The Aesthetics of Digital Weaving:
Tactile Sensibility in the Art of Lia Cook and Grethe Sørensen

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1. Introduction

No meaning can be conveyed without form.

—George Kubler, *The Shape of Time*

Woven art operates within a specific formal domain, one that has remained essentially unchanged since weaving was invented thousands of years ago; that domain is the forming of pliable planes of interlaced threads. The manner of this interlacing, the inner structure of the cloth, and the visual articulation of structure on the surface are the primary compositional elements of woven art. These elements distinguish this medium from other two- and three-dimensional art forms, including other textile arts. Exemplary woven art engages directly with this formal materiality, using structural elements to its advantage in its visual program. Fifty years ago, Anni Albers (1899-1994), the preeminent twentieth-century weaver, called this characteristic of textile art "a directness of communication."

"A fabric can be great art," Albers writes, "if it retains directness of communication in its specific medium. This directness of communication presupposes the closest interaction of medium and design….The more clearly the process relates to the form, the stronger the resultant impact will be." "In regard to visual articulation, texture, produced through the interlocking of threads, is the focal point in weaving." Directness of communication evidences itself in the cloth's texture or "tactile sensibility."[1]

Today, artists Lia Cook (1942) and Grethe Sørensen (1947) create woven textiles that rise to this level of great art using digital Jacquard hand looms. This technology did

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* George Kubler, *The Shape of Time: Remarks on the History of Things* (New Haven: Yale University Press, 1962), ix.

[1] Anni Albers, *On Weaving* (Middletown, CT: Wesleyan University Press, 1965), 62, 68, 75.

not exist during Albers's lifetime, yet the work of these artists exemplifies the seminal weaver's aesthetic of tactile sensibility with forms that she could only have imagined.

Digital-loom technology facilitates the rendering of complex weave structures in cloth, thus increasing the range of visual programs that can be expressed in the woven form. This has created fresh interest in the medium for both weavers and others in the arts. In a culture obsessed with photographic images, the ability to use Adobe Photoshop to reproduce a photo in woven cloth is one reason for the new interest in digital weaving. Beyond this, many users of digital-weaving technology focus on its capacity to produce nonrepeating representational or narrative imagery on a large scale, an effect that has largely eluded the individual artist/weaver other than through the use of traditional tapestry technique.[2] In many instances, the use of photographic processes in digital weaving disregards the cloth's tactile elements.[3] The cloth is judged by how realistically it reproduces the original photo, painting, or drawing. Woven art, which has long struggled to establish its place among the "fine arts" of painting and sculpture, has embraced its new digital potency with a focus on its visual rather than material effects.[4]

As the art historian George Kubler (1912-1996) points out, "A special character of major artistic invention resides in their *apparent* remoteness from what has gone

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[2] Mechanical Jacquard looms did have a limited ability to produce nonrepeating representational imagery but, as I discuss in chapter 2, this was not practical for the production of individual works of art and thus was rarely used for that purpose.

[3] Eva Basile, "Digital Tapestry," *Jacquard* 60 (September 2007): 13.

[4] Glenn Adamson identifies craft's material experience and specificity, in opposition to modern art's aspiration to purely visual effects, as one of craft's core principles. While outside the scope of this thesis, for a discussion of the confrontation between craft's materiality and modern art's opticality, see Glenn Adamson, *Thinking Through Craft* (New York: Berg, 2007), 4, 39. For a specific discussion of textile art in the art-versus-craft debate, see Elissa Auther, *String, Felt, Thread: The Hierarchy of Art and Craft in American Art* (Minneapolis: University of Minnesota Press, 2010), xi-xxx.

before them." (Emphasis added.) "As a result," Kubler argues, "it is easy to overlook the continuous nature of artistic traditions."[5] This paper, therefore, positions the digital Jacquard hand loom in a continuum of weaving technologies that spans thousands of years. It demonstrates that the distinctive digitally woven works of Cook and Sørensen are based on each woman's unique creative intuition and her ability to seamlessly integrate digital tools into an existing body of material-based craft knowledge. By maintaining the immediate relation with the working material and the work process that Albers believed was necessary for meaningful innovation in weaving, Cook and Sørensen use digital technologies to expand the horizons for the traditional woven form and give new life to an ancient yet enduring textile aesthetic: the tactile sensibility of cloth that Albers admired and advocated.[6]

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[5] Kubler, *Shape of Time*, 4, 63

[6] Anni Albers, *On Designing* (Middletown, CT: Wesleyan University Press, 1961), 15.

2. Anni Albers's Aesthetic of Tactile Sensibility

> Everything made now is either a replica or a variant of something made a little time ago.
>
> —George Kubler, *The Shape of Time*

Anni Albers was not only a distinguished and renowned twentieth-century weaver; she was a thoughtful, inspiring teacher and an engaging, eloquent aesthetic philosopher. As Nicholas Fox Weber argues, the combination of her exceptional woven art and her elegant, critical thinking on weaving and design elevated textiles as an art form. Weber notes that, thanks to Albers, "it has become completely acceptable for thread to be its own voice."[7] (Fig. 2.1)

Albers's textile aesthetic was grounded in her own experience as an artist working in the woven medium. Trained at the Bauhaus Weaving Workshop and influenced by important modern artists and critics such as Paul Klee and Wilhelm Worringer, Albers's woven artwork and thinking on weaving evolved from the doctrine of modernism. Modernism rejected narrative design and figurative imagery in favor of a universal language of pure abstract form. Truth in material and construction was a fundamental quality of this aesthetic. This meant that the building blocks of design had to be determined by the objective laws of construction, using processes that clearly relate to the resulting form. Ornament that was not a function of structure was unacceptable.[8] "The

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* Kubler, *Shape of Time*, 2.

[7] Nicholas Fox Weber, "Introduction: Why Anni Albers?" in *Anni Albers*, ed. Nicholas Fox Weber and Pandora Tabatabai Asbaghi (New York: Guggenheim Museum Publications, 1999), 9.

[8] See Paul Greenhalgh, "Introduction," in *Modernism in Design*, ed. Paul Greenhalgh (London: Reaktion Books, 1990), 12-15. For a fuller discussion of the Bauhaus and modernism see Gillian Naylor, *The Bauhaus Reassessed: Sources and Design Theory* (London: Herbert Press, 1985).

discipline of construction," Albers writes, "is a helpful corrective for the temptation to mere decoration."[9]

Although she took her cues from the modernist canons of truth in material and construction, in her exploration and application of those concepts to weaving, Albers articulated a timeless philosophy of the medium as an art form. Her essay collection *On Weaving*, published in 1965, remains to this day one of the most compelling expositions of the art and aesthetics of weaving.

The weavings of Ancient Peru constituted, for Albers, the archetype for the art form and the foundation of her aesthetic. "Of infinite phantasy within the world of threads…endlessly varied in presentation and construction, even though bound to a code of basic concepts, [the textiles of ancient Peru] set a standard of achievement that is unsurpassed," she writes.[10] Albers's aesthetic vision for weaving bridges the millennia since that era, and, as seen in the work of Cook and Sørensen, is as applicable to weaving created with sophisticated twenty-first-century technology as it was to Albers's own work of the mid-twentieth century.

For Albers, the fundamental nature of weaving is the horizontal-and-vertical intersecting of two separate systems of thread.[11] The more clearly this original formation is preserved and stressed in the visual program, the stronger the aesthetic impact of the weaving. This directness of communication, in the form of the intrinsic relationship between the visual and the structural, was at the heart of Albers's aesthetic standards for

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[9] Albers, *On Weaving*, 65.

[10] Ibid., 69.

[11] Ibid., 19-21. For a full discussion of weaving versus other textile formation techniques, see Irene Emery, *The Primary Structures of Fabrics* (New York: Thames & Hudson, 2009).

woven art. As she explains in *On Weaving*, the ability to "convey understanding of the interaction between medium and process that results in form" is one of the distinguishing features of weaving as an art discipline. Tending to purely visual properties of the surface is only a part of the actual work of weaving. "The inner structure together with its effects on the outside are the main consideration, " she writes.[12] Structural materiality identifies and differentiates the woven surface.

Albers's own weaving spanned both functional fabrics and woven art. Her Bauhaus training focused on hand-weaving models for machine production of furnishing fabrics. She enjoyed designing textiles for functional applications and continued to do this work for architects as well as high-end commercial textile manufacturers such as Knoll Textiles after she immigrated to the United States. Albers began to focus on weaving unique works of art in the 1930s and 1940s while she was an instructor in textiles at Black Mountain College.[13]

While structure was generally dictated by considerations of utility in functional textiles, Albers explains, non-functional textiles allowed "the aesthetic qualities" of

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[12] Albers, *On Weaving*, 21, 38, 65.

[13] Pandora Tabatabai Asbaghi, "Anni Albers 1899-1994," in Weber and Asbaghi, *Anni Albers*, 170; Marion L. Buzzard, "Anni Albers" in *Anni Albers: Prints and Drawings* (Riverside, CA: University of California, 1980), 3-4. The Bauhaus Weaving Workshop was the most successful of the Bauhaus workshops in terms of its collaboration with industry. Albers's Bauhaus diploma was awarded in 1930 for her 1929 design of a wall covering with unique sound absorption and light-reflecting qualities for a new auditorium in Bernau, Germany. Anni and her husband Josef immigrated to the United States in 1933 after the Nazis closed the Bauhaus. They became teachers at the experimental art school Black Mountain College near Asheville, North Carolina, where Anni began to use the loom to make art. *Anni Albers Textiles*, a one-artist show of her woven art, opened at the Museum of Modern Art in New York in October, 1949. This successful exhibition, arranged by Edgar Kaufmann Jr., then director of the department of Industrial Design at MOMA, traveled to twenty-six museums in the United States and Canada. See Asbaghi, "Anni Albers," 161-2, 170, 173.

structure to "move to the foreground."[14] Making art was a vital part of Albers's life and she thought as critically about the aesthetics of woven art as she did about the requirements of industrial design.[15]

For Albers, directness of communication in weaving manifests itself in a work's texture or "tactile sensibility." It is the "result, apparent on the surface, of the manner in which interdependent thread units are connected to form a cohesive and flexible whole." Tactility, the visual articulation of inner structure, defines the specificity of the textile medium. While woven cloth is essentially a two-dimensional form, texture is, in its essence, a dynamic, three-dimensional surface quality. At the heart of woven art is the "intriguing performance of a play of surfaces"—the visual effects that are precisely the result of the manner in which the threads are interlaced.[16]

In weaving, structure is the intellectually constructed form. Albers used the French word for material, "*matière*", to describe the qualities of weaving that are perceived aesthetically. Matière is the dynamic, spatial surface quality of the cloth, the creation of depth in a single plane. It is the visual articulation of texture, a quality of appearance. "[Matière] has to be approached non-analytically," Albers argues. It is not only a legitimate medium of the artist but also the most important aesthetic feature of woven art. The essence of weaving as an art form is precisely its ability to gain "representational means through the use of different surface qualities." Albers considers tactile surface characteristics to be a means as fully expressive as line or color. In fact,

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[14] Albers, *On Weaving*, 47.

[15] In chapter 9 of *On Weaving*, "Designing as Visual Organization" Albers spells out in thoughtful detail the steps required in designing a textile for hypothetical wall-covering material. Ibid., 73-9.

[16] Ibid., 62-64, 75.

she considers the color and character of the thread to be supporting elements of woven composition that should be used to underline the structural appearance of the fabric.[17] Implicit in this aesthetic is the idea that texture can be visually perceived, that the tactile properties of woven cloth converge with the purely visual ones, such as color.

Albers's high regard for tactility was also a function of what she perceives as a diminution in our sense of touch. Albers blames modern industry for providing a full range of finished products, eliminating the need to actually work with materials and idling our tactile sense. "Our tactile experiences are elemental," Albers argues. "If we reduce their range…we grow lopsided." She believes that matière effects in textiles will rekindle an awareness of touch and the creative capacities that are activated by it.[18]

Simplicity, creativity, and discipline are also foundations of Albers's aesthetic. Intricacy and complexity are not, in her view, "high developments" or evidence of advancements in the art form. She advocates instead for *simplicity,* which she carefully defines as "not simpleness but clarified vision." Expanding textile art comes then, and perhaps paradoxically, from what she calls "condensation," referring to a rigorous focus on basic concepts.[19] Importantly, this is not to be construed as a reliance on established patterns, which Albers derisively calls "approved repetition." The past success of traditional "recipes" for weaving does not guarantee their future relevance. Instead, she

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[17] Ibid., 47, 63-65, 75-76.

[18] Ibid., 62. Since Plato, Western philosophy has traditionally privileged sight as the most sophisticated of the senses and ranked touch as the lowest sense, with repercussions. This hierarchy is, as Adamson describes, the root of the binary opposition between the material in craft and the optical in modern art. See Adamson, *Thinking Through Craft*, 39. While beyond the scope of this paper, for more on textiles and touch beyond the writings of Albers, see, for example, T'ai Smith, "Limits of the Tactile and the Optical: Bauhaus Fabric in the Frame of Photography," in *Grey Room* 25 (Fall 2006): 6-31; and Jessica Hemmings, ed., *The Textile Reader* (London and New York: Berg, 2012), part I: "Touch," 3-53.

[19] Albers, *On Weaving*, 47.

sees vast opportunities for fresh, inventive, intelligent, and imaginative forms with a return to fundamental principles of weaving.[20] She seeks originality and creative freedom but always within the laws of the loom; thus she identifies the power of balance between innovation and discipline in woven expression. “There is no reason,” she writes, “why new contributions to textile development should not come from…the inventive use of elements of construction.”[21]

Albers also recognizes that expert knowledge of weaving is a prerequisite for working imaginatively within the specific formal domains of the craft. Proficiency in the fundamentals, allowing for the ability to develop a full range of weave structures from elementary forms to more complicated derivations, is needed. [22] Armed with expert knowledge, the grid of interlaced threads would not be a restriction but would stimulate a weaver’s creative energy.[23] “Acceptance of limitation, as a framework rather than as a hindrance, is always proof of a productive mind,” she says.[24] Albers believes that fully exploiting the possibilities of a medium is essential to creating high art.[25] For Albers, weaving was and will always be the forming of a pliable plane of threads by interlacing

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[20] Anni Albers, “Handweaving Today – Textile Work at Black Mountain College,” *The Weaver* 6, no. 1 (January/February 1941): 3.

[21] Albers, *On Weaving*, 61.

[22] Albers, “Handweaving Today,” 4.

[23] Anni Albers and Gene Baro, “A Conversation,” in Gene Baro, *Anni Albers* (Brooklyn: The Brooklyn Museum, 1977), 9.

[24] Albers, *On Weaving*, 39. Albers gave up weaving as her art medium for printmaking at age 67. In 1966, she completed her last major work of woven art, *Six Prayers*, a commission for the Jewish Museum in New York, two years after she made her first lithographs in 1964. She gave three reasons for giving up weaving: First, the fatigue of long hours at the loom; second, the opportunity in graphic art to breakaway from the rectilinear grid of weave construction; and third and perhaps most important, she offered, “Weaving is not generally recognized as an art but as a craft…,when the work is made on paper, its considered art. As a result recognition comes more easily and happily.” Albers and Baro, “A Conversation,” 6-8.

[25] Albers and Baro, “A Conversation,” 9.

them at right angles. She believes that "playfulness" that remains grounded in this formal domain will lead to what she considers "convincing innovation."[26]

The challenge, then, for woven art, operating within Albers's framework, is to develop designs within the natural grid of the weave structure that have sufficient visual complexity to be interesting.[27] "An orderliness that is too obvious," Albers says, "cannot become meaningful in [the] superior sense that is art."[28]

While Albers does not directly reference her own woven work in her writing, her weavings are the strongest evidence of her aesthetic philosophy. She skillfully met the challenge of making art within the formal domain of interlaced threads by exploiting the objective laws of sophisticated weave constructions. Albers used intricate weaves, such as gauze, and compound weaves, such as double-cloth and brocade, to create richly sculptural surface effects.[29] The lively, three-dimensional surface of *Open Letter* (1958), which is in the collection of the Josef and Anni Albers Foundation, was created using a plain weave featuring gauze variations and brocading with a simple black-white-and-red color scheme. *Black, White, Gold I* (1950), also from the collection of the Josef and Anni Albers Foundation, uses a plain-weave ground with unusual brocading. This piece uses several different threads in varying colors, weights, and materials to underscore the

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[26] Albers, *On Weaving*, 19, 70.

[27] See Mildred Constantine and Jack Lenor Larsen, *Beyond Craft: The Art Fabric* (New York: Van Nostrand Reinhold, 1973), 22. Constantine and Larsen credit Albers with the development of the "structural system of multiple harness weaving [as] a valid art form."

[28] Albers, *On Weaving*, 80.

[29] *Gauze* is a term used for weave structures that involve crossed threads. A *compound weave* is a construction that has more than two sets of elements (one warp and one weft). *Double-cloth* involves two complete sets of warp and weft interconnected at certain points. *Brocade* refers to patterning by means of supplementary thread elements. See Emery, *Primary Structures*, 74, 140, 171-2, 179-81.

construction.[30] (Fig. 2.2) The Cooper Hewitt Smithsonian Museum's collection includes several woven samples in double-cloth by Albers that demonstrate the versatility of surface effects available with this technique. (Fig. 2.3)

[30] Jean-Paul Leclerq, "On the Structure of the Weavings," in *Anni Albers*, ed. Weber and Asbaghi, 64-9. Leclerq provides a detailed description of Albers's innovative use of woven constructions.

3. Weaving Technologies

> Parallel to this overlapping of outer and inner characteristics in a work is the overlapping of artistic…and technological interests on the part of the weaver.
> —Anni Albers, *On Weaving*

> The idea of speed is seductive.
> —Lewis Knauss

Technology is an important facet of the history of art. All artists use tools, originally and typically mechanical, and now increasingly electronic and digital devices that extend the maker's physical capabilities.[31] While people use tools in everyday life, when artists use them, as Margo Mensing suggests, "they seek something else—to achieve some hitherto unforeseen result."[32]

Albers recognizes that machines often expand the opportunities open to the maker and she embraces the use of technology. She encourages weavers, and all craftsmen, to remain open to the creative possibilities offered by new tools.[33] In 1941, she presciently wrote, "Hand looms today are often limited technically. Why fit the theoretical knowledge to the present limitations of handweaving? Rather the theoretical work should be developed, expanding beyond the boundaries set to it now."[34] This suggested expansion offers new avenues for creative expression and artistic effects. As Brenda

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* Albers, *On Weaving*, 63.

** Lewis Knauss quoted in Margo Mensing, "Enter: Repeat," in *Bridging Worlds: The Visiting Artists Jacquard Project* (Philadelphia: Philadelphia College of Textiles and Science, 1996), Exhibition catalog, essay.

[31] Rebecca A.T. Stevens, "Introduction," in *Technology as Catalyst: Textile Artists on the Cutting Edge*, ed. Rebecca A.T. Stevens (Washington, DC: The Textile Museum, 2002), Exhibition catalog, introduction.

[32] Mensing, "Enter: Repeat," essay.

[33] Albers is critical of what she calls "a romantic overestimation of handwork in contrast to machine work." Anni Albers, *On Designing*, 15.

[34] Albers, "Handweaving Today," 4.

Danliowitz explains, "When it came to the opposition of the handmade and the machine-made object, Albers was a convincing advocate for a symbiotic rather than an adversarial relationship. Both methods of fabrication have their place in the creative process, where they can mutually enrich one another."[35]

Textiles thus offer excellent opportunities for understanding the role of technology in art. As the archaeologist Junius Bird explains, "The interconnections [between technology and art] are most evident in those fabrics where the desired results—the concepts of the artist—are achieved by structural means inherent in and inseparable from the craft itself….[Each of] all the many and varied ways in which fabrics can be created…in some degree influences, limits, or controls the end result…providing a challenge to the ingenuity, imagination, and skill of the artist."[36] Weavers have always had to operate within the limits of technology, and throughout history, as new weaving tools came into use, artists took advantage of them to produce innovative new textile effects.[37] "Weaving in any form is a constructive process," according to Albers.[38]

Albers understands the history of textile technology as a balancing act between two competing interests: speed and freedom of design. Weaving, which "builds a whole out of small parts," she writes, "is a process that is time consuming by its very nature."[39] The warp is a sheet of threads that run vertically and are laid out parallel to one another in

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[35] Brenda Danliowitz, "Introduction," in *Anni Albers: Selected Writings on Design,* ed. Brenda Danliowitz (Hanover, NH: University Press of New England, 2000), xii.

[36] Junius Bird, quoted in Mildred Constantine and Jack Lenor Larsen, *The Art Fabric: Mainstream* (New York: Van Nostrand Reinhold, 1981), 163-4.

[37] Stevens, "Introduction."

[38] Albers, "Handweaving Today," 3.

[39] Albers, *On Weaving*, 22.

a fixed order. With each row or pick of weaving, certain warps are raised to form the "shed."[40] The threads are then interlaced as the weft passes through the shed, under the raised warp threads and over the lower ones. The selection of raised warp threads in successive sheds creates the weave structure, the texture of the cloth, and its visual program.[41]

The earliest looms, such as those used by the ancient Peruvians, simply held the warp taut and in place, while the threads were selected and lifted manually and the weft inserted. (Fig. 3.1) Working in this way, while time consuming, was unrestricted, allowing the weaver total freedom in the order of interlacing warp and weft. Using these primitive looms, ancient Peruvian weavers mastered virtually every weave construction known to this day. Importantly, for the ancient Peruvian weaver, time was not a consideration. Textiles were the most highly valued sociocultural, political, and economic objects in pre-Inca societies, and significant resources were deliberately devoted to their production, including the allocation of specialized labor.[42]

After those primitive looms, as Albers so aptly recounts, "the main incentive" of early technological developments in weaving implements—the shed rods, heddles,

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[40] The "shed" is a v-shaped opening that is formed when some of the warp ends are raised and others are lowered. See *The Encyclopedia of Textiles by the Editors of American Fabrics Magazine* (Englewood Cliffs, NJ: Prentice Hall, 1960), 411.

[41] For simplicity, the process of weaving, in particular as it relates to the functionality of the loom, is generally broken down into three basic operations: (1) holding the warps under tension; (2) opening and changing the shed; and (3) inserting and beating the weft. See Eric Broudy, *The Book of Looms* (New York: Van Nostrand Reinhold, 1979), 8. While the evolution of loom technology has addressed all three of these operations, for the present purpose, this discussion focuses on the second step, the formation of the shed, as this is the action by which the warps are raised and the weave is structured.

[42] See Suzanne Baizerman,"Introduction to Pre-Columbian Double Cloth," in Adele Cahlander, *Double Woven Treasures from Old Peru* (St Paul, MN: Dos Tejedoras, 1985), 3-6, and Rebecca Stone-Miller, *To Weave for the Sun: Ancient Andean Textiles* (New York: Thames & Hudson, 1992), 17, 36.

harnesses, foot treadles—was "saving time." It was not a question of precision or reducing physical effort as was the goal with the mechanization of other crafts such as metalwork or woodworking. "Fabrics of great accuracy have been executed without much mechanical aid," Albers writes. And threads are not "a resistant material [that] has to be forced into shape." Unfortunately, all these time saving devices came at a price: "Each step towards the mechanical perfection of the loom…lessens the freedom of the weaver and his control of the design in working," according to Albers.[43]

The harness-and-treadle or shaft loom, the most common form of hand loom used today, is a direct descendent of the horizontal harness-and-treadle looms used in Europe in the Middle Ages.[44] (Fig. 3.2) On a harness-and-treadle loom, each warp thread is drawn through an individual heddle, a thin device used for controlling discrete warp ends. The heddles are suspended in groups on frames called harnesses or shafts. The harnesses are attached to foot pedals known as treadles. When a treadle is depressed, its associated harnesses and all the warps threaded on those harnesses rise, while the other harnesses remain down, forming the shed. The weft is inserted manually. Treadles are typically engaged in a repeating, predetermined order, and they, together with the threading of the warps on designated harnesses, determine the weave structure.

The harness-and-treadle loom greatly increased the speed of weaving. The use of foot pedals leaves the hands free to pass the shuttle. Lifting multiple warp threads to form the shed with one motion is also clearly faster than manually selecting and raising warps. But, at the same time, this type of loom constrains patterning. To lift any thread on a

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[43] Albers, *On Weaving*, 22, 25.

[44] Broudy, *Looms*, 141. The treadle loom was probably invented in China in the second or third century BC. Jennifer Harris, " Weaving," in Jennifer Harris, ed., *5,000 Years of Textiles* (Washington, DC: Smithsonian Books, 2004), 18.

given shaft, all threads on that shaft must be lifted. Harness-and-treadle looms have a fixed number of shafts and foot pedals.[45] The more harnesses or shafts, the more patterning possibilities there are. However, the number of shafts and pedals on a hand loom is limited generally to no more than twelve to sixteen, as having more would be unmanageable for a single weaver.[46] Warp threads, once threaded on their designated harnesses to accommodate the predetermined weave structure, cannot generally be rethreaded on different harnesses during the weaving process. As a result, repeat patterns are characteristic of hand-woven design. (Fig. 3.3) Once threaded, even compound harness looms have a comparatively small number of pattern shafts and corresponding treadles that can be conveniently managed.[47] Idiosyncratic patterns, such as pictorial and representational designs and curvilinear forms are almost impossible to render on a harness-and-treadle hand loom.

The draw loom and later the Jacquard loom were efforts to regain some of the freedom lost to harness-and-treadle looms. Each operated individual warp threads mechanically and facilitated the production of elaborate patterned and figured weaving in compound constructions.

The draw loom is thought to have been invented simultaneously in Syria and China in the first century AD. (Fig. 3.4) On a draw loom, a separate weighted string is attached to each individual warp thread. The strings are then attached in groups to a

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[45] Early medieval harness-and-treadle looms typically had two or occasionally as many as four harnesses. During the Renaissance, these looms were expanded to accommodate as many as twenty-four harnesses. See Broudy, *Looms*, 136, 146.

[46] Ibid., 124.

[47] Compound harness looms have two sets of harnesses — one for the ground weave and one for the figure or pattern. This is because the threading needed for figural patterns generally does not produce a stable woven cloth. Ibid.

numbered or coded cord called a leash or lash to create the design. Two people are required to work the loom: In addition to the weaver, a drawboy sits on top or at the side of the loom to pull or "draw" the leashes in the correct order. The number of leashes is of course fixed and limited by the ability of the drawboy to manage them but greatly exceeds the number of shafts that can be managed on a harness-and-treadle loom.

Draw loom technology spread west from its origins, throughout the Middle East and Byzantium, and eventually to Europe. Draw looms were used for centuries to weave intricately figured fine cloth, particularly luxury silks of great beauty. The historical importance of this type of loom has been compared to that of the printing press.[48] None of the exquisite patterned silk velvets and brocades of the Byzantine Empire; the elaborately figured lampas, damasks, and brocatelles of the Italian Renaissance, often woven with gold and silver threads; the fine-figured linen damasks produced in the Netherlands between 1500 and 1800; and the lavish polychrome "bizarre silks" of eighteenth century Lyon, France, could have been woven without the draw loom.[49] (Fig. 3.5)

The parameters of draw loom technology also influenced design: With a fixed number of leashes, draw loom compositions typically involve arrangements of discrete motifs that are repeated across the length and width of the fabric. While the nature of the motifs of these textiles changed over the centuries, the fact of the repeat persisted.[50]

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[48] N. Atasoy, W. Denny, L. Mackie, and H. Tezcan, *IPEK: The Crescent & the Rose: Imperial Ottoman Silks and Velvets* (London: Azimuth Editions, 2001), 198.

[49] See Atasoy et al., *IPEK,* 197; Harris, "Weaving," 19; Harris, *5,000 Years*, Part II, chapters 17-22, 165-87.

[50] Atasoy et al., *IPEK*, 18.

Despite the abundance of luxury fabrics produced on the draw loom, this technology was not without its challenges. The preparation of the draw loom was a lengthy process that demanded expertise and precision. Mistakes in threading the loom were not discovered until the cloth was woven, at which point it was uneconomical to make corrections.[51] Weaving a new design required retying the leashes, a time-consuming process. As a result, draw looms were often dressed to produce specific weave structures, which were then repeated in different colors or with minor variations.[52]

As early as the sixteenth century, inventors in France began experimenting with ways to improve the draw loom by replacing the drawboy with a more automated mechanism for raising warp threads. In 1804, Joseph-Marie Jacquard (1752-1834) finally succeeded with the official introduction of what came to be known as the Jacquard loom. (Fig. 3.6) This loom substituted punch cards and a machine for the leashes and drawboy. In this machine, each warp thread is attached to a hook associated with a needle. A series of cards precisely cut with holes are mounted on the loom to control the needles, with one card for each pass of weft. If there is a hole for a given needle, the needle along with its associated hook and warp thread is raised. If a needle does not find a hole in the card, the warp it controls remains lowered. Thus, designs no longer had to be tied up cord by cord and the series of cards for one pattern could be easily swapped out for another without retying the loom.[53] Shed formation would now be controlled by a single treadle and could be operated by a single weaver, working alone.[54]

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[51] Ibid., 198.

[52] Albers, *On Weaving*, 32-35; Alice Marcoux, *Jacquard Textiles* (Providence, RI: The Rhode Island School of Design, 1982), Exhibition catalog, essay; Atasoy et al., *IPEK,* 16.

[53] Marcoux, *Jacquard Textiles*, essay.

[54] Harris, “Weaving,” 19.

The Jacquard loom spurred a revolution in textile manufacturing. With its innovations, it became the dominant mode of manufacturing complex figured textiles for almost two centuries.[55] Initially used as a hand-operated loom for the production of luxury fabrics, the Jacquard loom disrupted labor markets as it reduced the need for the drawboys and the skilled workers previously required to thread draw looms. By the mid-nineteenth century, the Jacquard mechanism was successfully incorporated into automated power looms, eliminating the need for skilled weavers as well, and more importantly, facilitating the industrial production of intricately patterned textiles for a mass market.[56] (Fig. 3.7)

The Jacquard loom remained an industrial machine after it was automated and had certain design limitations. The number of warp threads that could be controlled horizontally was constrained by the size of the Jacquard device. The number of cards that could be realistically used for a single fabric was also limited, again generally necessitating repeats across the width and length of the fabric.[57] The Jacquard loom could be and was occasionally used to produce relatively small scale, nonrepeating

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[55] Alice Schlein and Bhakti Ziek, *The Woven Pixel: Designing for Jacquard and Dobby Looms Using Photoshop* (Greenville, SC: Bridgewater Press, 2006), 14. Mechanical dobby looms, which used punch card mechanisms to raise harnesses rather than individual threads, were invented in the mid-nineteenth century. These were used as an economical alternative to Jacquard weaving in order to produce textiles with less complex, principally geometric, rather than figured patterns. Lucy Trench, ed., *Material and Techniques in the Decorative Arts* (Chicago: University of Chicago Press, 2000), 122.

[56] Harris, "Weaving," 19. See also Trench, *Material and Techniques,* 246. Most technological advances in weaving textiles during the Industrial Revolution focused on speed by automating looms for mass production. These advances included automatic or "fly" shuttles and the use of steam-powered engines. The fact of mass-produced fashion textiles had far-reaching implications for both industry and consumers. Jacquard's punch card system would remain the most advanced means of warp manipulation for complex patterning until the end of the twentieth century.

[57] Marcoux, *Jacquard Textiles*, essay. Over time the size of the Jacquard mechanism increased, eliminating the need for horizontal repeats. However, vertical repeats persisted. The quantity of individual cards that could realistically be used, although often numbering in the thousands, was limited.

representational textiles. The well-known mid-nineteenth century weaving of a portrait of Joseph-Marie Jacquard and of the loom that bears his name is one example.[58] (Fig. 3.8) These small *tableaux tissés* were typically novelty fabrics and their pictorial realism was used to demonstrate the technical skill of the Jacquard designer/weaver.[59] The Jacquard loom was not widely used by artists for discrete works of creative expression.

Thus, even with the technical innovations of the draw and Jacquard looms, until the late twentieth century, manual warp selection remained the only means for weaving idiosyncratic designs without repeating patterns. Since the days of the ancient Andean weavers, variants of tapestry technique, which is a wholly manual weaving process, continued to be used (and are still used today) to create designs featuring complex use of multiple colors, such as pictorial, representational, or figurative imagery in cloth. (Fig. 3.9) Tapestry weaving is wholly dissimilar, both technically and functionally, from draw loom, Jacquard, or harness-and-treadle weaving.[60] Tapestry weaving may be generally described as those techniques where the warp threads are completely covered by successive discontinuous wefts in different colors. By covering a limited and variable number of warps, the wefts create the intended design in a mosaic-like fashion.[61] (Fig. 3.10)

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[58] Woven portraits of the inventor and his loom were produced upon his death in 1834 and were used to commemorate his achievements by showing off the capabilities of the loom. One of these woven portraits is in the collection of the Cooper Hewitt Smithsonian Design Museum. It is only 17½ inches high by 13½ inches wide. (Fig. 11) It is estimated that twenty-four thousand punch cards were required to weave this type of portrait. See James Essinger, *Jacquard's Web* (Oxford: Oxford University Press, 2004), 5. It was not economically viable to weave cloth commercially with designs that required this many punch cards.

[59] Basile, "Digital Tapestry," 9.

[60] See Broudy, *Looms*, 124.

[61] Raoul D'Harcourt, *Textiles of Ancient Peru and Their Techniques*, ed. Grace C. Denny and Carolyn M. Osbourne, trans. Sadie Brown (Seattle: University of Washington Press, 1962), 21. A

In the European tradition, tapestries were generally woven on vertical looms with no harnesses or treadles: Warp threads were selected and lifted by hand, guided by a cartoon placed behind the vertical warps. Using discontinuous wefts and hand manipulation of the warp, while enormously time consuming, affords the weaver complete freedom to create discrete areas of color. With weft threads custom dyed in a wide range of colors, this weave structure allowed the almost-literal reproduction in cloth of the pictorial and figurative imagery that dominated the Western European tapestries from the Middle Ages until the early twentieth century.[62] During the Renaissance, for example, while draw looms were being used to weave luxurious furnishing and fashion fabrics, the great patrons of the arts commissioned monumental narrative tapestries to flaunt their wealth and power.[63] (Fig. 3.11) It is only in the past fifty years, with the application of digital technologies to weaving, that complex idiosyncratic imagery could be rendered in woven textiles that use both warp and weft in the visual program, achieving finally a more perfect harmony between not only speed and freedom but also weave structure in intricate woven design.

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discontinuous weft does not run selvedge to selvedge across the full width of the warp. Instead, it is inserted in only those areas of warp as called for by the design.

[62] With the advent of modernism in the twentieth century, the pictorial tradition in tapestry fell out of favor. Neither the figurative imagery nor the weave structure of traditional tapestry conformed to the new modern aesthetic. Naylor, *Bauhaus Reassessed,* 109.

[63] These great patrons chose "tapestry as a medium of art." Thomas Campbell, *Tapestry in the Renaissance: Art and Magnificence* (New York: Metropolitan Museum of Art, 2002), 3. The ten tapestries of *The Acts of the Apostles* series (1561-21), woven in Brussels for Pope Leo X, after cartoons painted by Raphael, and the fourteen tapestries of *L'Histoire du Roi* series (1667-72), woven at the *Manufacture des Gobelins* in Paris, after cartoons by Charles LeBrun for Louis XIV, are examples of monumental tapestries from the European tradition.

4. The Digital Jacquard Hand Loom

> Among craftsmen, a technical innovation can often become the point of departure for a new sequence where all the elements of the tradition are revised in light of the possibilities opened to view by the innovation.
>
> —George Kubler, *The Shape of Time*

For more than one hundred years, Jacquard designers used point paper to hand draw the patterns used to "program" their mechanical looms. (Fig. 4.1) Point paper is a kind of graph paper on which each column and row corresponds to an individual warp or weft, respectively, and on which the size of the grid conforms to the ratio of the size of the warp to the weft. A darkened box on the grid indicates a raised warp thread and calls for a hole in the punch card for that row of weft. Historically, cards were punched manually, following the layout from the point paper.

In the course of the twentieth century, digital technology infiltrated industrial Jacquard textile production.[64] The innovations were driven by economics—the attempt to produce value through more efficient commercial production of complex woven cloth. Point paper was no longer drawn by hand but rather created by computer, using

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* Kubler, *Shape of Time*, 43.

[64] A discussion of Jacquard's loom and digital technology would be remiss without mentioning the recent research illuminating the debt owed by modern digital technology to Jacquard's loom. In the late 1830s, the British mathematician Charles Babbage (1791-1891) developed his plan for the "analytical engine," described as the first programmable calculating machine. Although it was never built, it is evident from Babbage's plans and autobiography that the mathematician was familiar with the Jacquard loom and that the analytical engine "relied entirely on the principle behind Jacquard's loom for its operation." This principle was quite simply the punch card: "the idea of having the presence or absence of a hole stand for a numerical quantity or a specific item of information." Essinger, *Jacquard's Web*, 164.

This notion of the presence or absence of a hole, which in Jacquard's application signified the position of a warp thread (up or down) in a given row of weaving, has evolved into the binary code (zeros and ones), which is the mathematical foundation for all computer languages. For a detailed history of Babbage and his analytical engine as well as the role of Jacquard's punch card principle in the development of modern computers, see Essinger, *Jacquard's Web*.

specialized software programs. The next step was computer-controlled card punching. Finally, punch cards were eliminated altogether, and in 1979 the first digital Jacquard looms, entirely controlled by computer, were available for industrial use. The point paper type files produced on the computer linked seamlessly to software that controlled the raising of individual warp threads. While early machines still required pattern repeats, today's industrial Jacquard looms offer the opportunity to create designs with no repeats in height or width.[65]

The early industrial innovations, however, were of little consequence to the individual textile artist.[66] Until the late 1990s, digital Jacquard looms were designed and built almost exclusively for industrial purposes. They were large, heavy, and very expensive machines designed for the wide fabrics and long runs desirable in commercial production. It was prohibitively expensive, if at all possible, for individual artists to get time for experimentation or production of small-scale works on commercial digital looms. Further, industrial looms, designed for high-speed production, could only accommodate certain weave structures. Unusual weaves—for example those with long floats—created friction and stress on the threads. Broken threads were time consuming to repair and the downtime was expensive.[67]

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[65] Schlein and Ziek, *Woven Pixel*, 16-18.

[66] Computer technology was also applied to the dobby loom format. The Compu-Dobby introduced by AVL Looms in 1982, and its successors, used software programs to create designs and to interface with an electronic dobby mechanism that raised selected harnesses. These looms were accessible to the studio weaver and stimulated tremendous interest in complex multiharness weave structures by both facilitating weaving with multiple shafts and increasing the number of harnesses that could be manipulated on the loom. Today, AVL's V-Series dobby looms may be outfitted with up to forty harnesses. While digital dobby looms dramatically increase woven patterning opportunities, the arrangement and sequencing of warps on a finite number of harnesses still does not allow for the total freedom of manipulating individual warp threads.

[67] Lia Cook, interview by the author, November 2, 2014.

In the 1980s and 1990s, textile manufacturers, educators, and artists alike recognized the wealth of creative possibilities open to woven art through true Jacquard technology and created opportunities for artists to have access to industrial Jacquard looms.[68] These "Jacquard projects" introduced weavers to the technology and to the prospects for innovative new art forms. Implicit in each of these projects was the recognition of the value of technology as a tool to extend the artistic capabilities of the artist's hand.

In 1980, seventeen American weavers, including major figures in the fiber arts field such as Ed Rossbach, Gerhardt Knodel, Cynthia Schira, Lesley Shearer, and Lia Cook, were invited to participate in the first Jacquard project, held at the Rhode Island School of Design (RISD), in Providence, RI.[69] RISD identified efforts to create imagery using complex multiharness weave structures as "an emerging new direction in contemporary woven textile art" and recognized the utility of the Jacquard loom as "a practical means for weaving the most detailed images that can be accomplished in woven structures"—structures "that would otherwise take enormous amounts of time to execute on a conventional loom." At the time, RISD was the only art school in the United States

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[68] The fiber arts revolution of the sixties and early seventies, like the culture of the time, emphasized freedom of expression and witnessed an explosion of free-form, off-loom woven constructions by artists such as Sheila Hicks, Lenore Tawney and Claire Zeisler. By the late seventies, there was renewed interest in loom-woven and loom-controlled works. In their book, *The Art Fabric: Mainstream*, Mildred Constantine and Jack Lenor Larsen called this trend "the new classicism," a movement in which they include the work of weavers such as Warren Seelig, Trude Guermonprez, and Lia Cook. They also referred to Albers as the "arch-classicist." As an offshoot of this, several artists, like those who participated in the RISD Jacquard project, developed strong interests in more complex loom-controlled weave structures. See Constantine and Larsen, *The Art Fabric*, 22-23, 163-69.

[69] The artists were Adela Akers, Merle Barnett, Carole Beadle, Lia Cook, Lillian Elliot, Terry A. Gentille, Francoise Grossen, Nancy Guay, Diane Itter, Gerhardt Knodel, Alice Marcoux, Ed Rossbach, Cynthia Schira, Lesley E Shearer, Sherri Smith, Maria Tulokas, and Katherine Westphal.

to have an industrial Jacquard loom. Built in 1910, it was a mechanical machine, not a digital loom: it still used punch cards to control the patterning.[70] (Fig. 4.2)

In the RISD project, the artists' designs had to conform to the limitations of the loom: the school's machine had a very narrow four-and-one-half-inch repeat. The material and number of warp threads per inch were fixed and the loom could only accommodate specific types of weft threads. The artists were given very specific instructions on how to document their designs, using the traditional manual point-paper process. They submitted their completed point paper before arriving in Providence in order to allow time for the RISD technician to cut the punch cards needed to program the Jacquard mechanism. Each artist then spent three to five days at the loom, working at all times with a RISD technician.[71] The project concluded with an exhibition of the textiles created by the invited artists alongside historical Jacquard fabrics, which was held at RISD in 1982. (Fig. 4.3) The exhibition subsequently traveled to the Cooper Hewitt Museum in New York.

The artists in the RISD project all recognized the possibilities offered by the Jacquard mechanism: "The loom was drawing in three dimensions…," observed Gerhardt Knoedel, "[recreating] the image which I had prescribed." "The Jacquard loom allows a great deal of freedom…of imagining…[including the exploration of the] textural subtleties of form," commented Cynthia Schira. At the same time, the inherent limitations of the machine were evident to the artists. The exhilarating freedom of operating four hundred independent warps was tempered by the boundaries of the almost two-hundred-year old technology: the predetermined and narrow repeats, the size and type of thread,

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[70] Marcoux, *Jacquard Textiles*, essay.

[71] Ibid.

and the fixed nature of the cards mounted on the loom. “The process seemed so inexorable,” noted Ed Rossbach, “it frustrated my efforts to think creatively.” It was not practical to start, stop, make changes, and start again. And while the weaver conceived of the design, he or she ceded control over how the fabric was woven to the machine’s automatic shuttle. Nonetheless, they recognized, in Lesley Shearer’s words, that “there is much potential waiting to be realized.” Even Rossbach concluded, “All I wanted was the chance to make a new point paper, to try again.”[72]

In 1991, five weavers participated in a groundbreaking Jacquard project organized by Beatrijs Sterk, the editor of the German magazine *Textilforum* and the head of the European Textile Network. Müller Zell GmbH, a Jacquard textile mill in Germany, had recently opened a unique “high-tech unit.” This unit featured what was, at the time, the revolutionary Dornier Rapier electronic Jacquard loom, controlled by computer software rather than punch cards. Eager to explore and publicize the artistic and technical innovations possible with their new digital loom, Regina and Werner Henschel, the owners of Müller Zell, invited the textile artists to work on the digital loom during the month of August, while the factory would otherwise be closed for the summer holiday. The group included four Americans, Cynthia Schira, Pat Kinsella, Sheila O’Hara, and Lia Cook, none of whom had ever worked on a digital loom. The German weaver Hanns Herpich, who had worked on Müller Zell’s new digital loom on previous occasions, joined them. Vibeke Vestby, a weaving professor from Norway’s National College of Art and Design in Oslo, was also on hand to provide technical advice to the artists, along with

[72] Marcoux, *Jacquard Textiles*, artists’ statements.

three plant managers, two master weavers, and four computer programmers from Müller Zell.[73] (Fig. 4.4)

For the Americans, their first opportunity to work on an electronic Jacquard loom was a revelatory experience. The Müller Zell Dornier Rapier loom could handle a variety of warp and weft configurations and large repeats (e.g., two-and-one-quarter by three-and-one-quarter feet). More important, gone was the tedium of drawing point paper—a process that Schira estimated took her over one hundred hours to complete when working on the RISD project. Designs were scanned into the computer; manipulated into weave programs using sophisticated, fully electronic CAD/CAM technology; and then fed directly into the loom. It was also significant that if the artist chose to make an alteration in design after seeing the fabric being produced, the computer interface allowed the changes to be made and incorporated immediately into the weaving process. The speed of the process and the capacity of the machine to manipulate individual threads facilitated "a creativity that many artists perceive to be missing…sometimes from hand weaving." Schira called it "an experience more akin to the spontaneity of glassblowing than to the deliberateness of hand weaving."[74] Still, the size and cost of the Dornier Rapier loom coupled with the sheer volume of technical support required made this digital technology impractical for an individual artist's studio.[75]

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[73] Cynthia Schira, "The Jacquard Project," *American Craft* 52 (February-March 1992): 38. The Dornier Rapier electronic loom was introduced in 1989 by the German specialty-engineering manufacturer Lindauer Dornier GmbH.

[74] Schira, "Jacquard Project," 40.

[75] Cook, interview, November 2, 2014. Cook subsequently returned to Müller Zell, the management of which graciously allowed her to use the loom for another personal weaving project. However, the technician there did not appropriately adjust the loom to accommodate Cook's weave structure, a complex triple-cloth. The loom broke down and was out of operation

The five artists produced a variety of work in this collaboration with industry, which was exhibited both in Germany and in the United States. Sheila O'Hara opted for pictorial imagery with her swimming fish pattern. Pat Kinsella juxtaposed brightly colored abstract forms. Lia Cook wove with a custom warp (produced at Müller Zell's expense), painted with an image of a draped fabric, and used a damask weave structure to superimpose a second drapery image.[76] (Fig. 4.5)

A second Jacquard project was held in the United States in the early 1990s. The Bridging Worlds: The Visiting Artists Jacquard Project was conceived by and hosted at the Philadelphia College of Textiles and Science, School of Textiles and Materials Technology (STMT) from 1993 to 1995. The intent behind the project was to revisit the Jacquard project originally held at RISD in the early 1980s, this time using the state-of-the-art industrial digital Jacquard technology housed at the STMT and thus build "a bridge between industrial processes and creative thinking."[77] Bhakti Ziek, then assistant professor of woven design at the STMT, oversaw the project.

Cook and Schira were among the ten artists who each spent five days in residency at the STMT over the two-year period.[78] There, assisted by graduate weaving students in the textile design program at the STMT who acted as technicians, each artist used a computer to design their cloth, which was then manufactured on the school's industrial

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for an extended period of time. Müller Zell was reluctant to permit individual artist's projects after that costly experience.

[76] Schira, "Jacquard Project," 40.

[77] Richard A. Nigro, "Preface," in *Bridging Worlds*.

[78] The group consists of Lia Cook, Virginia Davis, Emily DuBois, Barbara Eckhardt, Lewis Knauss, Gerhardt Knodel, Christine LoFaso, Fuyuko Matsubara, Laura Foster Nicholson, and Cynthia Schira. At the time, all were professors in the textile field at universities in the United States, except for Davis and Nicholson who were studio artists. Cook and Schira participated in both the RISD and Müller Zell jacquard projects. Knodel had participated in the project at RISD.

Jacquard loom. The STMT's loom, a Somet Jacquard system loom with a Staubli head, had the kind of limitations typical in an industrial digital Jacquard at that time: It had a fourteen-inch repeat with ninety ends per inch in a fifty-six inch warp and a choice of only two warp configurations — white cotton-polyester thread, or a rotation of black cotton threads and white cotton threads that could be used for double-cloth constructions. Given those limitations, most of the participants—particularly those with previous industrial Jacquard experience—took advantage of the production and speed capabilities of the loom, endeavoring to create as much cloth as possible rather than to produce unique works of art. It was an opportunity to explore possibilities rather than artistic statements.[79] As Cook explained at the time, "One of the things that computer Jacquard technology can do is to create a large quantity of cloth in infinite variation within a short period of time." As a result, one of her goals was " to create a vocabulary of images that [she] could reconfigure in different ways producing a series of large scale fabric lengths, each different."[80]

From a design perspective, the artists in this project largely chose to "treat the fabric graphically rather than to explore textures and structures," thus taking advantage of the Jacquard technology's unique ability to reproduce representational imagery.[81] Using photographs or drawings as sources, they created a diverse body of work featuring a range of pictorial forms: Cook created an image of hands against drapery, Virginia Davis depicted Mao Tse-Tung and Marilyn Monroe, and Laura Foster Nicholson rendered garden tools and plants. (Fig. 4.6)

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[79] Mensing, "Enter: Repeat," essay.

[80] Lia Cook, quoted in Mensing, "Enter: Repeat," essay.

[81] Mensing, "Enter: Repeat," essay.

While the artists were thrilled with the speed of the loom and its graphic capabilities, they experienced a sense of separation from the actual weaving process. The STMT's industrial loom used a fully automatic shuttle for inserting weft. There was no actual hands-on participation in the interlacing of thread. Not only did the artists feel "the loss of making," but the cloth they produced lacked "the individual marks and changes" that are the result of hand weaving.[82]

In her essay for the exhibition catalog for the work produced in the Bridging Worlds project, Margo Mensing speculated on the future of digital Jacquard technology in textile art.[83] At the time, the STMT was the only educational institution in the United States with a digital Jacquard loom. It was an industrial loom, as the school was focused on training students for careers in industry, not the arts. It was not clear at that time, given the considerable cost of the Bridging Worlds project, how the school would extend the opportunity to work with digital Jacquard technology to other artists or permit the participating artists further use of the loom.[84] "One thing is certain," Mensing concluded, "the artist can not follow this route on her/his own."[85] Mensing may have been unaware at the time of work underway to make digital Jacquard technology fully accessible to the individual artist in a hand loom format.

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[82] Emily Dubois quoted in Mensing, "Enter: Repeat," essay. Industrial looms are generally carefully and tightly modulated so that each pick of weft has the same tension and is beat into the warp with consistent density, resulting in regular and precisely woven cloth, which is generally desirable in a commercial context. In the past few years, however, industrial Jacquard looms have been given the ability to mimic certain effects of handweaving.

[83] Margo Mensing was an adjunct assistant professor at the School of the Art Institute of Chicago.

[84] Mensing, "Enter: Repeat," essay. The Bridging Worlds project had a number of corporate sponsors, including Sunbury Textiles Mills, Inc., and Cotton, Incorporated.

[85] Mensing, "Enter: Repeat," essay.

The genesis of the Thread Controller (TC) digital Jacquard hand loom later produced by Digital Weaving Norway was one weaver's determination to correct the persistent imbalance between speed and creative freedom in woven art. In the mid-1980s, Vibeke Vestby (1954) was a weaver and professor at the National College of Arts and Design in Oslo, Norway, with a strong interest in complex, multiharness weave structures and figured compositions. Both she and her students were frustrated by their inability to realize complex designs with the available weaving technology. The college had a drawloom, which offered interesting design possibilities but proved impractical: tying the leashes was cumbersome and time consuming and it was nearly impossible to find someone to act as drawboy for a project of any size. Vestby obtained two old, discontinued mechanical Jacquard looms for the school from a weaving mill in Norway. Eliminating the drawboy facilitated and sped up the actual weaving, but the manual point paper/punch card process proved too time consuming for small-scale or one-off projects. Commercial services were available to punch cards mechanically, but they were too expensive for an educational setting. Computer-controlled dobby looms offered another alternative, but even this technology was insufficient. "No matter how many harnesses I had on a dobby loom, I always needed one more for my pattern," Vestby remembers.[86]

Vestby was aware of the electronic Jacquard loom technology and related software used in industry, even if she only "dreamed of having access to such equipment." She was convinced that if a computer could be programmed to control a studio-size sixteen harness dobby loom with manual weft insertion, it could also be programmed to control a thousand individual threads on a similar loom. Her opportunity

[86] Vibeke Vestby, interviews by the author, Providence, RI, July 12-16, 2014.

came in 1990 when the government of Norway announced a special grant program for educational institutions. The Information Technology Program was intended to direct some of the government's surplus revenue from North Sea oil drilling to research projects whose purpose was to incorporate new technology into more traditional endeavors. Vestby applied for and received two $250,000 grants, one in 1990 to fund a feasibility study for a digital Jacquard hand loom and the second in 1991 for the development of an actual prototype. She worked with her weaving students as well as with colleagues in the Industrial Design Department at the college on developing specifications and then teamed up with Tronrud Engineering, a Norwegian engineering company that specializes in automating complex production processes, to build the prototype.[87]

Vestby envisioned an easy-to-use digital hand loom that would be controlled by the artist from the initial design through the weaving of the cloth. Industrial Jacquard technology required specially trained technicians: this was impractical and unrealistic for an artist's loom. The loom had to be manageable for an individual weaver working alone. Maximizing freedom of design, ease of loom preparation, and facility of weaving with hand-inserted weft were further objectives.[88] "Only then can the loom become a powerful tool in a creative process," Vestby says. "We wanted this freedom…with the advantage of a hand operated loom, which makes possible that the weaver controls every single pick." With a hand loom, the artist can also employ a range of techniques that are not

[87] Ibid. Tronrud did not operate in the textile industry and had no specific expertise in textile processes.

[88] Ibid.

possible in industry, including painted warps, unusual weft materials, unusual weave structures, discontinuous wefts, and various finishing treatments.[89]

The first working prototype of the TC loom was introduced at the Internationale Handwerksmesse—Talentbörse, a specialized trade fair for skilled crafts, in Munich in March 1991, and it was well received. Vestby was convinced there was a market for the new loom but struggled to find funding for further development of the technology. The Norwegian government refused to fund the commercialization of the loom and the Information Technology Program was discontinued in 1992.[90]

In 1995, Tronrud Engineering decided to revisit the project and approached Vestby, who retained the patent for the prototype loom. Tronrud was interested in developing a product for the individual end-user market, something apart from the industrial applications of its typical projects. With Tronrud's engineering and production skills and Vestby's understanding of Jacquard principles and hands-on weaving experience, together the two created a loom that would be intuitively, intellectually, and functionally accessible to individual textile artists.[91] In 1995, Digital Weaving Norway, a newly formed division of Tronrud Engineering, brought the Thread Controller 1 (TC-1)

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[89] Vibeke Vestby, "TC-1 History", http://dwn-tc2.blogspot.com/p/tc-1-history.html, accessed October 17, 2014. Discontinuous wefts are wefts that do not run selvedge to selvedge. The painted warp that Cook used at Müller Zell was produced for her and paid for by the company at considerable expense. This experiment on an industrial loom would be costly and difficult for an artist to replicate. Cook, interview, November 2, 2014.

[90] Vestby, interviews, July 12-16, 2014. Vestby used the period in between the creation of the prototype and the reengagement with Tronrud to further her understanding of Jacquard principles, including a stay in 1992 at La Fondazione Arte della Sette Lisio, a study center for Jacquard silk weaving outside Florence, Italy.

[91] Tronrud's lack of experience with industrial Jacquard machinery may have facilitated the development of the TC loom. Rather than attempting to adapt industrial technology to a hand loom format, the company focused on reengineering the hand loom to manipulate individual warp threads. Vestby, interviews, July 12-16, 2014.

loom to market.[92] (Fig. 4.7) In 1997, Vestby left her teaching position at the Oslo College of Art and Design to commit herself full time to the marketing and further development of the TC loom at Tronrud Engineering.[93]

In addition to the loom itself, Vestby and Tronrud had to develop software for weavers to use in design development and for the interface between the weave files and the loom. In the 1990s, only industrial Jacquard programs existed and they were more expensive than the TC loom itself. Their early design software Weave for Windows was developed by a Tronrud engineer. It was based largely on dobby design programs and was fairly limited in terms of realizable weave structures. Ultimately, the development of the now-sophisticated interface software would be outsourced to specialized programmers.

In about 2000, Vestby began to use Photoshop in the design process by scanning old Jacquard point papers into Photoshop and manipulating them.[94] In 2006, two American weavers and college professors, Bhakti Ziek and Alice Schlein, published the book, *The Woven Pixel: Designing for Jacquard and Dobby Looms using Photoshop*, a self-study guide to using Photoshop to design for the digital loom. Today, Photoshop is the most commonly used digital design software for digital weaving because it is widely

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[92] Ibid. In the mid 1990s, at about the same time as Vestby's work in Norway, AVL Looms, the American company known for its digital dobby looms, introduced its own version of a digital Jacquard hand loom, which is an AVL hand loom outfitted with a Jacquard head made by TIS, a French manufacturer of industrial digital Jacquard equipment. This setup is much larger than the TC loom and was adopted primarily by educational institutions in the United States, such as the Savannah College of Art and Design, where it is still in use today. Today, AVL manufactures its own Jacquard head. Peter Straus, vice president, AVL Looms, interview by the author, November 20, 2014. The discussion here focuses on the development of Digital Weaving Norway's TC loom as that is the loom used by Cook and Sørensen.

[93] Vestby, interviews, July 12-16, 2014.

[94] Ibid.

available with easily accessible technical support and training and it can be readily used to convert photographic images to weave structures.

The TC-1 was adopted widely in Europe by artists and teaching institutions but only selectively in the United States.[95] It was expensive and Vestby saw an opportunity to make the loom less expensive and even more weaver friendly. In July 2012, after two years of development, the Thread Controller 2 loom (TC-2) was introduced at the Handweavers Guild of America's Convergence Conference in Long Beach, California.[96] (Fig. 4.8)

The TC loom is a groundbreaking innovation in the continuum of devices developed for balancing speed and freedom in complex woven design. The TC offers the complete freedom of the earliest manual warp selection—allowing a nonrepeating design across the entire length and width of a woven textile using a variety of weave structures—combined with the speed and flexibility of twenty-first-century digital technology. At the same time, the TC preserves what Vestby calls "the weaver's intimate relationship with material and structure."[97]

The TC loom is set up in much the same way as is a traditional hand loom, except that there are no shafts or harnesses. Each warp thread is passed through an individual heddle, which in turn is attached to its own individual air cylinder rather than to a harness. A laptop computer operates the loom software that identifies the heddles to be

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[95] As discussed later in the paper, Cook was an early adopter of the TC-1 loom, acquiring her first loom in 1999.

[96] Vestby, interviews, July 12-16, 2014.

[97] Ibid.

raised for each pick of weft. The selected heddles are lifted by means of a compressor and air pump attached to their respective air cylinders.[98]

Design programs for the TC loom are very much like vast sheets of point paper but produced on the computer. The loom itself requires only the input of a computer file in a TIF format. TIF is short for TIFF, or tagged image file format. These files are also known as tagged image bitmap files and are widely supported by graphic-design and image-manipulation applications. The bitmap is a graphic composed of a grid of pixels in different colors. Each column corresponds to a warp thread and each row corresponds to a pick of weaving.[99] The TC loom reads bitmaps in only two colors, black and white. A black square in a given row calls for the warp thread corresponding to the square's column to be raised in that pick of weaving. A white square in a row indicates that the corresponding warp should remain lowered in that pick.

The weaver depresses a single foot pedal to change the weaving shed. Wefts are inserted by hand. The computer screen, visible to the weaver, clearly shows which line of weft is being woven. The program can be stopped and reversed if the weaver wishes to unweave one or more rows. Minor changes in the design may be made directly on the laptop at the loom. For wholesale changes to the pattern, the program is removed and manipulated in the original design software, such as Photoshop, before reloading it to the loom.

The immediate relationship between the weaver and the weaving with the TC loom is unique. The ability to start, stop, unweave, and make changes to the design

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[98] This description of how the TC loom operates is based on my personal experience. I was a student in an instructional workshop on the use of the TC-2 loom taught by Vibeke Vestby and Cathryn Amidei in Providence, RI, which was held from July 12 to 15, 2014.

[99] A pick is an insertion of weft.

exceeds even that available with a traditional harness-and-treadle hand loom.[100] This remarkable feedback system allows weavers to adjust their work in response to what they just wove and preserves a vital human connection to the process.[101] The TC loom's manual weft insertion is another human connection to the weaving. When inserting and beating the weft manually, the weaver controls the weft tension as well as the density of the weave, preserving the opportunities for spontaneity, improvisation, and diversity inherent in hand work.[102]

This chapter began with the premise that all artists use tools. Making, as Glenn Adamson notes, is almost always a triangulation between the artist, material, and tools. In the context of advanced technology, "there is no particular reason why any particular type of tool should be considered ineligible for this relation," he argues. The transformation of traditional forms of making demands the transformation of the skill required on the part of the maker. Or, in Adamson's words, "Craft skill…is not simply eroded….Rather it [is] displaced into new types of activity." For example, computers, he points out, do not necessarily increase the mediation between the hand of the maker and the finished product.[103] The computer becomes a new medium, as Malcolm McCullough argues in his book *Abstracting Craft*. In the case of the digital hand loom, the technology is of a type

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[100] Cook, interview, November 2, 2014.

[101] See also Glenn Adamson's discussion of Norbert Weiner's notion of feedback loops, which Adamson suggests can be applied to systems of motions, people, and machines. In the context of crafts, Adamson writes, "Craftspeople operate by calibrating the motions of their work in direct response to the work that was just performed." Glenn Adamson, "The Persistence of Craft in the Age of Mass Production," in *The Craft Reader*, ed. Glenn Adamson (Oxford: Berg, 2010), 241.

[102] The craft theorist David Pye characterized this sort of difference between hand and machine work in terms of the difference between the workmanship of risk and the workmanship of certainty. See David Pye, "The Nature and Art of Workmanship," in Adamson, ed., *Craft Reader,* 344-5.

[103] Adamson, "Introduction," in Adamson, ed., *Craft Reader*, 2; Adamson, "Persistence of Craft," 241.

that, to use McCullough's words, "supports the subtleties of the hand" and requires "a new type of active skill" on the part of the weaver.[104]

That active skill is the mastery of digital design software used to create the bitmap for programming the loom. It is a specialized skill, a craft in its own right, or in Peter Dormer's words, "a process over which a person has detailed control, control that is the consequence of craft knowledge."[105] Importantly, complex original designs using any digital design program require not only proficiency with the software but also expert knowledge and ingenuity in the use of weave structure.

Creating a digital weaving of any originality or complexity is not quite as simple as feeding a randomly generated bitmap into the loom. As previously noted, the TC loom reads bitmaps in only two colors: one for raised warps and the other for lowered warps. A red (or blue) pixel in the bitmap, for example, does not automatically create an interlacing of warp and weft that will appear red (or blue) in the weaving. This is one of the reasons why the term "woven pixel" can be misleading. All color effects must rather be established by the weaver by directing the interaction of one or more of the following fundamental constructive elements: the layout or sequencing of colored warp threads in the threading of the loom, the sequencing of the colored weft threads in the weaving, and the weave structure itself. The computer gives the weaver the tools to control these

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[104] Malcolm McCullough, *Abstracting Craft: The Practiced Digital Hand* (Cambridge, MA: The MIT Press, 1996), 22.

[105] Peter Dormer, "The Salon de Refuse," in *The Culture of Craft*, ed. Peter Dormer (Manchester, UK: Manchester University Press, 1997), 7.

elements, but designing with them still requires fundamental knowledge of the woven form.[106]

What Anni Albers said of earlier technological developments in weaving is still true with the digital hand loom: ”We are still dealing in weaving, as at the time of its beginning, with a rigid set of parallel threads in tension and a mobile one that transverses it at right angles.”[107] Weaving on the TC loom means working with a fixed set of warp threads and a finite set of weft threads. The “theory of the constructive process” for both hand and machine weaving is still, as Albers stated more than fifty years ago, “fundamentally the same.” What the loom does offer, as the work of Cook and Sørensen will demonstrate, are possibilities for sophisticated, new three-dimensional woven surfaces. Albers would have welcomed the new technology. Even fifty years ago, she encouraged handweavers to stay engaged with “contemporary problems” and warned of the “dangers of isolationism” and the “resentment of an industrial present.”[108] The TC loom offers opportunities for “a return to fundamentals” that “stimulates new experimentation,” and clears the way for new aesthetic effects grounded in the materiality and tactility of interlaced threads.[109]

[106] Appendix 1 discusses one of the methodologies that exist to allow nonweavers, without the informed use of constructive weave elements, to use digital looms. This type of work has an intentionally different aesthetic effect from that achieved by Cook and Sørensen.

[107] Albers, *On Weaving*, 22.

[108] Albers, *On Designing*, 15.

[109] Albers, “Handweaving Today,” 4.

5. Lia Cook

> No formal sequence is every really closed out by the exhaustion of all of its possibilities in a connected series of solutions. The revalidation of old problems in new circumstances is always possible.…An entire older tradition can become a point of departure when technical novelties require its reactivation. For long intervening periods, a formal sequence may nonetheless seem inactive simply because the technical conditions for its revival are not yet present.
>
> —George Kubler, *The Shape of Time*

The critical relationship between medium and design that preoccupied Anni Albers is central to Lia Cook's artistic practice. Cook's focus is the construction of imagery in textiles, where the imagery is intrinsic to the structure.[110] Weaving, according to the artist, is the central unifying process in her work, which has taken many different forms since she first learned to weave in Sweden in the 1960s.[111] Carol Westfall describes Cook's prodigious output over the past four decades as a quest towards the perfect union of material, imagery, and technique.[112]

Cook originally studied photography and printmaking. However she chose the fiber medium, and weaving in particular, precisely because she knew the challenge of woven construction would provide a framework for her creative process. As it was for Albers, the structural possibilities of weaving's vertical/horizontal interlacing are a stimulative force for Cook. "I've always liked it [weaving]," she says, "because it imposes certain limits which then I like to play around with and to break….So the

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* Kubler, *Shape of Time*, 40.

[110] Lia Cook, "The Past is Prologue" (paper presented at the Textile Society of America Sixth Biennial Symposium, New York, September, 1998), 35.

[111] Lia Cook, "Weaving: New Technology and Content" (paper presented at the Ninety-Fifth Annual College Art Association Conference; "When is Technique Central to Meaning" panel chaired by Janet Koplos and Bruce Metcalf, New York, February 14-17, 2007). Audiorecording courtesy of the College Art Association.

[112] Carol Westfall, "Lia Cook." *Shuttle, Spindle & Dyepot* 36, no. 1 (Winter 2004/2005): 38.

structure of weaving is something to push against."[113] (Fig. 5.1) This challenge drives what Geraldine Craig calls the "relentless innovations in woven form" that distinguish Cook's work.[114]

While Cook's earliest work focused on "translating ways of image making between the printed form, the photographic form, and the woven form," her objective was always to create images that were "embedded" in the structure of the weave, not simply applied to the surface of the fabric. She thinks of woven textiles as three-dimensional objects whose "final" look depends precisely on weave structure.[115]

In her early work, she used paint, dyes, and a variety of photographic, printing, and finishing processes to compliment complex woven forms produced on a twenty-harness dobby loom to achieve her goals. In *Interweave II* (1975), she transferred an enlarged photographic image, using a nineteenth-century iron-silver print process, to the photosensitive surface of cloth that she had hand woven from ikat-dyed threads. Her objective was to highlight the interaction between the intersecting threads of the weaving and the microscopic details—the "dots" (later to be known as "pixels")—that made up the photographic image.[116]

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[113] Oral history interview with Lia Cook, 2006 August 22-29, Archives of American Art, Smithsonian Institution.

[114] Geraldine Craig, "Witty Agents," in *Lia Cook, Weaving and Innovation: Digital Fibers Converse with Neural Networks* (Madison: University of Wisconsin, Madison, 2013), 4. Cook's commitment to experimentation and innovation was strongly influenced by her graduate studies under Ed Rossbach at the University of California, Berkeley in the 1970s. Rossbach was a trailblazing fiber artist in his own right but also encouraged his students to "follow their own unique direction." "His trust and respect for the individual as a creative being," Cook writes, "provided…the impetus to continue experimenting." Lia Cook, "Ed Rossbach: Educator," in *Ed Rossbach: 40 Years of Exploration and Innovation in Fiber Art*, ed. Ann Pollard Rowe and Rebecca T. Stevens (Asheville, NC: Lark, 1990), 108, 115.

[115] Oral history interview with Lia Cook; Cook, "New Technology."

[116] Lia Cook, interview by the author, December 5, 2014.

A few years later, Cook returned to her fascination with the interaction between the particles of an image and the intersections of thread with a series of works on what she called "canvas." Each canvas was a pure white surface that she hand wove with a repetitive pattern. She then hand painted the individual threads of the woven surface in a variety of colors to create a visual composition. *Two Point Four* (1980) is one work from this series in which interlaced threads are also the subject matter of the design.[117] (Fig. 5.2)

Much of Cook's work from the 1990s was also self-referential, involving fabric as both subject matter and three-dimensional object. This work more explicitly explored the sensory status of cloth as a tactile object and underscores her preoccupation with the haptic experience of textiles. Her 1993 installation *Material Pleasures* included six textile panels, each dobby woven with hand-painted warp and weft, featuring sensuous images of draped cloth with highly textural damask-like micropatterns. The physical draperies that frame the ensemble heighten the sensual experience by creating an impression of a glimpse into veiled private space.[118] (Fig. 5.3)

She created her later *Point of Touch* series by painting with oils on linen cloth and then cutting the cloth into strips and weaving them as weft into a painted warp. She used this process to render images of textiles draped across parts of the human body to explicitly emphasize the physical experience of cloth. *Point of Touch: Bathsheba* (1995), now in the collection of the Oakland Museum of Art, focuses figuratively and metaphorically on the sensual relationship between the textile and the body. The

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[117] Ibid.

[118] The draperies were designed by Cook and Jacquard woven on the industrial digital Jacquard loom at the Müller Zell factory in Germany.

micropattern of the cloth, with its distinctive hand motif, adds to the work's statement on tactility. (Fig. 5.4)

Cook was drawn to Jacquard weaving because of its unique ability to translate imagery into cloth. In the late 1970s, she was given one of the small textile portraits of Joseph-Marie Jacquard, "a Jacquard of Jacquard," she calls it, which stimulated her curiosity.[119] More than a decade before the invention of the TC loom she uses today, Cook immersed herself in researching Jacquard weaving, both the traditional mechanical forms and the emerging digital technologies that "brought a new technological and conceptual focus to her work."[120]

As described in chapter 4, Cook participated in the Jacquard projects at RISD in 1980, at Müller Zell GmbH in 1991, and at the Philadelphia College of Textiles and Science from 1993 to 1995. Cook also pursued independent study during this period. In 1981, with a grant from the National Endowment for the Arts, she studied historical examples of Jacquard cloth in Lyon, France, and at the Victoria and Albert Museum in London. She returned from that trip to her studio in California with an early-nineteenth-century Jacquard head from Lyon and an early-twentieth-century Jacquard loom from England, which she adapted for use in her work. (Fig. 5.5) In 1990, Cook studied ancient silk-weaving techniques with mechanical Jacquard looms as an invited artist in residence at the Fondazione Arte della Seta Lisio in Florence, Italy.[121] She gained an intimate knowledge of hand Jacquard practices: drawing point paper by hand, using a hand-

[119] Cook, "Past is Prologue," 35.

[120] Craig, "Witty Agents," 4.

[121] The Fondazione Arte della Seta Lisio was established in 1971 to help preserve traditional forms of Jacquard silk weaving through the study of historic textiles and the creation of new work using mechanical Jacquard techniques. The fondazione's work continues today.

operated punch card machine, and lacing the cards by hand. She continued her research in her California studio, experimenting with small weavings she produced on her mechanical Jacquard looms. She acknowledged, however, that the time and labor involved for her to use the mechanical Jacquard for unique weavings was prohibitive. With one card needed for each line of weft, it would take three months to punch the cards by hand for a large piece with no repeats. While punch cards made sense for industry, with its long runs or patterns with repeats, mechanical Jacquard weaving was not economically viable for an artist's discrete works of creative expression.[122]

Armed with a strong base of knowledge in historical Jacquard forms and driven by an unshakeable curiosity and commitment to experimentation, Cook sought out opportunities to use emerging digital technologies. In the mid-1990s, the Montreal Center for Contemporary Textiles (MCCT) was one of the first educational centers to offer workshops and studio time for working on an early digital Jacquard hand loom. The center had an AVL loom outfitted with a digital Jacquard head made by TIS, a French manufacturer. For several years, Cook developed designs on a computer in her studio in Berkeley and traveled regularly to MCCT in Montreal to use the center's equipment for the actual weaving.[123]

After this experience, Cook decided make digital Jacquard weaving the core of her creative practice. The coupling of the scope and flexibility of manipulating individual threads with the speed of a late twentieth-century computer enabled by the new technology offered what Cook describes as a spontaneity and an appealing immediacy for

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[122] Cook, "New Technology."

[123] Lia Cook, "Jacquard Adventures," *Jacquard* 60 (September 2007): 34.

her work.[124] She purchased her first TC loom, the TC-1, from Digital Weaving Norway in 1999.[125] (Fig. 5.6)

"With new technology," Cook says, "I am able to pose more questions, explore more nuances in expression and content."[126] Without the need to rethread harnesses or create new punch cards, Cook is free to experiment and research. She can produce and study work, and create and modify designs and weave structures quickly and, as compared to mechanical Jacquard, relatively effortlessly. This experimentation extends the artist's understanding and perception of possibilities. "Digital technology," according to Cook, "has allowed the inherent complexity of weaving to be explored in new ways….Work is being created that could not have been conceived of before."[127] Like Albers, Cook believes that technology can stimulate creative expression.[128] Cook's receptivity to technology does not diminish her estimation of the value of handwork. Both Albers and Cook recognize hand weaving as foundational to working with more automated forms of the craft.

Using technology is also not a reversion to mass or automated production. Cook uses digital technology to get closer to her craft: in fact, it is, she says, "a more intimate

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[124] Cook, "New Technology."

[125] Cook's long association with the TC loom began quite by accident. After working in Montreal with the TIS digital Jacquard head, her original intent was to buy the TIS equipment. TIS, however, had gone out of business and its equipment was no longer available. Undaunted, she bought a TC-1 from Digital Weaving Norway. She now has two TC-1s in her studio, her original loom and one other. Both have been updated by the manufacturer. Cook, interview, November 2, 2014.

[126] Lia Cook quoted in Stevens, *Technology as Catalyst,* artist's statement.

[127] Cook, "New Technology."

[128] Albers, *On Designing,* 7

and individualized process."[129] Working in series has long been and still is characteristic of Cook's artistic practice.[130] She likes to "take an idea and really explore it in more depth and in a more nuanced way." "I like the idea of being able to take something and mine it and mine it and mine it once again….You can take anything and just push it."[131] Freed from the burden of manual punch cards, the digital loom allows Cook to fully and efficiently probe the range of woven structures available through the manipulation of individual warp threads. Artists have long recognized the value of technology in freeing them from what studio jeweler Stanley Lechtzin calls "the overwhelming physical investment" of handwork. Reducing the time and physical effort needed to create work, Lechtzin explains, "[opens] up the opportunity to continue to explore the permutations of an idea until we have finished with it."[132]

Using her TC loom, Cook's innovative work of the twenty-first century has focused on the translation of photographs from the artist's childhood into cloth through weave structure. *Binary Traces: Kay*, *Face Map: Half Seen*, *and Digit Maps: Four Centimeters*, a 2005 series of digital weavings by Cook, now in the collection of the

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[129] Lia Cook, quoted in Wendy Weiss, "Weaving Life in Black and White," in *Faces and Mazes: Lia Cook*, ed. Wendy Weiss (Lincoln: University of Nebraska, 2009), 18-19.

[130] "When I find a technique or a process and a concept that works well together," Cook says, "I like to explore that in more depth. So that is the idea of the series." Oral history interview with Lia Cook. See also Inez Brooks-Myer, ed., *Lia Cook: Material Allusions* (Oakland, CA: Oakland Museum of Art, 1995). Interestingly, Cook does not specifically weave samples: She will design and weave an entire piece, making changes at the TC loom, if and as needed. If she is satisfied with the piece when it comes off the loom, she explains, it's a finished work. If she is not satisfied, it's a sample. Cook, interview by the author, August 25, 2014.

[131] Oral history interview with Lia Cook.

[132] Stanley Lechtzin quoted in Helen Drutt English and Peter Dormer, *Jewelry of Our Time: Art, Ornament and Obsession* (New York: Rizzoli International, 1995), 27. See also Bhakti Ziek, "Digital Technology for Textiles," in Stevens, *Technology as Catalyst,* essay.

Cooper Hewitt Smithsonian Design Museum, are illustrative examples of Cook's digital oeuvre.[133]

Binary Traces: Kay is a translation into cloth of an old photograph of the artist's Aunt Kay. Like many of Cook's weavings derived from photographs, she purposely made it many times larger than life (fifty-six inches high by fifty-one inches wide) in order to, in her words, "intensify the emotional confrontation with the work."[134] (Fig. 5.8)

The emotional impact of the oversized image embedded in the construction of the cloth is intended to heighten the awareness of the textile itself, an effect in Cook's work that Chelsea Miller Goin calls "an epistemology of touch."[135] Cook actively seeks to create a physical and emotional response in her viewers, a response to the material presence of cloth, to the idea of touch, to the idea of "something you would feel."[136] Using digital weaving technology, Cook has, to borrow a term from Kubler, "reactivated" Albers's exploration of tactile sensibility.

Importantly, in *Binary Traces: Kay*, Cook is not simply reproducing a heroic-scale photo in cloth; the photo is her "raw material." Her intent is to "extract just enough visual information" from the photograph for the image to be recognizable, in the

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[133] In this paper, I do not provide a comprehensive survey of Cook's vast body of digital weaving but choose instead to focus on an in-depth analysis of key works. In the full context of the artist's work, it is important to note that Cook uses a variety of processes and structures in her digital weavings. Works such as *Traces: Intent* (2002) and *Blur Girl* (2003), for example, are woven in color, using a technique that differs from that used in *Binary Traces: Kay* and its companion pieces, discussed herein (Fig. 5.7)

[134] Cook, "New Technology."

[135] Chelsea Miller Goin, "The Technological Style of Lia Cook," in *Lia Cook: Material Allusions,* 11.

[136] Oral history interview with Lia Cook.

"suggested hazy nature of memory."[137] Cook's primary mission is to orchestrate a deliberate exploration of the sensuality of physical cloth, precisely using those effects that Albers's calls matière. "I really want people who've never had any experience with weaving…to be able to discover that the image is not created by a dot of ink but that it is created by the way the threads interlace," Cook explains.[138]

As a part of this mission, the work purposefully choreographs "a specific perceptual encounter."[139] When viewed from a distance, it looks like a large, slightly out-of-focus, black-and-white photographic image. This is intended to make the viewer move closer to bring the image into focus, a typical human reaction. But as the viewer approaches the work in the attempt to resolve the image, the opposite occurs. As Cook says, "The image breaks down and the pattern begins to emerge."[140] (Fig. 5.9) There is what Judith Leeman calls "a perceptual limit" built into the work.[141] Cook describes this as the "threshold at which the image dissolves," explaining it as "the moment of instability that is created when that transition [between image and pattern] takes place." This threshold is the heart of Cook's digital weaving because this is where the materiality of the textile is revealed.[142] The pattern is the weave structure; it is the visual articulation of the interlacing of threads—the texture of the cloth.

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[137] Cook, "New Technology."

[138] Oral history interview with Lia Cook.

[139] Judith Leemann, "Lia Cook: Re-Embodied," *Textile: The Journal of Culture and Cloth* 5, no. 3 (Fall 2007): 334.

[140] Oral history interview with Lia Cook.

[141] Leeman, "Re-Embodied," 334.

[142] Oral history interview with Lia Cook; Cook, "Jacquard Adventures," 35; Lia Cook, "Artist's Statement," Seager Gray Gallery, www.seagergray.com/Artist-Detail.cfm?ArtistsID=678, accessed June 1, 2014.

Pattern recognition—or the attempt to reduce visual complexity—is a fundamental trait of human behavior. Works such as *Binary Traces: Kay* take advantage of this in order to engage the viewer. As Kerstin Kraft notes, “Patterns attract perception.”[143] While earlier works were woven in color, *Binary Traces: Kay* and its two companion pieces are rendered in black and white. The black-and-white color scheme eliminates the distraction of polychrome threads and, as I will discuss further, the high contrast between the two colors puts the patterning into sharp relief.

But Cook’s weavings are not patterned in the traditional sense: They are not the symmetrical or otherwise systematic repetitions of static motifs that one might be accustomed to seeing in woven cloth. (Fig. 5.10) Each weaving is an elastic repetition of idiosyncratic units, units that are not necessarily identical but rather similar enough to be recognizable to the human eye.[144] The pattern is more rhythm than replication. In some areas of *Binary Traces: Kay*, the viewer identifies what appear to be tiny white capital *L*s, scattered against a black background. Elsewhere, black, upside-down *L*s appear sprinkled across a white background. In still other areas, concentrations of these *L*s produce a stair-step effect. (Fig. 5.11)

This apparent pattern in *Binary Traces: Kay* is the weave structure, produced by the way the threads interact with one another. At the same time, it is also the means by which the work communicates important information.[145] When we recognize a pattern,

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[143] Kerstin Kraft, “Textile Patterns and their Epistemological Functions,” *Textile: Journal of Cloth and Culture* 2, no. 3 (December 2004): 275, 282, 287.

[144] Kraft, “Textile Patterns,” 277. For a discussion of idiosyncratic patterning in contemporary design, see Paul Andersen and David Salomon, *The Architecture of Patterns* (New York: W.W. Norton, 2010).

[145] See Sanford Kwinter, “Pan-Patternism,” in Andersen and Salomon, *Architecture of Patterns*, 10.

we are inclined to assume there is some significance to it and we attempt to decode it.[146] In the case of Cook's weavings, decoding the pattern reveals that the work is a textile. The pattern units are not "the dots of a print or the pixels of a photo or the brush strokes of a painting;" they are configurations of threads—the weave structure.[147] To paraphrase Sanford Kwinter, the threads, the formerly invisible scaffold for our perceptual experience of Kay's image, are forced out of hiding.[148] Or in Cook's own words, "the physical presence of the thread becomes dominant." She explains the process as, "You can no longer read it as a flat two-dimensional object and you begin to understand that it is a textile, and it is constructed, and that material quality takes over….There's some kind of sensuality about the image being this obvious textile."[149]

Traditional shaft-loom hand-weaving patterns are "conservative": they are generally homogeneous, stable structures. Determined by shaft-loom technology, they necessarily revert to the grid, emphasizing the conventional form. Digital technology in weaving, as in other mediums, is a liberating force. With the digital loom, Cook creates interlacings of threads that are fluid, heterogeneous, and unstable. They are protean, promiscuous patterns, akin to the ones Andersen and Salomon describe in *The Architecture of Patterns*. Her weave construction "traffics between its surface appearance and its hidden structure." It achieves a dynamic equilibrium between the two registers of its dual nature: On an abstract level, the pattern of threads creates a recognizable image.

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[146] Kraft, "Textile Patterns," 282.

[147] Cook, interview, August 25, 2014.

[148] Kwinter, "Pan-Patternism," 9.

[149] Oral history interview with Lia Cook.

On a physical level, it is cloth. The pattern of threads in *Binary Traces: Kay* does not simply "communicate its identity;" it "actively performs and produces it."[150]

Face Map: Half Seen, the smallest piece in the Cooper Hewitt series, is only ten-and-one-half inches high by eight inches wide. This work is based on the upper-left-hand quadrant of the image of Kay used in *Binary Traces: Kay*. (Fig. 5.12) Because of its diminutive size, the image dissolves more dramatically into thread: the interlacings are more granular, more active. These finer interlacings of thread create a different pattern: a maze, rather than *L*s and stair steps.

Weave structure is explicitly both subject and object in the self-referential third work in the Cooper Hewitt series. For *Digit Map: Four Centimeters*, Cook takes a close-up photograph of the labyrinthine maze pattern in a small area of *Face Map: Half Seen*, dramatically enlarges it, and then reweaves it in an oversized scale format (forty-two inches high by fifty-two inches wide). (Fig. 5.13) At first glance, the image depicted in *Digit Map: Four Centimeters* may not be immediately comprehensible. A closer examination of the work reveals the mazelike weave structure of the cloth and the subject of the work becomes apparent: It is the materiality of the cloth itself. The maze, to borrow a phrase from Andersen and Salomon, functions as both process and image and is able to "foreground the sensual."[151] (Fig. 5.14)

Cook's digital weaving is tangible evidence of Albers's prediction, noted earlier, that the expansion of textile art would come paradoxically from "condensation," or a

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[150] Andersen and Salomon discuss how the use of digital technologies has reinvigorated the use of patterns in architecture. Many of the characteristics of these new and exciting forms of patterning identified by the authors are applicable to the dynamic patterning of woven construction in Cook's digital work. See Andersen and Salomon, *Architecture of Patterns*, 14, 32, 45.

[151] Andersen and Salomon, *Architecture of Patterns*, 14.

rigorous focus on basic concepts.[152] The possibilities for woven construction offered by digital technology are almost infinite. Cook's use of the technology is a potent means of expression because it is disciplined. These three works, *Binary Traces: Kay*; *Face Map: Half Seen*; *and Digit Maps: Four Centimeters,* like all of Cook's digital oeuvre, are the result of the artist's innovative use of fundamental elements of weave construction, innovations made possible by the use of the digital loom. Cook's inventive thinking is a function of her expert knowledge of and engagement with weave structure, coupled with her mastery of digital technology.[153]

Each of the three textiles in the Cooper Hewitt series is made with smooth cotton thread. Cook's emphasis is on tactility produced by weave structure, rather than tactile effects produced by highly textured threads. To create this structure-based tactility, the three textiles are each woven in plain weave, the simplest form of interlacing, but with a compound construction known as double-cloth. Double-cloth, as the name implies, is composed of two complete weave structures—two sets of warps, each with its own set of wefts. Each set of warp and weft constitutes its own independent plane, enabling the weaver to produce two distinct layers of cloth with different colors or other features simultaneously. (Fig. 5.15) Albers was a double-cloth enthusiast because of the range and apparent complexity of effects the weaver can achieve with this very simple yet sophisticated construction.[154]

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[152] Albers, *On Weaving*, 47.

[153] Cook, "New Technology." As previously discussed, Cook uses a variety of techniques in her digital weavings. In this paper, I focus on her elegant double-cloth constructions.

[154] Albers writes, "Double weaves have a special nimbus about them for reasons not clear to me. They are thought to be intricate, hard to grasp, open only to advanced students. To my mind they are simple to understand and can be handled by anyone with just common sense." Albers, *On Weaving*, 50. Double-cloth was popular among the Bauhaus weavers, but it was Albers who

Double-cloth offers unique design opportunities in the manner in which the two layers may be combined. The weaver may cause the independent planes to deliberately intersect at specific points along the vertical or horizontal axis, such that either one or the other set of warps interlaced with one or the other set of wefts appears on the face of the weaving. When the two planes intersect, the elements from the back of the fabric are brought to the face and woven there, while the elements from the face are brought to the back and woven there. (Fig. 5.15) The interchange of planes creates a transposition of colors or other features.[155]

With a traditional "block" double-cloth, each of the two planes may be divided into two, three, or more blocks or segments with a dynamic relationship such that the face of the cloth is composed of blocks from each intersecting plane. Double-cloth, perhaps more explicitly than other weave structures, allows "elements of a dynamic and spatial nature" to be used in creating the surface effect of the fabric.[156] The transposition of segmented planes creates a cloth with real depth and three dimensions.

Each block of a plane, however, must be controlled independently of the others. On a harness-and-treadle hand loom this means that each block requires its own set of harnesses (at least the two minimum required for plain weave). Therefore, the number of harnesses on the loom limits the number of blocks. With an eight-harness loom, for

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pushed the technical limits of this weave structure. She produced several remarkable works in triple-weave, a structure using three complete planes of warp and weft, which offered opportunities for even-more-complex designs. See S. W. Weltge, *Women's Work: Textile Art from the Bauhaus* (San Francisco: Chronicle Books, 1993), 72.

[155] See Emery, *Primary Structures*, 156-8; Albers, *On Weaving*, 50-1.

[156] Stolzl writes, "Fabric…has to be a surface and always has to have the effect of a surface. This does not imply that elements of a dynamic…and spatial nature are excluded from consideration. These elements count in as far as they are means of designing the surface and are subject to the laws of plane geometry." Gunta Stolzl, "Weaving at the Bauhaus," in *Bauhaus: Weimar, Dessau, Berlin, Chicago*, ed. Hans Wingler (Cambridge, MA: MIT Press, 1969), 116.

example, each plane can only be manipulated in two blocks.[157] With a digital loom that allows the weaver to manipulate each warp individually, the planes of thread can have as many blocks or segments as there are individual warp threads.[158]

The interchange of planes in the double-cloth construction of *Binary Traces: Kay*; *Face Map: Half Seen*: *and Digit Maps: Four Centimeters* creates a deliberately concentrated color effect. One plane of threads in each work is white warp and weft and the other is black warp and weft. The white warp is always interlaced with white weft, and the black warp with black weft.

The visual program for each weaving is a bitmap derived from the original photos in only two contrasting colors—black and white. To do this, Cook uses a functionality of Photoshop to reduce the photo's pixels to only black or white. In *Binary Traces: Kay*; *Face Map: Half Seen*; *and Digit Maps: Four Centimeters,* the black or white pixels in the bitmap are realized in the textile by segments from the similarly colored layer of fabric, causing the two planes to be fully integrated throughout the textile. The black layer appears on the face for the black pixels and the white layer appears on the face for the white pixels. Cook is not trying to produce shades of gray but rather heightening the textural effects of the cloth. The use of smooth cotton thread and the limited color palette in the visual program, as well as in the weaving, coupled with the high degree of color contrast between the black threads and the white threads amplifies the appearance of the weave structure and therefore the visual effect of the sculptural surface of the cloth.

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[157] Two planes times two segments times two harnesses equals eight harnesses in total.

[158] Albers would use Jacquard attachments to weave some of her more intricate designs rendered in triple- or quadruple-cloth. Weltge, *Women's Work*, 104.

The visual complexity of the weave structure is deceptive. The different visual patterns and apparent complexity of the woven form are produced by the way the threads interact when the independent planes of black plain weave and white plain weave are transposed in successive rows of weaving. Using single threads in the warp and weft creates the maze pattern. Using double-weight thread elements creates the stair-step pattern: two threads are woven as one in both the warp and the weft. In each case, Cook's use of double-cloth results in a coherent fabric—a textile that holds together.

Cook's artistry in the inventive yet disciplined use of basic elements of weave construction is further evidenced by *Su Series*, a group of fifteen small-scale weavings, each approximately sixteen by twelve inches, first displayed together at Cook's solo exhibition *Neuronets + Net Works,* held at Chicago's Perimeter Gallery in April and May of 2014. While much of Cook's work, like *Binary Traces: Kay*, is deliberately oversized in order to intensify the response to her woven imagery, *Su Series* uses a program of multiples, rather than increased scale, to heighten the viewer's awareness of the materiality of the cloth. (Fig. 5.16)

All of the pieces in *Su Series* are derived from the same childhood photograph of the artist. (Fig. 5.17) When the fifteen weavings are viewed together, their shared foundational image is recognizable, but it is their diversity that is most apparent. Cook uses weave structure to render an image of the child's face and simultaneously to create a series of heterogeneous, unstable patterns. As the image dissolves, these patterns, some closely related, stimulate a curiosity on the part of the viewer: their obvious differences, their apparent similarities, and their very instability all need to be understood. Decoding the pattern reveals the weave structure and the physical presence of the cloth. The threads are again forced out into the open. The juxtaposition of the fifteen textiles, each individual and distinct in spite of their common source image, makes the tactile sensibility of the cloth the dominant feature in *Su Series*.[159] (Fig. 5.18)

The underlying image of the child in each of the works in *Su Series* is first reduced to pixels in only two colors, black and white, as was the case in the Cooper Hewitt series. The two-color image in each is then created by a ground-weave structure using a double-cloth construction, with one plane of fabric used for each color.[160] Each ground weave manifests a variant of one of four identifiable patterns formed by the interchanging of two planes warp and weft: a multicolor block pattern, seen in *Vibration* (2014), *Hyper Pixel* (2014)*, Blue Screen* (2014), *and Data Dearest* (2014); a maze pattern, seen in *Squares* (2008), *Lips* (2009), *Pure Maze* (2013), *Neuro Nets* (2014), and *Neuro Tracts* (2014); a stair-step pattern, seen in *Mega Data R* (2014), *Mega Tracts* (2014), and *Mega Tracts II* (2014); and finally a "satin" pattern, seen in *Little Amazed* (2006), *Intensity Data* (2013), and *Neural Tracts* (2014).[161] (Figs. 5.19-5.22) As Cook explains, "Knowledge of complex techniques of weaving, along with the power of the computer, allows me to create structures that translated the image in new ways."[162]

The multicolor block pattern is the most intricate of the double-cloth constructions in *Su Series*: Its two planes of cloth are not woven in plain weave nor in single colors. (Fig. 5.23) One of the two planes is constructed of warp units of green

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[159] As with *Binary Traces: Kay* and its companion pieces, the works in *Su Series* are woven with smooth threads, with texture effects created by weave structure, rather than by the threads themselves. The materials used in *Su Series* are cotton and rayon.

[160] Nine of the fifteen works in *Su Series* also use supplementary wefts to create line patterns superimposed on the image. These will be discussed later in the paper.

[161] I thank Lia Cook for her assistance in analyzing the weave structures in *Su Series.*

[162] Cook, "New Technology."

thread and blue thread interlaced with black weft, while the other is constructed of warp units of red thread and yellow thread interlaced with white weft. Importantly, the use of colored threads is not intended to achieve a polychrome effect in the image but rather to create planes of cloth in two contrasting colors. As previously noted, Cook still uses a two-color black-and-white bitmap of the child's face as the source image. The blue/green/black plane of fabric is woven on the front of the cloth for the black pixels of the grid, with the red/yellow/white plane woven on the underside. The reverse is true for the white pixels. In *Blue Screen* and *Data Dearest*, the warp units are comprised of four alternating colored threads (green, blue, green, blue or red, yellow, red, yellow) interlaced with the corresponding weft. The more granular surface of *Vibrations* is a function of a more detailed bitmap and narrower warp units, with only two threads per warp unit (green and blue or red and yellow) interlaced with the corresponding weft. In *Hyper Pixel*, which is based on a coarser bitmap, units of two warps interlaced with one weft appear in minimum groups or blocks of four, causing the more exaggerated pixelated surface effect.

The maze and stair-step patterns are both plain-weave double-cloth structures, similar to those in *Binary Traces: Kay* and *Face Maps: Half Seen*. One plane of threads is white warp and weft and is woven on the front of the cloth for the white pixels of the bitmap and the other plane is black warp and weft woven on the front for the black pixels. As is the case with all of Cook's double-cloths, the reverse side of the weaving is the negative of the face. (Fig. 5.24)

The maze patterns in *Squares, Lips, Pure Maze, Neuro Nets,* and *Neuro Tracts* are formed from more detailed bitmaps, with smaller thread units of two warps woven together with single wefts. (Fig. 5.25) In *Squares and Lips*, colored threads are used as complementary elements with the white weft to create additional color effects. In these constructions, the colored complementary threads are periodically substituted in the white plane of the ground weave for the white weft. This results in the checkerboard macropattern in *Squares* and the red lips and blue-shaded or red-shaded background in *Lips*. (Fig. 5.26)

In *Mega Tracts, Mega Tracts II,* and *Mega Data R*, Cook weaves using a coarser bitmap, one with half the number of pixels and heavier warp and weft—each warp consisting of four threads woven as one unit, interlaced with a weft of the same weight. With the loss of the fine detail achieved in the maze weavings, the effect of the interchange of these planes of cloth results in the appearance of the stair-step pattern. (Fig. 5.27)

Lastly, the satin pattern in *Little Amazed, Intensity Data*, and *Neural Tracts* is not really a pattern per se, nor is it a true satin weave.[163] In fact, there is no weave structure at all. Using a solid black warp with a solid white weft, the black areas of the bitmap are all warp and the white areas are all weft. (Fig. 5.28) Cook describes the result as a sketch, like a charcoal drawing but in thread.[164] In order to ensure a reasonably stable fabric, she

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[163] According to Emery, the term satin is commonly used both to describe a type of woven fabric with a smooth, lustrous appearance and to designate a simple float weave structure "characterized by long floats of one set of elements and more or less evenly distributed single 'ties' of the other on each face." Emery, *Primary Structures*, 108. Strictly speaking, Cook's satin is not a true double cloth either in that it does not have two complete sets of elements (warp and weft). However, Cook treats the single elements (black warp and white weft) as individual planes in the construction.

[164] Cook, "New Technology."

uses a functionality of the TC loom to automatically limit the length of the warp and weft floats with periodic interlacings that disappear into the rich texture of the cloth.[165]

Like Albers, Cook believes that texture, the three-dimensional surface of woven cloth, engenders a distinctive human response. When her work is exhibited, Cook explains, she is struck by the desire to touch stimulated by "confronting these …woven faces that look photographic at a distance but dissolve into maze patterns up close, and finally into intersecting threads."[166] In ways that were not available to Albers, Cook has endeavored to scientifically measure that response. Over the past several years, Cook has broadened her practice to include empirical research in what is today called haptics—the branch of psychology that investigates the sense of touch. Part of her research has included behavioral studies at exhibitions: viewers of her work were asked to complete written surveys ranking the intensity of their responses to her weavings as compared to similarly sized printed photographs of the same images.[167] The results were then collated and depicted graphically in data charts. (Fig. 5.29)

In 2011, Cook was an artist in residence in the University of Pittsburgh TREND program.[168] Working with the scientists in the TREND lab, she carried out a series of experiments designed to map the human brain's emotional response to her woven images.

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[165] A "float" is the portion of a warp or weft thread that extends unbound over two or more threads of the opposite set. Emery, *Primary Structures*, 75. Fabrics with very long floats tend to be unstable; that is to say, they don't hold together.

[166] Lia Cook, "An Investigation: Woven Faces and Neuroscience." *Textile Forum* 4 (December 2010): 42.

[167] Cook has not yet been able to obtain the technical resources needed to fully evaluate the survey data. Cook, interview, August 25, 2014.

[168] TREND stands for Transdisciplinary Research in Emotion, Neuroscience, and Development. The TREND program was sponsored by the Department of Psychiatry at the University of Pittsburgh School of Medicine under the direction of Dr. Greg Siegle.

Using data from fMRIs and EEGs, the researchers found evidence that "the material and structural aspects of the textile" evoked a different and typically more intense emotional response than a two-dimensional printed photograph.[169] She also used diffusion spectrum imaging to map the neural pathways of her own brain. These neural pathways, also known as "fibers," are bundles of neurons in the white matter of the brain that connect parts of the nervous system.[170] (Fig. 5.30)

Cook's collaborations with neuroscientists have in turn stimulated new work in which data from her research is graphically depicted as part of the visual program of the weavings. Nine of the works in *Su Series* use this device. In these weavings, Cook uses colored supplemental wefts to depict either data charts from her behavioral research comparing emotional responses to weaving with responses to photographs (*Intensity Data*, *Mega Data R, Blue Screen*, and *Data Dearest*) or to depict images of her own neural fiber tracts (*Neuro Nets, Neuro Tracts, Neural Tracts*, *Mega Tracts*, and *Mega Tracts II*). The renderings of the data charts or neural tracts are superimposed on the trace image of the child's face in the cloth.[171] (Figs. 5.31-5.32) Supplementary wefts are weft elements that are not needed for the construction of a coherent fabric—that is to say, the textile could have been woven without them. Therefore, there are no structural requirements for these threads and they may be used rather freely.[172] Cook takes

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[169] fMRI stands for functional magnetic resonance imaging. EEG stands for electroencephalography. Cook, "An Investigation," 42.

[170] Ibid., 43.

[171] Portions of the data charts are cut off in some of these works. For use in her weavings, Cook manipulated the images of her neural pathways using sophisticated biomedical imaging software. Cook, "An Investigation," 42-3.

[172] Although these supplementary wefts apparently run counter to Albers's admonition against purely decorative, nonstructural elements in weaving, Albers herself used them often in her

advantage of this to construct overlays to the image rendered in the ground weave that add a self-referential element to the work.

Su Series demonstrates Cook's virtuosity in weaving and the power of digital technology, as she achieves the maximum effect from a minimal number of constructive elements. She uses weave structure as the primary element, employing digital technology to expertly manipulate a fundamental-yet-sophisticated double-cloth construction. She then adds other effects by simply varying either the color or the weight of the threads. To these features, she may add more explicit information about the human response to touch, such as the data charts or fiber tract images. Cook intends to continue to add new works to *Su Series*. Ultimately, she envisions a whole wall of weavings, possibly as many as a hundred individual works, each woven differently and collectively evidencing the potent interconnections between structure, tactile articulation, and human perception.

Framing Cook's work in the tradition of Albers raises the question of their divergent choice of visual composition. Cook's digital weaving uses representational imagery derived from photographs, whereas Albers's work was firmly rooted in the traditions of the Bauhaus and modernism, which rejected representational imagery in favor of a pure, universal language of abstract form.[173] The visual programs of weaving by Albers and other Bauhaus weavers, including those called "tapestries" and those Albers called "pictorial"—such as *Pasture* (1958), now in the collection of the

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woven artwork. This can be seen in works such as *Under Way* (1963), which is in the collection of the Hirschhorn Museum, Smithsonian Institution.

[173] Paul Greenhalgh, "Introduction," 12-15.

Metropolitan Museum of Art—were abstract designs, largely derived from the grid structure of warp and weft interlacing.[174] (Fig. 5.33)

Traditional European tapestry was one casualty of the modern aesthetic, which rejected tapestry's narrative design and figurative imagery. Moreover, tapestry technique in weaving, whatever the visual program, was not, in modern design terms, a truthful construction. Its mosaic-like construction did not reflect the interlacing structure of warp and weft on a loom. Warp threads, which are completely covered by successive discontinuous wefts, play no role in the visual program. They are passive participants, serving as a hidden skeleton for the weft.

In her writings on weaving and design, nowhere does Albers advocate a rigid adherence to the modernist dogma of abstract form. Rather, her intention was, to borrow a phrase from Walter Gropius, to "exert a revitalizing influence" on the field.[175] With respect to traditional European tapestry in particular, she articulates a more nuanced view, focusing on the disconnect between the medium and the visual program. For Albers, the real challenge of traditional European tapestry is that its pictorial elements "demand the greatest possible freedom from the structural scheme." She considers this flawed disconnect to be due in large part to the practice in European tapestry of

[174] The grid was in fact the preferred visual idiom of Bauhaus design. As Leah Dickerson points out, the grid was the "structuring framework" for a wide variety of works, as seen, for example, in Paul Klee's paintings and Josef Albers's glass works. The natural grid of the loom was compatible with this aesthetic. It produced logical geometric forms in perfect unity with the means of construction. See Leah Dickerman, "Bauhaus Fundaments," in *Bauhaus: Workshops for Modernity,* ed. Barry Bergdoll and Leah Dickerman (New York: Museum of Modern Art, 2009), 19-21.

[175] Walter Gropius writes, "The object of the Bauhaus was not to propagate any 'style,' system, dogma, formula, or vogue, but simply to exert a revitalizing influence on design." Walter Gropius, *The New Architecture and the Bauhaus*, trans. P. Morton Shand (Cambridge, MA: MIT Press, 1965), 92.

commissioning cartoons from great painters, an attempt, in her view, to *replicate* great paintings in woven cloth. “Trespassing into another art form, however great that art form may be, does not necessarily bring forth great art works,” Albers writes. The visual programs of these cartoons are those of paintings not weavings. The visual program of a painting follows rules that are inherent to that medium and different from those of textile construction, she argues. As a result, Albers believes European pictorial tapestries are weakened by designs that are not intrinsically related to the woven form. “The original concept [of the painting] as well as the transposition [into weaving] suffers by the very fact of indirectness,” she writes. The result diminishes both art forms.[176]

Importantly, Albers acknowledges that it is possible to construct figurative imagery with “an expressive directness.” She cites examples that use tapestry technique, including *The Unicorn Tapestries,* which she describes as “truly weaverly in their components,” and the figurative tapestry weavings of ancient Peru, suggesting that they were “all…conceived within the weaver’s idiom.” These works were conceptualized as textiles, not woven reproductions of paintings. Albers also acknowledges the efforts of some of her contemporaries in the 1960s: “At present…the efforts of weavers in the direction of pictorial work have only in isolated instances reached the point necessary to

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[176] Albers, *On Weaving*, 66-70. The practice of weaving tapestries after cartoons by famous painters, which dates to the fifteenth century, was revived after World War II by the French artist Jean Lurcat. With prompting by Lurcat, the French tapestry workshops at Aubusson produced works after paintings by Picasso, Leger, and other celebrated modern painters, as well as his own. While these tapestries were not figurative or representational, they evidenced the same flawed disconnect between mediums as did the earlier tapestries. Although Albers is not explicit on this point, the disconnect between mediums is a function of the fact that painting strives for purely visual effects while her textile aesthetic calls for tactile effects rooted in the materiality of the cloth. Also implicit in Albers’s criticism is her objection to the secondary role accorded the craftsperson in all tapestries woven after great paintings. It was the painter’s role as designer that was prized, whereas the weavers remained unknown and unacknowledged.

hold our interest in the persuasive manner of art." Albers considers those that did reach this point to be "experimental—that is, searching for new ways to convey meaning."[177]

Today the digital Jacquard loom, by exploiting the congruence of the bitmap with the woven grid, has opened new opportunities for textiles to create figurative imagery that is part and parcel of the structural scheme. Although Cook derives her source images from the most pictorial of mediums, photography, she develops them specifically as textiles. She is not using the image to construct a narrative in the traditional sense.[178] Cook uses digital technology to create new ways of conveying meaning about textiles, or, to borrow a phrase from Albers, "conquering new territory," achieved with her highly sculptural woven surfaces.

However, the technology itself is not "the aesthetic consciousness" in Cook's work.[179] Weaving pixels is not an end but the means to an end. While the bitmap is a necessary part of the design process, the result transcends the notion of woven pixels. The original image is not merely translated but transformed by its rendering in interlaced thread, taking on new and different meaning. Weaving pixels is a tool to achieve an independent aesthetic objective: creating a three-dimensional tactile surface. As Gropius says, "A work of art remains a technical product but it has an intellectual purpose to fulfill as well, which only passion and imagination can achieve."[180]

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177 Albers, *On Weaving*, 69-70.

178 Cook, "New Technology."

179 In his commencement address at the Tyler School of Art in 1995, the artist Dennis Adams said, "Capture the most advanced computer technologies for artistic production, but without religious faith. Remember, they are only tools, not an aesthetic consciousness." Dennis Adams, quoted in Mensing, "Enter: Repeat," essay.

180 Gropius, *New Architecture*, 91.

6. Grethe Sørensen

> Every important work of art can be regarded both as a historical event and as a solution to some problem…Any solution points to the existence of some problem to which there have been other solutions…. As the solutions accumulate, the problem alters.
>
> —George Kubler, *The Shape of Time*

In her 1959 essay "Constructing Textiles," Anni Albers considers the hypothetical visitation of an ancient Peruvian weaver to her present-day world of textiles. She supposes that certain aspects of contemporary weaving might intrigue him—for example, the speed of mechanized looms, the uniformity of threads, and new synthetic yarn materials. However, Albers concludes, he would find little to surprise him in his area of greatest interest, the manner of the interlocking of threads—the actual structure of the weaves. "In his search for inventiveness in weaving techniques," Albers explains, "he would find few, if any, examples to fascinate him."[181]

Should Albers's time-traveling weaver—or Albers herself—return today, they would find something to marvel at: the inventive "random" weave structure employed in the past decade by Danish weaver Grethe Sørensen using digital-loom technology.

Sørensen is a skilled and disciplined weaver who, until the mid-2000s, was little known outside her native Denmark. In 1972, she completed her program of study in textiles at the College of Art and Design in Kolding, Denmark, where, after graduating, she taught for almost twenty years. Since then, she has made her living as an independent artist, supported in part by prestigious grants from Denmark's Statens Kunstfond.[182] In

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* Kubler, *Shape of Time*, 30.

[181] Albers, *On Designing*, 12-13.

[182] Grethe Sørensen, interview by the author, December 11, 2014. The Statens Kunstfond is the primary government funded arts foundation in Denmark.

1994, the Danish art journal *Hrymfaxe* called Sørensen one of the finest young talents in Danish textile arts in recent history.[183]

For Sørensen, like Albers and Cook, the interrelationship of medium and design, in the form of the embedding of the visual program in the woven structure, is paramount in her art. "Woven textile constructions are my personal medium of expression," she explains. "The experience of a motif emphasized by thread and construction is essential."[184]

Her early large-scale weavings, which she calls "tapestries," highlight the highly controlled and constructive qualities of her textiles.[185] She hand wove works such as *Tapestry with Grey Grid* (1993) and *Yellow and Grey in Two Parts* (1999) on a damask shaft loom, using hand-dip-dyed, crisp linen threads.[186] (Fig. 6.1) The precisely graduated colors of the thread are highlighted by the technically sophisticated woven structure: She used loom-controlled warp- and weft-faced satin weaves for the backgrounds and systematic, freehand manual thread selection to achieve the fine lines of the designs. Her orderly compositions and the weave structures that realize them are carefully planned and executed, with an intellectual rather than expressive bias. The results are refined and serene, with an emphasis on the textural quality of the woven material and a three-dimensional visual effect. The precision and self-imposed discipline that Sørensen

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183 Lisbeth Tolstrup, "*Med letheden intakt*," [With ease intact] *Hrymfaxe Kunsttidsskrift* 1 (March 24, 1994): 40.

184 Grethe Sørensen, "From Traditional to Digital Tools" (paper presented at the Textile Society of America Twelfth Biennial Symposium, Lincoln, NE, October 2010), 1.

185 Sørensen consistently refers to her works as tapestries in the sense that they are large, nonfunctional weavings intended to be displayed on a wall. Sørensen has never created works using the traditional weft-faced tapestry weave structure, nor has she copied paintings. The visual programs for her weavings are her own and conceived in the context of the medium.

186 On Sørensen's damask shaft loom, one group of yarns is threaded through heddles on harnesses to weave the background. Other yarns are controlled as on a draw loom for the pattern.

employed in the making of these early tapestries would serve her well in her later work with new digital-weaving technologies.

Woven construction provides a set of structural possibilities for Sørensen's artistic practice in the same way that it did and does for Albers and for Cook. Her work has been a continual exploration of new modes of expression within the limitations of the woven form; new solutions to the "problem" of working with interlacing threads. She calls her pursuit of new ways to create cloth with designs intrinsic to the weave structure "a kind of personal textile research."[187] Yet, as Kirsten Nissen points out, Sørensen's continual experimentation "in no way hinders the pronounced clarity with which her work appears."[188]

Her innate curiosity and the challenge of developing new expressions in weaving made Sørensen receptive to the idea of the digital loom. She was presented with the opportunity to work with the new technology when the Kolding College of Art and Design in Denmark acquired a TC-1 loom in 2000. At the time, she admits, she was not particularly adept with digital technologies; although she had had some experience with a computerized dobby loom, she used her computer almost exclusively for word processing. All of the designs for her earlier weavings were created by hand: she drew and painted with watercolors on paper to map out her compositions. Her experience with Jacquard weaving was also limited: She had worked intermittently between 1983 and 2000 as a designer for a damask mill in Kolding that specialized in bed linens and tablecloths. This job involved hand drawing and the mill had a conservative attitude

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[187] Sørensen, "Traditional to Digital," 1.

[188] Kirsten Nissen, "Textildesigner/DK," in *Traces of Light: Weaving of Grethe Sørensen* (Copenhagen: Rundetaarn, 2012), exhibition catalog, 34.

toward design. She continually asked herself, “What can I do that is new?” and “How can I use this technique in other ways?”[189] The TC loom gave her an opportunity.

The TC loom at the college in Kolding was available for use by weavers unaffiliated with the school for four weeks, twice a year. Sørensen took advantage of this to thoroughly familiarize herself with the technology: “I had to size up and test this new tool in all possible ways before it eventually became an integral and familiar part of my world.” The loom itself was not the issue; it was the digital design software that was the challenge, but it was also the inspiration. She did not want to simply transfer her early work to a new means of production on the digital loom. Sørensen was compelled to “create something totally different from what [she] had done before,” with designs as well as woven constructions based on digital technology. In order “to be free to avail herself of all the possibilities and explore the new landscapes which digital tools give access to,” her expertise with digital design software had to complement her proficiency in weave structure. She did not want to be hampered by a lack of technical skills. Sørensen is completely self-taught in the use of the loom and in Photoshop, which has replaced her pencil and watercolors as her primary design tool.“[I] found my own personal way into the digital world,” she explains.[190] (Fig. 6.2)

The digital Jacquard loom, in its ability to read information from digital design programs and use that information to establish the structure of woven cloth, transformed Sørensen’s work. Using Photoshop as a “drawing program” has led Sørensen to a series of new expressions in woven textiles, a chain of new solutions to the structural limitations of creating imagery embedded in the woven grid. In a happy coincidence,

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[189] Sørensen, interview, December 11, 2014.

[190] Sørensen, “Traditional to Digital,” 1.

Photoshop is among the tools that her husband, Bo Hovgaard, a videographer, routinely uses in his own work in film and photography. She works collaboratively with him to explore the artistic possibilities offered by the program and other software used for video animation. Their collaboration has produced a series of works related to elusive optical phenomena captured by photography and video.

Interferens (*Interference*) (2004) was Sørensen's first body of work created with digital technology.[191] (Fig. 6.3) She used video animation software to explore the visual phenomena that result when two perforated planes are placed on top of each other and then shifted off center. These phenomena, known as *moiré* effects, are created when visible light passes through unaligned holes in the planes. As Sørensen revolves and realigns the planes in the software program, the optical effects manifest themselves as virtual three-dimensional forms. Working exclusively in black and white, she then "fixes and expresses" the virtual forms in cloth, using the surface effects of different weave structures to underscore "the physical stratification of the planes."[192]

To create the "weave files" for *Interferens*, Sørensen used a function of Photoshop to reduce the images of her forms to three "colors," two blacks and one white.[193] This technique is commonly referred to as posterizing, as it resembles the photographic process originally used to create posters. Using another function of Photoshop, she then "filled" the colored areas with specific patterns, with one pattern for

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[191] Sørensen's *Interferens* tapestries were exhibited in a one-person show at the Sønderjyllands Kuntsmuseum in Tønder, Denmark in 2005. They are also the basis for a line of commercial fabrics designed by Sørensen for the Danish textile manufacturer, Kvadrat.

[192] Grethe Sørensen, "New Tools Open Up for New Possibilities," in *Grethe Sørensen vævninger over temaet interferens* [weaves the theme interference] (Tønder, Denmark: Sønferjyllands Kuntsmuseum, 2005), exhibition catalog, 8.

[193] A "weave file" is a bitmap that is read by the digital loom specifying which warp threads are to be raised in which picks of weaving. It is created for that purpose.

each color. Each pattern is a distinct black-and-white bitmap that, when read by the digital loom, establishes the weave structure for the corresponding area of the composition. In *Interferens*, Sørensen weaves using only black and white warp and weft (no grays) and creates two layers of subtle black planes by using the digital loom to weave one layer in a black warp-faced satin and the other in a black weft-faced satin.[194] Typically, weave structures are assigned to achieve specific colors in cloth woven on the digital loom, but other effects, such as contrasting textures, as with Sørensen's black planes, are possible.[195]

The perpendicular orientation of the threads in the warp-faced versus weft-faced satin—in other words, the visual articulation of the contrasting textures, producing a classic damask effect—is sufficient to create the contrast necessary to establish the presence of the two planes. Behind these layers, the background is woven in white, which simulates the light shining through the perforations.

After the black-and-white *Interferens* project, Sørensen moved on to include color in her exploration of the artistic possibilities of digital weaving. The first project she tackled involved weaving a traditional color wheel, with the primary colors and all the color gradations in between. In her initial attempts, she used the same posterizing

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194 Sørensen, interview, December 11, 2014. Warp-faced satin is characterized by warp floats on the face, with the weft used intermittently as ties. Weft-faced satin is characterized by weft floats on the face, with the warp used intermittently as ties. The vertical warp floats and horizontal weft floats are perpendicular.

195 When assigning weave structures, particularly to achieve specific colors, the weaver must also establish the appropriate order of threads with different colors or other features in the warp and the appropriate sequencing of threads with different colors or other features in the weft. Neither Photoshop nor the digital loom has the capabilities needed to automatically determine these essential elements of the woven construction. Without the appropriate warp and weft configurations on the loom, the structures prescribed in the weave file will not necessarily achieve the desired effect. Users of digital looms often use "weave blankets" to facilitate assigning weave structures to their designs. See appendix 1.

technique as in *Interferens*, dividing the polychrome color wheel into distinct areas of color and then assigning color-based weave structures to each.[196]

Sørensen found the results of the posterizing approach awkward: The continuous gradations of color were converted to distinct regions of a limited number of defined colors with abrupt changes from one color to another. This did not achieve the elegant and smooth transitions from color to color that she was looking for. But it was not only a question of color; the texture of the cloth was just as important. The visual properties of the juxtaposition of different weave structures—the variety of "tactile values"—did not, to her mind, produce a beautiful surface effect. (Fig. 6.4) In fact, they further detracted from the soft color gradations that she was trying to achieve. And dividing the wheel into thinner and thinner slivers of distinct colors, each with their own corresponding weave structure, was not the solution. Sørensen knew there had to be another way to achieve her objective.[197]

Sørensen's creative intuition led her to devise a different way to construct her color spectrum, resulting in the structure she calls "random weave." It is, in a sense, a nanotech approach operating at a microlevel: The design is reduced to a designated and limited number of primary and secondary colored pixels that correspond to the colored threads to be used in the weaving. The weave is then structured such that each colored pixel is represented in the construction by a visible thread of the same color. Operating on the same premise as eight-color printing, or the use of colored pixels on a computer screen, the visual mixture of the colored threads can be used to produce a full spectrum of colors that transition smoothly from one to the next. "I could transform the beauty of my

[196] See appendix 1.

[197] Sørensen, interview, December 11, 2014.

color spectrum on the screen directly into a weave construction," Sørensen explains.[198] In *Color Spectrum* (2006), Sørensen's "random" weave achieved the elegant convergence of color and texture she sought—the fluid succession of color with a consistent tactile character. (Fig. 6.5) This weave structure will be examined in more detail later in the paper in the context of Sørensen's *Rush Hour 2/Shanghai* (2012).[199]

Sørensen acknowledges that her experience with weaving and her understanding of weave construction were vital in the evolution of her work with digital-loom technology.[200] Testing her ideas with real thread on the loom was also key. As she experimented with ways to realize her color wheel, Sørensen was working on her own TC-1 loom, which she had purchased for her studio in 2004. She wove multiple samples until she arrived at the process for her random weaving technique. "The coincidences that happen while playing with materials and constructions are invaluable and cannot be replaced by computer screens," Sørensen explains.[201] The material imperative is not unique to the digital age. Fifty years earlier, Albers said, "A design on paper…cannot take into account the fine surprises of a material and make imaginative use of them."[202]

Color Spectrum led to several more projects in which Sørensen collaborated with her husband on video-based designs. These included *Out of Focus* (2006) and *Millions of Colors 1-7* (2009), both of which were based on frame grabs from video animations of

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[198] Sørensen, "Traditional to Digital," 3-4.

[199] There are other colored pixel-based techniques that are used to render colors in digital weavings. The specific process used by Sørensen, discussed in more detail later on, is one that she came upon in her color wheel experimentation and later refined for her *Traces of Light* series. Lia Cook, for example, in works such as *Traces: Intent* and *Blur Girl*, uses a rather different colored pixel-based process to achieve her range of colors.

[200] Sørensen, "Traditional to Digital," 7.

[201] Ibid.

[202] Albers, *On Designing*, 13

slowly streaming, oversized colored pixels.[203] (Figs. 6.6-6.7) "The digital tools…build bridges that give me access to other media where I can …express myself. I am still rooted in woven textiles – but the combination of the two media enriches both," she explains.[204]

The exhibitions of these works featured both Sørensen's weavings and similarly sized screens showing Hovgaard's videos from which the weavings were taken. While designing and weaving the 2009 tapestries, Sørensen also focused on refining her random weave technique, arriving at the process and construction used in her monumental *Rush Hour 2/Shanghai* (2012), now in the collection of the Cooper Hewitt Smithsonian Design Museum. (Fig. 6.8)

After her work derived from video animation, Sørensen sought inspiration in video imagery taken from the real world. *Rush Hour 2/Shanghai* was part of the *Traces of Light* series, eighteen large-scale weavings developed by Sørensen from videos shot by her husband at night in cities around the world. Hovgaard's videos captured the light coming from the headlights of moving cars, traffic lights, and illuminated advertising signs in nocturnal urban environments. "In the darkness, physical things disappear and man-made light[s]…trace their own patterns and forms in the night," Sørensen explains.[205] The video camera was intentionally unfocused, capturing a "sensory," or impressionistic, image of the lights of the city at night. Photorealism was not the objective. She argues that the visual composition taken from the photo should always be

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[203] Sørensen also used her random weave construction to create a line of upholstery fabric called Millions of Colors for the American design company Wolf-Gordon.

[204] Sørensen, "Traditional to Digital," 6.

[205] Grethe Sørensen and Bo Hovgaard, "Traces of Light: A Sensory Image of City Light," in *Traces of Light: Weaving by Grethe Sørensen, Video by Grethe Sørensen & Bo Hovgaard* (Copenhagen: Rundetaarn, 2012), exhibition catalog, 9.

blurred, an abstraction.[206] "The unfocused camera works as a filter that transforms the realism of the colored lights and signs into patterns of circular spots of colors."[207] Sørensen's weave structure in the *Traces of Light* series artfully captures the delicate transparency and the depth of colors created by this elusive light. (Fig. 6.9)

The *Traces of Light* tapestries were displayed in a dramatic installation at the prestigious Round Tower exhibition space in Copenhagen in 2012.[208] (Fig. 6.10) As with exhibitions of Sørensen's earlier digital work, her tapestries were featured alongside large-scale projections of Hovgaard's nocturnal video footage. This successful exhibition drew international attention to Sørensen's digital work and her random weave technique.

Albers argues that effective visual programs for woven art must be carefully and deliberately conceived in the context of the medium. On the one hand, ethereal motifs of light might seem unlikely subjects for textural cloth. Light itself is nothing but electromagnetic radiation visible to the human eye; it has no haptic materiality. On the other hand, Sørensen is using the video frame grab to gather what Bruce Wand would have called "reference imagery," fine details about colors, patterns and forms that can be captured and used in her work. She uses digital technology, Photoshop, to deconstruct those details and then the digital loom to reconstruct them in cloth. In her artistic process,

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[206] Sørensen, interview, December 11, 2014.

[207] Sørensen, "Traditional to Digital," 6.

[208] Copenhagen's Round Tower or Rundetaarn is one of the most popular tourist attractions in the city. The tower's library hall is now an art exhibition and performance space, open to artists by application. The large number of visitors to the Rundetaarn ensures that exhibitions there have high exposure; hence the application process is highly competitive. Sørensen and Hovgaard conceived and proposed their joint exhibition of textiles and video for the Rundetaarn, which was accepted and funded by a grant from Denmark's Statens Kunstfond. Sørensen, interview, December 11, 2014.

the "random yet structured beauty" of the particles of light is well suited to woven cloth.[209]

The origin of *Rush Hour 2/Shanghai* was a frame grab from one of Hovgaard's videos shot in Shanghai, China, which Sørensen chose for its balanced composition.[210] (Fig. 6.11) But the frame grab was only the beginning. Sørensen spent weeks at the computer manipulating the image, adjusting the visual language with the weaving process and structure in mind. Contrast adjustments are critical. Weaving dampens the colors because the intersections of thread cannot be as fine as the individual pixels of the original image. On the other hand, strengthening the colors must be done carefully to preserve the color contrasts that create the sense of depth in the image.[211] The circles of light occupy multiple planes in space and this effect must be preserved. (Fig. 6.12)

The next steps involve more specific adjustments relating directly to the details of the planned woven construction. For these, Sørensen had to begin at the loom. As Linda Candy explains, artists using digital tools to work in concrete rather than virtual arts must define a set of constraints for the computer. One of the attractions of working with digital design tools is the computer's ability to represent the underlying structure of the work. In the computer's virtual world, the elements for doing so are infinite; in the real world, they are not. So in order to develop a viable weave program, for example, the constraints that

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[209] Bruce Wand, *Art of the Digital Age* (London: Thames & Hudson, 2006), 39. Wand describes how digital artists use photos to abstract patterns and other information—with "random yet structured beauty"—from the natural world, which they then reinterpret in their art.

[210] I thank Grethe Sørensen for her assistance in analyzing the design process and weave structure in *Rush Hour 2/Shanghai.*

[211] Sørensen, interview, December 11, 2014.

make up the underlying structure of the work must be made explicit for the computer.[212] As discussed earlier, the nature of the thread to be woven as well as the colors and layout of the warp and the colors and sequencing of the weft must be established. The computer does not do this. Fixing these parameters is a matter of artistic judgment, with direct consequences for the character of the textile produced. Weavers such as Sørensen are accustomed to this process of making constraints explicit. Weaving is inherently a rule-based process. For example, when weaving on any loom, with any production process, the warp, once threaded, is largely fixed.

Because of its size, Sørensen wove *Rush Hour 2/Shanghai*, like the other large tapestries from the *Traces of Light* series, on an industrial Jacquard loom at the Digital Lab in the Audax Textielmuseum in Tilburg, the Netherlands. (Fig. 6.13) The Textielmuseum's looms are among the only industrial Jacquard looms in Europe available to artists. Sørensen's TC loom is not large enough to weave the actual tapestries, although, as previously noted, weaving samples on her personal digital loom is an integral part of her design process. "In spite of the fact that most of my work will end up being woven on a Jacquard machine," Sørensen explains, "it will always pass through my hands in the development process. To me the sample weaving process is essential."[213] (Fig. 6.14)

The Tilburg loom presented one immediate constraint: it is warped with standard smooth cotton threads, alternating in color between black and white.[214] With the black

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[212] Linda Candy, "Constraints and Creativity in the Digital Arts," *Leonardo* 40, no.4 (2007): 366-7.

[213] Sørensen, "Traditional to Digital," 7.

[214] Because warping is a time-consuming and laborious process, most industrial Jacquard looms are warped with hundreds of yards of a basic set of threads. It would not have been possible for

and white warp as a given, the only means for Sørensen to introduce other colors is in the weft. She devised a system of eight colors of weft threads in a fixed sequence: black, red, green, blue, white, cyan, magenta, and yellow. The six colors, other than black and white, are those from the basic color model, the RBG/CMY model. This model is the most commonly used because it "bears closest resemblance to how we perceive color."[215] The combinations of these colored threads in the weft of Sørensen's random weave enables her to artfully compose a rainbow of colored light.

The keys to Sørensen's random weave are that she consistently uses the full rotation of eight wefts and that each weft is "continuous," that is to say, each weft thread runs the full width of the weaving from selvedge to selvedge. This means that each line of pixels in the image is woven by a full sequence of eight continuous wefts.[216] In most rows, all eight colors are not needed to realize the design. Sørensen has structured the weave such that a colored weft appears on the surface only in that segment of the row where it is called for. For the remainder of its pass, it is woven underneath the face of the

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Sørensen to specify a different warp. In order to create a balanced weave, and because of the complexity of the weave structure itself, Sørensen uses smooth cotton threads in the weft as well.

[215] Adobe Technical Guides, "The RGB (CMY) Color Model." http://dba.med.sc.edu/price/irf/Adobe_tg/models/rgbcmy.html. Accessed December 15, 2014. Red, green, and blue are the three most commonly used colors in additive combinations, which are those that use projected light, as is done in CRT (cathode ray tube) displays. Cyan, magenta, and yellow are the most commonly used for subtractive combinations, which are those that use reflected light, as is done with printing. In additive combinations, the colored light is added to a black field (the absence of color) and the eye perceives the combinations of red, green, and blue. In subtractive combinations, one begins with a white field that reflects the full spectrum of colors and pigments are added that absorb certain wavelengths. For example, cyan absorbs red so only blue/green or cyan is visible and so on. In *Rush Hour 2/Shanghai,* as in all the *Traces of Light* weavings, red, green, or blue weft are always interlaced with black warp; similarly, cyan, magenta, or yellow weft are always interlaced with white warp.

[216] "Continuous" wefts run the full width of the warp. As noted earlier, traditional tapestry technique uses "discontinuous" wefts, which do not run selvedge to selvedge. Instead, they are inserted in specific areas of the warp, creating fields of colors in a mosaic-like fashion. See page 20 of thesis, and Emery, *Primary Structures*, 78-9.

textile. Put another way, *Rush Hour 2/Shanghai* has one hundred picks per centimeter of weft (approximately 35,000 in total), but only approximately twelve-and-one-half picks per centimeter appear on the face.[217] The remaining wefts are woven into the middle and reverse of the cloth, creating a truly three-dimensional textile, with dramatic aesthetic effects I will discuss later. (Fig. 6.15) Because of the large number of weft insertions, the 6,114 individual warp threads are tripled in the weaving to reduce the number of actual interlacings: three warp threads (either all black or white) are woven as one. Otherwise, the sheer volume of interlacings would make the cloth too bulky to weave.[218]

Having established these physical parameters, Sørensen uses Photoshop to make the necessary adjustments to the bitmap of the image. She first resizes the bitmap to account for the aspect ratio—the ratio of the size of the warp and weft threads in the weaving. Next, she reduces the colors in the bitmap at the level of the pixel to the eight index colors of the weft threads. (Fig. 6.16) Following that, she must adjust the size of the bitmap (the number of pixels in the rows and columns of the grid) to account for the triple-thread warps and the eight-thread weft sequence. Then, because each weft insertion is a thread of a single color, she must expand each row of polychrome pixels into eight separate rows, one for each colored weft insertion in the proper sequence. (Fig. 6.17) She renders the final weave file, however, only in black and white because the digital loom does not read color, only black (warp up) or white (warp down).[219] The color effect is realized because the physical wefts are inserted in the weaving in the eight-color sequence that precisely matches the separated colors of the eight rows of pixels.

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[217] Sørensen uses smooth cotton threads that are fine enough to be packed into layers as they are beat into the cloth.

[218] Sørensen, interview, December 11, 2014.

[219] Ibid.

Lastly, Sørensen changes the structure of the weave on the reverse side of the tapestry to a satin in order to give the cloth greater stability and adjusts the random weave on the face in certain areas to eliminate overly long floats and to ensure a consistent thickness.[220] Long floats and bulky areas would interfere with the weaving process on the Textilmuseum's industrial loom. As Julie Hanus writes, "Modeling a form digitally with the goal of producing a real world object requires a keen attentiveness to all the properties of the intended material."[221]

The development of the weave files for the tapestries in the *Traces of Light* series was a rigorous and disciplined process involving as much art as science. Because Sørensen had little immediate control over the actual weaving on Tilburg's industrial loom, her traditional craft practice was displaced into the development of the weave file. Sørensen spent months going back and forth between her work at the computer and sampling on her TC loom. She practiced her craft with one hand in the virtual world and the other in the physical.

Sørensen's random weave is unlike any traditional weave construction. However, her structure is not "random" in the sense of arbitrary or accidental. As I have shown, it is quite deliberately planned. Instead, random refers to the fact that Sørensen is not imposing a preexisting weave structure on the cloth. The interlaced construction of threads in each weaving is a function of the unique arrangement of colored pixels in the

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[220] Sørensen, interview, December 11, 2014. The random weave Sørensen used in her *Color Spectrum* and *Millions of Colors* tapestries more closely resembles a classic double-cloth structure: the tapestries are reversible, with complementary colors appearing on either side. However, this earlier structure involved layers of loose warp threads in between the face and reverse of the tapestries and was less stable.

[221] Julie K. Hanus, "Brave New World," *American Craft Magazine* (October/November 2014). http://craftcouncil.org/magazine/article/brave-new-world. Accessed October 1, 2014.

underlying image.[222] Thus, the precise order of the interlacings in *Rush Hour 2/Shanghai* differs from that of the other tapestries in the *Traces of Light* series. And yet while Sørensen is, in a sense, weaving pixels, the abstract nature of the image and the sophistication of tactile surface obscure the tapestry's bitmap origins.

In spite of their random, or unique, construction, these weaves do have, as Sørensen points out, "their own character."[223] In *Rush Hour 2/Shanghai*, the qualities of the inner structure manifest themselves in the highly textural surface of the cloth with a certain consistency, a clarity of expression. It is evident that the tapestry is woven with a coherent weave structure, even though it is no structure at all in the traditional sense. (Fig. 6.18) These tactile effects are quite deliberate and are as important to Sørensen as the creation of color effects. "The manual work with thread and construction is essential in order to be able to play with the tactile values embedded in the textile…Computer programs will never have the sensuous knowledge of your hands."[224] The soft bodies of light are not only realized in the weave structure but also enhanced by it.

Rush Hour 2/Shanghai's sophisticated weave structure is integral to its attraction. Images of floating circles of light from the headlights of moving cars at night are ubiquitous in contemporary television and motion pictures. The visual complexity of the textile, in the appearance on the surface of the interlaced threads, engages the viewer with this otherwise pedestrian image. The soft circles of light are not merely projected on the surface; they are embedded in an active woven construction. The sensuous tactile surface

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[222] Sørensen's random weave differs from the more common posterizing approach used in digital weaving in which predetermined weave structures are imposed on the image. See appendix 1.

[223] Sørensen, "Traditional to Digital," 4.

[224] Ibid., 7.

of *Rush Hour 2/Shanghai* rescripts our encounter with this arguably ordinary phenomenon.

The multiplicity of interlocking threads creates a unique sculptural surface that elegantly simulates the soft circles of light with depth and warmth. (Fig. 6.19) For every one hundred weft threads, eighty-eight are embedded in the volume of the textile. (Fig. 6.15) While the notion of double-cloth is helpful in understanding the multilayer nature of this construction, it is not a true double-cloth: There are more than two layers, but each layer does not necessarily have a complete set of both warp and weft elements. This creates a transparency between the layers. To borrow a phrase from Guiliana Bruno, "Distinctions between inside and outside…dissolve into the depth of surface."[225]

The face of the tapestry is transluscent, hinting at the layers of interlacing colored threads below the surface. (Fig. 6.20) This allows for true matière effects: The layers have reflective and refractive qualities that generate not only depth but also the luminosity of light and a sense of motion.[226] It is a vibrant, animated surface. The circles of light are realized in cloth but not fixed by it: they approach, recede, and shift in the three-dimensional space of the textile.

The visual articulation of weave structure creates a remarkable transposition of ethereal light into a material form. White light is made up of all the colors in the visible spectrum; in Sørensen's tapestry, the white circles are similarly made of many colored particles. Black is theoretically the absence of visible light but in the illuminated city, at

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[225] Giuliana Bruno, *Surface: Matters of Aesthetics, Materiality, and Media* (Chicago: University of Chicago Press, 2014), 5.

[226] Sørensen specifies that works like *Rush Hour 2/Shanghai* should be hung a few inches off the wall instead of flush with the wall to accentuate the volumetric effect.

night, light is never totally absent: the black areas of the tapestry reveal the vestiges of colored light in the darkness. (Fig. 6.21)

The juxtaposition of Hovgaard's video and Sørensen's textiles, which so artfully capture the ethereal nature of the optical phenomena, adds another dimension to Bruno's recent arguments "for a shift in focus away from the optic and toward a haptic materiality" in contemporary media.[227] The video is a virtual manifestation of light, one that Bruno would argue embodies its own materiality—that of the screen.[228] Sørensen has refashioned that image; she has made the virtual tangible, giving it form and structure in her tapestry. Borrowing another phrase from Bruno, the circles of light in *Rush Hour 2/Shanghai* "haptically materialize in motion" in a sculptural three-dimensional space.[229] Digital weaving technology has broken down barriers between virtual and physical media.

The digital Jacquard loom and its ability to read information from digital design programs as weave structure transformed Sørensen's work. "I feel I have got a gift," she said recently. "It is like starting over after twenty-five years, a new opening to a new world."[230] "Beginnings," Albers wrote, "are usually more interesting than elaborations and endings. Beginning means exploration…a potent vitality not yet limited, not

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[227] Bruno, *Surface*, 3.

[228] Ibid., 3-7. Bruno argues with respect to materiality, "The physicality of a thing one can touch does not vanish with the disappearance of its material but can morph culturally, transmuting…into another medium."

[229] Ibid., 96.

[230] Grethe Sørensen, interview by Matilda McQuaid, Head of Textiles, Cooper Hewitt Smithsonian Design Museum, New York, December 10, 2013. I thank Ms. McQuaid for inviting me to sit in on this interview.

circumscribed by the tried and traditional."[231] Digital technologies have enabled Sørensen to discover and realize what Albers so passionately sought: "Fresh and discerning ways to use the surface qualities of weaving."[232]

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[231] Albers, *On Weaving*, 52.

[232] Albers, *On Designing*, 15.

7. Conclusion

> I have never regarded technique as the automatism of a "craft," nor as the curiosities, the recipes of a "cuisine"; but instead as a whole poetry of action and…the means for the achievement of metamorphoses.
>
> —Henri Focillon, *The Life of Forms in Art*

Directness of communication in weaving—tactile sensibility—is not a singular aesthetic. As is evident in the work of Lia Cook and Grethe Sørensen, it can be manifested in woven cloth in dramatically different ways. (Fig. 7.1) In works such as *Binary Traces: Kay* and *Su Series*, Cook derives her visual programs from photos of real people. Sørensen, on the other hand, extracted *Rush Hour 2/Shanghai* from non-representational videos that capture elusive forms of light. Cook applies double-cloth weave structures that she has devised to the visual information she has purposefully abstracted from her photos. Sørensen manipulates pixel-level data embodied in her video frame grab and uses the data intrinsic to the image to generate a unique weave structure. Cook's works put the viewer in motion—they ask you to approach them and then step back from them. At a distance, her weavings present the shadow or suggestion of a face. Up close, they dissolve into unstable, idiosyncratic protean patterns formed by the interlacing of threads. Sørensen's work presents a surface in motion. Her random weave forms a coherent and serene three-dimensional woven surface. Its luminous reflective and refractive qualities suggest the movement of headlights that approach and recede in space.

The works of both artists, however, are similar in that they both operate within the specific formal domain of woven art, in Albers' words, "the forming of a pliable plane of threads by interlacing them rectangularly."[233] In 1965, Albers observed that this formal

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* Henri Focillon, *The Life of Forms in Art* (New York: Zone Books, 1992), 102-103.

[233] Albers, *On Weaving*, 19.

domain has remained essentially unchanged since it was invented in a preceramic age.[234] Fifty years later, that is still true. Even the introduction of the digital hand loom has not altered the fundamental nature of the woven form. The ability to digitally control the raising and lowering of individual warp threads has not altered the essential grid nature of the interlacing of warp and weft.

What has changed—and what has enabled artists like Cook and Sørensen, to realize inventive and imaginative new works that use Albers's pliable plane—is the power of digital design software. This development is not unique to weaving. As Christiane Paul explains, the digital technology revolution of the 1990s made both hardware and software more refined and affordable: "[The] technology has now reached such a stage of development that it offers entirely new possibilities for the creation and experience of art." Some forms of digital or new media art are virtual, with works that are "produced, stored, and presented exclusively in the digital format." Others, like digital weaving, use these technologies as tools in a variety of ways for the creation of works with traditional materials and processes, and/or with the use of 3D printers and other digital fabrication techniques.[235]

Weavings such as *Su Series* and *Rush Hour 2/Shanghai* demonstrate their respective maker's skill in the use of digital design software in the context of the woven

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[234] Ibid.

[235] Christiane Paul, *Digital Art* (New York: Thames & Hudson, 2008), 7-8. Paul's book gives a comprehensive overview of the field of "digital art." For recent observations on the role of digital fabrication technologies in traditional craft mediums, see Hanus, "Brave New World." Interestingly, digital weaving is omitted from these and most other discussions of new media art. *Out of Hand: Materializing the Postdigital*, the 2013 exhibition of digital art at the Museum of Arts and Design in New York, only included one example of digitally woven art: a self-portrait of the artist Chuck Close designed by Close in cooperation with Magnolia Editions and produced by expert weavers on an industrial Jacquard loom at the Flanders Mill in Belgium.

form. Each of these artists has the capacity for abstract visual thinking that enables her to create weave files by manipulating the bitmap in Photoshop.[236] Cook and Sørensen use this skill along with the power of software to explore those formal qualities of weaving that are inaccessible with traditional tools. Cook's double-cloth structures and Sørensen's random weave could not be realized without the ability to manipulate individual warp threads. More significantly, without software, these forms would be impossible, in a practical sense, to design manually. Creating a point paper by hand for either artist's work is unthinkable.

Both Cook and Sørensen use photographic images as the reference imagery for their weavings. As a result, Photoshop, while it is not weave design software, has become an essential element of their artistic practices.[237] It is the functionalities of Photoshop that allow Cook to reduce her childhood photos to a black-and-white bitmap and to assign one of two planes of double cloth to the appropriate corresponding pixels. Similarly, Photoshop enables Sørensen to reduce her video frame grabs to eight index colors and then create a weave file with a few key strokes by separating each row of pixels into eight rows by color. These functionalities were not built for designing weaves, but because of the congruence between the bitmap and the point paper grid, Photoshop has a particular affinity for the conventional process of weave design, and many weavers, like Cook and Sørensen, have appropriated it for this purpose.[238]

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[236] McCullough, *Abstracting Craft*, 52. According to McCullough, computers have expanded our capacity to visualize abstract symbolic structures.

[237] While specific weave design programs for digital looms exist, weavers working with visual programs based on photographic imagery consider that none has the range of capabilities, flexibility, or the affordability of Photoshop.

[238] McCullough, *Abstracting Craft*, 150. McCullough discusses how a digital tool should have an affinity to a conventional analog process but not be limited by it.

Importantly, these functionalities do not merely simulate the manual process of drawing point paper designs and are not bound by the physical or cognitive limitations of that process.[239] Many of Photoshop's highly automated software commands, according to Lev Manovich, use generative algorithms, which augment and extend the capabilities of previously existing design practices.[240] These generative algorithms empower artists like Cook and Sørensen to push beyond the traditional structural boundaries of their art.

The power of software, however, also poses a challenge. Software has the ability to manipulate any form of digitized data, irrespective of what it represents. This leads to a blurring of boundaries between media. Put another way, anything that can be scanned into Photoshop can be manipulated into a weave file. But to what end? In general, as McCullough notes, idioms do not necessarily translate well from one art form to another.[241] In the specific case of digital weaving, Eva Basile echoes Albers when she says, "Using technology to create [woven] works conceived from another medium is a debatable operation."[242]

The seemingly endless creative possibilities and the detachment of working in virtual space make it vital, Jane Harris argues, for the artist to enter the digital world with

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[239] Ibid., 62, 150. McCullough discusses how tools introduce abstractions that extend the powers of the mind.

[240] Manovich also argues that software may play more of a direct and possibly independent role in creative processes. He observes: "Software applications shape our world and our imaginations (what people imagine they can do with software)…[by] making some design choices seem natural and easy to execute, while hiding other design possibilities." Manovich suggests that the augmentation of creative processes by automated generative algorithms may introduce new, and sometimes unforeseen, welcomed or unwelcomed, properties in the resulting media. Lev Manovich, "Inside Photoshop®," *Computational Culture* 1 (November 2011), http://computationalculture.net/inside-photoshop. Accessed December 2, 2014. New media theorists such as Manovich have only begun to examine the unique agency of digital design software. Its effect on digital weaving remains to be explored.

[241] McCullough, *Abstracting Craft*, 201.

[242] Basile, "Digital Tapestry,"13.

a clear conceptual and aesthetic objective. For those using digital tools to work in traditional physical media, experience-based, expert knowledge of the tangible qualities of materials and of the hands-on process of making provide essential and meaningful guides.[243] "Ultimately, as Paul points out, every object—even the virtual one—is about its own materiality, which informs the way it creates meaning."[244] A material provides a unique sets of formal possibilities and constraints, what McCullough calls "affordances." Affordances are not always obvious but they are discoverable. Understanding them and using them appropriately and effectively is good workmanship, McCullough explains, and it is what great artists do well.[245] Digital tools do not obviate the need for good workmanship; they heighten it.

Cook and Sørensen bring the requisite knowledge-based aesthetic clarity to their digital weaving. This is why their work exemplifies Albers's aesthetic of tactile sensibility. Their focus is firmly rooted in an understanding of materials and construction processes derived from their previous experience as hand weavers. Craft and technology are not incompatible: Craft is essential to working well with technology. Perhaps, as Peter Dormer suggests, we just need to think differently about craft.[246] Dormer explains, "It is not craft as 'handcraft' that defines contemporary craftsmanship. It is craft as knowledge that empowers a maker to take charge of technology."[247] Craft as knowledge

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[243] Jane Harris, "Crafting Computer Graphics," *Textile: The Journal of Cloth and Culture* 3, no. 1 (January 2005): 26-7.

[244] Paul, *Digital Art,* 70. Even in the digital art world, according to Paul, "the formal aspects of a work are always inextricably interconnected with its content."

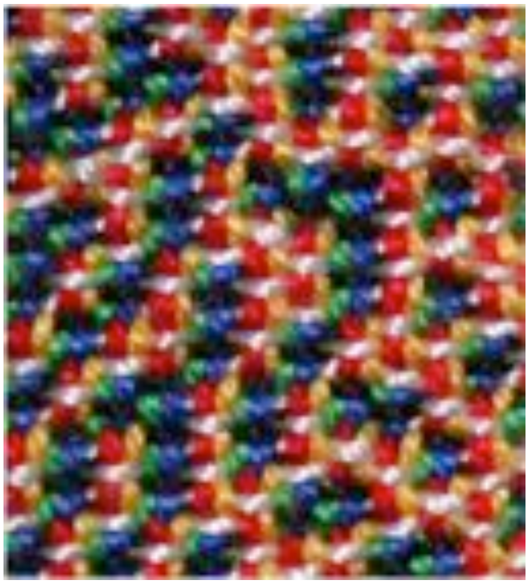
[245] McCullough, *Abstracting Craft*, 199-201.

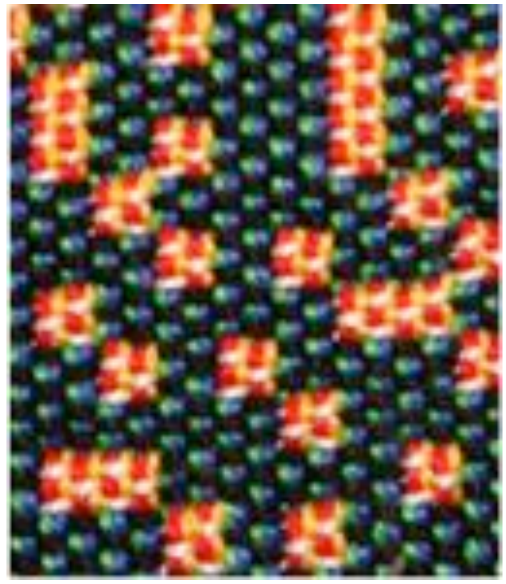
[246] See Dormer, "Salon de Refuse," 2-16; and Peter Dormer, "Craft and the Turing Test for Practical Thinking," in Dormer, *Culture of Craft*, 137-57.

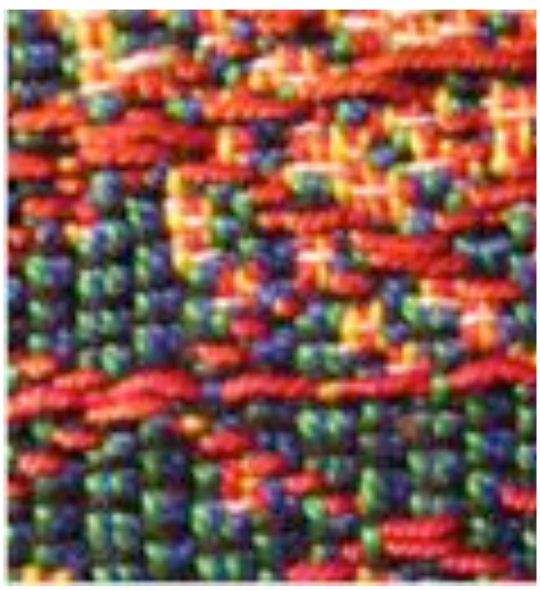
[247] Dormer, "Craft and the Turing Test", 140.

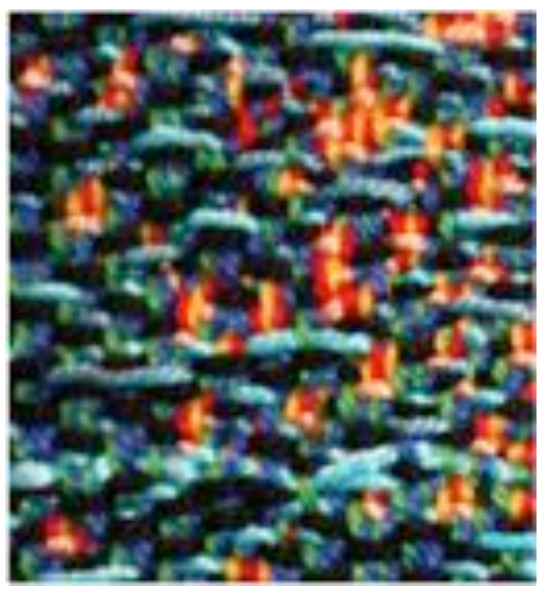
empowers Cook and Sørensen to use digital tools to return to the fundamental nature of the textile medium, which is precisely the awakening of our tactile sense. But craft as knowledge is not sufficient. Ultimately, each woman's personal artistic vision, creativity, and curiosity lead her to unique explorations of the woven form.

Figure 45
Su Series, Multicolor Block Pattern Details


Vibration


Hyper Pixel


Data Dearest


Blue Screen

Photos by the author and Perimeter Gallery

Figure 46

Su Series, Double Cloth Face and Reverse

Pure Maze, Face

Reverse

Neuro Tracts, Face

Reverse

Photos by the author, courtesy of Lia Cook

Figure 47
Su Series, Maze Pattern Details

Squares

Lips

Pure Maze

Figure 47, continued
Su Series, Maze Pattern Details

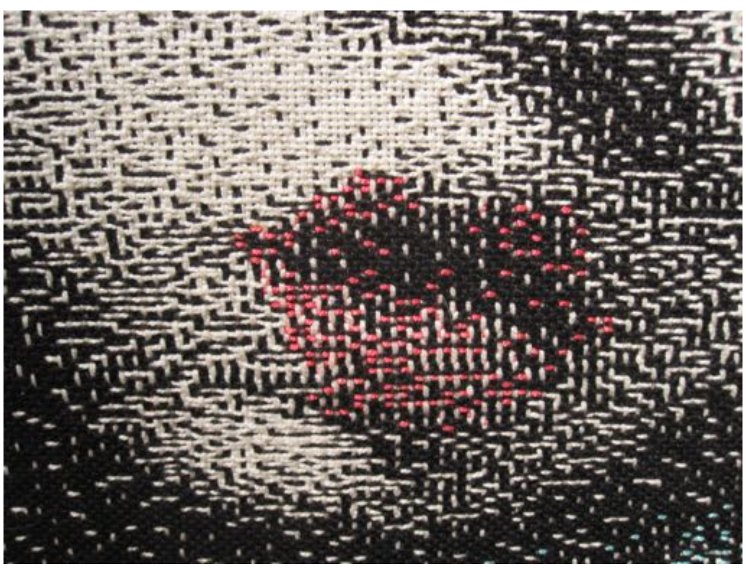
Neuro Nets

Neuro Tracts

Photos by the author and Perimeter Gallery

Figure 48
Su Series, Complementary Weft Details

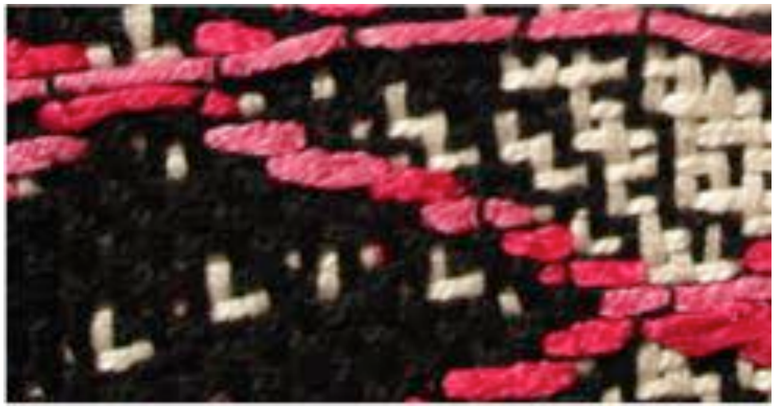
Squares



Lips

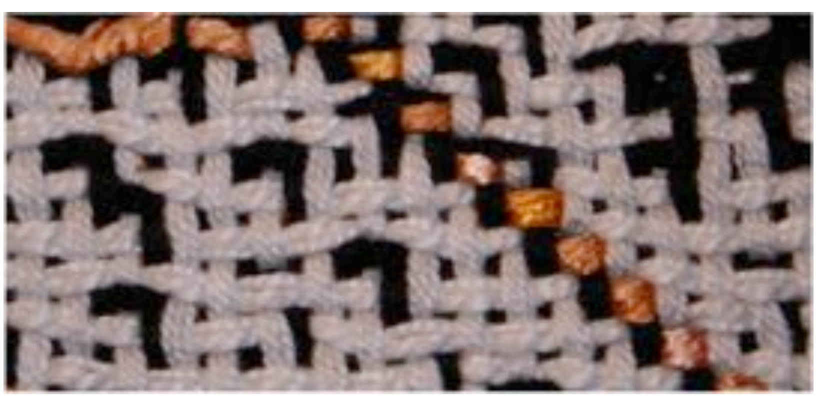
Photos by the author

Figure 49
Su Series, Stair Step Pattern Details



Mega Data R

Mega Tracts

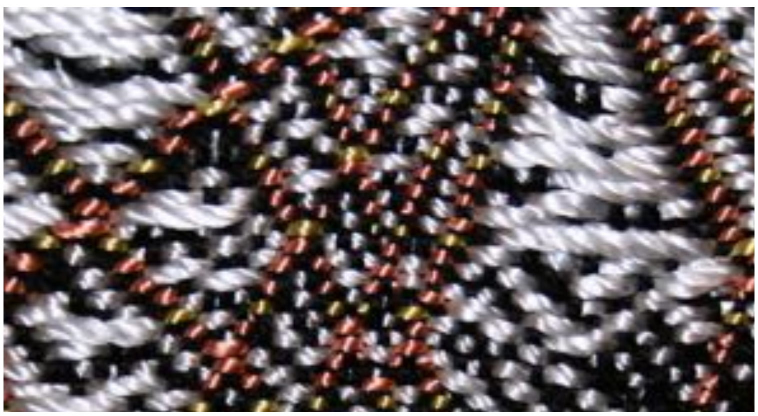


Mega Tracts II

Photos by the author and Perimeter Gallery

Figure 50
Su Series, Satin Pattern Details


Little Amazed


Intensity Data


Neural Tracts

Photos by the author and Perimeter Gallery

Figure 51
Emotional Impact of Photos versus Weavings
Data Chart of Lia Cook's Research Results

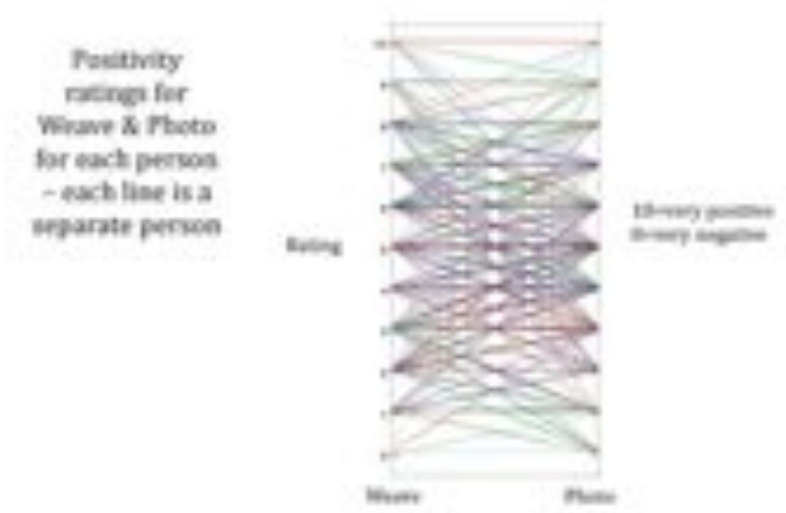
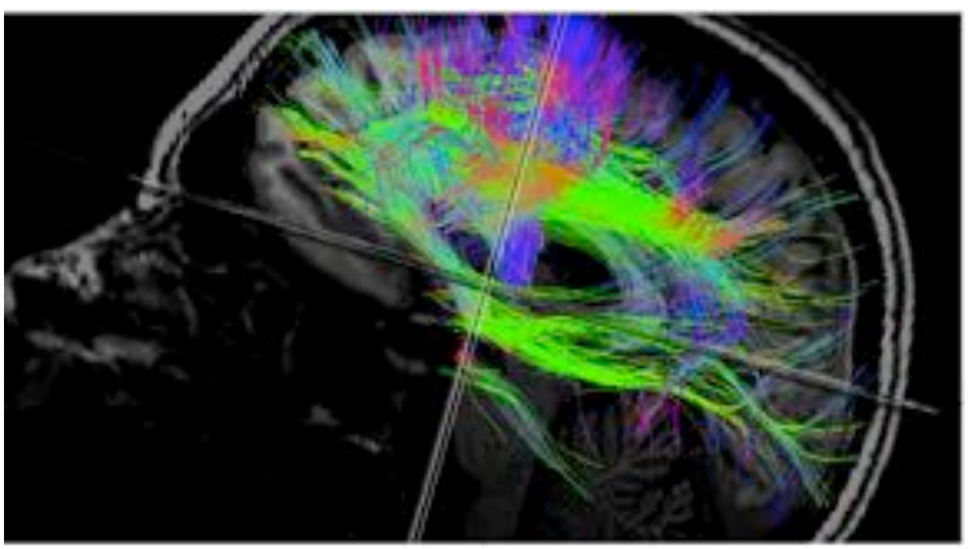


Figure 52
Emotional Response to Woven Images
Neural Pathway Imaging



Images courtesy of Lia Cook

Figure 53
Su Series, Supplementary Wefts: Data Charts


Intensity Data


Mega Data R


Data Dearest

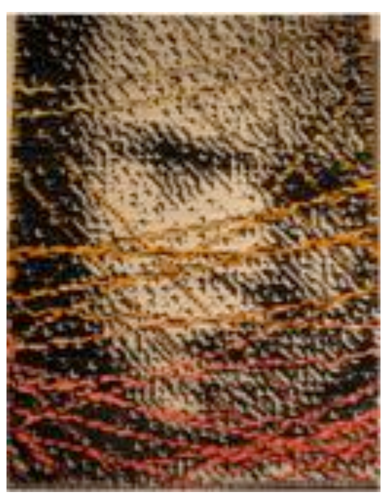

Blue Screen

Photos courtesy of Lia Cook

Figure 54
Su Series, Supplementary Wefts: Neural Pathways


Neuro Nets *Neuro Tracts*

Neural Tracts

Mega Tracts *Mega Tracts II*

Photos courtesy of
Lia Cook

Figure 55

Anni Albers
Pasture, 1958
Cotton, woven
14 × 15 1/2 in.
Metropolitan Museum of Art
69.135