Blackwork Embroidery Pattern Generation Using a Parametric Shape Grammar

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Abstract

Design tools with computational algorithms have been aiding artists for many years in 2D and 3D, from offering a digital drafting table or canvas to applying image filters or other mathematical transformations. However, there are many more non-digital creative tasks that can benefit from computer-aided design. This paper presents an interactive parametric shape grammar for blackwork embroidery pattern generation, whose patterns are then implemented (sewn) using an unmodified home embroidery machine. A design tool executes the grammar-guided user input, enumerates expanded pattern possibilities, and compiles patterns into an immediately sewable file format. The grammar is capable of generating published embroidery patterns as well as infinitely possible new patterns, and has future applications in other areas of surface pattern design and crafts.

Introduction

”Embroidery” is a broad term that roughly encompasses any embellishment by thread, or materials held or strung via thread, on nearly any material, most commonly on textiles. In the multi-millennial lifespan of embroidery, while many fundamental stitches remain the same, dozens of styles and approaches have been classified (Leslie 2007). This paper chooses to focus on non-freeform blackwork embroidery, one of the most restrained styles, as a first approach to embroidery pattern generation.

The objectives of this work include (1) representing counted-stitch embroidery digitally; (2) discovering local properties of stitches to develop into grammar rules capable of generating previously published blackwork embroidery patterns as one possible measure of quality; (3) offering those stylistically different grammar rules as agency to a designer of embroidery patterns; (4) providing instant visualization of enumerated pattern possibilities; and (5) enabling anyone to discover, explore, and enjoy embroidery or related applications of this grammar or pipeline. In order to accomplish these objectives in the following text, we introduce related embroidery and shape grammar history, give an overview of our architecture, discuss the expressive space of our current system, and demonstrate the validity of its generated patterns. A sample of our system’s generated patterns can be seen in Figure 1.

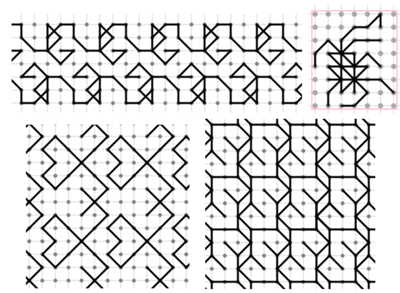

Figure 1: Generated samples by our parametric shape grammar. These demonstrate borders, focal designs (motifs), and two examples of space-filling patterns.

Related Work

Figure 2: 16th centure Tudor blackwork (PKM 2009).

Blackwork as counted-stitch black embroidery on white fabric has a mixed cultural heritage, but it was popularized in 16th century Tudor England, as seen on the caps, cuffs, coifs of people in paintings from that time (Geddes and McNeill 1976) (see Figure 2). The current classification of blackwork, in spite of its name, is not always worked in black nor in a single color. Blackwork, sewn using back stitch and double running stitch, is characterized by dense, complex, and self-similar geometric shapes. Joshua Holden has developed mathematical graph proofs on solving reversible hand sewing approaches to blackwork designs based on these stitches (2005). However, our system focuses on embroidery machine stitch-outs. Patterns designed by artists have been used alone (as motifs), repeated horizontally or vertically (as edges or borders), or horizontally and vertically (as space-fillers).

It is often tedious and troublesome to create fresh patterns, where an author carefully transcribes dozens or hundreds of stitches rotated or duplicated across a motif or pattern. Procedural pattern generation alleviates these boring and repetitive pattern design tasks, offering the designer instant visualization of alternative patterns or applications, such as turning a motif into a fill. Our digital representation also allows users who want the design, but do not have the time, skill, or inclination to sew it out.

Originally formalized by G. Stiny, shape grammars are systems of transformation rules that change one shape into another (1980). Shape grammars belong to a class of techniques involved in procedural generation and have been applied to many artistic and technical topics, from office chairs (Hsiao and Chen 1997) and motorcycles (Pugliese and Cagan 2002) to art (Stiny and Gips 1971; Kirsch and Kirsch 1986) and architecture (Koning and Eizenberg 1981; Çağdaş 1996; Wonka et al. 2003). Parametric shape grammars extend regular shape grammars to be more sensitive to their surroundings, and allow us to more intelligently select which shape rules to expand. As a first draft for this approach, our parametric expansion rules are based off of local density and visual connectedness of stitches (within two stitches) and are detailed below.

Architecture

We have chosen stitches, broken down as straight lines (graph edges) with end points (graph vertexes or nodes), to represent the final pattern sewn as a path on a graph with spacial context. This structure parallels hand embroidery, where the nodes are places where the needle punctures the fabric. The graph pattern is laid down over a grid of arbitrary size, representing any scale of evenweave fabric the stitcher may use. This representation accomplishes our (1) goal.

Figure 3 presents a high-level view of the architecture and user workflow while using our tool. Each of the numbered stages represents a phase of building up the complexity of the design from starting line (Figure 3.1) to output readable by an embroidery machine (Figure 3.5). The rectangular sub-boxes represent additional constraints or options that the author may specify. In stages 2-4, the generation is driven by the author and generated/visualized by the tool for rapid development.

Stage 1: Start

To help initiate creativity and avoid the blank canvas problem, the architecture always seeds the generative space with a line of a random orientation for the user to generate from (Figure 3.1) (van Gogh 1884). To help support the author, the following rules and transformations are applied via clicks of buttons, so zero skill or expertise is required to make elaborate patterns.

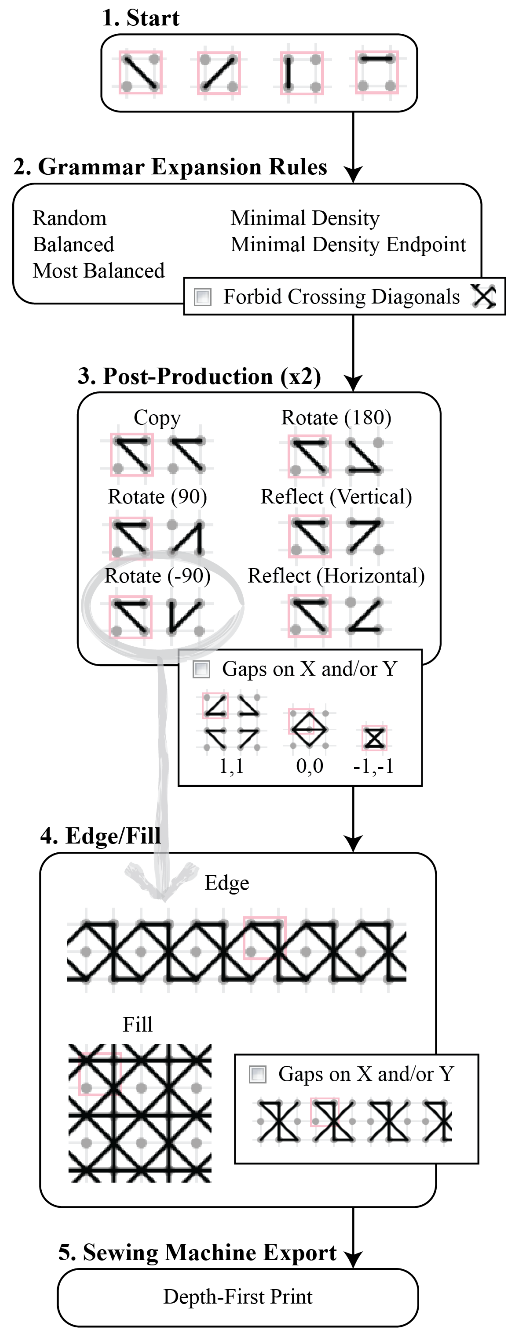

Figure 3: An architecture overview, or workflow pipeline, with stages 1 through 5.

Stage 2: Grammar Expansion Rules

Aligning with our octal linked list data structure, there are eight possible directions of expansion from a single point: up, down, left, right, upper-right, upper-left, lower-left, and lower-right. A single application of any grammar rule transforms a node into a node-and-line extending out in one of these eight directions, generating an edge in the graph and another point if necessary. At each request for a rule application, the system generates every possible stitch growth on the current design and ranks them based on the expansion protocols below. Depending on the protocol, the system picks either the top rule, a weighted random selection, or a completely random selection and executes the rule. All of the generated samples in this paper have not been hand-altered in any way in order to preserve the authenticity of the claims in this paper.

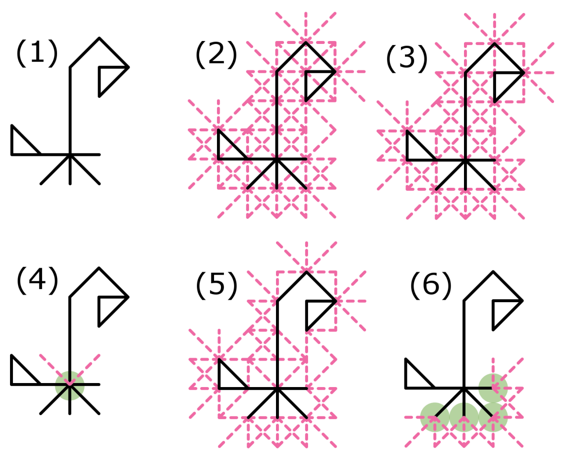

Figure 4: Suppose (1) is the design in its current state. (2) shows all valid expansion rules that can be chosen by Random Expansion as dotted lines; (3) shows (1)'s lines minus Crossing Diagonals. (4) highlights the most dense point on the design, so expansion strategies that maximize density will rank the two lines connected to that point highly. (5) shows (3) without dense endpoints – that is, without lines that would create another cycle in the graph. (6) minimizes density of the new line to the extreme, and would highly rank the showing lines because the highlighted points currently one have one line attached.

Random Expansion The rankings of rules are fundamentally ignored in Random Expansion, and any valid rule is chosen in this expansion protocol (Figure 4.2). Validity requires only that the line does not currently exist. However, if the author has the "Forbid Crossing Diagonals" checkbox checked, a grammar rule is also invalid if it creates a diagonal line that would cross another existing diagonal line (Figure 3.2 causes Figure 4.3).

Density-Based Expansion Density is a score applied to each node that represents how many lines are connected to it. Every new line increases the density of two nodes. The Minimal Density expansion protocol selects lines that increase the designs density the least (Figure 4.6). A design following only minimal density appears as a meandering line. To take additional advantage of our density scores, we offer a "Minimal Density Endpoint" expansion protocol, which only takes into account the density of the far end of the new line (Figure 4.5).

Balanced-Based Expansion Balance is another approach to analyzing the properties of a node and its edges. A node's balance is dictated by how many instances of symmetry it currently has. For example, a node with all possible eight lines attached has maximum balance. Any line that increases the balance of any node is considered as part of the Balanced expansion protocol, while a line that increases the balance of both line endpoints is preferred by the "Most Balanced" protocol. Balanced formations generate tight stars and would, for example, favor the new lines in Figure 4.4 or the lines that were excluded in Figure 4.5.

Stage 3: Post-Production Transformations

Because nearly every blackwork pattern researched for this project contained some form of self-similarity, and that would be extremely difficult to ensure with the grammar alone, we separated the design of pattern section repetition into a separate phase. Post-production has two steps: duplication, reflection, or rotation on the horizontal and then vertical axes. The user also has the option of offsets for these blocks: to allow them to overlap or be given space. The post production transformations are shown in Figure 3.3.

Stage 4: Edge/Fill Visualization Techniques

The eventual application of most modern blackwork patterns are as edges (around a picture, cuff, or collar) or as fills (to repeat and fill out an enclosed space). Both example uses can be seen in Figure 2. Because of the modular creation of our design and its post-production, it was an easy expansion to repeat the design horizontally and vertically to visualize these eventual uses for the patterns. Optional gaps or overlaps can be added between the whole of the design, similar to how post-production added gaps between the transformations.

Stage 5: Sewing Machine Export

Our pipeline converts the design into a planned series of needle positions using depth-first search, and then we output a design directly to a common embroidery format: DST.

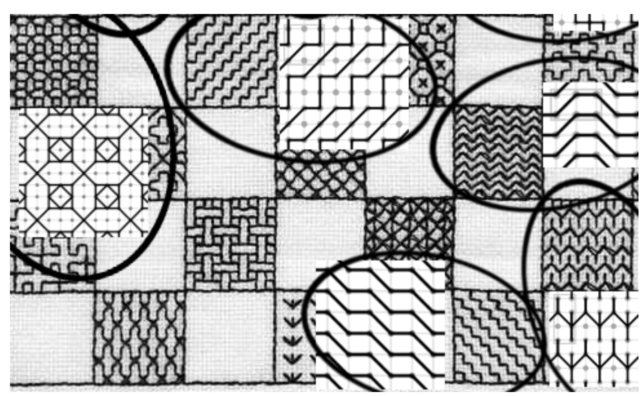

Figure 5: Part of a modern blackwork embroidery sampler, which we have altered to highlight pairs of the original fill patterns and samples made with our system (Renata 2008).

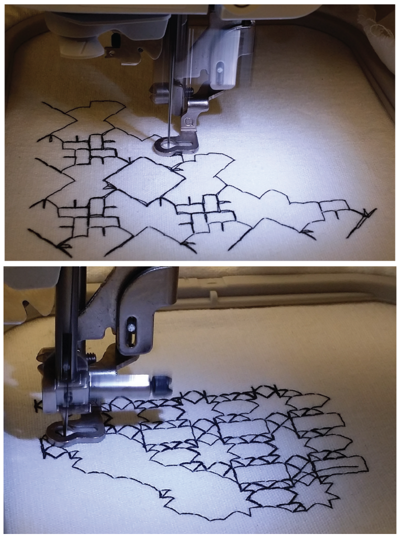

Figure 6: Designs created by users at an informal demo.

Discussion and Evaluation

One measure of our success of goal (2), the capability to generate previously published blackwork embroidery patterns *solely with our expansion rules*, was either trivially simple or exceptionally challenging, depending on the design. For fill patterns especially, some designs are repetitions of tiny elements, so it was easy to match a few previously published hand-authored instances of patterns. However, the possibility space for stitch configuration is exceedingly rich, so it was very challenging to exactly match published patterns that were made up of more than a handful of stitches. However, we did generate very similar designs to many we have seen (See Figure 5). Further samples of matched patterns can be found in publications such as: (Haxell 2012; Hogg 2010). The patterns generated by the grammar exceeded our expectations, as well as those sewers and naive users to whom we informally demoed the system (Figure 6).

A formal user study was outside the scope of this project, but the various forms of grammar rule expansion and post-production did offer distinctly different styles of patterns. Minimal density offers open and loose patterns, while most balanced expansion creates great density. As for demonstrating our visualization usability goals in (3), (4), and (5), feel free to demo our system online[1].

While we did implement various other graph algorithms for our design (minimum spanning tree and cliques), they ended up not being as practical or understandable as those embroidery properties we developed and outlined above (density and balance).

Conclusion

We answered our research goals by developing a web-based design tool capable of outputting designs for hand or machine embroidery. The parametric shape grammar generated previously hand-authored patterns, as well as new designs using our grammar expansion rules. These grammar rules were applied to produce visually distinct patterns, and we successfully sewed arbitrary generated patterns. Similar crafts that use motif repetition and tessellation, such as wallpaper, fabric, or surface pattern design, can also make use of this grammar, design principles, and the pipeline presented in this paper. While there are more usability improvements and feature expansions to add, we have a solid and efficient architecture using novel applications of digital graph algorithms for physical crafts.

[1] https://users.soe.ucsc.edu/ agrow/Blackwork/

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