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Weavy

Interactive Card-Weaving Design and Construction

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Weaving combines two sets of yarns—the warp and weft—to create a fabric sheet (see Figure 1). In particular, card weaving is a simple, easy-to-use method that usually employs simple cardboard squares with four holes.[1] Users can produce patterned woven bands, ribbons, straps, and hair accessories. However, designing patterns typically is laborious and requires knowledge, experience, and skill.

The Weavy system helps users design and construct original card-weaving patterns. They paint on a digital canvas, and Weavy automatically updates the pattern. It's so simple and straightforward that even children can use it. (See the accompanying video and demo program at www.geocities.jp/igarashi_lab/weavy/index-e.html.)

Card Weaving

Card weaving is similar to pixel art (where all pixels are the same size), but each pixel in a woven band is a diamond or trapezoid, not a square. A card-weaving pattern is typically designed by hand, using a rectangular grid we call a *structural model* (see Figure 2a).

The number of cards, n, determines the band's width (the number of warp yarns). The number of holes in a card, m, determines the number of colors for each column. Figure 2 illustrates card weaving with $n = 1$ and $m = 4$. The user first prepares the yarns and cards. The cards are used to create the *shed*—the area between the upper and lower warp yarns, through which the weft is passed and where the warp's ends are fixed.

The user splits the warp into two top yarns and two bottom yarns and passes the weft through the shed. Then, he or she rotates the card. Figure 2d shows the system following a further pass of the weft yarn and a 90-degree clockwise card rotation, which is the forward direction here. The pattern changes if the user rotates the card counterclockwise (backward).

Card weaving can employ multiple cards, arrayed horizontally (see Figure 3). Increasing the number of cards widens the fabric.

Three factors determine the design. The first is the warp yarn colors, which are arrayed in an $m \times n$ matrix (see Figure 4a).

The second factor is the order in which the yarns pass through each card. Each stitch of the final woven cloth is diamond-shaped or trapezoidal (see Figures 4b and 4c). The diamond's orientation is determined by how the warp passes through the card (front to back or back to front). All warp yarns must pass through in the same direction for a given card.

The final factor is the cards' rotation pattern, which users can vary by changing the rotation direction and sequence. Figure 5a shows a V-shaped pattern, in which the user rotates the cards forward. Figure 5b shows a chevron pattern, in which the user rotates the cards backward. Figure 5c shows the pattern when the user rotates the cards four times forward and four times backward (designated F4B4). Figures 5d and 5e show variants of this theme achieved with different combinations of forward and backward rotations.

Weavy

Weavy comprises two modules: the design assistant and construction guide. Instead of a structural model, it employs a *display model* (see Figures 2b and 4b), a diamond-based grid that more intuitively relates to the final pattern. We call each grid section a *cell*.

The Design Assistant

Weavy's design assistant offers a standard design mode and a free-painting mode. Once users have

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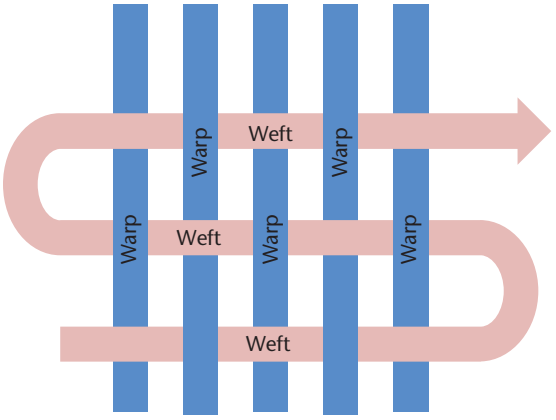


Figure 1. Weaving combines two sets of yarns—the warp and weft—to create a fabric sheet.

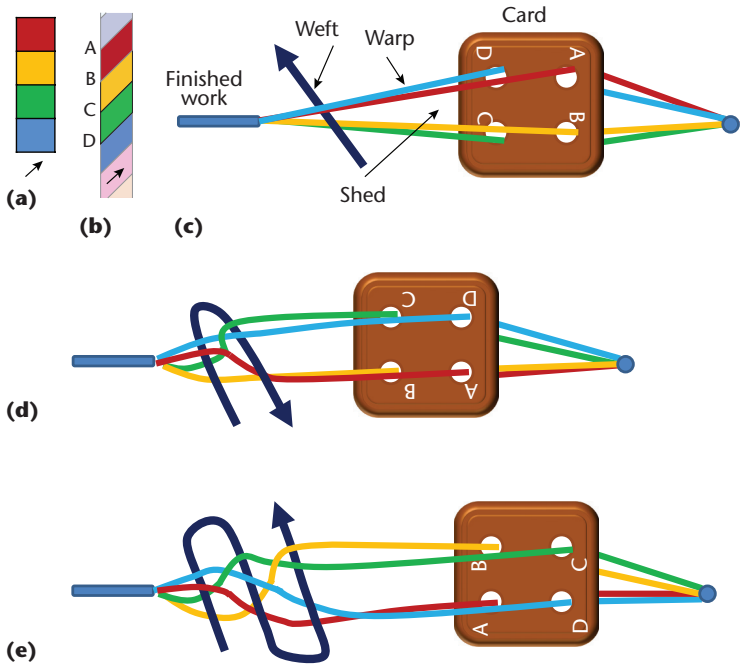


Figure 2. Card weaving using one card with four holes. (a) The structural model. (b) Weavy's display model. (c) The corresponding side view of card weaving. (d) Rotating the card 90 degrees clockwise. (e) Rotating the card another 90 degrees clockwise.

selected a mode, they can't change it unless they close and restart the application.

Standard design. In this mode (see Figure 6a), users create a design using repeated elements. They first specify the color of the warp yarns in a $4 \times n$ matrix. They can then change the number of cards and the direction of the yarns passing through each card by clicking on the corresponding arrow (see Figure 7). Each cell's final orientation depends on how the yarn passes through the hole—that is, whether it's up or down.

Users repeat a set of steps until they're satisfied with the fabric's length. They can check the final design in the system before weaving it.

Free painting. In this mode (see Figure 6b), users design with a background color, a foreground color, and no repetition. Using the two colors, they first paint an arbitrary pattern on the band. Then, Weavy automatically determines each card's rotation pattern. Users weave in sets of two rotations, so a cell in this mode is twice the size of a cell in the standard design mode.

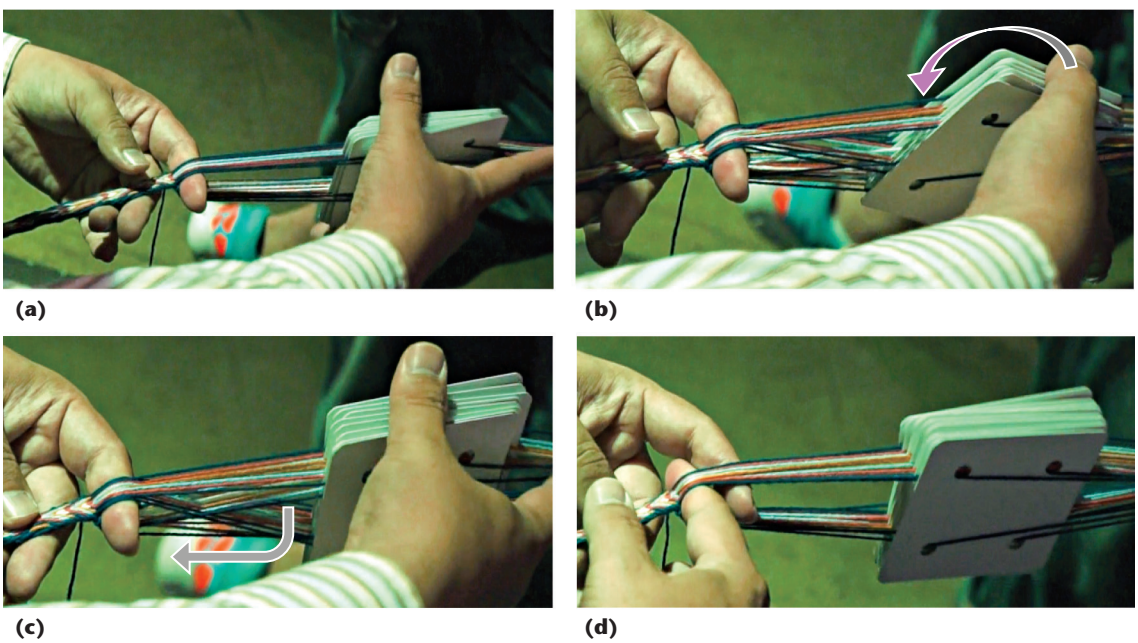


Figure 3. Using multiple cards, arrayed horizontally. (a) The user splits the warp into the top and bottom yarns. (b) The user rotates the cards 90 degrees clockwise. (c) After rotation, the user splits the warp yarns again. (d) The user passes the weft through the shed. Increasing the number of cards widens the fabric.

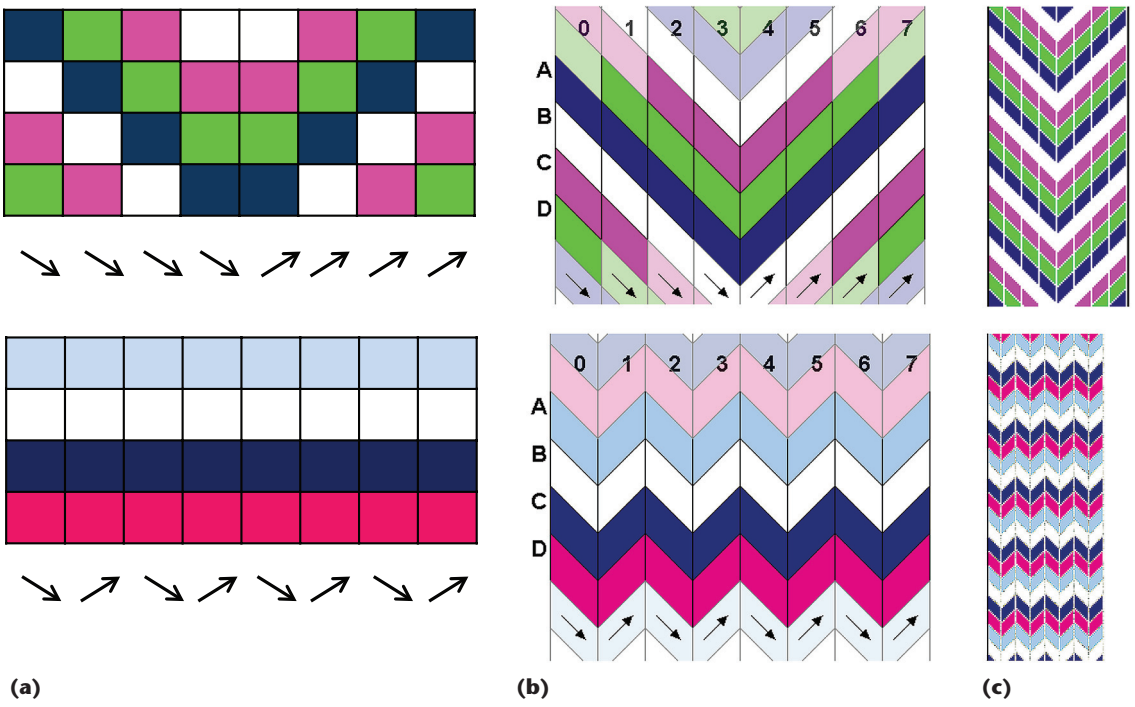


Figure 4. Card-weaving patterns. (a) The regular rectangular-grid representations, or structural models. (b) The display models. (c) The final designs. Designs are determined by the color of the warp yarn in an $m \times n$ matrix, where m is the number of holes in a card and n is the number of cards.

Weavy also visualizes each cell's orientation, which is determined by the rotation direction. Each cell's shape depends on the neighboring yarn color. If the previous yarn color is different, the cell is a diamond. If that color is the same, the cell is a trapezoid.

When users click on a cell, Weavy automatically changes the foreground or background color and updates the cell shape (see Figure 8). Users can choose a background and foreground color for each card. To rotate the pattern's orientation, they push the Rotate button.

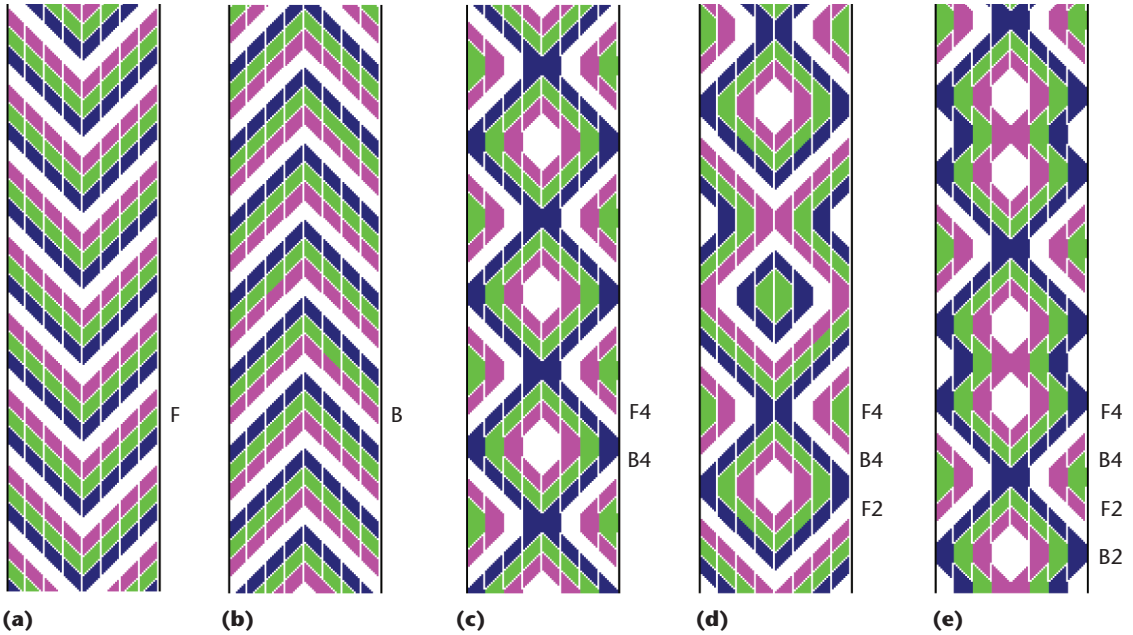
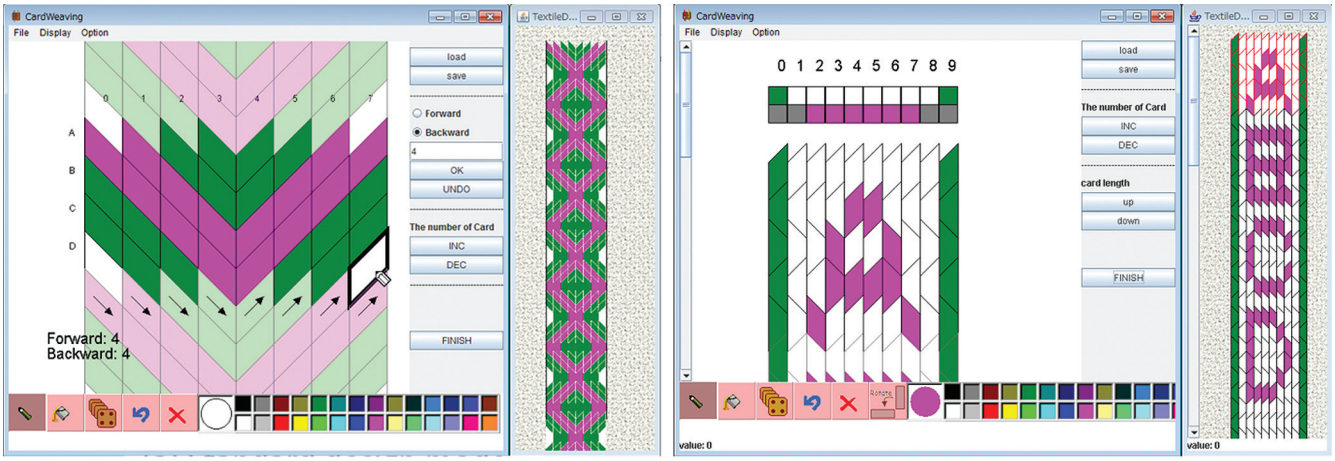


Figure 5. The cards' rotation direction determines the design. (a) A V-shaped pattern, in which the user rotates the cards forward. (b) A chevron pattern, in which the user rotates the cards backward. (c) The pattern when the user rotates the cards four times forward (F4) and four times backward (B4). (d) A variant of the pattern in Figure 6c. (e) Another variant.



(a) (b)

Figure 6. Weavy's design assistant. (a) In standard design mode, users create a pattern with repeating elements by specifying four yarn colors and the card rotation direction at each step. (b) In free-painting mode, they paint an arbitrary pattern; the system automatically determines each card's rotation pattern.

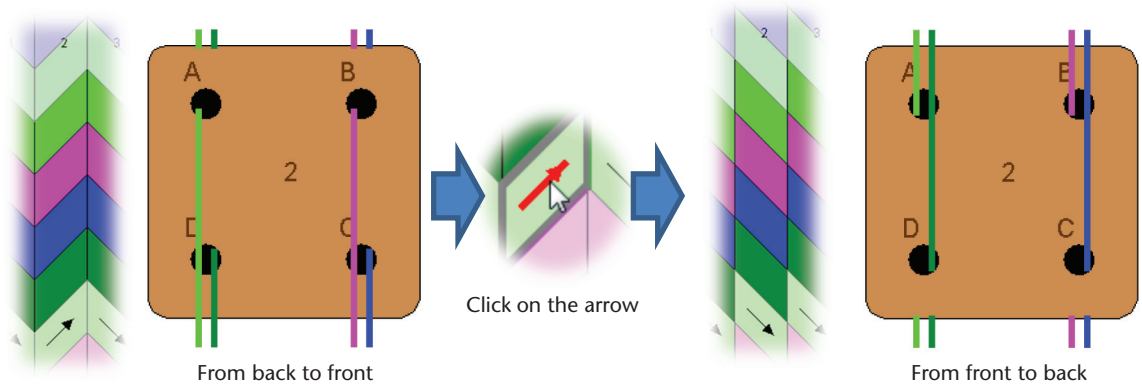


Figure 7. The pattern's final orientation. The orientation depends on how the yarn passes through the holes—that is, whether it's up or down. Users click on the arrow in the design assistant to change the yarn's direction.

The Construction Guide

Weavy's construction guide helps users correctly weave the patterns they've designed (see Figure 9). Following the construction guide, they pass the warp yarn through the holes of each card.

Standard design. In this mode, the user splits the warp into $2n$ top yarns and $2n$ bottom yarns and passes the weft through the shed. Then, he or she rotates all the cards 90 degrees forward or backward according to the cards' rotation pattern. The user then splits the warp into $2n$ top yarns and $2n$ bottom yarns again. The user repeats these steps.

Free painting. In this mode, the construction guide illustrates each card's rotation direction (see Figure 10). To weave a pattern, users mark the edge where holes C and D are on the card and insert the warp through the card. During weaving, they'll pass the yarns with the foreground color through two adjacent holes and the yarns with the background color through the other two holes. Users start from the marked position, which is the reference orientation (see Figure 11a).

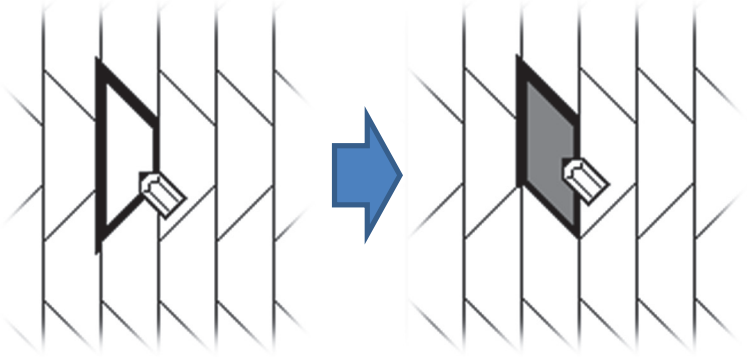


Figure 8. In free-painting mode, when users click on a cell, the system automatically updates the cell's shape.

Next, the system shows each card's rotation direction (see Figure 10). The user rotates the cards in the required directions (see Figures 11b and 11c). In this way, the upper warp yarn's color is visible. Then, the user passes the weft through the shed.

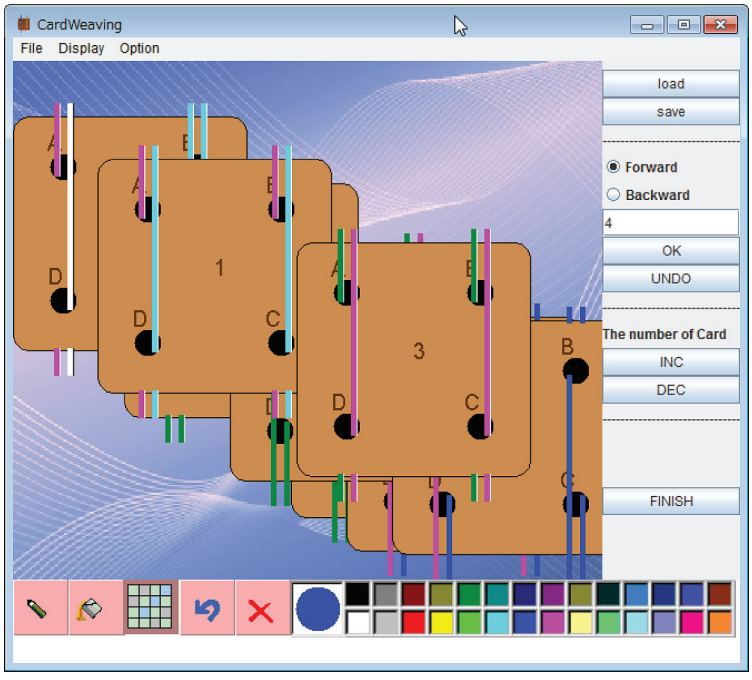


Figure 9. Weavy's construction guide helps users correctly weave the patterns they've designed.

Finally, the user rotates each card in the direction required by the pattern and passes the weft through the shed. This returns the card to the reference position (see Figure 11d).

Results

Weavy ran in real time on a PC using a 1.7-GHz Intel Core i5 processor. With it, we designed and fabricated a number of textile designs; Figure 12 shows some examples. Each design session typically took about 10 minutes; the weaving took one to three hours. Figure 12b shows bands woven in standard design mode (the top example) and free-painting mode (the bottom example).

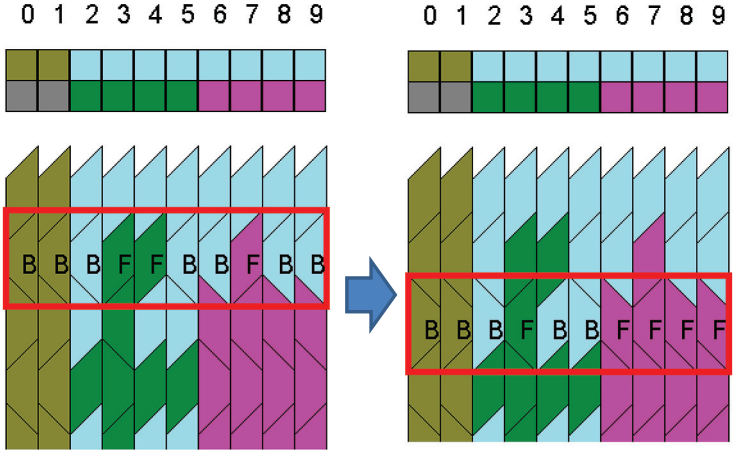


Figure 10. The construction guide in free-painting mode. There are 10 cards (0–9). The red rectangle shows the current row. "B" shows that the user rotates the card backward; "F" shows that the user rotates the card forward.

User Studies

To evaluate Weavy, we exhibited it at the ACM Siggraph 2013 Studio and ran a workshop for children.

Siggraph 2013 Studio

Our booth had areas for designing patterns with Weavy and then weaving them (see Figure 13). We presented a brief tutorial and gave the participants sufficient time (a few minutes) to create a design (see Figures 14a and 14b).

We prepared eight cards, with the warp fixed at both ends. The participants created a long woven band, experimenting with different rotations (see Figure 14c). During the three days, the band grew to 172 cm.

We had 130 visitors, including researchers, engineers, artists, and students. Example comments were, "I did not know card weaving," "Interesting!," "Amazing!," and "I want to introduce this software in my workshop."

The Workshop

Six children, ages 6 to 9, participated in the workshop, accompanied by their parents. After a brief tutorial, the children spent approximately 20 minutes creating designs (see Figure 15a). They passed the warp through the cards according to the construction guide and then wove bands, which took approximately one hour (see Figure 15b).

Figure 15c shows some completed bands. The children quickly learned how to use Weavy and, furthermore, enjoyed the process. They also provided valuable feedback for future development. For example, the system shows only multistep instructions such as "F2B2," but the children had difficulty remembering the current count. So, they desired step-by-step instructions, such as showing "B" after the user completes "F" two times.

On the basis of the user studies' results, we believe that the participants didn't really understand the principles of card weaving. However, they were able to design and create their own bands. Also, creating design variants without a support system is usually difficult if the user doesn't understand the principles. Nevertheless, the participants were able to design variants.

We plan to include more advanced assistance, such as image and voice recognition. Also, rotating the card might be impossible when the construction guide specifies certain sets of directions in which to pass the warp. One example would be when the user passes the A, B, and C warp yarns from back to front and the D warp yarn from front to

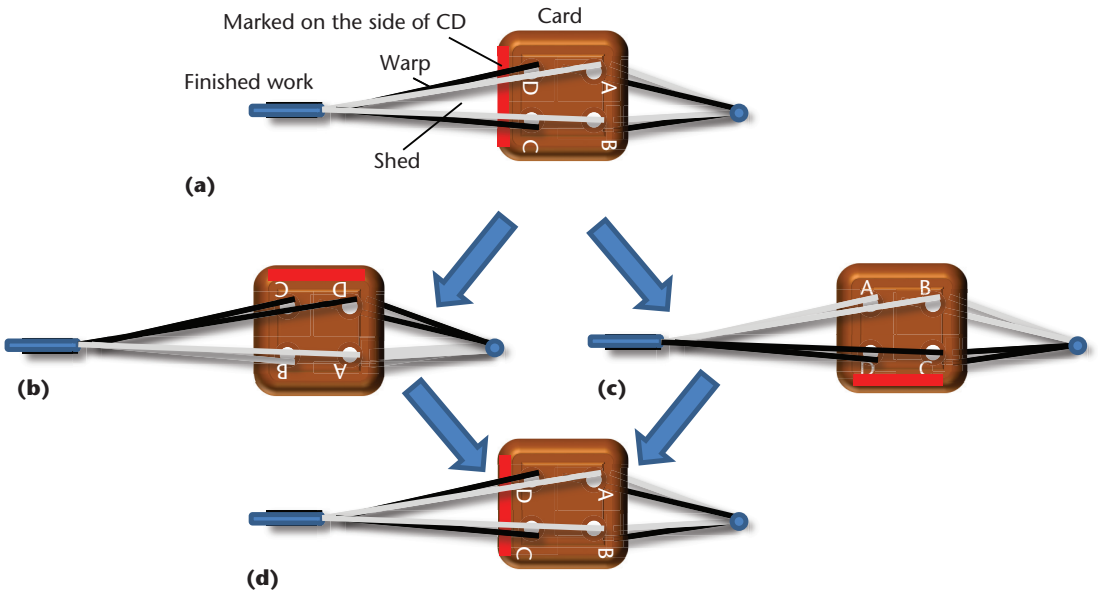


Figure 11: Making a band using free-painting mode. (a) The user starts at the reference position. (b) For the foreground color, the user rotates the card clockwise and passes the weft through to the shed. (c) For the background color, the user rotates the card counterclockwise and passes the weft through to the shed. (d) The user then rotates the card in the opposite direction and passes the weft through the shed.

Figure 12. With Weavy, we (a) created these designs and (b) wove these bands. Each design session typically took about 10 minutes; the weaving took one to three hours.

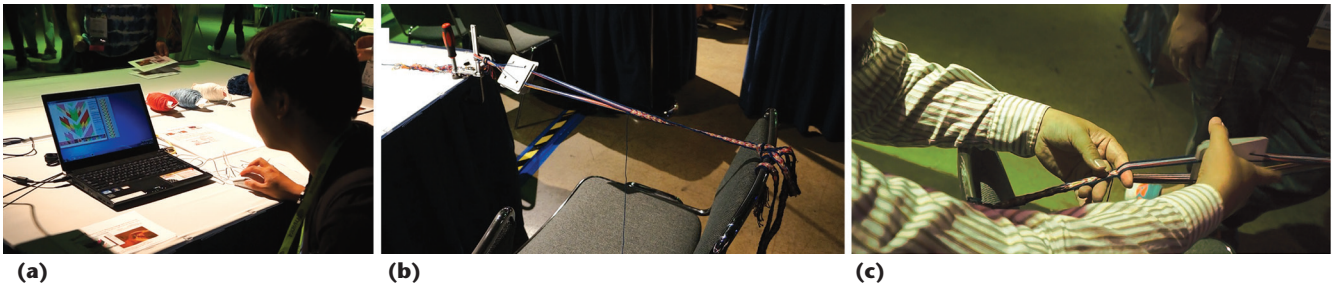


Figure 13. Weavy at the Siggraph 2013 Studio. (a) A participant designing a pattern. (b) The area for card weaving. (c) A participant creating a band. We presented a brief tutorial and gave the users sufficient time to create their designs.

back. Discovering these errors might not be easy, but it would be useful for the design assistant to show them to the user. In addition, users might have difficulty remembering how far through a sequence they are and determining the direction in which to rotate the card. Perhaps the system could also give guidance on this.

Finally, a visualization of the weaving mechanism should help novices understand the process. For example, the "Sewing Machine" Wikipedia

Related Work in Design and Construction Support Systems

Various interesting systems use state-of-the-art graphics techniques to support the fabrication of physical objects.

Design Support

Plushie combines 3D modeling and physics simulation to let novices easily design stuffed animals (see Figure A).[1] It automatically generates the corresponding 2D pattern. Like Weavy (see the main article), Card Weaver (www.theloomybin.com) is a design system for card weaving. However, it supports only patterns with simple repetitions and doesn't support free painting. Researchers have also devised systems for designing quilts,[2] pop-up cards,[3] beadwork,[4] and mechanical toys.[5]

Construction Support

Spyn lets knitters record, play back, and share information on the creation of hand-knitted objects.[6] It combines computer vision with patterns of infrared ink printed on the yarns to correlate locations in the knitted fabric with messages recorded during knitting.

Beady provides a step-by-step guide using 3D graphics to assist manual beadwork construction (see Figure B).[4] Alec Rivers and his colleagues proposed a method that lets unskilled users create an accurate physical replica of a 3D model.[7] They used a projector and camera to scan a work in progress. The system projected multiple forms of guidance onto the replica, indicating information such as which areas required more material and which required removal of material.

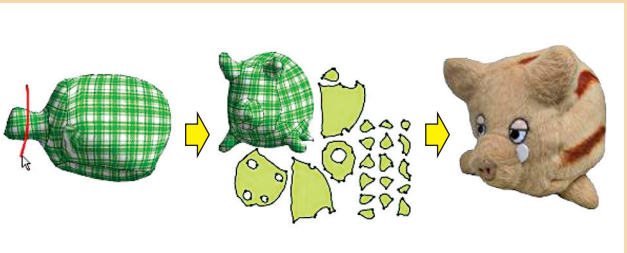


Figure A. The Plushie system lets nonprofessionals design their own plush toys.

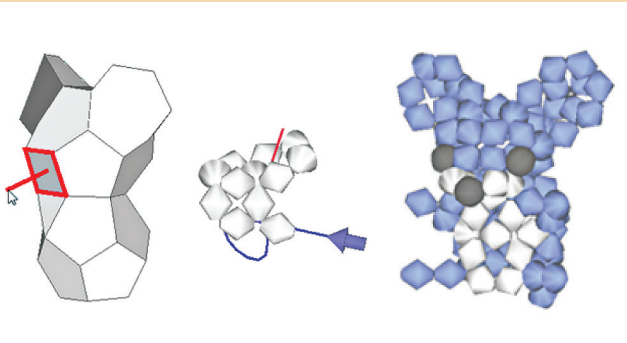


Figure B. Beady is an interactive system to assist the design and construction of customized 3D beadwork.

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page has a simple GIF animation that clearly explains the sewing-machine mechanism (see http://en.wikipedia.org/wiki/File:Lockstitch.gif). We plan to implement a similar illustration.

For a look at other design and support systems for fabricating physical objects, see the sidebar.

Acknowledgments

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Reference

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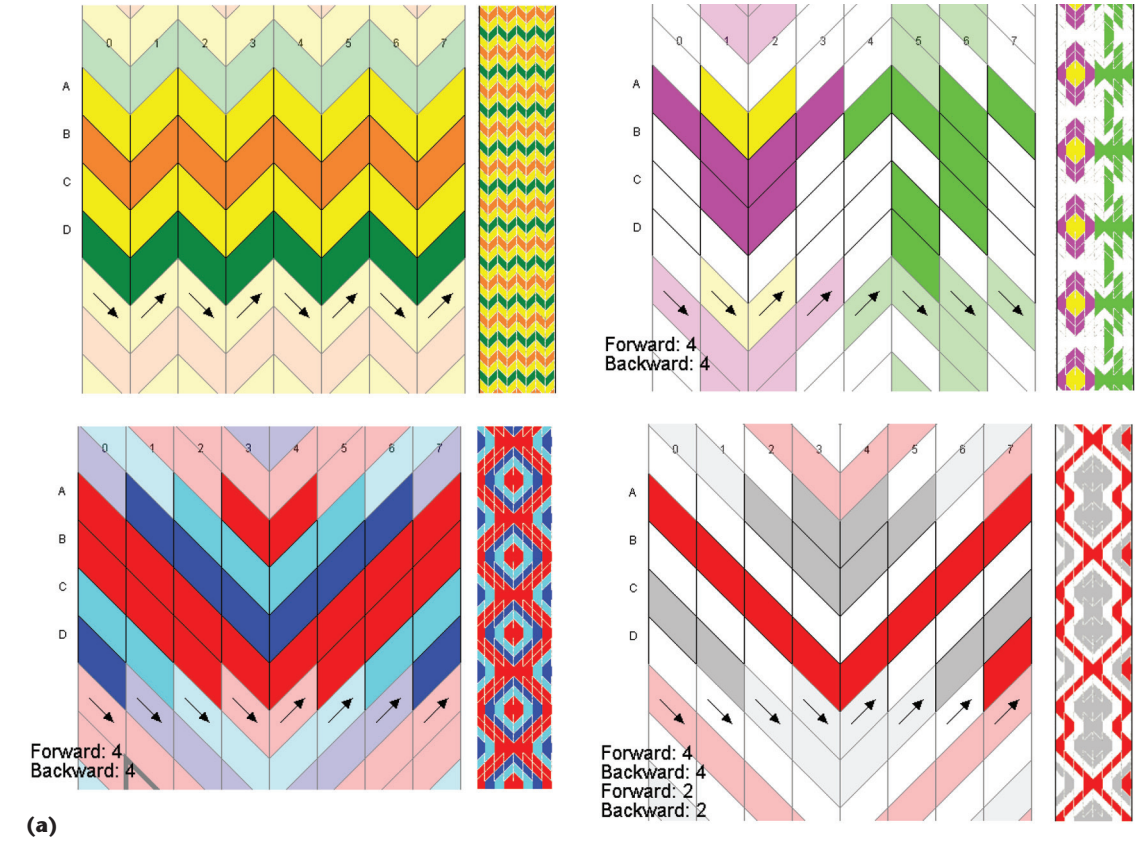

Figure 14. Patterns by the Siggraph participants in (a) standard design mode and (b) free-painting mode. (c) A long band woven by participants, which reached 172 cm.

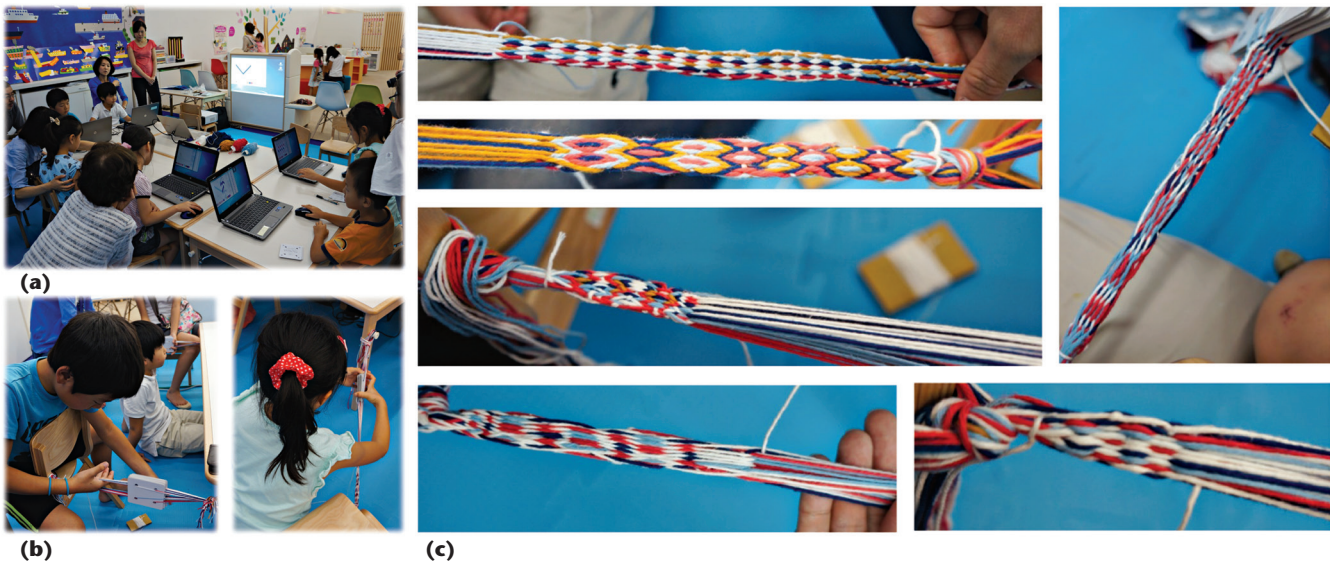

Figure 15. Children using Weavy. (a) Designing an original pattern. (b) Weaving bands. (c) A selection of bands. The entire process took approximately two hours.