Mistaken Ancestry: The Jacquard and the Computer

Abstract

The punched-card-driven loom introduced by Joseph-Marie Jacquard in the early years of the nineteenth century was the culmination of a number of efforts to mechanize the tedious work of manipulating the separate threads in a draw loom. The data constituting the desired pattern were introduced to the loom via a set of cards with punched holes. Noting the use of punched cards with the computers of the 1960s and also the fact that the intrinsic binary nature of weaving (a given thread is either "up" or "down") is shared by the binary circuitry of computers, weavers have been heard to claim that the Jacquard loom is the ancestor of the modern computer. This idea is the result of a profound misconception about the nature of computers. A Jacquard loom is no more like a computer than is a player piano, which also used punched holes as an input device. For a computer, the role of punched cards was only to provide a mechanism for enabling it to receive the data it needs to accomplish the significant and revolutionary aspects of its functioning, namely to carry out the sequential steps of any processing of its data whatever, so long as these are spelled out with utter precision and subject only to limitations of space and time. The use of binary logic in computer circuitry is a great simplifying tool, deriving from the work of mathematicians such as Leibniz and Boole, but is by no means an essential aspect of the nature of computers.

MARTIN DAVIS AND VIRGINIA DAVIS

Virginia Davis works with ikat weaving and other resist techniques, both as an internationally exhibited artist and from a technical, historical, and ethnographic point of view. Her awards include four Visual Artist grants from the NEA and the New York State Council for the Arts and a Fulbright to India. Her MA in Sociology/Anthropology is from the University of Illinois, Urbana. Her interest in Mexican culture began while, as a graduate student, she was an assistant to Oscar Lewis on an anthropological field trip to Mexico.

Born in New York City in 1928, Martin Davis was a student of Emil L. Post at City College and his doctorate at Princeton in 1950 was under the supervision of Alonzo Church. He has been on the faculty of the Courant Institute of Mathematical Sciences of New York University since 1965, was one of the charter members of the Computer Science Department founded in 1969, and is now Professor Emeritus. He is a visiting scholar at the University of California, Berkeley. His most recent book, *Engines of Logic*, is a popular account of the intellectual pre-history of the computer from the seventeenth century to the earliest modern programmable computers.

Textile, Volume 3, Issue 1, pp. 76–87
Reprints available directly from the Publishers.
Photocopying permitted by licence only.

Mistaken Ancestry: The Jacquard and the Computer

Weavers are often heard to say that the Jacquard loom was an ancestor of the computer, sometimes even that the Jacquard loom was a computer. The weaving process itself is often said to be binary like computer circuitry, with the "thread-up" and "thread-down" of the weaving corresponding to the 0 and 1, the bits, of computers, and their programs. The punched cards used by Jacquard as an input device for his automatic loom are said to be a key component of early computers.[1] The proposed but never built, Analytical Engine of Charles Babbage is pointed to as an important bridge between the Jacquard and modern computers. Finally there is Lord Byron's daughter, Ada Lovelace, said to be a powerful mathematician who brought Babbage's invention to the attention of the world. Ada is the hero and an icon of feminism in Sadie Plant's confusing and diffuse hagiography (Plant 1997), of which more later.

In this article, we bring together our knowledge and experience as mathematician/computer scientist on the one hand and artist/weaver/teacher/textile researcher on the other, in our attempt to tell the story in a clear and factual way. We try to replace half-truths and outright confusions with accurate explanations. We begin with the history of the Jacquard loom itself. This is followed by a glimpse at the inner natures of modern computers. Finally we take our own look at Charles Babbage and Ada Lovelace.

Evolution of the Jacquard Loom

The history of the loom weaving of intricate pattern weaves reaches back to the draw loom of the Han Dynasty (206 BCE–220 CE) in China. A "draw boy" stands on top of the loom to sequentially select and draw up the groups of warp threads needed to create the elaborate figured weaving. The use of the draw loom, which spread westward, is said to have reached Europe via the Crusaders' stay in Damascus (Birrell 1973: 221). This style of draw loom was in use in Europe until 1604 when a Frenchman, M. Simplot, engineered the placing of the tied-together groups of draw cords (called *simples*) at the side of the loom so that the draw boy (or girl) could stand there and coordinate better with the weaver (Glazier 1923: 13). There was a long slow evolution and tinkering with this system to improve its operation, in particular to reduce the necessity of the second person selecting and drawing up the pattern threads. Better selection methods for the tied groups of draw cords arrived in 1727 when Basile Bouchon used a band of perforated paper for the selection of pattern groups (Birrell 1973: 222). Very soon, in 1728, Jacques de Falcon used a perforated card for each shed. The cards were laced together and rotated on a drum, the appropriate warp threads falling through the perforations at each rotation. Still a draw boy was needed to lift the groups.

The eighteenth century had a fascination with automata. Jacques de Vaucanson, 1709–82, was a mechanical genius who was known for automated figurines (Haftner 1979: 54). In 1738, he built an automaton, "The Flute Player," followed in 1739 by "The Tambourine Player" and "The Duck." The last was especially noteworthy, not only imitating the motions of a live duck, but also the motions of drinking, eating, and "digesting." Appointed inspector of silk manufacture in 1741, Vaucanson's attention was drawn to the problems of mechanization of silk weaving. In 1745, taking into account the inventions of his predecessors, he succeeded in automating the loom by means of perforated cards that guided hooks connected sequentially to the pull cords, but which still needed a draw boy. Power was to be supplied by windlass, falling water or by animals. This invention was ignored for several decades. He invented many important machine tools and made improvements adopted by the silk industry. Toward the end of his life, he collected his own and others' inventions in what became in 1794 the Conservatoire des Arts et Métiers (Conservatory of Arts and Artisanry) in Paris (*Encyclopaedia Britannica* 2004: "Jacquard loom"). At the beginning of the nineteenth century, with the need for the French silk industry to compete in the world market, Napoleon, who had heard of Joseph-Marie Jacquard (1752–1834) because of his other inventions, summoned him to Paris in 1800. Jacquard, who already had ideas for improving the draw loom, found Vaucanson's loom at the Conservatoire. With reconstruction, clever modification, and careful engineering, the device, which came to be known as the Jacquard head, premiered in 1804 (Marcoux 1982: 1). The improved system of laced sequences of cards punched with holes, each hole representing a group of warp threads to be raised, speeded the process immensely (Figure 1). Only the weaver was required. The device was accepted and eventually spread worldwide. Jacquard was awarded a gold medal and the Cross of the Legion of Honor in 1819 (*Encyclopaedia Britannica* 2004: "Jacquard, Joseph-Marie").

Modern Computers

The appearance of an object ordinarily suggests its function. From ancient military chariots and horse- or mule-drawn carts to contemporary cars, bicycles, and trucks, the very appearance of these various "carriages" is clearly connected with their function: to carry people or objects from place to place on rolling wheels. On the other hand there is almost nothing in the appearance of today's computers to suggest that they do the same sort of thing as those that were around forty years ago. In those days, cartoonists had a difficult time selecting an appropriate image that their viewers would identify as a computer. For a while it was a large console the size of a room, with flashing lights. Later, cartoonists depicted the computer as a tape drive. While a tape drive is only a peripheral device rather akin to a tape recorder in which no real processing of data takes place, it at least had the virtue that it could be seen to be in motion, providing assurance that something was happening in the depths.

Because the really significant actions of computers occur invisibly, deep in their interior, it is easy to mistake the peripheral devices that bring data into or out of the machine for the computer itself. It is as though one were to identify a contemporary desktop computer with its keyboard, mouse, and monitor. Here is an example of a typical text that makes this error:

> *Within the digital revolution of the twentieth century, the role of textile technology is equally seminal. One of the many ironies, as any first-year computer science student is well aware, lies in the fact that the forerunner of the first computing machine—Charles Babbage's Analytical Engine—was based on the early nineteenth-century Jacquard loom. Joseph-Marie Jacquard's system of pattern punched cards to store and process information for his automated loom were translated into the first computer punched cards. Weaving, after all, is a process of information storage, a binary system of interlocking threads, mirroring the 0s and 1s of computer programming (Bachmann 1998: 27).*

There are indeed many ironies here. To begin with, few "first-year computer science students"

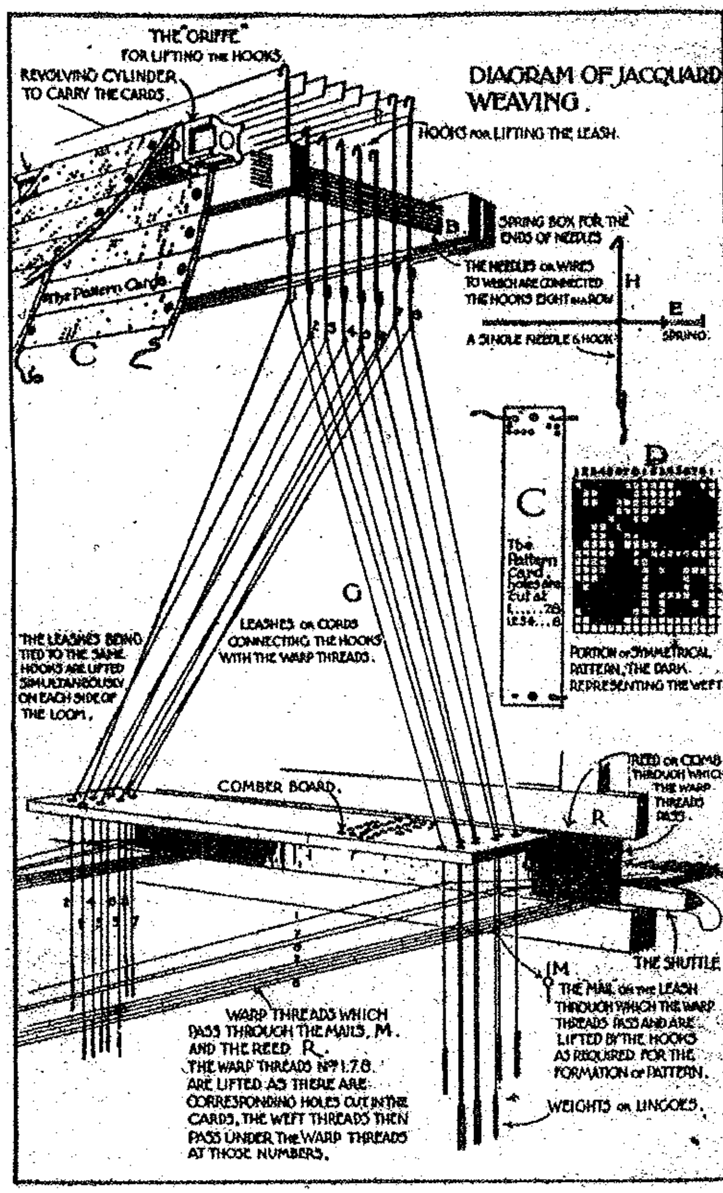

Figure 1
The Jacquard loom (from Glazier 1923: 16).

have so much as heard of Charles Babbage or of the Jacquard loom.[2] Now it is perfectly true that Babbage borrowed the idea of using punched cards from Jacquard, but as just discussed, as a mere peripheral device, the punched-card reader would have been at most a superficial component of Babbage's project (had he ever been able to complete it—more on this later). In any case, the idea of using holes in paper or cardboard to hold information that could be handed over to an automatic mechanical device went back, as we have seen, to the early years of the eighteenth century. One can find numerous applications of this idea that have nothing to do with either weaving or computers. The rolls of paper used by player pianos are an example.[3] Another is teletype tape. This consisted of long narrow strips of paper with successive rows, each row having five positions where a hole could be punched, thus permitting thirty-two different possibilities. It was originally introduced as a mechanized substitute for the Morse code of dots and dashes of telegraphy. As it happens, it was this teletype tape rather than punched cards that were typically used for input for the early computers that began to be developed after the Second World War. The use of binary logic and arithmetic in today's computers is certainly a great engineering convenience, but is by no means an essential matter. And, by the way, the dots and dashes of Morse code are just as binary as the holes or lack thereof in Jacquard's punched cards. Finally, today's computer programmers have little or nothing to do with the "0s and 1s of computer programming." They write their programs in a language that uses locutions like:

```
while X > 5 do HaveFunWith(X)
```

in which one can see neither 0s nor 1s.

The computers that began to be built after the Second World War differed from all earlier automatic calculators (including Babbage's never completed Analytical Engine) in being designed to be *all-purpose* or *universal*. This is what accounts for the fact that today, as everyone knows, computers are used for many tasks that have no evident connection with those four dismal arithmetic operations, with which all of us spent so much time when we were children.[4] Writers use word-processing programs to speedily edit text, check spelling, find synonyms, even attempt to correct grammar and make stylistic suggestions. Musicians use computers as tools for composition and for desktop publishing of music. Artists and designers use computers to create, edit, and combine images much as writers edit and combine text. That such all-purpose computing devices were even possible was not at all obvious. As late as 1956, Howard Aiken, who had been instrumental in the development of large-scale automatic calculating equipment at Harvard in the 1930s and 1940s, and who still did not understand that all-purpose computers were already on the market, could bring himself to say:

> *If it should turn out that the basic logics of a machine designed for the numerical solution of differential equations coincide with the logics of a machine intended to make bills for a department store, I would regard this as the most amazing coincidence that I have ever encountered (Davis 2000a, b: 140).*

The March 29 1999 issue of *Time* magazine proposed a list of the twenty most significant scientists and thinkers of the twentieth century. On this list was Alan Turing, whose life encompassed triumphs and tragedy, and who had first proved in 1937, on the level of pure mathematical theory, that in principle an all-purpose computing device was quite conceivable. After the Second World War it was Turing and John von Neumann who showed how to translate this conception from theory to practice.[5]

Modern computers work with digital data. Digital data are pieces of information that can be expressed as sequences of symbols. The ten digits we use to represent numbers are symbols. The twenty-six letters of our alphabet are symbols. The marks musicians use to represent sounds are symbols. Computers could be constructed to manipulate digital data made up of any number of symbols. It is mainly the properties of the electronic circuits out of which contemporary computers are constructed, that have dictated the use of binary data, just two symbols. The fact that two symbols suffice is not profound. It is clear from the Morse code alphabet of dots and dashes. This principle may be called: binary logic. In addition there is the fact that if numbers are represented using just the two symbols 0 and 1, it is easy to perform arithmetic operations on them (as was realized already by Leibniz in the seventeenth century). Combining binary logic with binary arithmetic provides a great simplification for computer engineers. Nevertheless the calculators that were built before the Second World War, and even the ENIAC that was built during the war used the familiar decimal arithmetic we all learned in school. It was only when the possibility of making *all-purpose* computers was understood, that it was realized that no special equipment would be needed (as had been thought) to translate back and forth between binary and decimal input and output, that that task could be safely left to an all-purpose machine.

What modern computers do is to execute *algorithms*. That word just means procedures working with digital data that can be made absolutely explicit, procedures that consist of individual steps each of which can be carried out in a completely specified routine manner, without the exercise of thought. Modern computers can execute any algorithm whatsoever, subject only to limitations of space and time. This is precisely the sense in which they are all-purpose, universal. To belabor the point, Jacquard looms, marvelous machines that they are, do not execute algorithms. Holes in the cards correspond in a one-to-one manner only to a group of particular threads being raised. That is all.

It may not be amiss to mention that all of us contain in our very DNA, digital data that serve as the blueprint from which we are literally embodied. As it happens, those data are not binary, but use an alphabet of four symbols. Molecular biologists are just beginning to understand how all of this works. One may speculate that buried in the DNA are processes that function like miniature universal computers. But at this point, mere speculation is what this is. Even with respect to weaving, it is only partially correct to characterize it as necessarily binary. Weavers are quite familiar with double weaves whose sets of warps may appropriately be represented in terms of a four-symbol alphabet (just like DNA!): namely top-layer-up, top-layer-down, bottom-layer-up, bottom-layer-down.

Rather than dwell on a mythical historical relationship between the Jacquard loom and the modern computer, one should take pleasure in their fruitful union. The computerized Jacquard loom is a powerful tool, used not only for industrial production, but also by a number of textile artists in their artwork. The designer/artist weaver has available powerful programs, called CAD (Computer Aided Design), for manipulating images. Their output can be directly coupled to the input of a computer-controlled Jacquard loom providing a scope and ease utterly beyond what was possible with punched cards in pre-computer times. Although for the most part, beyond the resources of the individual studio in cost and space requirements, there are facilities in the United States, Canada, and Europe where artists can take designs, use programs, and see the woven output. Weavings by Lia Cook, Cynthia Schira, and others, produced in this manner, were in a 2002 exhibition, *Technology as Catalyst: Technology on the Cutting Edge* at the Textile Museum, Washington, DC; a catalog is available. Another example is "Mao to Marilyn" (see Figure 2) designed and produced at the Philadelphia College of Textiles on their computerized Jacquard loom in 1993 as part of a project

Figure 2
"Mao to Marilyn" designed and produced at the Philadelphia College of Textiles on their computerized Jacquard loom in 1993 by Virginia Davis.

inviting artists to explore this medium.[6] Here, images from two separate Jacquard-woven ribbons, one of Mao Tse Tsung, the other of Marilyn Monroe, were scanned in and manipulated using a CAD program to change one image into the other in stages. The double-weave structure in alternately black and white warp for this Jacquard weaving of Jacquard weavings emphasizes the photographic properties and also references the use of these properties by Thomas Stevens. Stevens, in Coventry, England, *c* 1860, used the Jacquard to produce postcard-size inexpensive pictures dubbed "stevensgraphs" or sometimes called "textilographs." In present-day weaving, the computer has provided weavers with new options and great flexibility. An analogue image can be scanned in, altered if desired, and/or an image can be digitally created. Then the computerized Jacquard loom serves as the "output device" producing a weaving with fiber, color and scale chosen by the artist.

Two Sad Stories: Charles Babbage and Ada Lovelace

Charles Babbage, born in 1791, was an important nineteenth-century British mathematician. Realizing the importance of mathematical tables, he became obsessed with the problem of machines to aid in their preparation. His first venture, the *Difference Engine*, could probably have been built successfully if not for rather typical problems involving payments from the government arriving late or not at all and a dispute with the craftsman to whom he had given the task of actually building the device. By the time these difficulties had been overcome, he had been sidetracked by his more grandiose project: the *Analytical Engine*. The Difference Engine could only add and subtract. It could be used to construct tables when a particular mathematical trick using only those operations would work. (The trick involved subtracting successive values and then subtracting the results, and so on until a constant value was reached.) Although ingenious, this technique was severely limited.

It was the proposed Analytical Engine that began to take on some (but by no means all) of the attributes of the modern all-purpose computer. The Analytical Engine was to be a decimal (not binary) machine. As input device, there was, of course, to be the punched-card reader like that on a Jacquard loom. The cards were to contain not only data, but also the successive instructions to be executed, making up the program. There was to be a small internal storage for data. Typical instructions would call for additions, subtractions, multiplications, and/or divisions of the data. There were also to be instructions that would cause the computation to "branch:" proceeding one way or another depending on how some arithmetic test came out. The basic design was logically impeccable, and the large-scale calculators at Harvard in the 1930s and 1940s may be thought of as realizations of Babbage's dream. The Harvard group, led by Howard Aiken, accomplished this by using components based on electricity (mainly electromagnetic relays) that were not even dreamt of in Babbage's day. Poor Babbage tried to do it all with purely mechanical components. And he really tried. If existing machine tools could not produce gears and such with the needed tolerances, Babbage went ahead and built better machine tools, a useful contribution in itself. But ultimately the enormity of the task defeated him. He died in 1871. There is some reason to believe that Aiken knew Babbage's work and was directly influenced by it.

If the Analytical Engine could have been built, it would certainly have been a very useful tool. But it would not have been an all-purpose computer. Babbage's machine would have involved three quite separate categories. There was the machine itself: in contemporary terms "hardware." There was the program: "software." And there was the numerical data. Three quite separate categories of things. It was the fundamental theoretical work of Alan Turing in 1937 that demolished the wall separating these three categories. Turing introduced and studied a kind of abstract mathematical "machine" and presented a convincing argument that such "machines" could compute anything that could be accomplished by a human being with pencil and paper following a given list of explicit instructions to be followed exactly. Turing showed, by a mathematical construction, that there was a particular "machine" of the type he had been considering, that could simulate any "machine" of his type, that all-by-itself could compute anything that any of his "machines" could compute. He called this machine "universal." Turing's universal machine was designed to take as input a detailed description of the "behavior" of the machine to be simulated, and then, in effect, to "read" this description and do whatever it is that that machine would have done. As one of us has put it:

> *People had been thinking about calculating machines for a long time, since Leibniz's time and even earlier. Before Turing the general supposition was that in dealing with such machines the three categories, machine, program, and data, were entirely separate entities. The machine was a physical object; today we would call it hardware. The program was the plan for doing a computation, perhaps embodied in punched cards or connections of cables in a plug board. Finally, the data was the numerical input. Turing's universal machine showed that the distinctness of these three categories is an illusion. A Turing machine is initially envisioned as a machine with mechanical parts, hardware. But its [description as input to] the universal machine functions as a program, detailing the instructions to the universal machine needed for the appropriate computation to be carried out. Finally, the universal machine in its step-by-step actions sees the [description of a machine] as just more data to be worked on. This fluidity among these three concepts is fundamental to contemporary computer practice. A program written in a modern programming language is data to the interpreter or compiler that manipulates it so that its instructions can actually be executed (Davis 2000a, b: 165).*

It is this fluidity that has made possible the incredible variety of tasks that our computers are asked to perform.

Ada, Countess of Lovelace, was born in 1815, daughter of the famous poet Lord Byron. Ada's mother, apparently upset by rumors of Byron's affair with his half-sister, obtained a legal separation from him when Ada was two months old. Ada never saw her father. Her title resulted from her husband becoming an earl a few years after their marriage. She had an ambition and drive to do something spectacular, quite remarkable for a woman, and especially a woman of her station, at that time. The domain in which she chose to make her mark was mathematics, but unfortunately her talent did not match her zeal. Although she was able to obtain the help of the accomplished professional mathematician Augustus De Morgan as a tutor, she never got beyond the elements of calculus, which gave her no end of trouble. The excellent biography by Dorothy Stein (Stein 1985) details some of the exercises with which she struggled, all at the advanced high-school or college freshman level (A-level maths in the UK).

She was enthralled by Babbage's proposed machines and developed a friendship with him. He evidently hoped that her connections would help in his efforts to gain support (see also Holt 2001). In 1843 she undertook the translation into English of an article in French about the Analytical Engine written by the Italian mathematician Luigi Federico Menabrea. Babbage welcomed the project as providing sorely needed publicity for his ideas, but he took seriously ill before the manuscript was ready for publication, and it contains some revealing errors (Holt 2001: 92; Stein 1985: 90). The publication contained, in addition to the translation, some of her own notes including the often-quoted statement: "The Analytical Engine weaves algebraic patterns, just as the Jacquard-loom weaves flowers and leaves." Evidently having allowed herself to see in the merely peripheral punched-card reader something of the essence of Babbage's invention, she formulated this statement that may well be responsible for some of the confusions that this article seeks to dispel. Ada was twenty-eight years old when this, her last publication, appeared. Her life was pretty awful. She suffered from persistent mood swings that suggest bipolar disorder, and had a large number of purely physical disorders. She took opium several times a week, which seems to have provided her with some relief. She became a compulsive gambler, repeatedly pawning the family jewelry. Poor Ada was just shy of her thirty-seventh birthday when she died a painful death of cancer of the uterus.

Perhaps the saddest thing about Ada Lovelace's sad life is the mismatch between her abilities and her ambitions, and how those thinking to memorialize her persist in inflating her accomplishments. Perhaps the most egregious offender is Sadie Plant. Referring to Gibson's "cyberpunk" novel *Neuromancer*, she grandiloquently proclaims:

> *[Gibson's] cyberspace was . . . implementing . . . works of non-fiction: Alan Turing's universal machine had drawn the devices of his day—calculators and typewriters—into a virtual machine that brought itself on-line in the Second World War; Ada's Analytical Engine, which backed the punched-card processes of the automated weaving machine; and Jacquard's loom, which gathered itself on the gathering threads of weavers who in turn were picking up on the threads of the spiders and moths and webs of bacterial activity (Plant 1997: 13–14).*

From the nonsense about Turing's universal machine (which had nothing to do with typewriters), to the apparent attribution of Babbage's concept to Ada Lovelace, to the final invoking of bacterial webs, there's almost nothing in this overwrought prose that makes the least bit of sense. Plant takes Ada's habit of referring to her own abilities in the most grandiose fashion at face value, quoting her as though her ridiculous assertions were unquestionable truth. Some samples:

> *I do not believe that my father was (or ever could have been) such a Poet as I shall be an Analyst.*

Since her father, Lord Byron, was one of the greatest English poets, and Ada struggled to master the most elementary parts of mathematical analysis, this is a truly sad assertion (Plant 1997: 150). Writing to Babbage, Ada proclaimed:

> *I do not think you possess half my forethought, & power of seeing all possible contingencies (probable & improbable, just alike) (Plant 1997: 20).*

On the same page, Plant takes at face value, Ada's assertion:

I am a Prophetess born into the world, & this conviction fills me with humility, with fear and trembling!

It seems that Plant sees herself as a champion of women's abilities and accomplishments. But there are far worthier examples than poor Ada Lovelace. Many women in the nineteenth century managed to attain a good knowledge of the mathematics of their day despite the overwhelming obstacles they faced (obstacles that by no means have entirely vanished). There are even two, Sophie Germain (after whom a school in Paris is named) and Sonia Kovalevsky, who became world-class research mathematicians during that century.

People who drive a car may well have little notion of how an internal combustion engine works. But almost all of them surely have at least a coarse picture of what happens under the hood: the burning of the fuel propels some parts that are connected to the wheels and causes them to turn. Alas, most computer users cannot visualize what is really happening inside those powerful machines even at that crude level. This makes it impossible for them to evaluate in a critical manner claims made about the relationships between these tools on which they have become so dependent and other devices from which they may have evolved. We hope that this article will help a little.

Notes

1. It is not only among weavers. A Google search using the words "Jacquard, loom, computer" will find hundreds of sites, many of them making such claims.
2. One of the authors has taught many such "first-year computer science students."
3. One of us, as a child, used to enjoy listening to Rachmaninov or Paderewski move the keys activated by pedaling the player piano with which she had just been struggling.
4. "Ambition, distraction, uglification, and derision" in Lewis Carroll's terms.
5. There has been much controversy about these matters. Writers have not hesitated to term the number-crunching automatic calculators of the 1930s and 1940s "all-purpose." Such writers see the revolutionary advances in the postwar machines as consisting only of the use of electronics and a storage device shared by programs and data. To emphasize the importance of Turing's conceptual insights is in no way to minimize the great achievements of the engineers (Davis 2000a, b: 177–97).
6. The artist, one of the authors, ordinarily uses a simpler computerized dobby loom in her work.

References

Bachmann, Ingrid. 1998. "Material and the Promise of the Immaterial." In Ingrid Bachmann and Ruth Scheuing (eds) *Material Matters: The Art and Culture of Contemporary Textiles*. Toronto: YYZ Books.

Birrell, Verla. 1973. *The Textile Arts*. New York: Schocken Books.

Davis, Martin. 2000a. *The Universal Computer: The Road from Leibniz to Turing*. New York: Norton.

Davis, Martin. 2000b. *Engines of Logic: Mathematicians and the Origins of the Computer.* Paperback edition of Davis 2000a. New York: Norton.

Encyclopaedia Britannica. 2004. CD edition.

Glazier, Richard. 1923. *Historic Textile Fabrics*. New York: C. Scribner's Sons.

Haftner, Daryl. 1979. "The Programmed Brocade Loom and the Decline of the Drawgirl." In *Dynamos and Virgins Revisited: Women and Technological Change in History*. Metuchen, NJ: Scarecrow Press.

Holt, Jim. 2001. "Ada Perplex." *New Yorker* March 5 2001: 88–93.

Marcoux, Alice. 1982. *Jacquard Textiles*. Providence, RI: Rhode Island School of Design.

Plant, Sadie. 1997. *Zeros + Ones: Digital Women + the New Technoculture*. New York: Doubleday.

Stein, Dorothy. 1985. *Ada: A Life and a Legacy*. Cambridge, MA: MIT Press.