An Interactive Multi-touch Sketching Interface for Diffusion Curves

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ABSTRACT
Diffusion curves are effective 2D vector-graphics primitives, for creating smoothly-shaded drawings with rich colors and unique styles. Conventional drawing systems for diffusion curves often require users to successively layout curve geometry and then specify colors, which is rather tedious for complex drawings. This paper proposes a novel multi-touch sketching interface for efficient design of 2D vector graphics with diffusion curves. In sharp contrast to previous interfaces, we develop a family of multi-touch gestures, allowing users to simultaneously sketch multiple diffusion curves and also to interactively edit and tune curve geometry and colors. Our experiments show that this not only brings novel painting experience to users but also provides a practical and effective tool for vector graphics design, useful for styles like silk painting, Disney cartoon, art poster, and photo-realistic effects. Lastly, we conduct a user study to explore the interface’s intuitive and efficient drawing capability with both professional 2D artists and novice users.

Author Keywords
Multi-touch interface, Algorithms, Design

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User interfaces; I.3.4 Graphics Utilities: Paint systems

INTRODUCTION
Diffusion curves [10] are 2D vector-graphic primitives that can effectively generate smoothly-shaded images. Basically, each diffusion curve has two pieces of information: 1) curve geometry, often defined by 2D splines; and 2) two sequences of colors, each along one side of the curve. After sketching diffusion curves on a 2D drawing canvas, we can apply the Poisson equation [2] with curve colors as boundary conditions to solve for color values over the 2D canvas. Thus, we can spread colors like heat diffusion, e.g., see Figure 1 (b&c). Lastly, since splines are used as the curve geometry, resultant drawings can have infinite resolution.

To draw with diffusion curves, users often start with a freehand-style sketch using 2D input devices like mouses and tablets. Each sketched curve is first converted into a 2D spline geometry (Bézier splines or B-splines), see Figure 1(c); then, users can specify colors along each side of the curve, see Figure 1(d). Such a procedure could be rather tedious when the drawing is complicated and requires spatially-varying colors. Moreover, users may also need to further adjust the curve geometry by adjusting the control points of the spline.

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Figure 1. Diffusion curves (see (a)) enable effective generation of smoothly-shaded 2D vector-graphics (see (b)). After sketching a spline (see (c)) and specifying colors on it (see (d)), we can apply a Poisson equation solver to generate the drawing on the canvas (see (e)).

Recent boom of multi-touch technology in the market of consumer computer systems enables general users to directly use their fingers to interact with the graphical contents. Such interactions have been widely manifested in many applications on smart phones and laptops, and demonstrated to be very intuitive with general users. This paper proposes a novel multi-touch sketching interface, enabling interactive and practical design of 2D vector graphics with diffusion curves. We take advantages of the intuitiveness and efficiency of multi-touch to support simultaneous sketching of multiple diffusion curves and at-the-spot tuning of diffusion colors. In detail, a family of multi-touch gestures is proposed for sketching and editing diffusion curves, as well as specifying and tuning curve colors. Users can simultaneously sketch multiple diffusion curves with different colors, see Figure 2 (bottom). Finally, we developed our proposed interface into a working system and tried it with a number of users, including professional artists and novice users, demonstrating its values as a practical drawing tool.

PREVIOUS WORKS
Diffusion curves. Diffusion curves were first introduced by Orzan et al. [10] as 2D vector-graphics primitives for modeling images with only colors defined along region/curve boundaries; a multi-grid solver was employed to efficiently
solve the Poisson equation. Later, Jeschke et al. [6] presented an alternative Laplacian solver, it can run as fast as the multi-grid solver, but is simpler to implement and feasible for arbitrary image resolutions. Moreover, they [7] also extended diffusion curves to 3D surfaces, enabling vector textures on 3D objects. Very recently, Takayama et al. [11] generalized 2D diffusion curves to 3D diffusion surfaces for modeling anisotropic solid textures.

**Multi-touch interaction.** Multi-touch [4, 9, 12] has been employed as an intuitive and effective interaction method in wide ranges of applications. Igarashi et al. [5] developed multi-touch interactions to intuitively manipulate 2D shapes while Bae et al. [1] presented a 3D sketching system for professional designers to create conceptual models with pen and finger gestures. Recently, Lepinski et al. [8] designed multi-touch marking menus that significantly outperform traditional marking menus while Fu et al. [3] proposed multi-touch gestures for exploring large-scale virtual space.

**OUR MULTI-TOUCH SKETCHING INTERFACE**

Our interface supports the following four major operations:

1) **Select Colors with Multi-touch.** Each diffusion curve has at least four colors, two on each side of it, to produce spatially-varying colors (by linear interpolation) along the curve geometry, see Figure 1 (a&d). In our interface, users can multi-touch the color palette with four fingers (see, Figure 3 (left)) to specify these boundary colors with visual feedback shown on the screen. To make it more practical, users can flexibly select or adjust one, two, three, or four colors by simultaneously touching the palette with respective number of fingers, and our system determines the color-touch match by the order of finger-screen contacts. Moreover, users can further apply multi-touch on the drawing canvas to exchange colors on diffusion curves.

2) **Sketch Multiple Curves with Multi-touch.** In addition, users can use multi-touch to sketch multiple diffusion curves simultaneously. Our design is motivated by the following observations on finger and hand ergonomics:

- Fingers of the same hand can naturally move together (in parallel) to sketch curves with similar shapes at the same time, e.g., rainbow and water wave;
- When using both hands, the non-dominant hand can easily follow the dominant hand so that associated fingers from both hands can easily draw mirror-reflected shapes.

To sketch multiple diffusion curves, the user can subsequently select colors for each planned curve. Associated colors for each curve are immediately shown next to the curves’ endpoints as visual feedback, and users can then exercise the above ideas to simultaneously sketch multiple curves with one or two hands on the canvas. We found that rainbow can be easily drawn with multiple fingers of one hand while the heart shape can be easily drawn with fingers from two hands.

3) **Adjust Colors with Multi-touch.** Users can adjust curve colors while sketching a diffusion curve; hue, lightness and saturation can be interactively adjusted by first multi-touching (with another finger) an empty location near the circular color tag followed by a finger drag. As shown in Figure 3 (right), dragging perpendicular and parallel to the curve’s local tangent adjust the hue and lightness, respectively, at the related color tag based on the finger displacement. Performing an angular change towards the opposite direction of lightness adjusts the saturation. Compared to the conventional painting interfaces which require switching to the palette panel window for color tuning, users of our interface can directly and interactively adjust colors at the spot. This strategy helps minimize contextual switch, thereby allowing users to concentrate on their designs on the drawing canvas.

4) **Additional Features.** Users can also directly edit the control points or curve segments like other works, e.g., [5]. Since diffusion curves are vector graphics which are scalable, we provide a zoom mode for users to view, edit, and sketch at appropriate scale. Supported with a real-time multi-grid solver that runs on a high-performance graphics board, we can diffuse colors interactively while the drawing scale is changed. Users can thus sketch fine details with higher...
precision on important parts in their drawings. Lastly, users can also apply the at-the-spot color tuning method to adjust colors on the palette, as well as swap selected colors.

IMPLEMENTATION AND RESULTS

Hardware. Our multi-touch sketching interface was implemented and experimented on a Dell workstation T3500 with a 2.67GHz Xeon CPU, 12GB memory, a GeForce GTX295 (1792MB) graphics card, and a 3M 19" multi-touch display. See Figure 2 (lower right) for the hardware setup.

Software. To solve the Poisson equation at interactive speed, we developed a multi-grid solver on the graphics processing unit (GPU); its rough idea is to first solve for low-frequency components with a coarse domain and then iteratively refine high-frequency components with a finer domain.

Results. Figure 4 shows four example vector graphics drawings by an artist using our interface. As demonstrated in the accompanied video, our system can support interactive painting on a canvas of resolution 1920 × 1080; with the GPU support, it can update the visuals with multi-touch interaction at 20Hz, e.g., with the examples shown in Figure 4.

USER STUDY

We conducted a user study to explore the benefits of our multi-touch interface for general users. Our interface is compared against the conventional diffusion curves sketching interface by Orzan et al. [10]. As geometry and color are two key elements in diffusion curves painting, our goal is to measure how the interfaces help users to specify these two elements. Note that experienced artists and novice users may have very different painting styles that could lead to inaccurate measurements in the study. To counteract such discrepancy, strokes employed in our study are simple and distinctive, and after consulting with several artists and pilot-testing with some users with different levels of painting skill, two experiments with varying difficulty are designed.

Participants. Twenty-four participants were recruited in our user study, and they were divided into two equally-sized groups: G1: 7 males, 5 females, mean age 27.3; and G2: 8 males, 4 females, mean age 25.8. Among the participants, six are professional 2D and 3D artists while others are novice users. The six professional artists were split randomly and equally into the two groups.

Overall Procedure. Before going to the tasks in the experiments, we first introduced the key concepts of diffusion curves to the participants, and gave them 5 minutes to try and get familiar with the sketch-based input device. There are two stages in the user study. In the first stage (for G1), we first showed our proposed interface to the participants, and gave them 5 minutes to try the operations in the interface. Then, they were asked to complete two painting tasks (two experiments) with it. After that, we moved to the second stage and introduced the conventional interface to them. Again, we gave them another 5 minutes to try the interface. After that, they were asked to do the (same) two experiments but with the conventional interface this time. To eliminate potential discrepancy about familiarity with the interfaces, G2 did exactly the same tasks as G1 but in a reverse order when using the two interfaces. During the course of the user study, the time taken by each participant to complete a task was measured. Moreover, to help the participants (especially the novice users) complete the tasks, we showed them the expected diffusion results before starting the tasks.

Experiment #1: The first experiment is to evaluate the performance of specifying and adjusting colors on a simple diffusion curve. Participants were asked to first sketch an arbitrary stroke with four specific colors, and then increase the brightness of one color and decrease the others, see Figure 5 (left). Since a number of successive interface clicks are required to specify colors with the conventional interface, adjusting colors on an existing diffusion curve using the conventional interface with single input (mouse, tablet, or finger) is much more tedious.

In contrast, our multi-touch interface allows the participants to directly use their (four) fingers to select and adjust colors. To adjust colors, participants can simply touch one endpoint with a finger and then move another finger to a certain direction to control hue, saturation and lightness. With the multi-touch interface, participants can directly specify and adjust colors at the spot without switching frequently between the canvas and color palette. Furthermore, since the resultant drawing can be updated in real-time with the multi-touch interaction, immediate visual feedbacks are provided to the users. As shown in Figure 6, the average time to complete this experiment task with the multi-touch interface is 2.0 times shorter than that with the conventional interface.

Experiment #2: The second experiment compares the multiple-curve sketching function (in multi-touch interface) with the single-stroke sketching function (in conventional interface). Sketching multiple curves with similar shapes is very common in many practical scenarios, e.g., water wave, hair strands, and rainbow. Participants were asked to sketch a rainbow...
that requires tedious working steps for constructing diffusion curves, our interface supports a family of new multi-touch gestures, enabling users to simultaneously sketch multiple curves, edit curve geometry, and interactively adjust the multi-parameter in curve colors at the spot. Using the working system we developed, we conducted a user study to show the practical value of this interface design with both professional artists and novice users. Results show that our interface not only brings new painting experience, but also provides a practical and effective tool for vector graphics design, typically useful for styles like silk painting, cartoon, art poster, and photo-realistic effects.

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