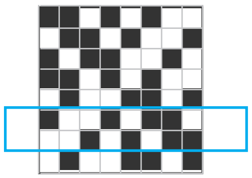
TRY THIS.

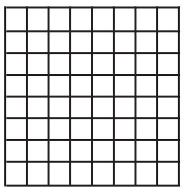
Test your knowledge after reading by answering these questions.



draft a

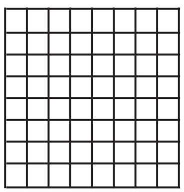
1. Draw the cross section of the draft rows outlined in blue

2. Is this structure single or double layered?



3. Draw the inverse of ***draft a*** in the grid to the left

4. Which of the three core structures was ***draft a*** derived from?

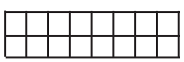


5. Create a two layer weave draft that has structure ***a*** on top, and structure ***b*** on the bottom layer

 ***a***

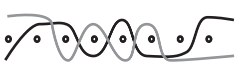
 ***b***

6. Draw a draft corresponding to the cross-section below

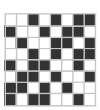


answer key

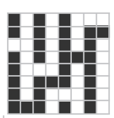
---

1. 

2. *single, the interlacements in the center prevent the structure from being pulled into two separate layers*

3. 

4. *this draft has several twill sections that have been rotated around a central point.*

5. 

6. 

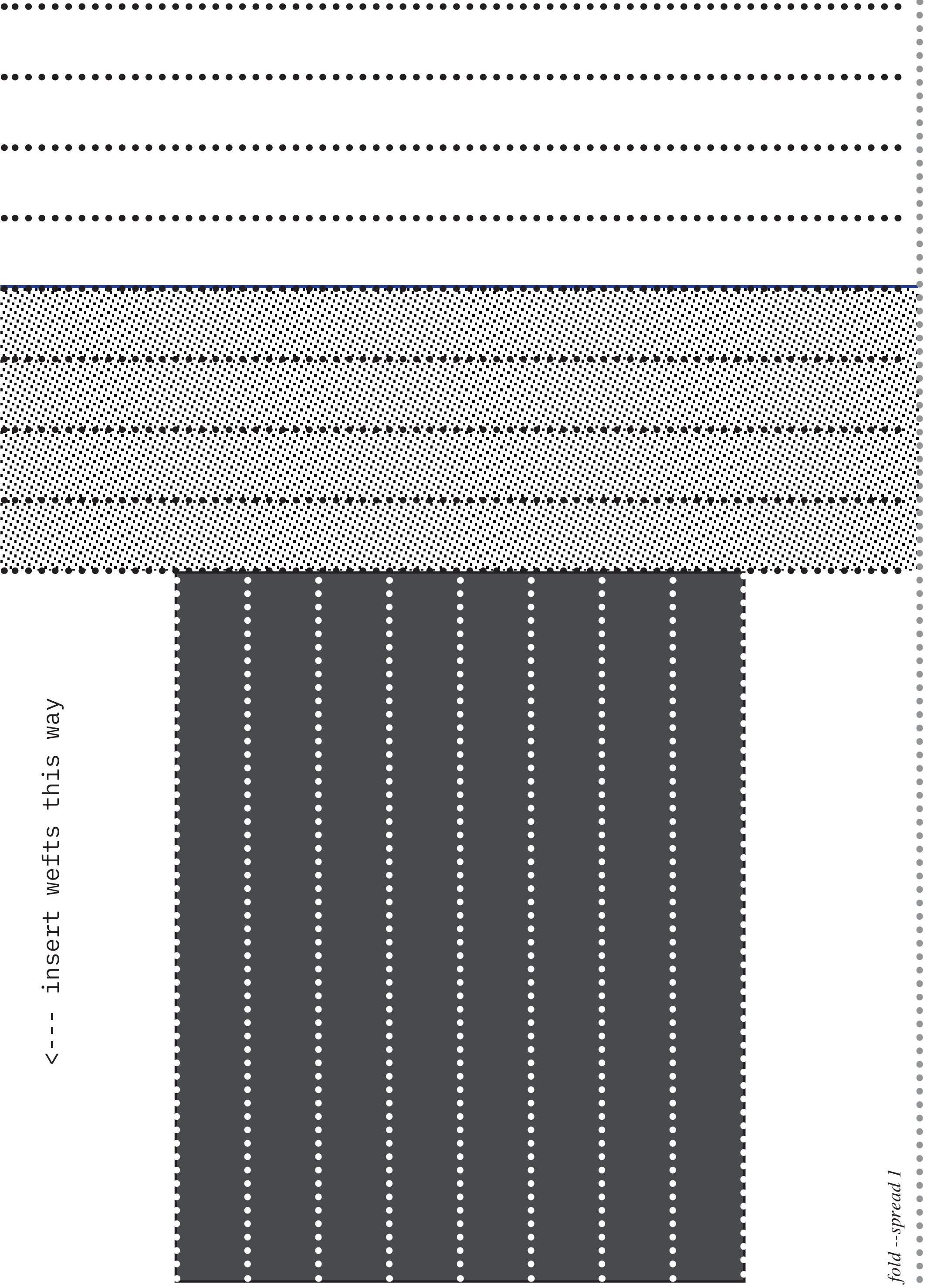
fold --- front and back covers

WEAVING AND DRAFTING FORCE SENSORS

This workbook is an excerpt from:

Laura Devendorf, Sasha de Koninck, and Etta Sandry. 2022. An Introduction to Weave Structure for HCI: A How-to and Reflection on Modes of Exchange. In Proceedings of the 2022 ACM Designing Interactive Systems Conference (DIS '22). Association for Computing Machinery, New York, NY, USA, 629–642. https://doi.org/10.1145/3532106.3534567

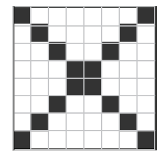
separate cover (this page) from internal pages (pages 4-11) — *fold cover* — *fold each internal page and stack folded pages atop eachother* — *assemble, place internal stack inside cover. bind as desired*



this is your “loom”

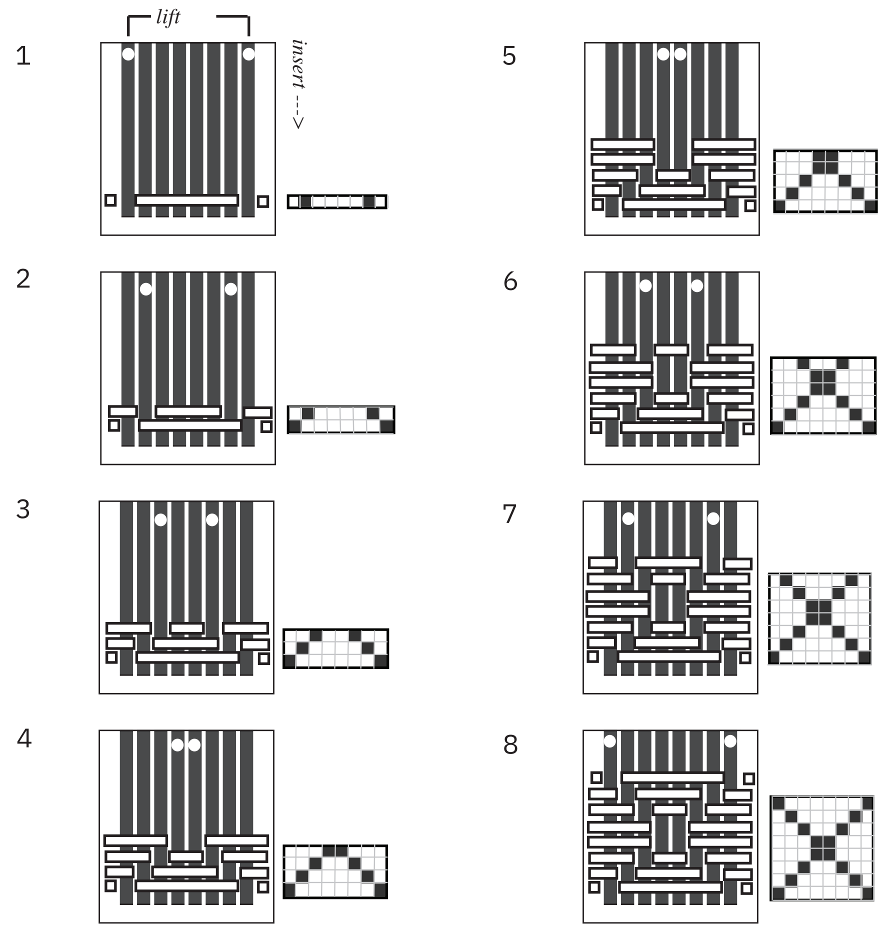
LET’S FOLLOW A WEAVE DRAFT

The pattern a weaver follows to create cloth is called a **DRAFT**. It is a binary map or plan that tells them which warps/heddles to lift on each pick. A ■ cell represents a raised warp, a □ cell represents a lowered warp. Our draft is followed from the bottom up.



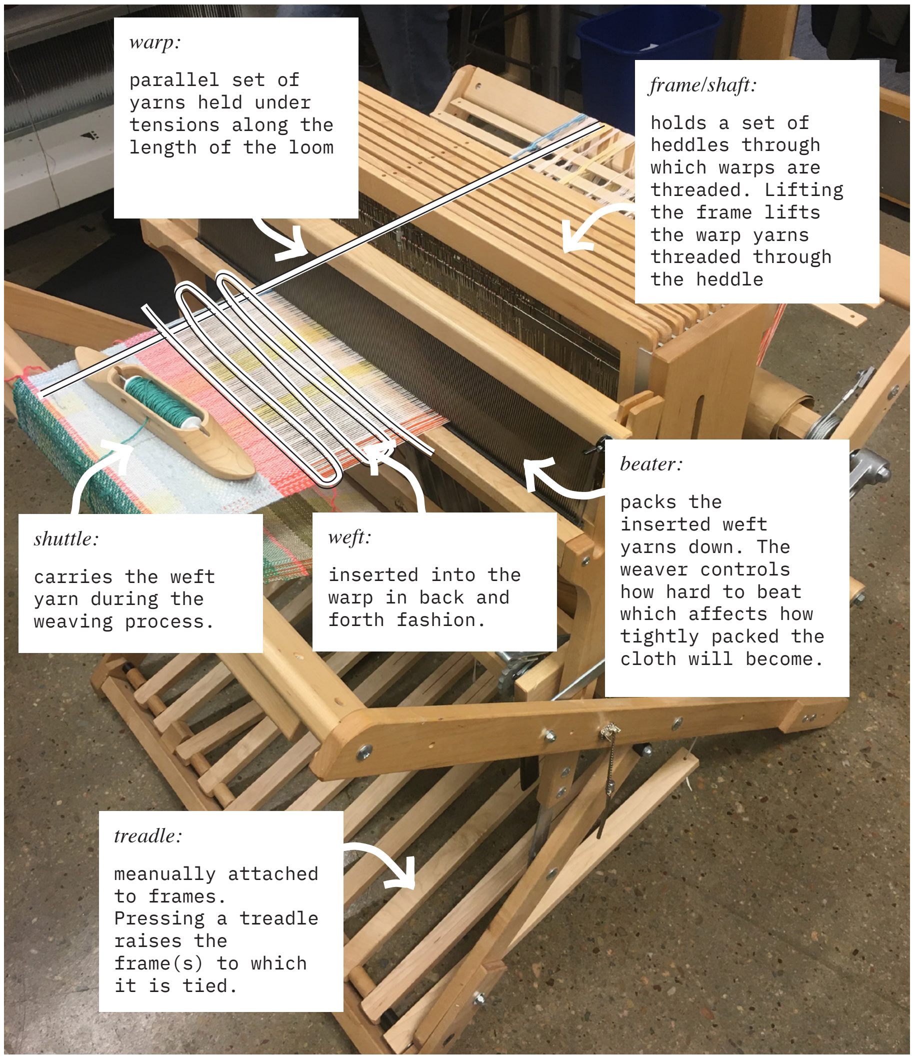
TRY THIS.

Cut out the paper loom on the left and we’ll weave a draft together. Lift the black warps and insert the wefts as indicated below

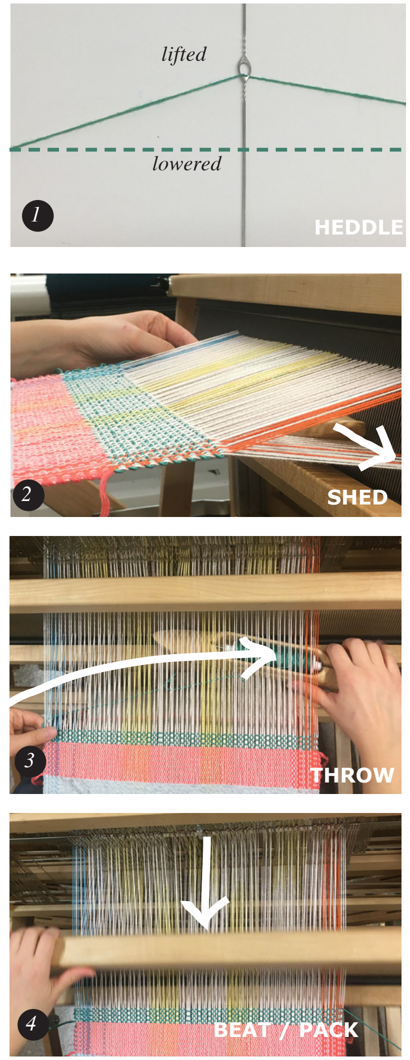


THE HANDWEAVING PROCESS and TERMS TO KNOW

Understanding the structural possibilities of woven cloth depends on a deep understanding of the processes by which woven cloth is assembled. While, as Albers writes, “Any weaving, even the most elaborate, can be done, given time, with a minimum of equipment” [3], we focus on a class of equipment used primarily in industry and western weaving style: the horizontal or two-beam weaving **LOOM**.



fold -- spread 2



The images on the left and above depict a **HARNESS LOOM** *where the pattern is “programed” into the loom by threading heddles on different shafts, which are lifted and lowered using treadles while weaving.*

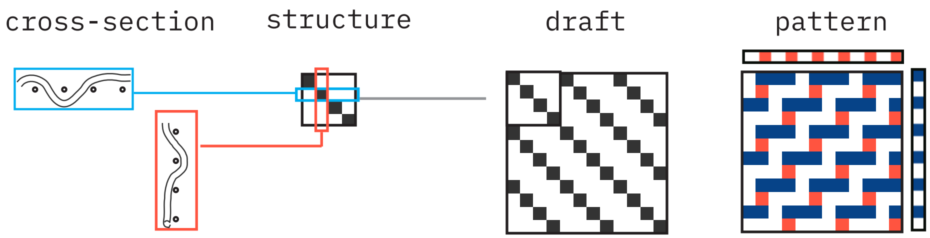
The following cycle is repeated during the process of weaving:

1. Following a **DRAFT**, the weaver raises a selection of warp threads. On your paper loom, you did this by hand. On a computerized jacquard loom, a bitmap image tells the machine which heddles to raise and lower just like you used the black and white cells to determine what to lift or not.
2. When heddles are lifted, they raise the warp threads that are threaded through them and create a **SHED**, which is the term for the space between the raised and lowered warp threads.
3. A **SHUTTLE** carrying the weft thread is **THROWN** through the shed, adding a weft row, or **PICK**, to the cloth.
4. A weaver closes the shed (lowers all warps) and **BEATS**, pressing the new weft on top of the previous weft. This pressing **PACKS** the weft yarns in the weave
5. Repeat 1-4

Many of the samples created in this book were made using the computer controlled **JACQUARD LOOM** *show above. Jacquard looms allow for each heddle to be lifted independently of the others. This loom is a TC 2, contains 30 warps per inch and is 43” wide. It is programmed with bitmap images.*

DESIGNING WOVEN STRUCTURES

Woven cloth can be understood in multiple ways–a mechanical system, a multi-material assembly, a textured image–to name a few. The images below show four different representations of the same woven cloth. Each representation makes different qualities of the cloth more readily visible. Representations are closely interrelated, for instance, changing the draft can change both the pattern and structure. Because we are interested in sensing, and sensing is possible when a mechanical deformation of a material leads to a change in its electrical characteristics, we focus more deeply on structure as it is represented by draft and cross-section.



describes what we might see if we cut the cloth and examined its cross section.

describes the smallest repeating unit within a draft (or section of a draft)

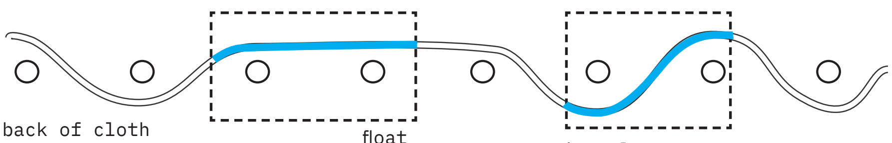
describes the whole cloth, may contain regions of different repeating structures.

describes visual qualities of the resulting cloth, generally accompanied by information about materials and colors.

DEFINING FLOATS AND INTERLACEMENTS

The combination of floats and interlacements determines the qualities of the cloth. For example, longer floats can create denser and softer cloth while more interlacements create more rigid and thin structures. We believe that the cross-section makes it easiest to visualize floats and interalacements and therefore the most helpful when focusing on the mechanics of the cloth.

front/face of cloth *circles represent warp ends, curvey line represents the movement of the weft yarn in and out of the warps*



yarns that stay on the same side between successive warps or wefts are called warp floats and weft floats respectively.

an interlacement describes a yarn that moves from the front to back of the cloth (or vice versa)

for reference, the cross section would be representing the following draft row 

fold --spread 3

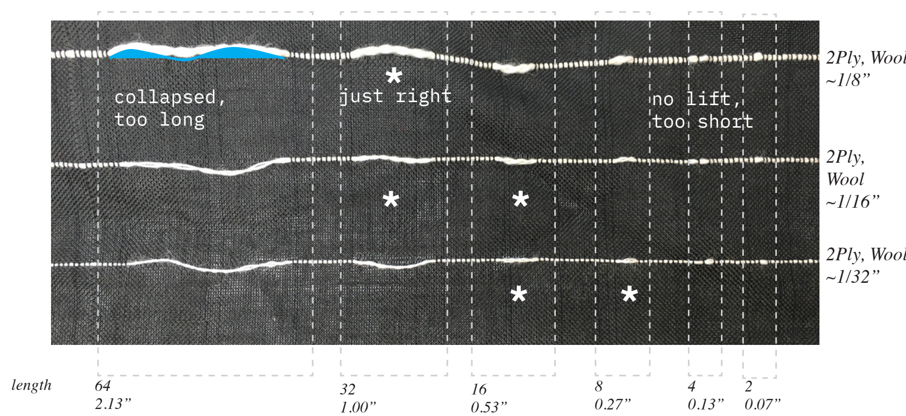
FLOATS ARCH and STACK, INTERLACEMENTS SPREAD APART

As you weave pick by pick and beat the weft in between, floats and interlacements push and pull on each other to shape the fabric in three dimensions. Interlacements will constrain the movement of the weft and create air and space between the crossing warp and weft. Floats are mobile and move like a bezier curve, arching outward from the surface of the cloth. When considering force sensing, in which you want yarns to touch proportional to force, this arching is useful in keeping the yarns separated when no pressure is applied, and in close contact with pressure.

fun with floating steel yarn and magnets

floats of a length specific to each material will spring back to shape after being pressed. We call this the sweet spot.

We aimed to identify a sweet spot, in which the arch is maximized and consistent. Floats shorter than the sweet spot do not contain much vertical lift from the surface and floats longer than the sweet spot tend to collapse and rest upon the surface of the cloth. The sweet spot will vary for each material a weaver chooses as well as the setup of their loom. The best way to identify this region is to test different float lengths on your loom and with your desired materials but in general, thicker yarns will have longer sweet spots than thinner yarns of the same material.



* *the asterisk marks floats that we felt to be in the sweet spot*

DESIGNING STRUCTURES VIA DRAFTING

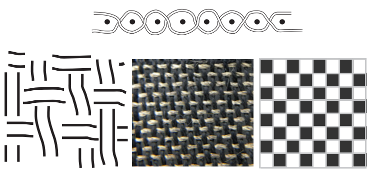
The first approach to designing woven structures is to design the draft. In this proces, weavers typically begin with a core structure (left) and apply different manipulations (right) or derivatives to it to generate new structural variations.

most interlacements---most airy

most floats---most dense

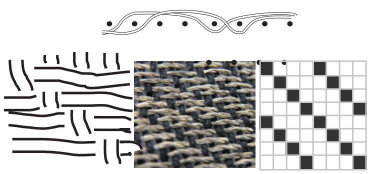
CORE STRUCTURE

tabby



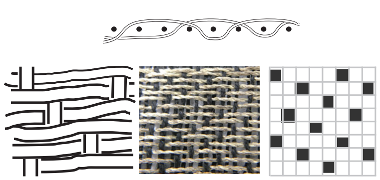
Tabby describes a structure composed entirely of interlacments. In a balanced cloth, this creates the most space between weft yarns, creating a light and thin cloth. The air between wefts means that each weft is electrically insulated.

twill



Twill offsets interlacements in subsequent picks by one. This allows yarns to more tightly stack atop each other, creating more durable and slightly thicker cloth. The wefts are electrically insulated unless the cloth is pulled diagonally in the direction of the twill.

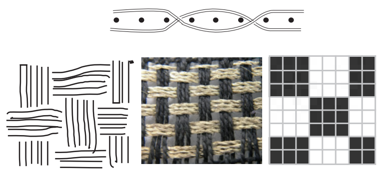
satin



Satin maximizes the distance between interlacements on subsequent picks creating thicker cloth and a tighter stacking than twill. The wefts are electrically insulated unless the fabric is pulled in either diagonal.

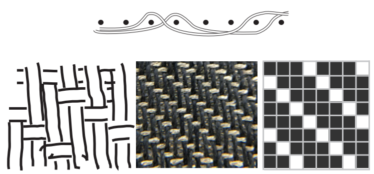
DRAFT MANIPULATION

enlarge



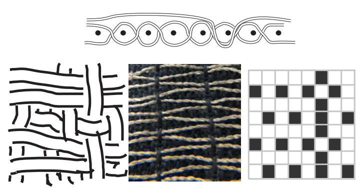
Basket weave is an enlarged version of tabby where warps and wefts interlace every nth row and column. The structure above is a 3/3 basket weave. Note how the enlarged floating regions function like a single thicker yarn.

invert



Inverting a structure swaps all weft floats to warp floats and vice versa. Put another way, inverting moves all the weft floats to the back face of the cloth. This twill is said to be "warp facing" as there are more warp floats than wefts on the face of the cloth.

interlace

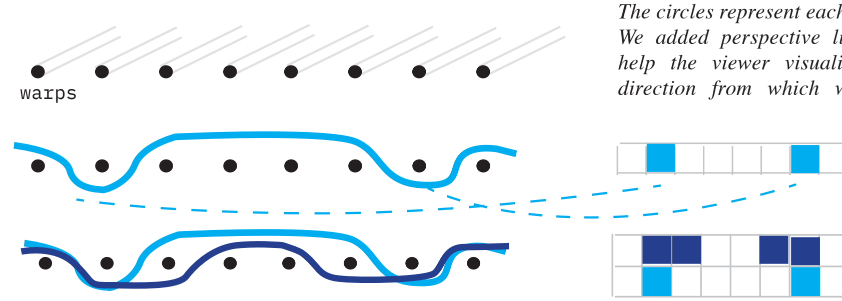


Interlacing takes two structures and interlaces their rows together. For example, if you want your satin weave to be thinner, you might interlace it with tabby. Tabby adds space between wefts, where the satin adds floats above the surface of the cloth.

fold -- spread 4

DESIGNING STRUCTURES VIA CROSS-SECTION

We can also focus on structure more centrally in design by drawing the cross sections of your cloth and then translating those into draft.

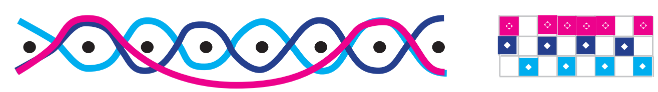


The circles represent each warp. We added perspective lines to help the viewer visualize the direction from which we are

Draw each weft yarn in the pattern you'd like it to interlace with the warp yarns and move between the faces of the cloth. Then, fill in a square for each warp yarn the weft moves under in the draft.

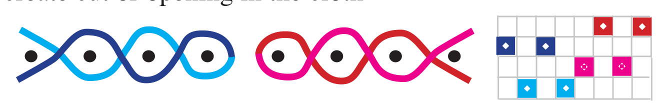
INTERESTING CROSS-SECTIONS TO EXPLORE

place a yarn to one side of the cloth



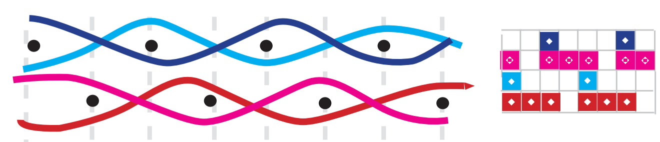
this structure places the pink yarn on the back surface of the cloth

create cut or opening in the cloth



only weaving half the width of the loom with two different yarns can create openings.

weave two layers at once

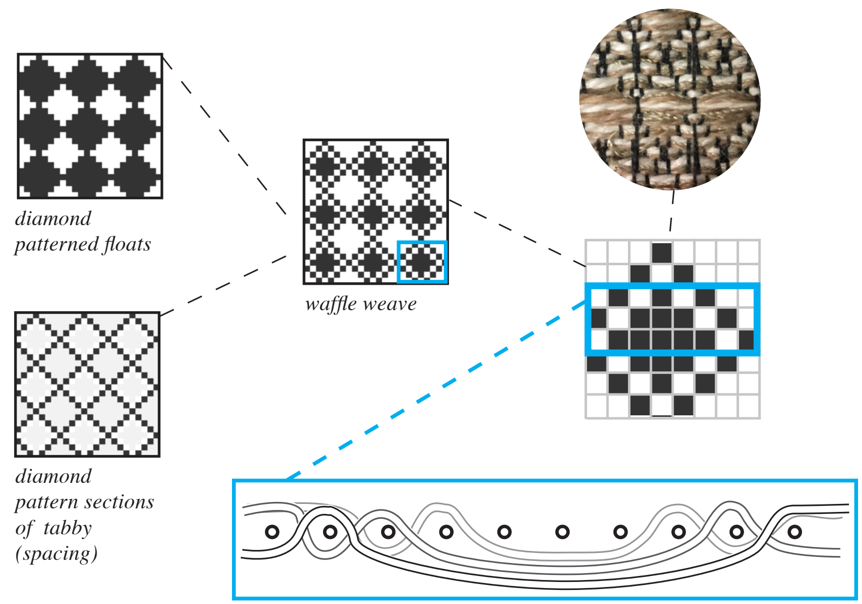


creates two layers atop eachother. Here, we move the circles representing warps to two rows to more easily visualize the layers

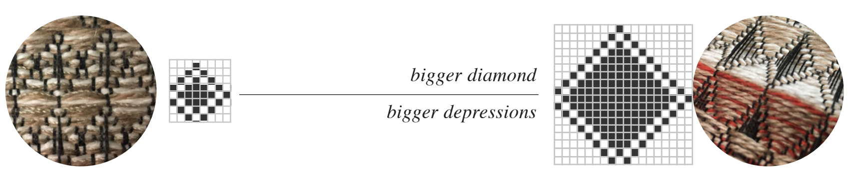
FORCE SENSITIVE WEAVE STRUCTURES 1: WAFFLE WEAVES

The first class of force sensors emerge from a class that Cyrus-Zetterström describes as "Structures that Form Uneven Surface Textures and Openings" and include the structures classified as cord, honeycomb, waffle weave and crepe weaves to name a few. A waffle weave is a structure with floats organized into large diamond shapes, bound by sections of tabby weave between the diamonds. "The long warp and weft floats tend to draw the fabric together, while the closely woven tabby areas tend to extend it. In this way, ridges and depressions are formed" [7].

how to make a waffle structure



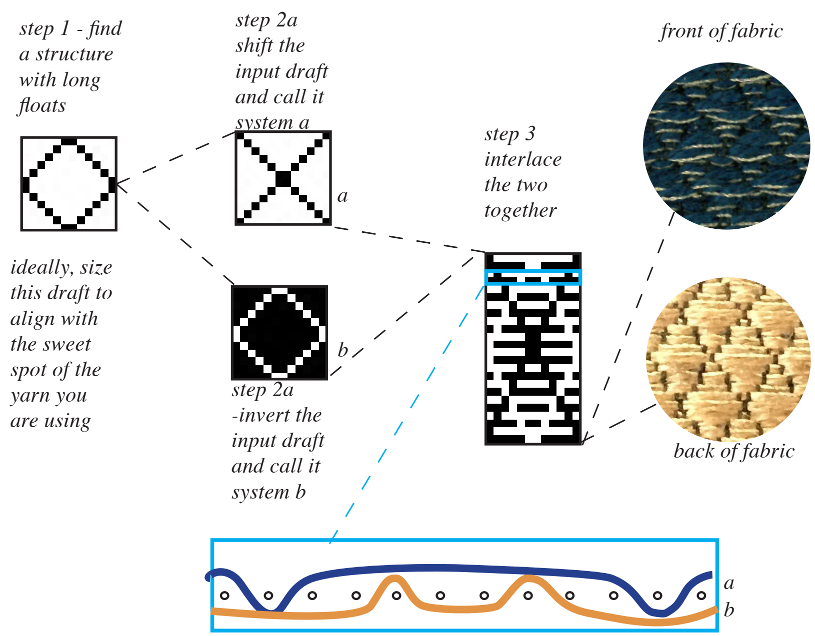
the waffle shapes form becuase of a combination of overlapping flloats and the tabby edges (which prevent the structure from collapsing)



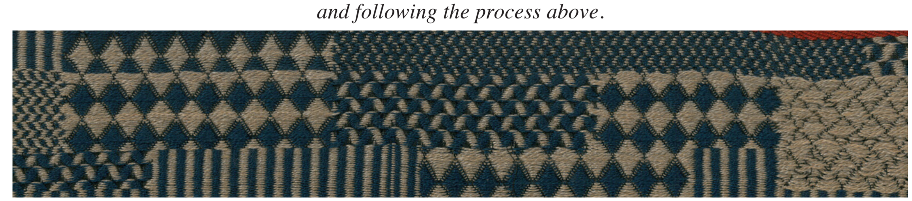
FORCE SENSITVE WEAVE STRUCTURES 2: MULTI-PIC STRUCTURES

The second class of force sensing structures are multi-pic structures. It's useful to think of these structures as having two weft systems or two structures that are interlaced into each other. For simplicity's sake, consider a weft system as describing wefts of a particular color, let's say blue and tan. Two pic structures ensure that the weft system a, or the blue threads and weft system b, the tan threads, tuck in ways that place a/blue on one side of the fabric, and b/tan on the other. Using this technique, one can create bold 2-color graphic patterns. From a sensing perspective, you can create fabrics where there are several small pockets, almost like bubble wrap.

how to make a 2-pic structure

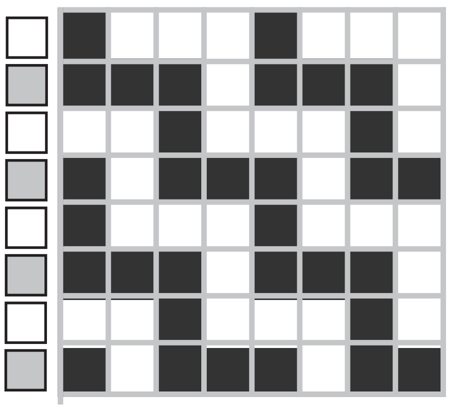


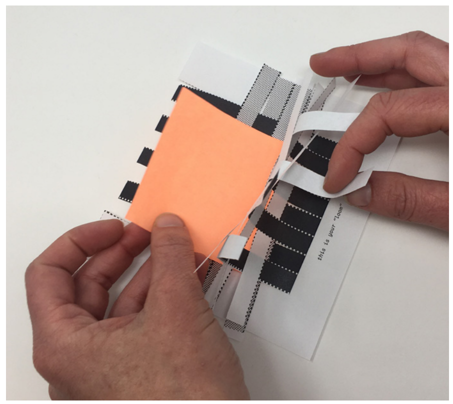
An assortment of two pic structures in blue and tan. Each derived from different starting structures and following the process above.

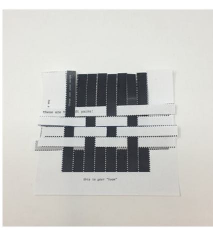


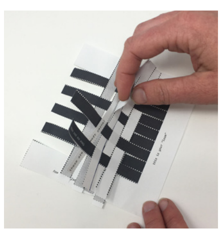
FORCE SENSITVE WEAVE STRUCTURES 3: MULTI-LAYER STRUCTURES

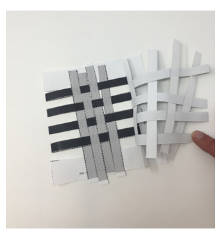
Multilayered structures have already captivated the HCI audience in that they are quite simple to formulate and lead to a comfortable mapping between existing cognitive models of sensors as laminated or multi-layer systems and woven structures (e.g. [9,30]). Yet, there are aspects of multi-layered weaving that have yet to be explored, such as the binding of layers, the introduction of pockets, or the ability to "inlay" patterns on each layer. The most important rule when considering multilayer drafts is that every layer will reduce the warp-resolution (calculated in warp ends per inch) by half. Thus, if your loom is warped at 30 ends per inch, a two layer weave will have each layer woven at 15 ends per inch, and a 5 layer weave would have 6 ends per inch.

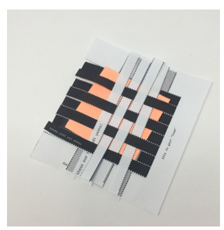












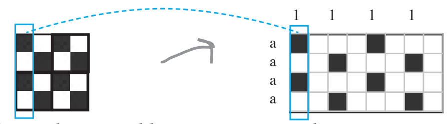
TRY THIS.

Follow this draft on your paper loom. Alternate grey and white on each pick. If you pull up a warp you will be able to pull up the entire first layer. Now you can insert something (perhaps a sensing something) in between the layers.

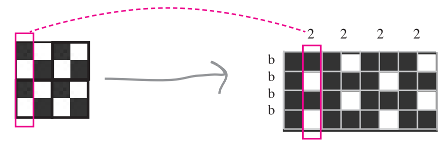
fold --spread 6

A FORMULA FOR MULTI-LAYER WEAVES

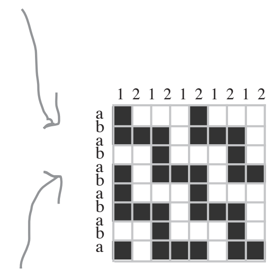
Weaving has its own unique calculus which allows us to follow a formula to draft multi-layer structures. This involves dedicating particular warps to particular layers and then mapping the structure onto those layers.



To give the top layer a tabby structure, map the structure to the warps assigned to layer 1.



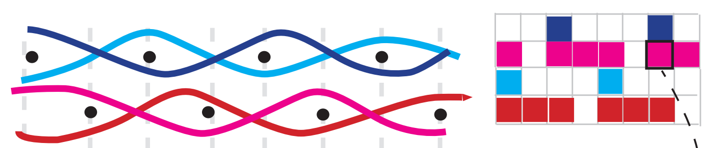
To give the bottom layer a tabby structure, map the structure to the warps assigned to layer 2 and lift the warps assigned to layer 1.



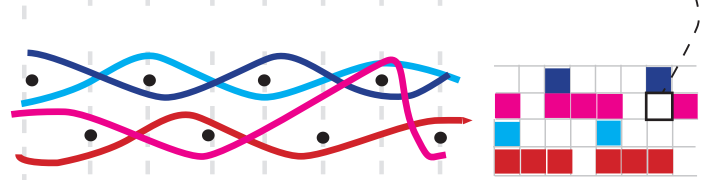
interlacing the two drafts together results in a two-layred cloth with a tabby structure on both layers

JOINNG LAYERS

At times, you may want to weave a two layer fabric but have it function as a single layer in some regions and a hollow layered structure on another. This can be acomplished with a technique we called joining.

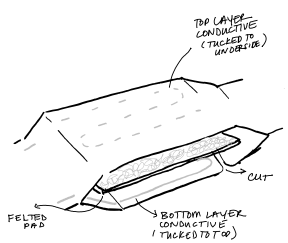


start with the two-layer tabby structure we introduced on spread 4.

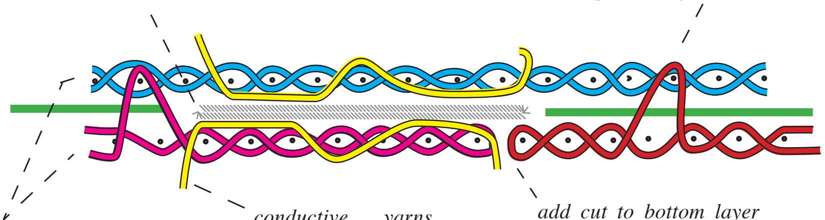


modify at least one layer to interlace into the other layer under a weft float. If only sparcely interlaced, the binding yarn will be mostly invisible.

FORCE SENSITVE WEAVE STRUCTURES 3: MULTI-LAYER STRUCTURES



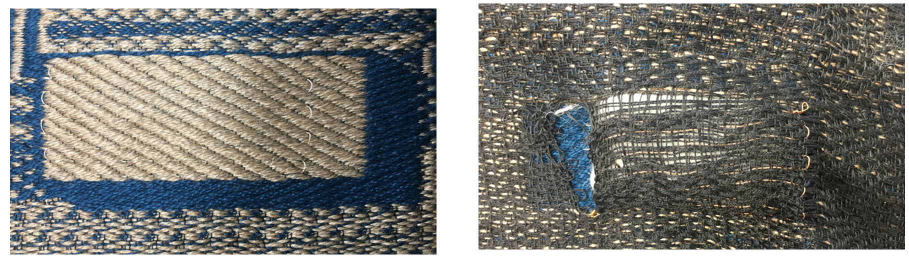
The force sensors that we believe offer the best performance took a structure which integrates techniques introduced on the previous page and integrates a non-woven structure. Two conductive pads are embedded on the inside of the separate layers. We sandwich a resistive felted pad between. The fibers in the felt compress on press and expand back on release. We hand felted our pads so that they would be very airy but consistent. This assembly is not purely woven, instead, it uses the weave as a kind of custom container or circuitry structure for the felted steel inside the pocket. This offered advantanges for speed of production and opportutnities for reuse via modular design. Futhermore, it created quite robust force sensing values. This suggests that multiple fiber structures can play well together, and that knowledge of one might be complemented by knowledge of another.



fold --- spread 7

NEEDLE FELTING SENSOR PADS

Felt is a non-woven structure that entangles fibers directly into cloth rather than passing through a "yarn" step. This structure complemented our woven sensing by allowing us to quickly make robust sensor pads to slip in wired pockets. We created sensor pads by needle felting a mix of roughly 80% merinox roving and 20% churro wool roving (to add air and structure). We needle felted until the pads were about 1/4" thick at rest and that they would not rip when pulled.

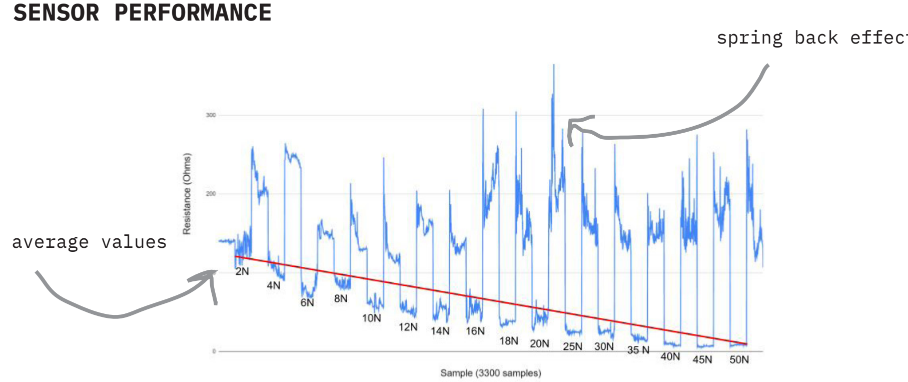


photos of the front and back sides of our multi-layer structure

details of the conductive yarns peaking to the surface at the edges of the pocket

detail of the felt pad inserted inside the pocket opening

SENSOR PERFORMANCE



We characterized this force sensor using a digital force gauge and an Arduino code to measure output voltage. These tests revealed a correspondence between the force exerted on the fabric and the associated resistance change. After the press was released, we observed a bounce back effect which we attribute to the inherent spring of the felted wool. Overtime, the fibers may compress, in which case, we can replace the old pads with new pads by simply inserting them into the pocket.

LESSONS LEARNED MAKING A FABRIC THAT REMEMBERS

The techniques outlined in this workbook were all discovered and developed through the development of “A Fabric that Remembers.” This fabric is inspired by the inherent memory of yarns (to hold shape, smell, etc) and forms of memory imparted through computation (e.g. data stored). It aims to bring attention to the multiple ways fabrics hold memories. A Fabric that Remembers is a woven cloth with six force sensitive regions which, when pressed, transmit press data to a cloud server. A web-based user interface reads from the server and updates the pressure collected on a device. It has modes to show press data in real time as well as records of presses over time.

The cloth, in its current form, has developed over the past three years. We took inspiration from a structure demonstrated by Kobakant [37] that used waffle weave and began to search for structures with similar mechanical qualities. Part of this search involved chance by making a habit of throwing a conductive yarn with each pick of any draft we wove to see if the resulting cloth would have interesting sensing properties. When doing this on a file of swatches left by a former artist in residence, we discovered that multi-pic structures offered sensing as well as opportunities to use bold colors and visual patterns. This opened our eyes to the realization that the design space was much wider than we originally anticipated (see lesson 1).

We turned our attention to developing 2-pick structures that could support force sensing. Because thinner conductive threads are more plentiful and conductive than thicker conductive yarns, we created our sensors by throwing both a conductive thread and thicker non-conductive yarn on each pick. We found that the ratio between these yarns determines just how much the conductive yarns will touch (or not) to create the changes in resistance required. We found a good match between a 2/10 weight woolen weaving yarn and conductive thread (234/35 statex silver coated nylon) as the wool supports the structural and color qualities of the cloth where the resistive thread allows for the sensing capabilities. After discovering the structures and yarn-width ratios that worked, we looked for a particular yarn that would bring aesthetic value to the project (see lesson 2). We found a tencel/merino blend in the approximate size we needed that offered an airy structure, lustrous sheen (that would emphasize the texture of the fabric), and a wide variety of color-ways we could explore. We used these to make A Fabric that Remembers (version one), which was included in a major interactive exhibition which hosted roughly 42000 visitors. When we got the fabric back, it no longer worked and we determined that the silver coating on the yarns wore off (lesson 3). Furthermore, the connections between conductive yarns in the fabric by knotting had become loose or entirely pulled apart.

To remedy our fabric, we needed a new structure that did not rely on the resistive yarns we originally used. In parallel experiments, we saw good sensing results from conductive felt made from stainless steel and merino wool fiber blends. This led us to envision a` pocket structure detailed on the previous page. We added pocket openings on the backside of the fabric to allow the felted pads to be inserted and removed, and supported the pockets by binding the double weave in areas that were not to be used as sensing pockets. We also began to reinforce all connections with crimp beads, which seem to be more durable and lead to more stable sensor readings. The felted inserts to the pocket created a subtle “puff” in the regions that were to be pressed, leveraging a human’s desire to press something that appears squishy.

Lesson 1: Create opportunities for chance discoveries

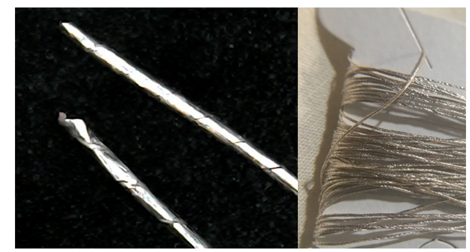
samples created by chance and their resulting resistance measurements

Lesson 2: Fine tune the ratios between yarn-widths prior to making final material selections.

turning the ratio of wollen yarn to resitive yarn. Approximate scale between yarns shown on right

Lesson 3: Use pure metal threads or foil wrapped threads (or test the durability of the conductive coatings).

Looking at Karl Grimm silver yarn through a microscope reveals it to be foil wrapped



Lesson 4: Use crimp beads to reinfoce connections between conductive yarns

Applying a crimp bead between silver thread and silicone coated wire