Revisiting the Jacquard Loom: Threads of History and Current Patterns in HCI

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ABSTRACT

In the recent developments of human computer interaction, one central challenge has been to find and to explore alternatives to the legacy of the desktop computer paradigm for interaction design. To investigate this issue further we have conducted an analysis on a fascinating piece of machinery often referred to as one of the predecessors of the modern day computer, the Jacquard loom. In analysing the Jacquard loom we look at qualities in design and interaction from some different perspectives: how historical tools, crafts, and practices can inform interaction design, the role of physicality, materiality, and whole-body interaction in order to rethink some current conceptions of interaction and design of computational devices.

Author Keywords

Whole body interaction, sustainable interaction design, materiality, History of HCI.

ACM Classification Keywords

H.5.2 [Information Interfaces And Presentation]: User Interfaces - Interaction styles;

INTRODUCTION

The mechanics of the Jacquard weaving loom is often referred to as one of the predecessors of computer science, and even though it is an altogether mechanical construction without electrical components, its sophisticated design of a long series of interconnected punched cards, used to produce patterns on fabric, has been regarded as an early form of computer programs [10]. Even though the importance of the Jacquard loom for the computer science domain is widely acknowledged, the emphasis when referring to the loom is mostly placed on aspects of computation and logic [26], and not on aspects of usage and interaction design. An analysis of the loom from an HCI perspective has thus yet to be properly conducted.

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Over the last few decades, use cases and concrete benefits of interaction resources beyond desktop and laptop settings have been increasingly analysed and illustrated in research in HCI, especially in the areas of tangible and physical interaction design. Given the physical manifestation of the Jacquard loom in relation to this focus on physicality, embodiment and alternative forms of interaction in our research community, we see its design as particularly interesting to explore.

This paper aims to provide insights in the mechanics of, the interaction with, and some of the processes around a Jacquard loom, in the light of the kind of technologies that we develop and see around us today. The discussion is based on observations and interviews of personnel at a historical silk weaving mill, with a Jacquard loom from the mid-1800s still in use. The loom that we studied is almost identical to the original design from 1805, as depicted in Figure 1, and is based on a common model in many industrial weaving houses in Europe in the 19th century. We use the observations of the loom to revisit some of the central themes in current discussions on where human-computer interaction is headed, including notions of sustainability, tangible interaction, whole body interaction, post-wimp interfaces and a drive towards industrial design within the community.

Figure 1. Jacquard introducing Napoleon to his newly invented loom in 1805, by R Ledoux. At the top left corner is a chain of punched cards controlling the pattern woven into a fabric.

BACKGROUND

The Jacquard loom is an early example of the kind of machines that played central roles in the industrial revolution, where parts of complex and laborious activities became automated. The loom is a sophisticated piece of machinery that required expert skills to build and maintain, but that dramatically simplified the complexity of the actual weaving activity, making it possible to make more complex patterns while also increasing the production speed.

The core invention of the Jacquard loom was a clever mechanism that automated the use of punched cards, which made it possible to encode more complex weaving pattern into the operation of a loom. Although there was no actual computation performed using the cards, the invention is still considered an important step in the history of computing hardware. The idea of punched cards was later used by Charles Babbage in constructing the first mechanical computing device, the difference engine. This was later developed into the analytical engine, whose fundamental structure was later used when designing the first programmable computer, about a century later. From these historical developments of computing machinery, an issue that emerges is how the design and operation of the original Jacquard loom may be relevant for modern day trends in HCI and what we may learn from them as designers of new computational artefacts.

In particular, much focus has been put into exploring how physical and bodily manifestations and actions make electronic or virtual objects ‘graspable’ [14] and ‘tangible’ [33] in the literal as well as metaphorical sense – being easy to understand and ‘get a grip of’ [16]. In that sense, embodied and tangible interaction with digital artefacts have predominantly been conceptualised as bridging a gap between the world in which we live and act, and the world of computation.

A discussion that has been growing in HCI for some years now, is how this framing of interaction with computers still to a large extent is influenced by assumptions of what constitutes a computer interface, grounded on the heritage of our field in desktop computing in office contexts. Some of these assumptions have had to be revisited with new contexts for interaction being explored, such as mobile, social, and leisure oriented use settings. Given the many forms that computational artefacts may take, we see an alternative opportunity to deepen our understanding of the fundamentals of interaction design to be the investigation of human machine interactions before desktop computing was established, preceding even digital machines.

The history of computing consists of many examples of physical forms of computing and interaction. Examples range from the abacus, Napier’s bone [5], and the slide-rule. A common theme of these is that they are based on ingenious compositions of material and mathematical coding schemes, alongside simple methods of manipulation.

Related is also the development of various kinds of automata, such as the Pianola, the self-playing piano.

An issue in relation to these historical perspectives concerns how to understand the materials involved in computational and interactive processes [7, 36]. Many of the materials we see in use for instance at a bookbinding workshop [29] or in Jacquard loom weaving are over a hundred years old, but still remain fully functional and useful. In contrast, several of the computational materials, devices as well as information, often become useless already after 10 years. This is not to say that these old technologies are necessarily better, but it says something about how the tools and practices that can help us rethink present conceptions of interaction in HCI. Materiality and how to turn it into a central aspect of interaction design has been addressed from a number of viewpoints. The dominating theme of these concerns is captured by Blanchette [3], who proposes a framework from which not to view digital information as something immaterial and independent of physical circumstances, but rather as something that must be conceptualised as dependent upon and intrinsically intertwined with its material manifestations. Examples of work along these lines include Vallgård’s [35] notion of *computational composites* as a vocabulary from which new computational materials can be looked upon. Robles and Wiberg [28] have proposed the notion of *texture* as a way of thinking of the relation between the physical and the digital as they come together in interactive spaces. Other more practical approaches include Sundström et al’s [30] explorations of how we can look at digital and computational properties from the point of view of materiality, proposing the notions of inspirational bits and experiential artefacts. These notions attempt to support designers to attend to digital artefacts as a material, in just the same way as wood or clay would be attended to, i.e. as materials that need to be shaped according to their specific qualities, rather than as materials that can be described in generalised sketches and prototypes.

In line with these explorations we also see increasing influences in HCI and tangible interaction research from disciplines with a more immediate concern for the physical aspects of interaction resources, such as *industrial and product design* [6]. A goal of much research in these domains has been to take advantage of the kind of interaction that we see with many pre-digital cognitive artefacts such as the abacus [33] and to support a stronger connection to our *bodily skills* developed when using physical artefacts for interaction [20]. Other values that have been discussed are the increased possibilities for social interaction around physical objects, and issues of persistence and personal attachment.

The concern with bodily activity has recently been addressed in work that specifically look at the role of the body in interaction and how we can design for more engaging forms of interaction. In light of the Jacquard loom

Figure 2. The weaving process using a Jacquard loom. From left to right: a) mounted punched cards hanging in the loom, b) assembled loom with hooks and strings in this case 4800 threads, with four visible repetitions of the pattern along the width, c) weaving the fabric, d) the final silk, e) a fabric woven using different coloured weft thread in a loom run with one chain of cards.

there are a number of properties, such as its sheer size and weight that speak to forms of interaction that we argue are still underexplored in interaction design. Interaction with such a machine requires us to engage physically involving our whole bodies through big movements and muscular exertion in a quite different fashion to most tangible and mobile technologies that have been studied in HCI. *Whole-body interaction* of this kind has been addressed in a number of areas, perhaps, primarily gaming [18], but also in studies that attempt to find design that steer away from cognitively oriented conceptions of human action, and eye-hand style interaction that still dominate today [17, 22, 32]. Instead they develop conceptions that give room for a larger space of human bodily capabilities.

In analysing the Jacquard loom we look at qualities in design and interaction from the perspectives discussed above: how historical tools, crafts, and practices can inform interaction design and the role of materiality and whole-body interaction in order to rethink some current conceptions of interaction and design.

THE JACQUARD LOOM: MECHANICS AND INTERACTION

Before discussing the Jacquard loom from the perspective of modern day technologies we will start with an overview of its mechanics and usage (as it occurs in the silk weaving mill that we have studied). We do this by discussing how the machine is operated and interacted with through the different steps in the weaving process: moving from artist image, to paper draft, to punched cards, to assembled loom, to the final fabric (see picture sequence in Figure 2).

The study was based on repeated visits with observations and interviews with the two employees that master the loom daily, and introductions given by the manager and a guide of the mill, as well as discussions with a researcher at the Swedish School of Textiles, who is an expert in the historical aspects of the inventions of Jacquard. The technical description is also based on literature, such as the historical accounts provided by Essinger [10].

The mechanics of the Jacquard loom

The specific Jacquard loom that we studied is a wooden construction of approximately 4 x 4 meters wide and 3 meters high, set up in the mill in the year 1862. As with all looms, fabric is created by throwing a weft thread back and forth through a set of warp threads strung and stretched through the construction.

Jean Marie Jacquard's invention, in the year 1804, was that he partially automated the process of making repeatable patterns woven into a fabric. This made it possible to create fabrics with high resolution patterns with less effort and in much less time than before, by reducing the need for the draw boy, who had to manually lift the warp threads at each pattern shed. This revolutionised the whole textile industry, and especially, the patterned silk that was now possible to make with this machine became highly popular and also available to a broader market. The silk fabric that is produced in the examined loom consists of 4600 up to 5600 warp threads on a fabric width of 60-70 cm. A jacquard machine with 600 hooks is used, the design is repeated four times and two threads go together in each heddle, giving a resolution in pattern of 40 stitches per centimetre. The technique that made this possible utilised sequences of punched cards, made of cardboard, within which the pattern of the fabrics were encoded. The pattern in the loom depicted in Figure 2d, consists of 2520 punched cards, resulting in a 31 cm high pattern repeated four times over the width of the fabric.

Through a complex mechanical construction depicted in Figure 3, the holes in the punched cards control what warp threads to lift, thereby affecting which colour will be visible at each point in the final fabric. For each line of weft thread, one card or a group of cards stitched together in parallel determines what warp threads should be lifted on that line. If a pattern is repeated along the width of the fabric, the loom is threaded so that several harness cords are connected to each hook that correspond to each possible hole on a punched card, either mirrored or in a repeated fashion. The length of the pattern depends on the number of punched

cards hanging in the loom, with complex patterns requiring thousands of cards.

The process of making a fabric using this technique involves a number of steps, including the making of the pattern itself and transferring it to point paper, the punching of cards, the threading of the loom, and the actual weaving process. Below is an overview of these separate steps.

From design to point paper

The patterns of the fabrics to be woven in the loom were drawn by hand by artists who collaborated with the weaving mill. The patterns range from smaller illustrations or images, to geometric and floral patterns of different size. Patterns were generally designed so that they could be mirrored and repeated over the whole cloth, to make the weaving process more efficient. In northern Europe the most popular use of the machine was to make silk with mirrored decorative floral patterns, used primarily in the forms of head kerchiefs worn by women at special occasions, e.g. when going to church. More luxurious fabrics consisted of larger and more delicate patterns with several colours, requiring larger numbers of punched cards.

The drawing created by the artist was then transferred to a pattern on a checkered point paper (see figure 4a). This was most often done by a weave master at the factory who had knowledge of the particular loom, e.g. the thickness of the silk and the number of threads in the loom (the “pixel resolution” of the final image). To help the later process of translating the drawing to punched cards, the grid was marked with thicker lines to group the points in sequences of 12, the number of holes that could be punched at each line of the cards. The colours on the point paper rarely corresponded to the colours on the finished weave, since each pattern could be used for several different colour combinations (see Figure 2e). The pattern was adapted according to restrictions of the grid since each position on the grid can only contain one colour. Together with the point paper, instructions were also produced that specified how the colours on the point paper should be interpreted.

Figure 3. Schematics displaying the core mechanics of the Jacquard loom: The holes in the punched card (a) affects whether the lifting hooks (b) that are attached to the individual warp threads, hooks on to pegs in a bar (c). When the bar is raised by the weaver by pressing a pedal, the attached hooks will raise the corresponding warp threads.

From point paper to punched cards

Based on the point paper drawing, the cards are punched using a lisage machine (see Figure 4c), a practice referred to as ‘reading’ the point paper draft. When using the lisage machine, the point drawing is read line by line according to the instructions that are needed to interpret the colour codes. The lisage machine has twelve keys that each correspond to a position on the rows on the punched card. The holes are made by pressing a ‘chord’ of keys corresponding to the 12 possible holes in that row of the card, and simultaneously stepping on a pedal to punch the holes and feed the card one row forward. When the cards have been punched they are stitched together in a chain that can later be hung on the roller in the jacquard machine. For a big and complicated pattern a chain of cards can contain several thousands of cards. As the creation of punched cards is an extremely time consuming process, each chain of cards was carefully marked and stored in crates when not in use so that it could be reused on later occasions.

Figure 4. From left to right: a) the original pattern on point paper, b) relationship between the dots on the point drawing and the holes in the punched cards, c) the lisage machine at the studied weaving mill, with keyboard and foot pedal used for making holes in punched cards, d) the practice of punching cards using the lisage machine in the early 19th century.

The Jacquard loom was one of the first machines to make practical use of punched cards to store and control a sequence of operations, thereby not only making it possible to automate the reproduction of a woven pattern image, but also making it possible to reprogram how the loom would run and to use basic computational structures such as sequencing and iteration.

From punched cards to assembled loom

The loom then has to be threaded, a process where the threads in the warp are threaded in the heddels attached by the harness cords to the hooks corresponding to possible holes in the feed of punched cards. If the pattern is repeated and/or mirrored on the weave then several harness cords are attached to each hook. This is a complex process in which thousands of warp threads have to be assigned to the appropriate hooks in order for the loom to correspond to the pattern. This involves knowing how the pattern is repeated and mirrored and assigning hooks in correspondence to that. This process could take up to two weeks for a simple pattern and up to three weeks for more complex patterns. Because of the huge work invested in the threading, it was rarely altered. Instead, to alter the pattern, a new chain of punched cards were hung in the loom, using the same threading.

From assembled loom to weave

The actual weaving process involves a number of separate actions: When stepping on a pedal the warp threads get lifted by the hooks according to the holes in the current punched card. Simultaneously, the next punched card in the chain is fed into place. The weaver then flicks the shuttle with the weft thread across the warp through the shed and thrust the beater to compress the weft and warp yarn. When the pedal is released the loom falls back since the harness cords are stretched with lead weights and the next card is pressed against the roller to prepare for the next sequence in the pattern. To mirror a pattern along the length of the weave, the chain of cards can be run backwards, thereby producing the pattern in the reversed order. The weavers continuously have to compare the pattern with the unfolding weave in order to find sources of error.

DISCUSSION

When studying the Jacquard loom with the eyes of a 21st century HCI researcher, a number of qualities become visible. Some of these may be aspects that we value today but that were probably not considered significant at the time of its original use. Here we discuss these qualities in terms of four themes:

- Materiality and digital representations
- Graspability and complex mechanics
- Whole body interaction.
- Sustainability and age

Theme 1: Materiality and digital representations

We now stand at a point in technological development where the distinction between the digital and the material is increasingly blurred, and we even see projects in which our most mundane objects, like the clothes we wear, and the fruit and vegetable that we buy at the supermarket, are becoming part of our digital and interactive experiences. This raises fundamental questions regarding our understanding of when something can be considered digital and what constitutes a digital artefact. In current HCI research, issues concerning materiality is broadly construed [9], and is explored from a number of perspectives such as its potential as a design resource [30], its aesthetics qualities [36], and its representational opportunities [11]. By revisiting the early forms of binary representations as they took shape in the Jacquard loom, we can observe an earlier point in history where there also was a less distinct boundary between representations and interactional resources, and thus gain new insights into aspects like materiality, representations and interaction.

As stated in the introduction, the Jacquard loom is often discussed as being a predecessor of the modern day computer. A key feature of the invention was the use of punched cards, in which fabric patterns are represented in the form of holes and absence of holes in a long chain of punched cards stitched together. The mechanics of the punched cards could be regarded as the birth of the binary representation, making it possible to ‘digitize’ material objects, creating a form of ‘code’ only possible to interpret by running it through a mechanical device.

While the loom clearly executes a form of code, a question of relevance is what in this weaving process might be considered programming - especially as there is no digital or even electric element used. One approach could be to look upon the whole process as programming – where the final fabric would be considered as a form of ‘program’. Another approach is to focus more on the transformation from different representational forms, e.g. from point paper to cards, or the complexities involved in stringing the loom. In this setting, we have chosen to look upon the sequence of punched cards hanging in the loom as the ‘program’, and the actual weaving process, producing the patterned fabric, as the ‘runtime’ representation of this program. In terms of interaction design, this is an early example of the distinction between separate roles of end users (the person sitting at the loom weaving), and programmers/coders (involved in making the sequence of cards and installing it in the loom).

However, to the person weaving or making punched cards, there are probably other aspects that are more immediate to their practice than to interpret how the pattern is encoded in the cards, e.g. how handle the shuttle, finding a rhythm in the use of the foot pedal, monitoring the process and identifying possible sources of errors. When running the chain of cards for the first time, the weaver can monitor the outcome and identify any sources of error, reverse the

execution and physically repair the cards by filling in holes or adding new ones, effectively debugging and correcting the code in a very concrete manner.

In the case of the Jacquard loom the mapping between the code and what is represented is very close. It is basically a one-to-one mapping where each point on the drawing is represented by a hole or absence of hole on the punched card. However, on the punched card, there is no representation of colours, which can be available in the point graph. The code is made visible through a completely transparent physical construction, while in modern day computers, the machine code is hidden from user in layers of abstraction. In some subdomains of HCI, such as in tangible interaction and end-user programming, there has been longstanding efforts made towards making these layers of abstraction accessible and interpretable by end users. These ideas have successfully been implemented in a number of cases, ranging from early works on graphical interfaces such as the Sketch pad [31] or visual programming environments such as in Smalltalk [15], to Ishii's early work on tangible interfaces [33]. This ties back to the current interest in how different materials and representations can be used to design for more useful, interesting and meaningful forms of interaction.

We see several examples of how the properties of the materials in the loom constrain and enable certain ways that representations take shape and are being used. One example is how the resolution of the point paper and the width of the silk threads transform the design of the pattern. The resolution of the point paper as well as the size of the silk threads limits what can be represented, thereby requiring materially dependant transformations of the original drawing to the format of the grid. The subsequent step in the process is to transform the point paper into chains of punched cards to be mounted on the loom. In this step each point on the grid is translated to a hole/absence of a hole on a piece of cardboard. In the next step the perceived difference between the representation and the original pattern design increases even more. The pattern is at this point basically impossible to decode, even to the trained eye. However, now the representation is instead 'readable', or at least possible to make use of, in the machine. The two representational steps (point drawing and punched cards) are thus here highly materially dependant and only gain meaning and usefulness through how they play out in their different contexts of use (the intermediary step of going from drawing to point paper, and the production of punched cards that will run the production of the fabric).

The current developments in technology with a variety of physical materials being interwoven with interactive technology, require further explorations in to what these materials afford in terms of both computation, and user interaction and activity. The material nature and physical dependencies of the representations used in the Jacquard loom highlight the inherent contradiction in the long-lasting

view of 'the digital' as being something essentially different from the physical [3]. Despite common assumptions, computation can never be understood through a distinction between the digital and physical. Aspects of materiality inevitably become an essential element of interaction and interaction design. The different materializations that digital representations take, unavoidably affect how they play out in meaning making practices.

Theme 2 – The Graspability of Complex Mechanics

Much of the discussion of interaction with technology, in particular the values at the core of tangible interaction, has turned towards phenomenology [7] and ecological psychology [24], by introducing concepts such as ready-at-hand and present-at-hand, and affordances. These theories provide ways of understanding the use and perception of physical objects, and how the concrete properties of artefacts structure how people appropriate and use them. However, the kinds of examples that are used as analogies have mostly been mechanically fairly simplistic such as 'the blind man and his cane', 'the hammer', etc, which differ significantly in complexity from the artefacts we try to design in HCI.

These notions have been particularly influential in educational explorations of tangible objects within HCI, including for instance the development of Montessori manipulatives [27], Marshall et al's exploration of tangibles for learning [23], Antle's design for embodied schemata and metaphors [1], and van den Hoven's MoSo tangibles [2]. A common hypothesis that all these examples bring forth is that the physical form of the artefacts will make them more conceptually comprehensible, than a 'purely digital representation', e.g. on screen. This hypothesis is easily made given that most tangibles in HCI have a rather simplistic physical form, often mimicking children's toys such as blocks, cards, and basic vehicles or figurines.

Throughout our analysis we have revisited the double meaning of *graspable* as something that can be picked up and acted upon, and as something that can be understood and given meaning. What we would like to discuss further is how 'graspable' in interaction design usually refers to singular human actions such as moving something from one position to another, while much human action, including the ones discussed here, tend to be about larger complexities of activities that emerge over time through the simultaneous use of several different artefacts in highly collaborative use settings.

What becomes apparent in the design of the Jacquard loom is that physical form does not necessarily imply simplicity or understandability. This is obvious also from looking at more mundane physical artefacts that we commonly interact with and that are structurally fairly complex, e.g. shifting gears of a bike, zipping a jacket, locking a door. It is easy to draw parallels between this observation and the discussions in early HCI, where hiding away complex structures of programming from the end user was a primary

goal in the design efforts. Similarly, end users do not necessarily benefit from being able to observe all the details of a physical apparatus, at least if that is not necessary in order to conduct the activity at hand.

We suggest that there is a need to further reflect on how the discussions around tangible interaction seldom have concerned these structurally complex artefacts, of which silk weaving with the Jacquard loom may be an extreme example. The activities are built up of not only of a multitude of physically interlinked artefacts, but also of people with specialised roles that through joint and coordinated action produce a weave. Contrary to this, most tangible interfaces are designed for activities in which groups of users are supposed to coordinate to form a common perspective [12, 34].

To avoid this simplistic notion of physicality as something that *as such* is simple and easy to comprehend, we need to arrive at a notion through which the artefacts used in an activity, in this case weaving, are not primarily understood as meaningful as isolated objects, but through their role in the larger process or activity. The meaning of a specific hole in a card, and its role in the production process cannot be understood only by studying the card and the *lisage* machine where it is first placed, but needs to be seen through its connectedness to the other artefacts and actions in the weaving process. The obvious but important point here is that the Jacquard loom was invented to make the work process more efficient, not to make its various physical parts more understandable by its users. Another important point to make is that the loom was developed based on a practice of Jean Marie Jacquard himself, who worked as a draw boy, at a weaving mill.

Clearly, the loom is graspable through the physical manipulations that can be performed, and the concepts of ready- and present-at-hand still apply to the interactional resources handled by e.g. the person weaving or operating the *lisage* machine. However, it is not graspable in the sense that one would normally reach out and touch all of its parts, at least not as an ‘end user’ or observer of the process. Neither is it graspable in the sense that the details of its workings can be immediately understood through such manipulations. For something to be graspable it implies that it involves some kind of information to be understood, or grasped, which in this case could be the very functioning of how it all is put together, bridging the pattern produced in the new fabric with the chain of cards and strings hanging in the loom. Despite the fact that most, if not all the components of the loom are clearly visible, to most people they would not appear simple and immediately understandable. Quite the opposite, the physical form of the representations used in this machinery, where a grid of holes on a card represents colours along only one weft thread in the final pattern, makes the process appear very abstract and complex in relationship to the actual fabric that is being produced.

Theme 3: Whole body interaction

A third aspect that we would like to bring to discussion concerns the kind of opportunities for physical interactions that an interactive artefact like the Jacquard loom allows for. Qualities such as its sheer size, mechanical structure, and material engagements mirrors several of the design and experiential qualities emphasised in recent work on spatial, room based and whole body interaction [e.g. 22, 32]. Naturally, the whole body is involved in all kinds of interactive devices, but here it is explicitly catered for in the construction. Interaction at all steps of the weaving process naturally involve actions performed through a diverse set of movements that engage the body in a range of different ways. From our discussions with the staff at the silk weaving mill, they conveyed how despite the physically repetitive work of weaving, they have rarely experienced any physical strains.

Interacting with the loom is not only about looking and manipulating the materials with hands and fingers, but also feeling the texture of materials in the hands, stepping on foot pedals to feed-forward the punched cards, and flicking the shuttle with the weft thread across the warp. These sets of actions together form a kind of whole body interaction that can be understood as a physical process occurring in the physical space with the new material that is being created. The Jacquard loom is not designed for a clean office setting, it is worn down due to its use over time, and this wear appeals to our senses. What has been given less consideration is how the sheer size of an artefact may be of aesthetic value, in contrast with the recent emphasis on the small and handheld (and easy to throw away) in HCI.

Recently, we have seen a number of studies that have investigated physical and bodily interaction in activities such as skateboarding, golf, and horseback riding. A common theme in these studies is that they focus on the activity as ‘performed’ and what is achieved through the activity. It should be noted that the Jacquard loom is primarily a machine designed for making a production process more efficient, and not for allowing users to have a kind of whole body experience as suggested in [22, 32]. We are thus not claiming that the Jacquard loom caters for whole-body experiences as such. However, it provides an example of a focused kind of interaction that involves our whole bodies in an interesting fashion, something seemingly worth reflecting upon in the design of technologies that make better use of the capabilities of the human body.

The making of fabric with the Jacquard loom is also a collaborative process involving a number of persons with separate roles that are specialized around particular parts of the fabrication process. This industrial setting differs from traditional ‘handicraft’ making practices, where the creator has more control over all the steps in the process. In this case the weaving of the fabric can be characterised as a process of distributed activity in which a blend of human

actors cooperate with processes generated by informational artefacts, conducted through inherently physical practices.

The loom and the weaving process is not designed to move information between different actors but to enable particular physical actions. This is made more efficient with information represented in a specific form (point paper, punched cards, an assembled loom, final fabric). So a question to ask here and for any kind of physical interaction is what type of description gives the richest understanding of the process. One way of looking at the process of Jacquard weaving is through the distinction between how the artefacts produced throughout the process *represent information*, versus how they provide *resources for action* [13]. In this case, the machine is designed with manual operation in mind, taking into account e.g. muscle strength and the amount of power needed to lift the weft threads, resulting in a design that utilises the body weight by using foot pedals in the interaction. The entire construction of the loom can be looked upon through the properties and dimensions of the human body.

The human body is naturally present in the design of most interactive technology, at least in the design of hardware and casings and movement-based interactive systems. What the loom illustrates is a more extended perspective of the body, going beyond the movement of people and fingers, where also other physical properties like human weight, size, muscle strength, and cooperative action is naturally incorporated in the design.

Theme 4: Sustainability and age

One issue that emerges when looking at a 140 year-old Jacquard loom is how it has sustained and endured throughout centuries of very rapid technological developments. Even though the specific loom we studied resides in a museum it is actually used for production, and similar looms still exist and are used around the world. Its age thereby suggests some form of qualities in the interaction that could be worth considering when designing new interactive products.

Sustainability in the design of new interactive technology is a topic that has received increased attention in the HCI community recently [4, 8, 19, 21, 25], and is all the more remarkable when compared to just a few years back when these topics were rarely discussed at all. We see the design of the Jacquard loom as having an immediate relevance to these topics not only in its sustainable design, but also as it illustrates an interactive, although not electronic, machine with properties of computation.

The machine is built entirely out of natural materials: wood, paper, strings of silk, cotton and linen. These materials are not in themselves everlasting, but compared to the plastics and composite materials out of which most industrial designs are made today, these seem to have aged with much grace, while keeping the functionality of the overall machinery intact. Thus, many individual parts of the

construction have been exchanged over the years, but the overall functionality of the machinery has persisted. Moreover, the machine is powered solely by muscular force.

Verbeek and Kockloren [37] discuss how artefacts today are thrown away while they still are working both because of our cultural obsession with the new, but also because many modern artefacts are designed so that they cannot be repaired. They list four possible directions for sustainable design: 1) a focus on services, e.g. repairing and upgrading, rather than only production of new artefacts, 2) eco-design, i.e. minimize pollution throughout a product's life cycles through e.g. the use of organic materials, 3) recycling, of the whole product and its components, and 4) working to expand a product's life span. We see all these strategies to be manifest in the design of the Jacquard loom. We are not claiming that these strategies were purposefully pursued when the Jacquard loom was originally designed. However, in line with the reasoning of Verbeek and Kockloren, its design reflects a cultural climate quite different from ours, from which current interaction design practices can learn.

Recently, we have seen a number of studies that attempt to understand old technologies and practices and how these can be aligned with and inform design of modern day information technologies. One example is Rosner's and Taylor's study of bookbinding workshops in England [29] and how the practices of traditional techniques and tools allow us to rethink topics such as restoration, authenticity, and long-term use. Aspects of authenticity and value is interesting in relation to the intrinsic properties of purely digital (software) objects that they can be copied infinitely, possibly devaluing the perceived value of the object. Hand-crafted objects on the contrary, display to the user that they have been shaped from efforts of a human hand. As discussed by Rosner and Taylor, physical objects also provide connections to our history and past, such as an old newspaper found underneath the wallpaper of an 19th century house or just a mobile phone from the mid 90's are often valued sources of reflection and remembrance. To incorporate qualities related to these aspects in the interaction has been proposed as a potentially strong driving force for the development of tangible and physical interfaces (see e.g. [29] and [38]).

From the point of view of interaction, sustainability is not only about the length a product remains functional, it is also a quality of how it is practically interacted with. We see this form of sustainability expressed in the approach to using the loom. The respect shown and kept in the design, that this artefact will not and should not easily be thrown away is a way of valuing the craft and the unique skills manifested in assembling and setting up the loom in the nineteenth century.

To conclude, in line with a general societal concern, sustainability and durability have lately become important aspects of interaction design. Qualities of the loom that are

interesting with respect to this include that it is built in natural materials, that parts can be repaired and replaced and that it is powered by muscle force. All these are properties that have recently surfaced as challenges within the field of HCI, especially in the work on wearable computing and DIY practices, and that may be further explored also more broadly in interactive systems design.

CONCLUSIONS

In our analysis of the Jacquard loom we have chosen to place it into the context of contemporary streams and issues discussed within the HCI community, rather than to reflect on its qualities from a conventional perspective of computer science. We are aware that this approach is unusual to HCI, and that it may not be read as a result in terms of designing and understanding novel technologies. Yet, our analysis suggests several interesting openings for how the field could be expanded and perhaps even be inspired into new directions.

In analysing the loom and the activity that surrounds it, several design qualities are revealed that shed light on some of the current topics in interaction design and HCI. Under each of our four themes we have provided an extended perspective with concrete examples. First, we have discussed the Jacquard loom in terms of materiality and digital representations, and how this connects to the recent interest in physical materials and their role in interactive systems design. This topic becomes increasingly important as interaction design integrates with areas such as industrial and product design. Second, we reflected on the concept of graspability in relation to complex mechanical structures, of which the loom is a very prominent case. A point we make is that physicality does not necessarily imply understandability. In a sense, the preoccupation with making machinery understandable is somewhat peculiar to HCI, and can be contrasted to other values such as efficiency and productivity. Third, we discuss how the design of the loom in a fundamental way incorporates the human body in its interaction, tying in to current trends in HCI towards whole body experiences. For instance the framing of interaction with artefacts as an embodied process that is distributed over several artefacts and persons, not only offer a point for reflection but could also inspire new design solutions. Our last theme concerns aspects of age and sustainability of the examined loom in relation to the often much shorter life span of many present day technologies.

Finally, the approach used here for analyzing the loom could potentially be used for looking at how contemporary technologies manifest the conceptual themes of current HCI practice. The analysis could thereby be read as a step in the direction of interaction criticism, as proposed by e.g. Bardzell (2009), and also as adding an unusual perspective to existing collections of interactive artefacts (e.g. the online collection of Bill Buxton). In short we hope that our

analysis contributes to a broadened view of interaction within the HCI area.

What we ourselves have found the most exciting in this endeavour is how it has triggered questions around age, materiality, and the basic principles of computational and digital actions, (principles that we often take for granted without reflecting on how they are embedded in historical trajectories). We also hope that it can increase the understanding of the historical grounding of our discipline and how we can learn from, and get inspired by past traditions and practices.

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