human-assembled lists and categories of cool sites, and Web rings, which created through a common navigation bar a circle of related sites that were linked to one another," writes Isaacson. Jimmy Wales had been involved in several Web rings and realized the value of user-generated content, having seen this particularly in a sports ring where users provided better knowledge than any expert. Wales decided to create a free encyclopedia (Nupedia) that would be written by volunteers. "Imagine a world in which every single person on the planet is given free access to the sum of all human knowledge," Jimmy Wales has said. "That's what we're doing."

The first concept for Nupedia had been to use experts, but few contributed. The second idea, Wikipedia, which used wiki software to create an encyclopedia, flourished. Anyone could edit a page and results popped up instantly. Key to Wikipedia was the principle that articles must have a neutral point of view. This resulted in their being straightforward, even when tacking controversial topics, and made it easier for people with different approaches to contribute. By creating a consensus article and weaving together different strands, Wikipedia became a model of how digital tools can be used to find common ground in society. One month after its launch, Wikipedia had 1,000 articles. At the beginning of 2014, it had 30 million articles in 287 languages. Proclaims Isaacson: "The result has been the greatest collaborative knowledge project in history."

Isaacson concludes: "Wikipedia was not about building a machine that could think on its own. It was instead a dazzling example of human-machine symbiosis, the wisdom of humans and the processing power of computers being woven together like a tapestry."

Jerry Yang, David Filo and Yahoo!: When Hall created Justin's Links from the Underground in January 1994 there were 700 hundred websites in the world. By the end of 1995 that number had jumped to 100,000. Anyone could access content and distribute it, but people also needed a way to find what they needed in this exploding universe.

By 1994, various engineers were producing crawlers, which moved from server to server on the Internet compiling an Index. These search tools, with names like AltaVista, Lycos and Excite, used link-hopping robots (bots) that moved around the Web grabbing URLs and information about each site. This information would be tagged, indexed and placed in a database that the query server could access.

Stanford graduate students Jerry Yang and David Filo created a directory that was organized by categories such as education, business, entertainment, government that were then broken down into subcategories. They named their directory to the Web "Yahoo!" Filo and Yang did not build their own crawler; they licensed it, focusing instead on the importance of the information their employees served up. Yahoo!'s reliance on humans resulted in its being best at providing news, rather than being a search tool. "The Yahoo! team believed, mistakenly, that most users would navigate the Web by exploring rather than seeking something specific," writes Isaacson. "Automated search engines would become the primary method for finding things on the Web, with another pair of Stanford graduate students leading the way."

Larry Page and Sergey Brin: Like many great innovators, Larry Page and Sergey Brin had complementary personalities. Page, the son of a computer scientist and a programmer, grew up in the world of computing. Far quieter, Sergey Brin's parents were mathematicians, Russian Jews who emigrated to the U.S. when he was five-years old. Soon after the two met up as graduate students at Stanford in the fall of 1995, they became an inseparable duo.

Page's interest in human-computer interaction led him to decide on a dissertation that would assess the relative importance of different sites on the Web. Because of the way the Web was designed, there was no way to analyze the relative importance of sites. Page wanted to figure out a way to gather a huge database of the links and then follow them in reverse to see which sites were linking to each page. Mapping the Web was a huge task so Page built a Web crawler that started from his home page and followed all the links it encountered. By July 1996, he had collected 24 million URLs and more than 100 million links.

From BackRub to Google: At that point, Brin joined Page on the project he called BackRub. The plan for BackRub was to be a compilation of Web backlinks that would be the basis for a possible annotation and citation analysis. "Amazingly, I had no thought of building a search engine," Page admitted. "The idea wasn't even on the radar." But "as the project evolved," writes Isaacson, "he and Brin conjured up more sophisticated ways to assess the value of each page, based on the number and quality of links coming into it. That's when it dawned on the BackRub boys that their index of pages ranked by importance could become the foundation for a high-quality search engine. The revised project became known as PageRank, and thus Google was born.

In an academic paper they spelled out their complex formula: "A page has a high rank if the sum of the ranks of its backlinks is high. This covers both the case when a page has many backlinks and when a page has a few highly ranked backlinks." Page and Brin named their search engine Google, playing off the word "googol," which is the figure 1 followed by 100 zeros equal to 10100. In refining Google they allocated more bandwidth, processing power, and storage capacity to their Web crawlers than others so it indexed 100 pages per second. They studied user behavior closely so that they could understand when users found the results they wanted on the first click and when they had to keep looking, a feedback loop that enabled them to refine search. Page and Brin began to license their software to other companies but there was a lack of interest. They eventually launched their own company in September 1998, with money from investor Andy Bechtolsheim, who also brought in other prominent funders.

"In addition to making all of the World Wide Web's information accessible, Google represented a climactic leap in the relationship between humans and machines," writes Isaacson. "The approach that Page and Brin took might appear, at first glance, to be a way of removing human hands from this formula by having the searches performed by Web crawlers and computer algorithms only. But a deeper look reveals that their approach was in fact a melding of machine and human intelligence. Their algorithm relied on the billions of human judgments made by people when they created links from their own websites. It was an automated way to tap into the wisdom of humans—in other words, a higher form of human-computer symbiosis."

chapter twelve:

ada forever

Ada Lovelace would have been pleased to discover that calculating devices had morphed in the 1950s into general-purpose computers that, as she once imagined, would "combine together general symbols in successions of unlimited variety." In the next 30 years, computers became small enough to be personal devices because of microchips and were also able to be connected to the Internet through packet-switched networks. Writes Isaacson: "This merger of the personal computer and the Internet allowed digital creativity, content sharing, community formation, and social networking to blossom on a mass scale. It made real what Ada called 'poetical science,' in which creativity and technology were the warp and woof, like a tapestry from Jacquard's loom."

But can machines think? Alan Turing created the Turing Test and tried to dismiss Ada's contention that no machine would ever be a "thinking" machine. He called her belief "Lady Lovelace's Objection." Observes Isaacson: "It's now been more than sixty years, and the machines that attempt to fool people on the test are at best engaging in lame conversation tricks rather than actual thinking. Certainly none has cleared Ada's higher bar of being able to 'originate' any thoughts of its own."

Lady Lovelace's Objection: Experts have predicted for generations that artificial intelligence (AI) is on the horizon, but so far it hasn't emerged. The press focused a bit on AI after IBM'S chessplaying Deep Blue beat world chess champion Garry Kasparov in 1997, and then again in 2011 when Watson, IBM's natural-language question-answering computer, won at *Jeopardy!*. Watson won because it had 200 million pages of information in its four terabytes of storage to draw on, but as Isaacson notes, it also tripped up in ways that showed it wasn't human. When asked, for example, about the "anatomical oddity" of a former Olympic gymnast Watson answered "What is a leg?" while the correct answer was that the Olympian was missing a leg. Watson's problem was understanding oddity, according to the IBM specialist who ran the Watson project: "The computer wouldn't know that a missing leg is odder than anything else."

Brilliant idiots: "Computers today are brilliant idiots," says John E. Kelly III, director of IBM Research. "They have tremendous capacities for storing information and performing numerical calculations—far superior to those of any human. Yet when it comes to another class of skills, the capacities for understanding, learning, adapting, and interacting, computers are woefully inferior to humans." Ask Google a hard question, such as 'What is the depth of the Red Sea?, and it will instantly respond, '7,254 feet,' something even your smartest friends don't know," writes Isaacson. "Ask it an easy one like 'Can a crocodile play basketball?' and it will have no clue, even though a toddler could tell you, after a bit of giggling." Perhaps in a few more decades there could be machines that think like humans—but maybe not.

Human-computer symbiosis: Ada Lovelace declared that "the Analytical Engine has no pretensions whatever to originate anything. It can do whatever we know how to order it to perform." Lovelace envisioned a partnership between machines and humans, with humans bringing originality and creativity to the relationship. Augmented intelligence, not artificial intelligence, would result. The teams that built Deep Blue and Wilson have adopted this symbiosis approach. "The goal is not to replicate human brains," says IBM's Kelly. "This isn't about replacing human thinking with machine thinking. Rather, in the era of cognitive systems, humans and machines will collaborate to produce better results, each bringing their own superior skills to the partnership."

In recent years, Watson has been collaborating with physicians on cancer treatment. Commented a breast cancer specialist at New York's Memorial Sloan Kettering Cancer Center: "Computer science is going to evolve rapidly, and medicine will evolve with it. This is co-evolution. We'll help each other." In 2012, IBM launched a new division called Watson, whose mission is to commercialize "cognitive computing." Computing systems will be able to move data analysis to the next level by teaching themselves to complement the human brain's skills. This view of machines and humans getting smarter together has been called "bootstrapping" and "co-evolution."

"Artificial intelligence need not be the holy grail of computing," writes Isaacson. "The goal instead could be to find ways to optimize the collaboration between human and machine capabilities—to forge a partnership in which we let the machines do what they do best, and they let us do what we do best."

Lessons from the journey: This book has chronicled the many strands of innovation that created the digital age. Beyond the power of human-machine symbiosis, what lessons might be drawn from the tale?

1. **The importance of collaboration:** Creativity is a collaborative process. Innovation comes from teams more often than from the actions of lone geniuses.
    - While the digital age may seem revolutionary, it is based on the ideas handed down from previous generations. Collaboration has also been between contemporaries and between generations.
    - The most productive teams, at places such as Bell Labs, brought together people with a wide variety of specialties.
    - Although the Internet provided a tool for far-flung and virtual collaborations, another lesson of digital-age innovation has been that physical proximity is beneficial.
    - The best leadership comes from teams made up of people with complementary styles.
    - Creating a great team often involves pairing visionaries who generate ideas with operating managers able to execute them. Visionaries who lack these partners often become footnotes in history.

Concludes Isaacson: "The Internet facilitated collaboration not only within teams but also among crowds of people who didn't know each other. This is the advance that is close to being revolutionary. But never before has it been easy to solicit and collate contributions from thousands or millions of unknown collaborators. This led to innovative systems—Google page ranks, Wikipedia entries, the Firefox browser, the GNU/Linux software—based on the collective wisdom of crowds."

2. **Team building in the digital age:** There were three ways that teams were built in the digital age.
    - Government funding and coordination brought together the groups that built the original computers, such as Colossus and ENIAC, and networks (ARPANET). This often occurred in collaboration with universities and private contractors as part of a government-academic-industrial triangle.
    - Private enterprise, with the lure of profit, also brought teams together at places like Bell Labs and Xerox PARC and at entrepreneurial companies such as Texas Instruments, Intel, Atari, Google, Microsoft and Apple.
    - Peers freely shared ideas and made contributions as part of a voluntary common endeavor in efforts such as the building of Wikipedia and the Internet. "Commons-based peer production," as this type of collaboration has been labeled, was based not on financial incentives but by other forms of reward and satisfaction.

"The values of commons-based sharing and of private enterprise often conflict, most notably over the extent to which innovations should be patent-protected," observes Isaacson. "Innovation is most vibrant in the realms where open-source systems compete with proprietary ones."

3. **Leadership:** The most successful endeavors were run by leaders with a clear vision who also fostered collaboration.
    - Brilliant individuals who could not collaborate tended to fail.

- Collaborative groups that lacked passionate and willful visionaries also failed.
- Most of the successful innovators and entrepreneurs were product people who cared about, and understood, the engineering and design.

4. **"Man is a social animal":** Almost every digital tool was commandeered by humans for a social purpose: to create communities, facilitate communication, collaborate on projects and enable social networking. Although the PC was originally perceived as a tool for individual creativity, it soon led to the rise of modems, online services and eventually Facebook, Flickr, and Foursquare.

5. **Machines are not social:** "Digital Tools have no personalities, intentions or desires. … They are what we make of them," notes Isaacson.

6. **Ada's lasting lesson—poetical science:** As Ada Lovelace pointed out, individuals bring creativity to the machine-human partnership.
   - In an age of cognitive computing, humans can remain relevant because they are able to think differently and possess an imagination that algorithms lack. Human imagination, as Lovelace said, "brings together things, facts, ideas, conceptions in new original, endless, ever-varying combinations."
   - Human creativity encompasses values, intentions, aesthetic judgments, emotions, personal consciousness and a moral sense.
   - People who love technology need to appreciate the liberal arts, and those who love the arts and humanities need to appreciate the beauties of math and physics.

In conclusion: As Walter Isaacson comes to the end of *The Innovators*, he offers some key observations worth quoting in their entirety:

- "At his product launches, Steve Jobs would conclude with a slide, projected on the screen behind him, of street signs showing the intersection of Liberal Arts and Technology. At his last such appearance, for the iPad2 in 2011, he stood in front of that image and declared, 'It's in Apple's DNA that technology alone is not enough—that it's technology married with liberal arts, married with the humanities, that yields us the result that makes our heart sing.' That's what made him the most creative technology innovator of our era."
- "C.P. Snow was right about the need to respect both of 'the two cultures,' science and humanities. But even more important today is understanding how they intersect. Those who helped lead the technology revolution were people in the tradition of Lovelace, who could combine science and the humanities."
- "The next phase of the Digital Revolution will bring a true fusion of technology with the creative industries, such as media, fashion, music, entertainment, education, literature and the arts. Until now much of the innovation has involved pouring old wine—books, newspapers, opinion pieces, journals, songs, television shows, movies—into new digital bottles. But the interplay between technology and the arts will eventually result in completely new forms of expression and formats of media."
- "This innovation will come from people who are able to link beauty to engineering, humanity to technology, and poetry to processors. In other words, it will come from the spiritual heirs of Lovelace, creators who can flourish where the arts intersect with the sciences and who have a rebellious sense of wonder that opens them to the beauty of both."

A note on the writing of the book:

In writing *The Innovators*, which is a work of contemporary history, Walter Isaacson, in addition to thanking experts, friends and family, drew upon interviews with many of the digital age's key players, including Tim Berners-Lee, Bill Gates, Andy Grove, Gordon Moore, Larry Page, Jimmy Wales, Evan Williams, and Steve Wozniak. "I also tried something different for this book," he writes, "crowdsourcing suggestions and corrections on many of the chapters." While getting reader comments isn't a new idea, Isaacson turned to the Internet for his "comments and corrections" making the request of thousands of people whom he didn't know. "This seemed fitting, because facilitating the collaborative process was one reason the Internet was created. One night when I was writing about that, I realized that I should try using the Internet for this original purpose. It would, I hoped, both improve my drafts and allow me to understand how today's Internet-based tools (compared to Usenet and the old bulletin board systems) facilitate collaboration."

"I experimented on many sites," he explains. "The best, it turned out, was Medium, which was invented by Ev Williams, a character in this book. One excerpt was read by 18,200 people in its first week online. That's approximately 18,170 more draft readers than I've ever had in the past. Scores of readers posted comments, and hundreds sent me emails. This led to many changes and additions as well as an entirely new section (on Dan Bricklin and VisiCalc)."

Summary by Lois Gilman

Lois Gilman has written for a variety of magazines, including *Corporate Board Member, Money* and *Time*. She has worked on the program development of numerous business conferences, including the Fortune Global Forum and the Wall Street Journal CEO Council. Gilman was a head researcher at Time Life Books; a senior reporter at *Time* Magazine; a program research manager at Fortune conferences; and the Web files editor of *Business 2.0* magazine. She is also the author of *The Adoption Resource Book* and *The New York Parents' Book*.

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