Enhancing access to high quality tangible information through machine embroidered tactile graphics

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1 INTRODUCTION

Static visual aids (e.g., anatomical diagrams in a textbook, COVID-19 trends visualized in a line graph on the web) play an increasingly important role in education and science communication. For blind or low vision (BLV) individuals, non-visual diagram representations (e.g. written description, data sonification, etc.) are used to communicate visual information. A common approach is tactile graphics consisting of raised lines, textures, braille, and other tactile features to facilitate non-visual interpretation. Tactile graphics are typically created using Braille embossers, which require simplification and conversion of an image source file to an embossing file format which specifies dot sizing and orientation to be punctured on heavy weight paper [nls 2021; Prescher et al. 2014]. However, tactile graphics have limited textural diversity [Minatani 2018], causing confusing overcrowding of indistinct textures, particularly in complex tactile graphics [Bornschein et al. 2015], and can fail to meet user expectations of comprehensibility [Rosenblum and Herzberg 2015].

We present an alternative: machine embroidered tactile graphics. The plethora of stitch types and embroidery techniques allow for a diverse set of structures and textures. If the correct embroidery techniques are used, tactile graphics can afford greater clarity, even for complex examples. Choosing a "correct" or optimal set of embroidery patterns to maximize clarity in an embroidered tactile graphic is a difficult design problem. In this work, we present an optimization pipeline to embroider texturally distinct tactile graphics, validating results from a set of qualitative studies, and suggestions on how to iterate on our pipeline to design even more compelling embroidered graphics.

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2 DEMO REQUIREMENTS

A table large enough for a 40 by 30 poster and table space for several 11 by 11 tactile graphic prototypes.

3 GENERATING OPTIMAL GRAPHICS

Our overall goal is to embroider a tactile graphic representation of a visual image such that a BLV user can distinguish the various regions of the graphic easily. Our pipeline begins with a scalable vector graphic (SVG) file containing an image made up of named, colored regions, and converts it to a format which represents which regions are adjacent to which other regions. We optimize for the best assignment of textures to these regions. Goodness is estimated based on the difference between adjacent textures and the overall assignment's validity for the whole graphic. The result is a list of region names and associated textures. Finally, in a manual step, the SVG is loaded into the Embrilliance embroidery software and a stitch path is calculated using the assigned textures. The resulting stitch file is then printed on an embroidery machine. Braille labels are also generated and attached to the embroidered result, as described at the end of this section.

Representation. We assume that every basic shape in the SVG markup (e.g., `<circle>`, `<path>`) corresponds to an individual region in the image, each shape is labeled with a unique, readable id (e.g., "`id=fountain`"), and that the shapes are color-coded to indicate conceptual similarity. We assign two shapes with the same color the same texture and shapes with different colors different textures. This is converted into a graph: nodes represent regions, and edges indicate that two regions are adjacent. Adjacency is calculated using bounding box collision detection.

Textures. We pre-define a set of embroidery patterns the optimization algorithm selects from. 34 textures were placed on a single linear continuum representing a progression of roughness which was empirically determined by a co-author with over five years of tactile graphic experience. Fig. 1 shows 10 of these textures.

Objective Function. Our objective function encodes three measures: *continuity*, a hard constraint specifying that two regions of the same color must have the same texture assignment; *neighbor contrast*, meaning regions should have maximally distinct texture assignments relative to one another; and *general contrast*, meaning each color in the tactile graphic should be assigned a distinct texture relative to all other textures used in the tactile graphic. Because continuity is a hard constraint, it is maintained during sample generation, rather being included in the objective calculation. The other two objectives are measured as described below.

Recall that we represent each graphic using an graph $G(\mathbb{N}\mathbb{E})$. Each edge in $\mathbb{E}$ represents two regions with overlapping bounding boxes. Each node in $\mathbb{N}$ is a region r with an assigned color c and an assigned texture t, which we denote as $r_{(c.t)}$. The set of all pairings $(c.t)$ is denoted as $\mathbb{P}$. We denote general contrast, G as the overall range of roughness among the textures found in the graph, $\sum_{(c_1.t_1,c_2.t_2)\in\mathbb{P}\times\mathbb{P}} |D(t_1,t_2)|$ where D is the distance between t_1 and t_2 on our linear roughness continuum. We denote *neighbor contrast* as the the sum of the distances between the textures assigned to adjacent regions in the graph, $\sum_{(r_{1_{c_1.t_1}},r_{2_{c_2.t_2}})\in\mathbb{E}} |D(t_1,t_2)|$.

Optimization. We used the OPTIMUM framework [Hofmann 2021] to implement our optimization. To initialize the optimization, each color c is assigned a random, different, texture t from the 34 available textures. New design samples are generated by randomly selecting a new texture from the set of possible textures. A generated design is added to the population only if the it is better than the best design in the previous population. OPTIMUM supports defining constraints for minimally acceptable designs. We require *neighbor contrast* to be at least $|\mathbb{T}|/(1.5 * |\mathbb{P}|)$, where $\mathbb{T}$ is the set of available textures (34 in our case) and general contrast to be at least $|\mathbb{T}|/(2 * |\mathbb{P}|)$. 1.5 and 2 were empirically chosen to ensure that there is distance between textures, while allowing that distance to be smaller for textures that are not adjacent. The final output of this optimization is $\mathbb{P}$, the association between colors and textures.

Braille. A tactile graphic without text labels is akin to a visual image without labels. We follow the common standard of using Braille Labels. We empirically determined that legible Braille conforming to the Braille Authority Guidelines dot size and spacing standards could be produced using the reverse side of the Candlewick 3 Motif Fill in the Embrilliance software. Braille legibility was tested by one co-author who has over a decade of Braille reading experience. Braille labels were embroidered separately and fastened to the main embroidered tactile graphic fabric.

4 VALIDATION OF RESULTS

We conducted a qualitative 75 minute study with five Braille-literate BLV participants, who were recruited through email announcements and in-person gatherings. Each participant interacted with a four embroidered, and four similar embossed, tactile graphics of varying complexity and shared their feedback. Embossed graphics included a bar graph, Venn diagram, human brain, and map. Embroidered graphics (Fig. 1) included a bar graph, Euler diagram, bone and another map. We varied the graphics to avoid a learning effect. Examples of questions asked of participants included "what was helpful/confusing about this tactile graphic?", "what feedback

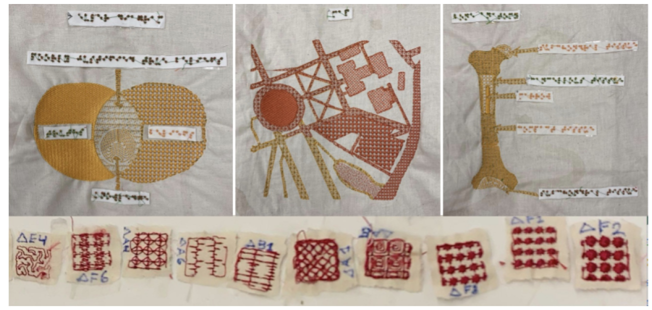

Figure 1: Embroidered graphics of an Euler Diagram, a map, and a bone, above samples showing the textural continuum.

do you have, on the Braille labeling in this tactile graphic?" and "which kind of tactile graphic is your preference, and why?"

Each participant stated multiple times that the embroidered textures were more distinct than any textures present on the embossed tactile graphics, and that, especially in simpler diagrams (i.e., bar graph, venn diagram), the added contrast helped to differentiate between regions of the graphic. P3 commented in reference to the textures used to fill the bars in the identical histograms: *"The vertical columns on the cloth one are far more distinct than on the paper one... On the paper one ... they ... expand ... as you go down and I'm not understanding what that's for"* (P3)

For medium to complex tactile graphics, shapes that were less predictable, participants found the textures distinct but the overall graphic less comprehensible. For example, they were unable to determine the outline of key shapes or identify map landmarks for both embroidered and embossed graphics. Embroidery could address this in future work by adding distinct region outlines, something our optimization does not yet support.

Finally, some participants expressed excitement for using embroidered tactile graphics in artistic contexts. *"From ... creativity related stuff, I would actually... enjoy embroidered graphics as opposed to real graphics, they ... feel like you're doing ... homework"* (P2)

To summarize, BLV people face a significant accessibility barrier when interpreting visual content. BLV individuals deserve equal access to visual information, with just as much clarity, detail, and timeliness as sighted people. We believe that embroidered tactile graphics have the potential to achieve this goal and look forward to rich additional research on this topic.

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