The Live Loom

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Abstract

This paper introduces the Live Loom, a warp-weighted hand-loom augmented with computer control, using a visual live coding environment. The traditional weaving technique of colour-and-weave interference patterns are explored, revealing the digital, computational nature of weaving that predates the invention of discrete mathematics as it is commonly understood. Early results of live coding such patterns, in the process of learning how to weave, is shared.

Introduction

Live coding is the exploratory practice of changing code while it runs. A live coder uses a programming language as a live interface to a running process, and therefore its inputs and outputs. This allows the programmer to participate in the performing arts, for example to create live coded music, video or dance. Live coding may be used to refer to any use of code in any kind of live situation, but for the purposes of this paper, we will focus on live coding as live improvisation, where code is written without a fixed aim, often from a notional 'blank slate'.

Weaving is a textile craft, where parallel threads known as the warp are held under tension, allowing a second set of threads known as the weft to be passed over and under the warp threads to create a textile fabric. Different textile techniques produce different results; for example in terms of structure, weaving and knitting have very little in common with each other.

This paper investigates how live coding and weaving can be brought together, looking for ways to ground the contemporary practice of live coding in ancient craft. In the following I take a loosely auto-ethnographic approach, introducing the Live Loom, and its use both for understanding weaving and reflecting on the shared history of live coding and textile practice that it might reveal.

Background

Connections between textile craft and computation have been very well explored in the digital arts and beyond. However, as David McCallum notes, such work often does not engage with structure or long history of textiles, but instead treats the three dimensional structure of weave as a simple grid or raster (McCallum, 2018, 0.3.1). McCallum's own work explores the notion of 'glitch' in media art and how it transfers to textile structures, but given that the latter has developed over a far longer period than the former, it is not surprising that along the way he finds much that media art can learn from textiles. In the weaving industry, the technology of computer-controlled looms is of course also well developed. In the present work we are interested in analogies with live coding and 'hands on' computer control. Such interaction is not afforded by most machine looms, where the human weaver is replaced by a machine. However, hand-operated computer controlled looms do exist, and the present work is much inspired by experiments I conducted on the TC1 loom in Textiles Zentrum Haslach, Austria (McLean and Harlizius-Klück, 2018).

Stitching Worlds is a recent, far reaching project imagining a world where textiles more overtly formed the basis of contemporary electronic technology (Kurbak, 2018). Works produced from this project include the "Embroidered Computer" with Irene Posch and collaborators, a working 8-bit computer embroidered in gold. This work integrates textile electro-mechanical relays into a fabric, demonstrating that a feminist approach to linking textiles with computing goes far beyond metaphor - textiles can compute.

Feminist alternative history

Although not the primary focus of the present work, comparing the contemporary practice of live coding with the ancient craft of hand-weaving has potential to support and extend a somewhat obscured feminist history of computation. Feminist perspectives on computing and weaving are hardly new, a well-known reference point being Sadie Plant's influential text "Zeros and Ones: Digital Women and the New Technoculture" (Plant, 1998). However, the once dominant role of women in computer programming has been steadily erased since the 1960s and '70s (Hicks et al., 2017), and despite recent efforts, gender diversity in software engineering is an ongoing problem.

As a relatively new interdisciplinary practice that tries to reject hierarchies[1], live coding offers an opportunity to build a gender diverse culture, and this opportunity is a core topic across live coding research and practice (Armitage, 2018). Turkle and Papert related gender to the plurality of relationships between coder and program observed in children, describing a more conversational approach to coding, with mid-course corrections rather than fixed-goals as bricolage (Turkle and Papert, 1990, p. 136). This approach is certainly evocative of live coding, with the suggestion being that it is one likely to be favoured by girls, but discouraged by instructors in favour of more fixed design processes.

Armitage (2018) brings together female perspectives on live coding in the Algorave scene, relating one interviewee's experience of live coding "… as a way of working through their daily life, adding structures to it and providing functions for being. These lived patterns merge with their daydreams and expressions of colour and geometry to form her live coded visuals." (Armitage, 2018, p. 39). This again evokes Turkle and Papert's bricoleur, and indeed the ancient social and intellectual function of weaving in building a personal cosmos (Harlizius-Klück and Fanfani, 2017).

Setting aside the Jacquard machine

The Jacquard machine is a well known device for individual control of threads in the weaving process, classically through the use of punch cards. From across computer science and popular culture, the Jacquard machine is often invoked as part of an 'origin story' of

[1] See for example the Algorave Guidelines - `https://github.com/Algorave/guidelines`

computation, following Charles Babbage's mention of it as an influence. However, the Jacquard machine does not do computation, it is merely a mechanism for accepting input data. The Jacquard machine therefore brings a fundamental misunderstanding to the topic of weaving and computation which is very difficult to work around.

Yes, weaving is computational, and yes, the Jacquard machine allowed data to be fed into that computation. But the same computational nature is present in all weaving, including traditions of hand weaving developed over millennia (Harlizius-Klück, 2017). The computation was already there before Jacquard, and by helping automate the weaving process, his device only takes humans further away from that computation. So while Jacquard's machine is often described in terms of the beginning of the relationship between weaving and computing, the opposite is true - it was an end.

So let's try to wipe the Jacquard machine from our minds in the following discussion, not because the technology isn't interesting and useful, but because the discussion around it is so full of misunderstanding. Once we do that, we are able to see that such machinery did not introduce any computation to weaving - the computation was there already. As will become evident in this paper, the computation is not in the machine, but in the weave.

Introducing the Live Loom

Having set one mechanism aside, I introduce another. The Live Loom is a warp-weighted loom, with solenoids attached so that warp threads may be individually picked from software. First, I explain the technology of the warp-weighted loom, and later explain the electro-mechanical attachments on the Live Loom.

The primary purpose of any loom is to hold a group of parallel threads, the warp, in parallel and under tension, allowing weft threads to be woven over and under the warp threads. The warp-weighted loom is an ancient technology, where tension comes from the effects of gravity, by attaching weights to the bottom of the warp threads. By contrast, on modern looms warp threads are generally horizontal, and held in tension through mechanical means. The essential components of a warp-weighted loom are therefore very simple, consisting of a frame holding two horizontal bars in place, one to hang the warp from, and another below separating alternate threads, keeping them in order, and creating a potential gap (using weaving terminology, the natural shed) for the weft to pass through by default. The simplicity of the loom is also its advantage - the simpler the loom, the fewer constraints and therefore more possibilities there are to weave complex structures on it.

The weaving process involves a weft thread going over and under the warp threads, following one of a very large range of possible patterns, for example creating tabby, twill or satin structures (Emery, 2009, see also Fig. 1). Selective warp threads are pulled forward, creating a new gap or shed between the pulled and non-pulled warp threads, through which the weft travels in a straight line. When the warp threads are returned, the weft is trapped inside, and the next shed is prepared.

Weaving technology

The Live Loom is shown in Figure 2. Although it carries a contemporary 'maker' aesthetic due to its laser cut plywood construction, at its core, it is a hand-loom following an ancient warp-weighted loom design. The additional electro-mechanical parts do not replace the core functions of the loom, but rather augment them in order to allow threads to be selected using a computer language as well as directly by hand. The hardware and software designs are available as open hardware/free software (McLean, 2019).

The Live Loom is fitted with a number of solenoids (currently sixteen), mounted on two axes to double the number that could otherwise fit in a given space. The solenoids are controlled by an arduino micro-controller, via a bank of relays. When activated, each solenoid will push against a stick, which pulls its corresponding warp thread forward via a string. In this paper we refer to the wooden stick and string collectively as the heddle. With each solenoid controlling one

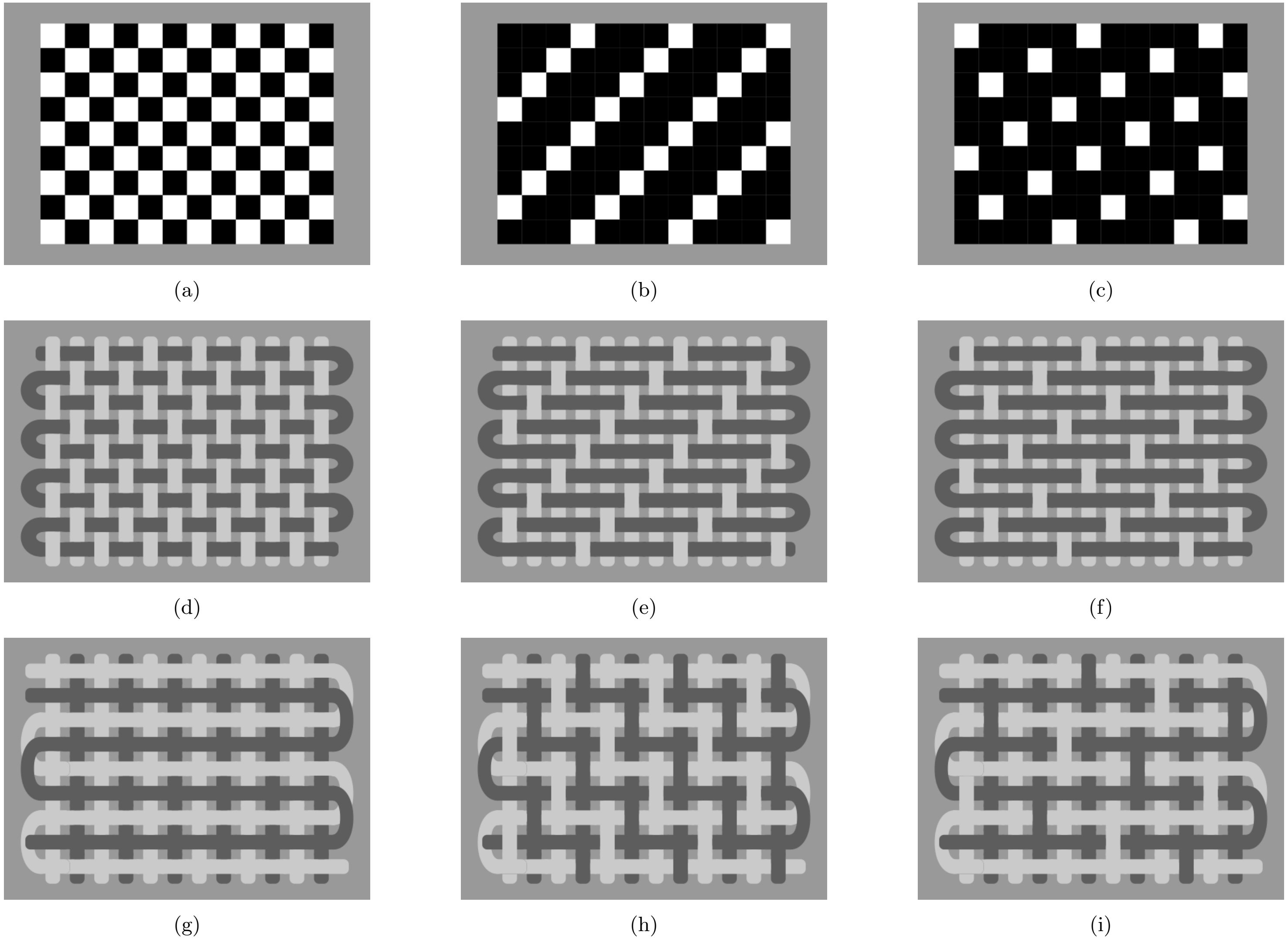


Figure 1: Fundamental weave structures, shown with binary 'draft' structure (top), simulated weave with light warp and dark weft (middle), and simulated weave with alternating light and dark warp and weft (bottom). These different structures lead to different physical properties and therefore uses (Emery, 2009).

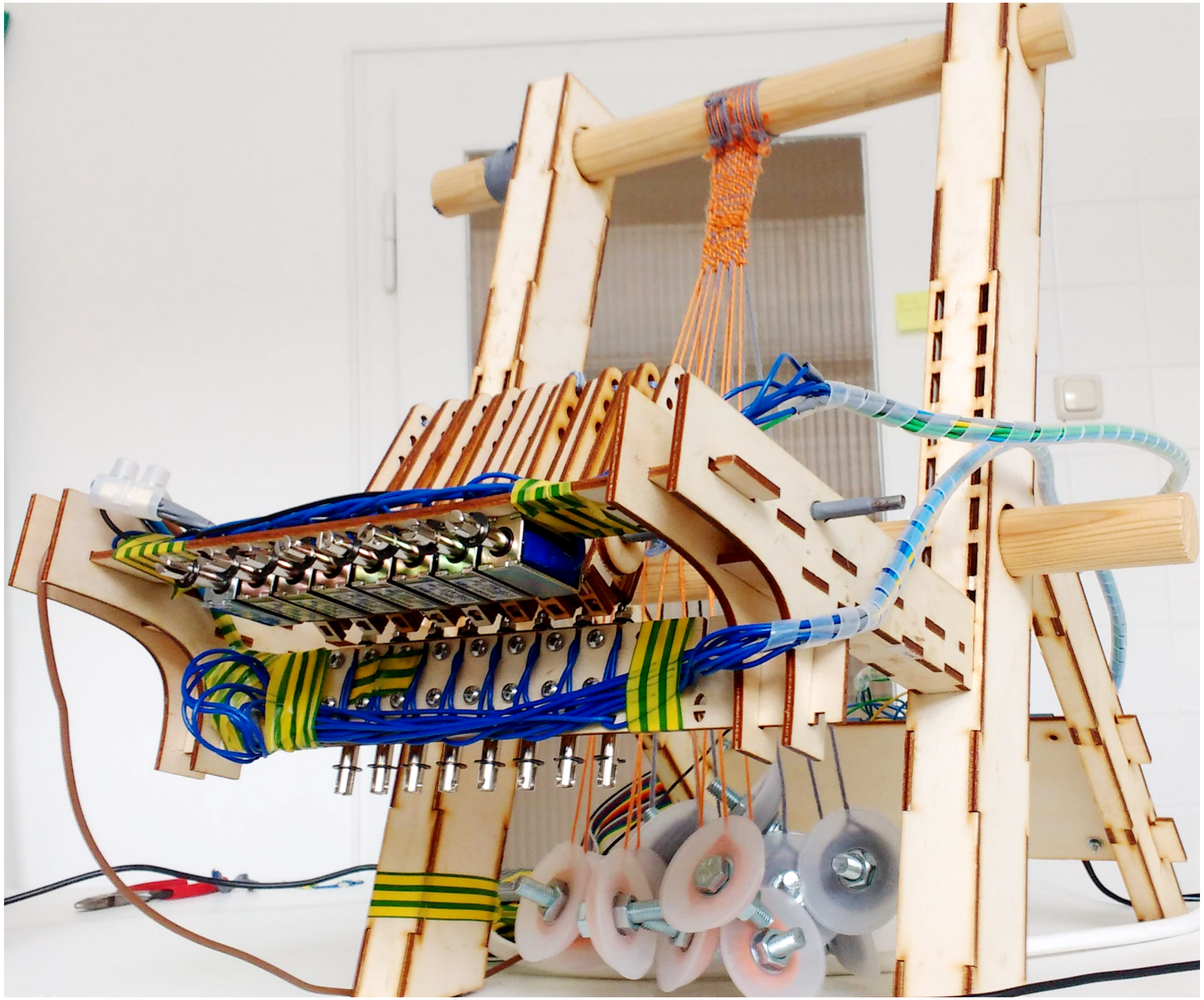


Figure 2: The Live Loom, a warp-weighted loom, with live-codeable heddles via solenoid actuators.

warp thread, the resulting weave is currently constrained to sixteen threads across.

Crucially, these solenoid movements are not designed to fully create a shed. Instead this movement only 'offers up' warp threads to the human weaver-coder, who then pulls the threads further by hand. This seems like a deficiency of power and leverage, but is not; this 'offering up' means the weaver can choose whether or not to pull each thread. This is particularly useful at the edges of the weave, where adjustments are often required to produce a good fabric. The suggestive nature of instructions sent via the solenoids reminds of the live coding choreographic work of Sicchio (2014). We can think of this process as not directly live coding a textile weave, but instead suggesting bodily movements to produce the weave. When live coding people rather than computers, it is humane to respect their ability to exercise creativity and agency in the way they interpret instructions given to them.

Computing a weave

Before introducing a language for live coding the loom, lets first look closer at the computational nature of weaving itself, focussing on colour and weave effects. Such effects bring together different dimensions or systems. Firstly, the structure of the weave - the arrangement of ups and downs in the grid created by the meeting points of warp and weft. Secondly, the colour patterning of warp and weft threads. The visible colour at a particular point of the weave then depends on two things - whether the warp or weft thread is visible (i.e. whether the weft is under or over the warp) and what colour that thread is. The result is an interference pattern between these two systems, creating a deterministic, logical outcome that is nonetheless very difficult for the layperson to predict.

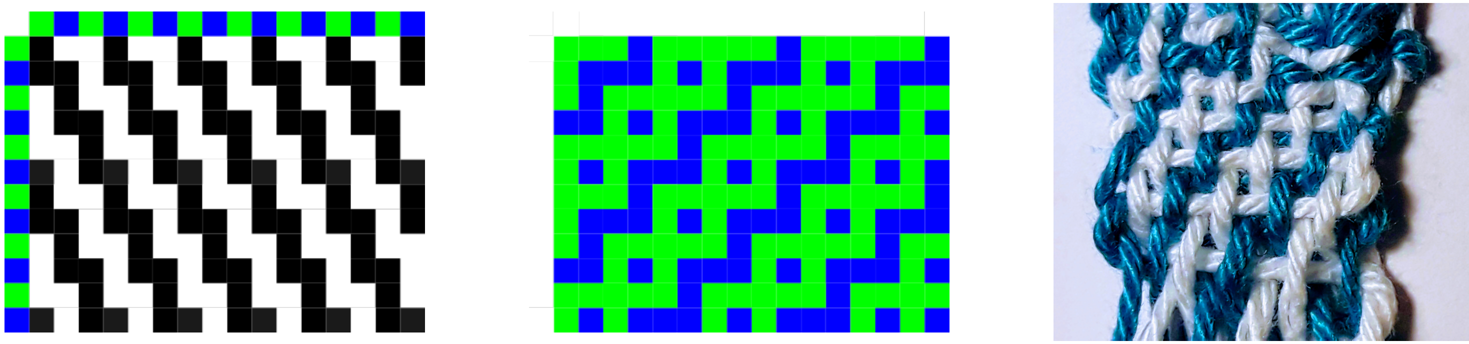
As a simple example of this, consider the weave structure shown in Fig. 3a, known as a draft pattern. The black-and-white grid shows the pattern of weft ups and downs represented as white and black squares respectively. For example, the first row shows a weft thread going under one warp, over two warps, and repeat. The second row shows a weft thread going under two warps, over one warp, and then repeating.

There are also coloured squares at the top and bottom, showing the pattern of warp and weft thread colours respectively, in this case both alternating between light green and dark blue. In order to find what colour will be visible, we look at the weave structure. For black squares, we know the warp colour is shown, so follow the column up to find its colour, otherwise we follow the row to the left[2]. From this we can see that where warp and weft meet with a matching colour (in this case, every other cell in a checkerboard pattern), the visible colour cannot be changed by the structure. This is analogous to the Moire effect seen by placing one net over another, with the visible result being the interference of the upper and lower structures.

If we plot out the result of this interference between thread colour and weave structure, we arrive at the image shown in Fig. 3b. This result will be surprising to a layperson, not only is the vertical and horizontal stripe of warp and weft not visible, but the diagonal runs in a different direction to the underlying weave structure. This experience will be familiar to those who have explored algorithmic interference patterns in livecoding software such as TidalCycles or Hydra, simple inputs often create unexpected, more complex results.

Finally, Fig. 3c shows a fabric woven using this structure and alternating white and blue threads, created by a workshop visitor on the Live Loom. The same features hold in the weave itself, although are not too well defined, due to interaction between the threads, and variation in density. The left and right edges are a mess, because in practice such a structure simply cannot be woven at the edges. Weft threads generally travel from left to right for one row, and from right to left on the next. Therefore, if a weft ends a row over a warp, and begins the next row also over a warp, then it will not be woven at that

[2] In practice, there are other variables which change which colour thread is visible, for example if weft threads are tightly packed, warp threads are hidden completely.



(a) Draft Pattern (b) Result (c) Actual result

Figure 3: A draft pattern and the result of virtually and actually weaving it.

point. A more experienced weaver would make consistent changes at the edges (known as the selvage), such as adding plain weave border, to ensure a coherent result. The above description of colour and weave effects should give us pause for thought. Weaving predates computer programming and indeed discrete mathematics in general, but nonetheless is a discrete, logical and therefore digital computational system. Furthermore, any hand-loom affords exploration of this system. When considering the computational nature of weaving then, we must be careful not to be dazzled by the machinery or electronics of industrial and contemporary weaving technology, when it is the ancient technology of the threads themselves that provides the environment for computation.

Coding the draft

We have already seen that weaving drafts are a form of code, which can compute unexpected results when interpreted. Such weaving drafts are themselves binary, digital images, developed well before electronic digital computers. It is therefore straightforward to add a further level of abstraction by using a programming language to create a draft. The purpose of doing so is to create patterns from patterns, making a rich space to explore weaving and gain tacit knowledge both about how it works, and its relation to computation as it is more conventionally understood in the context of programming languages. Each such layer of abstraction takes us further away from the material, but just as live coding of music brings together the experience of coding and listening, the Live Loom brings together coding with seeing and touching.

Figure 4a shows the current version of the Live Loom coding interface. The code is shown on the left, using the visual live coding interface Texture (McLean and Wiggins, 2011), originally designed as an exploratory interface for the TidalCycles environment, but here re-purposed for a system designed for discrete, binary draft patterns. The set of available symbols and keywords are on the top right, which may be dragged into the code using a mouse. On the bottom right a window into the draft pattern is shown, with the row most recently being sent to the Live Loom marked with blue squares on either side. Finally the row number is written below, which in this case is higher than the number of rows shown, as the previous rows have scrolled off the top. The weaver-coder can manipulate the code with a mouse, while using arrow keys on a keyboard to step forwards (or backwards) through the draft, sending each warp lift to the loom to be actuated by the solenoids and woven by the weaver.

Perhaps most notable is what is not shown in the software interface. In particular, simulation of thread colour (such as that shown in Fig 3) could easily be included, but is not, indeed thread colour is not dealt with at all in the software, only on the loom. Keeping colour on the loom takes focus away from any simulation on screen and places it in the 'ground truth' of the material. After all, colour is only one quality of thread, alongside thickness, material, ply, tightness and direction of twist, tension and density of warp and weft, and so on. Trying to simulate all of these continuous variables on-screen would be an insurmountable task, and focussing the software on the singular task of planning the discrete structure of ups and downs works very well.

It is important to recognise that although the binary grid of a weaving draft is contained in two dimensions, the structure it describes is very much three dimensional. Indeed certain two-dimensional patterns will result in more than one fabric, one on top of the other, creating the possibilities of double weave structures.3

Live Loom language

The language currently used by the Live Loom is the pure functional programming language Haskell, using its list datatype. Standard Haskell lists are 'lazily evaluated', which means that infinitely long lists can be represented and calculated on demand. A weave structure is simply represented by a one dimensional list of Boolean values, where true and false stands for up and down (or if you prefer, over and under) respectively.

Listed in Table 1.1 below, the current number of functions for composing draft patterns on the Live Loom is small but already provides a very rich space of possibility. The weaver-coder begins with a list of ups and downs, then applies functions to transform that list and/or combine it with other lists. The result is a language interface that produces surprisingly complex results from simple elements.

name	**description**
[]	An empty list
:	Adds a value to a list
up / down	Keywords representing the boolean values of up (over) and down (under)
cycle	Repeats a list forever
backforth	Reverses every other row
offset n	Offsets each row from the last, by the given number of threads
shift	Shifts each row by one thread
rev	Reverses each rows
every n f	Selectively applies function f to every nth row
invert	Turns all ups to downs, and vice versa
zipAnd a b	Combines two lists, resulting in up when both lists have an up
zipOr a b	Combines two lists, resulting in up when one or both lists has an up
zipXOr a b	Combines two lists, resulting in up when only one list has an up

Table 1.1: The values, functions and operators available in the Live Loom code interface.

Working at the Live Loom

Figure 4 shows the Live Loom software interface next to the woven outcome. This starkly shows the perceptual gap between code, draft and weave, with little visual correspondence despite the structures of the draft being a logical outcome from the code, and the weave being that of the draft. The code is represented as a branching tree, the visual interface directly showing the branching normally represented by parenthesis (McLean and Wiggins, 2011). This particular code creates the draft pattern shown, which perhaps has the appearance of vines growing up a wall. When this structure interferes with the alternating colours of warp and weft, the final result appears in the weave as (to my eyes) legs leaping into the air (Fig. 4b).

It is humbling that this leap from draft to weave constitutes ancient knowledge, demonstrating mathematical logic that predates our conventional view of mathematics. This brings historical grounding to the analogous logical leap from code to draft, shown alongside.

It is worth noting that adding an additional level of abstraction to the drafting of weaves is not novel. Indeed, it is very common in weaving for patterns of threads to be grouped into a number of shafts, where weave structure is created by patterns for lifting these shafts. The binary grids we consider in the present paper are in such cases drawn down from a draft composed of of threadings (how the threads are grouped into shafts) and treadlings (how the shafts are lifted over time). In a sense, the live coding language introduced in this paper provides a flexible, interactive alternative to lift plans.

Music of the loom

The solenoids are not triggered at once but in sequence, to even out the use of electrical power, with less needed to hold a solenoid than to move it. The most time-efficient way to do this would be to trigger the 'up' threads, pulling the warps one after the other, evenly spaced in time. However I have found it much more useful to include 'down' threads in the timing, so each row takes the same amount of time to actuate, no matter how many warps are being pulled forward. This gives a clear rhythm to each row, where the 'clunk' of a solenoid is heard for an up, and a silent pause is heard for downs. This rhythm breathes life into the weaving process, making it easier to orient myself in the pattern and spot errors, as I compare the rhythm I hear with the threads I see. It also brings rhythmic enjoyment to the repetitive nature of weaving, compelling me forward into the next row.

The solenoids have a particular 'duty cycle', meaning that it is best not to keep them activated for too long, otherwise they may overheat. Once a solenoid is activated, the micro-controller holds it in place, giving enough time for the weaver to place a hand on the heddles and pull selected warp threads forward. Although born from a technical need, these few seconds add an additional sense of regulated timing to the process of weaving. However if the heddles are not caught in time, the weaver-coder can repeat the lift with a quick press of the up arrow key. The weaver can also unweave by stepping backwards through the structure with the left arrow, removing rather than adding the weft by hand, for each step.

Live Coding

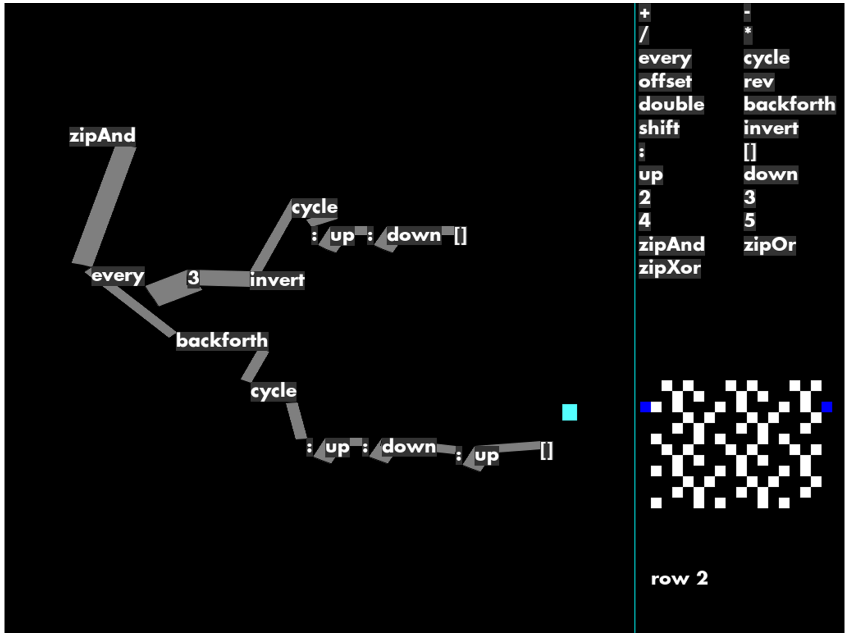
So far we have discussed action, but not live reaction. We have looked at coding the loom with a draft, and coding the coding of the loom by introducing a language for composing a draft, but we haven't discussed live coding - the changing of code in response. Let's do that now.

Changing patterns

Live coding of music is often characterised by comparatively slow, continuous changes. Changes are heard immediately, but the complexity of music grows with the code. The experience of the Live Loom is rather different, where a small change tends to have a large, global effect, but each change takes time to become apparent; rows are only produced at a rate of a few per minute, and it might take two or three repeats of a pattern before its nature can really be felt. These big differences from small edits are due to multiple levels of interference, between code, draft and weave.

A change from one pattern to the next also presents a problem of transition, where one pattern might not sit well with the next, potentially creating a physically uneven structure, with undesirable floats (see below). It can take a disturbed row or two before the weave settles into the next structure. There are certainly parallels here with live coding music and indeed music in general, where a sudden change can be jarring, without a careful transition. Managing this transition is probably best done at the loom, adjusting each shed at the heddles by hand.

At this slow pace of change though, we are in the domain analo-



(a) Code (left) and resulting draft structure (bottom right)

(b) Resulting weave

Figure 4: Live Loom software interface and the woven result

gous to slow coding rather than frenzy of an algorave. Where each decision has long term consequences, there is a need for careful consideration. Furthermore in weaving we work with physical thread, rather than with the metaphorical thread of time as with live coding of music. This means that we are able to undo a weave in a way that we cannot undo music, and change our minds. By unweaving, the weaver, like the mythological figure of Penelope, resists external forces.

Embracing error

Live coders are known for embracing error, and so it is fortunate that it is so easy to produce a draft which is unweavable. For example, there is the problem of 'floats', lengths of unwoven fibre created wherever there is a contiguous series of either ups or downs in the warp or weft direction. Indeed, where there are only either ups or downs in a given row or column, that thread will not be woven into the fabric at all. In response to a problematic draft, the weaver can do one of three things – change the code to look for a more weavable draft, ignore activated heddles or pull additional ones to change the weave directly, or just attempt to weave the pattern anyway.

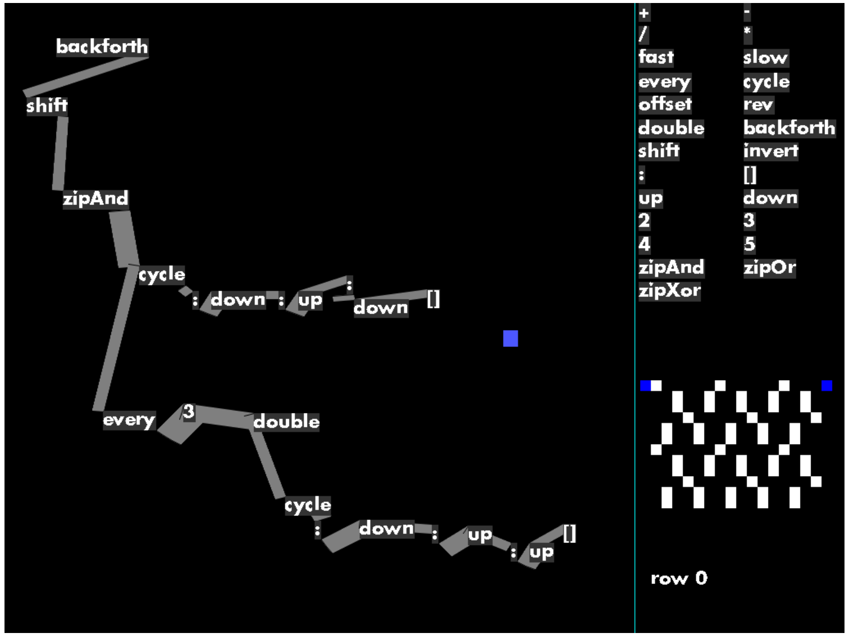
In the draft shown in Figure 5a, the draft looked unweavable to my naive eyes, due to the pairs of identical rows within it. Where this happens, pairs of consecutive wefts are passed through the same shed. I thought this would result in a mess, but out of curiosity went ahead anyway to produce the weave shown in Fig. 5b. I found that with care the wefts would still run parallel and stay in order, largely maintaining the 'correct' structure on-screen. Furthermore, because the repeat in the draft consists of an odd number of rows, and I was weaving with two different wefts, the wefts would alternate between either travelling through the same shed from one side to the other together, or in opposite directions. By embracing this 'error' I arrived at a (to me) surprising, pleasing, and subtle result, although there are undoubtedly many such surprises on the way to becoming an experienced weaver, and I have far to go.

Weaving the edit

Decisions at the Live Loom are taken slowly, responding to problems and opportunities as they arise in the weave. Figure 6a shows the starting point for another improvised weave, a draft appearing to be a kind of hatched vertical pattern, drifting downwards to the left, with lines sometimes joining or breaking. When it came to weaving this structure (see Fig. 7), two features slowly became apparent – the pervasive pairs of ups and downs on the weft, offset from one row to the next, seemed to result in the warp spreading out vertically, and therefore partially hiding the warp at points where I expected it to be visible. This created an a partly weft-faced weave. However, some long floating threads were present on the warp direction, and the weft-facing only accentuated the presence of these long warps lying on top.

After weaving 20 rows of this pattern (Fig. 7), I hit a snag - the pattern of repeating warp floats drifted until they sat at both edges of the fabric, seen in Fig. 6b. I realised that having floats at the selvage would cause the textile to lose its otherwise uniform width, and I decided I neither wanted this effect or to change it by hand; I had been enjoying working the two wefts together at the selvage, and felt that having a warp float there would create a mess. So instead I changed the structure to that seen in 6c, adding code to invert every other row, as an effort to break up warp floats. However, after a few rows of weaving the edit (Fig. 7) to the point in the interface shown in Fig. 6d, I realised that by breaking up some floats, I had only created new ones. Another tweak shown in Fig. 6e, this time changing a number from 3 to 1, seemed to fix it. However once I started weaving I realised the floats were still there, but now so long that they took up the whole edge and so were no longer visible on-screen!

This time I decided having such long floats was an interesting enough challenge to pursue, and embraced this compounded error as an opportunity to experiment more with creating extra binding points at the selvage by hand. I continued with this structure for 53 rows, up until the point seen in Fig. 6f. The resulting weave shown in 7c did indeed turn out to be interesting, the resulting weave curiously appearing to be much more coherent than the draft pattern. As the long floating warp threads stepped one warp to the left, they cycled between white and blue, over a steep diagonal. This time, the resulting motif reminded me of Quipu knots. The resulting experimental weave we have seen in Fig. 7 charts an experiment in three stages.



(a) Live Loom code and draft showing pairs of identical rows.

(b) The resulting weave, showing pairs of wefts that have travelled through the same shed.

Figure 5

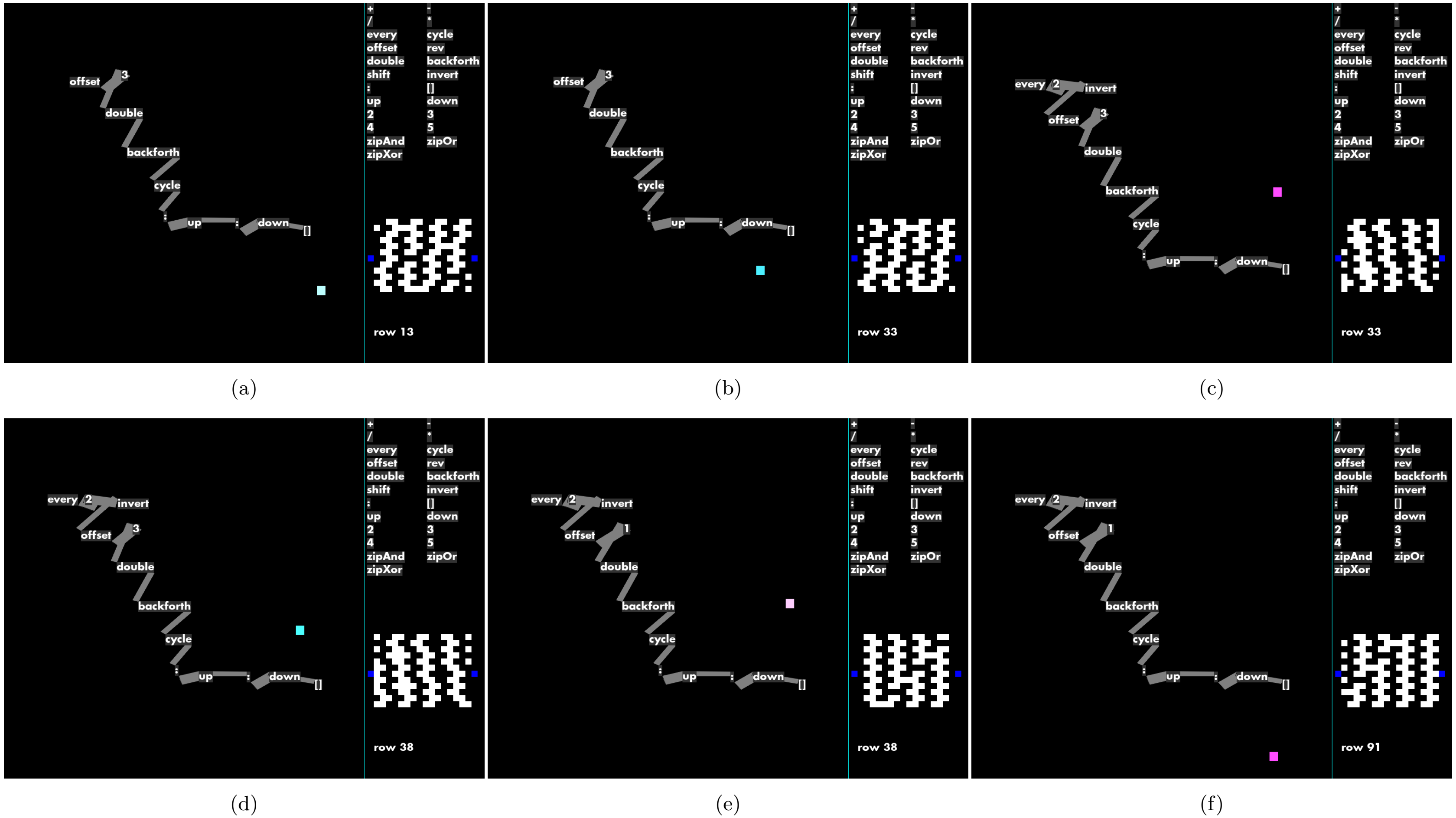


Figure 6: Screenshots of Live Loom interface at six different points in the weaving of fabric (see Fig. 7)

First, the initial serendipitous discovery of a) a weft-faced structure with warp floats. Then transition b) as I searched for a solution to a perceived problem at the selvage. Finally a longer section c), with some manual experimentation at the selvage. The resulting fabric tells a story of its making, from a starting point, to prevarication and decision, with further learning points charted along the edge as I learned to deal with the selvage.

Conclusion

This paper has explored how the principles of live coding may apply to the warp-weighted loom. However, in connecting a live coding pattern language to the practice of weaving, we find that weaving is already abundant with computational patterns, and in particular that historical drafting techniques already demonstrate a similar computational abstraction from the resulting woven textile, as code does from media in the live coded performing arts. Nonetheless by adding another layer of abstraction to that which has been present in weaving since ancient times, and using solenoids in communicating movement from the code to the weaver, the Live Loom allows creative exploration of woven patterns in a way that is sympathetic to the repetitive, yet cognitive nature of hand-weaving. There is much to follow the preliminary work introduced here. This paper has purposefully focussed on understanding of weave from the perspective of live coding, taking care to have respect for this technological craft that has developed since Ancient times. It could be however that weaving practice could benefit from such a computer language interface, for example replacing the current relatively time-consuming process of uploading bitmap images whenever the pattern is changed on a TC2 loom. Introducing 'real' trained weavers to the Live Loom would undoubtedly also turn up valuable criticism of its design. Furthermore while some hands-on workshops have already been conducted, more involved long-form work with workshop participants are needed to explore the possibilities of the loom in helping people explore the complexities and possibilities of hand-weaving.

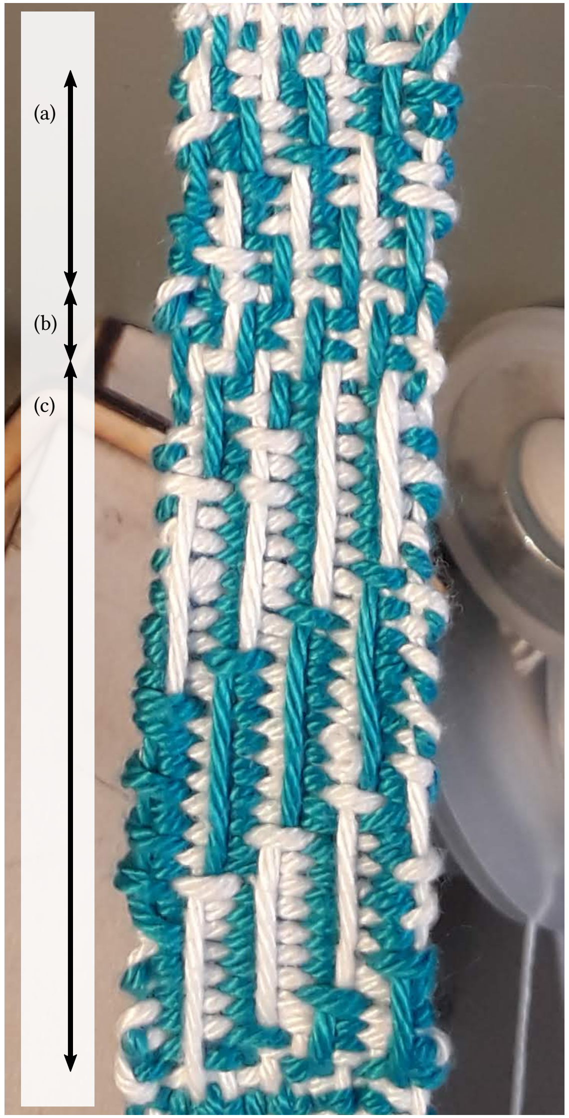


Figure 7: Result of improvised weave edits shown in Figure 6

Acknowledgements

This research is conducted by the PENELOPE project, with funding from the European Research Council (ERC) under the Horizon 2020 research and innovation programme of the European Union, grant agreement No 682711.

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