Thermochromorph: Dynamic Relief Printing with Thermochromic Inks

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Figure 1: *Thermochormorph* is a novel workflow for producing visually dynamic relief printed images. Our method combines complementary thermochromic inks with a CMYK-based relief printing process.

Abstract

Thermochromorph is a novel relief printing technique that produces multicolored images that transition into each other through changes in temperature. Our process utilizes two sets of CMYK thermochromic inks that exhibit complementary color-changing behaviors: one shifting from color to transparency, the other from transparency to color at the same activation temperature. We describe our printmaking workflow, provide an open-source software toolkit, showcase prints made with our system, and facilitate an artist workshop. By incorporating new materials and technology with the rich history of printmaking, our work extends the expressive capabilities of relief printing as the medium continues to evolve.

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• **Human-centered computing → Interactive systems and tools**; • **Applied computing → Fine arts**.

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fabrication, printmaking, design tools, color-changing

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1 Introduction

Both digital and analog printmaking continue to offer opportunities for exploration in materials and technology. *Relief printing* is a form of analog printmaking that involves carving a design into a block of material, applying ink or pigment to the carved block, and then transferring the image onto paper or another surface [Fobiri et al. 2021; Griffiths 1996]. Relative to other manual printmaking techniques, such as screen printing, relief printing requires fewer materials and shorter setup times, which supports a faster iteration process with lower stakes. The relief printing process has three core components: the printing matrix (i.e., the block), the printing surface, and the ink. The practice of substituting materials in these components can have a significant impact on the affordances and outputs. Artists and practitioners have explored using different materials to create the printing matrix, from synthetic materials, such as linoleum and rubber [Csiky 2019; Morley 2016], to natural materials such as fruits and vegetables [McMahon 2013]. Similarly, practitioners have explored printing on different surfaces, such as fabric [Casprowiak 2008] and clay [Wandless 2006]. In this paper, we explore how changing the ink can alter the dynamics of relief printing. We propose that thermochromic inks, which change color through temperature, can make relief prints more visually expressive and physically interactive.

Artists have experimented with different methods and techniques for the relief print creation process. In particular, a number of contemporary printmakers have developed hybrid methods which combine the time-honored traditions of the craft with the affordances of modern digital tools. For example, Katsutoshi Yuasa combined digital CMYK imaging techniques with hand-carved *Mokuhaga* block printing to create intricate prints with photographic detail [Yuasa 2023], while Mike Lyon developed custom software and used CNC machining to create blocks [Lyon 2023]. In a similar vein, we create our thermochromic prints using digital processes (via CMYK imaging and laser cutting) supplemented with analog techniques (via manual printmaking and thermochromic inks). Our software design tool and chosen imaging process establish a groundwork of predictability, while the printing process and inks introduce serendipity into the final outputs.

In contrast to commercial offset lithography, which yields predictable and uniform outputs, handmade prints are unique due to the inherent imperfections of the manual printmaking process—raising questions of repeatability and reproducibility [Gover 2015]. Unlike standard prints, thermochromic prints are also dynamic: images can now transition into each other, and the way they transition varies depending on how heat is applied. This facilitates a viewing experience that changes in response to touch [Torres et al. 2019; Yu et al. 2023] or different ambient conditions [Koe 2018; Tan 2018].

Thermochromic inks have seen a range of applications in Computer Graphics and Human-Computer Interaction research. For instance, *Anabiosis* [Tsuji and Wakita 2011] and *Electronic Origami* [Kaihou and Wakita 2013] demonstrate how thermochromic inks can be used to make paper more interactive, whereas *Ebb* [Devendorf et al. 2016], *Eunoia* [Song et al. 2018], and *Social Textiles* [Kan et al. 2015] are examples of color-changing textile displays made from threads coated with thermochromic paint. *ChromoSkin* [Kao et al. 2016b] and *DuoSkin* [Kao et al. 2016a] showed how thermochromic inks can even be used to make on-skin interfaces. Hennerdal et al. made picture-to-picture transitions possible by screen-printing CMYK thermochromic ink images on top of static ink images [Hennerdal and Berggren 2011]. By applying thermochromic inks to an artistic domain, our work broadens our understanding of relief printing's expressive potential and offers insights that may inspire innovative approaches to this time-honored printmaking technique.

2 Background

Thermochromorph prints are two multicolored thermochromic images that fade into each other. We achieve this by applying a CMYK-based relief printing method to two types of thermochromic pigments with distinct activation properties. Here we explain the CMYK printing process and then describe the properties of our thermochromic inks.

2.1 CMYK printing

To facilitate the creation of multicolored images, we use *CMYK printing*. CMYK printing, also known as *four-color process printing*, is a widely used color reproduction technique in the printing industry. It involves combining four ink color channels: Cyan (C), Magenta (M), Yellow (Y), and Black (K) in varying proportions to create an array of colors.

Converting an RGB digital image into a CMYK-printable image involves first decomposing the image into its constituent C, M, Y, and K channels. Each channel is then converted into a series of *halftone dots*, which are small, discrete dots of varying size and spacing. Larger and denser dots appear darker, while smaller and sparser dots appear lighter. Compositing these four channels simulates a broad range of hues and shades, making it possible to reproduce full-color images.

2.2 Relief printing

We fabricate the CMYK-printable image via relief printing. In relief printing, the raised areas of the printing matrix hold ink. Since only the non-recessed portions of the matrix come into contact with the printing surface, pressing the inked matrix against the surface leaves an impression of the image. As each block holds only one color at a time, four separate blocks are required to produce a multicolored image in a standard four-color CMYK printing process.

2.3 Thermochromic pigments

Since we want our thermochromic images to fade into each other at the same activation temperature, we sourced two types of thermochromic pigments (from *Shenzhen Dongfang Color Technology Co., Ltd.*) with complementary color-changing properties:

(1) color-to-clear thermochromic pigment, which changes from color to transparent at an activation temperature of 35°C
(2) clear-to-color thermochromic pigment, which reverses its visibility from transparency to color under the same activation temperature

For each type, we acquired Cyan, Magenta, Yellow, and Black pigments. In the case of the clear-to-color powder, which did not have yellow, we made an adjustment by substituting it with orange pigment as it was the closest match to the desired color. In addition, while the vendor offers the same pigments at other activation temperatures, we opted to use pigments with an activation temperature of 35°C since this temperature range aligns more closely with typical environmental conditions and user comfort.

We refer to images printed with color-to-clear pigments as *cold* images (since they are visible at room temperature) and images printed with clear-to-clear pigments as *hot* images (since they are visible at the activation temperature).

3 Software

To help users navigate the complexity of preparing their blocks, we provide open-source software[1] that converts RGB images into relief printing files and previews their prints (Fig. 2).

Figure 2: The *Thermochromorph* interface shows a preview of the CMYK halftone for the target image and provides CMYK block thumbnails below the halftone image. Users can switch between (a) cold and (b) hot image previews.

3.1 Features

Once the user specifies their input images, the *Thermochromorph* interface generates and renders the CMYK halftone representations and fabrication files for the hot and cold images (Fig. 2a). Users can switch between previewing the two images by pressing a hot key (Fig. 2b). To help users understand how the image is constructed, the interface shows thumbnails of the four CMYK layers and provides users with the option to toggle the visibility of each individual color layer. This feature is useful during the printmaking process as it allows users to see the intermediate expected outputs for each printing layer.

Our fabrication process supports an image resolution of 50 dots per inch. By default, our software sets the print width to 4.5 inches and produces fabrication files from the default width. Users have the option to adjust the width of their image, which changes the level of detail in the final print (larger widths allow for greater image detail).

[1]http://github.com/tichaesque/Thermochromorph

3.2 Implementation

Our system initially takes the input RGB image and performs a standard color conversion process to extract the CMYK channels. We then rotate each channel by a specified screen angle. Yellow (Y) uses an angle of 0°, Cyan (C) uses an angle of 15°, Magenta (M) uses 75°, and Black (K) uses an angle of 45°. These are standard angles in the printing industry that have been selected to minimize moiré patterns and achieve optimal color separation and reproduction in the final printed output [Sperber 2023]. Using the rotated CMYK channels, we generate halftone images for each one via *amplitude modulated halftoning*, which is a technique to convert continuous-tone images into halftone images [Zhang and Zhang 2019]. The size of the dots is determined by the tone color they represent, with larger dots used for darker tones and smaller dots used for lighter tones. This technique produces a regular grid of dots that split the original image into a halftone image with different-sized dots. Our system uses halftone dot widths that span from ε to 2.2ε with a grid cell size of 2ε, where ε represents the smallest dot diameter that the laser can engrave without compromising the shape of the dot (which in our case is 0.02in). After generating the halftone pattern, we rotate the halftone image back to its original orientation.

When generating our fabrication files, we want to engrave the portions of the image that will not receive ink. For each image, we create 'negatives' for each of their CMYK halftones by rendering the dots in white and background in black, since black represents an engraving operation for our laser cutter (ULS PLS 6.150D). Since relief printing produces a mirrored image, we flip the results horizontally to ensure that the outputs match the target images.

4 Printmaking workflow

Creating a *Thermochromorph* print involves a series of steps (Fig. 3) for preparing the materials, including the inks and blocks.

4.1 Material mixing

Due to the lack of readily available pre-mixed thermochromic block printing inks, we formulated our own. We combined a water miscible, oil-based transparent block printing base (Speedball Professional Relief Ink Transparent Base) with each thermochromic pigment (described in Section 2.3) following a ratio of 1:5 by weight. This ratio ensured a balance between pigment concentration and ink viscosity.

4.2 Fabrication

Our fabrication process has several steps, from preparing woodblocks to layering inks to achieve the desired visual effect.

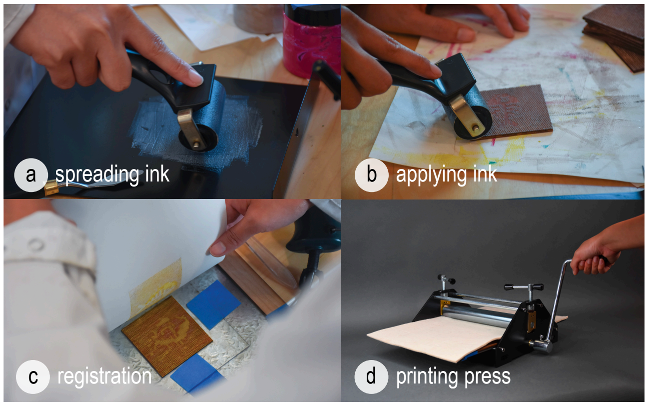

Figure 3: The printmaking procedure comprises (a) coating ink onto the rubber brayer, (b) transferring ink onto the block, (c) registering the block to ensure proper alignment, and (d) using the printing press to transfer ink from the block to the printing surface.

4.2.1 Block preparation. We used hardwood blocks because of their durability and ability to show high-resolution details. We laser cut and engrave 25mm walnut sheets (engraving depth ≈0.3mm) using the fabrication files generated by our software. Following the laser cutting process, we rinse the woodblocks with water to remove any residual particles and ensure a clean surface.

4.2.2 Inking the block. To ensure even and smooth ink distribution across the block surface, we use a rubber brayer to spread a thin layer of ink onto a plate (Fig. 3a). Once the ink evenly coats the brayer, we apply the ink onto the block (Fig. 3b).

4.2.3 Registration. We achieve proper registration with a frame registration jig, which positions the printing block for the current layer (Fig. 3c). We then place our printing surface (e.g., paper) on top of the block and secure it with tape.

4.2.4 Printing the images. We use a printing press to make our prints, which ensures that pressure is evenly applied across the printing surface (Fig. 3d). We then follow an 8-layer printing process (Fig. 4), starting with the hot image using clear-to-color inks in YCMK order. Since the hot image is only visible at the activation temperature, we can check the color of each layer by warming the printed image with a heat gun. If any areas did not receive sufficient ink, we can perform additional printing passes by reapplying ink to the block and using a precision tool (e.g., a spoon) to apply focused pressure in those specific regions. After printing the hot image, we print the cold image in YCMK order with color-to-clear inks.

5 Exemplar Prints

We present three dynamic prints to illustrate *Thermochromorph*'s expressive range (Fig. 5).

Our first print takes both of its frames from a *Batman* comic drawn in the 20th century [Comics 2015]. This application takes the comic book idea of conveying a progression of events by creating a transition between Robin preparing to punch and then punching with a "POW" sound effect. To enhance the comic book aesthetic, this print uses custom blocks for the black line art. This result opens up possibilities to convey sequenced data to the audience while still maintaining the physical nature of printed media.

Our second print is a label depicting a fish and its underlying skeleton, which gradually appears as the print is heated. This label can be used to display important temperature information that warns users of potentially hot surfaces. As the surface cools, the fish design returns, indicating to users the surface is safe to touch. This approach could be used more broadly to provide important temperature-related safety information in products in a visually appealing way.

Our third print displays the same subject from two different viewpoints, a frontal view and a profile. As the temperature changes, the viewpoint of the subject gradually shifts, giving the effect of motion. This shows how users can leverage the heating and cooling process to create the illusion of movement, which could be incorporated into broader creative workflows, such as animation.

6 Artist workshop

Artist workshops provide an opportunity to introduce practicing artists to new fabrication and methodological frameworks in an informal, exploratory context. To understand how the unique affordances of *Thermochromorph* prints and their fabrication process can impact creative outcomes, we conducted a workshop with three artistic practitioners.

6.1 Workshop and participants overview

Prior to the workshop, artists prepared two images for the color changing transition to be used for subsequent print creation. Artists were given no creative direction other than an image size constraint of 4x5 inches. We structured the workshop as an interactive, 6-hour group printmaking session and provided all materials needed to construct *Thermochromorph* prints. Two of our team members facilitated the workshop, conducting a thermochromic printmaking demonstration and guiding artists through the fabrication process detailed in Section 4.2. The workshop was followed by individual, 30-minute interviews focused on their experience with the *Thermochromorph* fabrication process, whether thermochromic inks changed participants' approaches to artmaking, any perceived benefits and limitations of the process, and whether participants would integrate our *Thermochromorph* pipeline into their repertoire of artistic methods.

We recruited three workshop participants (P1, P2, and P3) through media arts and architecture mailing lists. P1 is a contemporary artist working at the intersection of visual art, performance, and computer science. P2 is a composer, filmmaker, and visual artist who frequently works with virtual reality. P3 has a background in computer science, graphic design, and music composition. P1 was the only participant with prior printmaking experience, and none of the participants had worked with thermochromic materials before.

6.2 Workshop results and insights

All participants successfully completed their prints within the allotted time (Fig. 6). Our interviews with the artists revealed three key themes, which we discuss below.

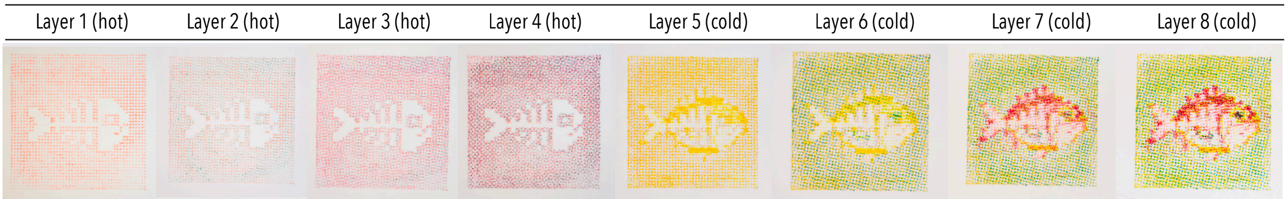

Figure 4: Our method follows an 8-layer printing process that starts with printing the hot image followed by the cold image.

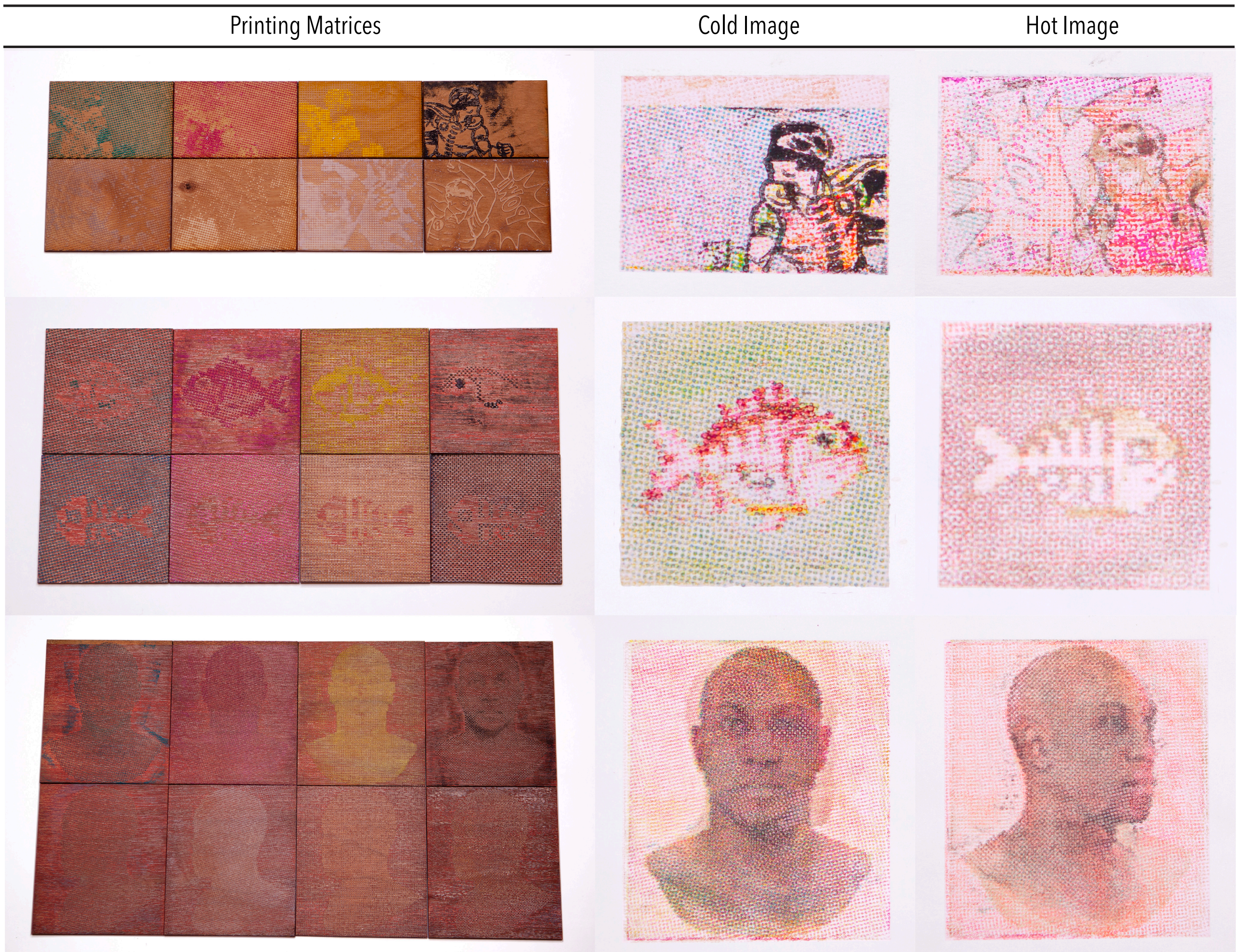

Figure 5: *Thermochromorph* prints made by the authors.

6.2.1 Fabrication complexity presents an opportunity for aesthetic exploration and creating new tools. The artists' reflections on the fabrication pipeline highlighted key organizational components of the process that enabled new modes of creative work as well as related challenges.

All participants appreciated having the software as a visual aid while making their prints. However, a current limitation of our software is its singular, dot-based half-tone image processing method. P1 and P2 wish to experiment with designing new half-tone patterns. P2 wondered if the halftone pattern could become other geometries, such as stars or diagonal lines, which can yield more varied visual results. Additionally, as the printing matrices are digitally fabricated, P1 felt that the process was "very conducive to digital image making," and would like to develop graphics programs to work with it. This highlights the value of having open-source software for new workflows (such as thermochromic printmaking) that artists can adapt for their own creative processes. It also suggests the potential

Figure 6: Prints from the artist workshop. Rows 1, 2, and 3 are prints made by participants P1, P2, and P3, respectively. (Image Credits: Row 2 Cold Image ©Karen Savage-Blue; Row 2 Hot Image ©Kelly Hrenko)

for creating new tools that offer real-time, responsive feedback to accommodate diverse artistic styles and iterative processes.

During fabrication, all participants noted the challenge of rolling the ink and applying uniform force to all parts of the printing matrix, which are common challenges in printmaking more broadly. Our process also requires maintaining the correct layer order and avoiding confusion between the different ink types. P1 noted that these organizational factors made the task slightly more challenging, as their previous printmaking experience was limited to single-layer designs. However, P1 also appreciated how increasing print layers (8 total) introduced a unique color-changing element to the works.

All participants emphasized being unaware of the visual capabilities of thermochromic printmaking prior to the workshop. For P3, the workshop expanded their understanding of "the physical aspect of making," as they "didn't know the possibilities with printmaking itself." Despite being new to the process, all participants were satisfied with their results and felt like the prints matched their intended designs. This suggests that the expressiveness and quality of the outputs help balance the added fabrication complexity.

6.2.2 Dynamic affordances spark surprise and encourage experimentation. The temperature-dependent dynamic affordances of the pigments toyed with the artists' conscious expectations. Artists were captivated by the responsiveness of the color-changing inks: for P2, printing the first layer of thermochromic ink and "taking the heat gun and seeing a circle of orange radiate across the page...was the moment of awe and wonder." P2 commented that an "element of surprise comes in", which created an exciting, anticipatory "feeling of not knowing how something will turn out." The inks cultivated a sense of play and prompted artists to experiment with the materials' affordances. For instance, P1 would heat up the bath used to rinse inked brayers to observe the color-changing effect in the water.

Subsequently, we see the potential for the dynamic affordances of *Thermochromorph* prints to prompt new kinds of aesthetic decisions. While animated graphics are frequently associated with purely digital mediums, the dynamic behavior of thermochromic images inspired two of the artists to select more animated imagery despite its analogue nature. P1 constructed their image with an animated video game character to "subvert expectations" and "match the character to the thermochromic material." P3's image was constructed through generative AI, and aesthetically inspired by claymation sculpture.

6.2.3 Thermochromic prints empower new narrative and material explorations. The *Thermochromorph* prints' fluctuating imagery evoked hidden messages and discrete sequential image display for the participants: inspiring future works ranging from everyday object integration to storytelling.

The narrative possibilities of thermochromic prints were brought to light by P2, who suggested that it would be interesting to send color-changing postcards with "a clever image...maybe some kind of comic or sequential storytelling...to reveal some kind of story element." Additionally, image transitions could be used to create visually changing vinyl records, or semi-photographic "metaphors to play with memory," suggested P2.

The notion of a concealed image becoming visible inspired two artists to explore what it means to discreetly integrate thermochromic properties in diverse applications. To integrate thermochromic properties "into everyday objects such as pillowcases and lampshades" one could "fireproof" them suggested P1, while P3 suggested going "beyond paper" by creating "internally heated objects." For P3, "the ability to have a secret image is very appealing" in an environment where heat changes without user influence, thereby emphasizing "the subtle image coming to light."

Overall, the diverse creative applications proposed by the artists present an opportunity for utilizing *Thermochromorph* to express and embed information in both 2D and 3D forms.

7 Limitations and future work

Despite the promising potential of our dynamic relief printing approach, there are some limitations which can be addressed in future work.

Image Resolution. The resolution of our morphing images is constrained by the smallest dot size that our laser cutter can engrave. This limitation arises from the laser cutter's resolution and durability of the chosen material. Alternative techniques like screen printing can enhance resolution, but may require more time and materials. This highlights a trade-off between image resolution and production efficiency.

Print Quality. Since the pigments are not entirely invisible in their 'clear' states, the clarity of the transitions depends on how thickly the ink layers were applied during the printmaking process. Depending on how dense the underlying hot printing layers are, a faint residual hot image may be visible in the cold state. Similarly, the hot image may appear faded as a result of being obscured by the cold image layers. As this limitation is intrinsic to the pigment properties and its interaction with the solvent, 'mastery' of the technique involves accounting for these properties during the printmaking process (e.g., by minimizing the number of printing passes per layer). In future iterations, we will explore image processing techniques to modify the overlay of halftone patterns for the hot and cold images, which may help to reduce these visual artifacts.

8 Conclusion

In this paper, we introduced *Thermochromorph*, a relief printing technique that makes use of thermochromic inks to create multicolored images that transition between one another. We detailed the materials, fabrication procedure, and image processing workflow. Furthermore, we presented and discussed *Thermochromorph* prints, illustrating this technique's potential to enhance the expressiveness of relief printing. Finally, we demonstrated how our thermochromic relief printing process can be applied through an artist workshop. We hope that by sharing our printmaking process and providing an open-source software toolkit, we can empower everyone—including artists and researchers—to shape the landscape of dynamic relief printing.

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