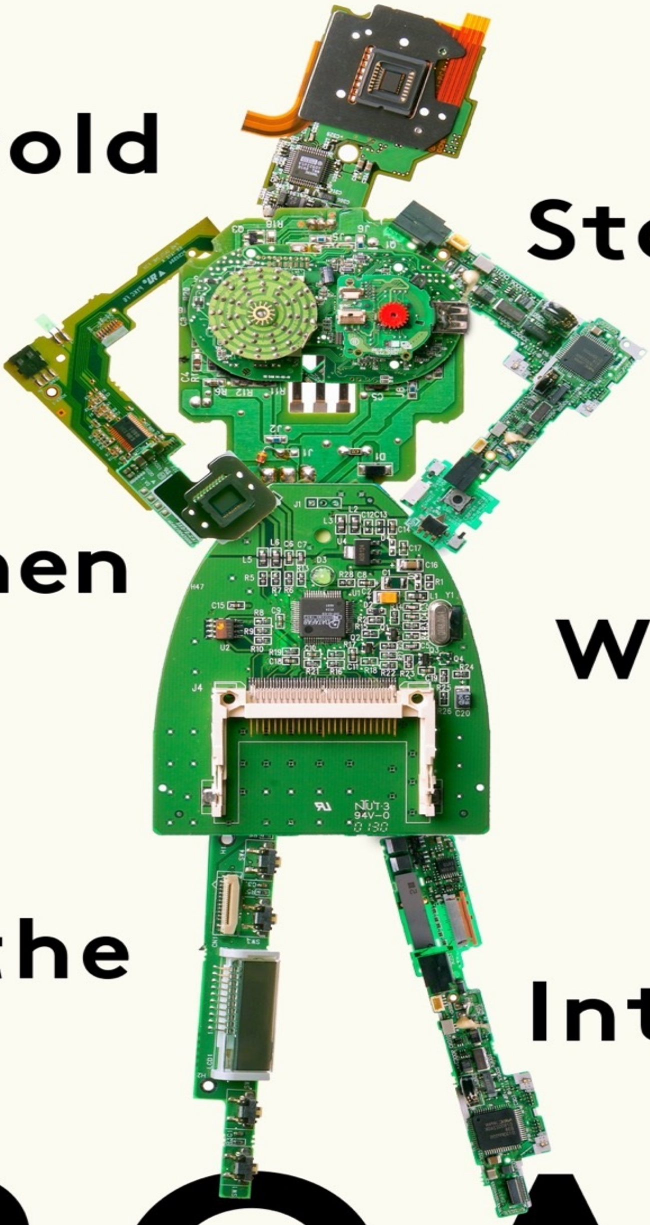

The Untold Story of the Women Who Made the Internet

BROAD BAND

Claire L. Evans

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PORTFOLIO/PENGUIN

Portfolio/Penguin
An imprint of Penguin Random House LLC
375 Hudson Street
New York, New York 10014

ISBN: 9780735211759 (hardcover)
ISBN: 9780735211766 (e-book)

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Version_1

For the users

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Introduction

THE DELL

When I was younger, I had a Dell.

It was a beige box fastened to the Internet with a 28.8K modem that screeched with every connection. Its keys were as tall as sugar cubes and slightly concave. The installation occupied the elbow of an L-shaped desk in my bedroom's inner sanctum. Over the years, I laid stickers in geological strata across the white laminate of my desk. Peeled one at a time, they'd have revealed earlier versions of the girl sticking them, like a candy passing through its flavors as it melts in the mouth. A teenage girl's room is a cockpit, an altar, and a womb: it contains her most sacred things, and it holds her as she grows, until eventually it ejects her into the world.

The Dell underwent its own changes. It ran every Microsoft operating system from MS DOS to Windows 95. The DOS era was wonderful: games on floppy disk, terminal commands. Over time, my monitor's blunt plastic bezel thickened with coats of glitter nail polish and Post-It notes. *GET A LIFE,* I wrote across the Dell's frame, in Sharpie, in anger, in devotion.

When the Internet came into my life, it was as though my monitor became a glass gate. It opened to an infinite channel. When the modem stuttered, I'd shower it in compliments: *You are such a good modem, and I believe you can do anything*. It was my own compulsive folk tradition. I believed, then, that information, like people, needed support on its journey across the world. In my early years online, I learned how to write HTML and built rudimentary sites honoring my favorite bands. I sent passionate e-mails to estranged summer camp friends. I found answers to the questions I was too shy to ask. I made pen pals I was afraid of meeting. I journaled in pocket communities now obsolete. In short, I became myself, enjoying the freedoms the computer afforded me, freedoms both *from*—isolation, shyness, ignorance—and *to*—learn, experiment, discover, and play.

I abandoned the Dell when I left for college with a Sony VAIO, one of those tragic interstitial laptop models that will likely populate future museums of technology, with a detachable base that served mostly to heat the tops of my thighs. Like most consumer electronics in the United States, the Dell was likely landfilled, or else dispatched by container ship to China, Malaysia, India, or Kenya, where it was disarticulated like a chicken carcass, cables snipped, guts stripped of valuable metals and ores. Today I think about how the glitter-encrusted monitor must have looked to the underpaid laborers, working in a toxic field of unprocessed e-waste, who ground my Dell into plastic dust. Even once they've grown obsolete, computers never fully disappear—they only become somebody else's problem. Being mass-produced, they form part of our cultural memory, avatars, like my Dell, of childhood landscapes, or, like the Macintosh I never had, of personal computing as a whole. Doubtless this is why we so often consider the history of technology as a row of progressively smarter machines: from Chinese abaci to room-sized cabinets tended by pliant workers, from refrigerators with cathode-ray screens to ever-smaller incarnations of silicon and plastic, dwindling finally to the familiar handheld pane of glass. Anywhere along the line, it's tempting to eulogize the box. To point to one and say, "The people who made this changed the world." This story is not about those people.

This is a book about women.

It's also a book about the use of computers, real and potential. This is not to say that men make and women use—far from it—only that the technological history we're usually told is one about men and machines, ignoring women and the signals they compose. Female mental labor was the original information technology, and women elevated the rudimentary operation of computing machines into an art called programming. They gave language to the box. They wrestled brute mainframes into public service, showing how the products of industry could serve the people, if the intent was there. When the Internet was still an unruly assortment of hosts, they built protocols to direct the flow of traffic and help it grow. Before the World Wide Web came into our lives, female academics and computer scientists created systems to turn vast storehouses of digital information into knowledge; we abandoned those in favor of brute simplicity. Women built empires in the dot-com era, and they were among the earliest to establish and grow virtual communities. The lessons they learned in the process would serve us well today, if we'd listen.

None of this quantifies cleanly, which makes these women's contributions to computing difficult to catalog and even harder to memorialize. Although this book owes a debt of gratitude to the fine historical research it cites, I also drew from first-person accounts given by the women in these pages and from the fragmentary documentation characteristic of technological history: screenshots, chat logs, abandonware, outdated manuals, and eroded Web pages. I've done my best to explore what software artifacts remain, learning Unix commands and the social conventions of old-world online culture with the diligence of a student abroad. May the servers whir long enough to support more virtual tourism, because these places will become only more precarious with time. An irony: even as computer memory multiplies, our ability to hold on to personal memories remains a matter of will, bounded by the skull and expanded only by our capacity to tell stories.

There are technical women in these pages, some of the brightest programmers and engineers in the history of the medium. There are academics and hackers. And there are culture workers, too, pixel pushers and game designers and the self-proclaimed "biggest bitch in Silicon Alley." Wide as their experiences are, they've all got one thing in common. They all care deeply about the user. They are never so seduced by the box that they forget why it's there: to enrich human life. If you're looking for women in the history of technology, look first where it makes life better, easier, and more connected. Look for the places where form gives way to function. A computer is a machine that condenses the world into numbers to be processed and manipulated. Making this comprehensible to as many people as possible, regardless of technical skill, is not an essentially feminine pursuit. Nothing is. That being said, the women I talked to all seemed to understand it implicitly and to value it as fundamental, inalienable, and right.

To live with a box that connects the world to itself is expansive, life altering, and even a little magic. But the box itself is still only an object. If not taken to pieces and recycled, it'll poison Earth for millennia, a permanence justifiable only if we believe what happens before the landfill is worthwhile. Spiritual, even. Computers are built to be turned on, cables are meant to be patched in, and links are made to be clicked. Without the human touch, current may run, but the signal stops. We animate the thing. We give it meaning, and in that meaning lies its worth. History books celebrate the makers of machines, but it's the users—and those who design *for* the users—who really change the world.

Women turn up at the beginning of every important wave in technology. We're not ancillary; we're central, often hiding in plain sight. Some of the most wondrous contributions in these pages bloomed in the grubby medians of the information superhighway. Before a new field developed its authorities, and long before there was money to be made, women experimented with new technologies and pushed them beyond their design. Again and again, women did the jobs nobody thought were important, until they were. Even computer programming was initially passed off onto the girls hired to patch cables and nothing more—until the cables became patterns, and the patterns became language, and suddenly programming was something worth mastering.

A few notes before we go. I take as a given in this book that sex is to gender as body is to soul. "Woman" means something different for everyone. There's no end to the ways in which it can be inhabited, and any loosening of the categories liberates a great many individual lives. That being said, women often share experiences, and particularly in environments where we are in the minority, it's nice to look for commonalities that can bolster our solidarity. One more: the history of computers is an alphabet salad. We'll meet ENIAC and UNIVAC and ARPANET and PLATO and the WWW. It can be difficult to read these acronyms without feeling like the past is yelling at you. Please don't despair. It's half the fun.

Onward now. My Dell is gone, its memory wiped. What remains of it isn't etchings on a hard drive but markings on a person: the user pushing symbols around. My memories of the Dell are like memories I have of family and friends. They're memories of time spent together, of journeys traveled. Memories of revelation and transgression. That's the miraculous thing about technology: it's never wholly separate from us. Just as a hammer strengthens the hand, or a lens the sight, the computer amplifies a person, extending the touch of even a teenage girl into the world. I am the computer, and the computer is me.

I won't be the last to feel this way. And I certainly wasn't the first.

PART ONE

The Kilogirls

Chapter One

A COMPUTER WANTED

It's 1892 in New York City. In January, an immigration processing center called Ellis Island opened for business. In March, in Springfield, Massachusetts, a YMCA instructor desperate to keep a class of stir-crazy youngsters entertained indoors hosted the first public game of "basket ball." But the winter is over, and it's the first of May, just shy of summer, just shy of the twentieth century. It's before the screen, the mouse, the byte, the pixel, and one hundred years before my Dell, but there's a strange notice in the classified pages of the *New York Times*.

A COMPUTER WANTED, it says.

This ad is the first instance of the word "computer" in print. It wasn't placed by an indiscreet time-traveler, someone trapped in the Gilded Age and jonesing for the familiar glow of their MacBook. It was placed by the United States Naval Observatory in Washington, DC, which was by then several decades into a mathematical astronomy project: calculating, by hand, the positions of the sun, stars, moon, and planets across the night sky. The observatory's directors were not in the market, that spring, to buy a computer. They were looking to hire one.

For close to two hundred years, a computer was a job. As in someone who computes, or performs computations, for a living. Had one been browsing the *Times* that May Day in 1892 and decided to answer the classified ad, they'd soon be taking an algebra test. The Naval Observatory job was cushy, relatively: those who lived nearby worked in a cozy, informal office in Cambridge, far from the observatory itself, which was perched on a bluff above the Potomac. They clocked five-hour days, charting the skies from individual tables by a roaring fire, pausing often to discuss the scientific ideas of the day. The rest worked from home, from detailed mathematical plans they received in the mail. Computing, as one historian has noted, was the original cottage industry.

Every day, these computers—much as computers do today—would chip away at complicated, large-scale math problems. They wouldn't do it alone. Our new hire would be part of a team: everyone crunching their share of the numbers, some correcting each other's work for extra income. With pen and paper alone, the Naval Observatory team would chart the skies, just as other computing offices throughout the Western world would advance ballistics, maritime navigation, or pure mathematics. They wouldn't receive much individual credit, but whatever the problem was, they'd have been instrumental in solving it.

Computing offices were thinking factories. The nineteenth-century British mathematician Charles Babbage, whose desire to calculate by steam led to important early developments in mechanical computing, called what the human computing offices of his time did "mental labor." He considered it work one did with the brain, just as hammering a nail is work one does with the arm. Indeed, computing was the grunt labor of organized science; before they were made obsolete, human computers prepared ballistics trajectories for the United States Army, cracked Nazi codes at Bletchley Park, crunched astronomical data at Harvard, and assisted numerical studies of nuclear fission on the Manhattan Project. Despite the diversity of their work, human computers had one thing in common. They were women.

Mostly, anyway. The Naval Observatory hired only one female computer for its Nautical Almanac Office, although she was by far the most famous among them: Maria Mitchell, a Quaker from Nantucket Island, who had won a medal from the king of Denmark before she was thirty for discovering a new comet in the night sky. It came to be known as "Miss Mitchell's Comet." At the observatory, Mitchell calculated the ephemeris of Venus, being, as her supervisor told her, the only computer fair enough to tackle the fairest of the planets.

Her presence as a woman in a computing group was unusual for its time, but it would only become less so. Maria Mitchell discovered her comet only a year before the Seneca Falls Conference on the Rights of Women, which was largely organized by Quaker activists. Her church was the sole religious denomination allowing women to preach to its congregations, and Maria's father, an amateur astronomer, lobbied aggressively for her accomplishments to be recognized. Before the end of the twentieth century, however, computing would become largely the purview of women. It was female mental laborers, breaking intractable problems down into numerical steps much as machines tackle problems today, who ushered in the age of large-scale scientific research.

By the mid-twentieth century, computing was so much considered a woman's job that when computing machines came along, evolving alongside and largely independently from their human counterparts, mathematicians would guesstimate their horsepower by invoking "girl-years," and describe units of machine labor as equivalent to one "kilogirl." This is the story of the kilogirls. It begins, as the most beautiful patterns do, with a loom.

THE SPIDER WORK

The loom is a simple technology, but in the warp and weft of thread lies the weaving of all technologically literate society. Textiles are central to the business of being human, and like software, they are encoded with meaning. As the British cultural theorist Sadie Plant observes, every cloth is a record of its weaving, an interconnected matrix of skills, time, materials, and personnel. "The visible pattern" of any cloth, she writes, "is integral to the process which produced it; the program and the pattern are continuous." This process, of course, historically concerns women. Around looms, at spinning wheels, in sewing circles, in ancient Egypt and China, and in southeastern Europe five centuries before Christianity, women have woven clothing, shelter, the signifiers of status, even currency.

Like many accepted patterns, this was disrupted by the Industrial Revolution, when a French weaver, Joseph-Marie Jacquard, proposed a new way to create cloth—not by hand, but by the numbers. Unlike a traditional loom, singularly animated by its weaver's ingenuity, Jacquard's invention produced remarkably complex textiles from patterns punched into sequences of paper cards, reproducible and consistent beyond a margin of human error. The resulting damask, brocade, and quilted matelassé became highly coveted all over Europe, but the impact of Jacquard's loom went far beyond industrial textile production: his punched cards, which separated pattern from process for the first time in history, would eventually find their way into the earliest computers. Patterns encoded on paper, which computer scientists later called "programs," could meaningfully entangle numbers as easily as thread.

The Jacquard loom put skilled laborers, male and female, out of work. Some took out their anger on the frames of the new machines, claiming as a folk hero the apocryphal Ned Ludd, a weaver said to have smashed a pair of stocking-frames at the end of the previous century. We use the term *Luddite* now in the pejorative, to describe anyone with an unreasonable aversion to technology, but the cause was not unpopular in its time. Even Lord Byron sympathized. In his maiden speech to the House of Lords in 1812, he defended the organized framebreakers by comparing the results of a Jacquard loom's mechanical weaving to "spider-work." Privately, he worried that, in his sympathy for the Luddites, he might be taken as "half a frame-breaker" himself. He was, of course, not—and he was dead wrong about the spider work, too.

Even as Byron made his case, Jacquard looms were producing a quality and volume of textiles unlike anything the world had ever seen. The mathematician Charles Babbage owned a portrait of Joseph-Marie Jacquard woven from thousands of silk threads using twenty-four thousand punched cards, a weaving so intricate that it was regularly mistaken for an engraving by his guests. And although the portrait was a fine possession, it was the loom itself, and its punch card programs, that really ignited Babbage's imagination. "It is a known fact," Babbage proclaimed, "that the Jacquard loom is capable of weaving any design which the imagination of man may conceive." As long as that imagination could be translated into a pattern, it could be infinitely reproduced, in any volume, in any material, at any level of detail, in any combination of colors, without degradation. Babbage understood the profundity of the punched-paper program because mathematical formulae work the same way: run them again and again, and they never change.

He was so taken with the Jacquard loom, in fact, that he spent the better part of his life designing computing machines fed by punch cards. To describe how these worked, he even adopted the language of the textile factory, writing of a "store" to hold the numbers and a "mill" where they could be processed, analogous to a modern computer's memory and central processing unit. Numbers would move through Babbage's machines, coming together as thread becomes whole cloth.

Babbage's machines—the Difference Engine, a hand-cranked mechanical calculator designed to tabulate polynomial functions, and the more complex Analytical Engine—were so far ahead of their time that they're generally considered historical anachronisms. His mechanical designs required a level of technical precision never before attempted, although the British government, for whom mathematical tables were a point of national interest, was willing to try. It funded construction of the Difference Engine in 1823, with an initial grant of seventeen hundred pounds; by the time it wrote off the project, nearly twenty years later, having spent ten times as much, there was still nothing to show for what the prime minister had by then determined to be a "very costly toy," and "worthless as far as science is concerned," save some partial models and four hundred square feet of confounding schematic drawings.

The machines made Babbage famous—and perhaps infamous—but very few people alive in his time were mentally equipped to understand what they were supposed to do, let alone how. One of those people was Lord Byron's daughter, Ada. In her short life, she would make one thing certain: that the spider work her father had so disdained would proliferate, unstoppable, into the following century and beyond.

RAYS FROM EVERY CORNER OF THE UNIVERSE

Ada's alchemy was peculiar. She was the child of a passionate yearlong marriage between Byron and a bright, mathematically inclined aristocrat named Anne Isabella Milbanke, or Annabella. Byron was, in a former lover's estimation, "mad, bad, and dangerous to know," his passions Romantic in every sense; Annabella, on the other hand, was so sensible and well-bred that Byron teasingly called her the "Princess of Parallelograms." The couple separated amid rumors that the louche Byron had a more-than-fraternal relationship with his half sister Augusta.

Amid the scandal of that separation, the last thing Annabella wanted was for Ada to inherit any of her father's wildness or to suffer as a consequence of his notoriety. To keep her daughter on the straight and narrow, Annabella began a rigorous course of mathematical instruction from the time Ada was four years old. Math—the opposite of poetry. Or so she thought.

Byron absconded to Italy shortly after Ada's birth. He never made her acquaintance, although he inquired after her often. "Is the Girl imaginative?" he wrote to Augusta, knowing full well that Annabella, who kept their daughter purposefully secluded, would divulge nothing directly. Byron died unromantically of the flu in Greece in 1824, when Ada was only nine. As he died, he called to his valet, "Oh, my poor dear child! My dear Ada! My God, could I have seen her! Give her my blessing!"

His body was returned to England by ship, and huge crowds gathered in the streets of London to see his funeral procession of forty-seven carriages. When Ada finally learned her father's name, she wept for him, although it doesn't appear that she or her mother held his legacy in high esteem—Byron's portrait, in their home, was concealed under heavy drapery until Ada was twenty. But his mercurial spirit was alive in her. "I do not believe that my father was (or ever could have been) such a *Poet* as I *shall* be an Analyst; (& Metaphysician)," she wrote to Charles Babbage later in life, "for with me the two go together indissolubly."

Ada King, Countess of Lovelace

Ada's sharp analytical mind was inflected by a wild imagination. Prevented from a formal university education by her gender, she thrived under private tutelage. A precocious and very lonely child, she designed flying machines and marched around the billiard table playing violin. She was also frequently ill, prone to episodes of what was then called hysteria, and barely survived a serious three-year bout of measles, during which Annabella took advantage of her daughter's bedridden condition to double down on schoolwork. But Ada was indomitable, agitated, and charismatic, and when she outpaced—and in one case, seduced—her tutors, she educated herself with books and through correspondence with some of nineteenth-century England's most illustrious minds.

She was only a teenager when she struck up a close friendship with the well-known scientist Mary Somerville, who would answer her questions and encourage her studies. The logician Augustus De Morgan sent her problems by post, only to be astounded by the power of thinking represented in her responses. Had she been a man, he marveled, her "aptitude for grasping the strong points and the real difficulties of first principles" would have made her "an original mathematical investigator, perhaps of first rate eminence." She did not shrink away from difficulty, and she had a peculiar way of learning: she questioned the basic principles of mathematics to drill down to their fundamental meaning and understand them completely.

Ada first met Charles Babbage when she and her mother went to see his Difference Engine, the first of his very expensive, very unfinished mathematical machines, in London. She was seventeen; Babbage was forty-two. He displayed the machine—a piece of it, anyway—in a salon where he hosted Saturday-night soirées that attracted the most prominent names in society: Charles Darwin, Michael Faraday, Charles Dickens, the Duke of Wellington. It wasn't long after Ada's ritual debut in court, where she had worn satin and tulle and made whispered pronouncements to her mother about the various dukes to whom she was presented: Wellington, she liked, and the Duke of Orleans, too, but the Duke of Talleyrand? He was an "old monkey."

Ada diligently made the rounds, but she held her social obligations in low esteem. She was, however, immediately mesmerized by Babbage's machine, a hulking block of interlinked brass gears and cogs. "While other visitors gazed at the working of this beautiful instrument with the sort of expression, and I dare say the sort of feeling, that some savages are said to have shown on first seeing a looking-glass or hearing a gun," wrote an onlooker, "Miss Byron, young as she was, understood its working, and saw the great beauty of the invention."

Not long afterward, Ada became Ada Augusta King, after her marriage to a sensible aristocrat a decade her senior, and then, three years later, her husband's peerage elevated, the Countess of Lovelace. By the age of twenty-four, she'd borne three children—one, a son, named after her father—and was managing her family's homes in Surrey and London, but she continued to study mathematics every day, and she remained fascinated by the Difference Engine.

She pleaded with Babbage to let her be of service to his machines. "I hope you are bearing me in mind," she wrote to him in 1840, "I mean my mathematical interests. You know this is the greatest favour any one can do me." Being a countess came with social obligations Ada found immensely distracting from her true passions; she wanted a professional path, a vocation, to practice mathematics in some useful way that might cement her legacy as her father's poems had cemented his. Her letters—to Babbage, to her mother, to her many friends—reveal a woman consumed by the crippling fear that she might not have the opportunity to make her mark on mathematics. She was certain of her own unique talents: both her immense reasoning faculties, drilled into her by her mother's homeschooling, and her "intuitive perception of hidden things," the legacy of her absent father. "I can throw *rays* from every quarter of the universe into *one* vast focus," she wrote to her mother, who worried she might be mad.

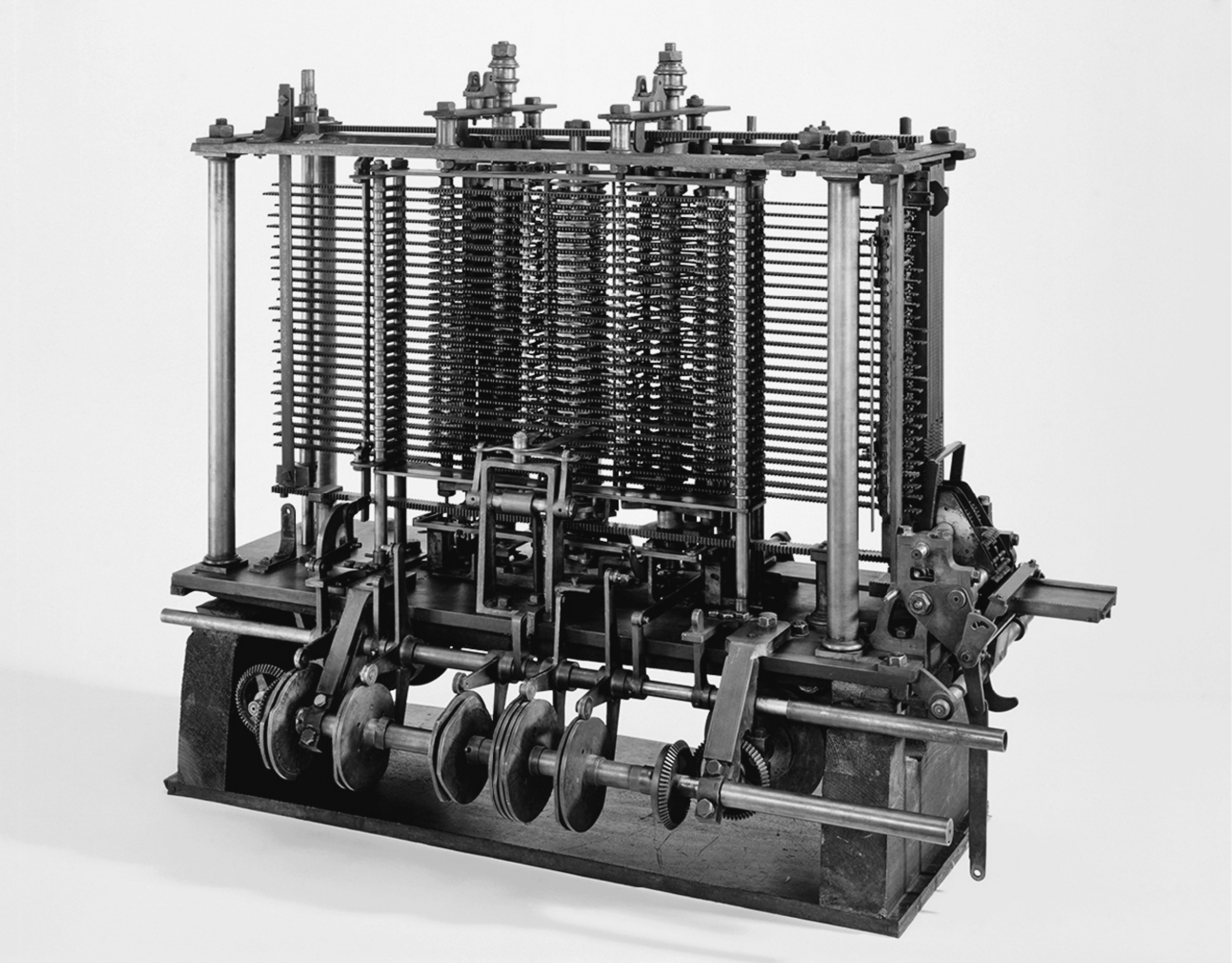
Ada had affection for her husband—she called him "my *chosen* pet"—but she devoted her mental life to Babbage and his machines. She became his acolyte, and then his mouthpiece. His iconoclastic way of thinking appealed to her; she admired the imagination of his inventions. Having been raised in isolation, under the rigorous tutelage of a mother hell-bent on curbing any trace of Lord Byron's poetical fancies, Ada felt validated by Babbage. Like her, he understood that the manipulation of numbers—the highest levels of mathematical thought—had profound metaphysical implications. That math was a form of poetry in itself.

But by the time Ada was married, Babbage had all but given up on the Difference Engine. Impressive as it might have been to the British society passing through his Saturday soirées, it was only a very complicated adding machine, churning out rows and rows of numbers using the method of finite differences. The Difference Engine could have been used to tabulate error-free mathematical tables, to precisely "calculate by steam" the sorts of things human computers had by then been doing with only occasional errors for more than a century, but Babbage was no longer interested in anything so practical. He had a bigger idea.

The Difference Engine's precisely milled cogs and wheels stored thousands of numbers, but Babbage longed that they store *variables* instead—abstract symbols standing in for numbers. Such a machine could do much more than arithmetic. It would be capable of solving *every* kind of problem. He began to make plans for a second, far more ambitious engine, one that would make the conceptual leap from mechanized arithmetic to full-fledged general-purpose computation. He called it the Analytical Engine.

If the Difference Engine was ingenious, the Analytical Engine was brilliant. Had it ever been fully built, the Analytical Engine would have been able to multiply two twenty-digit numbers in three minutes. The Harvard Mark I, an electromechanical computer built in the 1940s using some of Babbage's basic computing principles, was capable of the same task in about six seconds, albeit nearly one hundred years later; today, my laptop does it in under a millionth of a second. But the Analytical Engine was not an electronic machine: it was a cumbersome mechanical thing, its cranks, rods, and spinning gearwheels designed to be powered by steam. The word "engine" is right: to an untrained eye, the partial model of the Analytical Engine currently on display at the Science Museum in London looks like something pulled from the belly of a train. It has the formidable and hulking physical presence of a bank vault.

It was a tough sell. After all the money it had wasted on Babbage's Difference Engine, the British government certainly wasn't going to spring for a new model with even fewer immediate applications, and Babbage had nobody to lean on: in his obstinacy, he'd made his share of enemies in the British scientific community. In the hopes of stoking interest in his machine, Babbage accepted an invitation in the fall of 1840 to go to Turin and share his plans for the Analytical Engine with a group of Italian scientists and philosophers. He hoped that "the country of Archimedes and Galileo" might prove more enlightened than his homeland, but things didn't go as planned.



A small portion of the Analytical Engine’s “mill”

Seated in Babbage’s Turin audience was a certain L. F. Menabrea, a young military engineer who would later become a diplomat, and then the Italian prime minister. Soon after the presentation, Menabrea wrote a detailed paper, “*Notions sur la machine analytique,*” for a Swiss journal. When the intellectually curious Ada came across the paper, she immediately began to translate it, correcting Menabrea’s mistakes as she went. She presented the unsolicited translation to Babbage; impressed, he asked her why she hadn’t just written an original paper, seeing as she was so familiar with the machine and its architect. The thought had not occurred to her. Babbage suggested that she should, at least, add some of her own notes to the translation. This compromise between modesty and intellectual ambition was amenable, and she undertook the project straightaway. But by the time they made it to the printer’s office, Ada’s notes—which she signed only with her initials, AAL—had taken on a life of their own. They were nearly three times longer than Menabrea's original text, and an order of magnitude more sophisticated.

In her notes, Ada synthesized the vast scope of Babbage's vision. It was no easy task: by the time he died, he'd dedicated thirty volumes of plans to the Analytical Engine. Enlivening her technical analysis with flights of metaphysical fancy, she aimed to make the machine comprehensible—and exciting—for an educated Victorian audience, particularly those among the scientific community and the British government, whom Ada and Babbage both hoped would come to their senses regarding the machine. Babbage was obstinate and not a particularly good political player, and Ada knew his brilliance could easily be overlooked by those who found his temperament intolerable. "My dear and much admired Interpretress," he admitted.

But Ada didn't only explain the technical workings of the Analytical Engine. She imagined the impact it could have on the world, teasing out the implications of general-purpose computing to anticipate the transformative power of software. She understood that if the Analytical Engine manipulated symbols, then anything that could be represented symbolically—numbers, logic, even music—could pass through the machine and do wondrous things. "The Analytical Engine *weaves algebraical patterns,*" she wrote, using a textile metaphor, "just as the Jacquard loom weaves flowers and leaves." The possibilities were limitless, and hers was just the mind to articulate them: mathematically brilliant and poetically incisive in equal measure.

The work was taxing on her, mentally as well as physically. Like many patients at the time, she was prescribed laudanum for her maladies. Through an opiate haze, she labored in bursts of feverish energy between social appointments and periods of illness. Her mother disapproved of the work, and she tried to contrive family dramas to distract her, but Ada was tenacious. Correspondence between Ada and Babbage during this time was brisk and highly intimate. They sent letters back and forth across London, often several times a day. She chided him for his sloppy work, bristled when he edited her writing, and caught his errors, all the while referring to herself as his "Fairy," an apt description for the mathematical sprite she was. "That brain of mine is something more than merely mortal," she boasted as she sorted out all the ways the machine could deduce Bernoulli numbers. "Before ten years are over, the Devil's in it if I have not sucked out some of the life-blood from the mysteries of this universe, in a way that no purely mortal lips or brains could do."

The Analytical Engine would never be completed, but it represents the conceptual dawn of the computer age. The four components of its design—input, storage, processing, and output—remain core components of all computers today, and the strikingly original notes that Ada prepared to explain this new kind of machine would presage the literature of computer science by nearly a century. To demonstrate how the engine could calculate Bernoulli Numbers without any assistance from a "human hand or head," she wrote mathematical proofs that many scholars characterize as the first computer programs ever written, and all for a machine that never even existed. Although Ada had three children, she referred to her notes on Menabrea's essay as her firstborn. "He is an uncommonly fine baby," she wrote to Babbage, upon completing her draft, and "he will grow to be a man of the first magnitude & power."

It's telling of Ada's time that she characterized her work as male and signed her notes with only her initials. Although she was encouraged in her lifetime by high-profile supporters—Babbage chief among a circle that included her tutors, husband, and scientific friends—her path was decidedly unorthodox. Even her mother barely tolerated it. "Not even countesses," writes Sadie Plant, "were supposed to count." Beyond her friend Mary Somerville, she had few female peers, and her accomplishments required a dogged and persistent self-education, a near-manic dedication to mathematics that defied convention and damaged her health.

Ada had been prone to illness her entire life, suffering from bouts of dizziness, pain, fainting, and nervous malcontent. Her symptoms were written off as hysteria and managed with her regular doses of laudanum, which she anticipated eagerly, her eyes burning. At thirty-six, the same age as her father, Ada died of what really ailed her: uterine cancer.

She had all but given up on mathematics. In her final years, she bet compulsively on horse races, using her mathematical acuity to calculate odds for an ad hoc syndicate of male friends. One biographer has suggested that she hoped to win the fortune required to build Babbage's Analytical Engine, but she lost so often and so spectacularly that she was forced to borrow money from friends and pawn family jewels. By the time she succumbed to protracted bed rest in London, she had become more like her father—mad, bad, and dangerous—than any Princess of Parallelograms. Floating in and out of reality with doses of laudanum, wine, and chloroform, she echoed the family chord of recklessness and tragedy. “I do dread that horrible struggle, which I fear is in the Byron blood,” she wrote to her mother. “I don’t think we die easy.”

Like her father’s, Ada’s work outlived her, although it would be nearly a century before it was properly recognized. It took until the beginning of the computer age, when the magnitude of their prescience became undeniable, for her *Notes* to be republished, in a British computing symposium; its editor marveled, in 1953, that “her ideas are so modern that they have become of great topical interest once again.” Ada was lucky to have been born wealthy, noble, and relatively idle. Even without a professional path, she was able to educate herself, and she had time to privately follow her passions. Still, she could have done so much more, and it’s evident that she wanted to. Many brilliant women—born in the wrong centuries, the wrong places, or hoping to make an impact on the wrong field—have suffered similar fates, and far worse.

Reading Ada’s correspondence, I see someone I wish I could reach out to, across the centuries, and say: you’re right. Nobody can see it but you. But you will have inheritors. Granddaughters and great-granddaughters. They will sprout up everywhere, all over the world, and work with the same dogged, unrelenting focus. Other people will keep getting the credit, until one day they won’t anymore. And *then* your history will be written, a hundred times, by teenage girls at their desks in the heart of their kingdoms, on machines beyond your wildest imagination.

KILOGIRLS

By her insistence, Ada Lovelace was buried next to her father in a small church near his ancestral estate of Newstead Abbey. Her coffin, finished in soft violet velvet, bore an inscription of the Lovelace family motto, an axiom she’d embraced as her own while toiling over her notes on Babbage’s Analytical Engine. LABOR IPSE VOLUPTAS, it read. “Labor is its own reward.”

Labor would remain its own reward for a long time. By the end of Ada’s century, although technically gifted women like her could find employment as computers on either side of the Atlantic, their formal titles weren't accompanied by commensurate status or compensation. In the 1880s, for example, the astronomer Edward Charles Pickering hired only women to analyze and classify stellar data for his Harvard lab, including his own maid, Williamina Fleming. Although he would later champion the women working in the observatory, even presenting papers on Fleming's behalf at astronomical conferences, Pickering didn't hire them out of advocacy. He'd just wanted twice as many workers on the job, given that women were paid half the going rate. "The Harvard Computers are mostly women," complained the director of a competing observatory, which employed only men, to a colleague, and they can be "got to work for next to nothing."

Known to history as "Pickering's Harem," the Harvard Computers cataloged ten thousand stars; Williamina Fleming, the erstwhile maid, discovered the Horsehead Nebula and helped develop a common designation system for stars, while her colleague Annie Jump Cannon could classify spectra at a rate of three stars a minute, and with a remarkable consistency that allowed her to discover a number of new and unusual stars. These women quite literally mapped the cosmos, but their wages were equivalent to those of unskilled workers—paid between twenty-five and fifty cents an hour, they earned barely more than they would have if they'd worked in a factory.

In the United States, the number of female office workers increased near the end of the nineteenth century, with a significant uptick after the American Civil War. Major wars have an unmistakable effect on gender and work, opening new employment to women; in this case, many were battlefield widows, looking to support themselves by helping to coordinate the affairs of an increasingly complex world. After the Civil War ended in 1865, as historian David Alan Grier writes, female computers were no longer "the talented daughters of loving fathers" as Maria Mitchell had been, "or the intelligent friends of sympathetic men," like Ada. They were "workers, desk laborers, who were earning their way in this world with their skill at numbers."

The First and Second World Wars, too, ushered thousands of women into the workplace as typists, clerks, and telephone operators, to say nothing of riveters. But it was the telephone companies that were the first mass employers of a female workforce. In 1891, eight thousand women worked as telephone operators; by 1946, nearly a quarter million. Women were a nimble workforce. capable of working collaboratively in networks and fluid groups—we still speak of secretarial "pools"—adaptable to the needs of the enterprise. They staffed switchboards, kept records, took dictation, and filed documents. These rote office tasks are now increasingly performed electronically by digital assistants and automated telephonic systems, many of which still speak, in the default, with female voices.

As female voices buzzed across the growing telephone networks in the first half of the twentieth century, the term "girl" was used interchangeably with "computer." One member of the Applied Mathematics Panel, a division of the National Defense Research Committee that administered a human computing group in the early 1940s, ballparked a unit of "kilogirl" energy as being equivalent to roughly a thousand hours of computing labor. The National Advisory Committee for Aeronautics—the predecessor to NASA—kept its own pool of "girls," which included black women as early as the 1940s, working in a segregated west section of Langley Research Center. One of these, the mathematician Katherine Johnson, who joined the Space Task Force in 1958, hand calculated trajectories for Alan Shepard's and John Glenn's spaceflights. The Computing Group at Langley ran all its analytical calculations by hand, using the material ephemera of the gig: slide rules, magnifying glasses, curves, and early calculating machines. Johnson is often quoted as saying that she was a computer back in the days "when the computer wore a skirt."

The last significant human computing project in the United States, a reference book of mathematical tables funded by the Works Progress Administration—and overseen by another female mathematician, Gertrude Blanch—was published just as computing machines made it effectively obsolete. Human computing thrived as a stopgap between the emergence of large-scale scientific research and the capacity of hardware to carry out its calculations; eventually, the tireless machines that emerged from the spike in computer science research during the Second World War wore down their competition. After that war, the machines took over, decisively and permanently, shifting the definition of the word "computer" for the first and last time. The job description, which once required a unique cohesion of human effort, changed too: onetime human computers went from rivals to keepers, no longer executing the functions of the machine but rather *programming* those functions to be executed.

Human computing offices performed in girl-years the number crunching that machines can now perform in fractions of a second. But for a few centuries, groups of women working in hives and "harems" were the hardware: distributed biological machines capable of prodigious calculations beyond the mental capacities of any single individual, calculations that cataloged the cosmos, charted the stars, measured the world, and built the bomb. That the mathematical labor might have been, in some cases, broken down into relatively simple steps for each individual is beside the point. It's the accumulation of all those steps, executed simultaneously and collectively, that prefigured our connected, calculating, big-data world. Alone, women were the first computers; together, they formed the first information networks. The computer as we know it today is named for the people it replaced, and long before we came to understand the network as an extension of ourselves, our great-grandmothers were performing the functions that brought about its existence.

The arrival of computing machines may have emptied human computing offices, but it didn't push women from the field. Quite the opposite: many women who had been computers themselves found work tending their replacements. Female hands lifted from pencils and slide rules to desk calculators and switches, then relays and punch card tabulators. Coaxing information into and out of the new machines was considered a woman's job, too, on the level with typing, filing documents, and patching phone calls from place to place. Not that it was easy. Dealing with early mechanical computers required a keen analytical mind and limitless patience. Just like the women whose math moved mountains, early computer programmers and operators were tasked with enormous, intractable problems. Their creative solutions often meant the difference between life and death.

Chapter Two

AMAZING GRACE

Grace Hopper was thirty-six, tenure tracked, and married when Japan attacked Pearl Harbor. She taught mathematics; her husband, Vincent, literature. The couple spent their summers fixing up an old farmhouse in New Hampshire, on sixty acres of land they'd bought during the Depression for $450. They played badminton, and Grace hooked rugs, a skill she'd picked up as a kid, summering at the family compound on Lake Wolfeboro.

Grace and Vincent lived the usual headaches of married academics. As Grace began her graduate studies at Yale, Vincent was working toward his doctorate at Columbia. Somehow she made time to help him research his eight-year-long thesis project, a history of number symbolism, by reading Syrian, Babylonian, and medieval texts on the subject. When she started teaching at Vassar in 1931, she audited courses in her spare time, picking up fluency in astronomy, geology, physics, and architecture. Her intellectual ambidexterity was legendary on campus: to impress students, she'd sometimes write a German sentence on the chalkboard with her left hand, and when she got to the middle, she'd switch to her right hand and finish the sentence in French.

When Grace was a junior teacher at Vassar, she picked up the classes students dreaded and nobody else wanted to teach, like calculus, trigonometry, and mechanical drawing. To revitalize them, she updated old schoolwork with new concepts, much as good teachers do now. To make topography fun, she'd tell her mechanical drawing classes they were tracing the borders of fantastic imaginary worlds, and she updated the ballistics problems common to calculus textbooks to involve rockets, which were then beginning to capture the public imagination. As a result, her classes swelled with students, drawn in from departments across the college. It earned her the respect of her superiors and the unbridled resentment of her colleagues.

In the winter of 1941, Grace and Vincent were in New York City. Vincent had found a job teaching general literature at New York University's School of Commerce, and Grace had arranged a yearlong faculty fellowship from Vassar to study at NYU herself, under Richard Courant, one of the few major figures in applied mathematics. It was a nice vacation from the breakneck weekly commute they'd been driving along the Hudson, between Poughkeepsie and the city, in a Model A Ford she called Dr. Johnson. Grace liked Courant, who specialized in differential equations with finite differences, something she'd learned "one jump ahead of the students" to teach her calculus course at Vassar. Courant had a cute accent—he was a German émigré—and his lectures were always engaging. She enjoyed tackling unorthodox problems under his tutelage, even if he sometimes scolded her for taking equally unorthodox approaches to them. All in all, it was a "gorgeous year." Then everything changed.

Grace and Vincent heard the announcement on a tinny little radio, sitting at a double desk in the study they shared, surrounded by books: a violent and sudden attack at a naval base in Hawaii had left 2,403 Americans dead. The following day, the United States declared war on Japan; within a week, the conflict extended to Japan's allies, Germany and Italy.

Everybody in Grace's life wanted into the war. Vincent tried for a commission but was turned down for wearing glasses. Grace's brother, scrawny as her whole family was and with a blind spot about level with a chalkboard, didn't make the cut, either. Undeterred, they both volunteered under the draft and got in. Grace's cousin became a nurse. By the summer of 1942, everyone seemed to be gone; all the men enlisted, all the women in her family in the military's new female branches, save her sister, who had children. Grace wanted to do her part, too, but she was sixteen pounds underweight and considered too old for service. Mathematics professors, being a classified profession, weren't allowed to enlist without a release. She took a summer appointment at Barnard College to teach special war-preparedness mathematics courses for women, but it wasn't enough. All summer, midshipmen would march by the Barnard dormitories from a training ship on the Hudson, and Grace would watch them, longing to be in the navy, too.

Back upstate, she chafed with loneliness and directionless patriotism. “I was beginning to feel pretty isolated sitting up there,” she said, “the comfortable college professor.” She aggressively lobbied Vassar to let her go into the service. She gave the college an ultimatum, which wasn’t much of one: six months or she’d leave anyway. And even though she was too old, and too thin, and her eyesight wasn’t much better than her brother’s, she did. The day those bombs fell on Pearl Harbor, the path of completely respectable middle-class life had been at Grace Hopper’s feet, but she wouldn’t take one step further. Within a few years, everything forked: she separated from Vincent, she quit her job, and she joined the U.S. Navy. It wasn’t the first remarkable thing she’d ever done, and it would not be the last.

Grace turned thirty-seven on her first day at the United States Naval Reserve Midshipmen’s School in Northampton, Massachusetts. She picked up the navy talk quickly—bulkheads, decks, and overheads. She’d always been good with languages. She’d taught herself German, Latin, and Greek by reading closely with a dictionary at her side, corralling the new words into each sentence like mathematical variables. Mastering military protocol was trickier, especially because it was so often at odds with social expectations. Rank and civility collided in doorways. Sometimes she’d stop to let admirals go through the doors first, but they’d try to treat her like a lady, a comedy of errors. “We usually ended up going through together,” she recounted. “Which was bad.” But she liked the drills. She thought they were like dancing.

She was smaller than the other recruits, and older, training alongside the students she’d been teaching only months before. But after a career in academia, commuting around the Northeast while trying to maintain two homes and a strained marriage, the constraints of military life felt like a vacation. She didn’t need to think about anyone else anymore; she didn’t even need to pick out her own clothes in the morning. There were few comforts—even nylons were rationed—but her domestic responsibilities had disappeared. “I just reveled in it,” she told a historian years later. Unlike the youngsters she enlisted with, she “had the most complete freedom . . . I just promptly relaxed into it like a featherbed and gained weight and had a perfectly heavenly time.” With meat rationed, she ate fresh fish from the New England coast and lobster every Sunday night. She was named battalion commander and graduated first in her class, in itchy lisle stockings.

Although Grace was certain the navy would have sent her to sea had she been a man, the newly minted Lieutenant Hopper would never spend a day on board a navy ship. Instead, something in her employment history rang a bell—of all things, her study of finite differences at NYU, under Richard Courant. The navy changed Grace's orders overnight. In training, she'd assumed her military career would be spent cracking enemy codes with the elite group of mathematicians and logicians at the Communications Annex, the navy's cryptographic brain trust, overseen by one of Grace's former Yale professors. She even studied cryptography to prepare for that eventuality. Instead, the navy sent her to Harvard, where, as she liked to say, she became the third programmer of the world's first computer.

When she arrived at Harvard in July 1944, she promptly got lost. The Navy Liaison Office was nowhere to be found, and Grace hadn't been given any information about where she was to be stationed, or why. She wandered the campus, until she was finally led into the basement of the university's Cruft Physics Laboratory by an armed guard. A hawkish, six-foot-four man with an exaggerated widow's peak greeted her at the door, already irritated. The first words out of his mouth: "Where have you *been?*" Taken aback by the sight of him, she said she'd just come from Midshipmen's School and had spent the morning looking for the right place. "I was a little bewildered and at that point of course thoroughly scared of a commander," she remembered. "I told them you didn't need to do that," he muttered. He didn't think women needed service training. He asked if she'd found a place to live yet. She told him she'd only just arrived. "Well," he answered, "get to work and you can get a place to live tomorrow."

Get to work she did. Grace never saw any action during the war, but she did tame two beasts. The first was this bristly man, Lieutenant Commander Howard Aiken. While a graduate student in physics at Harvard, Aiken—a great admirer of Charles Babbage—had designed a mechanical arithmetic device capable of solving any problem, from basic arithmetic to differential equations, that could be simplified down to numerical analysis. It was a matter of convenience: his own doctoral dissertation had been a nightmare of extensive, tedious calculations. His machine, built by IBM in exchange for the rights and donated to the university for wartime use, would be Grace's second beast. Because Aiken had imagined it as a series of daisy-chained calculators doing the work of a dozen men, it was an Automatic Sequence Controlled Calculator. Everyone at Harvard called it the Mark I computer.

The Mark I was assigned to the navy's Bureau of Ordnance to run ballistics problems for the war effort, and Aiken needed mathematicians who knew their way around differential equations with finite differences, precisely what Grace had been studying under Richard Courant that glorious year before the Japanese bombed Pearl Harbor. But Grace didn't know any of this yet. As she made Aiken's acquaintance, she heard a racket in the next room. Aiken led her to the source of the sound. "That is a computing engine," he said. Grace examined the thing, stunned. "It was all bare," she remembered; weighing in at ten thousand pounds, the Mark I stood a hulking eight feet tall, with thousands of moving parts and some 530 miles of wiring. Its inner workings were exposed, churning and noisy. "All I could do was look at it," she recalled. "I couldn't think of anything to say at that point."

The Mark I was closer to Charles Babbage's mechanical engines than to a computer in the modern sense of the word: inside its steel casing, a spinning driveshaft powered by a four-horsepower motor drove a sequence of gears and counter wheels along the entire installation. Code for the Mark I was written by hand, in pencil, on standardized code paper, and then transferred—literally punched—onto spools of three-inch-wide tape, much like the score sheet for a player piano or the pattern card of a Jacquard loom. The positions of holes in the tape, using a unique eight-bit code, corresponded to the numerals, process, and application of a given calculation. Although the Mark I was programmable in the sense that it accepted these punched-roll tapes, the distinction between hardware and software at that time was blurry, even nonexistent: every calculation called for switches to be flipped, cables to be patched.

Howard Aiken introduced Grace to her crewmates, two navy ensigns who'd arrived at Harvard while she was still in Midshipmen's School. She found out later that they'd been bribing each other to get out of sitting next to the new recruit; "they'd heard this gray-haired old schoolteacher was coming and neither one of them wanted the desk next to me." Aiken gave her a codebook, just a few pages of alien commands, and an assignment: to write a program for the Mark I that would compute the interpolation coefficients for the arctangent to an accuracy of twenty-three decimal places. “And then he gave me a week to do it in,” she said, “to learn how to program the beast and to get a program running.” The problem itself was not particularly mysterious for Grace—she did have a PhD in mathematics, after all. It was the machine she found inscrutable. It had no manual, and there was no precedent from which to draw, as the Mark I was the first of its kind. Grace was good at a lot of things, but she didn’t have an engineering background, and she didn’t know switches from relays. Aiken was testing her.

A born autodidact, she threw herself into the challenge. She pored over the codebook and picked the brains of the two ensigns, mostly the twenty-three-year-old Richard Bloch, a recent Harvard graduate and math whiz who would become her closest collaborator. Some IBM engineers were still milling around, debugging the machine; she gleaned what she could from them, too. She stayed late every night, bootlegging an engineering education by examining the Mark I’s blueprints and circuit diagrams. Sometimes she slept at her desk. Years later, when Grace was an established figure in the new field of computer programming, she’d always assign the hardest jobs to the youngest and least experienced members of her team. She figured they didn’t have the sense to know what was impossible.

Her first year at Harvard was nonstop, and as new programmers joined the team, Grace ascended the ranks. Using the same diligence and ingenuity she’d brought to teaching, she made herself invaluable. The gray-haired schoolteacher from upstate New York met eminent mathematicians, engineers, and pretty much everyone in the microscopic world of computing. “It was fascinating,” she said, a “hotbed of ideas and concepts and dreams and everything under the sun.” The computing project was in such high demand during the war that Aiken designed a second computer, the Mark II. Grace learned that one, too.

Like his machines, there was no manual for Aiken. He was temperamental, petulant, and obsessive about details. He took great pride in being the commanding officer of his own invention. Although the Mark I was built by IBM and tucked away in an Ivy League basement, Aiken ran its operation like a naval facility. Discipline was strict. His entire staff was expected to show up in full uniform and call him “commander.” The computer was a “she,” like any navy ship. Aiken worked people ragged; when mistakes were made, he was prone to “bawling out” the perpetrator. His criticism could be so immediate, and so fervid, that Grace often did her debugging after hours for the sake of peace and quiet. But she learned to think of her boss as a machine himself. “He’s wired a certain way,” she told Bloch, who was often getting into trouble with their superior. “If you understood Aiken and understood how he was wired, he was excellent to work with. I never had any difficulty. But if you tried to tell him what was right, heaven help you.”

Aiken’s commitment to military hierarchy was harsh, but it ultimately worked in Grace’s favor: treatment in his Computation Laboratory, by and large, was commensurate to rank and ability over gender. Uniforms and formal titles helped dissolve traditional roles, as did the laboratory’s complete isolation from the outside world. And although Aiken had never wanted a woman officer in his ranks, he was forced by his adherence to protocol to accept Grace’s assignment. And anyway, as Grace told Howard Aiken, he was *going* to want a woman around.

She was right. She eventually became Aiken’s “right-hand girl,” and it wasn’t long before she was solely responsible for the Mark I. She wrote the code that solved some of the war’s thorniest mathematical problems, and she even wrote the missing manual for the computer, a truly laborious five-hundred-odd-page document full of circuit diagrams and operational codes. Along with her colleague Richard Bloch, she developed a system for coding and batch processing that turned the lab into the most efficient data-processing center of its day. She maintained order in a grueling wartime environment that felled lesser ensigns. And beyond her fundamental competence, there *were* some material perks to having a woman on the team. When the Mark I was having mechanical issues, Grace would sometimes “pull her mirror out of her pocketbook and stick it in front of the cams and look for sparks.” By the end of his career, Aiken had but one assessment of his colleague, his highest commendation: “Grace was a good man.”

Like a navy submarine, the Mark I was staffed twenty-four hours a day by a crew working in eight-hour shifts, and the computer was up and running an impressive 95 percent of the time during the war. The demand for wartime calculation was relentless, and time-sensitive requests came to the Computation Laboratory from all corners of the conflict. Grace, who had always been an omnivorous thinker, auditing courses at Vassar on every subject imaginable, took to the work. She learned to translate complex oceanography, minesweeping, proximity fuse, and ballistics problems into simple arithmetical steps, making regimented order of a messy, violent world.

The Mark I's calculations were impeded by all manner of failures: faulty code, faulty relays, and machine stoppages signaled by ominous clangs and shudders. To stay ahead, Aiken's team often worked late. One night, in September 1945, a large moth flew into the computing room through an open window, drawn in by the light on the machine. Grace found its corpse not long after, beaten senseless by one of the relays. She scotch-taped it into her log from that day, with a note: *first actual case of bug being found*. "Bug" is engineering slang that dates to at least the 1800s—even Thomas Edison used the word to refer to mechanical glitches, to "little faults and difficulties"—and Grace was known around the lab for her blackboard doodles of little bugs and monsters, each the cause of some lab snafu: a dragon who chewed holes in the punch tape, and a "gremlin that had a nose that picked up holes and put them back in the tape." After the moth incident, she bought a box of plastic bedbugs in town and scattered them around the back of the computer on a lark, causing a two-day panic.

During the war, the Computation Laboratory was isolated from the handful of other computing projects in the world, and Grace Hopper, handling the lab's everyday computational needs, had neither the time nor the opportunity to see what the rest of the field was doing. But sometimes the field came to her. Grace had been working in the Computation Laboratory for only a few months, for instance, when the physicist John von Neumann came to visit. Von Neumann had mobility; he spent much of 1944 visiting different computing projects in the United States, looking for a machine brawny enough to crack a complex partial differential equation. The Mark I was the first large-scale computer on his tour, and for three months that summer he decamped in a conference room at Harvard, outlining his problem on a blackboard while Richard Bloch set it up on the computer. Grace, still new at the lab but handy with a differential equation, assisted every step of the way.

Neither Grace nor Richard knew the specifics of the problem's application; to them, it was only an interesting mathematical challenge. And von Neumann was a character, a garrulous Hungarian theoretician who was as much of a celebrity in his day as his Princeton colleague Albert Einstein. As Bloch and von Neumann worked on the problem, they'd run back and forth between the conference room and the computer, von Neumann calling out numbers just as the Mark I would spit them out, "ninety-nine percent of the time," Grace observed admiringly, "with the greatest of accuracy—fantastic." After three months, von Neumann took their results back to a desert town in New Mexico called Los Alamos, where he was consulting on the Manhattan Project. The partial differential equation turned out to be a mathematical model for the central implosion of the atomic bomb. Grace never knew, until the bombs fell on Nagasaki and Hiroshima, precisely what she had helped to calculate.

There was not always time for Grace to consider where all the math *went*, and to what end. The calculations kept coming, some—like von Neumann's—almost inconceivably complex. To save on processing time, Grace and Richard invented coding syntax and workarounds that set the groundwork for the way code is written to this day. As early as 1944, Grace realized she could save herself from rewriting code from scratch for each problem by holding onto reusable scraps, which came to be known as subroutines. In wartime, this was done informally: coders on the crew would share their notebooks with one another, copying over relevant bits and pieces longhand. Eventually, this practice was formalized, and future computers were built with libraries of subroutines already in place, enabling even novice coders to call on tidily packaged sequences of program instructions. When Grace's code got thorny, she made a habit of annotating the master code sheets with comments, context, and equations, making it easier for colleagues to unravel her handiwork later. This system of documentation became standard practice for programmers, and it still is: good code is always documented.

Efforts like these, which simplified and broadened the accessibility of computer programming, were Grace's calling card. Back before the war, when she was still teaching at Vassar, she'd make her students write essays about mathematical problems, because there was no sense in learning math if you couldn't communicate its value to anybody else.

When she reentered the civilian world to work for the first commercial computer company, she would continue with that logic. Grace's most lasting contributions to the emerging field of computer programming all have to do with democratizing it: she pushed for programming advances that would radically change the way people talk to computers. With her help, they wouldn't need advanced mathematical terms, or even zeros and ones. All they'd need is words.

THE ENIAC SIX

The war was over before Grace had the chance to set eyes on any computing installation but the one at Harvard. And yet, there was another only three hundred miles to the south, at the University of Pennsylvania's Moore School of Electrical Engineering. Like Aiken's machines, its construction had been funded by the military to crunch numbers for the war effort. This room-sized installation of conduit and steel was the Electronic Numerical Integrator and Computer (ENIAC).

Technically, the ENIAC was faster than the machines on which Grace had cut her teeth. Where Howard Aiken's Mark I could trundle through only three calculations a second, the ENIAC was equipped to handle five thousand. This almost unbelievable warp-speed jump in processing was due to the fact that the ENIAC didn't rely on mechanical relays, gears, or driveshafts; instead, some eighteen thousand vacuum tubes, like slim light bulbs, served as its computing switches, flitting off and on in the darkness of the machine. Uncoupled from the limitations of grinding machinery, the ENIAC's vacuum-tube switches illuminated a new, ineffable realm of electronic pulses and signals. Computing would never look back.

Because these early computers were developed under wartime secrecy, computing history is full of conditional, contested touchstones—and more than a few acrimonious debates about the provenance of the "first" computer. Several machines qualify, and so the title is meted out in different ways: the Mark I, for instance, was the first *electromechanical* computer, while the ENIAC, which transcended the Mark I's physical limitations, was the first—and fastest—*electronic* computer. Across the ocean, in labs just as secret, British scientists built similar machines, each earning its own qualifier: stored-program, general-purpose, digital, binary. In these early days, every computer was an island.

When Grace Hopper visited the University of Pennsylvania in 1945, she was shocked to discover just how different the ENIAC was from the Mark I and Mark II computers with which she'd become so familiar. "The tremendous contrast," she noticed, "was the programming." Although Grace was an expert coder, she wouldn't have been able to work on the ENIAC without special training. The principles may have been similar, but the hardware and the programming approaches developed to exploit that hardware were unique. Where Grace was accustomed to writing code on paper reels, the ENIAC had to be physically reconfigured for every problem, with sections of the massive machine plugged together, essentially becoming a custom computer with every job. Any gains the ENIAC's vacuum tubes made in processing speed, the machine lost in setup time: where a calculation might take only a second to run, it could take a day to prepare, by which time the slower Mark I, with its nifty punched-roll tape, would have already been done and onto something else. A case of slow and steady winning the race—possibly for the last time in the history of technology.

Visiting Penn, Grace discovered something else that likely impressed her just as much. She wasn't the only female computer programmer on Earth. The ENIAC lab was full of women. In 1944 alone, at least fifty were working on the ENIAC in different capacities, as draftswomen, assemblers, secretaries, and technicians. Of these ranks, six women handled the time-consuming and intellectually demanding job of readying mathematical problems for the computer, plugging them in, then executing, debugging, and executing again to achieve the final results. Three among them, like Grace, were math majors. The other half had their mathematics schooling supplemented by U.S. Army training. These women, known to history as the ENIAC Six, were the peers Grace Hopper never knew she had. Some would later become her colleagues; a few, eventually, her friends. They were Kathleen "Kay" McNulty, Betty Jean Jennings, Elizabeth "Betty" Snyder, Marlyn Wescoff, Frances Bilas, and Ruth Lichterman.

The ENIAC Six were all former human computers, pulled from the Moore School's computation section, a lab that employed some one hundred mathematically inclined women. While Grace had come to

Harvard straight from basic training, they'd spent the early years of the war effort in a basement, hand calculating firing tables: small, printed books shipped out with every new weapon sent to the front lines. Soldiers used these books to determine precisely at which angle to fire their guns —"basically *Angry Birds,*" as one historian of the ENIAC has pointed out —in order to hit their target. As with the arc of *Angry Birds* projectiles, external factors like weather and the drag placed on the shell by air resistance affected the point of impact, and these variables were accounted for by the female computers calculating mathematical models back on the home front.

It took a human computer about forty hours to calculate a single ballistics trajectory in all its variations. This meant that during the war, the U.S. Army was dispatching weapons faster than it could produce instructions on how to use them. The demand for human computers was ceaseless, and when the army's Ballistics Research Lab ran out of female math majors in the Philadelphia area, it began a national hiring search. One recruitment ad reached Betty Jean Jennings through a supportive calculus teacher in northwest Missouri; Ruth Lichterman caught one on a bulletin board at Hunter College in New York. Once at Penn, they joined the women scribbling the imaginary arcs of distant artillery shells for the boys on the front.

The Moore School women worked using pencil, paper, and a giant analog calculator called a differential analyzer—an onerous tabletop machine based on a design from 1920, which used gears and shafts to provide an analogy to the problem. The analyzer was fairly inaccurate, so the women interspersed its results with their own hard-won hand calculations, smoothing out the differences to create the final firing table. It was an imperfect system: arduous, fallible, and certainly far too slow for such a quickly developing, modern war. Although the computers worked six days a week, in two shifts, they could never keep up with demand. Folks around the Moore School began to entertain other possibilities.

Around this time, in 1941, the army sponsored an intensive, ten-week electrical engineering course at the University of Pennsylvania. Grace Hopper had taught a similar kind of course at Barnard before enlisting: it was tuition-free, geared toward practical applications in defense, and open to anyone with a math or engineering degree. One of the students in the Penn course was a physics professor from nearby Ursinus College named John Mauchly, a genial tinkerer who would, in his later years, sport horn-rimmed glasses and a puckish goatee. While in the class, he began to kick around the idea of a computing machine that used vacuum tubes. He discussed it with the course's laboratory instructor, J. Presper Eckert, or "Pres." Pres wasn't a star student, but he was known around the Moore School as a capable and inventive engineer. He'd shown promise early, bumming around the Philadelphia lab of Philo Farnsworth, the inventor of the television, as a kid; by the time he was an undergraduate, professors consulted him on circuit designs.

Pres thought John Mauchly's vacuum tube idea was interesting. Everybody knew vacuum tubes were too delicate for use in a computer—like light bulbs, they blow out—but Pres figured that if the tubes weren't pushed to their limit, they'd hold steady. The pair started designing circuits. John took a teaching position at Penn, happy to be closer to Pres, and, once settled, discovered the human computers at the Moore School. In their backbreaking calculations, he found the perfect application for his vacuum-circuit computer. He dictated a proposal to his secretary, Dorothy, who shunted off a memo to the university's civilian liaison with the military.

The memo was lost in the shuffle, as memos sometimes are. It wasn't until an informal conversation between the differential analyzer's maintenance man, a friend of John's from Ursinus College named Joe Chapline, and Colonel Herman Goldstine, a military liaison with the Ballistics Research Laboratory in nearby Aberdeen, that the idea came up again. When Chapline mentioned his friend John's electronic computer, Goldstine saw the potential immediately. He tried to hunt down the lost memo, to no avail. Fortunately, the secretary, Dorothy, managed to re-create it from her shorthand notes. Like most secretaries in her day, she was trained in shorthand, a type of rapid writing, which is scribbles to the uninitiated. If it weren't for Dorothy's ability to code and decode what was at that time a largely female language, the original proposal for the electronic computer might have been lost.

The reconstituted memo was brought to army brass, who didn't need much convincing. John and Pres secured their funding in 1943 and started building the ENIAC right away. They hired engineers and former telephone company workers, who were good with relays, but most of the people who actually wired the ENIAC were women, part-time housewives with soldering irons on an assembly line. The most important hires were the human calculators, chosen from the best of the Moore School group, who would translate the ballistics computations they knew so well for the new machine. Nobody thought much of assigning women to this job. It seemed only natural that the human computers should train their own replacements. Further, the ENIAC looked like a telephone switchboard, reinforcing the assumption that its "operators" should be women, their task "more handicraft than science, more feminine than masculine, more mechanical than intellectual."

By 1944, construction on the ENIAC, then known as "Project X," took up most of the first floor of the Moore School building. One night, Pres and John conducted an after-hours demo for one of their new hires, Kay McNulty. They brought Kay and a colleague into a room where—behind a sign warning HIGH VOLTAGE, KEEP OUT—two of the ENIAC's accumulators were wired together by a long cable with a button on the end. One accumulator displayed a five. They pushed the button. The five jumped to the other accumulator, moved three places over, and transformed to a five thousand. John and Pres looked excited. Kay couldn't see why. "We were perplexed and asked, 'What's so great about that?' You used all this equipment to multiply five by one thousand," she said. "They explained that the five had been transferred from the one accumulator to the other a thousand times in an instant. We had no appreciation of what that really meant."

It meant that the ENIAC could calculate at speeds previously unimaginable, by human or machine. And although it was funded by the military to churn out firing tables as fast as the army could manufacture guns, the ENIAC was much more than a ballistics calculator. Pres and Mauchly had designed a *general-purpose* computer—think of the difference between Charles Babbage's one-note Difference Engine and the speculative Analytical Engine, which so entranced Ada Lovelace. It could perform an essentially limitless number of computational functions, as long as new programs for it were written. In its time at the Moore School, it would calculate the zero-pressure properties of diatomic gases, model airflow around supersonic projectiles, and discover numerical solutions for the refraction of shock waves. Hardware may be static, but software makes all the difference. And although it took some time to settle in, that truth came with a corollary: those who write the software make all the difference, too.

The ENIAC Six were an odd mix, thrown together by the circumstances of war. Betty Jean Jennings grew up barefoot on a teetotaling farm in Missouri, the sixth of seven children, and had never so much as visited a city before pulling into the North Philadelphia train station. Kay McNulty was Irish, her father a stonemason and ex-IRA; Ruth Lichterman, a native New Yorker from a prominent family of Jewish scholars; Betty Snyder, from Philadelphia, her father and grandfather both astronomers. Marlyn Wescoff, also a Philly native, had been hand calculating since before the war, and she was so adept that John Mauchly said she was "like an automaton." They all met for the first time on a railroad platform in Philadelphia, on their way to the Aberdeen Proving Ground, a marshy plot in Maryland the army had converted into a weapons testing facility. Bunked together, they became fast friends. Even after long days training on the IBM equipment they would be using to tabulate and sort ENIAC data, they stayed up late talking about religion, their vastly different family backgrounds, and news of the secret computer. "It was just a great romance, I think," John Mauchly hazarded when asked why these women volunteered for a job they knew so little about. "There's a chance to do something new and novel—why not?"

The reality might have been more pragmatic: in the 1940s, a woman with mathematical inclinations didn't have many options in the job market. When Kay McNulty approached her college graduation, she had a hard time finding any employment that might make use of her math major. "I don't want teaching," she explained. "Insurance companies' actuarial positions required a master's degree (and they seldom hired women, I later found out)." If the only other options are teaching math at a secondary-school level or executing tedious calculations for an insurance company, the opportunity to work in a brand-new, relatively well-paying field represented a hugely exciting change of scenery for all the women who signed up.

Computing was so new a field, in fact, that none of its qualifying attributes were yet clear. During her job interview with Herman Goldstine, Betty Jean Jennings recalled being asked what she thought of electricity. She replied that she had taken a college physics course back in Missouri and knew Ohm's law. No, no, said Goldstine, from behind the desk: Was she *afraid* of it? The job would require her to set switches and plug in cables, he explained, and he wanted to make sure she wouldn't get spooked by all the wiring. Betty Jean said she could handle it.

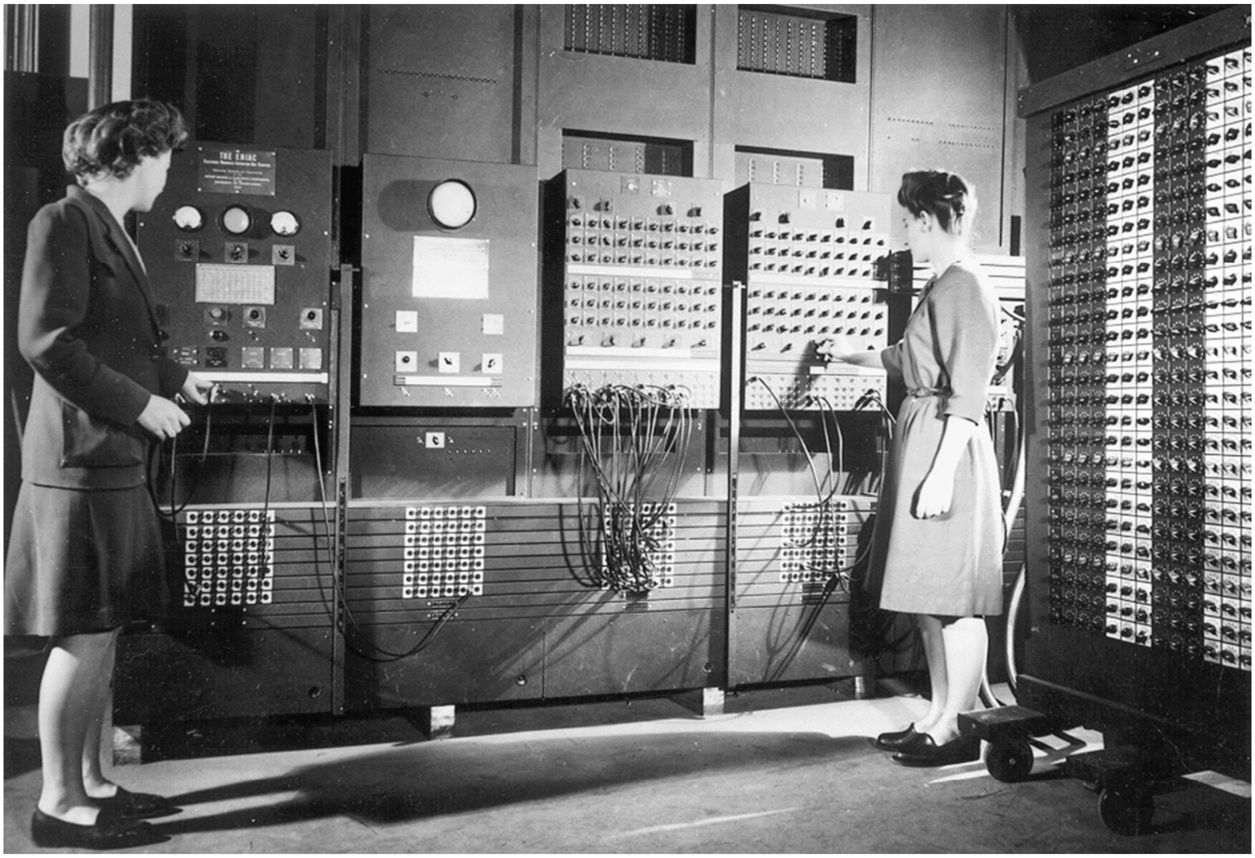
The ENIAC Six trained on paper, writing programs for a machine they hadn't met. When they were finally shown the finished ENIAC in December 1945, what they encountered was a massive, U-shaped assemblage of black steel housed in a room big enough to hold it along with some miscellaneous furniture. It had forty panels, grouped together to create thirty different units, each addressing some basic arithmetic function: accumulators for addition and subtraction, a multiplier, and a combination divider and square rooter. The sprawling visual effect of the machine was overwhelming. Programming, the six learned, would not be a desk job. The women would stand *inside* of the ENIAC to "plug in" each problem, stringing the units together in sequences using hundreds of cables and some three thousand switches.

There were no instructions to read, no courses to take. The only manual for the ENIAC would be written years later, long after the women had reverse engineered it from the machine itself. Built by electrical engineers, the ENIAC came with nothing but block diagrams of circuits. Just as Grace Hopper had before them, they taught themselves what to do, becoming hardware adepts in the process.

They started with the vacuum tubes and worked their way to the front panels. Betty Snyder borrowed maintenance books for the machine's punch card tabulator from a "little IBM maintenance man by the name of Smitty," who told her he wasn't allowed to lend them out but did anyway, just for a weekend, so she could figure out how the ENIAC's input and output worked. They found a sympathetic man to let them take a plugboard apart and make their own diagram for reference, even though his supervisor wasn't sure they'd be able to put it back together again (they were). It was hot and there was construction everywhere, including in the room above the one in which they worked. One day John Mauchly popped in and said, "I was just checking to see if the ceiling's falling in." They started going to him with questions, and eventually made headway.

Knowing how a machine works and knowing how to program it are not the same thing. It's something like the difference between an intellectual understanding of internal combustion and being a fighter pilot. John Mauchly and J. Presper Eckert essentially built a jet, gave the keys to six women without pilot's licenses, and asked them to win a war. It was daunting, but it presented an opportunity for the women to claim space for themselves in a field so young it didn't have a name. "At that time it was new and no one knew what to do," explained Betty Jean Jennings. Not even the men who designed the ENIAC had given much thought to how it would run. They'd ignored the actual workflow of setting up problems. In 1973, Mauchly himself admitted that he and Pres had been "a little cavalier" about programming, saying that they "felt that if we had the machine capable . . . there would be time enough to worry about those things later."

As it turned out, Mauchly found other people to worry about those things—six people, in fact, in wool skirts and thrilled by the challenge. "How do you write down a program? How do you program? How do you visualize it? How do you get it on the machine? How do you do all these things?" wondered Betty Jean. It would be up to the ENIAC Six to figure it out.



Betty Jean Jennings (left) and Frances Bilas (right) operate the ENIAC's main control panels.

Today, programming can be tricky, but it's accessible. To write code, you don't need to study circuit diagrams, take apart components, and invent strategies from scratch. Instead, you simply need to learn a programming language, which acts as an intermediary between coder and machine, just as a shared spoken language can bridge a gulf of understanding between people. You tell the machine what to do in a language you both understand; the machine then translates and executes your commands on its own. The ENIAC had no such language. The computer accepted input in only the most elemental of ways, and so the ENIAC Six rolled up their sleeves and met the machine on its level. As Betty Jean Jennings recounted:

> Occasionally, the six of us programmers got together to discuss how we thought the machine worked. If this sounds haphazard, it was. The biggest advantage of learning the ENIAC from the diagrams was that we began to understand what it could do and what it could not do. As a result we could diagnose troubles down to the individual vacuum tube. Since we knew both the application and the machine, we learned to diagnose troubles as well as, if not better than, the engineer.

Unlike Grace Hopper, who managed a team of operators punching her handwritten code into the Mark I's tape loops, the ENIAC Six moved around inside the great machine itself. They replaced individual burned-out vacuum tubes from among thousands—several burned out every hour, despite Pres's design—fixed shorted connections, and wired control boards. They wrote programs, feeding them gently into the machine with much trial and error. The job required a combination of mechanical dexterity and mathematical know-how, to say nothing of organizational skills: punched cards containing the ENIAC's programs needed to be sorted, collated, tabulated, and printed. The word "programmer" didn't exist yet, but Betty Snyder thought of herself as a "cross between an architect and a construction engineer." Betty Jean Jennings was more blunt. "It was a son of a bitch to program," she wrote.

Unfortunately, none of this effort did the U.S. Army any good. Although it ran a number of one-off calculations, the war ended before the ENIAC became fully operational as a ballistics calculator. In peacetime, however, the ENIAC was no longer secret, and the computer was unveiled to the public in 1946, with much fanfare and two different demonstrations. The first, for the press, was by all accounts a bit lackluster. The second, for the scientific and military community, was a hit, thanks largely to a demonstration of a trajectory calculation programmed by Betty Jean Jennings and Betty Snyder.

The two Bettys, as they were sometimes known, were the aces of the ENIAC programming team; after the war, they both went on to long and pioneering careers in the commercial computer industry. As was common in the history of human computing, the pedagogy of the Moore School emphasized working partnerships, with teams of two people seeking out errors in each other's work. Betty Jean and Betty were ideal partners, because they delighted in finding each other's mistakes. They both wanted perfect code and never let their egos get in the way of achieving it. "Betty and I had a grand time," Betty Jean wrote in a memoir. "We were not only partners, but we were friends and spent as much of our free time together as possible."

A few days after the first ENIAC demonstration, Herman Goldstine, their military liason, and his wife, Adele, invited Betty and Betty Jean over to their apartment in West Philadelphia. Adele trained the human calculators at Penn and had always struck Betty Jean as an impressive, big-city woman; at the Moore School, Adele lectured sitting on her desk, with a cigarette dangling from the corner of her mouth. Betty Jean was surprised to find the Goldstine apartment rather ordinary, with few personal touches and a set of twin beds. As Adele served the Bettys tea and the Goldstine cat leaped uninvited onto their laps, Herman asked them if they could set up a ballistics calculation on the ENIAC in time for its unveiling to the scientific community twelve days later. It was a big ask, and Betty Jean sensed that Herman Goldstine was nervous about the demonstration. Well-known scientists, dignitaries, and military brass would be there, and everyone was keen to see that the ENIAC worked as advertised. Not much has changed, it seems, about the way tech keynotes are anticipated and prepared.

The Bettys asserted vigorously that yes, absolutely, they could make it happen. They were bluffing. Although they'd spent the last four months working out a ballistics trajectory program on paper, they hadn't actually plugged it into the ENIAC yet, and they had no idea how much time the transfer would take. They started the next day.

Betty Snyder was twenty-eight; Betty Jean Jennings had only just turned twenty-one. They knew they'd been asked to do something important and that everyone they worked with was counting on them. The pair worked around the clock for two weeks, living and breathing the trajectory program. Their colleagues Ruth Lichterman and Marlyn Wescoff supported them by hand calculating an identical trajectory problem on paper, mirroring step-by-step how the ENIAC would process the calculation. This would help the Bettys debug the ENIAC if it made any errors. Men popped by with offerings: the dean of the Moore School left them some scotch, and John Mauchly came in on a Sunday with a bottle of apricot brandy. They didn't really drink—maybe a Tom Collins on special occasions—but Betty Jean kept a taste for apricot brandy for the rest of her life.

The night before the big demonstration was Valentine's Day, but the Bettys didn't go on any dates. Their ENIAC program had a massive bug: although they'd managed to model the trajectory of the artillery shell perfectly, they couldn't figure out how to make it *stop*. When their imaginary shell hit the ground, the mathematical model kept going, driving it through the earth with the same velocity and speed as it had while shooting through the air. This made the calculation worse than useless. If they didn't find some way to stop the bullet, they'd embarrass themselves in front of eminent mathematicians, the army, and their employers. In desperation, they checked and rechecked settings, comparing their program with Ruth and Marlyn's test program, but they were stuck. A little before midnight, they left the lab. Betty took the train home from the university campus to her house in suburban Narberth. Betty Jean walked home in the dark. Their spirits were low.

But Betty Snyder had one trick left: when stuck on a logical problem, she always slept on it. Wearily, she spent her hour-long train ride home that night considering the artillery problem and its various potential solutions. When she fell into bed, her subconscious began to untangle the knot. The next morning—February 15, 1946—Betty arrived at the lab early and made a beeline to the ENIAC. She'd *dreamed* the answer, and knew precisely which switch out of three thousand to reset, and which of the ten possible positions it should take. She flipped the switch over one position, solving the problem instantly. Betty could “do more logical reasoning while she was asleep than most people can do awake,” marveled Betty Jean.

The ballistics trajectory demonstration was a huge success, thanks to the Bettys’ clever ballistics program and a little old-fashioned razzle-dazzle from John and Pres, who placed halved Ping-Pong balls over the ENIAC’s neon indicators. During the demonstration, staff dimmed the lights in the room, showcasing the ENIAC’s thinking face in feverishly blinking orbs of light. The program was faster than a speeding bullet, literally: the ENIAC calculated the trajectory in twenty seconds, faster than it would have taken a real shell to trace it. The Bettys and Kay McNulty hustled over to the tabulator, made printouts, and handed them out to the audience as souvenirs.

The event made headlines. The women were photographed alongside their male colleagues—they remember flashbulbs—but the photos published in newspapers showed only men in suits and military decorations posing with the famous machine. The press had a field day with the ENIAC, presenting it as a fruit of the war effort unveiled for the better living of the American people. Because of their unfamiliarity with computing, journalists called the ENIAC a “giant brain” and a “thinking machine,” a mischaracterization that has persisted in the popular consciousness, enthusiastically supported by science fiction writers, ever since. The ENIAC couldn’t think. It could multiply, add, divide, and subtract thousands of times per second, but it couldn’t reason. It was not a giant brain. If there were giant brains in the room, they belonged to the people who built—and ran—the machine.

It irked the ENIAC women to read newspaper articles claiming the machine itself was clever; they knew better than anyone that it was just a room full of steel and wire. “The amount of work that had to be done before you could ever get to a machine that was really doing any thinking to me just staggered the mind,” complained Betty Jean, and “I found this very annoying.” It was more than annoying; it effectively erased her. The 1946 *New York Times* story about the ENIAC demonstration breathlessly reported that “the ENIAC was . . . told to solve a difficult problem that would have required several weeks’ work by a trained man. The ENIAC did it in exactly fifteen seconds.”

As historian Jennifer S. Light points out, that claim ignores two essential factors: first, that the "several weeks' work" would never have been done by a man in the first place. It would have been done by a female computer working long hours at the Moore School. Second, the claim that the ENIAC solved the problem in "exactly fifteen seconds" completely disregards, through ignorance or willful dismissal, the weeks of work, again conducted by women, that went into programming the problem before it was even put on the computer. As far as the press was concerned, nothing outside of those fifteen magical seconds—not the hours of coding and debugging, not the labor of programmers and maintenance workers and operators—counted. Light writes, "The press conference and follow-up coverage rendered invisible both the skilled labor required to set up the demonstration and the gender of the skilled women who did it."

After the ENIAC demonstration, once the glad-handing and photo-ops were over, the university hosted a big celebration dinner. Judging from a menu for the event, no expense was spared. Military brass and members of the scientific community ate lobster bisque, filet mignon, and "fancy cakes." None of the ENIAC Six were invited—not even the Bettys, who had created the demonstration the dinner was held to celebrate. They'd helped introduce the century to the machine that would come to define it, and nobody congratulated them. The Goldstines snubbed them completely. Even their supporters, John Mauchly and J. Presper Eckert, were too caught up in the excitement of the day to comment on the demonstration program. On February 15, just as they had late the night before, Betty Jean Jennings and Betty Snyder went home dejected. It was cold, and they were exhausted. "It felt like history had been made that day," Betty Jean wrote in her autobiography decades later, "and then it had run over us and left us in its tracks."

History would run them over again and again. Neither Betty nor Betty Jean would be credited for writing the ENIAC demonstration program until they began to tell their own stories over fifty years later. Herman Goldstine, in his influential history of the ENIAC, wrote that *he and Adele* had programmed the February 15 demonstration themselves, a move of revisionist history that Betty Jean Jennings, late in life, called a "boldface lie." In subsequent retellings, the women were skipped over repeatedly. In some historical images, the ENIAC Six are captioned as models, if pictured at all. “I wasn’t photogenic,” said Betty Snyder. “I wasn’t included on any of the pictures of the entire stupid thing.” When the army used a War Department publicity shot of the ENIAC for a recruitment ad, they cropped out the three women in the picture entirely. The War Department’s own press releases about the ENIAC cited a vague, genderless “group of experts” responsible for the machine’s operation, and mention by name only John Mauchly, J. Presper Eckert, and Herman Goldstine.

It’s tempting to look at the historical association between women and software and assume some inherent affinity: that women appreciate the mutable, language-oriented aspects of programming, while men are drawn to the practical, hands-on nature of hardware. Some might posit as much from the Babbage-Lovelace partnership, Howard Aiken and Grace Hopper’s testy relationship a generation later, or from the gendered division of labor between male hardware engineers and female operators on the ENIAC. But in all of these instances, women have fallen on the software side not because the work was somehow more suited to them but because software, still inextricably entangled with hardware, wasn’t yet a category with its own value. As far as anyone understood it, software—the writing of code, the patching of cables—was really just the manipulation of hardware, and the title of “programmer” wasn’t yet distinct from the more menial “operator,” a rote job that leaned female because of a long female history of secretarial work. Further, the hiring of women to run computers like the ENIAC reflected a long tradition of women as computers themselves, laboring over applied mathematics in university and research settings. Women had been doing the math for as long as anyone could remember.

“If the ENIAC’s administrators had known how crucial programming would be to the functioning of the electronic computer and how complex it would prove to be,” Betty Jean Jennings eventually determined, “they might have been more hesitant to give such an important role to women.” At the time, it was difficult to perceive of programming as an occupation distinct from simply *operating* a computer and, indeed, the ENIAC women’s jobs were officially classified as “subprofessional, a kind of clerical work.” It would be years before those who approached computers began to define themselves in relation to them, as programmers or computer scientists, rather than as operators or electrical engineers. It would take even longer before a vision of programming as an art form with the potential to reshape the modern world came into focus.