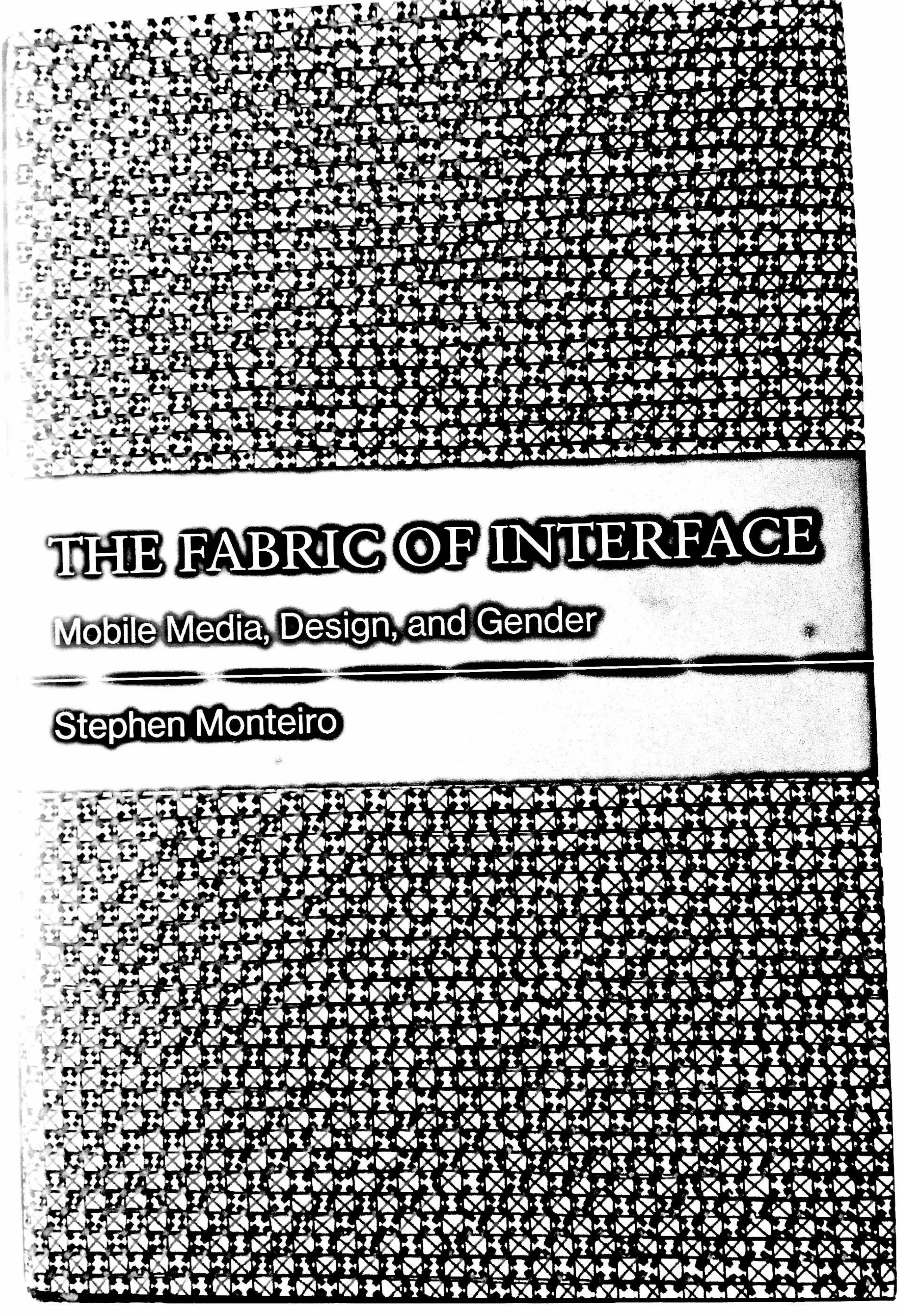

THE FABRIC OF INTERFACE

Mobile Media, Design, and Gender

Stephen Monteiro

1 Woven Memory

The texture of mobile media appears to be smooth and unmodulated. Clean, firm glass screens facilitate the quick, even movements of fingertips. Yet this seamless surface hides textured patterns of lines, channels, and filaments, some of them crafted by the hands of unseen workers in different parts of the world. Indeed, a smartphone or tablet can be at once a woven object, a sewn object, and a handmade object, from the fine grid of sensor filaments placed just under the glass to the soldered circuit boards deep inside the casing. And this condition is nothing new, but only the most recent example in computing and electronics' long reliance on textile culture and needlecraft to make its machines and networks function. Weaving, textile assembly, and digital culture share a long history. Some of it is well known, some of it is scarcely documented, and some of it undoubtedly has been lost. While this history has been left in the shadows of contemporary media culture, it should not come as a surprise when we think about the nature of textile production or computing. As different as fabric patterns and software may seem, they both represent highly structured systems of calculation. Just as a laptop, tablet, or smartphone converts the binary code of ones and zeroes of software and data—conveyed by switching electrical currents on and off—into meaningful images for us, a loom transforms rows of perpendicularly stretched thread into meaningful patterns through similar up/down, on/off settings. When studied closely, the overlap in computing and textile cultures is substantial. Their convoluted relationship surfaces in the forms and practices of early computers as well as those of contemporary networked mobile media. Today's digital devices and software, particularly those involving haptic, image-based interfaces, draw heavily on the cultural characteristics of textiles and needlecraft. This propensity has consequences for our understanding of the societal role digital media play not only in the content they aggregate and circulate, but also in their appearance and performance in the spaces of the everyday. This relationship, moreover, has been critical for the theorization and conception of the logic and mechanics of modern computing from its beginnings two centuries ago.

Algebraic Patterns

So many histories of modern computing begin in the nineteenth century with the Jacquard silk-weaving loom apparatus and its influence on Charles Babbage's Analytical Engine that the story stands as the originary mythology of digital culture.[1] However, this story is often conveyed simply as an inspirational tale of one technology impacting the design of another. The relationship between Babbage's ideas and textile culture are more complex, impacted not only by Joseph Marie Jacquard's device, but also Augusta Ada King, Countess of Lovelace's theorizations of programming and Babbage's views concerning production organization and labor in the textile industry. All of these are considered in this chapter as evidence of textile culture's fundamental role in the conceptualization of computing.

Although commonly called the Jacquard "loom," the apparatus invented by the French textile manufacturer and engineer in 1801 was more precisely a treadle-operated shedding mechanism that could be mounted over a drawloom (figure 1.1). The device automatically manipulated the vertical warp threads of the loom between each passage of the horizontal weft thread by means of a shuttle, the basic action of loom weaving (figure 1.2). The apparatus's automatic adjustment of threads was regulated by a system of pasteboard cards. Holes were punched on a card to correspond to a particular alignment of the warp rods—attached to the vertical threads of the loom—during a single horizontal passage of the shuttle. As each card passed under levers connected to the rods, those levers that lined up with the card's punched holes would fall, shifting the corresponding rods and their threads into the raised "on" position (figure 1.3). All other rods would remain in a default "off" position. The cards would be strung into chains—of hundreds or even thousands—to produce the "program" for the production of a specific cloth design.[2] In this configuration Babbage, an English mathematician and engineer, would later see the means of programmable, mechanized calculation.

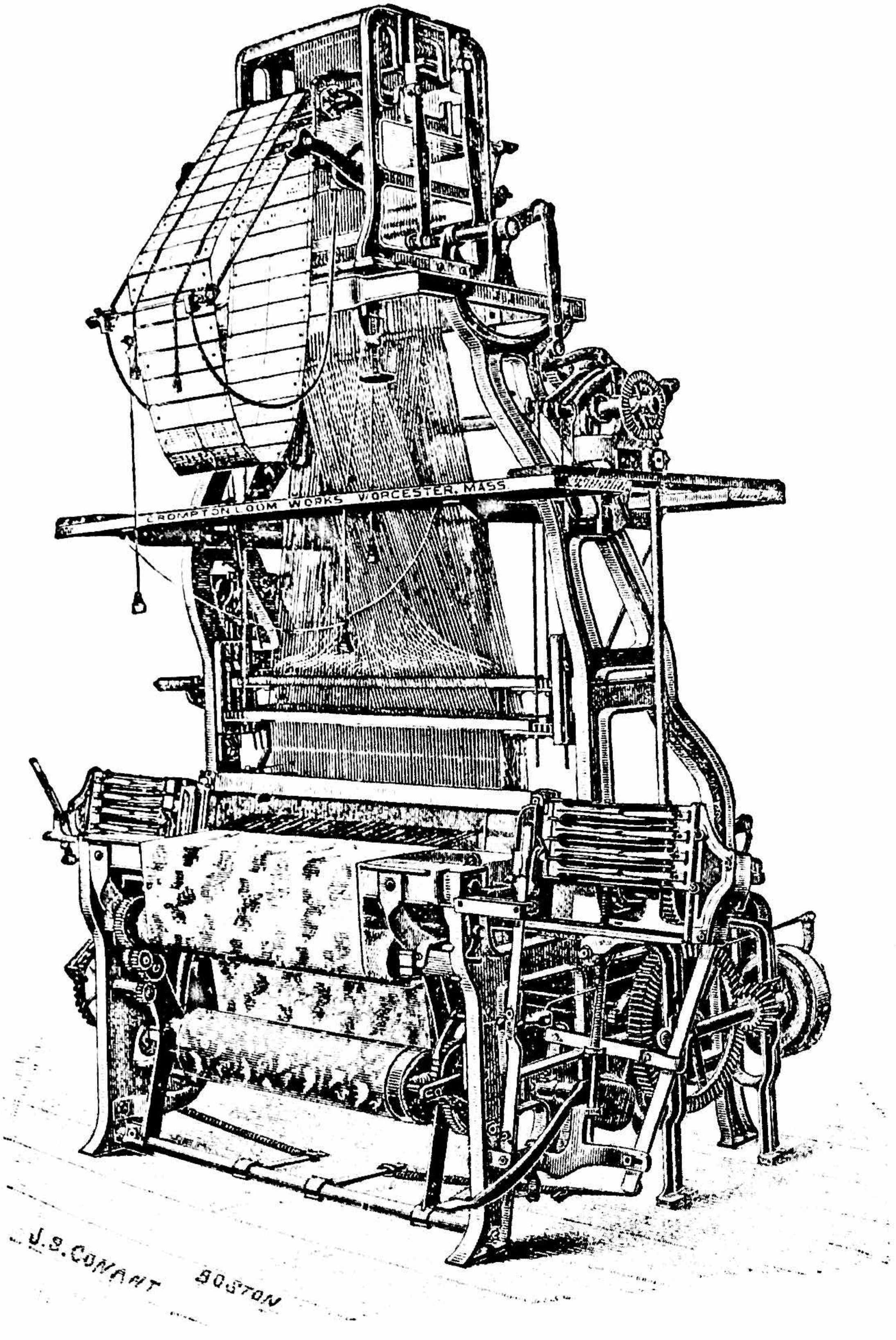

Figure 1.1
Loom equipped with a Jacquard mechanism, c. 1870. The punched cards used to adjust the warp threads can be seen extending from the upper left. Engraving by J. S. Conant Company, Boston.

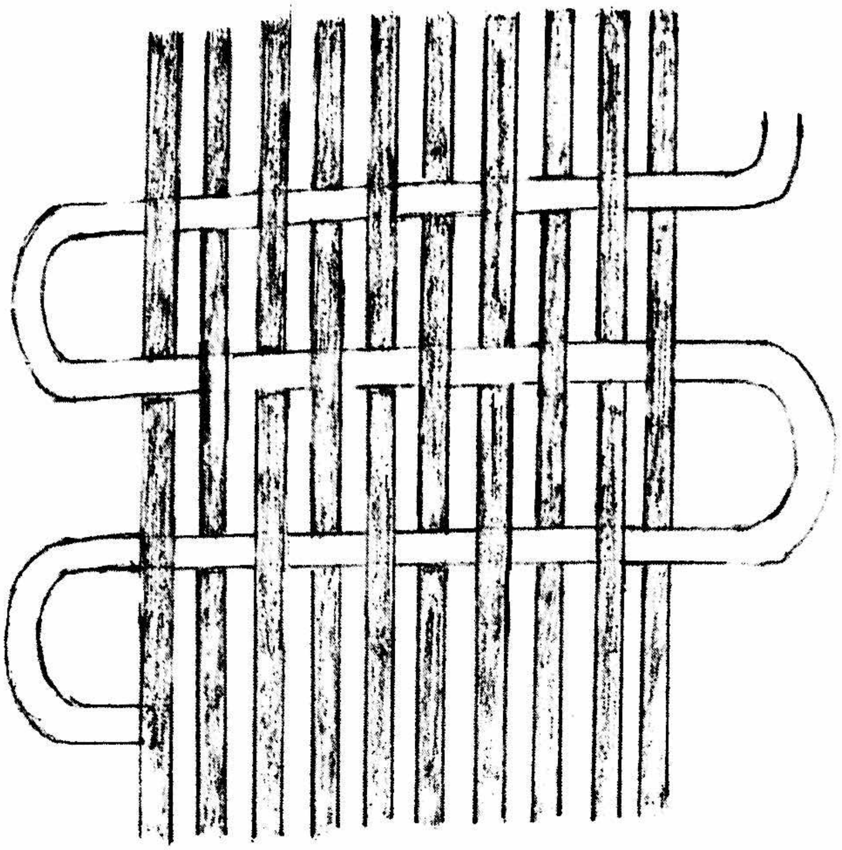

Figure 1.2

Diagram of a plain weave technique with a light weft thread passing horizontally through a line of darker warp threads that would be mounted on a loom frame. Drawing by Manisha Iyer.

Jacquard's apparatus permitted complex warp sequencing for elaborate patterns and images to be woven into silk textiles. It obviated the need for a human weaver to understand and execute these sequences. It replaced outright the drawboy (sometimes a drawgirl), who would sit above or beside the loom to manipulate weighted cords attached to warp threads according to the weaver's instructions.[3] Once a set of punched cards had been created to produce a specific image, motif, or pattern with this apparatus, the set could be stored, retrieved, and run at any time. Ostensibly, these programmed weaving combinations could be executed on any suitable drawloom, regardless of the talent or dedication of the operator. Once the first card was fed into the mechanism, the rest followed automatically. Like the more familiar example of the punched musical scroll in a player piano, Jacquard's card-based manufacturing system eliminated the need for real-time human calculations in the production of the piece. The passage of

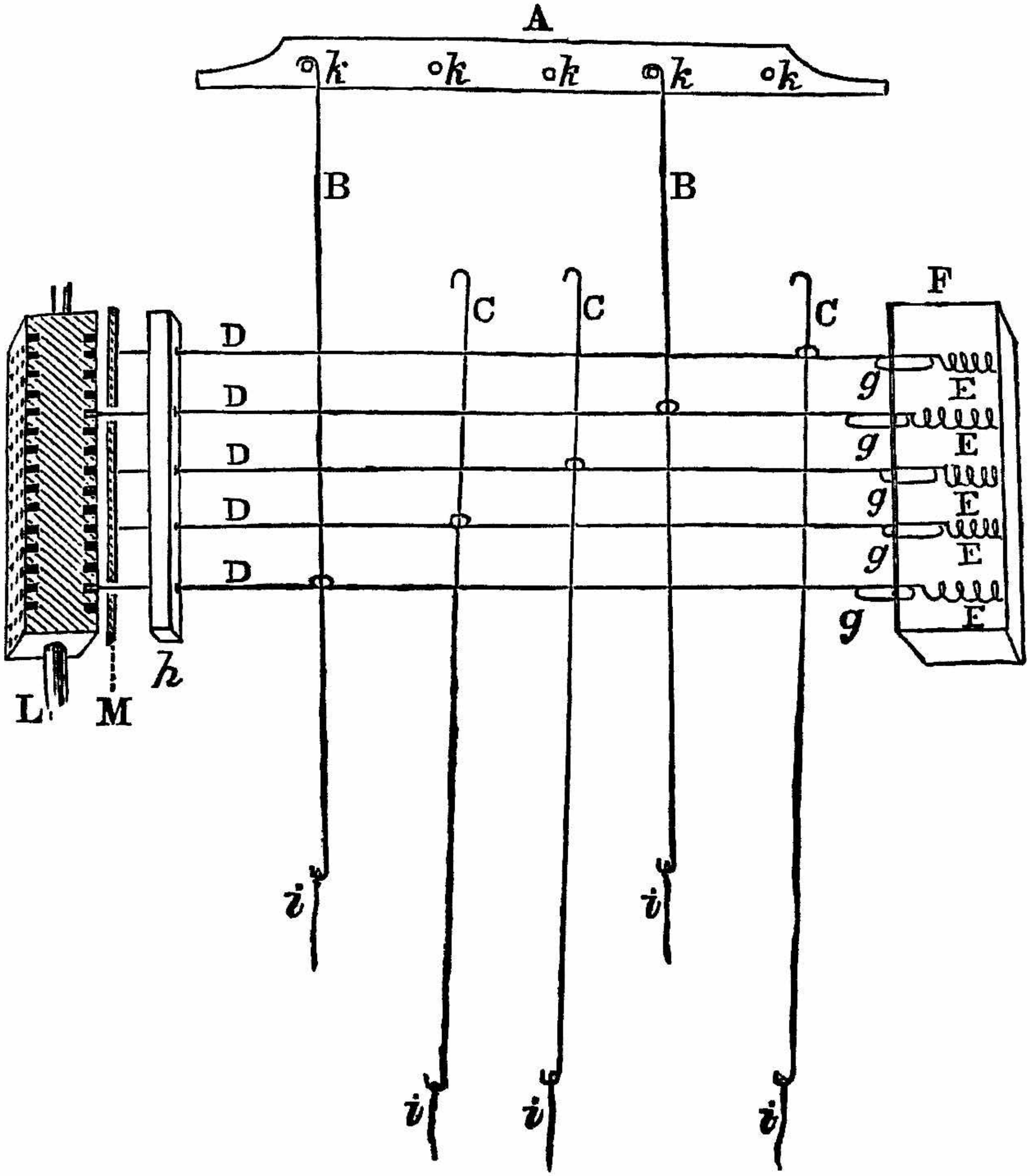

Figure 1.3
Schema of a Jacquard mechanism. The punched cards pass over the rotating block (L), causing rods (D) to either remain in place or drop, thereby allowing the warp thread hooks to either catch (B) or miss (C) the lifting bar (A) during a passage of the weft. From *Chambers's Encyclopædia: A Dictionary of Universal Knowledge* (London: Chambers, 1908).

hundreds of cards could render fabrics bearing intricate patterns and even entire images of a resolution comparable to that found in engraving or lithography (figure 1.4). Jacquard mechanisms are still fixed atop industrial looms today for the production of figured textiles. Contemporary examples rely on electronics rather than cards, however, and allow designers to weave directly from whatever pattern they create on a monitor through the use of "weave software," much like what-you-see-is-what-you-get desktop printing.[4]

Just as Jacquard's apparatus would have fundamental consequences for the architecture and functioning of digital computers, it profoundly influenced industrial production and labor systems, making it a key instrument in the Industrial Revolution as well as in the relationship between computing and social structures. While these aspects of Jacquard's invention and its history have received attention individually, they should be considered jointly.[5] The Jacquard apparatus's contributions to digital architectures and industrial management are inextricable. Together they establish computing's epistemological and material dependence on textile and needlecraft culture while situating this dependence in the social and economic consequences of the historical relationship between gender and labor.

Babbage recognized in Jacquard's invention the possibility of storing and executing calculations automatically, and he would later describe the functioning of such processes through the language of textile production. By the 1820s he had already invented the Difference Engine, which could mechanically execute long series of calculations through progressive operations and compile the results in printed tables. However, he saw greater value in a calculating device that could not only execute calculations based on an initial set of data and operations, but also initiate new operations during the process, with the results of ongoing calculations feeding back into the machine. He called this device the Analytical Engine. Like the Difference Engine, it would be constructed of gears, called "figure wheels." The wheels would be stacked forty-high on rows of vertical rods. Functioning on a decimal system (rather than the binary system of later, electronic computing), each wheel could be rotated like a dial into positions representing any integer from zero to nine. A numerical value with multiple digits would be rendered through the rotation of consecutive wheels on a given rod, each wheel representing a digit in the sequence. Thus the numerical value "847" would be represented by three wheels, with the first wheel rotated

Figure 1.4
Portrait of Joseph Marie Jacquard, entitled *A la Memoire de J. M. Jacquard,* woven by Didier, Petit et Cie by means of a Jacquard mechanism, 1839. Library of Congress photo LC-USZ62-105321.

to the eighth position, the second wheel rotated to the fourth position, and the third wheel rotated to the seventh position. Operations would be executed through studded "barrels" controlled by punched cards.[6]

The Analytical Engine was never built, in part because of the exceeding complexity of its mechanisms and the shortcomings of Victorian precision-tool manufacturing. Babbage was forced instead to content himself with simply describing the engine's properties. In addition to scores of diagrams and sketches, he relied on analogies dependent on Jacquard's apparatus and the textile industry. Babbage would claim that anyone familiar with the principles of Jacquard weaving and analytical formulas could understand his invention "without much difficulty." He identified the engine's two main components as the "mill" and the "store."[7] For any sizable textile production facility in Babbage's day, the mill was the main area of production. It required an adjacent store as a staging area for stockpiling materials throughout the production process. These goods included raw materials and thread before weaving in addition to finished textiles awaiting delivery. Similarly, the Analytical Engine's mill would be the site of execution of all operations and calculations. It would rely on its store for its materials and the stockpiling of results, whether for future operations by the mill or for delivery.

The operator of the engine need only insert material—in this case numerical values—into the store for eventual processing in the mill. In this computing machine, as in textile manufacture, when all processes were completed the finished goods—cloth or sets of numbers—would be extracted from the store. As such, Babbage conceived the store as both memory and output unit. The term "store" would remain in use through the frenzy of computing experiments of World War II. While describing the possibilities of stored-program computing in 1945, John von Neumann eschewed Babbage's terms and their industrial and cultural implications, instead describing the computer as a system of organs. In his "First Draft of a Report on the EDVAC," a founding document of modern computing, he explained that the calculating, controlling, and memory components of the computer "correspond to the *associative* neurons in the human nervous system. ... These are the *input* and *output* organs of the device."[8] Wendy Chun notes that von Neumann made this change "in order to parallel biological and computing components."[9] Von Neumann's choice of terminology attempts to naturalize the computer as a living, conscious entity capable of thought and cognition. While "memory" would become commonplace, von Neumann's evocation of the body did not readily take hold. A decade after his effort to shift computing's conceptual and semantic frame away from textile culture, computer memory itself would be manufactured as a textile of metal wires that replaced the vacuum tubes and mercury delay lines in use when von Neumann wrote his report.

As has been noted in most histories of computing, Babbage's engine would further emulate Jacquard's device in its use of punched cards as a type of read-only memory to compile and archive data that could be used to guide processing. This system for preserving and circulating data would find its greatest success, of course, in twentieth-century mainframe computing, which made the punched card synonymous with digital information technologies. In her study of the grid as a modern trope, Hannah Higgins claims that Jacquard's punched card serves as "the mechanism of transition between the soft grids of textile technology and the hardware of the information age; it translates the net from its physical expression in textiles to a modeling form that would tabulate, sort, and integrate."[10]

Textile production and the Jacquard apparatus did not contribute to Babbage's engine simply by allowing one mechanical epistemology to benefit another, however. Rather, they formed the conceptual underpinnings of that machine. The Analytical Engine required the mill and the loom to explain its processes, to make it meaningful as both concept and enterprise. This is reflected most strongly in the writings of Babbage's collaborator, Ada Lovelace, a key female presence in modern computing's early history and popularly known as the world's first programmer.[11] Perhaps Lovelace's most important contribution—more important even then the operation sequences she drafted for Babbage—was her interpretation of the Analytical Engine as a cultural object. This machine would not merely be a device for making calculations, Lovelace demonstrated; it would reframe the processes of production. The Analytical Engine was an achievement in design and interactivity, with the binary code of the punched-card system at its base. As Lovelace explains in the extensive notes accompanying her translation of Luigi Federico Menabrea's "Sketch of the Analytical Engine Invented by Charles Babbage, Esq.":

> The distinctive characteristic of the Analytical Engine, and that which has rendered it possible to endow mechanism with such extensive faculties as bid fair to make this engine the executive right-hand of abstract algebra, is the introduction into it of

> the principle which Jacquard devised for regulating, by means of punched cards, the most complicated patterns in the fabrication of brocaded stuffs. It is in this that the distinction between the [Analytical and Difference] engines lies. Nothing of the sort exists in the Difference Engine. We may say most aptly, that the Analytical Engine *weaves algebraic patterns* just as the Jacquard-loom weaves flowers and leaves.[12]

The Analytical Engine would generate irregular patterns or forms, equivalent to the image capabilities of a Jacquard-equipped drawloom. However, Lovelace adds, "It should be remembered also that the cards, when once made out for any formula, have all the generality of algebra, and include an infinite number of particular cases."[13]

The Analytical Engine's punched cards were of three types: operation, number, and variable. Operation and variable cards had forms, but not values, allowing the production of unlimited calculations as well as the interchangeability of cards to produce new numbers. In the case of the Jacquard apparatus, a card also represented the form—a particular sequencing of rods—but not the value of an operation, such as what type and color of thread was used. Forms might be repeated several times in the production of a particular textile motif. By making selections from existing sets of cards for the Jacquard apparatus and arranging the selections in different combinations, weavers potentially could vary the vertical sequence of forms in a textile to produce any number of designs. This occurred in the production of bed coverlets in mid-nineteenth-century America, for example. American weavers attached Jacquard apparatuses to handlooms and bought mass-produced mix-and-match card sets, like consumer-grade software programs, to produce their own, unique patterns.[14]

Indeed, a Jacquard-equipped loom functioned much like a programmed computer. The machine could be adapted to quickly perform any number of calculations simply by running punched-card programs. It could not, however, store any calculations or operations during the production process. That is, the system had no memory. If a calculation or operation needed to be repeated in the mechanism, it would have to be repeated in the chain of cards, substantially adding to the chain's length. Any deviation in the results from one passage of the cards to the next—from one woven piece to another—would be the product of material flaws (e.g., rod-card misalignment or thread inconsistencies and breakage) or human error (e.g., skipping a passage of the shuttle), rather than any change in calculations during the operation. Lovelace saw a symbiosis between loom and engine that would bring them closer together in their conception and functioning, however. In 1834, the year Babbage first envisioned the Analytical Engine, Lovelace visited English textile mills with her mother, Anne Isabella Byron, where she saw firsthand how punched-card systems contributed to silk ribbon production.[15] If the Analytical Engine could retain data obtained from punched cards for later access and use, Lovelace believed a similar system could be designed for the loom, to eliminate the necessity of repeating the same commands or patterns multiple times within any chain of cards. In speculation that extends beyond Babbage's own interest in the Jacquard apparatus and its links to computing, Lovelace explained that this weaving device could incorporate a further component, allowing for the storage and reintroduction of specific cards in the train of cards during production of a textile. She states:

> It has been proposed to use [backing] for the reciprocal benefit of that art, which, while it has itself no apparent connexion with the domains of abstract science, has yet proved so valuable to the latter, in suggesting the principles which, in their new and singular field of application, seem likely to place *algebraical* combinations not less completely within the province of mechanism, than are all those varied intricacies of which *intersecting threads* are susceptible. By the introduction of the system of *backing* into the Jacquard-loom itself, patterns which should possess symmetry, and follow regular laws of any extent, might be woven by means of comparatively few cards.[16]

Lovelace's description synthesizes the logic behind the processes of weaving and assembly. In form and value the Analytical Engine's functioning bears similarities—at least at the level of systems logic—to block-pattern textile assembly, for example. A block pattern is a basic template upon which any number of other garment patterns can be produced. The block pattern can be used to produce a specific object from multiple pieces of fabric or serve in the production of a variety of objects. In the Analytical Engine, cards could be "backed" in groups or batches to be used multiple times within a single operation or set of calculations. Natalie Rothstein notes the same with the Jacquard apparatus, where "the pattern could be changed in a few minutes, provided the cards were cut and laced together."[17] A set of cards used within an operation could therefore be reintroduced at a later point within the process to produce a pattern, while nevertheless modifying results, just as a block or motif pattern could be used repeatedly within production to create identical or different results,

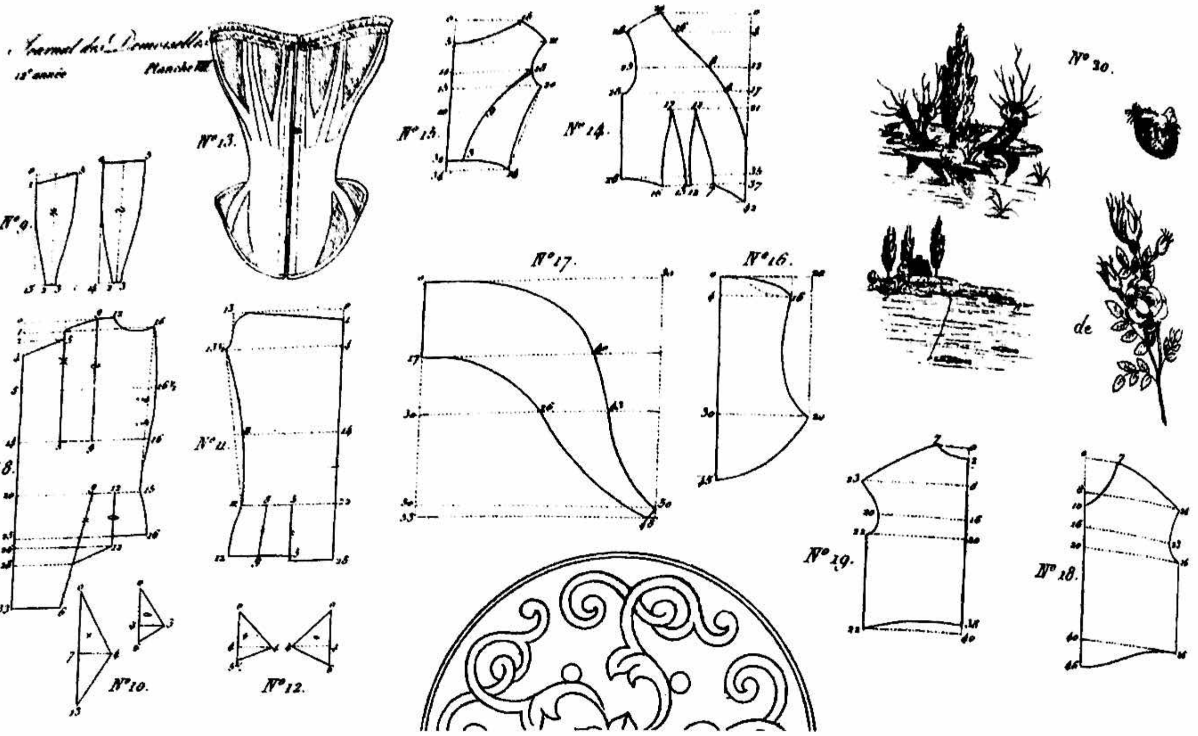

Figure 1.5
Pattern for a bodice, published in *Journal des Demoiselles*, August 1844.

depending on how this template was used in relation to other patterns. Just as the Analytical Engine's card system represents the basic formula or program upon which variations and synthesis can be introduced by entering different data, block patterns represent the material base upon which variations and synthesis of woven material can be produced to create garments.

Commercial patterns for home sewing began appearing in British and French periodicals during the same decade in which Babbage conceived the Analytical Engine (figure 1.5). Patternmaking manuals and mass-produced patterns would become a regular part of home-based textile and needlecraft culture in nineteenth-century Europe and North America, standardizing domestic production while allowing women to exchange patterns or work collectively on garments, even when separated by great distances.[18] In other words, patternmaking functioned as the home industry equivalent of punched cards by allowing reproducibility of results while serving as the base for variation. This was aided greatly by the spread of the sewing machine as a household appliance in the second half of the nineteenth century. Originally meant for use by men in large-scale manufacturing, the sewing machine became one of the century's greatest home consumer successes in a process of technological diffusion that would be matched a century later by the computer's shift from the mainframe and business software to home electronics and consumer software. As Tim Putnam notes, "Sewing machines had been designed for the workshop and only became home appliances when claimed by women as their own."[19] Together, the sewing machine and patternmaking brought textile culture into the home in new forms as mass-produced cloth was assembled at home either as piecework labor in the garment industry or as a leisure activity encouraged by the fashion plates and patterns found in women's magazines.[20]

Only a few decades earlier, automated production on machines equipped with mechanisms similar to Jacquard's device had brought textile production *out* of the home and workshop and into the factory, becoming a well-known sector of the Industrial Revolution. Histories of computing rarely broach the impact of Jacquard's invention on mass production and gender differentiation in the industrial workforce, yet it had lasting consequences that would shape the nature of the electronics industry—and its dependency on the textile industry—over a century later.[21] While women had woven at home for thousands of years, commercial textile production—often of larger and more elaborate pieces than could be reasonably made on a domestic loom—had been the domain of men. Pre-Jacquard silk weaving was considered a skilled profession, requiring careful calibration of the loom and calculation of warp configurations for each pass of the shuttle.

The Jacquard apparatus is emblematic of the generalized upheaval in production methods and labor requirements created by increased standardization, mechanization, and automation in the nineteenth century. When Jacquard introduced his device into the French silk industry in Lyon, weavers sabotaged it and made threats against his life.[22] It first came into use in Britain in English cotton mills around 1813 but took a decade to definitively penetrate the British textile industry, perhaps spurred by imports of cheaper, Jacquard-made French silks during the mid-1820s.[23] Nevertheless, mechanized power looms had begun to replace handloom weaving in Britain by the early years of the nineteenth century. The Luddite movement of the 1810s, protesting working conditions in the weaving and knitting industries, led to waves of frame smashing in northern England, including steam-powered looms that had been newly installed in Manchester mills.[24] Parliament's House of Lords, which included Lovelace's father, the poet George Gordon Byron, claimed that such revolts were the result of "the use of a new machine, which enabled the manufacturers to employ women, in work in which men had before been employed."[25] Though this was an oversimplification, the power loom had allowed commercial weaving to be recategorized as semiskilled or unskilled work, a change that facilitated the employment of women.

None other than Babbage would argue the benefits of this development in his widely read *On the Economy of Machinery and Manufactures*, published only two years before he conceived of the Analytical Engine as a computational transfiguration of the textile mill. Focusing on textile industries, Babbage explained that increased mechanization "does not ... invariably throw human labour out of employment" but rather "enables children and inferior workmen to execute work that previously required greater skill."[26] Noting that "during the whole of this period the wages and employment of handloom weavers have been very precarious," he reasoned that "a diversity of employment amongst members of one family will tend, in some measure, to mitigate the privations which arise from fluctuation in the value of labour."[27] The mechanization of textile production opened a door in this regard: "A hand-weaver must possess bodily strength, which is not essential for a person attending a power-loom," Babbage remarked. "Consequently, women and young persons of both sexes, from fifteen to seventeen years of age, find employment in power-loom factories."[28]

In the semiautomation of the loom and subsequent changes in required skills, the principles of computing and gender-defined labor structures entered into what would become a looped pattern. Women, especially those who were young and rural, would constitute the favored labor pool for nineteenth-century textile industries in Europe and North America. The pattern would repeat in the electronics industries of the twentieth and twenty-first centuries, where young, rural women have been regularly sought for assembly work, particularly in Asia.[29] By the late 1850s, for example, 83 percent of workers at the Courtauld silk mill in Halstead, East Anglia, were women. Not a single man out of the mill's more than one thousand employees tended one of its power looms. The few male weavers living in Halstead were employed instead in soft silk handloom weaving workshops.[30] Women textile workers in Halstead and elsewhere were paid less than men due to their "unskilled" status—winding and weaving for 15–50 percent less than what the mill's male clerks, overseers, and mechanics earned—even as the industry benefited from women's informal home training in needlework, sewing, weaving, and other textile-related crafts. As such acquired skills were considered part and parcel of homemaking and women's work, there was no attempt to acknowledge or reward them through a worker's status and compensation.[31] In a well-known American example, industrialist Francis Cabot Lowell exploited similar socioeconomic conditions in mid-nineteenth-century Lowell, Massachusetts, by recruiting young New England farm women to work in his urban textile mills, replacing home and hearth with dormitory and dining hall. The Lowell "mill girl" became a symbol of American industrial ingenuity. While men in the American textile industry negotiated their wages, mill girls were paid at fixed rates "high enough to induce women to leave the farms ... but low enough to offer the owners an advantage in employing women rather than men." This led to collective actions by the Lowell mill workers in the 1830s and 1840s in protest of meager wages and deleterious industrial conditions.[32]

Weaving Core

The "unskilled" domestic training of women in textile and craft practices returns repeatedly in the culture and economy of modern computing. Just as the processing and memory coupling of Babbage's mill and store has remained the basic paradigm of computing structures, textile-based manufacturing practices have continued to be the organizational paradigm behind digital production. Hand sewing and weaving were key design components of two of the most significant computing projects of the twentieth century—the invention of a real-time, interactive computer at MIT in the 1950s, and the construction of the navigational systems that took men to the moon and back in the 1960s. Both of these projects, to be considered here, are prominent historical examples closely related to broader practices of electronics assembly based on textile assembly techniques.

Recalling that neither Babbage's Analytical Engine nor any comparable device was built in the nineteenth century, for much of the first half of the twentieth century—and especially during World War II—but in some cases even into the 1960s, computers were the minds and pencils of women executing calculations in government bureaus, university laboratories, and similar research settings. In 1945, for example, nearly two hundred women were employed in this capacity during the construction of the U.S. Army's

Electronic Numerical Integrator and Computer (ENIAC).[33] After the end of World War II, the computer room at the United States Bureau of Standards, where the Standards Western Automatic Computer (SWAC) would be developed, was still filled with desks and chairs.[34] "On each desk was an electrically powered mechanical calculator operated by a skilled woman," recalls David Rutland. "Each woman had a work sheet with the numbers that she was to use in her calculation in the left-hand column. ... Across the top of the other columns were listed the operations. ... The results of some operations became the input data for the next operation."[35] Each woman's sheet was not only a grid of information, but one that represented a logical pattern of operations. As a system for recording data during operations, these sheets functioned as a form of memory, the store to the mills of the mind and mechanical calculator.

Jennifer Light has demonstrated how the transition from human computers to electronic machines at the end of World War II was initially accompanied by the creation of another feminized computing occupation: the computer "operator."[36] Female computers or clerical staff familiar with business machines became operators of mechanized systems such as ENIAC, until they were replaced by men after the war and the position was renamed "programmer" to mark a shift in both gender and status. Operators, like the first programmers who followed them, were required to understand and troubleshoot software as well as hardware. As operator Betty Jean Jennings explains, "Since we knew both the application and the machine, we learned to diagnose troubles as well as, if not better than, the engineer."[37] Among the greatest hardware problems was memory. Mercury delay lines, vacuum tubes, and other forms of storing data during this period proved to be inefficient and unreliable, requiring frequent maintenance and jeopardizing the effectiveness and accuracy of programs and calculations.

World War II had brought major breakthroughs in analog and digital computing as governments devised algorithmically functioning machines for making and breaking codes, predicting ballistics trajectories, and executing other tasks tied to the complexities of military operations. This growth only accelerated with the onset of the Cold War.[38] The need for reliable random-access memory within computing systems to support faster calculations, greater capacity, and flexibility in operations, would eventually fold women's textile labor back into the process of technological development. The "single most important computer project of the postwar decade," according to computer historian Paul Edwards, was the Whirlwind computer developed at MIT's Lincoln Laboratory.[39] Originally organized to produce an analog flight simulator, the project grew into the digital computer system behind the U.S. Air Force's Semi-Automatic Ground Environment (SAGE) air defense systems. Whirlwind led not only to real-time graphical screen interfaces, handheld optical input devices, and other elements that would become common to computing later in the century, but also to a new form of memory. Coincident current (or static) magnetic matrix storage, known as magnetic-core memory, was based on principles of electric current and magnetization. It quickly became the leading form of computer memory and remained standard into the 1970s.[40]

Core memory's material form was a wooden or metal frame strung with a taut grid of fine wires (figure 1.6). A small ferrite ceramic ring or "core" was suspended at each intersection of these wires (figure 1.7). This pattern of construction incorporated three types of wires: driving, sensing, and inhibiting. Driving wires would form the horizontal and vertical lines of the grid that held each core in place, while the sensing wire would be threaded diagonally at their intersections. The inhibiting wire would be threaded back and forth horizontally through each row of cores. Thus four wires passed through each core. Applying current through driving and sensing wires would produce a clockwise or counterclockwise charge to each core, depending on the direction of the current passing through it. Rings could be magnetized as positive or negative, equivalent to a one or zero when read by the computer's processor. The sensing wire allowed the binary data to be read, while the inhibiting wire prevented changes in polarity where necessary. Unlike other memory capacities developed at the time, a core's charge—that is, its memory—would remain even when the computer's current was disrupted or cut.[41] Several groups and institutions had been developing core memory independently, but Lincoln Laboratory was the most successful, building a prototype in 1952 and converting the Whirlwind's memory system from electrostatic cathode ray tubes to core by mid-1953.[42] "In five years' time, core memory would replace every other type of computer memory," explain Martin Campbell-Kelly and William Aspray. "The value to the nation of the core-memory spin-off alone could be said to have justified the cost of the entire Whirlwind project."[43]

Project director Jay Forrester sketched the basic configuration for core memory in 1949 and left it to MIT graduate student William Papian to

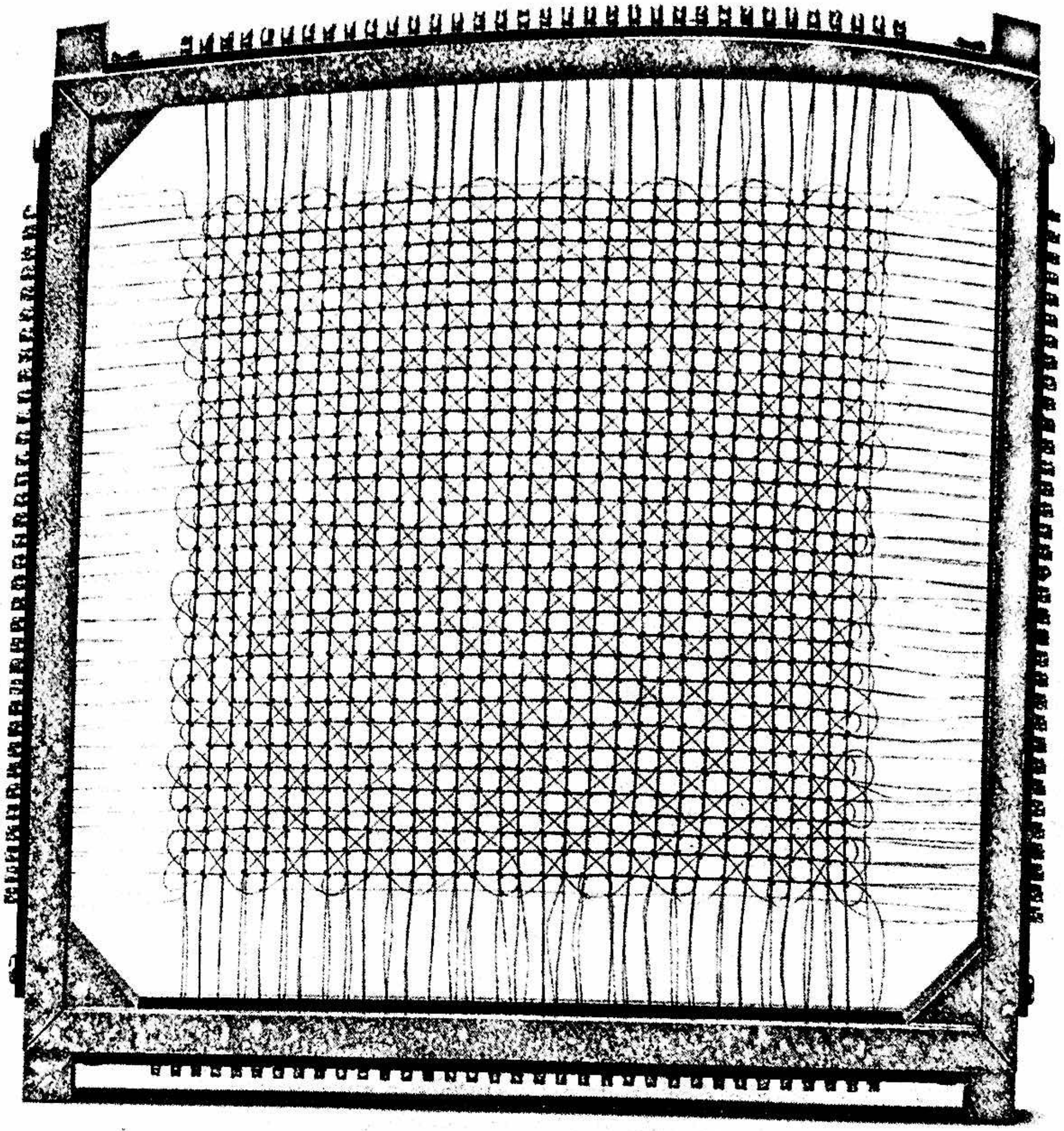

Figure 1.6

Core memory plane from Project Whirlwind, Lincoln Laboratory, MIT, c. 1953. Courtesy of the Computer History Museum, CHM image 102622505.

design a functioning system.[44] A single, 16 × 16 prototype array was built in 1952 and thoroughly tested on a specially built computer called the Memory Test Computer.[45] By early 1953 the prototype had been deemed a success and core memory was ready to be implemented, first in 32 × 32 arrays, then in larger, higher-capacity 64 × 64 arrays.[46] Stating in the project's biweekly report of January 2, 1953 that "design of the memory planes was completed, and construction of the mounting frames is in progress," the Memory Section hired Hilda G. Carpenter as a laboratory assistant and technician responsible for assembling the intricately patterned frames of

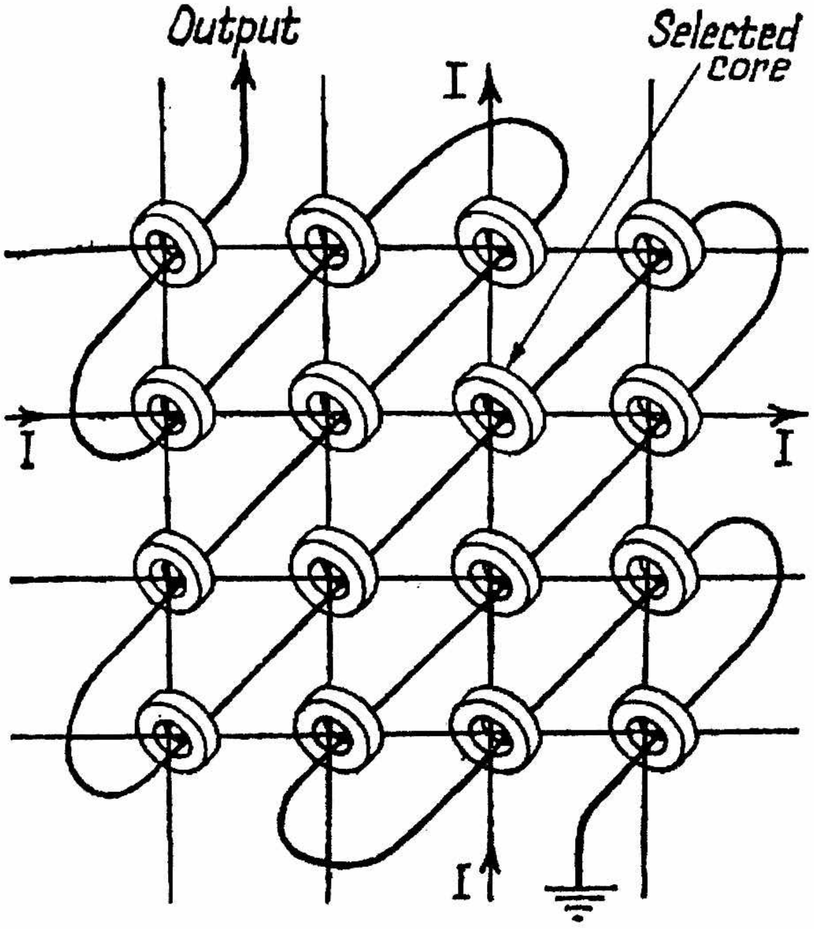

Figure 1.7
Diagram of core memory threading. From M. V. Wilkes, *Automatic Digital Computers* (London: Methuen, 1956).

wires and rings.[47] A report on memory plane construction from the following summer asserted that seventeen memory planes had been produced. A photograph appended to this report shows two women threading and testing planes at a lab bench (figure 1.8). Even with the aid of an assembly jig, a plane required four days to wire.[48] Each plane was composed of 1,024 cores suspended diagonally and turned in alternate directions in the 64 × 64 grid of wires.

"The final design was both simple and elegant," remarked British computer pioneer Maurice Wilkes, who called core memory "a brilliant achievement."[49] Bernard Widrow, an MIT graduate student involved in the implementation of Whirlwind core memory planes, would explain decades later: "This all had to be hand-wired. All the wiring in this memory plane was done by a woman who was a technician working in the lab. I don't

Figure 1.8

Project Whirlwind staff threading and testing core memory planes, Lincoln Laboratory, MIT, 1953. Photograph used and reprinted with permission of The MITRE Corporation. © 2016. All other rights reserved.

remember her last name. But her first name was Hilda. And Hilda wound all these memory planes. It's like knitting. ... Hilda wove all those wires. It's like weaving."[50] While Widrow's comments demonstrate esteem for the skill involved, his recollection of a first name, but not a last, reflects Carpenter's relatively low status as a laboratory assistant. Except to record her hiring, her name does not appear in the reports and memoranda of Project Whirlwind. She does appear as a model in an article on core memory production in a 1956 issue of the journal *Electronics*, however. Carpenter, a woman of color, is seen pouring cores into a sorting tray and weaving a plane of cores with a hypodermic needle. Yet even in this article, her name is absent.[51]

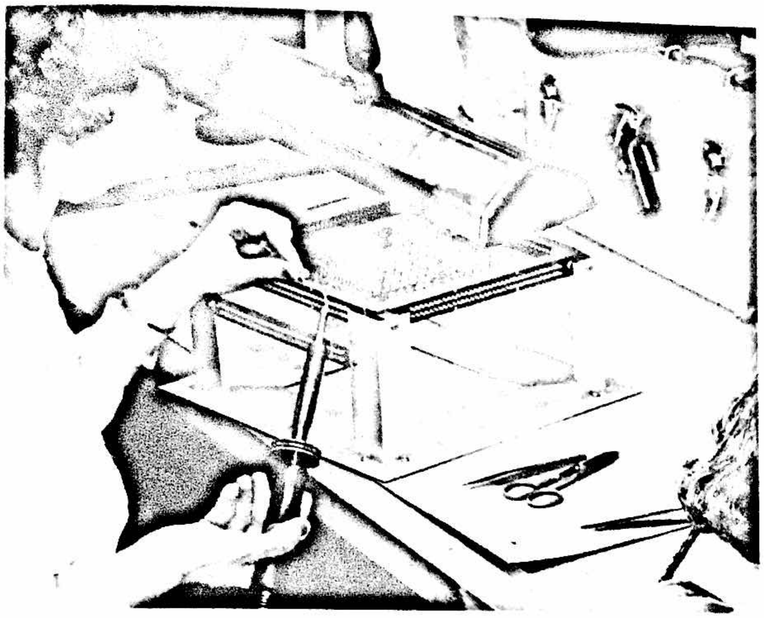

Figure 1.9

Detail from figure 1.8. Project Whirlwind staff member threading a core memory plane, Lincoln Laboratory, MIT, 1953. Photograph used and reprinted with permission of The MITRE Corporation. © 2016. All other rights reserved.

A memory plane would require about forty hours to fully wire in 1953 (figure 1.9).[52] The design and production of core memory drew on properties and practices of weaving, needlepoint, embroidery, and beading (figure 1.10). Cores were mounted like beads by "stringing" them on a driving wire. The grid of driving and inhibiting wires followed the form of traditional weaving, although technically they were not woven since the weft did not follow an over-under alternation with the warp but was merely laid over it. This technique was common to twentieth-century craft weaving, however. Craft weaving was popularized through mass-produced handloom kits, including Easiweave, Weave-It, Magic Loom, and the Lily weaving loom (figure 1.11). These kits typically contained a wooden, metal, or plastic six-inch square pinframe remarkably similar to the frame of the core plane. "Easiweaving is a novel and modern combination of two of the oldest handcrafts—weaving and needlework," one guidebook explained.[53] Weaving on such frames was a four-step process that began with threading two layers of yarn, first horizontally, then vertically (figure 1.12). The core memory plane's grid of driving and inhibiting wires resembled this pattern. The plane's added suspension of the core rings at the intersections of wire followed techniques of on-loom bead weaving, which locks a bead

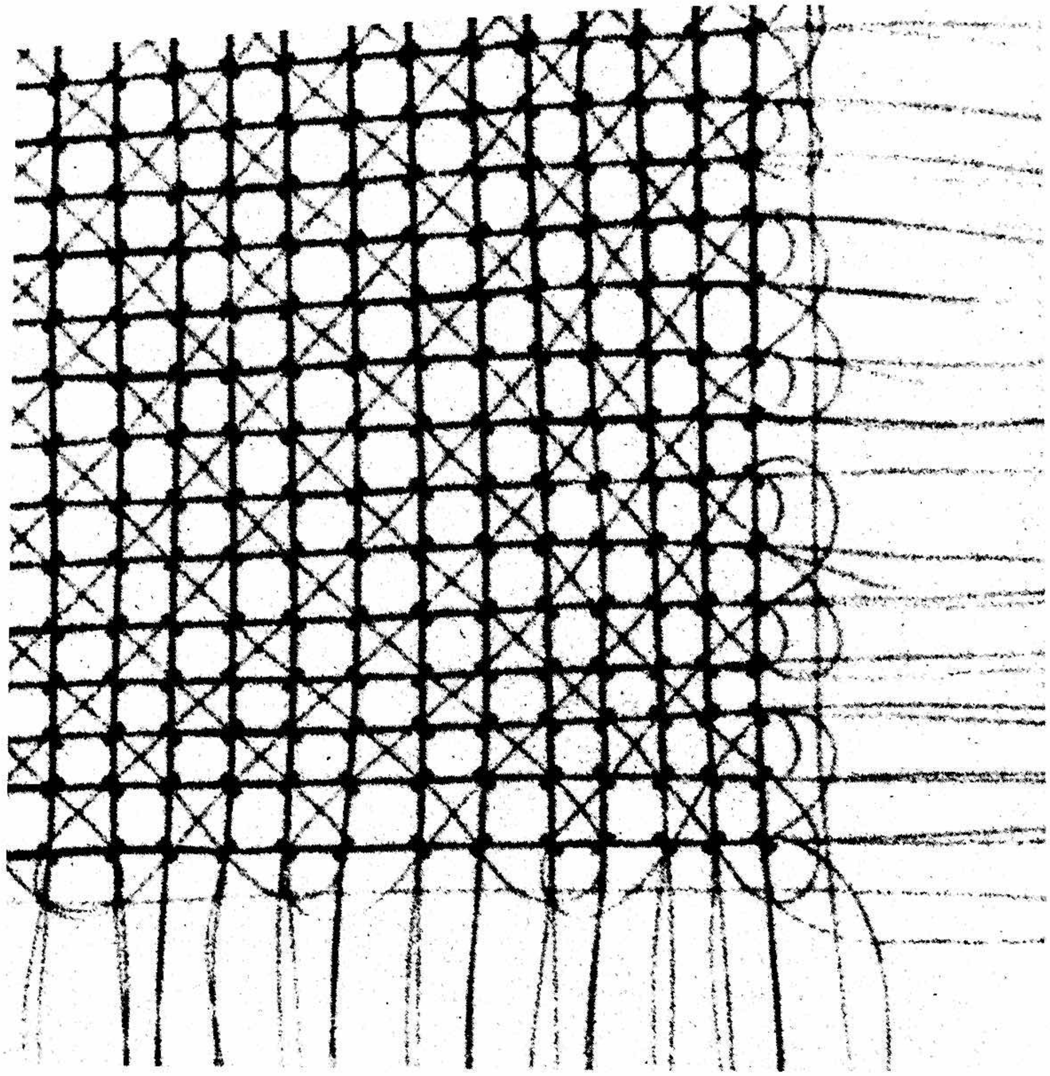

Figure 1.10

Detail from figure 1.6. Portion of a core memory plane from Project Whirlwind, Lincoln Laboratory, MIT, c. 1953. Courtesy of the Computer History Museum, CHM Image#: 102622505.

within the grid of warp and weft threads. The multiple threading of driving, sensing, and inhibiting wires accomplished this result. In fact, bead work instructions in twentieth-century hobby books suggest that weaving beads on a handloom be done only with "lengths of heavy linen thread or fine wire" capable of supporting the weight of the beads.[54] The diagonal threading of the sensing wires through the cores of the memory plane, for its part, has its roots in needlework, which regularly employs diagonal stitching across an underlying straight- and cross-grain weave. This detail draws on the logic of the final two steps in craft kit weaving, which rely on

Figure 1.11
Cover of *Lily Weaving Loom Instruction Sheet*, c. 1955.

needlework techniques of stitching through the threaded base to produce the weave of the textile. A similar bias stitch, diagonal weave orientation was available in some handloom kits, including the Bias Weave-It.[55] In both home weaving and core weaving, once the block was completed, it could be removed from the frame as a loose piece of fabric, to be sewn into patterns with other blocks or, in the case of memory, stretched onto a permanent frame to be soldered and mounted in the computer.[56]

When Lincoln Laboratory contracted IBM in 1953 to design the Whirlwind II—soon inelegantly renamed the AN/FSQ-7—the company embarked

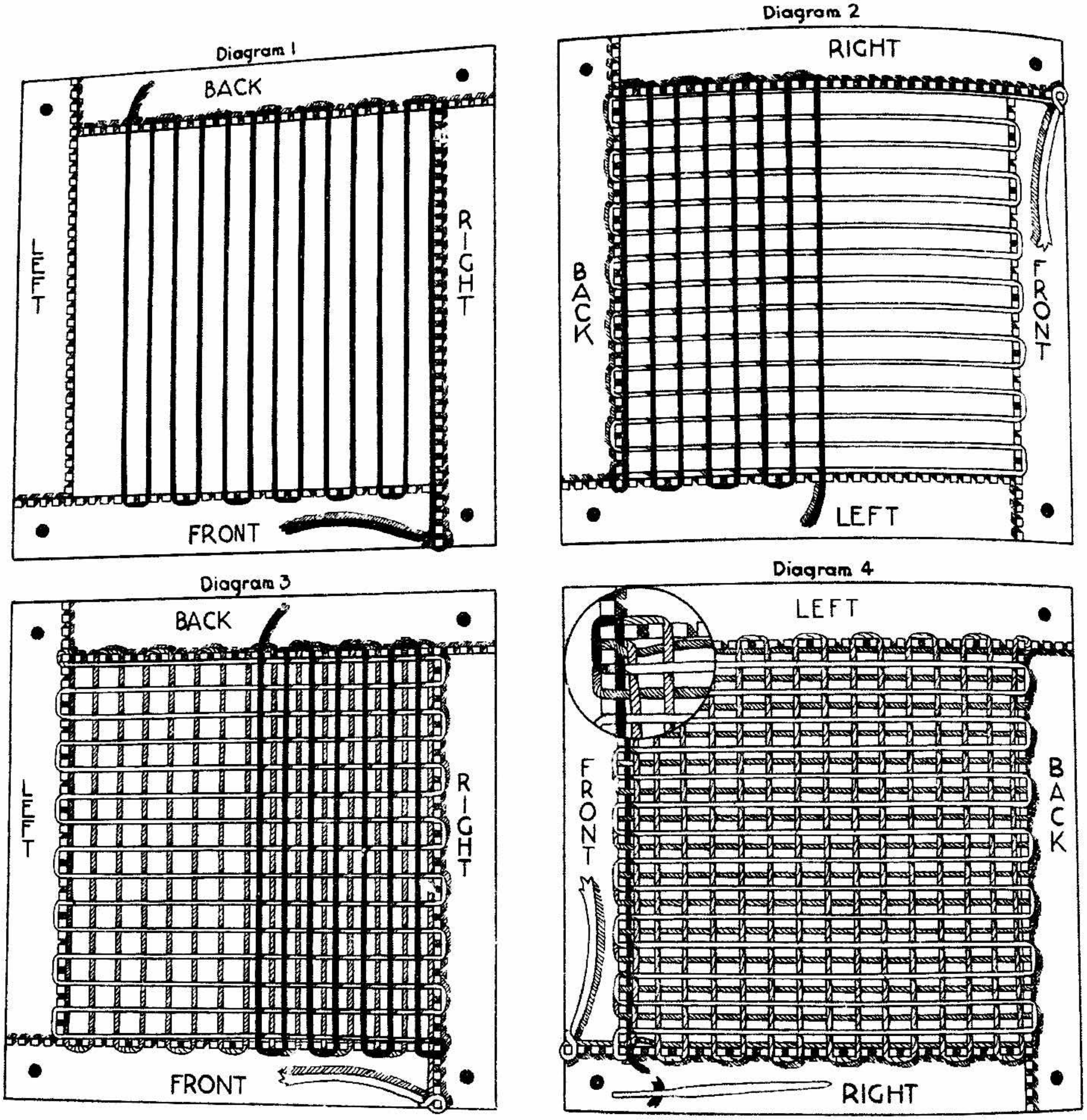

Figure 1.12

Diagram of threading and weaving processes on the Cynthia Easiweave Frame, c. 1935. From *Cynthia Easiweave Frame Directions*.

on a "crash research program" to improve core memory's reliability and speed. Core memory's superior properties when compared with other memory systems would contribute to the sales success of the IBM 704 in the mid-1950s.[57] As Michael Williams claims, "The commercial availability of magnetic core memory was the great watershed point in the development of computers."[58] Core memory required less space, less maintenance, and thus less downtime than other systems. The first successful minicomputer, the refrigerator-sized PDP-8 released by Digital Equipment Corporation in 1965, relied on transistors and core planes to minimize size while maintaining capacity.[59] Core memory would remain common into the early 1970s, when IBM finally halted development to concentrate on semiconductor technology.

Despite its success, core memory production remained slow, intricate, and laborious when compared with other computer components. To simplify and increase core memory production, IBM spent several years devising specifications for machine weaving. Fully mechanized production was difficult, however, given the configuration of materials and coordination of steps (particularly the bias stitch of the sensing wire), and a viable method would not be available until after core memory had been definitively overtaken by semiconductors.[60] Attempts to produce machine-woven, "screen memory" grids not requiring core beading also met with little success (figure 1.13).[61] Ultimately, IBM decided that its core matrix manufacturing specifications could be adequately applied and achieved through manual production. Rather than automated production machinery, IBM opted for a number of discrete instruments that followed the logic of home craft kits to simplify hand-wiring and eliminate errors in threading and configuring the core "beads." Described at length in the *Electronics* article for which Carpenter posed, this would remain the principal means of making core memory.[62] In this process, a plane weaver would pour loose cores into a matrix tray and manually sift them into the pattern mold to secure their proper orientation. She would then hand-thread the cores with wire inserted into a needle feeder at one edge of the frame. Once a line of cores was threaded, the wire would be taken up by the clamps of the wire wrapper fixed at the opposite edge of the frame. Molded plastic frames with grooves along the upper edge—almost identical to the plastic frames in Easiweave and other home weaving kits—would hold the wires.[63] This process, known as "winding" core, was little removed from either Carpenter's original work or

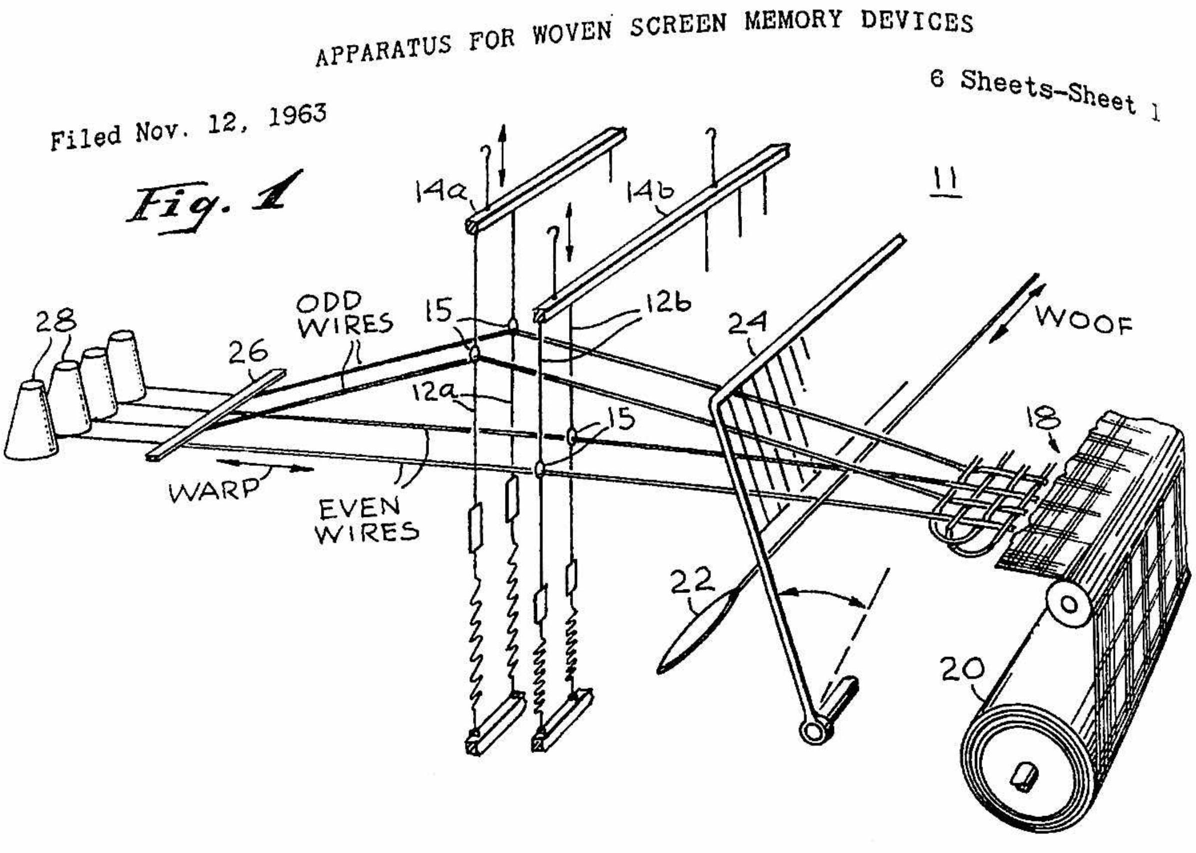

Figure 1.13
Diagram of a loom for weaving screen memory. From D. R. Boles et al., Apparatus for Woven Screen Memory Devices, U.S. Patent 3377581 A, 1968.

popular handloom techniques. Further attempts to simplify and improve the material aspects of core memory production concentrated on changing the weaving pattern itself. A new pattern developed by IBM in 1962 allowed one wire to serve as both a sensing and inhibiting line, reducing from four to three the number of wires threaded through each core. In the new pattern, the sensing wire shifted across two rows as it passed the central axis of the plane. This alteration had emerged during attempts to thread sensing wires in figure eight patterns requiring a shift by one row.[64]

Because the labor-intensive aspect of core memory production raised costs, IBM included steep markups on memory, which could be rented or purchased, in its larger accounts.[65] The price of core memory hinged on the cost of weaving, as the cost of manufacturing cores dropped from thirty-three cents per core in 1953 to a fraction of a cent by the early 1960s.[66] To maximize profit margins, IBM relocated core memory production to Japan and Taiwan in 1965, foreshadowing the practice of outsourced electronics manufacturing that would become routine for American companies later in the century.[67] The description in one history of IBM of how these events unfolded reads like a neoliberal colonialist fantasy:

> Taking bags of cores, rolls of wire, and core frames to Japan, [an IBM plant manager] returned ten days later with hand-wired core planes as good as those that had been wired by the automatic wire feeders in the Kingston [New York] plant. ... It was slow, tedious, meticulous work to string wires through each of the thousands of tiny cores in each core plane, but the cost of labor in the Orient was so low that production costs were actually less than with full automation in Kingston.[68]

Much of a decade's work in automating multiple aspects of the weaving process would be abandoned. Core weaving for IBM and many of its competitors was thereafter achieved through Asian manual labor.

Alongside the production of core memory for the world's mainframe computers (most of which were IBM systems), one of the most prestigious and expensive postwar computing projects was the development of hardware and software for the U.S. government's Apollo moon landing program. MIT's Instrumentation Laboratory and Raytheon Corporation collaborated on the digital guidance and navigation systems required to send humans to the moon. Here again, weaving and women's labor were critical to the success of the project, in this case through a little-used variation of core memory production. Navigational computing on board the command capsule and lunar module relied on standard core memory planes for its erasable memory, but the fixed memory guidance programs were constructed through a much rarer "rope" form of core weaving. Rope memory offered a secure and durable yet flexible and compact construction that reduced space requirements within the spacecraft's fuselage while increasing the memory's resistance to vibration, shock, and other physical risks associated with space travel.[69] Unlike the stacked-plane configurations of mainframe core memory, rope memory consisted of strands of cores threaded with relatively loose lengths of bunched wires (figure 1.14). Upon this base, sensing wires were threaded either through a core to produce a positive bit (one) or around a core to produce a negative bit (zero).[70] Contrary to woven memory planes, rope memory prohibited a change in a core's charge, since the difference between positive and negative charges would derive from the configuration of the threading itself. "This fixed memory is actually composed of magnetic cores with wires woven in and out, sewn in with a pattern, where the information ... is in the pattern of the sewing," Instrumentation

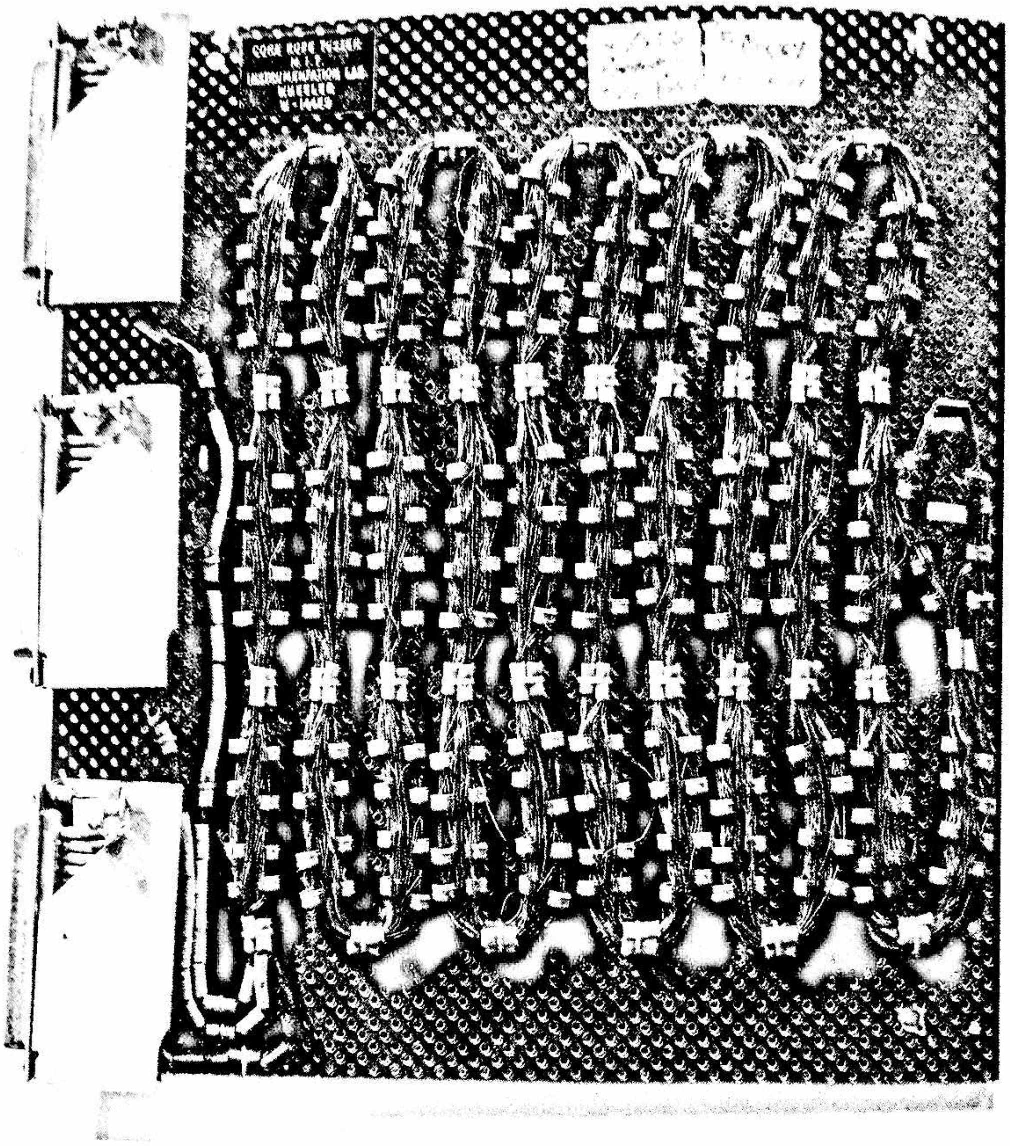

Figure 1.14

Apollo guidance system rope memory, mounted on a test panel, Instrumentation Laboratory, MIT, 1961. Photo by Nova13.

Lab Assistant Director Albert Hopkins evocatively explained.[71] Up to sixty-four sensing wires could be threaded through and around a single core, in any sequence, creating a far denser storage system than core memory planes, with up to four sets of 16-bit words per core.[72]

"We have to build, essentially, a weaving machine," systems designer Ralph Ragan told reporters as the construction of the guidance systems got under way. Raytheon hired retired or laid-off women textile workers to execute the task in its Waltham, Massachusetts, plant. The women represented

New England's dying textile industry, which had flourished in Lowell and surrounding towns and cities but would disappear by the 1970s in the face of competition from Japan and elsewhere.[73] These memory weavers worked alone or in pairs with the gridlike "weaving machine" that was little more than a frame holding the rope in place while they threaded the driving wire back and forth through it, like a weft shuttle, to weave the code into the cores.[74] While essentially beading, this handiwork also followed principles of embroidery already found in the threading of the sensing wire in grid-based core memory production. In both cases, new patterns of thread were added to an existing, invariable configuration. "We called it the LOL method. The 'little old lady' method of wiring these cores," states Richard Battin, an MIT Instrumentation Lab director involved in the project.[75] Twenty miles down the road from Lowell, the nineteenth-century mill girl had been replaced by her aged counterpart. As David Mindell explains, "NASA was well aware that the success of its flights depended on the fine, accurate motions of these women's fingers."[76]

Stitching Boards

While core formed the base of Apollo's guidance system memory, the guidance computer's processor was comprised of four thousand to five thousand of the first silicon chip integrated circuits for digital computing. By the time the Apollo program ended in the mid-1970s, silicon chip capacitor memories had replaced core as the preferred form of random-access memory. Unlike core, a silicon chip semiconductor's microscopic circuit patterns are not threaded by hand but imprinted through photolithography, layer by layer, into the wafer. To complete the circuit, minute quantities of aluminum or another conductive metal are poured into the imprinted channels.[77] Full circuits on small chips were fundamental to the development of the personal computer and remain integral to nearly all mobile, digital devices. Even with the automated mass production of silicon chips, however, women have remained primarily responsible for their assembly into larger electronic components through the soldering of integrated circuit boards and microchips. The relatively short history of core memory production would serve as an influential precedent in this change, having established the place of "unskilled" women's labor and the role of the global textile industry in the assembly of components basic to a computer's functioning. Assumptions concerning women workers' "natural" ability with small parts and meticulous, repetitive work would rest on the historical examples of electronic and textile production from the nineteenth and twentieth centuries, as well as on the unacknowledged and informal training of the home.

With the integrated circuit, the gendered and racial divisions already exploited by core production became more evident, expanding on a global scale. In the 1960s and 1970s, Fairchild Semiconductor—the "mother firm" in California's Silicon Valley, the hub of integrated circuit innovation—sought to exploit the weaving skills and limited employment opportunities of Navajo women on reservations in the U.S. Southwest by building an assembly plant in Shiprock, New Mexico.[78] Fairchild's promotional materials for the ill-fated Shiprock plant drew visual correspondences between the aesthetics of Navajo rugs and the design of integrated circuits.[79] Exploring the example of Shiprock in relation to the racialization of electronics manufacturing, Lisa Nakamura points out that Fairchild management believed Navajo weaving traditions gave women on the reservation the "natural" capability to "visualize complicated patterns and ... memorize complex integrated circuit designs."[80] Fairchild's promotional materials pointed out: "A Navajo woman weaves a perfectly patterned rug without ever seeing the whole design until the rug is completed. ... The blending of innate Navajo skill and Semiconductor's precision assembly techniques has made the Shiprock plant one of Fairchild's best facilities—not just in terms of production but in quality as well."[81] A journalist covering the beginnings of the plant explained that "the same adroit fingers which have made the Navajo Indians famous for fine rugs and jewelry are now turning out one of the indispensable adjuncts of this electronic age."[82]

Supported by federal government wage subsidies, the Shiprock plant employed mostly women in soldering chips and bonding wires. It assembled some of the early semiconductors used in the space program as components for the Apollo Saturn V rocket. After layoffs in the mid-1970s, however, the pall of colonialist exploitation by a federal government in collusion with a major corporate force in the military–industrial complex led to a well-publicized takeover of the plant by the American Indian Movement.[83] Though the event lasted only a few days, Fairchild closed the plant shortly after. By that time Silicon Valley had become the flourishing center of semiconductor research and manufacturing, with dozens of companies spinning out of Fairchild.[84] Much like Shiprock, however, 70–75 percent of semiconductor assemblers in Silicon Valley were women. Forty percent of these women were minorities.[85] In the 1980s, semiconductors produced in Silicon Valley were shipped to Asia to be bonded to circuit boards.[86] Production of semiconductors and circuit boards, like core memory production before it, migrated to Asia by the 1990s in what some American industry analysts called "the commodity memory debacle."[87]

In truth, Fairchild and its domestic competitors had moved overseas much earlier, just as IBM had, by establishing plants in Hong Kong in 1963, Taiwan in 1964, South Korea in 1966, Singapore in 1968, Malaysia in 1973, and the Philippines in 1974.[88] Whether owned by multinationals or local industrialists, such electronics facilities in Southeast Asia and China continue to rely heavily on women's manual labor to assemble integrated circuits.[89] In his book on the rise of the Japanese consumer electronics industry, Simon Partner establishes the historical affinities between textile and electronics production in Asia, arguing that the success of the electronics industry in Japan ultimately rested more on its relation to the country's textile industry than its technological innovations. According to Partner, success "derived not from the technological content of the products produced—that remained largely irrelevant—but from the availability of cheap labor to make products that did not easily lend themselves to automated manufacturing techniques."[90] In particular, Japanese electronics plants hired the same young, female workers regularly recruited out of middle school by textile mills. When IBM outsourced core memory production to Japan in the mid-1960s, the country's textile industry—supported mainly by this workforce—already had an international reputation for "social dumping," that is, producing and exporting woven goods at prices that suggested unlivable wages. "The similarity between the female workers in transistor and radio factories [of the 1960s] and those who had traditionally constituted the foundation of the textile industry is striking," Partner asserts. "Underneath the apparent revolution in technology development and industrial structure lay a profound continuity based on the abundance of extremely cheap, relatively docile female labor."[91] The young women in these electronics plants—often teenagers—would sit at assembly tables for hours, putting together components with tweezers for extremely low pay when compared with the earnings of workers in male-dominated industries. They were known as "transistor girls" by company management, a term that reemerges in twenty-first century discourse around gender, race, and electronics assembly through the figure of the Chinese "iPhone Girl."[92]

Gendering meticulous handwork and patience as female is an ideological construct extending across industries, cultures, and regions. It has thrived in the textile and electronics industries in Europe, Africa, the Americas, and Asia. An American management manual from the 1970s makes some general observations: "Many women are well suited for using precision tools, inspecting products, typing, and assembling small or intricate parts. ...They have more patience and adjust better to routine work—and they will stay with it longer than men. They are willing to give more attention to small details and exacting work."[93] Plenty of examples from the sociological and anthropological work done on gender and electronics labor around the world from the late twentieth century to today confirm such attitudes. A woman working at a Silicon Valley semiconductor assembly plant during the 1970s similarly observed: "Women make the best workers at this kind of thing because you have to be patient, you have to be good with your hands and the work is so tedious. Isn't raising children and doing housework tedious? I mean, women are good at this."[94] In a study of Malaysian electronics workers in the late 1980s, Les Levidow found that the "unskilled" labor of component assembly was done by women despite high unemployment among local men, in part because the work was feminized by manufacturers who found women to be "naturally better suited to the routinized work of the electronics assembly line: nimble fingers, acute eyesight, greater patience."[95] In *The Integrated Circus: The New Right and the Restructuring of Global Markets*, Patricia Marchak notes that studies of the success of electronics production and assembly in Asia have found that "patriarchal cultures and non-industrial lifestyles [there] ... train young women to become manually dexterous, a trait frequently cited by employers as a reason for preferring women over men in textile and electronics work."[96] In Asia today, young women are often recruited from rural areas to work in production facilities known as "assembly houses," a term underlining the domestic inflection of such work. In her firsthand experience as a worker in an electronics plant in Shenzhen, China, sociologist Pun Ngai estimates that 90 percent of the plant's assemblers were women, while an equally high percentage of the management were men. Reflecting the attitudes expressed earlier by American management specialists, she explains: "As usual, assembling tiny electronic components was often considered women's work because it required patience, care, sharp eyes, and nimble fingers."[97] In "'Nimble Fingers Make Cheap Workers': An Analysis of Women's Employment in Third World Export Manufacturing," Diane Elson and Ruth Pearson explain that the skill behind such production, because it is often acquired informally at home through lessons in sewing and needlework, is itself "socially invisible and privatized," allowing it to be construed in public and corporate spheres as "attributable to nature, and the jobs that make use of it are classified as 'unskilled' or 'semi-skilled.'"[98]

Despite the prevalence of surface-mount technology and wave soldering that embeds elements in circuit boards today through automated machinery, most contemporary electronics still require some hand assembly. Though sites of production may have changed, the example of the intersection of textile work with high-tech and appliance manufacturing given in a 1976 article on international subcontracting still resonates in today's electronics industries. "In Morocco, in six weeks, girls (who may not be literate) are taught the assembly under magnification of memory planes for computers," Michael Sharpston notes. "This is virtually darning with copper wire, and sewing is a traditional Moroccan skill. In the electrical field the equivalent of sewing is putting together wiring harnesses; and in metal-working, one finds parallels in some forms of soldering and welding."[99] Like the process of sewing together precut pattern pieces of fabric, workers in Asian assembly houses today typically perform such tasks as hand-feeding wire leads into the etched channels of printed circuit boards, soldering them, and snipping away excess wire. They align these boards with integrated circuit bonding machines that install the microcontrollers needed to ensure the device's proper functioning. A microcontroller "is 'stitched' to the board in a process that looks not unlike sewing with a sewing machine," according to one manufacturer's account.[100]

Gestures of Memory

The conditions of assembly houses occasionally have made headlines, as with the viral coverage of the iPhone Girl in 2008.[101] In this case, a test photo taken of an unidentified, smiling woman assembler was inadvertently left in the memory of a new iPhone as it left a Chinese production facility. Finding the image after he purchased the device in Britain two weeks later, the iPhone's owner posted the image online, where it quickly drew worldwide attention.[102] In a detailed study of the incident, Seth Perlow successfully illustrates the web of disjunctions and correspondences that typically exist between assemblers and users through the materiality of such devices and the different forms of labor they require, elicit, and extract across complex geopolitical, economic, and cultural interdependencies. According to Perlow, the unexpected visibility of the iPhone Girl exposes "the complex forms of world-sharing by which the material, economic, and affective connections between producers and users of consumer electronics get articulated." Her photo evokes the place of the body in the material construction of the digital object, which subsequently serves as the platform for the embodied performativity of the user. This performance of use is particularly noticeable with mobile touchscreen devices (and will be explored at length in chapters 3 and 4). "What happens," Perlow asks, "between the regimes of corporeal discipline under which one set of bodies assembles an iPhone, for instance, and those under which such devices get used?"[103] Both regimes share a focus on productive labor bound in short, repetitive strokes in seemingly small tasks involving complex forms and connections. However, while the labor of assembly is seen as tedious and menial, the labor of use is framed in fantasies of liberating performance, supported by the rhetoric of marketers, journalists, and scholars alike.

The emphasis on gestural techniques characterizing interfaces of contemporary media nevertheless subtly reinscribes the historical, corporeal discipline of equipment assembly into consumer use. It allows actions based in the Taylorist scientific management of bodies and behavior for efficient manufacturing to pass as gestures of freedom and play. "Consumer electronics constrain embodiment in an array of contexts, though with uneven severity," Perlow asserts. "By this view, the idealization of gestural interfacing as an escape from such discipline—as a more organic, spontaneous, or natural way of interacting with machines—elides the bodily suffering that repeated gesture itself occasions in the scene of production and elsewhere."[104] The gesture of consumption seemingly effaces the earlier one of production through what Perlow calls "aspirational affect," even as the user's action may bear traces of the preceding movement, both in its choreography and its consequences of component assembly (in this case, the user's linking of data in the network).

So the mill girl is followed by the transistor girl, who is followed in turn by the iPhone Girl. Jennifer Terry and Melodie Calvert point out the continuities between contemporary circumstances and earlier intersections of gender and labor:

> If women are particularly associated with "low-end" appliances such as ... sewing machines, to what extent does this depend on the historically specific siting of these machines in the home, or to their status as accessories of women's wifely and maternal duties? What do we make of the fact that ... a dramatically high percentage of the growing labor force in computer-based information management industries is female? Or that women in Malaysia and other parts of Southeast Asia are the primary assembly-line producers of the silicon microchips, the vital elements necessary for the very existence of the World Wide Web?[105]

The historical trajectory outlined in this chapter suggests an evolution of the history of textiles and hand production in computing that moves from the surface—or exterior—in the Jacquard apparatus's configuration of punched-card programming into the interior of modern computing's woven cores and integrated circuit boards by means of labor associated with the home, needlecraft, and domestic production. This history and memory then resurface—in literal and figurative ways—in contemporary tactile interfaces, their visual aesthetics, and the language and description of digital operations. The entwined history of textiles and computing traced here demonstrates that in both cases the labor of women remains invisible.

This invisibility is not only a matter of the political economy of technological production, however. Wendy Chun has demonstrated that digital technologies have continually and progressively relied on a paradoxical visibility and opacity in constructing the mystery of the device and its processes. This is particularly true in the function of software—a concept Chun asserts is historically gendered as female—and its use as metaphor. "Software seems to allow one to grasp the entire elephant [of new media] because it is the invisible whole that generates the sensuous parts," Chun states. It is "based on and yet exceeding our sense of touch—based on our ability to manipulate virtual objects we cannot entirely see." Software becomes an unknowable employed as a metaphor for the unknown.[106]

Embodied interface physically grapples with this unknown. It presents metaphors of action and materiality for otherwise unseen, unfelt, inscrutable processes, which bring to the surface in corporeal performativity not only the optical, electronic, textual, and digital processes of code and networked communication, but also the historically encoded performativity of gender and labor explored in this chapter. Coder Alan Sondheim claims that "every more or less traditional text is codework with invisible residue; every computer harbors the machinic, the ideology of capital in the construction of its components, the oppression of underdevelopment in its reliance on cheap labor."[107] The format and actions of mobile touchscreen interfaces, in their correspondences to the precision and skill of such labor and their deeper historical connections to informal, gendered labor training, become an interstice where this residue sticks. The histories laid out in this chapter, with their patterns of overlap, repetition, and recursion, suggest that contemporary shifts in material and social conditions of digital media reach back both temporally and spatially into the body of electronics and computing itself. Correspondences emerge at the intersection of craft culture, textile manufacturing, and methods of digital production and practice based on gestural and behavioral differences embedded in gender differentiation. These intersections occur throughout decades of digital media design at the level of hardware and software, leading us through a string of interactive models. Yet, the earlier textile forms of computing's hardware interiors come to the surface in a striking, very material way in the mobile touchscreen. The iPhone capacitive screen, which relies on electrical conductivity for converting finger contact and movements into commands, was designed with a fine mesh of wires just under its surface, echoing the grid of interlaced wires that formed the core memory of most mainframe computers. In describing first-generation iPhones, Jon Agar explains, "Sitting on the glass [under the cover lens] is a nearly invisible grid of fine electrical wires. ... The lines are about a millimetre apart. One line carries an electrical charge, while the other detects the slight disturbance caused in the electrical fields as your finger, acting like a weak capacitor, swipes the screen."[108] Here the touchscreen functions through variations of electrical impulses on the micro-fine wire grid, just as the core memory plane did. Now, however, those impulses are activated by the fingertip and the small, repeated strokes it makes across this base fabric, like a needle in embroidery, to build up small bits of data into a meaningful image.