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Weaving as Binary Art and the Algebra of Patterns

Ellen Harlizius-Klück

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Abstract

To refer to the Jacquard loom as a precursor of the computer is a common narrative in histories of computing beginning with Ada Lovelace comparing the punched card operated loom with the calculating engine designed by Charles Babbage: “We may say most aptly that the Analytical Engine *weaves algebraical patterns* just as the Jacquard-loom weaves flowers and leaves.” But this does not mean that Jacquard invented the algebra of patterns. He only constructed the first widely known and used mechanism replacing the drawboy by punched cards to feed pattern information into his mechanism. To control a weave means to decide whether a warp thread is to be picked up or not. Weaving has therefore been a binary art from its very beginning, applying operations of pattern algebra for millennia. Jacquard’s cards were the end of this story rather than its beginning, reducing the weaver to an operator who had to step on a single treadle repeatedly. This article argues that algebra is already involved in operating shafts or heddles on ordinary looms, that this algebra was applied tacitly until the first weaving notations were developed, and that these notations make the tacit algebra of patterns recognizable to non-weavers: inventors and engineers.

Keywords: history of computing; history of weaving; pattern weaving; Jacquard loom

ELLEN HARLIZIUS-KLÜCK
Ellen Harlizius-Klück is Principal Investigator in the project *PENELOPE. A Study of Weaving as Technical Mode of Existence*, which has been awarded an ERC Consolidator Grant in 2015 (Grant Agreement No. 682711). From 2014 to 2016, she was international Co-Investigator in the *Weaving Codes – Coding Weaves* Project, funded by the Arts & Humanities Research Council (AH/M002403/1). She also investigated the philosophy of ancient textile production in the Collaborative Project *Ancient Textiles,* (Centre for Textile Research, Copenhagen, Dept. of Ancient History, Hanover). In 2012 and 2013, she spent a Marie-Curie Senior Research Fellowship funded by the Gerda Henkel Foundation (COFUND) at the Centre for Textile Research, Copenhagen.

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Weaving as Binary Art and the Algebra of Patterns

> *We may say most aptly that the Analytical Engine weaves algebraical patterns just as the Jacquard-loom weaves flowers and leaves.*

This quote stems from Ada Lovelace's notes on a paper describing Charles Babbage's plans for the Analytical Engine, the first machine that could do general-purpose computation (Lovelace 1843, 696). Babbage's earlier invented machine, the Difference Engine, could tabulate polynomial functions but not general arithmetic. The Lovelace quote became a famous soundbite in the history of computing (Plant 1995, 50; Essinger 2004, 141; Davis and Davis 2005, 86). Perhaps as a result, it is now common to refer to the Jacquard loom as a precursor of digital calculating machines. James Essinger states: "… in essence a computer is merely a special kind of Jacquard loom" (2004, 87) or even that computers are "modern incarnations of Jacquard's loom" (2004, 263). *The Little Book of Beginnings and Breakthroughs in Science* devotes a paragraph entitled "Weaving Algebraic Patterns" to Ada Lovelace as "the world's first computer programmer" (1843; Verma 2015). Also, Subrata Dasgupta, in his account of the Genesis of Computer Science, has a whole chapter entitled "Weaving Algebraic Patterns" (2014, 17–27). And he provides an explanation of the analogy:

> *In the Jacquard loom, each distinct pattern to be woven is defined by a specific encoding of the pattern in a closed-loop series for punched cards. The loom reads this pattern and weaves the cloth accordingly. By changing the batch of punched cards, the loom weaves a different pattern. The same loom, a* finite *device, has the capability for, potentially, an* infinity *of weaving patterns. In the Analytical Engine, computation of each distinct mathematical function is determined by an ordered sequence of (arithmetic) operations on the values of variables. These sequences of operation (in present-centered language, programs) can be encoded as patterns of holes on punched cards. The machine reads a particular set of punched cards, a different sequence of operations corresponding to a different mathematical computation is performed. In the evocative words of Lovelace, the analytical Engine would weave 'algebraic patterns' much as the Jacquard loom wove 'flowers and leaves'.* (Dasgupta 2014, 21)

However, there have been objections to this analogy. An article written by a computer scientist and a weaver aiming to tell the story in a factual way with regard to "the inner natures of modern computers" (Davis and Davis 2005, 78) rejects it because the punched cards are only "the peripheral devices that bring data into or out of the machine" and should not be taken "for the computer itself" (Davis and Davis 2005, 79). The argument is made that also for Babbage's project "the punched-card reader would have been at most a superficial component" (Davis and Davis 2005, 80). Similarly, from the standpoint of loom technology, Jacquard invented a peripheral device that brings data to the loom by punched cards, but in fact any loom can be operated and any fabric be woven without such a device.

Sadie Plant writes: "Jacquard's system of punch card programs brought the information age to the beginning of the 19th century. His automated loom was the first to store its own information, functioning with its own software, an early migration of control from weaver to machinery" (1995, 51). Whatever we think is the true relation of loom and computer, Sadie Plant makes a point that is worth considering: that control has migrated from weaver to machine. Jacquard did not invent what Lovelace calls the algebra of patterns. Neither did he invent the binary structure of the weave. What he did do was to construct the first widely known and used mechanism that replaced the human being pulling the leashes of a drawloom, the so-called drawboy, who thus controlled the pattern on behalf of the weaver. Instead, Jacquard used punched cards to feed the pattern information into his mechanism. However, the binary pattern algebra was already present in the operation of the drawloom. The algorithms and programs were always there, just not in a manner visible to outsiders and non-weavers. The punched cards simply made the pattern algebra of weaving perceivable to someone interested in the construction of calculating engines on the basis of binary logic, someone like Charles Babbage.

The whole history of loom technology is a history of the migration of binary control from weavers to machines. Throughout this history, to control a weave meant to decide whether a warp thread was to be picked up or not. Therefore, from the very beginning, "weaving is a binary art," as stated by the computer pioneer Heinz Zemanek (1991b, 33). Jacquard's cards were the end of this story rather than its beginning, reducing the weaver from a coder of weaves, to an operator who had to step on a single treadle repeatedly.

This article intends to shed light on the algebraical patterns and codes of weaving before Jacquard. It states that the idea of coding weaves was the crucial step towards the invention of automated loom control mechanisms, no matter if they used pegs on cylinders or holes in cards. By this I want to widen the view that seems to be fixed upon the Jacquard mechanism. Instead I want to look at practices of weaving and geometrical patterning which engage algebraic thinking and ask how these were implemented. I will argue that a sort of algebra is already involved in operating shafts or heddles in ordinary looms, that this algebra was executed as a tacit inference until the first weaving notations were developed, and that these weaving-notations resemble the respective loom parts and make the tacit visual algebra of patterns recognizable to non-weavers and in particular, inventors and engineers.

In this article I bring together research results from: (1) the investigation of a weaver's journal and sketchbook from the eighteenth century; (2) the history of weave notation in which the sketchbook is embedded; as well as (3) investigations of a loom control device from the seventeenth century possibly connected to these early notations and the development of early binary loom control.[1]

From Drawloom to Computer Control—The Common Story

In order to challenge the common story of the invention of digital looms, we first need to introduce it. The most common loom works with shafts and treadles and is good for weaving plain or striped fabric. But it also can weave checkers, stars, lozenges or color and weave effect patterns like dogtooth or meanders that result from a certain weave structure combined with a specific order of colored threads. For more complex patterns it is necessary to lift individual warp threads and this is done with a drawloom—a device that was probably invented in China. The lifting of the warp threads was not done by the weaver but by an assistant standing at the side of the loom: a drawboy or *liseuse*. The history of computing, when referring to looms, tells a story of their improvement focusing almost entirely on subsequent inventions by French engineers, whose main interest was to spare the drawboy or *liseuse* necessary for pattern control on the drawloom. The usual list of inventors includes Bouchon, Falcon, Vaucanson and culminates with Jacquard.

Bouchon and Falcon

In her comprehensive book on the media history of punched card weaving, Schneider gives a short overview on drawloom improvements in the eighteenth century (Schneider 2007, 125–130). In 1725, Bouchon is named as the first to replace the work of the *liseuse*. But only later, when cooperating with Falcon, was he recognized by the city council with an award for his invention: "Commandments: of 1,000 *livres* to

Basile Bouchon, master in silk work, to compensate the expenses he had in seeking the secret to mount and work looms without the help of warp creel and draw-girl”.[2]

Bouchon started to use perforated paper tape running over a perforated cylinder. Hooks selected single warp threads when their straight end falls through a hole in the paper and the cylinder. Bouchon’s invention is said to be “the first, albeit basic, programmable loom available for weaving silk” (Fava-Verde 2011, 1), however, his control mechanism never made it past the prototype stage. The number of warp threads that could be controlled was quite small and the whole paper tape needed to be replaced when one hole was torn. Bouchon’s assistant Falcon in 1728 solved this problem by using a loop of smaller punched units that could be replaced separately when torn. Becker writes that Falcon’s progress was to use “pasteboard instead of Bouchon’s paper” (Becker 2009, 336). But according to Ganzhorn and Walther, Falcon’s “punched cards” actually consisted of wooden slats (*Holzbrettchen* [1975] 1984, 34, 43). Also, the question of the spared drawboy or -girl is a source of confusion. While Bouchon’s loom is workable without, Becker says that Falcon’s loom still needed a drawboy and that Vaucanson’s loom was the first to spare it. Davis and Davis, however, say that Vaucanson’s mechanism still needed a drawboy (2005, 79), which leaves the laurels for Jacquard. An explanation for this confusion could be that the looms often needed extra operators that were sometimes counted as drawboys and sometimes not.[3]

Vaucanson

Becker resumes: “Falcon’s loom was never generally used. Presumably it did not function with sufficient precision, and a drawboy had still to be employed.” He then comes to the loom constructed by Vaucanson in 1745 that “could be operated by the weaver himself without the assistance of a drawboy. Vaucanson also utilized punched cards and took them over a barrel placed uppermost on the loom. The weaver could move the barrel stepwise with a long treadle. This loom likewise never obtained any practical success” (Becker 2009, 341). While Becker thus describes the patterning device invented by Vaucanson as punched cards, Farva-Verde writes: “In the 1750s, Jacques de Vaucanson replaced the perforated card with a wooden cylinder which used a pattern of raised pins to control the shedding” (2011, 1). Essinger similarly talks about “a metal cylinder with spokes in it, basically a large version of the spoked metal cylinder used in the music boxes” (2004, 18).

It is true that Vaucanson used metal cylinders with pegs, pins or spokes for the androids and automats he is famous for, the Flute Player or the Digesting Duck. But for the loom the cylinder was made of wood with a grid of drilled holes (Figure 1), and needles coming from the harness scan this grid. Patterns are introduced by punching cardboard that is then wrapped around the cylinder.[4] The clear disadvantage of this invention is that the pattern has to fit to the cylinder’s circumference; otherwise a new cylinder is needed.

Jacquard

According to the way the story is usually told, Jacquard’s invention was the first to overcome this disadvantage. Instead of a cylinder, he used a four-sided prism with a grid of drilled holes (Figure 1). Each side of the prism had the size of a punched card. The cards were then knotted together to form a long and flexible chain running stepwise over

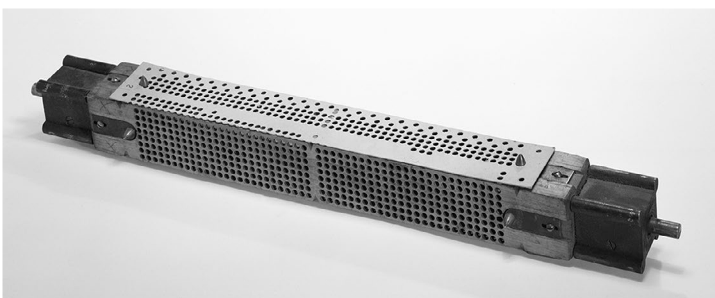

Figure 1
Jacquard prism. Courtesy Deutsches Museum, Munich.

the prism that could be used with any length of the card chain.

Albeit everyone is talking about "the Jacquard loom," it is important to stress that Jean Marie Jacquard (as well as Bouchon, Falcon and Vaucanson) did not invent a new loom, but a mechanized harness operating with punched cards replacing the drawboy or *liseuse*.[5] He was not the first to use a harness which was probably invented in Persia almost 2000 years earlier, nor was he the first to use punched paper for this, or the first to spare the drawboy, but his was the only machine that made it beyond the prototype stage.[6] It is "the Jacquard loom" that entered the history of computing only because Charles Babbage and Ada Lovelace, as well as some subsequent computer pioneers, use this expression to indicate an invention where highly complex algorithms for weaving flowers and leaves are controlled on the basis of punched cards storing binary information.

A remark on the efficiency of the new machines

It is another standard idea in connection to Jacquard's mechanism that it "speeded the process" of weaving (Davis and Davis 2005, 79). However, the technical capacity of mechanical looms was not convincing in the beginning of the development of such devices. In the famous Encyclopedia of Diderot and D'Alembert we read that the mechanism of Vaucanson was "as useless as it was costly" (Schneider 2007, 130). In fact, still around 1840 which is the time when Babbage and Lovelace cooperated on the idea of the Analytical Engine, the increase of production in using a Jacquard machine or any other mechanical loom instead of a handloom was only triple—and only then when the loom worked without thread-breaks or glitches, which was not the rule. Calculated from the production rate of a whole day, Paulinyi (1989) comes to a number of real picks between 70 and 90 per minute. The huge factories in Manchester at that time introduced a handloom with a system for gradually winding up the warp that was operated at a speed of 80 shots per minute. Paulinyi concludes that the big mechanical looms were technically inflexible and without cost benefit (1989, 84–85).

With the above in mind, the often-bemoaned resistance of weavers against the mechanical looms appears in a different light. To operate a loom with a Jacquard machine is not easier for the weaver. Much more strength and energy is needed to step on the one and only treadle, which nevertheless needs to be done with care. "When the weaver releases the treadle the considerable number of weighted leashes causes the inner part of the machine to fall heavily" writes Becker (2009, 345). And the body suffers from the unilateral strain of using only one foot (Bohnsack 1993, 38).[7]

It is true that the Jacquard machine immensely speeded up the preparation of the loom, which, in former times, was achieved by a complex system of threads operating on various levels of order in combination with the harness. This was the most time-consuming part, and the reason why patterns were rarely changed. The chance to keep up with the pace of fashion was therefore out of the question for drawloom-patterned silks.

The history of technology is full of stories on patents and inventors like Vaucanson, Jacquard or Babbage. But still craftsmen made a lot of improvements in the traditional sector. In a study of innovation in the eighteenth-century British textile industry, Griffiths, Hunt, and O'Brien (1992) compared patented and non-patented innovations from 1700 onward. The authors state that "that the majority of additions to the stock of productive knowledge over the eighteenth century, even in a technologically sophisticated industry such as textiles, were not patented" (Griffiths, Hunt, and O'Brien 1992, 886), and they assume that "any index constructed from this one source is likely to furnish a partial and ambiguous record of inventive activity and technical change" (Griffiths, Hunt, and O'Brien 1992, 889). "Furthermore, substantial additions to the stock of economically significant knowledge continued to be made anonymously and privately over the course of the century" (Griffiths, Hunt, and O'Brien 1992, 896).

Charles Babbage and the Idea of a Changeable Binary Code

According to Essinger "Babbage had toyed with the idea of programming his new machine by using a revolving drum featuring little raised studs as a mechanical means of inputting data and operating the machine".[8] But Babbage then hit upon the idea of using punched cards, like the Jacquard loom. On the 30 June 1836 Babbage wrote into his notebook: "Suggested Jacard's [*sic*] loom as a substitute for the drums" (Essinger 2004, 85).

As we already heard, the advantage of the cards lies in

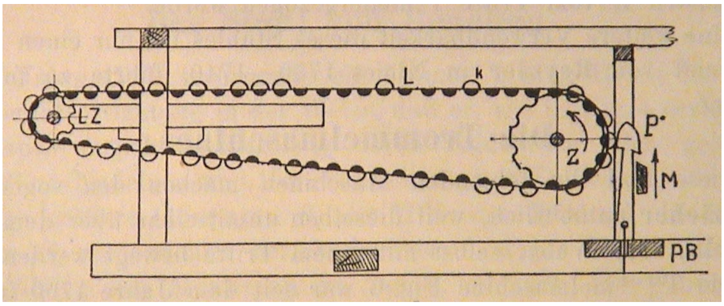

Figure 2
Diagram of canvas-machine from Kinzer 1908.

the flexibility of the length of the repeat. A chain of punched cards is potentially limitless whereas a revolving drum repeats itself by nature (Essinger 2004, 86). But both the revolving drum, as well as the punched card chain, work on the basis of a binary code. So, if the binary coding of weaving information is the essential knack that links looms and computers, there is no reason to prefer Jacquard's mechanism for the essential idea even if Babbage preferred it.

The main improvement of Jacquard's mechanism was the prism, that provided a possibility to quickly and easily change the pattern, and support any length of punched card chain. But a device used by weavers of Upper Austria implemented this idea already in the seventeenth century. Its principle is described by Heinrich Kinzer in a German handbook on Jacquard weaving as a "canvas-machine" (*Leinwandmaschine*, cf. Kinzer 1900, 5; cf. later Glafey 1937, 485) (Figure 2). With reference to the drum of Vaucanson he writes that in case of patterns with a large repeat, the drum would be too large, unhandy, and costly. Therefore, a small wooden cylinder was used and an endless (circular) linen strip was wrapped around, carrying wooden pegs glued onto it, which could then be stored for later reuse. Kinzer observes that "Out of these preceding inventions developed the up to date unique Jacquard machine" (Kinzer [1900] 1908, 5).

In the area of Upper Austria, the machine that was in use "before the new ones came from Lyon"[9] was known under the names "peg-machine" (*Stöckelmaschine*) or "crumb-machine" (*Bröselmaschine*) (Figures 3 and 4). The German word *Brösel* can denote a small part of something (cf. Harlizius-Klück 2012, 63), usually a crumb of bread, or it can be a short form of the name Ambrose (*Ambrosius*). Accordingly, there are two explanations of the name of the machine. Some say it stems from the pegs crumbling from the canvas strip (Figure 5) during use, and others that it is a short form of the inventors' given name. Heinz Zemanek was the first to mention the machine in a publication on the history of computing as early as 1976, but the machine never found its way into the standard story.

The crumb-machine

Heinz Zemanek was himself a key technologist, building the first transistor computer on the European continent. He was the first manager of the IBM Laboratory in Vienna, where he prepared the computer science exhibition established in 1974 in the Technical Museum Vienna, and was also involved in the exhibition at the Deutsches Museum, Munich (1988). In this latter exhibition, the *Bröselmaschine* is mentioned (Zemanek 1992, 47): a local Austrian device for sparing the drawboy given as part of the prehistory of computing, based in an area where weaving was once a major craft, the *Mühlviertel* (lit. mill quarter).[10]

Stating that we "tend to underestimate the skill and wit of our ancestors" (1976, 15), in a paper presented at the National Computer Conference in New York, Zemanek presents the cogwheels as digital as the score and nature of music[11] and points to the Salzburg Bull from 1502, a drum-driven organ with more than 200 pipes (cf. Adam [1973] 2004, 128). He mentions many other mechanic and automatic chimes from that area, rarely occurring in the history of automata probably because the names of the inventors are unknown, and they have not been awarded patents and prizes.

When referring to the prehistory of processing information Zemanek states: “Weaving is of more interest for information processing than we attach to it. That it is binary stems from the fact that each crossing of two threads means a natural digital-point. Many folkloristic weaving devices—in Europe, but also in Africa and Asia—are implementations of or tools for programmed processes” (1976, 16). This analogy is not drawn just because of the binary idea. Zemanek goes farther in making weaving a source of knowledge for Computer Scientists by saying that “weaving is in particular important in our present day advance from serial to parallel processing; weaving, in contrast to mathematics, is a naturally parallel process and might give us more ideas than we think” (1976, 16).

For Zemanek, the *Bröselmaschine* is a prime example of the digital nature of weaves, of which “… there are two programming units in existence, both in the province of Upper Austria.[12] They were made around 1740, and there are good indications that the invention was made between 1680 and 1690.[13] Wooden bars are glued on a closed loop strip of linen, and the bars operate the weaving device” (1976, 16).

Zemanek does not give details of either the location of the machines or the sources he is uses for the dating and description of them. From his account, it all appears to be hearsay from the discovery of an Austrian friend. This might be the reason why the machine never entered the English-speaking history of computing.[14]

Besides the works of Zemanek (1976, 16, 1991a, 47, 1992, 33), there are however some German and Austrian publications on the theme where the crumb-machine is mentioned and shown. The book of Ganzhorn and Walter was published by IBM in 1966, 1975, and 1984, and by the last edition includes the machine and a picture (1984, 45).[15] From this publication it is clear that the device is located in the Weaving Museum in Haslach (today, the Textile Centre Haslach), and that the main source of information is an article of Fritz Kreindl (1935) in *Melliand Textilberichte* (misspelled “Melliard” in the list of sources).

A manuscript in the State Museum of Upper Austria from 1799, containing patterns for looms using up to 40 shafts, mentions a method to weave drawloom patterns without a drawboy (cf. Adam [1973] 2004, 134).[16] This is taken as testation for the use of the crumb-machine. But the author, Franz Xaver Friepes, does not give any description of the device applied with this method. In his book on pattern and loom Becker states that our knowledge of loom development in the eighteenth century outside France is scarce. The reason might be that technological and craft-related knowledge was usually a secret of the weaver guilds (Hilts 1990a, 13). We therefore find no technological descriptions until the beginning of industrialization. In Italy “the weaving centers were rival business houses, each guarding inventions and technical improvements as business secrets. On the other hand, silk-weaving factories in France (Tours and Lyon) were state-subsidized and it was considered useful that the technical inventions should become known to as many craftsmen as possible” (Becker 2009, 334).

In Southern Germany and Upper Austria of the seventeenth century, weavers and non-weavers started to tinker with looms, patterns, and notations and cross the boundary of weaving patterns towards weaving images without using the huge drawlooms in use in the Italian and French workshops.[17] From this time and area stem the first printed weaving pattern books and the “first published technical description of a drawloom” (Hilts 199b, 9). Birgit Schneider in her overview on weaving as technical image processing asks whether this context was necessary to develop a weaving notation that could be used as data fed into a control mechanism on the loom (Schneider 2007, 121).

Coding Weaves: The Development of Binary Pattern Notation and Control

For millennia, pattern weaving was done without notation. Skilled weavers clearly did not make plans in advance, developing each and every step of the process and documenting these single steps in writing. The loom parts, like heddles or shafts, store most of the necessary information and skilled weavers can read bindings and patterns directly from fabric. Fabric samples were probably the best and most commonly used memory or storage for patterns.

Patricia Hilts, who prepared and commented on the facsimiles of the first pattern books in print, mentions such a sample book in Nuremberg. It is dated to 1693, belonging to a Barchent weaver. She knew of only two earlier manuscripts with notations: one dated to 1658 written by Thoman Lins, weaver in Tyrol,[18]

Figure 3
Crumb-machine (Bröselmaschine) from 1740. Weaving Museum Haslach, Upper Austria. Photo Courtesy Christina Leitner.

and another undated manuscript from Lucca in Tuscany, described and published by the historian of mathematics Gino Arrighi (1986). This Italian manuscript shows mainly notations with integers on lines resembling a musical score. Occasionally they are accompanied by pattern samples woven from narrow paper strips.

The first two printed books on pattern weaving

Parallel to the figural and botanical motifs woven with the huge draw-looms in Italy and France, there was a tradition in Southern Germany, Switzerland and Austria where linen fabric was woven with complex geometric motifs. We already, in the context of the crumb-machine, heard of a fabric called *Schachwitz*, a block patterned linen damask (Hilts 1990a, 21). Another typical patterned cloth type was *Kölsch* or *Golsch*, a linen cloth with a warp usually colored blue and with a white weft (Hilts 1990a, 23; note 71), a type of setup that makes it easier to control the design. Where the treadling is straight, the tie-ups for a *Kölsch* pattern resemble the point-paper drawing (cf. Hilts 1990a, 30). This is not the case for the color-and-weave-effect patterns where the draft does not show the color effect but only the structure of the weave. The technology for weaving *Schachwitz* and Kölsch is the context in which the standard for coding patterns was then developed.

In 1990, the Charles Babbage Research Centre in Winnipeg, Canada, published two facsimiles of the earliest printed books on weaving technology (Hilts 199a, 13) accompanied by a comprehensive comment by Patricia Hilts (1990a and 1990b). The two books were written and printed in Southern Germany not very far from the area of the crumb-machine, and among others refer to the cloth type called *Schachwitz* that is assumed to be woven with the machine.[19] The first one was written and published by Marx Ziegler, a weaver from Ulm, in 1677 (Figure 6). According to Hilts there are three extant copies in Ulm, Augsburg and Jerusalem (Hilts 1990a, 9).[20] The second book was a revised and extended version by Nathanael[21] Lumscher, bookbinder from Culmbach in South Germany, published in 1708 and reprinted in

Figure 4
Crumb-machine. Detail with cylinder and vertical hooks. Photo Courtesy Christina Leitner.

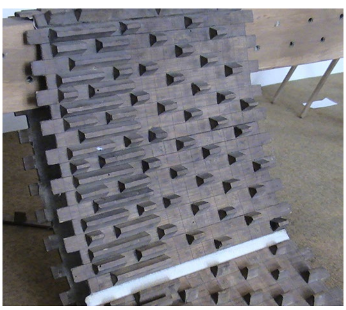

Figure 5
Detail of the pattern input strip for the crumb-maschine in the Weaving Museum Haslach. Wooden strips and pegs are glued onto the linen band. One peg is lost and the linen is visible. Photo Ellen Harlizius-Klück.

several editions until at least 1736.[22] For this book Hilts states that only two copies exist worldwide: one in the Victoria and Albert (V&A) Museum in London and one in the Deutsches Museum, Munich.

Both books reflect the development of weaving notation for the specific situation of Southern Germany. The block patterned twills and damasks of *Kölsch* and *Schachwitz* "required a distinct set of concepts and techniques," says Hilts (1990a, 42) where the shafts were divided into subsets, which then controlled units of weave structure—a notion that "was foreign to drawloom weavers" (1990a, 44). Patterns could be determined by a complex interaction of loom-parts and drafts (cf. Hilts 1990a, 32; Schneider 2007, 93) "or even by drafts and treadlings alone" (Hilts 1990a, 32). As an advantage of this system Hilts points to the drafting method of Ziegler that "allowed development of intricate large-scale patterns with a relatively small number of shafts" (1990a, 36). The weavers clearly took this chance to extend the possibilities of the looms considerably.

"Ziegler and Lumscher included some patterns for looms with as few as eight shafts, but most of their patterns required twelve or sixteen shafts, and some called for as many as thirty-two shafts" (Hilts 1990a, 27). The concept matured with the development of a draft notation that is today called profile notation. (cf.

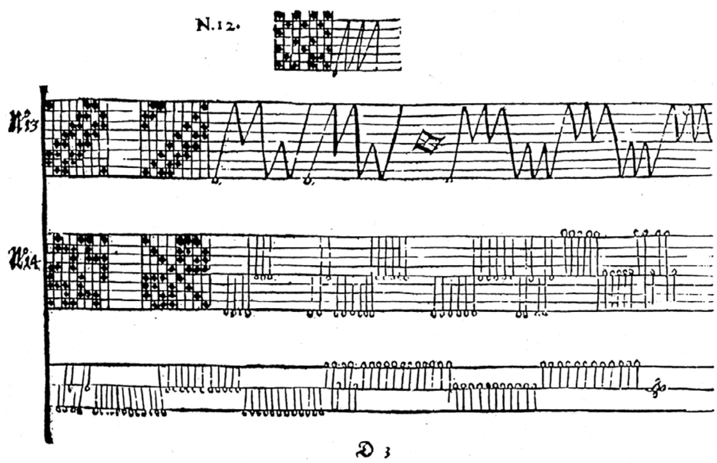

Figure 6
Page from the book of Ziegler 1677 (from Schneider 2007).

Hilts 1990a, 44) Lumscher was most likely the one introducing this way to mark the threading of a whole unit of a weave structure by a vertical stroke in a staff (Figure 7). The result in the words of Patricia Hilts: "Most important, profile notation freed weavers from thinking in terms of single threads and allowed them to think entirely in terms of units of structure" (Hilts 1990a, 44).

Here we have not only a close connection and interdependence of notation and production, but also the idea of a composition of draft parts producing a variety of patterns in the algebraical manner that Lovelace had in mind in her famous quote. However, the larger class of drawlooms does not work this way.

Lumscher and the drawlooms

Lumscher considerably extended Ziegler's book and among other new chapters included a description of weaving on small and large drawlooms as well as a how-to for constructing the small one. Both looms had shafts in the pattern harness and, as Hilts states:

> … they differed from drawlooms ordinarily pictured in eighteenth- and early nineteenths-century works. Lumscher's first or 'small drawloom', was a loom having only a pattern harness. His second or 'large drawloom,' had both a pattern harness at the rear of the loom, and a ground harness with a set of five treadle-operated shafts at the front of the loom. (1990b, 12)

Within such compound mountings, the two harnesses served two different functions: the ground harness provided the structure of the weave and ensured that the fabric would hold together whereas the pattern harness lifted warp threads to define the pattern (Hilts 1990a, 29). Ziegler and Lumscher accordingly distinguish between *Boden* and *Bild*: *Boden* indicating the weave structure and *Bild* the design. The terms roughly correspond to the meaning and distinction of "(back) ground" and "image."

Although both looms were used for weaving damask, Lumscher furthermore distinguished carefully between the point-paper patterns for the two different looms. For the small drawloom it was necessary to mark all binding points of the woven structure, whereas for the large drawloom only marking the pattern of the image was necessary because the overall satin structure of the weave was provided by another harness (cf. Hilts 1990b, 15) (Figure 8).

Hilts spent some time on comparing the copies in London and Munich coming to the conclusion that the copy in the V&A in London is in the original state only missing a point-paper. For the facsimile, she took this point-paper, a depiction of Abraham's Offering, from the copy in Munich that she calls incomplete.

She furthermore states that, because of the copy being re-bound, the placement of the point-paper is not clear. "For convenience, I have placed 'Abraham's Offering' at the end of Lumscher's weaving patterns" (Hilts 1990b, 16). To Hilts, it is

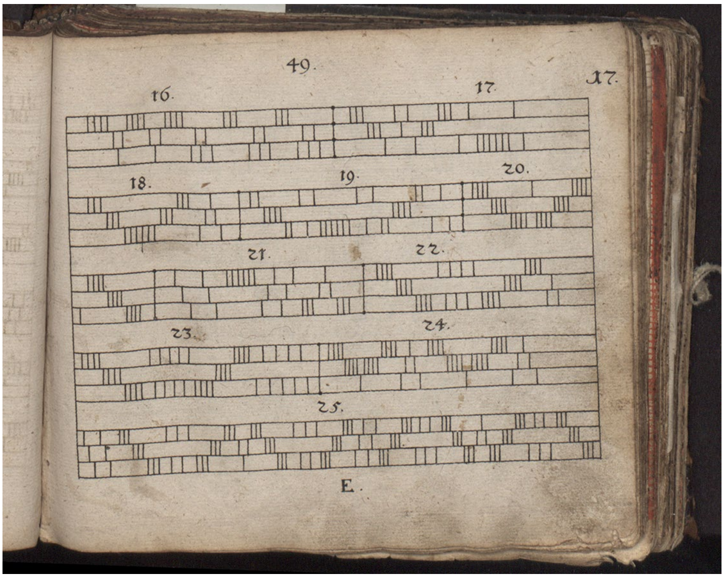

Figure 7
Page with profile notation from Lumscher's book (1708). Scan of copy from Deutsches Museum Munich, no. 34 (courtesy Deutsches Museum, Munich.

the only drawloom pattern provided by Lumscher (1990a, 32). However, the Munich copy also included a point-paper for a small drawloom that Hilts does not mention: the daffodil (Figure 9).[23]

The two point-papers represent the two different ways to provide a design for a small or large drawloom. The daffodil includes a representation for each thread whereas Abraham's Offering shows only the threads that have to be lifted additionally by the draw mechanism that cooperates with the basic weave that was probably a twill or satin setup.

The Munich copy: a weaver's journal

That this point-paper was part of Lumscher's book and not inserted by the owner of the Munich copy is clear from the fact that we today know of two further copies in German libraries. During my investigation of the Munich copy, I found them in the Germanic National Museum, Nuremberg, and in the University Library, Göttingen. In both copies both point-papers are included and the daffodil is incorporated between the plates 36 and 37. It also is included at the same position in the 1709 edition that was not known to Hilts. From this, it is clear that the point-paper with the daffodil was part of Lumscher's book and not inserted by the owner.

The London copy misses not only the two point-papers but also the patterns g–m. Furthermore plate 32 is included twice, plate 36 is turned by 180 degrees and the vignette at the end of the first part is different compared to all other copies including the 1709 one.[24]

We usually buy books with cover and a binding that keeps the pages and chapters in a predetermined order. But this was not the way books were sold in seventeenth-century Germany. From the pagination style and the catchwords[25] of the Lumscher copy we learn that the book was sold in sections that could be patched together by the customer as he found it convenient. Such sections were sold in envelopes or interim covers and their order was not predetermined as it is the case today.

The Munich copy is very special in yet another sense. The book got its present binding in 1748 with blank pages in between. The weaver, Johann Georg Thaller from Oberschwarzach in Lower Frankonia and two subsequent generations of weavers, made their own designs and notations on these additional pages (Figure 10). It was also used as a workshop journal including dyeing recipes, short reports on politi-

Figure 8
Point-paper of Abraham's Offering from the Munich copy (courtesy Deutsches Museum, Munich).

cal and private events like births of children, prices of daily goods etc. It even records a darkening of the sun in 1783 that caused a hot summer, so much good wine that there were not enough barrels to store it, and a cold winter with a lot of snow and subsequent flooding.[26]

Notation, Code, Pattern, Image

Schneider as well as Essinger are especially interested in the coding of pictures and the drawloom provides a precursor for technical image processing. Schneider observes in Ziegler's notations that already the tie-ups show which patterns could be woven (Schneider 2007, 96), which makes them distinct from the Italian or French

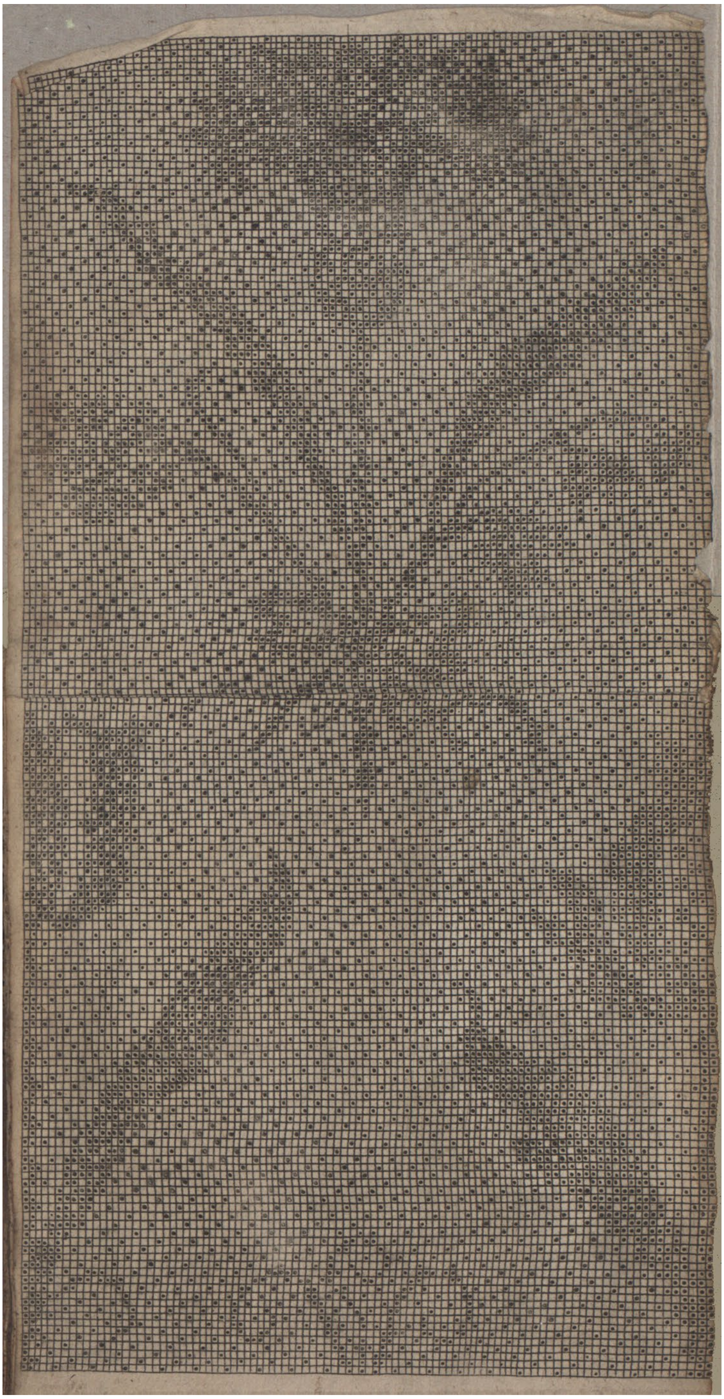

Figure 9
Point-paper with daffodil from Lumscher's book. Scan from Munich copy (courtesy Deutsches Museum, Munich).

ones. Where we see integers on lines accompanied by samples in the Italian manuscript and a sort of mechanical instruction in the French encyclopedia, no depiction of the pattern itself is included.[27] The German weavers started to employ a binary drafting technique where the image is visible as tie-up or *Bild,* which literally means "image."

However, this is only true for the special case of the *Schachwitz* and *Kölsch* fabrics with blue warp and white weft and a straight treadling. This way to set up a loom, with distinct colors of warp and weft, is not the usual way for checkered or patterned fabrics.

The early books on weaving are not only important for notation and storage of patterns but also for the development of drawloom mechanisms different from the line of the French inventors. A weaver could build these devices by himself (Hilts 1990b, 12) or ask a local carpenter.

Patricia Hilts concludes that the book of Ziegler has been published at the beginning of a period of rapid development in multi-shaft treadle-loom weaving that took place 1677 to 1708 (Hilts 1990a, 10, 32, 45). That Ziegler's book appears at the beginning of this period suggests that it could have even made this development possible by introducing notations that referred to special loom parts, making it feasible to connect the design process to the mechanism installed in the loom. Crucially, the fact that the weavers worked on both the weaving of images and of patterns in one fabric makes their story important for the later development of mechanisms that simply use the draft-paper for controlling the loom directly—such as the punched paper control of the French looms.

The books of Ziegler and Lumscher document a highly complex and intellectually demanding development of shaft weaving with draw mechanisms and harnesses. When the Jacquard loom prevailed, this tradition lost importance and was only carried on locally. Jacquard's loom can weave anything, patterned or not, and by this he has put an end to the highly algebraical weaving method of *Kölsch* or *Golsch*.

The Algebra of Patterns

Manipulation of symbols is what algebra means for us today. It is mostly seen as a generalization of arithmetical rules.[28] Algebra allows doing arithmetic in an algorithmic way. Simple algebraic notations are for example $2n$ denoting any even number (where n is a natural number) or $2n-1$ denoting any odd number. A similar generalization happens on the loom when two sheds are used for making plain weave. All odd-numbered threads are collected in one shaft and all even ones in the other. That this sort of algebra is indeed what weavers

Figure 10
Page with notations from Johann Georg Thaller in the Lumscher copy in Munich (scan no. 75).

have to execute might be illustrated by an instruction to calculate satin weaves for given repeats. In this case there is an equation system with two unknown integers to solve: progressing number and slope number. The instruction reads: Factorize the repeat in two integers fitting to the following conditions:

1. No number is equal to 1
2. The numbers are not equal to each other
3. The numbers are prime to each other
4. The numbers are prime to any third number. (Hauptmann 1952, 15)

Weavers had to "calculate" like this and satin weaves store this sort of algebra in their structure.[29] Ziegler's block pattern principle furthermore allows a sort of calculus for patterns being constructed by repeats, reverting and mirroring of pattern parts.

In fact, the Jacquard machine does not work algebraically. It is best known for the possibility of addressing each and every warp-thread singularly. It is this feature that makes the machine perfect for weaving portraits—like the famous portrait of Jacquard himself to which Babbage referred when presenting the idea of the Analytical Engine of one of his soirées (cf. Essinger 2004, 1–5). Such portraits contain no repeats—besides the structure of the binding that is now included in the one-to-one address of the machine and not a result of the addition of several shafts with particular groups of warp-threads.

Schneider in her account of the idea behind the punched card mechanism points to the fact that the draft notations enable a seamless connection of formalism and mechanism: The order of the holes in the punched cards could be directly derived from the notations on point-paper. But this means that the possibility to code a loom depended on the notation developed by the shaft loom weavers. As we heard, these notations were not only meant as store or memory for patterns but also served as an instrument for pattern generation. The block system notation parts could be combined to compose new patterns in a systematic way with building blocks adding up to bigger units (Schneider 2007, 112).[30] The treadling and the tie-up stand also for themselves and reflect geometrical properties of the pattern like symmetries and rotations that will be composed from parts of the blocks by using only part of the treadling sequence in a special order (Schneider 2007, 112–113). This close connection of code or design and loom construction was also stressed by Hilts: "Loom-controlled pattern weaving is a distinct branch of design in which art and technology are closely interrelated" (Hilts 1990a, 27).

Schneider is interested in weaving notations from the viewpoint of the prehistory of technical image processing and image coding. However, her remark on the block system makes it obvious that weavers understood and took advantage of the algebraical aspect of this system. Ada Lovelace mentioned such an algebraical approach to the patterns in her famous notes to the Menabrea paper as a possibility to improve weaving. She was aware that the Jacquard machine as it stood was not able to perform reverse or mirrored operations:

> *The mode of application of the cards, as hitherto used in the art of weaving, was not found, however, to be sufficiently powerful for all the simplifications which it was desirable to attain in such varied and complicated processes as those required on order to fulfill the purposes of an Analytical Engine. A method was devised of what was technically designated backing the cards in certain groups according to certain laws. The object of this extension is to secure the possibility of bringing any particular card or set of cards into use any number of times successively in the solution of one problem. … The process is alluded to by M. Menabrea in page 680 and it is a very important simplification. It has been proposed to use it 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 have algebraical combinations not less completely within the province of mechanism, than are all those varied intricacies of which intersecting threads are susceptible.* (Lovelace 1843, 796)

So, according to Ada, backing and reverting the card chain was a necessary improvement of the Jacquard principle to be useful for the Analytical Engine. She then argues that this could be fed back into the art of weaving and help producing repeated and reverted patterns. However, the block patterns of the South German weavers and the crumb-machine of Upper Austria already implemented such variations which are not typical for drawloom weaving and not essential for weaving pictures like the Jacquard portrait. Ada was not a weaver and probably not acquainted with the various methods of pattern weaving. Presumably she thought of drawlooms as the most advanced of their kind, which they are not when viewed under the perspective of pattern algebra. Both, Babbage and Lovelace seem to have admired the Jacquard loom for its capacity in weaving realistic images, but images like portraits do not need repeats or symmetry. There is no pattern and no algebra.

Conclusion

Besides the line of French inventors culminating in the Jacquard machine, there have been successful tools developed by Austrian and Southern Germany weavers to transform the drawloom with drawboy into a drawloom that could be operated by the weaver alone. The crumb-machine is the result of a mutual development of looms and weaving notations that culminated in the block-weaving methods with their algebraic way to organize threads in groups and subgroups piling up to geometrical symmetries. The notations make the interaction between machine parts and the sets and groups of threads visible.

It occurs that the mechanisms forming the historical line culminating in the one from Jacquard are all more or less failures, stored in collections devoted to tinkering mechanisms of inventors like Vaucanson's duck or his androids. On the other hand, we have the cheap, self-made, working and therefore outwearing mechanisms with untranslatable names invented and used by nameless regional weavers for weaving strange-named fabrics like *Kölsch* or *Schachwitz*. Such tools do not enter the collections of national museums as long as they are in use, and afterwards they hardly ever survive.

On one hand, the books of Ziegler and Lumscher made the art of weaving public, and its notation became standardized and common. With the notation close to the machine, they furthermore facilitated mutual understanding of the interaction between pattern drafting and loom parts for non-weavers and through this enabled engineers and inventors to play around with the mechanisms finally leading to an automated loom.

On the other hand, it is also true that the inventive work that weavers did day by day was and still is overshadowed by the new tools and the new masters taking the credit without being weavers. All the algebra that weavers did is buried and covered, hidden and misunderstood as a mere binary reading of something that is done better and easier by a mechanism scanning punched cards. This is the reason why it is necessary to object to the all-too-prominent Jacquard "loom" as ancestor of the computer.

Finally, the weavers' way to think algebraically entered the engineering of calculating mechanisms. Punched cards are the means by which this algebraic thinking was transferred from the brains of weavers to calculating engines. This means that it is the invention of coding algebra that really matters. The reason why the loom control was so successful for mechanic computation is that the punched cards made the binary basis of weaving obvious to non-weavers and, looking at the fabric in the second step, made them aware of the possibilities of such an approach with regard to algebra as a science of numerical patterns.

> *Weaving, Music Machines and Census have prepared as many ideas for the computer as calculating devices. Only part of the history of ideas is collected and described in publications of our days and in our language. A lot remains to be done.* (Zemanek 1976, 19)

Notes

1. A Scholar-in-Residence Grant of the Deutsches Museum conducted in the year 2006 allowed me to investigate the weaver journal. I am grateful to Helmut Hilz, head of the library, for hints and information on the background of book selling in the seventeenth century. Wilhelm Füßl made some wonderful weaver's sketchbooks with block pattern notation accessible from the archives of Deutsches Museum. Christina Leitner from Textile Culture Haslach gave me the opportunity to work in the Haslach archive for the sources on the crumb-machine and made it possible to see it in operation, to make photos and videos. The Arts and Humanities Research Council funded the cooperation with the computer scientists and live coders Alex McLean and Dave Griffiths on the weaving-coding connection that

finally led to this article (Grant Ref. No. AH/M002403/1).

2. “Mandements: de 1000 livres à Basile Bouchon, maître ouvrier en soie, pour l’indemniser des dépenses qu’il avait faites en cherchant le secret de monter et faire travailler des métiers sans le secours du cantre et de la tireuse” (Schneider 131, note 13; author’s translation). It should be mentioned that the loom still needed to be operated by two people: the weaver and someone pushing forward the punched cards (Bohnsack 1993, 31).
3. Cf. Bohnsack 1993, 31 and http://history-computer.com/Dreamers/Bouchon.html without further reference.
4. Cf. Schneider 142; cf. also http://history-computer.com/Dreamers/Vaucanson.html 4.3.2016 13:09.
5. It is often said that Jacquard as a child had to work as a drawboy himself in the workshop of his father. However, there is no direct evidence and some of the stories about his youth are legends (Schneider 263). It is documented, that his mother, Antoinette Rive, worked as *tireuse*, *liseuse du dessin* and *faiseuse de lacs* in the workshop of her husband who was a silk master weaver operating three huge drawlooms. For biographical information on Jacquard cf. Schneider 263, note 12, and Essinger 2004, 22–25.
6. “He took the idea of holes in paper as means of transmitting information from Bouchon, the punched cards and the hooks from Falcon, the idea of a self-acting machine from Vaucanson and its implementation as an additional device from the drum machine and thus also from Vaucanson” (Bohnsack 38; author’s translation).
7. Almut Bohnsack was professor for Textile Studies at the University of Osnabrück and installed a complete Jacquard workshop in the University premises with card supply and punching machine. I had the opportunity to work on the loom myself. Without regular operation the loom gets stiff and unworkable and a lot of effort and technical knowledge is needed to make it ready for take-off again.
8. Essinger 2004, 85. He goes on: “This type of drum was, of course, the basis for the control system of Jacques de Vaucanson’s loom.” But this is wrong. As we already heard, Vaucansons cylinder was perforated all over and a sheet of punched paper was wrapped around, scanned by pegs that lifted the respective warp threads.
9. The Jacquard loom became known in this area as “Lyon machine” from around 1825 onwards.
10. The term “mill” refers to the watermills of the area and not to textile factories.
11. The seemingly clear distinction of digital and analog is a result of a long debate ending in a convention not to talk about states in-between (cf. Pias 2005). This then enables a distinct definition as well as the often-stated higher precision of digital signals. In the information sciences and technology, a signal is called analog if it transmits the information by means of a proportional ratio. Signals are digital and containers of information when they are solely coded as natural numbers (Serres and Farouki 2001, 175). Often the difference of digital and analogue clocks is used to explain this allegedly fundamental distinction. But analogue clocks use gears that are discontinuous and work with the escapement to cut the continuous time into countable pieces: tick-tock. Even Norbert Wiener once stated: “Every digital device is really an analogical device” (cf. Pias 2003, 158).
12. Zemanek gave no source. The two units are: (1) in the Museum of Weaving in the Textile Centre Haslach, Austria; and (2) in the State Museum of Upper Austria, Linz.
13. Randell, in a short summary of the article of Kreindl, misunderstood the date of invention. The machine presented by Kreindl was made in 1740, but it was one of the last of its kind and the invention must have been made considerably earlier. Kreindl suggests a date around 1680 and not “in or before 1740,” as Randell says (cf. Randell [1975] 1982, 484).
14. Only Randell when referring to Bouchon as the first to use perforated tape for ornamental patterns mentions the article of Kreindl (1935) in a footnote (1982, 4). The machine is not discussed but the annotated bibliography gives a short summary (cf. note 13).
15. Ganzhorn and Walther call the parts of the programming mechanism “wooden pegs” (*Holzbrettchen*) similar to the ones in Falcon’s machine (1984, 45; cf. for Falcon 1975, 34 and 1985, 43).
16. The manuscript was written by the weaver Franz Xaver Friepes

around 1799 and contains an introduction, more than 300 threading drafts, more than 400 tie-ups and around 200 drawdowns for weaving *Schachwitz,* a fabric decorated with flowers and ornaments in the typical geometrical style of the region (cf. Oberösterreichischer Musealverein 1937, 29–30).

17. Essinger wrongly assumes that the drawloom is the first loom "that made it possible to create a pattern" (2004, 10). Obviously, he employs the term "pattern" with the meaning of "image." Patterns can of course be created with simple shaft looms. And to weave repeated "images" that is: patterns that depict something like stars or flowers, is also possible with shaft looms.
18. Cf. Library of The Austrian Museum of Folk Life and Folk Art, Vienna.
19. Cf. Adam 1973, 134 and note [16].
20. The catalogue of the exhibition "Textiles Open Letter" pretends to present a copy of Ziegler's book from 1677 on pp. 242 and 243 belonging to the CSROT library of Seth Siegelaub. However, as the title page presented in the catalogue shows, this is a late edition of Lumscher's book from 1725 (Frank and Watson 2015, 242). There is no depiction of a loom in Ziegler's book.
21. Throughout the two publications Hilts misspells the name as "Nathaniel".
22. Patricia Hilts knows the editions from 1708, 1711, and 1720 and argues that Lumscher refers to these when he writes in the edition of 1725 that 4000 copies were sold in three editions. However, there is also an edition from 1709 and an edition with minor corrections from 1708. If we do not consider the last one as an edition in itself, the first editions from 1708, 1709 and 1711 span over only three years which makes the sales an even better success.
23. The copy in Munich is listed in the library catalogue with Marx Ziegler as author and Nathanael Lumscher as publisher. The whole book and manuscript is presented online at http://digital.bib-bvb.de/webclient/DeliveryManager?custom_att_2=simple_viewer&pid=2398723. A short introduction and overview gives Harlizius-Klück 2007.
24. Dorothea Peters suggests that the V&A vignette was printed from a fragile woodcut that broke and was subsequently replaced by the sturdier one we see in the other copies and also later in the 1709 print (conversation at Deutsches Museum in 2007).
25. On the text pages the first word of a page is printed at the end of a separate last line on the preceding page (in German: *Kustoden*).
26. The transcription reads: "Im Jahr 1783: ist die Sonn den Somer so Verfinster/=t geweßen und einen Nebell und gehab daß es einen/schrecken un der dem Volck gemacht habe und war/ein solges thüres Jahr daß Mann glaubte es müste/Nun alles Verterben und war ein so gutes Wein/Jahr daß Nun Faß Zu Wenig waren einzuthuen/Der Eimer habe gegolten .2. gulten .2. taller und war/so gut daß die trauben wie die Roßinen geweßen seynt/geweßen dar auff ist Nun erfolgt ein so differ/schnee den Winder Zum Denck mahl ist Bett stund an/gestelt worten Zu Besorgen ein großes Waßer wie/Nun auch". Obviously, this refers to the effects of the eruption of the Laki, a volcanic fissure in Iceland that caused eight months of emissions of sulfuric aerosols and ash blown southeast as a fog so thick that ships could not navigate. The book clearly demonstrates that local weavers were not as poor and illiterate as some histories of the trade suggest.
27. Schneider (2007, 83–124) compares different notation systems for weaving under the perspective of technical image processing.
28. There is, however, a discussion about the relationship of arithmetic and algebra showing that different cultures have different traditions and concepts of algebra. For example, Subramaniam and Banerjee (2011) state that algebra is rather a foundation than a generalization of arithmetic. Possible historical and cultural dependencies of the algebra of patterns and the development of algebra will be pursued in an ERC Consolidator Grant at the Deutsches Museum in Munich (PENELOPE-682711, principal investigator: Ellen Harlizius-Klück).
29. There is a so-called geometrical algebra in Ancient Greece, based on a specific number theory called dyadic arithmetic or "theory of odd and even." It includes all arithmetical rules necessary for pattern calculations and the fact that

Plato mentions the odd-even distinction twice in the context of weaving is probably no accident. Cf. Plato, *Lysis* 206e–208d, *Statesman* 258c, Harlizius-Klück 2004, 93–106.

30. Schneider says, the *Schachwitz* notations did not look like fabric patterns but like music notations (2007, 85). The similarity might be explained by the fact that the guilds in Southern Germany were part of a distinct custom. Craftsmen (masters) like weavers, carpenters, joiners, woodcarvers, met in their spare time for composing and singing lyric poetry according to strict and artful rules that were coded in tabulatures, forerunners of the staff-lines we use today and similar to the notations that the weavers used for composing their patterns. These groups were called mastersingers (*Meistersinger*).

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