Point-Based Stylization: An Interactive Rendering Approach for Non-uniform Artistic Representation

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Abstract. Inspired by real-world point-based art forms such as Impressionism, embroidery, and pebble mosaics, we have discovered the creative potential of arranging points with distinct appearances within a unified form of expression. We propose an approach that facilitates the creation of non-uniform, art-directed representations for point-based geometry, allowing for interactive rendering in 3D space. Rather than replacing all points with a set of static image textures as input, a dynamic representation of points must be designed in a controllable way that enhances visual richness and creative freedom to the artist. We met this challenge by defining each point as multi-dimensional spatial data and replacing it with parameterized textured proxy geometry, resulting in varied painterly strokes. Notably, the textured proxy geometry remains interactive, empowering artists to dynamically modify the strokes after placement. To aid the creative process, we introduce a sketch-based authoring tool that allows artists to compose various styles by sketching a few curves in 3D space. We provide examples generated by our prototype in an oil pastel painting style to demonstrate its ability to create non-uniform stylizations for point-based geometry.

Keywords: Non-Photorealistic Rendering (NPR) · Point Cloud · Sketch-Based Interaction · Parametric Proxy Geometry

1 Introduction

Points are the basic geometric elements in three-dimensional space. Well-known for their simplicity, flexibility, and compactness, point-based geometry employs discrete points to represent geometric models. Point-based geometry can be obtained using 3D scanning like LiDAR sensors and photogrammetry or by sampling from polygonal mesh models. This has become an affordable and feasible source for design and art creation in recent years. The flexibility and efficiency of points enhance their potential applicability across various creative fields such as animation, data visualization, VR, architecture, and art. As evidenced by works such as "Ghost Cell" by Antoine Delach (2015) [8], "Virtual Depictions: San Francisco" by Refik Anadol with Kilroy Realty Corporation (2015) [26], "In The

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Eyes of The Animal" by Marshmallow Laser Feast collective (MLF) (2016) [12], a colored pencil painting technique by Hin Sun Lee (2022) [6], "What Homes Are Made Of" by Lucija Ivsic (2021) [2], etc., points can be transformed into different representations, ranging from realistic scenes to science fiction or non-photorealistic styles.

2 Research Context and Goal

Observing various forms of expression in the real world, we can identify numerous cases that can be described from a point-based perspective. This type of point-based expression is prevalent across different art and design fields, including painting, crafts, and architecture. We studied examples from styles, such as Impressionism, Pointillism, metal texturing, embroidery, torn paper art, mosaic tiles, and pebble floors (See Fig. 1). We found that arranging diverse elements in specific patterns on the canvas or space can yield a wide spectrum of visual variations. For instance, in Impressionism, the character of the works lies in the composition of brushstrokes. Artists manipulate various factors, such as color, position, size, and shape, to arrange the strokes, resulting in an image that conveys rich information through the points. How artists manage these elements directly influences the representation of points, reflecting the artist's personality and painting style.

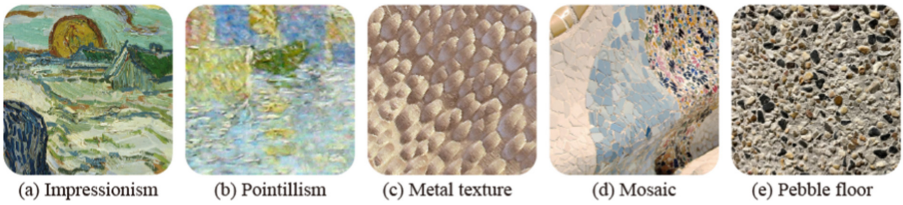


Fig. 1. Point-based expressions in real world. Detail from (a) Two Peasant Women, Vincent van Gogh, 1889 (b) Bridge in London, Jan Toorop, 1889 (d) Park Guell, Antoni Gaudi. photoed by tiburi.

Despite the vast potential of point-based representation, exploration of art-directed rendering for points in the digital environment remains relatively under-researched. Existing studies on point-based geometry rendering mainly focus on geometric representations of point clouds, like point set surface representation [1,16] and point cloud visualization [21,22]. However, these studies pay less attention to the non-uniform stylization and artistic expression achievable through art-directed parameterization and interactive data control. This study aims to fill the research gap by devising a novel method for non-photorealistic rendering of point-based geometry.

In this paper, we put forward a point-based stylization approach grounded on the concept of extended spatial data [17,25]. Spatial data is defined to store

multi-dimensional information related to coordinate. We extend spatial data to temporarily store a set of dynamic parameters that produce parametric textured geometry, enabling the creation of images in an oil painting style with diverse stroke types. We concentrate on the process of creation rather than traditional rendering techniques or automated rendering processes. A prototype of sketch-based interactive technique is presented to continuously modify spatial data, leading to dynamic rendering results that allow the combination of different painting techniques. The proposed non-photorealistic rendering approach for point-based geometry is not confined to the oil pastel style, but can be utilized to define other artistic representations.

The following section discusses the research background of stroke-based non-photorealistic rendering and explores methods closely related to the concept of parametric proxy geometry. Section 4 describes the design concept and implementation of a point-based stylization system, presenting the dynamic creation process and discussing the limitations and next steps for the current system prototype. Finally, our work is concluded in Sect. 5.

3 Background and Related Work

In non-photorealistic rendering (NPR), points have often been depicted using strokes that encompass a wide variety of subjects, including but not limited to oil painting [10,15], sketching [19], colored pencils [28], mosaics [7], and plants [5]. Stroke-based NPR has been extensively explored across different rendering domains, such as images, models, and physically-based digital painting systems. Varied strokes can be achieved through image processing and texture-based rendering techniques [10,11], with the distribution of strokes being determined by properties of the input [29,30], including the colors and contours of the image, and the normal vectors and curvature of the model. These features enable the computer to generate effects that resemble human-made art.

Interactive NPR emphasizes on empowering users to modify rendering results via parameter adjustments, modifications to the input stroke texture, and alterations to the source images. The design of Interactive NPR should accommodate both the algorithm and user interaction, focusing on flexible and controllable parameter modifications that leverage the capabilities of both the computer and user creativity [13]. An image abstraction filter by Haeberli [10] allows for user-guided stroke direction using a second input image with a black and white gradient. Schwarz et al. [23] provide users control over stroke unit properties through an interactive canvas, diverse tools, and color palettes. Semmo et al. [24] facilitate manipulation of the generated stroke flow field using intuitive finger-based interactions. Chiew et al. [3], while not exclusively focused on strokes, afford users the ability to add effects such as smudging and painting through shading techniques applied to the original model. Compared to a fully automated process, an adjustable parameter field opens the door for modification or replacement of parameters, enabling artists to engage in an ongoing cycle of experimentation and refinement of visual effects. An essential consideration is the design

of a specific toolkit that allows artists to access parameters in an intuitive and meaningful manner.

The image and texture-based methods mentioned above cannot be directly applied to point-based geometry for artistic representation. The former calculates strokes on the entire canvas, while the latter operates on individual strokes, resulting in fundamentally different approaches. However, NPR offers a viable solution through the utilization of proxy geometry, a technique generates new geometric strokes based on the original point coordinates. Proxy geometry can be created automatically from the model [4,14] or drawn by the artist in the digital painting environment [20,31]. The rendered proxy geometry may be controlled through algorithms and input images, and further modified based on the neighborhood relationships and attributes of the model [9,27]. This utilization of proxy geometry serves as the core of technology in our proposed system.

Traditional methods of altering appearance typically fall into two extremes: global parameters, e.g. filter-like adjustments, and pixel-level modifications, e.g. physical particle simulations. Our proposed method is situated between these extremes, recognizing that each point in the rendering carries unique information that influences the representation of points. This concept presents a challenge. First, we aim to preserve the ability to create unpredictability and complexity in the artwork through pixel-based techniques. Second, our system should allow users without artistic training to easily control and stylize points using a limited set of parameters. This approach seeks a balance between visual richness and a concise parameter set for our non-photorealistic rendered strokes, fusing the strengths of both methodologies. A potential solution to this problem involves utilizing spatial data as a parameter field, continuously modifying the proxy geometry parameters to guide the point representation. The parameter field must be interactively adjustable during the rendering process, a feature that may introduce additional complexity and unforeseen outcomes during iterative design and interaction.

4 Point-Based Stylization Approach

4.1 Concept and Design

The viewer's perception of texture in painting or drawing extends beyond the mere presence or absence of individual strokes. When multiple strokes combine, they collectively create an organized representation of texture [18]. These grouped strokes can effectively portray surface texture, tactile qualities, or other visual attributes of an object. Even if individual strokes are altered or removed, the group maintains a relatively consistent representation of texture. This is because the viewer's perception mainly depends on the collection and arrangement of the overall strokes. Such grouping of strokes in painting can yield richer visual effects and a sense of texture. Strokes that share similar appearances or are organized in a particular pattern are visually coherent, implying that they belong to the same ensemble.

In traditional NPR, most of the stroke placement is automated, lacking an design of the interaction that enables users to manipulate visual representation through point grouping. Taking inspiration from the real-world practice of sketching before painting, artists often simplify and deconstruct a scene's composition with preliminary lines on paper. Sketching assists artists in considering the fundamental elements of a composition and creatively recombining various colors and strokes. It serves as a tool to achieve stylized effects. Our proposed system includes a sketch-based authoring tool for point-based stylization with adjustment layers, allowing artists to utilize sketches to steer the stylization process (Fig. 2).

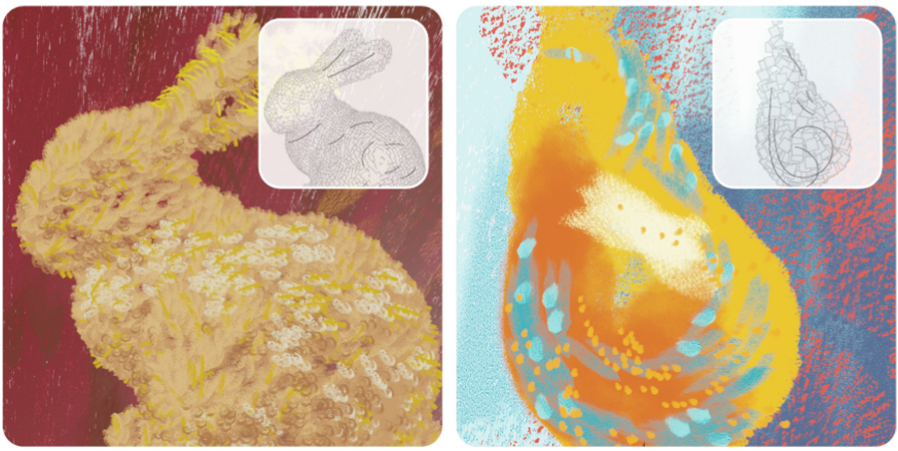


Fig. 2. Our technique's examples illustrate the concept of sketching before painting.

In an adjustment layer, points in three-dimensional space can be clustered by one or multiple sketched curves. The adjustment layer not only serves as a parameter buffer to modify the representation of the spatial data group, but also as a reference for the placement of textured proxy geometry in space, creating continuous variations within the cluster. The rendering pipeline begins with the input points model, where our system replaces each point with a textured proxy geometry, initially rendered in an oil pastel painting style. Adjustment layers follow the initial attribute setting and can be sequentially applied to any local point. Once all adjustment layers are in place, each spatial data receives a set of modifications from the original data, which is then used to generate textured proxy geometry.

Art-Directed Representation for Spatial Data The proxy geometry, which replaces the original point, can be modeled as different types of instances. Both the geometric properties and rendered texture of the proxy geometry can be customized dynamically at any time. Thus, art-directed controls are condensed

into a concise set of key factors that can alter the appearance of proxy geometry rendering. Section 4.2 illustrates the generation of textured proxy geometry, created from a line or an arbitrary curve, and automatically produces a vector coordinate for forming the basic rendered stroke. By utilizing the vector coordinate, various effects, such as pressure, taper, smudging, edge effects, etc., can be achieved. All parameters that affect the rendering and geometric properties of the proxy geometry are stored individually in each spatial data, allowing automatic or manual modification.

Stylization by Sketch-Based Authoring Tool Each point-based geometry is defined as multi-dimensional spatial data. A collection of spatial data can be considered as a parameter field that stores information about the rendering process. This field allows parameters to be adjusted interactively at any stage of the rendering to create textured proxy geometry. The point-based stylization approach is achieved through the dynamic modification of spatial data, enabling variations in stroke shape, color, orientation, and painting effect in the generation and rendering of proxy geometry. Each adjustment layer comprises one or more curves sketched in three-dimensional space, clustering the points based on spatial relationships. The proposed sketch-based authoring tool promotes a nonlinear workflow, allowing interactive adjustments between sketching and painting, including the editing of curves and modifications to rendering parameters of textured proxy geometry, respectively (Fig. 3).

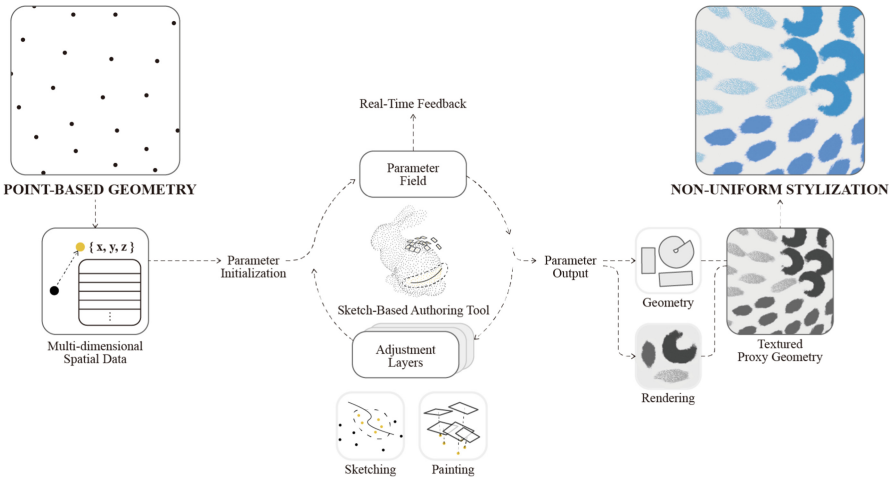


Fig. 3. Process of point-based stylization.

4.2 Create Textured Proxy Geometry from Spatial Data

Each spatial data holds the essential information required to create a stroke. Based on the information of each spatial data, we replace each point with proxy geometry that is rendered as a parametric stroke texture. Compared to a consistent representation for point-based geometry, this approach enables a more diverse and non-uniform appearance through textured proxy geometry. Such geometry must be adaptable to various sizes and shapes to produce coherent strokes. Our method automatically generates standardized two-dimensional vector coordinates, suitable for rendering proxy geometry with different source curves and geometric attributes. Parametric stroke is rendered using an alpha mask based on vector coordinates. We use the oil pastel painting style as an example to illustrate the process of proxy geometry generation and rendering. This fundamental method can be extended to other parameterized strokes, not limited to the oil pastel style (Fig. 2).

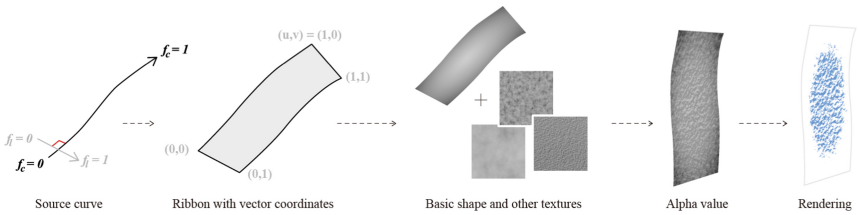


Fig. 4. Method to generate and render a textured proxy geometry.

A proxy geometry is derived from a source curve C and a perpendicular line primitive L with a length l. When L follows C, a ribbon of width l is created. The resolution of the ribbon can be adjusted based on the number of vertices in C, considering both the visual effect and computing performance. The parameters f_c and f_l are factors related to C and L respectively, with $0 \leq f_c, f_l \leq 1$. These factors are determined by the proportion of the curve's total length at each vertex. By applying these factors, we can derive vector coordinates $uv = (u, v)$, where u is defined by f_c and v by f_l. Generating standardized vector coordinates for proxy geometry from any given source curve C becomes straightforward. Moreover, the rectangular geometry, defined by texture coordinates uv with u,v values from 0 to 1, can be expanded to fit diverse stroke shapes. This flexibility allows artists to experiment with their preferred stroke styles, such as curly lines, short strokes, dots, circular strokes, and other types of curves.

Moving into the rendering phase, an alpha mask channel is necessary to define the stroke's shape, while a color channel sets its color. By remapping normalized coordinates to $uv + (-0.5, -0.5)$, we can generate circular gradient images. In addition, by adjusting the sampling position of the noise texture using random seed values assigned to each spatial data, we can overlay this

noise texture onto the original circular image. This process generates diverse stroke patterns through alpha blending. Afterwards, the material's texture can be either layered on top of this alpha mask or blended with the color output.

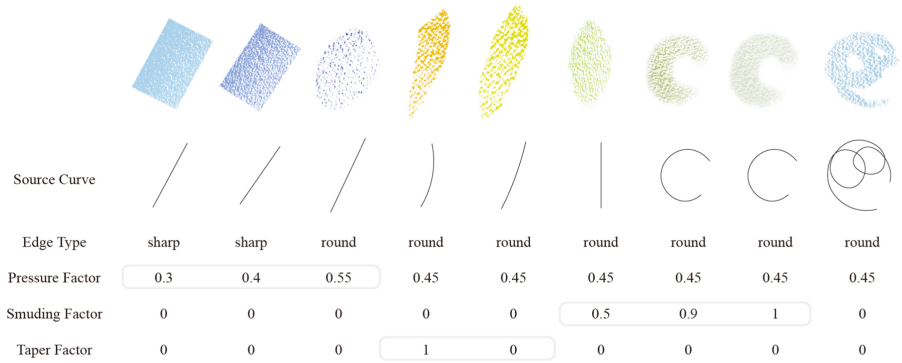


Fig. 5. Stroke variations.

The variability of painterly strokes is affected by a series of high-level and complex decisions made by the artists, such as brush pressure, painting motion, canvas texture, and more. We believe that several factors that contribute to the form of strokes can be condensed into a few key parameters. Each spatial data, capable of storing different data, can then be rendered with a distinct appearance. Using oil pastels as an illustrative case, Fig. 5 lists the parameters of the generated strokes using this method, showcasing the different styles that can be manipulated through these parameters. Accessible effects include pressure, smudge, and taper effects, with additional stroke textures generated by inputting paper texture.

4.3 Sketch-Based Authoring Tool for Point-Based Geometry

Based on the previous section, we realize that by transforming each source point into spatial data, we can create diverse representations. By individually modifying this data, we generate various textured proxy geometries, enhancing flexibility and control in the composition of different styles for point-based stylization.

Adjustment layers store a set of modifications written into a parameter buffer, which controls the style of the selected point groups. Multiple layers of adjustments can be applied sequentially, enabling changes to the parameters of the proxy geometry. This affords artists the flexibility to revisit and modify any adjustment layer at their convenience, altering both the parameters and the selection of point groups.

The adjustment layers use a sketched curve drawn in space, which allows batch modifications on selected neighboring point groups. The workflow involving adjustment layers is non-linear and consists of two parts: Sketching and Painting, allowing artists to freely switch between the two.

Sketching. This step involves drawing arbitrary 3D curves within space. Spatial data near these curves is selected based on geometric proximity, resulting in a subset of spatial data. This subset might contain points from one or several groups distributed throughout the model.

Painting. During the painting step, a collection of modified parameters is applied to the spatial data subset. The system offers four adjustment modes:

1. Stylization: Modifies the rendering results of textured proxy geometry.
2. Transformation: Alters the geometric properties, including rotations, translations, and scaling.
3. Duplication: Enables spatial data to be replicated, resulting in multiple proxy geometries representing a single point.
4. Density: Controls the probability of generating proxy geometry from the spatial data. By adjusting this parameter, the density of proxy geometries within the spatial data subset can be manipulated (Fig. 6).

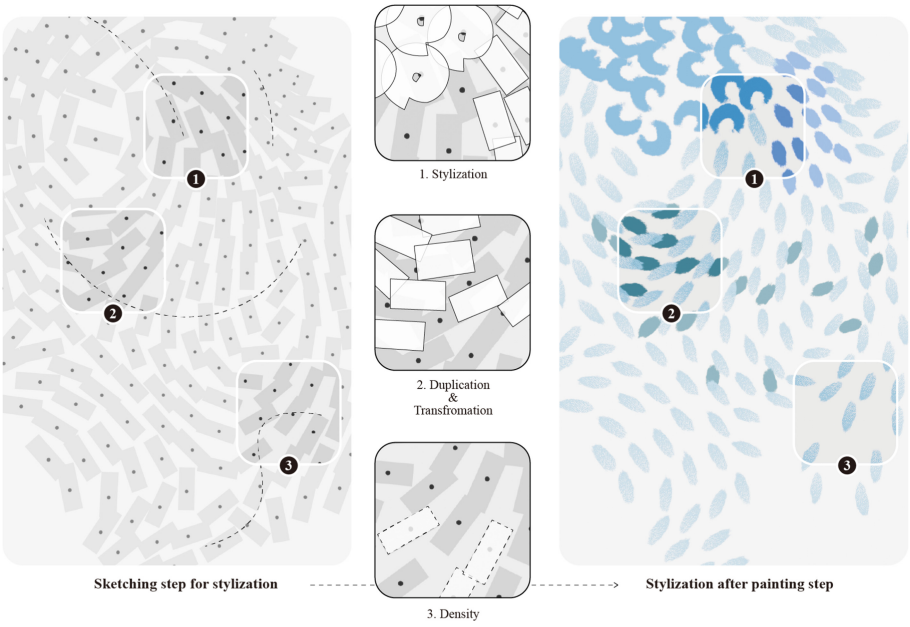


Fig. 6. Interactive workflow - sketching and painting.

The sketched curves and the rendering state of the proxy geometry are dynamic. This means that the curves can be edited during the sketching part, and the parameter buffer of the proxy geometry can be modified during the painting part. This interactive workflow empowers artists to create non-photorealistic styles for point-based geometry, encouraging constant experimentation and creative exploration with different textured proxy geometries (Fig. 7).

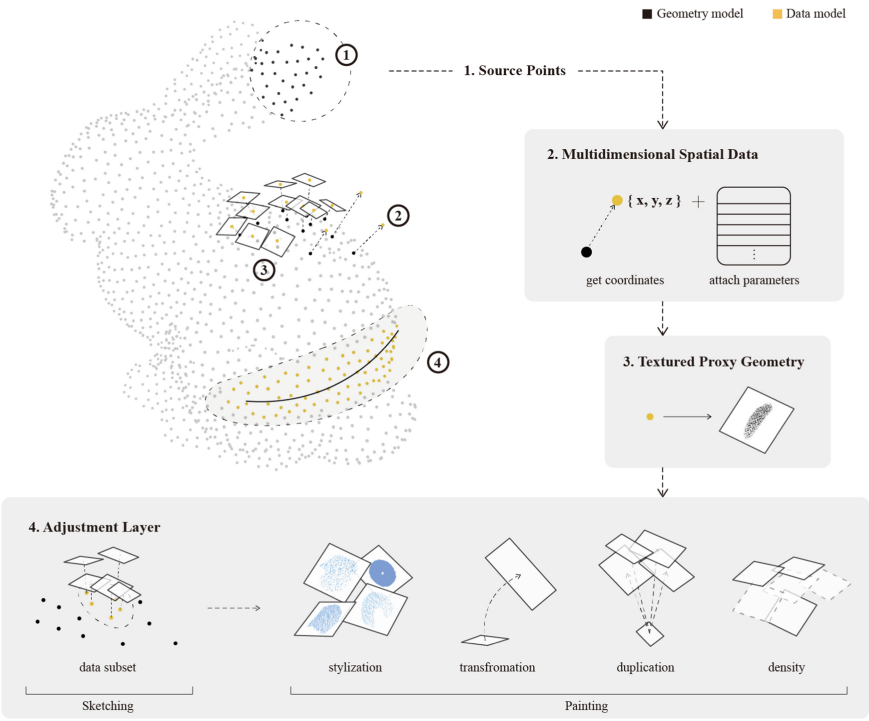


Fig. 7. System diagram of sketch-based authoring tool.

4.4 Dynamic Stylization Process

This section demonstrates the ability of our prototype in point-based stylization to create diverse non-realistic rendering results for point-based geometry, emphasizing the process of stylization and illustrating how different choices made during the transition between sketching and painting parts can significantly affect the final rendering. The stylization of the model is modified using different sketched

curves and parameters, allowing for unique stylizations. For example in Fig. 8 reveals how managing the density of two elementary stroke types, horizontal and vertical, can lead to distinct rendering outcomes (Fig. 8).

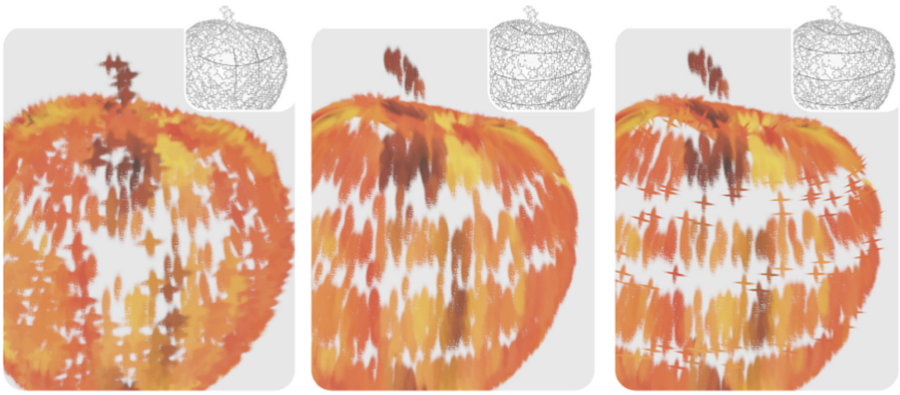
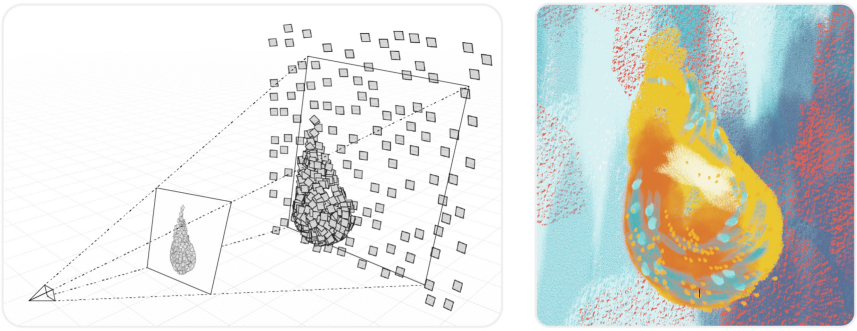


Fig. 8. Sketched curves determine the placement of the strokes.

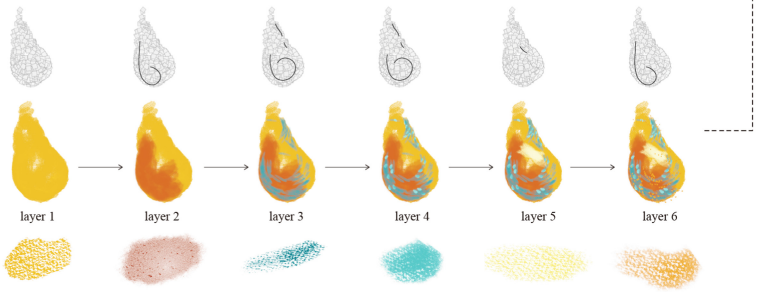
We describe the stylization process through a series of adjustment layers added sequentially in Fig. 9. Each layer can employ sketched curves to select different points, generating proxy geometry rendered as different strokes by modifying the parameter buffer. The placement and style of strokes can be controlled with just a few sketched curves. Furthermore, variations in style can be achieved by modifying the parameter buffer in each adjustment layer and the source curves that control the shape of proxy geometry, all using the same points model and sketched curves (see Fig. 9, Fig. 10).

4.5 Discussion

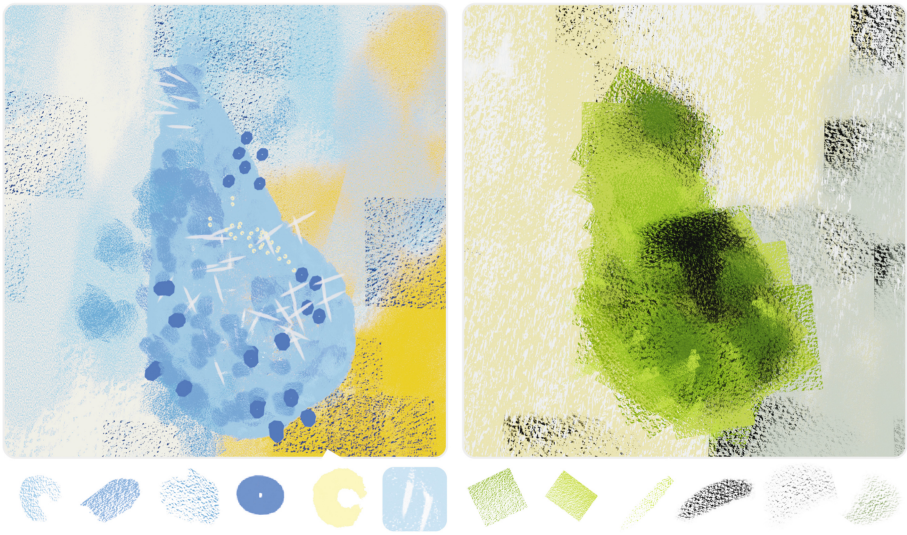
This prototype was developed using Blender version 3.5, a functional and free open-source 3D software. Many designers and artists in animation, gaming, digital art, and design fields actively explore Blender plugins, which provide the possibility of integrating this technique into existing creative workflows. Additionally, the proposed point-based stylization approach utilizes multi-dimensional spatial data as parameter fields for textured proxy geometry. This approach proposes a fundamental concept and is not dependent on the techniques provided by Blender. It can be implemented in other development environments. Furthermore, by referring to the studies of spatial data structures and algorithms, and designing a specialized data structure, more efficient point selection and processing of larger, more complex points can be achieved.



(a) Projection of proxy geometry to camera



(b) Stylization process of point-based geometry: Stepwise adding adjustment layers



(c) Style variations produced by modifications to adjustment layer parameters

Fig. 9. Dynamic stylization process.

Fig. 10. Different strokes controled by same sketched curves.

5 Conclusions

In this paper, we introduce a system that establishes a non-linear workflow for creating point-based Non-Photorealistic Rendering (NPR) using spatial data. We emphasize the capacity of points, as a form of spatial data, to hold multi-dimensional information, facilitating the creation of diverse rendering styles in point-based geometry. In traditional non-photorealistic rendering of points, where strokes are not generated using parameterized textures, artists often rely on inputting texture images of real strokes. This makes it challenging to effectively create different painting styles for point-based geometry.

Our rendering approach contributes a method to transform the oil pastel painting style into parameterized textured proxy geometry, thus simplifying the creation of oil pastel strokes to a few parameters stored in spatial data. We implement adjustment layers that dynamically modify local proxy geometries, allowing flexible and controllable combinations of different oil pastel strokes. This technique enables the representation of different stroke styles and distributions through a few basic 3D curves. Unlike traditional approaches where artists can only control global styles through parameter adjustments, our method promotes the exploration of a variety of compound oil pastel painting styles through continuous experimentation.

The concept of characterizing variations in stroke appearance with multi-dimensional spatial data can be extended to other rendering styles beyond the oil pastel painting style. By bridging the fundamental observations of point-based data and representation methods with interactivity, we aim to highlight the potential for points to enable diverse expressions. This research addresses the importance of the information attached to points and how this information can be effectively manipulated to enhance visual outcomes.

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