A VAN GOGH INSPIRED 3D SHADER METHODOLOGY

A Thesis

by

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ABSTRACT

This study develops an approach to developing surface shading for computer-generated 3D head models that adapts aesthetics from the post-impressionist portrait painting style of Vincent Van Gogh. This research is an attempt to reconcile a 2D expressionist style of painting and 3D digital computer generated imagery. The focus of this research is on developing a surface shading methodology for creating 3D impasto painterly renderings informed by Van Gogh's self-portrait paintings.

Visual analysis of several of Van Gogh's self-portraits reveal the characteristics of his overall rendering style that are essential in designing methods for shading and texturing 3D head models. A method for shading is proposed using existing surfacing and rendering tools to create 3D digital heads rendered in Van Gogh's style. The designed shading methodology describes procedures that generate brushstroke patterns. User controls for brushstroke profile, size, color and direction are provided to allow variations in the brushstroke patterns. These patterns are used to define thick oil paint surface properties for 3D digital models.

A discussion of the range of results achieved using the designed shading methodology reveal the variations in the rendering style that can be achieved, which reflects a wide range of expressive 3D portrait rendering styles. Therefore, this study is useful in understanding Van Gogh's expressive portrait painting style and in applying the essence of his work to synthesized 3D portraits.

DEDICATION

To my mother and father.

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CHAPTER I

INTRODUCTION

Painters have a unique form of expression that reflects their personal interpretation of the world. These interpretations are abstractions created by the painter. A painter makes informed choices to guide the viewer's eye to areas of interest while simplifying the unnecessary visual details [1].

With the advent of computing technologies and especially 3D computer graphics (CG), digital artists of today are provided with new means to visualize in a new kind of space: the 3D virtual space. This provides a new platform for experimentation. It allows for novel artistic approaches to create images that are new. However, the 3D virtual spaces are embedded within the same awareness of the visual world as compared to any other artist using traditional means. This research is an attempt to reconcile a 2D expressionist style of painting with 3D digital computer generated imagery (CGI).

In traditional painting, *impasto* refers to a technique where paint is applied on the canvas in thick-layers. This thickness of the paint pigment makes the brush or painting-knife strokes visible. This method of paint application produces rich textural details giving a 3D look to the 2D painting [2].

Vincent Van Gogh's rendering style is characterized by having rhythmic and broken brushstrokes as well as *thick* paint pigment. It is difficult to deny the energy in Van Gogh's brush marks; they create a unique experience for the viewer. The question is whether Van Gogh's painterly style can be applied to 3D digital forms. Can we experience the transformation of oil brushstrokes on canvas to digital brushstrokes in 3D virtual spaces? Can we create an experience similar to that of Van Gogh, where every stroke has been placed using a deliberate choice?

Artistic Intent

This research sought to take the use of brushstrokes and paint pigment to a new level of expression in 3D digital art. These are the most distinctive qualities that Van Gogh and many other post-impressionist painters used to add another dimension to create abstraction in paintings.

The artistic intent of this research is to understand the signature style of Van Gogh's self-portraiture and visualize 3D portrait heads rendered in a similar style. This project explores 3D digital shading and rendering techniques in adapting his painterly effects, especially impasto oil paint techniques, in 3D computer graphics.

Exactly re-creating Van Gogh's painting in 3D is not the agenda for this research. Rather, the intent is to observe Van Gogh's painting techniques to influence the design process for rendering digital 3D forms. This work is intended as an artistic exploration, where the results are unknown at the outset. The journey is more important than the outcome.

Goals and Objectives

The goal of this research is to study the impasto oil painting style of Van Gogh's self-portraits and to apply the salient features using 3D rendering technology to capture the overall essence of his artistic expression.

One objective is to develop a surface shading methodology for 3D models that creates a painterly rendering style that is informed by Van Gogh's painting techniques. Another objective is to apply the shading methodology to digital head models, to create virtual 3D heads inspired by Van Gogh's expressionist portrait rendering style.

CHAPTER II

BACKGROUND

Biography

Vincent Van Gogh (1853 – 1890) belongs in the pantheon of the world's great artists. In the earlier stages of his life he was involved in several professions, including experience as an art dealer and a clergyman. However, Van Gogh's artistic career began later around 1880 [3]. From age 27 to 37, Van Gogh lived in several places including Paris, Arles, Saint-Rémy and Auvers-sur-Oise, where he worked constantly toward developing his artistic expression [4]. During the last 10 years of his life, he produced hundreds of paintings, and his productivity is unmatched by any other artist in the 19th century.

Artistic Influences

There were several artistic influences that impacted Van Gogh's growth as an artist. Initially his methods complied with the Dutch techniques of representation such as the use of darker and earthy tones of color. Moving to Paris proved to be a significant phase in Van Gogh's artistic journey. Influences from the *Impressionist* and *Pointillist* motivated him to experiment with colors and shapes [5].

Impressionist painters' work highlighted the effects of passage of time. They painted outdoors in order to capture the transient effects of sunlight rather than emphasizing on the details. Their techniques made use of small, quick brushstrokes with *thick* paint effect (impasto) [6]. Pointillism on the other hand, used small disparate dots of pure color to depict the imagery. They relied on the perceptive ability of the eye to mix the color spots in order to create the wider range of color tones [7].

Impressionist and Pointillist groups revolutionized the use of color in painting, which inspired Van Gogh to experiment with color and brushstrokes and take it a step further. Even though Van Gogh did not follow the Impressionist methods and techniques of representation, he did acquire a lighter color palette[8].

Van Gogh is associated with the Post-Impressionism movement in art history. The post-impressionists (influenced by impressionists) were more inclined towards developing their "expressive" artistic style that portrayed emotion along with the visual imagery. Van Gogh along with other artists like Gauguin, Cezanne, and Toulouse-Lautrec exhibited diverse practices that differed dramatically from each other. Among those, Van Gogh's techniques became hallmarks of post-impressionism [9].

Van Gogh had a strong instinct for color. He used color as a medium for expression. He wrote, “*What color is in painting, enthusiasm is in life*”[10]. He experimented with Michel Eugène Chevreul’s Law of Simultaneous Contrast and Charles’s Blanc color theories [11]. According to their color theories, complementary colors (like red-green, orange-blue, and yellow-purple) play a key role in re-enforcing their true nature when juxtaposed. Van Gogh's work demonstrates a use of complementary colors that help in creating vibrancy on the canvas (see Figure 1) [12].

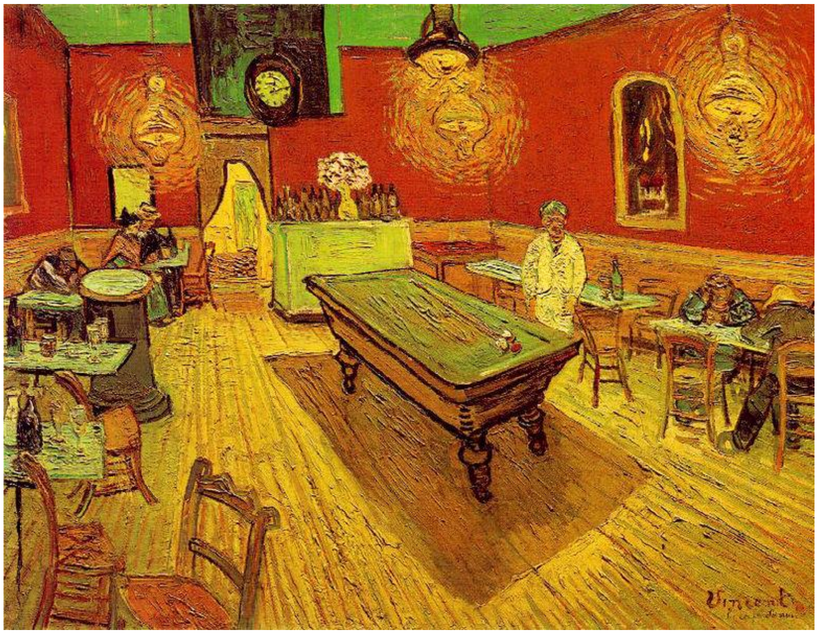


Figure 1. *The Night Café* by Van Gogh, 1888 [13]

Apart from color, Van Gogh's rhythmic brushstrokes have been of importance in describing his aesthetics. Each painting he did has a specific application of brushstrokes and color scheme. This created the uniqueness of each subject. Van Gogh laid thick paint (sometimes directly from the paint tube) in patches of color on the canvas with irregular touches of the brush, while leaving some areas of the canvas bare [8].

Historically, the impasto technique of adding color layers was used to bring realism to the painting; however Van Gogh used thick paint to reinforce the bright colors, the intensity of paint application and the movement of the brushstrokes in his painting. He made use of the "expressive" quality of impasto to create his art. Figure 2 illustrates Van Gogh's brushstroke application, expressing movement in the painting [14]. Therefore, brushstrokes and color are two important identified characteristics, which have influenced this research.

Figure 2. Detail of *Wheat Feld with Cypresses* by Van Gogh, 1889 [14]

Lev Manovich developed "Cultural Analytics" research study group in 2007 at Software Studies Initiative, UCSD. His research focuses on exploring and visually examining large cultural data sets. One of Manovich's research project made use of computational and visualization methods to visually analyze a set of digital images of Vincent Van Gogh's paintings created between 1881 and 1890. They used the average brightness and saturation information of the paintings as metadata to create a high-resolution visualization according to their creation dates. The results revealed that Van

Gogh’s Paris paintings are significantly more variable in their brightness and saturation values compared to his paintings created in Arles. In addition, the Arles paintings have an overall lighter and more saturated color palette than the Paris paintings [15].

Influence of Japonisme

Another influence on Van Gogh was Japanese art, especially Japanese wood block prints. The French term "*Japonisme*" means the influence of Japanese art on Western art. During 1860, many impressionist and post-impressionist artists including Van Gogh were influenced by Japanese woodblock prints (also known as *ukiyo-e*). He idolized Japanese prints for their exotic content and expressive character. Van Gogh's artistic style was influenced by several characteristics of Japanese art such as the use of bold designs, flat areas of bright and pure colors and use of simple lines and margins [16]. Figure 3 shows Van Gogh’s translation of a woodblock print by Hiroshige in an attempt to *Europeanize* Japanese art while maintaining his distinct style [17].

Figure 3. (Left) Woodblock print. *The Plum Garden in Kameido* by Utagawa Hiroshige, 1857. (Right) Painting, Oil on canvas. *Flowering Plum Tree* by Van Gogh, 1887 [17]

Portraiture

Van Gogh painted about 35 self-portraits from 1886 to 1889. Figure 4 shows the progression in his self-portrait renderings. Van Gogh was motivated to paint self-portraits to express his condition, his inner life and his psychological state at the time [8]. Most of Van Gogh's self-portraits suggest his strength as a draftsman. The anatomical structure of the skull is apparent underneath the painted skin surface in several of his self-portrait paintings.

Figure 4. Examples of self-portrait paintings by Van Gogh, 1853 - 1890 [18]

Even though Van Gogh is identified as a landscape painter, he was more inclined toward painting figures and portraiture [19]. Van Gogh's attempts at rendering portraits were based on capturing personality without utilizing photographic believability [8].

In most of Van Gogh's self-portrait and portrait paintings he tried to avoid the flatness of the painted surface. Van Gogh exhibited a distinctive quality in his treatment of color as compared to the portraits painted by other famous painters. The colors used by other painters matched the actual color of the skin. Van Gogh was unique in his choice of color application. He broke the actual color of the skin into multiple colors like greenish-red, yellowish-gray, white-black and many neutral tints (see Figure 5). These are obvious when seen up close. However, when seen from afar, the colors blend to depict movement and highlights on the subject's face [19].

Self-Portrait with Felt Hat as seen in Figure 5 shows the use of a bright color palette and energetic brushstrokes. It is considered a quintessential representation of his artistic style [5]. The hatching style applied on the face creates a pattern of stripes using complementary colors such as orange and blue. The red hair of the beard is mixed with strokes of green [19].

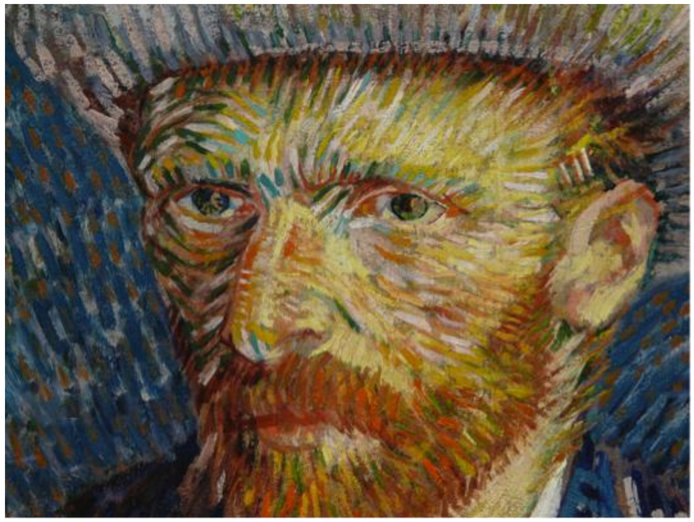


Figure 5. Enlargement of *Self-Portrait with Felt Hat* by Van Gogh, 1888 [20]

Van Gogh used his color palette to convey emotional response. Van Gogh painted the *Portrait of a Peasant (Patience Escalier)*, Figure 6, expressing a strong pulsating range of colors. In this painting, there exists an impression of strong sun on the skin. He repeated the yellow of the hat in the wrinkles of his face. Also, the turquoise of his jacket is reflected in his eyes, beard and cheek [21].

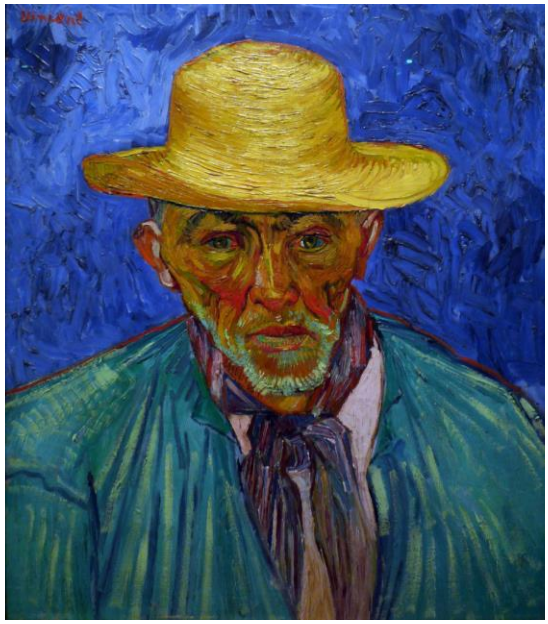


Figure 6. *Portrait of a Peasant (Patience Escalier)* by Van Gogh, 1888 [22]

Van Gogh painted several subjects. However this research focused on observing and understanding Van Gogh's style based on an analysis of his self-portrait paintings. Every self-portrait is distinctive in its application of brushstrokes and color usage. Moreover, the idea behind using self-portraits is to observe the same subject but with a unique experience, similar to what he does in his paintings. Therefore, to gain a better understanding of a particular rendering style of Van Gogh, I constrained my work to focus on his self-portraits.

CHAPTER III

RELEVANT SHADING AND LIGHTING CONCEPTS

This section discusses general concepts relevant to the creation of computer-generated images of 3D objects with a focus on 3D portraits.

A virtual 3D object has both form and surface attributes. These are usually achieved in two different creation stages. Creating the form is called geometric modeling. This typically involves generating and manipulating surface points which determine the polygons, subdivisions or parametric surfaces of the 3D model. Creating surface attributes is called appearance modeling or look development or shading. Surface shading depends on the surface attributes. Texturing is a way to define the surface attributes [23]. The lighting defined in the virtual environment is the third aspect that combined with form and surface attributes determine the image computed.

Surface Shading Concepts

In computer graphics, shading is the process for calculating the color of each pixel in the desired image. Shading is based on the defined properties of the virtual surface, the environment lighting and the shading model used [24].

Surface properties may include surface color, displacement, reflectivity and transparency [25]. The surface properties may be constant across a surface or more often vary across the surface. Surface texturing refers to the both processes and the results of varying attributes across a surface. A common way to vary surface properties is the use of various kinds of 2D texture maps. These 2D maps are usually implemented as data sets, typically image files, or procedures that overlay the surface based on parametric coordinate systems embedded in the surface geometry.

Shading models simulate the interaction of light with the surface material. Therefore, they are also termed as illumination models or lighting models [24]. Shading samples the surface description of the 3D object and based on its relationships to the environment lights, computes the rendered image pixels [26].

It is important to note the difference between shading and texturing. Shading is a process that defines the way in which light interacts with the modeled 3D surface, based on the characteristics of the surface material. Texturing, on the other hand, adds detail to the rendered surface by varying the surface properties from point to point [24]. Because texture maps provide a relatively simple and computationally inexpensive way to modify surface properties, they are efficient ways of adding shading detail to 3D objects.

Texture Mapping Concepts

Texture maps are often created as 2D images. The first texture-mapped images were generated in 1974 by Edwin Catmull [27]. According to Catmull’s texture-mapping technique, each point on the 3D surface has a corresponding 2D (UV) coordinates [24]. In Catmull’s scheme, surface color texture maps were defined in this UV texture space. Colors were extracted from the color map based on the surface UV coordinates. At each surface shading sample point, the extracted color was used in determining the corresponding image pixel value [25].

Effective use of texture maps requires an understanding of how the different surface properties affect shading. Texture mapping can be used to control multiple surface properties such as color, displacement, bump, transparency, surface normal vector, and specularity. However the shading model ultimately determines how the surface appears in the lit environment [28].

Types of Texture Maps

Initially, the texture maps were used only to provide surface color information [25]. However, they can be used to define various other surface attributes, as discussed below.

- *Color Maps* – With color maps, the color of each shaded point on the 3D surface is extracted from the corresponding UV coordinate location in the color map. Color maps are an efficient way to provide variation in surface color and thus add surface detail [23].
- *Bump Maps* - In 1978, Jim Blinn [29] introduced bump mapping, which simulates the appearance of surface bumps without actually modifying the surface geometry. In this technique, a map is used to alter the surface normal vectors. These modified normal values are used in the shading calculations to render images, where the surfaces appear to have bumps and indentations. Bump

mapping does not change the underlying geometry, but only the surface shading calculations based on the modified surface normals.

- *Displacement Maps* – Robert L. Cook [30] described the displacement mapping technique as an extension to bump mapping. Displacement map values are used to actually move the surface point positions and not just modify the normal vector values. After the surface points are displaced, new surface normals are calculated based on the new surface geometry. The displaced surface positions and computed surface normal are then used in the surface shading.
- *Transparency/ Opacity Maps* - Similar to color maps, these maps store opacity values. In these maps a value = 1 is usually considered fully opaque while a value = 0 is considered fully transparent. These maps are used to create transparency variations across the surface [31].
- *Other Maps* - Other surface properties such as diffuse reflection, specular reflection, specular roughness, etc. can also be controlled using texture maps that contain information to manipulate these properties across the surface [31].

Methods for Creating Texture Maps

A texture map is a 2D data pattern that is applied to a 3D surface. The patterns can be created and stored as 2D image files or they may be created procedurally. Painting maps using a 2D image program such as Photoshop or using image scans or photographs of a real world surface are common ways to create image texture maps. A procedural texture map is a synthetic texture produced by a programming model [32].

Procedural Textures

Procedural textures can be 2D or 3D [31]. When a procedural texture is defined as a generating function that computes the texture of a point in a 2D space, it is referred to as 2D procedural texture. When the texture is computed for the point in a 3D space it is referred to as 3D procedural texture. 3D procedures define the texture for all points in a 3D space [33].

2D procedural textures are usually computed in the UV space. This UV space is attached or embedded in the textured 3D surface. 3D procedural textures typically do not consider the surface UV coordinates, but rather are associated with the X,Y,Z surface coordinate [31].

Designing Procedural Patterns

Procedural patterns often follow a *divide and conquer* design philosophy [23]. To synthesize a procedural pattern, a multi-layered approach is pursued. Several simple layers of pattern are combined to obtain the desired pattern by placing them on top of one another [24]. Patterns are broken down based on the frequency content. Layering progresses from low to high frequency patterns [23].

Many texture patterns are based on procedural combinations, modifications or distortion of image textures [24]. In real production environments, a combination of the image textures and procedural techniques is usually preferred to create texture patterns. While a painted texture can be used to provide the underlying color of the 3D object, a procedural noise function can augment surface details such as displacements and bumps [34].

CG Lighting Concepts

Computer Graphics (CG) lighting is achieved by controlling light sources in a virtual environment. There are two categories of CG lighting- direct lighting and indirect lighting [25]. Direct lighting is sometimes referred to as local lighting, while indirect lighting is often called global lighting.

Direct Lighting

Direct lighting considers light falling directly on the surface from the virtual light sources present in the environment. Direct light sources may include directional lights, spotlights and area lights.

- *Directional Light* - Directional lights simulate parallel rays of light, similar to sunlight. Directional lights are characterized by direction but not position. These light sources are located at an infinite distance in a specific direction, which illuminate all objects in the scene from a single direction [32].
- *Spot Light* - A spotlight simulates light radiating from a single point source defined within a limited cone angle. The size of the cone angle as well as several other properties are user-controllable. Moreover, light coming from a spotlight

has a fall-off function such that the emitted light is strongest near the light's direction and becomes weaker towards its shape boundary [32].

- *Area Light* - An area light simulates a physical light with defined source area rather than a point location. Compared to other lights, area lights can produce high quality renderings but with increased cost of render time. There lights are good for still renders but can be disadvantageous for animations [32].

Indirect Lighting

Indirect lighting, often called global illumination, considers light both from direct sources as well as light reflected and refracted from other surfaces in the environment [25]. Methods such as image-based lighting (IBL), ray tracing and ambient occlusion simulate the effects of indirect lighting.

- *Image-Based Lighting (IBL)* - In this technique, instead of discrete light sources, an image, wrapped-around a sphere (or dome), is used to provide the lighting information. This wraparound image is typically a high dynamic range image (HDRI) that simulates real world lighting conditions [32].
- *Ray Tracing* - Ray-tracing is a technique that is used in computer graphics to render complex reflective and refractive light interactions to enhance the visual realism of the 3D rendered surfaces. This technique is useful in simulating physically accurate reflections, refractions and shadowing effects in 3D renderings [32].

- *Ambient Occlusion*- Ambient occlusion is a global shadow calculation technique that achieves subtle shadowing effects [32].

Portrait Lighting

The basic concepts of studio lighting can be applied to creating synthetic portraits using 3D digital lighting setup. In studio portrait photography, photographers use combination of methods to capture facial features. These methods include setting the posture of the subject, selecting an appropriate location for the camera and arranging the studio lighting setup [25].

Lighting in portraiture is of critical importance. Portrait lighting can be classified as *directional lighting* and *diffused lighting* [25]. Directional lighting produces characteristic highlights and shadows on the face of the subject, whereas diffused lighting reveals facial features with equal emphasis. Directional light sources may include natural light sources like direct sunlight, and artificial light sources like spotlights and floodlights. Diffuse lighting includes light from a single large area light source, light from multiple distributed light sources, light reflected off the surfaces, and skylight.

A directional lighting setup depends on the relative position of the face, light and viewer. These relative positions can be used to create light effects to emphasize or deemphasize facial form and texture. On the other hand, diffused lighting setup establishes a comparatively subtler, and more even look [25].

Common Portrait Lighting Setup

Standard Portrait Lighting

Photographic portraits and by extension computer generated portraits typically use a standard portrait lighting setup. The standard portrait lighting setup includes the following multiple sources of light [25].

- *Key Light* - The key light is the main light source for the portrait lighting setup. It simulates the brightest light source in the scene. It is often placed higher that the viewpoint.
- *Fill Light* - The fill light is placed on the side of the face opposite that of the key light. It usually is placed at the same height as the viewpoint. This light can be used to control the facial highlights. Varying the intensity ratios between the key light and fill light creates distinctive lighting effects.
- *Background Light* - The background light is used to illuminate the background, providing a visual interest to the background. This light is often placed between the head and the background, which creates tone and color separation between the face and the background.
- *Hair Light* - The hair light is used to highlight the hair. It is placed above and behind the head. The intensity of this light is adjusted depending on the reflecting properties of the hair.

A three quarter pose is a good element in any portrait photograph. In this pose, three-fourths of the form is illuminated. Following are the common lighting setups used to illuminate a three-quarter pose [25].

- *Short Lighting* – In short lighting, the key light is illuminating the side of the face that is turned away from the camera. This setup enhances facial contours and texture. It also makes the face appear thin and adds character to the face.
- *Broad Lighting* - In broad lighting, the side of the face facing towards the camera is fully illuminated by the main/key light source. This setup de-emphasizes the facial details. The highlighted side of the face is wider than the shadowed side. This also makes narrow faces appear wider.
- *Butterfly Lighting* - In this light setup, the key light is placed directly above the subject's eyes in front of the face. This creates a butterfly-shaped shadow under the nose. It also emphasizes ears, eyelids and high cheekbones creating subtle shadows underneath them.

CHAPTER IV

RELATED WORK

The following discussion presents several research studies and projects related to my current work. Some of these projects became stronger influences than the others. However, all are relevant since they expand on similar ideas of transferring the painterly styles into various other domains.

Dogs of Zone II - Lukasz Pazera, a Polish artist, produced a series of works titled “Postcards From The Zone” [35]. His work demonstrates abstract and experimental pieces of artwork that combine sketches and acrylic paintings with 3D rendering techniques.

Pazera experimented with merging traditional and digital worlds by making use of gestural drawings, photorealistic shading and using photographic details in the rendering techniques. In the experiments, he preserved the definitive characteristics of his 2D gestural drawings of dogs and wolves while rendering them using 3D digital techniques. His work is informed by a gestural rendering style. He created paintings with varying tonal values and used them as projection textures for various channels in the shader. He applied his rendering methodology to both still frames and animation.

A multi-layered approach that incorporated several hand-drawn sketches and acrylic paintings with 3D renderings led to enhanced complexity of the final images. The raw expression of loose brushstrokes is delivered in the final renders, which was motivational for this research. This project demonstrates a similar idea of preserving the nuances of the 3D digital medium. At the same time, it approaches the artwork with the same level of awareness and reuses the visual knowledge in a new context.

Figure 7. *Dog of Zone II* by Lukasz Pazera, 2010 [35]

Starry Night Interactive Animation - This is an interactive visualization of Starry Night that was created by Greek artist Petros Vrellis [36]. He recreated a distinctive aesthetic experience of one of the most famous painting by Van Gogh in an interactive 2D environment.

This visualization simulates the rhythmic brushstrokes in an interactive 2D space by using particle systems that flow in a fluid-like motion. Every particle denotes a single brushstroke, which has a color and direction. To augment the virtual 2D interactive experience, Vrellis used additional features such as surface interactivity and sound effects that respond to the brushstroke flow patterns.

This project is a good example of recreating a visual experience using new tools and medium. It also expands on the idea of sustaining the same underlying visual awareness while using a new set of digital production tools.

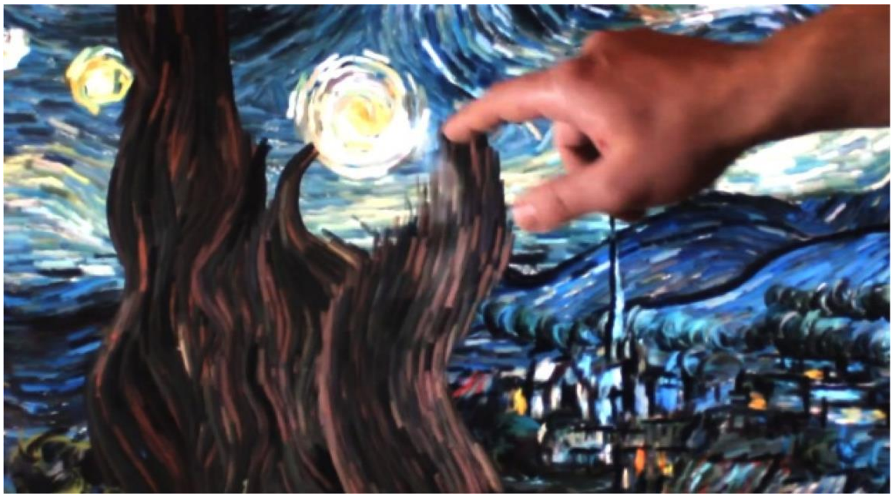


Figure 8. Frame from the interactive visualization of *Starry Night* by Petros Vrellis, 2012 [36]

Following are some of the examples of research papers that capture the essence of various kinds of painterly effects in 3D computer graphics. These examples further supplement and inform the range of possibilities in which painterly styles can be translated into domains such as film, animation and computer graphics.

Barbara J. Meier [37] presented a painterly rendering approach that used surface particles to position brushstrokes on the surface of 3D geometry. Each surface particle positioned an image of a brushstroke on the surface. Randomly placed brushstrokes were produced that “stick” to the 3D surface geometry. Meier’s method maintained temporal coherence in animated sequences. It also provides a more natural looking surface painting style than previous methods that used texture-mapped approaches.

Another research titled “Painting with polygons” [38] by Isaac Botkin provides a non-photorealistic rendering solution for creating hand-painted style in 3D digital renderings. Botkin’s study uses traditional polygonal rendering techniques. This enables the use of existing rendering tools and techniques. His rendering technique uses motion blur methods to render the normal displacements that distort the 3D surface without affecting the surface volume. The motion blur effects resulted in a transparent and layered brushstroke appearance. To further enhance the painterly effects created by overlapping strokes, hand-painted and procedural bump maps were incorporated in the rendering process. This research was also successful in creating brushstrokes in 3D space that maintained temporal coherence in animated sequences.

Michael Losure’s M.S. thesis, “A Non-photorealistic model for procedural painterly rendered trees in the style of Corot,” [39] studied tree renderings in the paintings of French painter Camille Corot and developed a system for procedurally generating and rendering painterly trees. Losure used a combination of existing tools like Autodesk Maya’a Mel scripting and RenderMan Shading Language (RSL) for generating and shading procedural trees. The animations of the painterly rendered trees displayed temporal coherence. Additionally, the overall system was generalized to apply a specific painterly style to a wide range of landscapes rather than mimicking any specific 2D painting.

The following are some of the examples that utilized various painterly effects in film and 3D animation. These movies utilized painterly styles in their production design.

What Dreams May Come (1998) - This live-action film, directed by Vincent Ward, utilized environments that had painted impressionistic qualities. Particle-based effects were used to create the flowing, wet-paint look of these environments. The effect used warped the environmental elements, giving them a brushstroke-like impression. The digitally created "painted" environments interacted with the live-action characters in the film [40]. This movie manifested the impressionistic painterly style to create an abstract painterly environment.

Figure 9. A frame from *What Dreams May Come, 1998* [40]

Réflexion (2012) - This short film was a collaboration between Paris studio Planktoon, and Disney artist, Yoshimichi Tamura. This movie inspired my study as it utilized an oil-painterly style in a 3D digital domain. The oil-painterly effects were achieved using a shader-based approach implemented in Pixar's RenderMan Studio.

Painterly style surface shaders were applied to the 3D characters and the environment sets [41].

Figure 10. A frame from the animated short *Réflexion, 2012* [41]

Bolt (2008) - In this Disney Animation feature, the art direction was based on a painterly approach applied to computer image rendering. The look-development was based on the style of American painters like Edward Hopper, George Bellows and Ashcan School artists. Disney developed several techniques and tools that aided in creating the painterly look of the movie [42]

Figure 11. A frame from the animated feature *Bolt, 2008* [42]

CHAPTER V

METHODOLOGY

This research is an artistic exploration based on a qualitative visual analysis of Van Gogh's self-portrait paintings. The intent of this research is to develop a surface shading approach based on the analysis that allows the characteristics of his work to be applied to the rendering of 3D virtual portraits. The visual analysis of several portrait and self-portrait paintings of Van Gogh discussed in Chapter VI identifies several visual characteristics of his rendering style. Common attributes were observed throughout his portrait paintings. These characteristics are addressed in designing the shading approach.

Existing 3D tools and rendering systems were used to achieve the painterly look inspired by Van Gogh's style. Before explaining the framework developed for the shading procedures, the design strategies that were addressed during the shading design process are discussed.

Design Strategies

To utilize Van Gogh's style in rendering 3D head models, a shader-based approach was pursued. This motivated me to explore existing tools and renderers that could facilitate synthesizing the desired painterly style. This resulted in a *hybrid* methodology for shading. Hybrid means a combined approach that includes both painting and procedural techniques.

The following considerations were taken into account while designing the surface shading approach:

- A hybrid approach was taken to design the shading methodology. I explored procedural methods that are driven by manually created texture images. This allowed artistic nuances in the procedurally generated surface shading.
- Van Gogh's style is comprised of many individual brushstrokes where each stroke has a specific color and direction. The complex nature of his numerous brushstrokes prompted procedural techniques to generate the brushstroke patterns rather than manually painting them.
- The two-dimensional procedural pattern approach was selected to utilize the two-dimensional UV texture coordinate space to generate the surface brushstroke information. This facilitates applying the brushstrokes to the 3D head surface.
- For generating brushstroke patterns that have controlled directionality, the concept of a 2D vector field was applied. The 2D vector field provides directional information for the generated brushstroke patterns. Directional information is associated with each point in the image space.
- Ways for providing user controls were explored that allowed variability in the procedurally generated brushstroke patterns.
- Using *layering* and *masking* techniques allowed controlled variations in brushstroke patterns. The procedural method provides multiple output patterns based on control settings used. Multiple patterns can be layered and masked to create more intricate controlled brushstroke patterns.

Framework

The shading approach developed is shown in Figure 12 below.

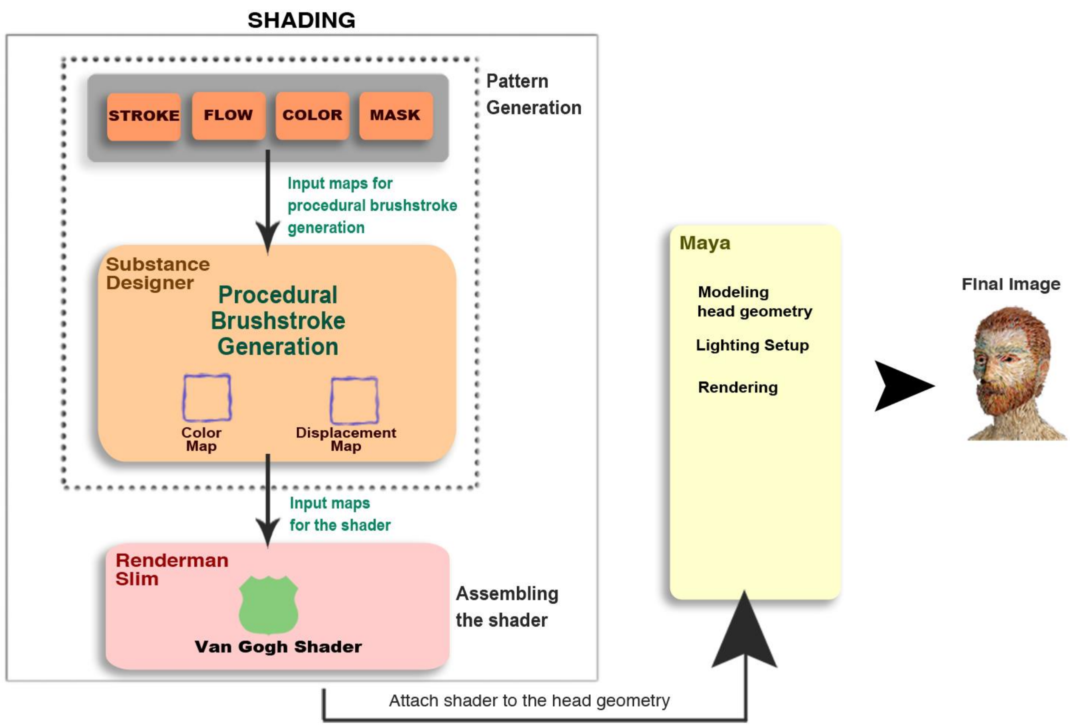


Figure 12. Shading framework

The approach is to create a surface shader paradigm that can be applied to 3D head geometry to create the desired virtual portraits. The 3D head geometry is created using geometric modeling software such as Autodesk Maya. Maya allows the 3D head geometry to be sent to a rendering system such as Pixar's RenderMan to create the desired images. RenderMan includes an interactive tool called Slim, which enables the user to create surface shaders with specific attributes.

The focus of this research is to create appropriate 3D head geometry and then, most importantly, to develop the surface shader needed to create the desired virtual portraits. The fundamental task is to create the procedural brushstroke information, which is the key component in creating the shader.

Procedural *pattern generation* is used to create the 2D texture maps containing brushstroke patterns. These procedural texture maps are then used to define surface properties such as color and surface displacements.

Pattern generation – The pattern generation process comprises of both painting and procedural techniques to create 2D procedural texture maps containing brushstroke patterns. Painting is used to create input image maps for the procedural pattern generation system.

The following are the steps used to generate procedural brushstroke patterns.

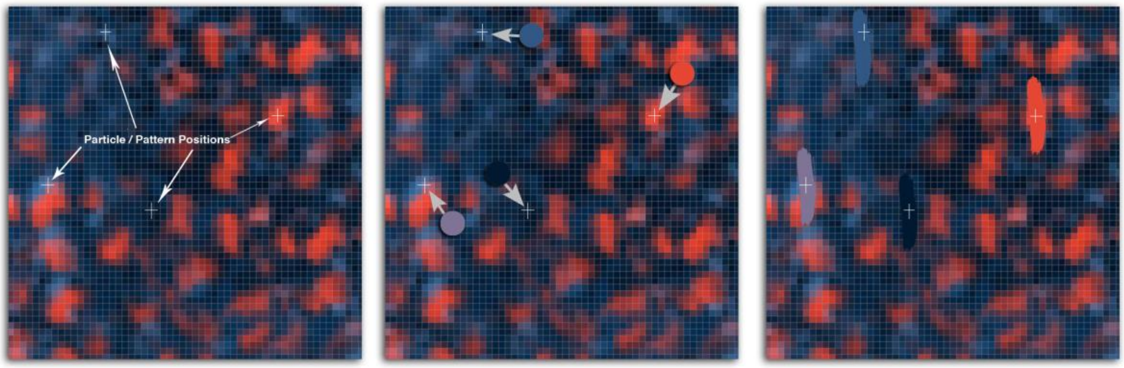
1. Create the brushstroke profiles used to define the generated brushstroke shape
2. Create color maps to define color for the generated brushstrokes
3. Create flow map to define orientation for the generated brushstrokes
4. Create image masks that controls where brushstrokes will appear
5. Generate procedural brushstroke patterns to be used in the shader. This uses the maps created in steps 1 to 4 as inputs
6. Use layering and masking to create more complex controlled brushstroke patterns

Shader specification – Procedural brushstroke pattern maps obtained from the pattern generation process are used as inputs to the created shader. Surface properties, such as color and displacement, are controlled by the shader using the brushstroke pattern maps.

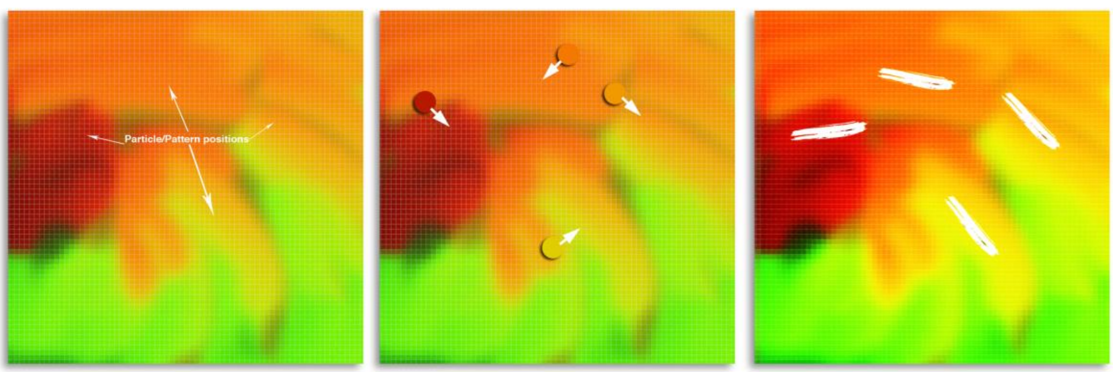
Procedural brushstroke generation - The following discussion explains the basic principle behind generating procedural brushstrokes maps. These maps are generated in a two-dimensional texture coordinate space (UV space). The brushstroke pattern maps are comprised of brushstrokes, each having a shape profile, a color and a direction.

Inputs to the brushstroke pattern generation include brushstroke profiles, color maps, and flow maps. A brushstroke profile is grey scale image defining stroke shape. It defines the shape of individual brushstrokes. Color and flow maps supply the color and direction data to the brushstrokes respectively. A color map is a digital image where each pixel has color information. A *flow map* is a color encoded 2D vector field [43].

Random positions are generated in the texture image space. Underlying pixel value from color and flow maps are sampled at these randomly generated positions and used to define the color and direction of the brushstroke. Brushstrokes are drawn at these random positions, each having an assigned color and direction. This process is illustrated in Figure 13.



Sampling pixel color from color map and assigning to brushstroke color



Sampling pixel color from flow map to assign brushstroke orientation

Figure 13. Color sampling from color and flow map to assign brushstroke color and orientation

CHAPTER VI

VISUAL ANALYSIS

This visual analysis identifies the characteristics in Van Gogh's work that inform the developed surface shading methodology. Observing Van Gogh's work enables us to understand his mastery of brushstrokes and use of color. Enhanced by his ability to portray lighting, this gives each self-portrait a distinct identity. In the following discussion these visual characteristics are identified and discussed.

The unique nature of Van Gogh's work is grounded in his expressive use of color, brushstrokes and the texture quality achieved through thick paint and rapid brush marks. For this research, the prime focus was on exploring the textural aspect of his style. However, lighting is critical in any form of portrait production. Therefore the lighting techniques seen in Van Gogh's self-portraits were further studied.

The self-portraits of Van Gogh shown in Figure 14 were referenced in the analysis process. Most of his portraits depict a three-quarter view of the left side of his face as viewed in mirror. The analysis has been done under three broad categories - brushstroke, color and lighting analyses. Several visual characteristics have been identified under each category.

Brushstroke Analysis

In Figure 14, the pointers A through D identify instances of the characteristics discussed.

Every Stroke is Apparent (A)

Observation of several of Van Gogh's portrait paintings reveals a wide range of brushstroke application. The overall painting is composed of numerous brush marks. However, the majority of strokes are clearly identifiable in color and direction. Every stroke is individually apparent to the viewer as a mark that has a definitive color and direction.

Multiple Brushstroke Create Flow Patterns (B)

Van Gogh uses multiple brushstrokes that have related directionality. These multiple brushstrokes create flow patterns that define the overall shape of the painted subject. These rhythmic patterns are unique to his style.

In his portrait paintings, the facial features and the overall shapes are derived from this flow of brushstrokes. The flow pattern starts around the eyes and spreads gradually to the rest of the face. The surface curvature is represented by the placement and orientation of these multiple brushstrokes. This flow creates the form of the face and other facial structures including the hair.

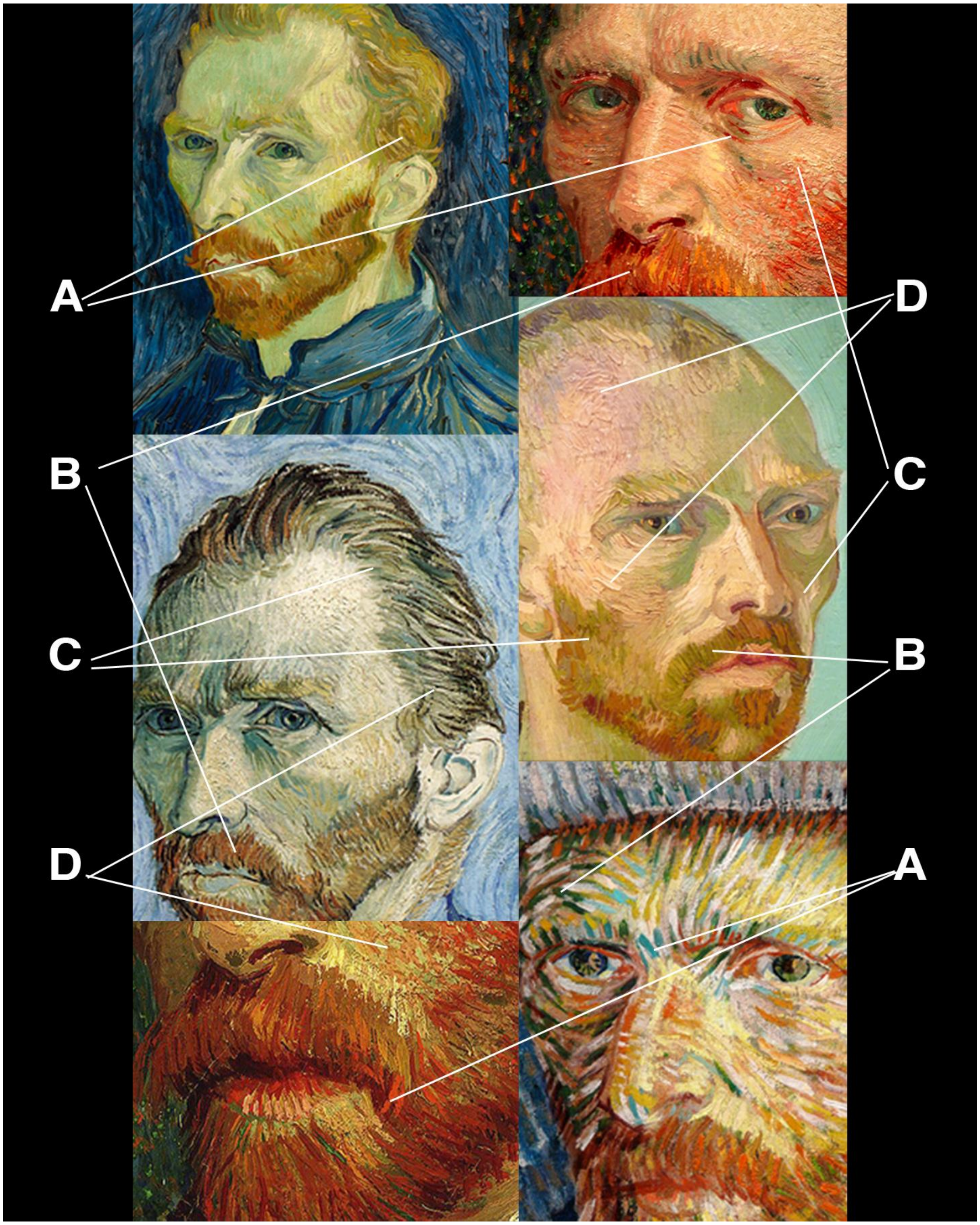


Figure 14. Examples of self-portrait paintings used for visual analysis by Van Gogh, 1887 - 1889 [20, 44 - 47]. Brushstroke analyses: A to D pointers identify the characteristic features

Brushstroke Layering (C)

As in many paintings, Van Gogh’s portraits show the use of multiple layers of brushstrokes. Strokes are layered in multiple levels. In some places the thickness of the paint is apparent due to this layering and the build-up of the paint. On the other hand, several other areas are painted with weak strokes that yield an almost chalky effect. In some cases, the layering is such that underlying strokes are visible. In other cases, the strokes are thick and opaque; the underlying strokes do not show through.

Brushstroke Variability (D)

Van Gogh's entire painting is composed of individual brushstrokes and all these brushstrokes have variability in their properties. The following observed brushstroke properties exhibit variability.

- *Profile* - Brushstrokes used to depict the skin are different than those used to paint facial features like hair. The strokes used to paint the hair are comparatively longer and wavier in shape than the strokes painted for the skin.
- *Size* - The sizes of the brushstrokes also vary significantly. Some brushstrokes form fairly long lines, while other brushstrokes are shorter marks.
- *Paint thickness* - There exists significant variation in brushstroke thickness. The thickness of an individual stroke depends on the pressure with which it is applied. There are several instances where the thickness of the strokes is used to enhance the surface materiality, adding volume and dimensionality to the overall image.

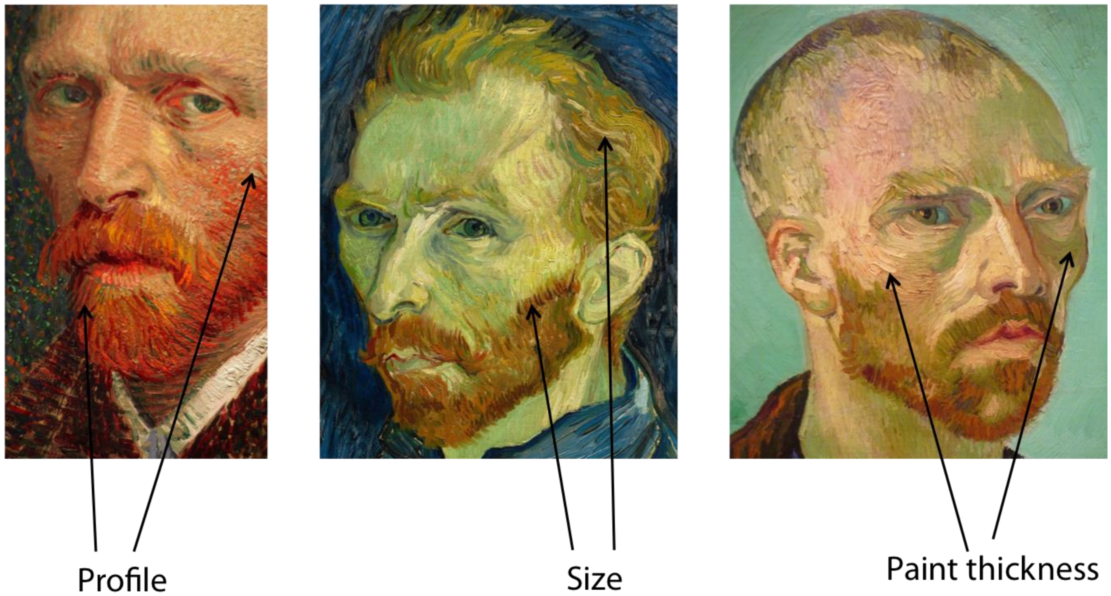


Figure 15. Identifying brushstroke variability- profile, size and paint thickness in self-portrait paintings by Van Gogh, 1887 - 1889 [44, 46, 47]

Color Analysis

Van Gogh's paintings display variation in his choice of colors to depict the face. Both warm and cool hues are observed in his self-portraits. In some paintings the skin is painted using pale and grey hues (see Figure 16) while in others intense yellow and orange hues along with red accents are used (see Figure 17). The colors depicted in the Figure 16 and 17 were identified by manually sampling using the color picking methods in Photoshop.

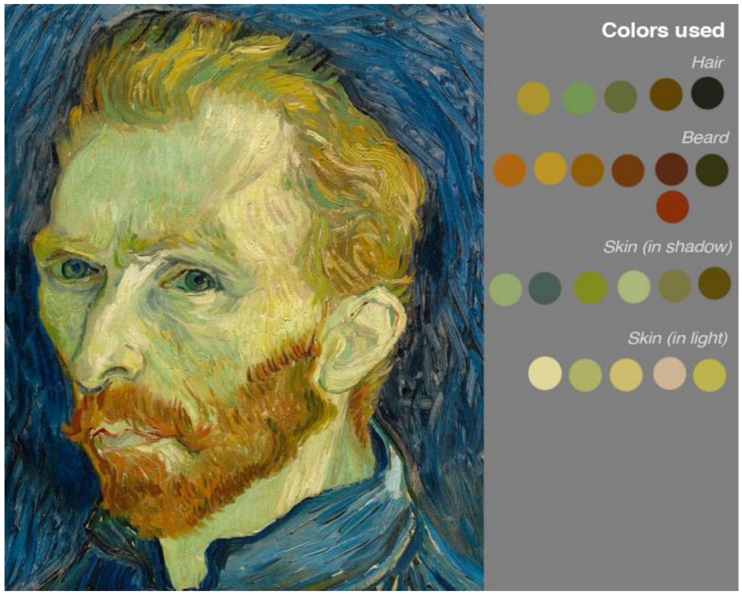


Figure 16. Color analysis of a self-portrait painting by Van Gogh, 1889 [44]. Pale and grey color palette observed

Figure 17. Color analysis of a self-portrait painting by Van Gogh, 1887 [46]. Warm color palette observed

As observed in several of his self-portraits, the color used to paint the beard is darker than the color used to represent the hair and eyebrows. Moreover, there are varying tones of colors observed in the face that give an overall impression of the face and hair. These colors are clearly observed since they have been placed as clear brush marks. There exists slight variation in the stroke color that projects an uneven look. The colors used to paint the brighter side of the face are higher in tone as compared to the colors used to paint the shadow areas. These self-portraits display an acute sense of color and hence attain certain uniqueness.

Lighting Analysis

The lighting observed in Van Gogh's self-portrait paintings informed the lighting setup for the virtual 3D head models.

Lighting is critical, as it helps in emphasizing the textural details; the properties of *impasto* oil painted surfaces. The lighting studies helped in two ways. One was to establish a portrait light setup informed by Van Gogh’s paintings and the other was to enhance the surface quality of the virtual 3D portraits.

To analyze the lighting in Van Gogh’s self-portraits, the digital reproductions of the portrait paintings (obtained from the internet) were converted to greyscale versions. Brightness and contrast adjustment settings were applied to identify highlight and shadow regions. By observing the light and dark regions, the direction of the dominant source of light was inferred. The lighting analysis depends on the perceived lighting effects in Van Gogh's self-portraits rather than relying on the light conditions in a museum. This research does not consider the lighting variations suggested in digital photographs (or digital reproductions) displayed on a computer.

The lighting observed in the majority of Van Gogh's self-portrait paintings could be broadly categorized into three setups- broad, short and back lighting. For the detailed analysis, the portrait paintings shown in Figure 18, 19 and 20 were used.

Van Gogh made use of natural sources of light along with artificial lights for his painting practice. Artificial sources of light could include lights from candles and oil-lamps. Natural sources consisted of direct light from the sun and diffused light from the sky for outdoor painting setups whereas light coming through windows or any of the artificial sources constituted his indoor painting setups.

Several of Van Gogh's self-portrait paintings can be categorized as examples of broad lighting (see Figure 18). The perceived right side of the face (facing the viewing angle) is well lit and suggests the presence of a strong natural light source. The left side of the face is comparatively lower in intensity and therefore indicates the presence of a natural fill or skylight in the environment.

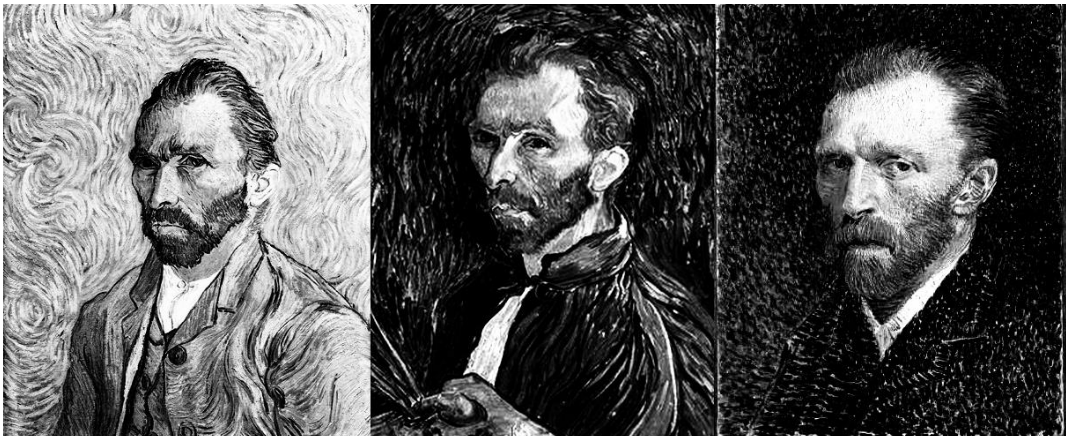


Figure 18. Lighting analysis of self-portrait paintings by Van Gogh, 1887 - 1889 [44 - 46]. Broad lighting observed

In contrast, an example of short lighting (see Figure 19) is seen in one of the earlier portrait painting of Van Gogh. Here, the right side of the face (facing away from the viewing angle) is brighter than the left side. The left side of the face however is not in complete darkness. There is some ambient reflected light that fills the areas that are not directly facing the light. Subtle cast shadows are observed on left side of the face.

Figure 19. Lighting analysis of a self-portrait painting by Van Gogh, 1886 [48]. Short lighting observed

Another lighting example is shown in Figure 20. A natural source of light is observed to illuminate the back of the head. Here the figure emerges from a strongly lit background while the majority of the face front is in shadow.

Figure 20. Lighting analysis of a self-portrait painting by Van Gogh, 1888 [49]. Back lighting observed

CHAPTER VII

IMPLEMENTATION

Software Used

The 3D modeling software used for this project was Autodesk Maya 2012 [50]. Pixar's RenderMan Studio [51] was used for shading and rendering tasks. Maya provides a comprehensive modeling, shading, lighting, animation and rendering workflow. RenderMan is seamlessly integrated with Maya. The procedural techniques for creating brushstroke patterns were implemented using Substance Designer (SD) [52] software by Allegorithmic. For 2D and 3D painting Pixologic Zbrush [53] and Adobe Photoshop [54] paint programs were used.

Shading Methodology Implementation

The shading methodology implementation is discussed in the following order:

- Procedural brushstroke pattern generation
- Shader creation

Procedural Brushstroke Pattern Generation

The following steps were performed to create procedural brushstroke patterns. The first four steps create inputs to the procedural pattern generation algorithm in step five. Each of these steps is discussed in detail.

1. Creating a brushstroke profile
2. Creating a color map
3. Creating a flow map
4. Creating a layer mask
5. Creating a procedural brushstroke pattern

Multiple brushstroke patterns were then layered to create a composite brushstroke pattern.

Creating a Brushstroke Profile

A brushstroke profile or pattern defines the shape characteristics for a single brushstroke. It is an input to the procedural algorithm. A brushstroke profile is a 2D greyscale digital image, where white is considered opaque and black is considered fully transparent. Grey values define varying levels of transparency.

Figures 21, 22 and 23 show examples of brushstroke profiles. A catalogue of strokes was created for use in the procedural brushstroke generation. These were created from image scans of real brushstrokes. The scans were converted to grey scale images. The intensity values of the image scans were adjusted to achieve a defining stroke shape while preserving some of the details in the stroke bristles.

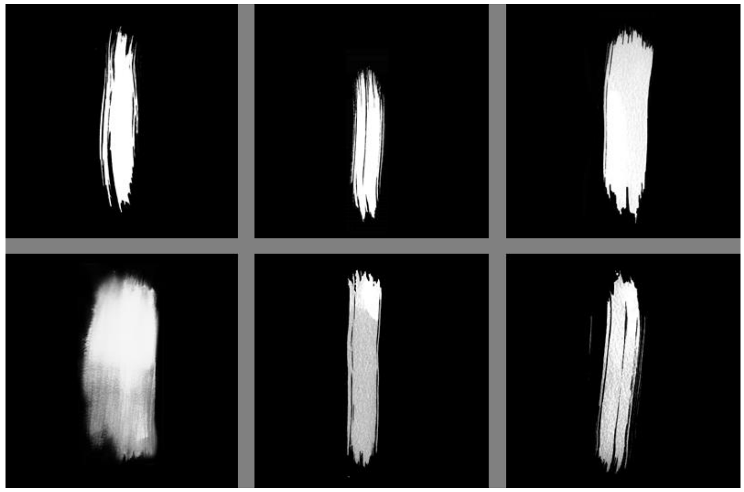


Figure 21. General brushstroke profiles

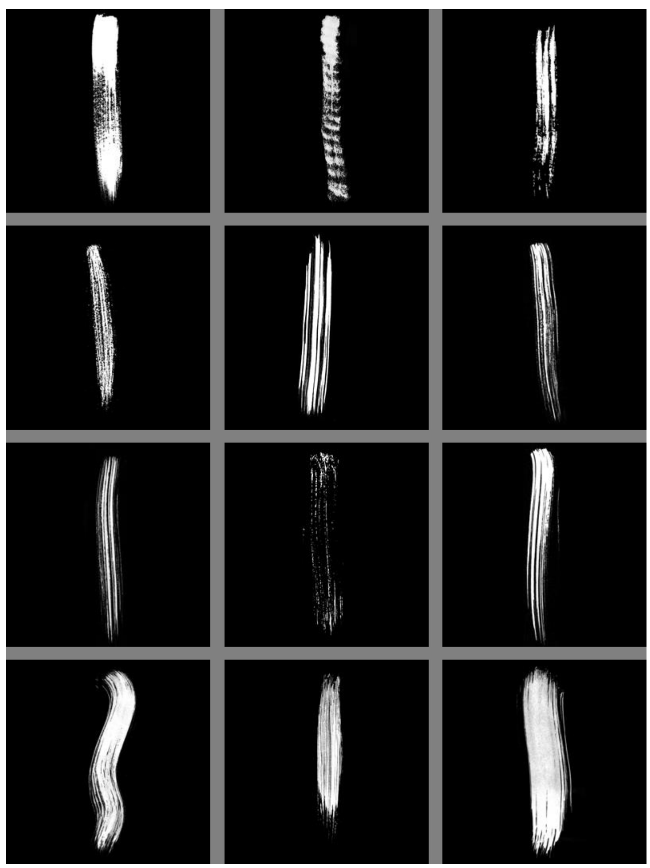


Figure 22. Long brushstroke profiles

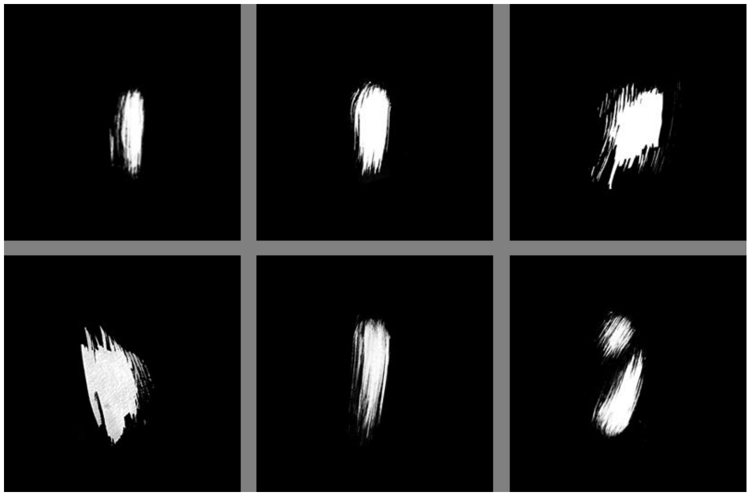


Figure 23. Short brushstroke profiles

Creating a Color Map

A color map is a digital image that contains color information for every pixel. The color map is used to select brushstroke colors. It was important to understand the use of color in Van Gogh's work to digitally paint these maps. Figure 24 shows examples of color maps created using Photoshop.

Complementary and broken colors were used to create these color maps. Broken color is a technique used by the Impressionist painters where color is applied using small dabs rather than blending colors together [55]. Figure 24(b) shows an example of broken color where different tones of red have been layered to create the color map. Figure 24 (a & c) shows a combination of broken and complementary colors.

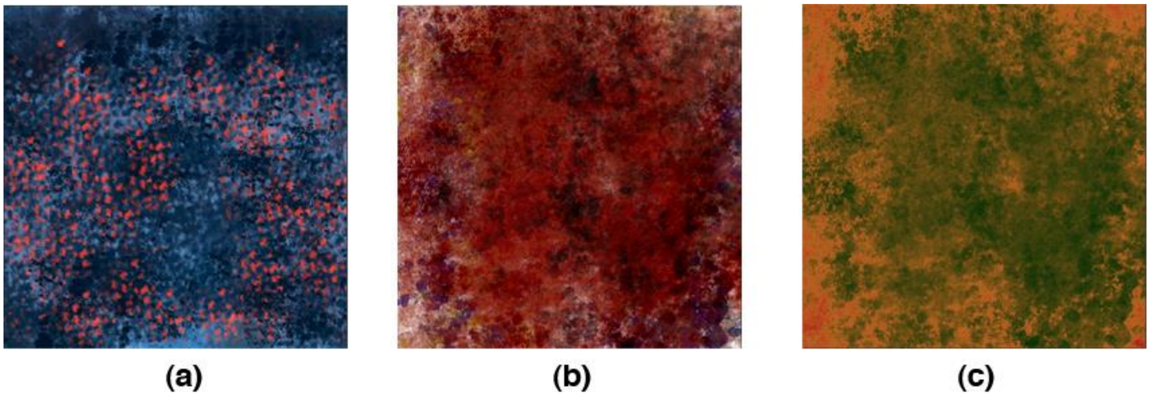


Figure 24. Examples of color maps

Creating a Flow Map

A flow map, also called a vector map [43], is the color encoding of a 2D vector field as a digital image. At every pixel location in the flow map, the direction of the 2D vector is encoded using two channels of color information. In this case, the two color channels used were red and green. The red channel was used to encode the x-coordinate values and the green channel was used to encode the y-coordinate values. The color coordinate system used to encode the vector field is illustrated in Figure 25.

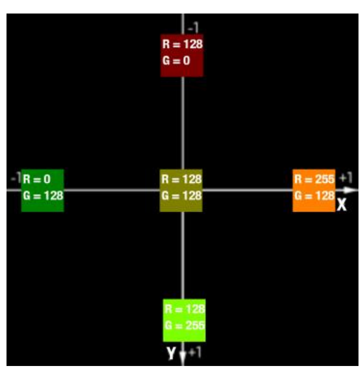


Figure 25. Color coordinates used for the flow map [43]

Illustration of a sparse 2D vector field and a dense version of its corresponding color encoding are shown in Figure 26.

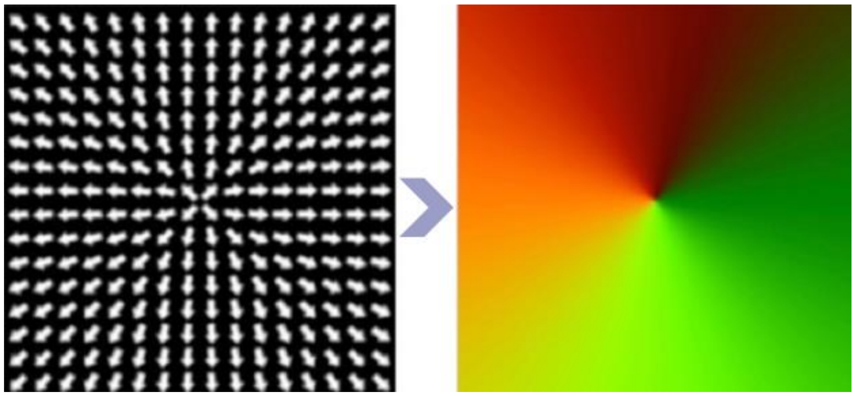


Figure 26. (Left) Sparse version of a 2D vector field. (Right) Dense color encoding of the 2D vector field [43]

A flow map must be created for each desired brushstroke pattern map. The flow maps were painted using Photoshop. The clone stamp tool was used to paint the flow map. The clone stamp tool copies pixel colors from a *source* image to a *target* image.

The source image used is the color-encoded image shown in Figure 27. This image is referred to as the *cone-map*. The flow map painting process starts sampling the color from the center of this image. The resolution of the cone map should be the same as the target flow map created. A general process of creating a flow map is explained below.

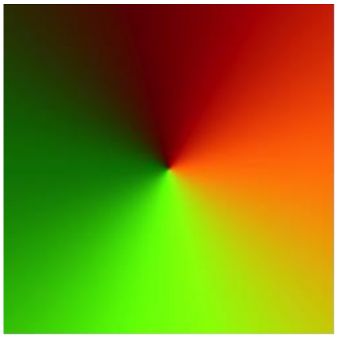


Figure 27. Source image (or cone-map) for painting flow map

The clone stamp tool samples the color starting from the center-most pixel of the cone-map. Adjustment settings were applied to ensure that the stroke origin is fixed at the center of the source image for each new stroke.

During the paint process, for every stroke made on the target image, the clone stamp tool samples the cone map image and stamps it on the target image. The color of the painted stroke is derived from the arrangement of colors in the cone map. The shape of the stroke path is the same in the cone map and in the target image. Figure 28 illustrates the flow map paint process, and Figure 29 shows the finished flow map.

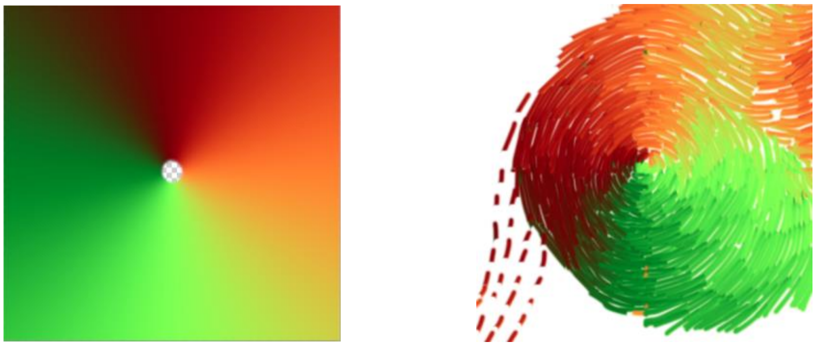


Figure 28. Flow maps painting process. (Left) Cone-map image. (Right) Partially painted flow map

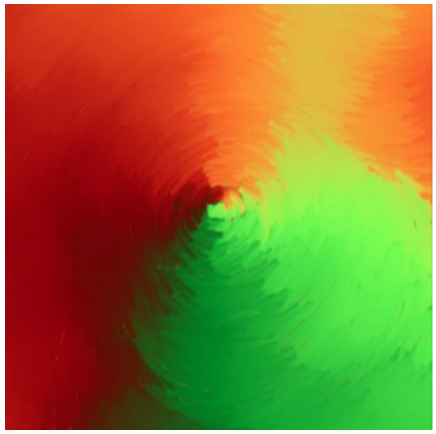


Figure 29. Example of the finished flow map

Creating a Layer Mask

When multiple patterns are combined, masks are used to control the visibility of individual brushstroke patterns. They are used as inputs to the procedural brushstroke generation process. The masks are grayscale digital images that control the overall opacity within a brushstroke pattern. The areas that are painted white in the mask are opaque in the brushstrokes pattern, while areas that are black result in transparent brushstrokes. In the procedural pattern generation system, these masks control the alpha channel of the generated brushstroke pattern image, thereby controlling the visibility of the brushstrokes in a given pattern. Figure 30 illustrates the masking process.

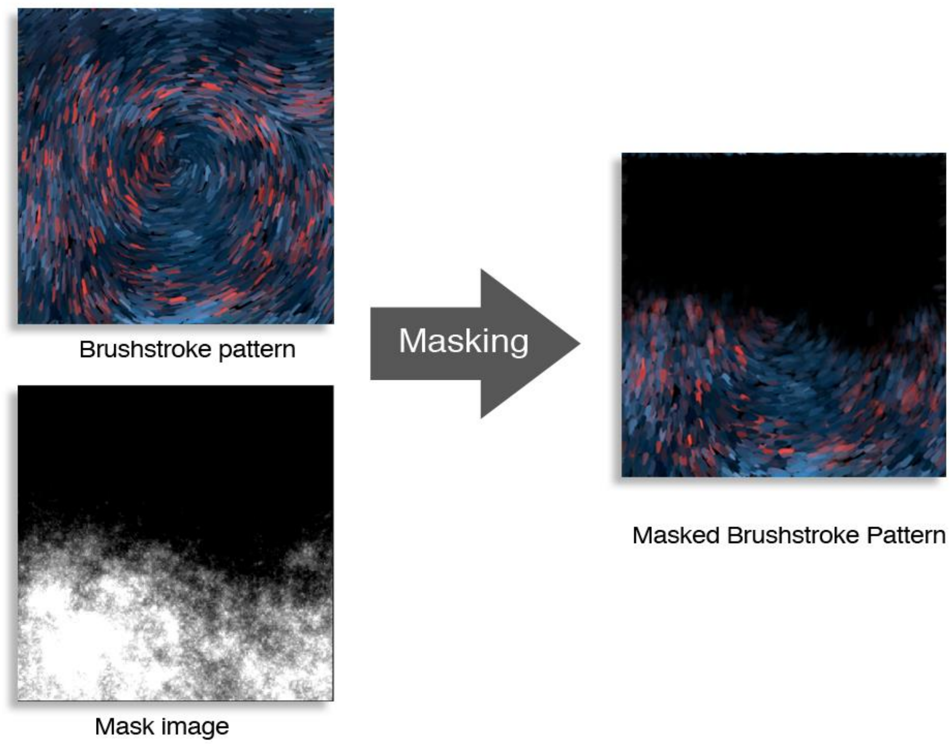


Figure 30. Using masks to control brushstroke visibility

Creating a Procedural Brushstroke Pattern

The following discussion describes the generation of the procedural brushstroke patterns. These brushstroke patterns were defined in a 2D UV image space. The procedural brushstroke generation process was implemented using the Substance Designer (SD) software. Once the inputs for the procedural process (color map, flow map, stroke profile and layer mask) were created, they were imported into the SD software as images.

To procedurally generate the brushstroke patterns, SD's Fx-map node [52] was used. The Fx-map is used to create iterated patterns. The Fx-map node can be customized to generate the desired brushstroke patterns. Customizing the Fx-map node to generate brushstroke patterns is the next discussion.

The Fx-map was designed to read four inputs:

- *Flow map*
- *Color map*
- *Brushstroke profile*
- *Mask map*

The Fx-map node allowed the following parameters:

- *Pattern* – Patterns are greyscale images. These can be image maps or they can be mathematically generated pattern. In this implementation, the pattern used was the brushstroke profile.
- *Color* – This defines the color of the pattern and the channel blending between multiple pattern images in the Fx-map. Color was selected from the input color map.
- *Pattern Size* – This was a scale factor applied to the brushstroke profile.
- *Pattern Offset* – This offset the brushstroke's position by a specified amount.
- *Pattern Rotation* – This specified the brushstroke's orientation.
- *Blending Mode* – This specified the blending process used when mixing the instances of the brushstroke profile into the composite brushstroke pattern map.

I created the following parametric user controls for the brushstroke pattern generation.

- *Stroke_size* – Controlled the size of the brushstrokes.
- *Stroke_size_variation* – Added variation to the generated brushstrokes' size.

- *Amount* – Specified the total number of brushstrokes.
- *Use mask* – Controlled the masking feature in the pattern generation process.

Algorithm

The steps followed to generate a single stroke in the brushstroke pattern image are:

- The brushstroke profile was used to define the pattern type.
- A random number generator gave random values between 0 and 1 for both x and y. These random values determine the 2D pattern_position. Note that the 0 to 1 range corresponded to the UV space. This pattern_position offset the pattern image from its default location in the brushstroke pattern space. Thus, the parameter pattern offset was set.
- Once the pattern position was defined, the pattern was assigned a color and direction. To assign a rotation orientation to the pattern, the flow map was used. The underlying pixel value from the flow map was sampled. The red and green channel values of the pixel gave a 2D vector direction. The red channel yielded the x-component, and the green channel yielded the y-component. A vector to angle function was used to return an angle for the vector using the inverse tangent function (angle = $\tan^{-1} x/y$). The returned angle was then used to rotate the pattern image from its default angle. This rotation angle was used to set the pattern rotation parameter.
- The underlying pixel color value from the color map was sampled at the pattern_position. The sampled color was assigned to the pattern image's RGB

channels. Similarly, the greyscale value of the mask map was used to assign the pattern image's alpha channel. Thus the mask map and color map together defined the color parameter of the pattern.

- The overall pattern size was defined by the two input control parameters – stroke_size and stroke_size_variation. The linear interpolation was used to create a blend between stroke_size and the stroke_size_variation parameter.

These steps generate a single brushstroke in the brushstroke pattern image. To generate many brushstrokes, the above procedure was made into a random iterative process. The *Amount* parameter controlled the number of iterations. Increasing the *Amount,* increased the number of strokes. Multiple instances of this customized Fx-map node were created with different input maps and user control settings to create more complex and layered patterns.

The illustration shown in Figure 31 is the SD node graph for the procedural process to create a single brushstroke pattern. Input maps were fed into the Fx-Map node, which was the procedural brushstroke generation node. The output from the Fx-map node was the procedural brushstroke pattern map. The created brushstroke pattern map was used as the color map for the developed shader (see Figure 32).

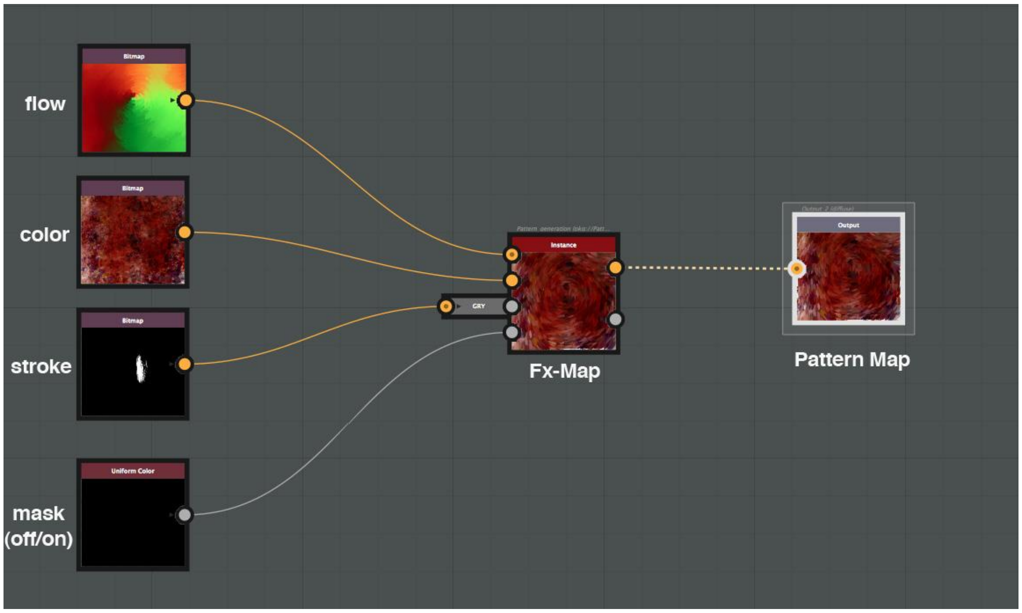


Figure 31. Node graph for generating a single brushstroke pattern

Figure 32. Output brushstroke pattern map used as color map

To create the shader displacement map the intensity of the color map was used. De-saturating the color map to a grey-scale map followed by level adjustments gave the displacement map (see Figure 33).

Level adjustments were important since it allowed me to control the thickness of the brushstrokes. Increasing the contrast between neighboring strokes created thick oil paint effects in the final render. Lower value contrast resulted in subtle paint strokes of reduced thickness.

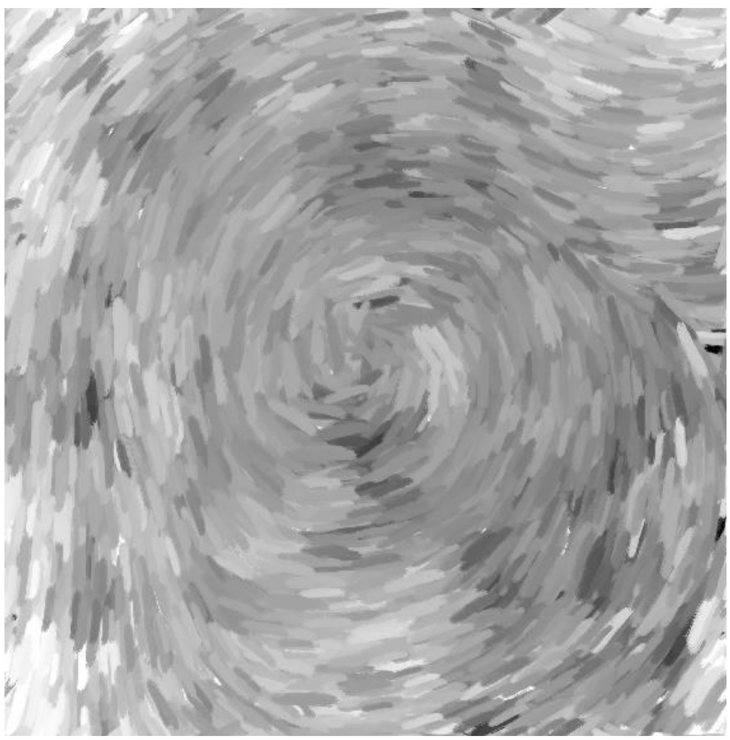


Figure 33. Displacement pattern map derived from color map

User controls for pattern generation

This section illustrates pattern variations achieved using the user controls. The input maps used are shown in Figure 34.

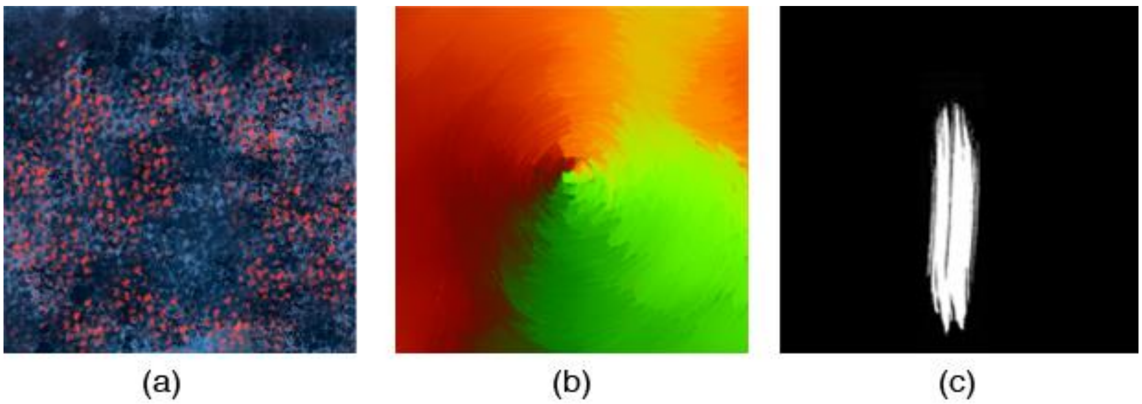


Figure 34. Input maps (a) Color map, (b) flow map and (c) brushstroke profile

Figure 35 illustrates the output maps that were created with different parameter settings. It shows how the settings modulated the created brushstroke patterns.

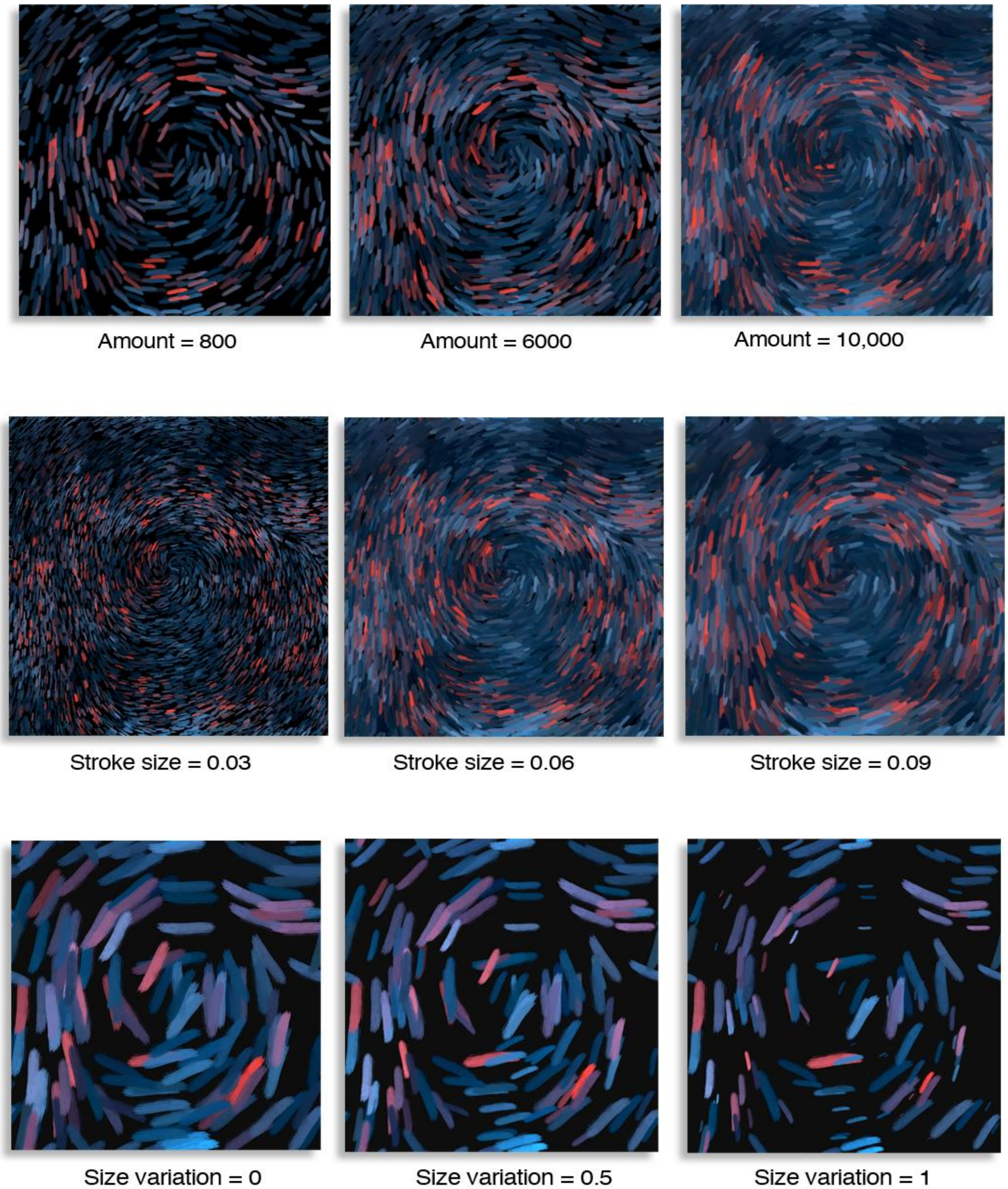


Figure 35. Variation achieved in stroke patterns

Layering Procedural Brushstroke Pattern

Every procedural brushstroke pattern generated contains instances of a single brushstroke profile. However, Van Gogh’s work displays variability in stroke shape. His brushstrokes also have varying levels of thickness. To achieve this variability, layering and masking techniques were incorporated to generate a layered brushstroke pattern.

Figure 36 illustrates the concept of layering for creating a layered brushstroke pattern. The same flow map was used for all three layers of brushstroke patterns. To begin, color 1 and brushstroke 1 were used to generate the first layer of brushstroke pattern. The generated pattern is shown in Figure 37. To add the second layer of brushstrokes, color 2, brushstroke 2 and mask 1 were used to generate the brushstroke pattern. Mask 1 controlled the areas where the brushstrokes would be visible. The areas that are masked out in the second layer show the underlying brushstroke pattern on layer 1. The result from layering two layers of brushstroke pattern as described is shown in Figure 38. Similarly, a third layer of brushstrokes is compiled using color 3, brushstroke 3 and mask 2. The result of layering these brushstroke patterns is shown in Figure 39.

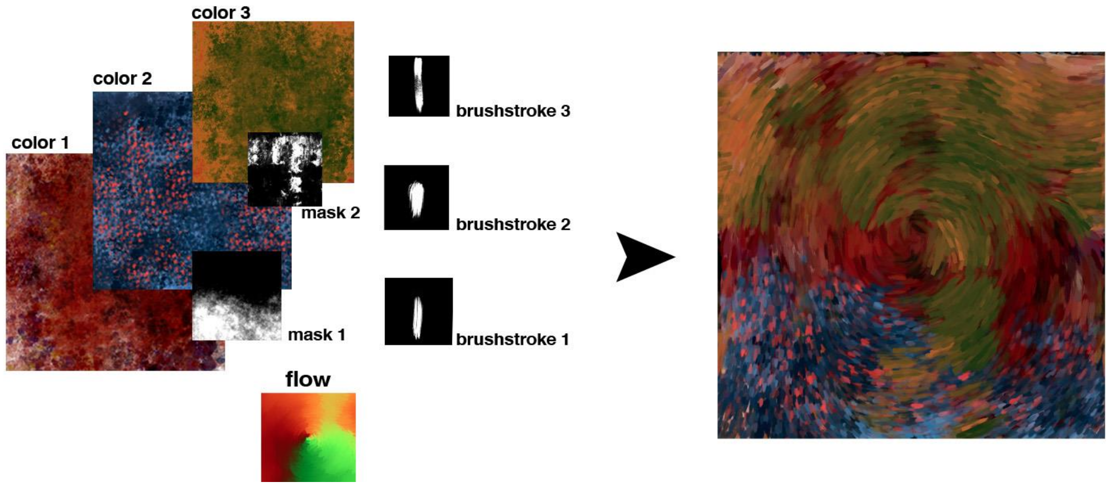


Figure 36. Layering procedural brushstroke patterns

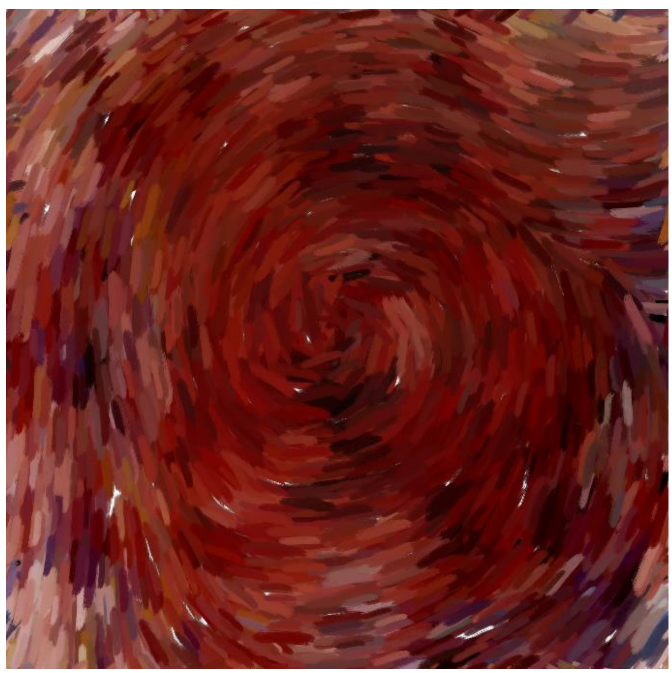


Figure 37. One-layer output pattern map

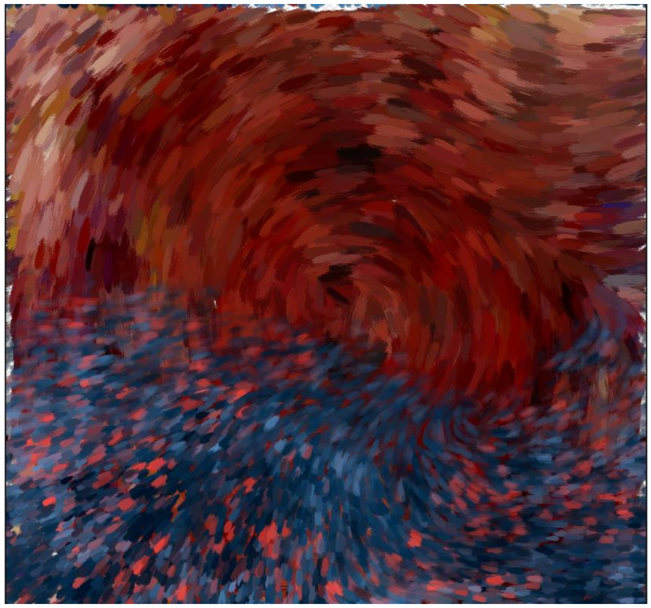


Figure 38. Two-layer output pattern map

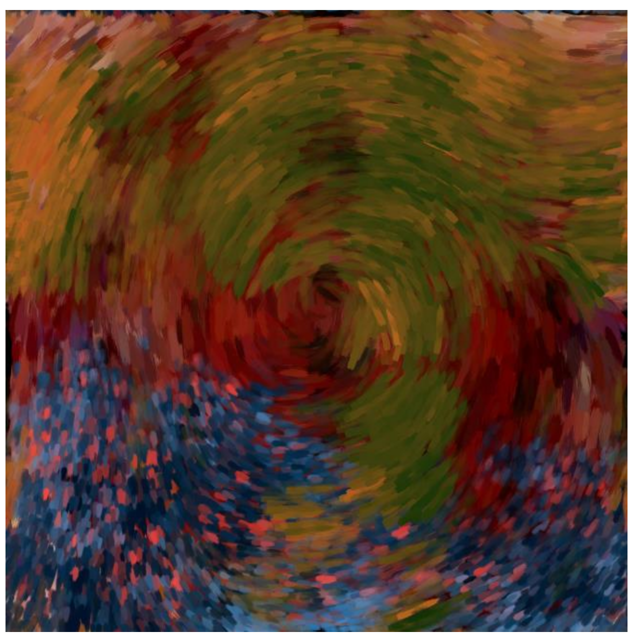


Figure 39. Three-layer output pattern map

The resulting pattern map obtained by layering multiple patterns was used to create the displacement map. All these maps were created within SD using available filter nodes. Figure 40 shows the resulting color and displacement map for a three-layer brushstroke pattern.

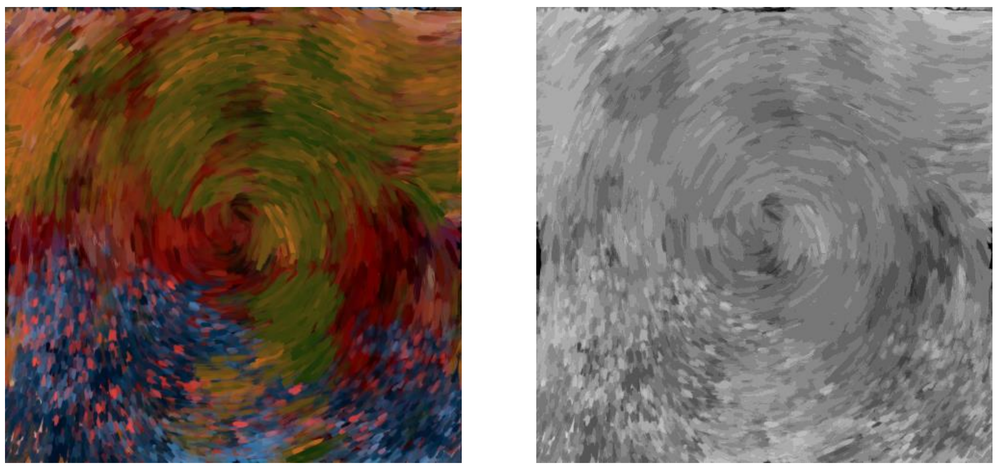


Figure 40. Three-layer color and displacement maps

Shader Creation

The following surface properties were incorporated in the Van Gogh shader creation process.

- Displacement- defines thickness in the paint strokes
- Diffuse color- controls the color of the brushstrokes
- Specular- controls the specular reflection from the oil paint surface
- Reflection – controls the reflective property of the oil paint pigment

RenderMan's shading network program, *slim* [56] was used to create the Van Gogh shader. The following nodes acted as the basic building blocks inside slim for creating the Van Gogh surface material.

- *All Purpose* – defines the diffuse, specular, reflection surface attributes
- *Combine* – defines the surface displacement and surface bump
- *Ensemble* – combines the surface shading with surface displacement
- *Utility nodes* such as Remap, Adjust, Correct, and ImageFile were used as filter nodes, image readers and to correct surface properties

RenderMan's *slim* [56, 57] provides a general-purpose shader called the All Purpose shader for creating a variety of surface types . This shader has several built-in controls for adjusting various surface attributes such as diffuse, displacement, bump, specular, reflection, roughness, etc. The All Purpose shader also provides features to add multiple layers of shading components like diffuse, specular, displacement etc. Although the All Purpose node has a built-in displacement feature, it was convenient to use a separate Combine node for displacement because it allowed visualizing the surface shading separate from the displacement. The Combine node can add multiple layers of displacements. The Ensemble node combined the results of surface shading and displacements together. The result is then attached to the 3D geometry.

Displacement and diffuse color - The displacement and color maps shown in Figure 40 were exported from the SD package and imported as images into the slim shading network. The color map defined the shader's diffuse color, while the displacement map was used to provide the surface deformation information.

Specular and reflection - A specular shading component was added to the surface shader. The specular amount was set to 0.5 to achieve the desired amount of specularity. The specular roughness was set to 0.01 to give sharp specular highlights.

To create physically accurate specular and reflection effects, the Fresnel reflection attribute was added. The Fresnel index of refraction was set to 1.5, which is the refractive index of the oil paint material. Finally the overall reflection was adjusted to 0.3 to achieve the desired amount of reflection from the environment. Figure 41 shows a simplified block diagram of the Van Gogh shader.

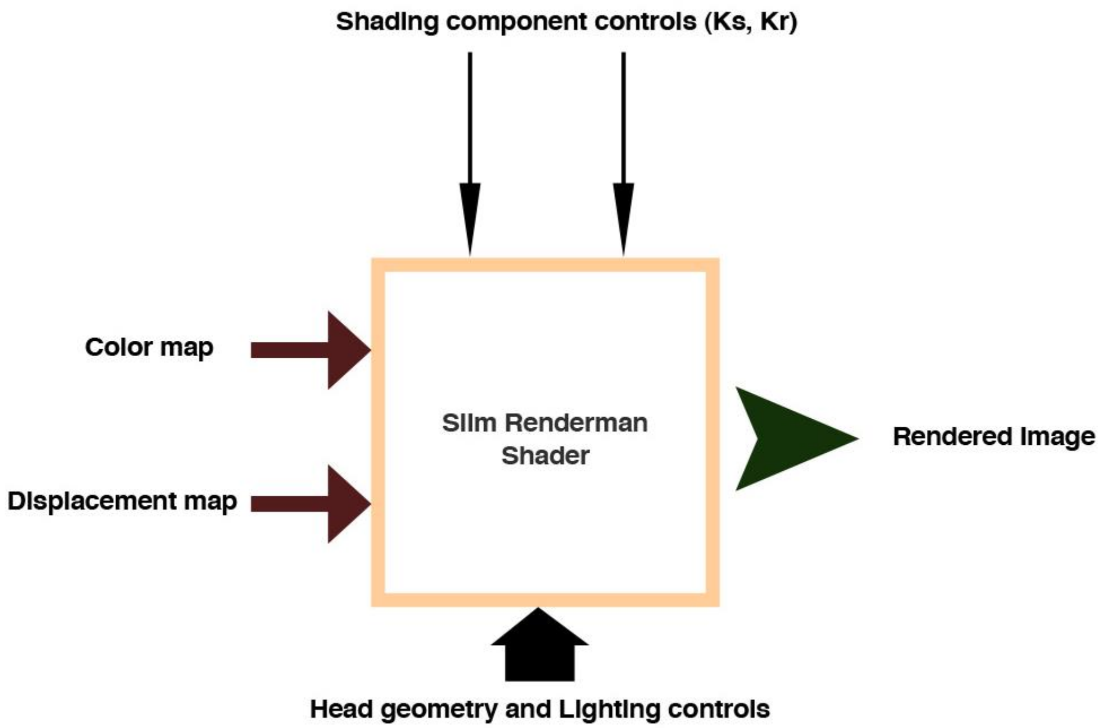


Figure 41. Shader block diagram

Intermediate Results

The following is a discussion of intermediate results achieved when developing the shading methodology. For these intermediate results, the shading approach was tested on a 3D plane. These intermediate results helped in evaluating the effectiveness of the rendered surfaces achieved using the designed shading approach.

Figures 42 and 43 illustrate three variations achieved using the designed process. To render the images in Figure 42, only one-layer brushstroke pattern was used to shade the plane. All the strokes on that layer were of the same profile shape. Therefore, a test using a multi-layer brushstroke pattern was performed. Figure 43 and 44 display the result achieved using a three-layer brushstroke pattern. Here, each layer has a different stroke profile. This result conformed well to the visual aesthetics identified in the visual analysis process. Further, this result also indicated that layering multiple brushstroke patterns is important to accomplish a Van Gogh informed rendering style.

Figure 42. Rendering of a 3D plane using a one-layer pattern

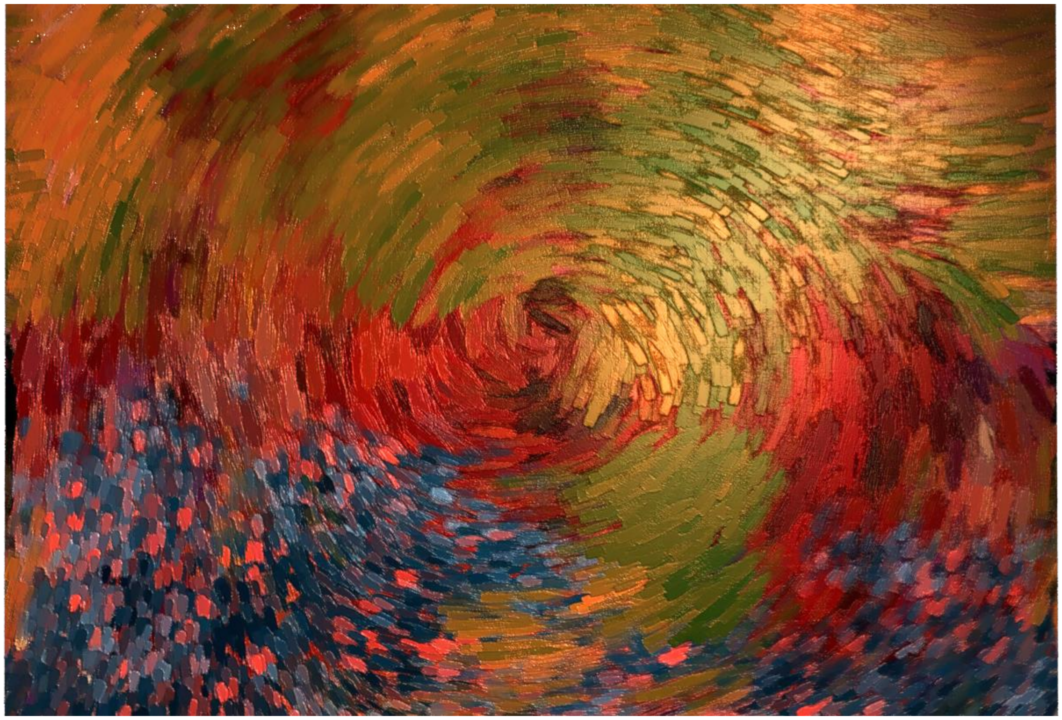


Figure 43. Rendering of the 3D plane surface using a three-layer brushstroke pattern

Figure 44. Enlargement of the rendered surface in Figure 43

Creating 3D Van Gogh Head

Creating the 3D Van Gogh head includes the following steps:

- Modeling
- Texturing and shading

Modeling

The implementation starts with the creation of a 3D polygon model of Van Gogh's head. Photographs and several self-portraits of Van Gogh were referenced in the modeling process. The base polygonal mesh was modeled in Maya. RenderMan's polygon sub-division was used to give a smooth look to the model. Figure 45 show three views of the created 3D Van Gogh head model.

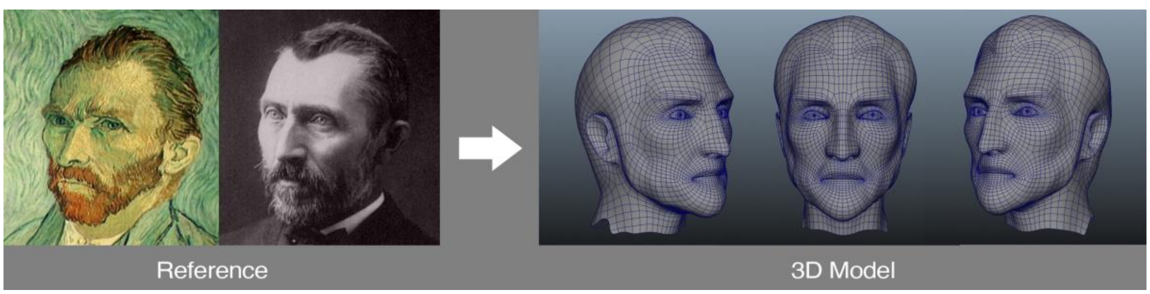


Figure 45. Van Gogh 3D head model and reference images used

Using the brushstroke shader described above requires the model to have a surface with UV coordinates. Polygonal surfaces do not have intrinsic UV coordinates, so a process to assign UV coordinates to the surface was needed. For the 3D head model, Maya's UV unwrapping feature was used. Figure 46 shows the head model with its corresponding unwrapped UV map. For this unwrapping, the seam was placed at the back of the head model. Multiple seams were avoided to maintain continuity in the brushstroke flow pattern.

The density of the UV points was reduced in regions around the eyes and mouth. This is because the procedural brushstroke patterns are not adjusted in size based on the density of the UV points. This significantly affects the results, since the same size stroke would appear smaller in a dense UV region than in a less dense region.

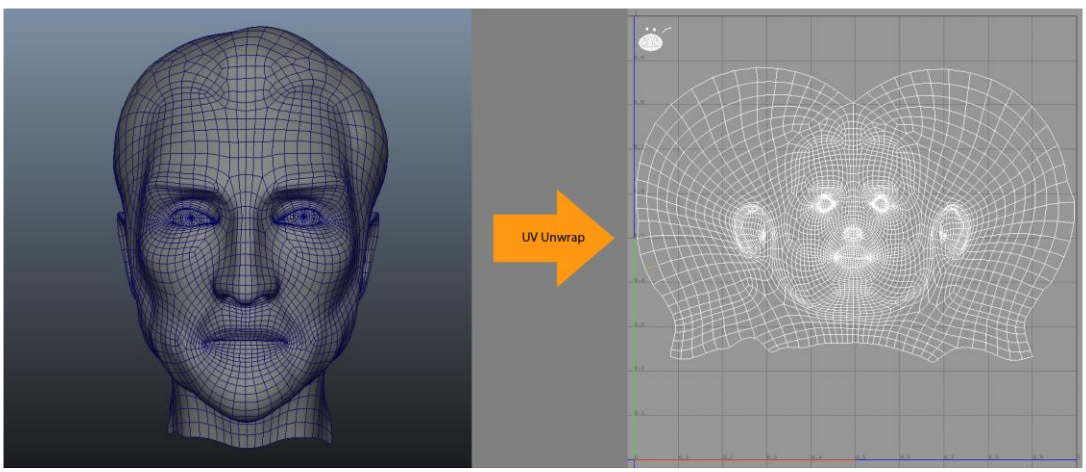


Figure 46. Van Gogh 3D head model UV unwrapped

Texturing and Shading

The following is a discussion of the shading process as it was applied to the head model. The process of creating the input maps for the brushstroke pattern generation is outlined.

Painting the Flow Map for the Head

The 3D head geometry was unwrapped into a 2D UV image. This UV image was used as the reference image to paint the flow map. Since the head surface geometry is highly curved, the flow map painting process is slightly different. To obtain guides for the flow map paint process, direction arrows were painted directly on the head model using a 3D paint program. These direction arrows defined brushstroke directions that follow the curvature of the face. Figure 47 illustrates the painted direction guides on the 3D head model. These guide arrows were transferred over to the UV map for the head.

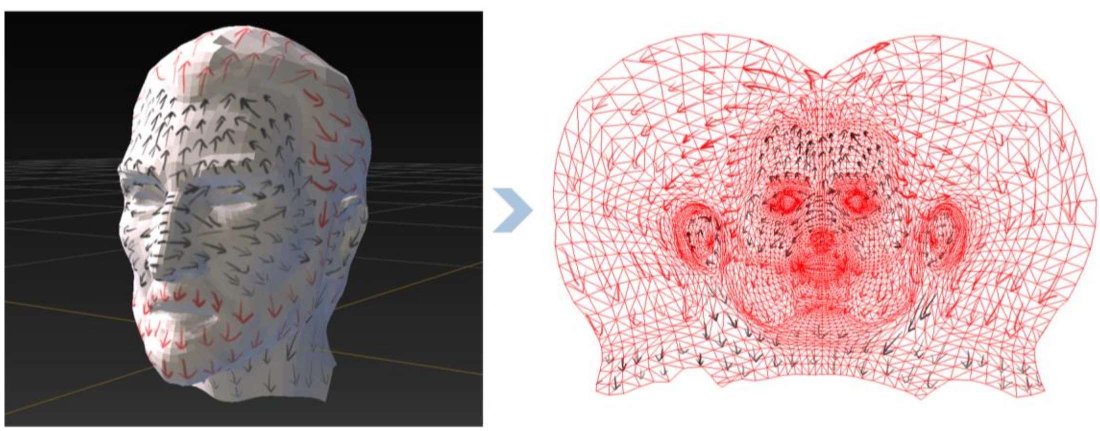


Figure 47. Painting direction guides for the head flow map paint process

Using the direction arrows as a basis for the flow map painting process, Figure 48 illustrates the steps taken to create the flow map for the head model. Photoshop's clone stamp tool was used to create this flow map. The painting process was discussed in the Shader Methodology Implementation section of this chapter. Figure 49 shows a completed head flow map painting.

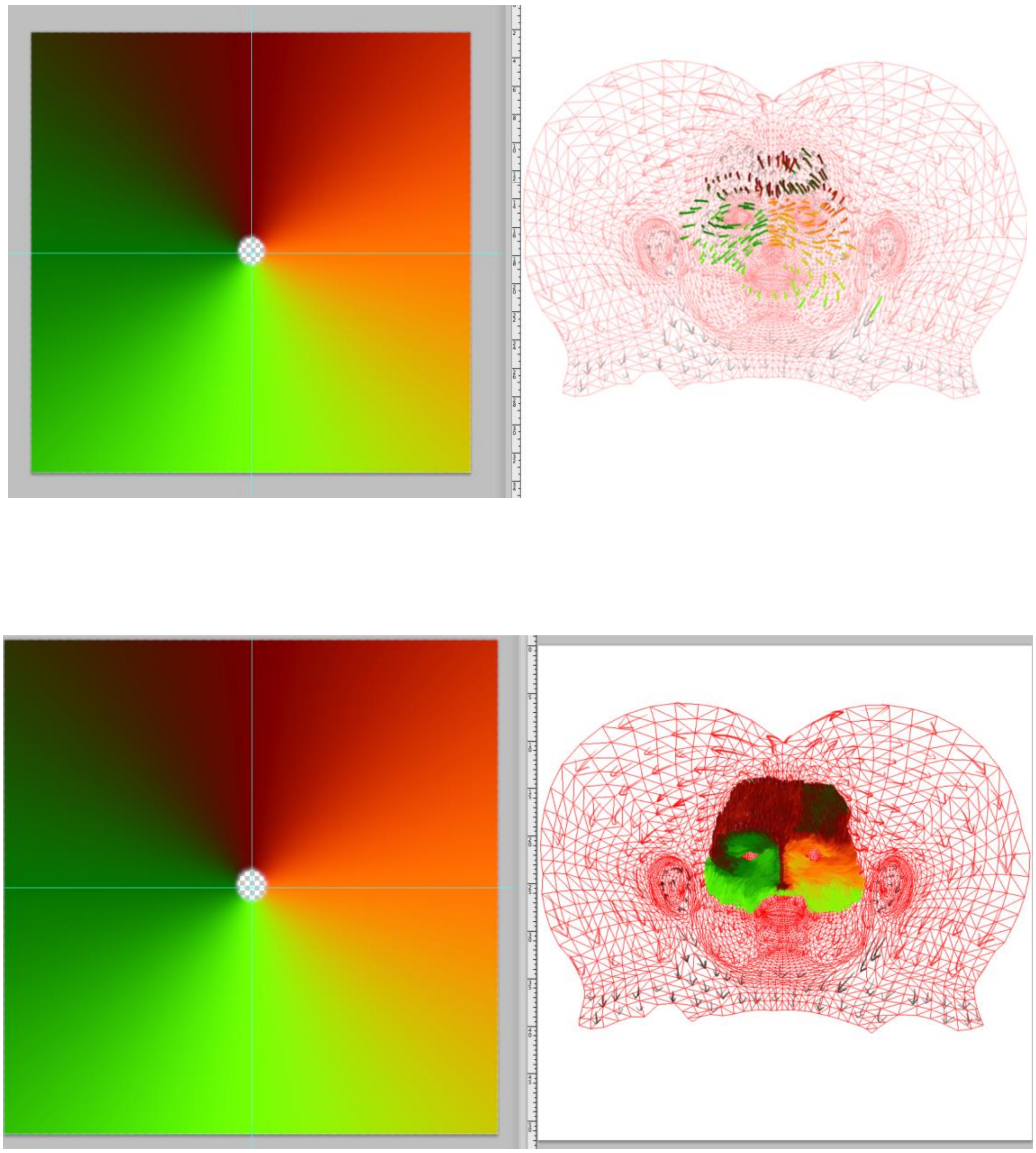


Figure 48. Head flow map painting process

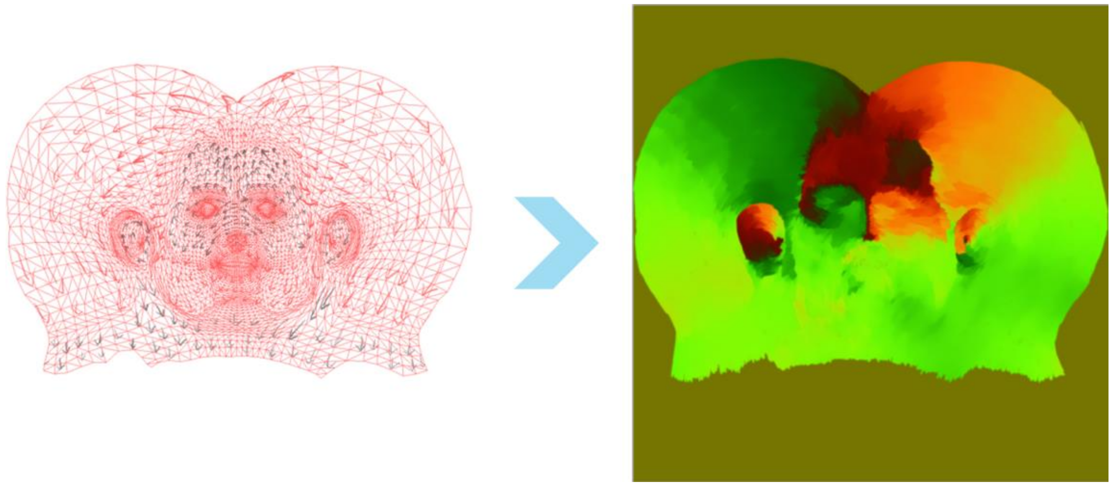


Figure 49. Completed head flow map painting

For shading the head model, multiple flow maps were created to re-define brushstroke directions for every layer of brushstroke patterns. This added variability in the direction of brushstrokes, resembling the ones observed in the paintings of Van Gogh.

Creating Color Map for the Head Model

The colors vary significantly in Van Gogh's portraits. For creating color maps for the head model Zbrush's *polypainting* technique [58] was used. Polypainting is a technique for painting directly on the 3D model surface. This method allowed precise painting of the color on the head model. In this approach, a single RGB value was applied to each polygon vertex. Therefore, polypainting allowed texturing without the need of UV coordinates.

To paint the color on the 3D Van Gogh head model, the principle of broken colors was incorporated during the painting process. The *spray* stroke tool in Zbrush was used, which applied the random instances of the chosen "brush alpha" in varying color intensities and sizes. To use the created polypaint texture external to Zbrush, the painted color information must be turned into a UV color map. The painted surface can then be exported as a color map [58]. Multiple color maps were created for the head model. These included color maps for skin and facial hair. The process of obtaining a color map for the head model is illustrated in Figures 50 and 51.

Figure 50. Painting directly on the 3D head surface

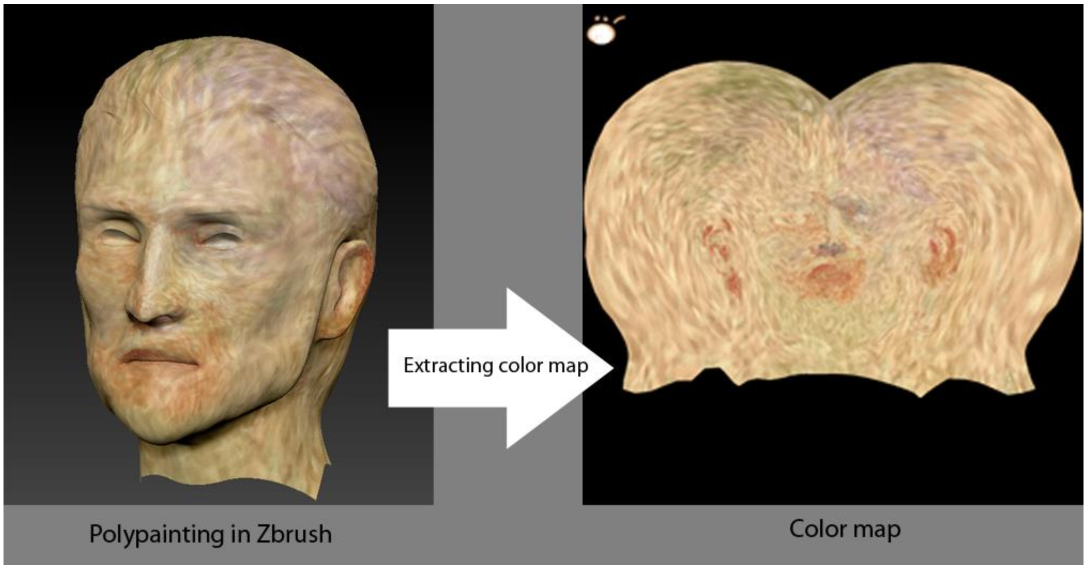


Figure 51. Capturing the polypaint data as a UV color map

Figure 51 illustrates an example color map used for generating brushstroke patterns that represent the base skin layer. The color map is exported in the form of a 16-bit RGB image. Several color maps for skin and other facial structures including hair were painted in a similar way.

Creating Masks for the Head Model

Painting the masks directly on the UV map would be a possible way to create masks for the head model. However, to generate alpha masks for the head model, I again made use of the polypainting feature of Zbrush. Painting the masks directly on the 3D model enabled better control when creating masks for each brushstroke pattern layer. This is illustrated in Figure 52.

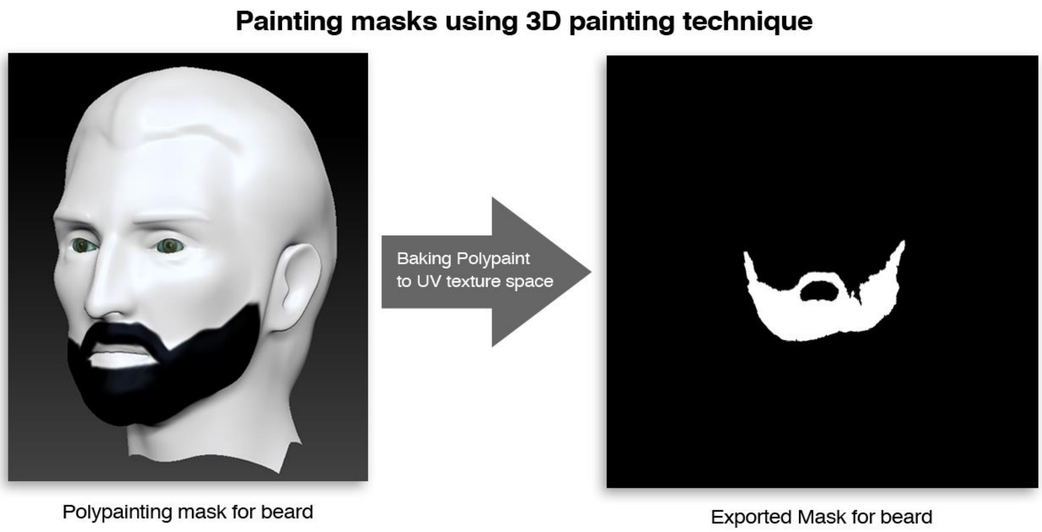


Figure 52. Painting a mask for the head model using Zbrush polypainting

Shading the Van Gogh Head

Upon close observation of Van Gogh's portraits, it was determined that separating the brushstrokes into their corresponding layers within the shader would be a good way of approaching the desired style. This approach allowed controlling the surface shading properties at each brushstroke layer.

Assuming the 3D surface of the face to be composed of several layers of brushstrokes, multiple brushstroke patterns were generated for the skin and facial hair. For each layer, a separate stroke profile, color map, flow map and mask were used to generate the corresponding brushstroke pattern for that layer. Each layer's corresponding displacement map was also created.

The process of shading the Van Gogh head involved layering several procedural brushstroke pattern maps into a single composite map. Five layers of brushstroke patterns were used to define the surface of the skin and facial hair. Layering these multiple brushstroke patterns produced a composite color map. The transparency of these added layers was controlled using mask maps. The combined pattern map was used as a color map to the shader's diffuse color parameter.

A surface displacement map was derived from the color map. The color map for each brushstroke pattern was de-saturated and level adjusted, creating variations in the stroke intensity. Level adjustment for each pattern layer was important since it helped in specifying the intensity of the strokes, which ultimately controlled the thickness of the brushstrokes. Increasing the value contrast between neighboring strokes created thick oil paint effects in the final render. Lower value contrast resulted in subtle brushstrokes with reduced thickness. Layering the value adjusted displacement maps for each brushstroke pattern layer created a composite brushstroke displacement map. This displacement map was used in the shader to provide surface deformations, emulating the paint strokes. Other surface properties like specularity and reflection were also modified to match the high specular property of oil paint. Figure 53 shows the process of progressively adding multiple layers of brushstroke patterns.

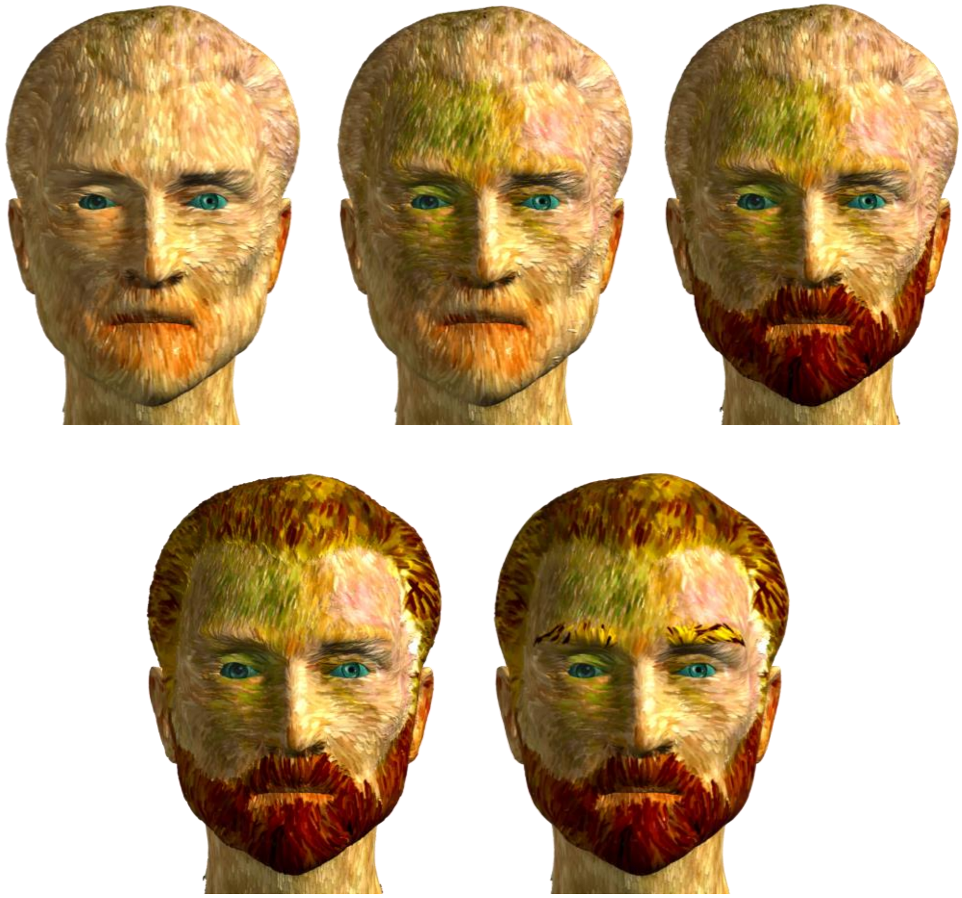


Figure 53. Progression in rendering by adding brushstroke pattern layers

Shading 3D Generic Head Model

The designed shading methodology used to create the 3D Van Gogh head model was also applied to a generic head model to test the efficacy of the methodology. I used the 3D model constructed by Christine Li, another student in the Visualization program. Figure 54 shows the acquired 3D head model. The results achieved by applying the shading methodology are discussed in Chapter VIII.

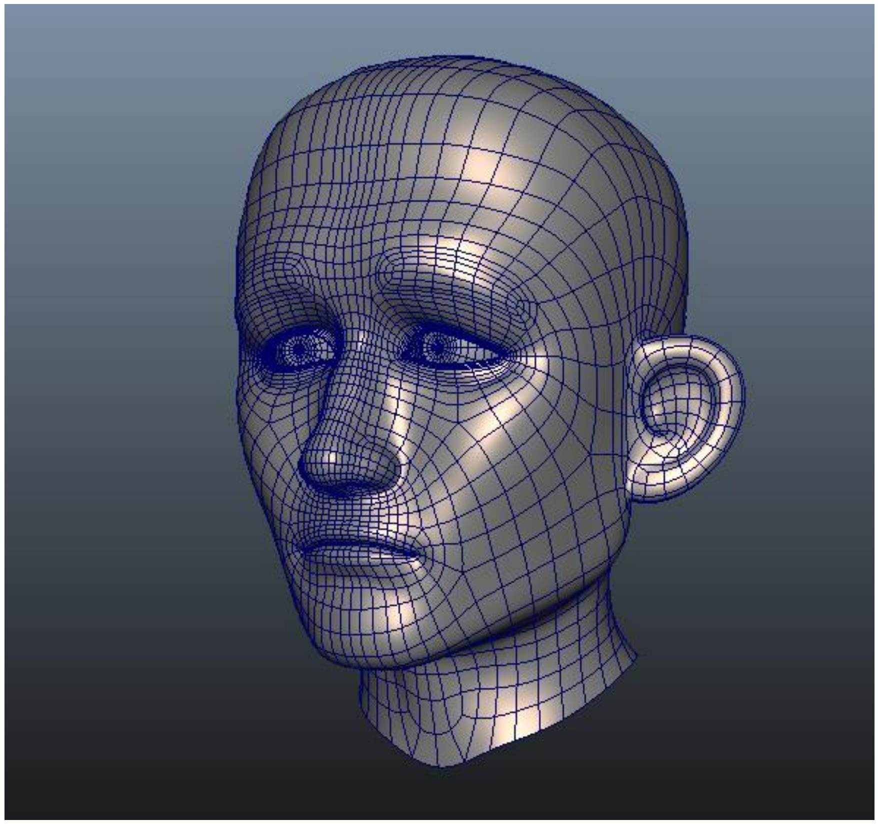


Figure 54. Generic head model by Christine Li

CHAPTER VIII

RESULTS

The discussion of the results is divided into three parts. In the first part of the discussion, the plausible range of results achieved using the several different controls that the shading methodology provided are illustrated and explained. To further evaluate the efficacy of the rendered style, the 3D generic head model is lit under three lighting conditions inspired by the lighting observed in the digital images of Van Gogh's self-portrait paintings. Following this discussion, the results achieved by applying the shading methodology to the 3D Van Gogh and generic head models are elaborated.

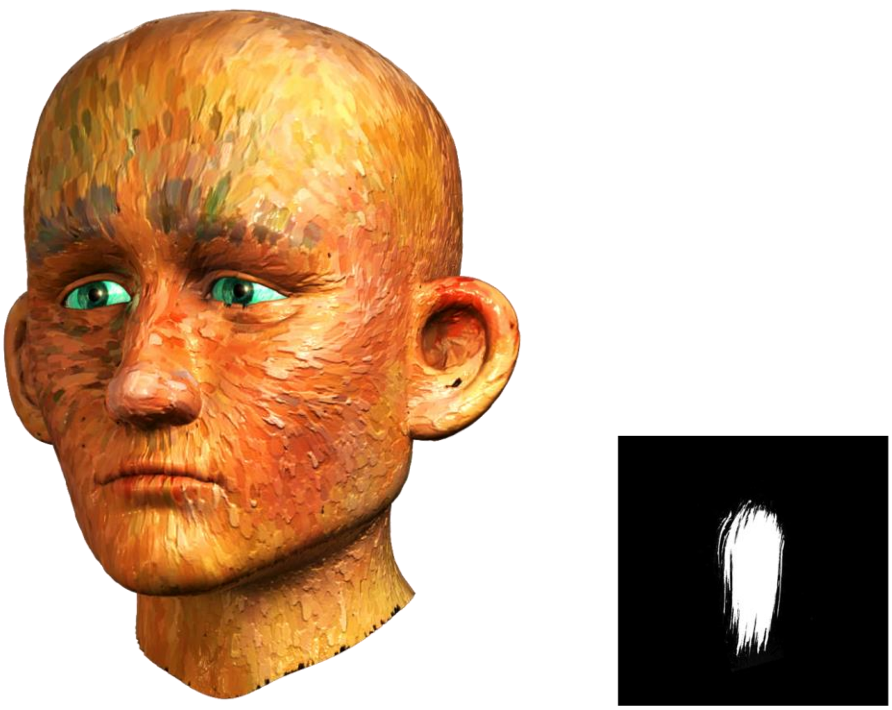
Range of Results

The developed shading methodology provides parameters to control brushstroke shape, color, size and direction. Using several combinations of these parameters, a range of results was achieved. These variations were tested on the generic head model. The range of results is discussed under the following conditions:

- Variability in the stroke shape for a given brushstroke pattern
- Variability in the use of color for a given brushstroke pattern
- Variability in the stroke size for a given brushstroke pattern
- Layering multiple brushstrokes patterns

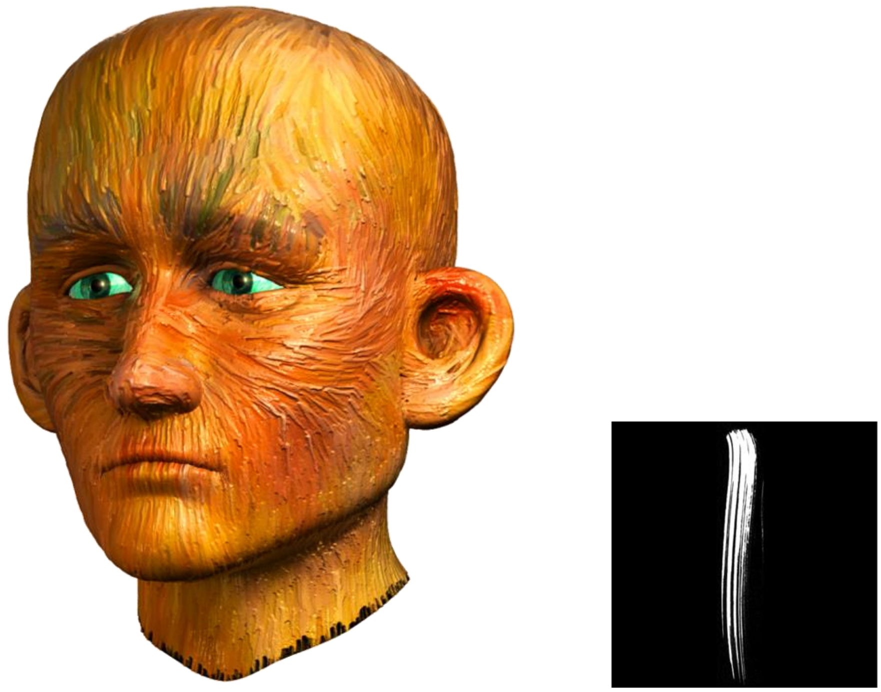
Variability in the Stroke Shape for a Given Brushstroke Pattern

Every brushstroke pattern is comprised of a single stroke shape (or profile). Changing the input brushstroke shape used in the procedural brushstroke pattern produced variations in the renderings. Figure 55 shows results achieved by altering the input brushstroke shape. In each of these cases, a single brushstroke pattern layer is used.

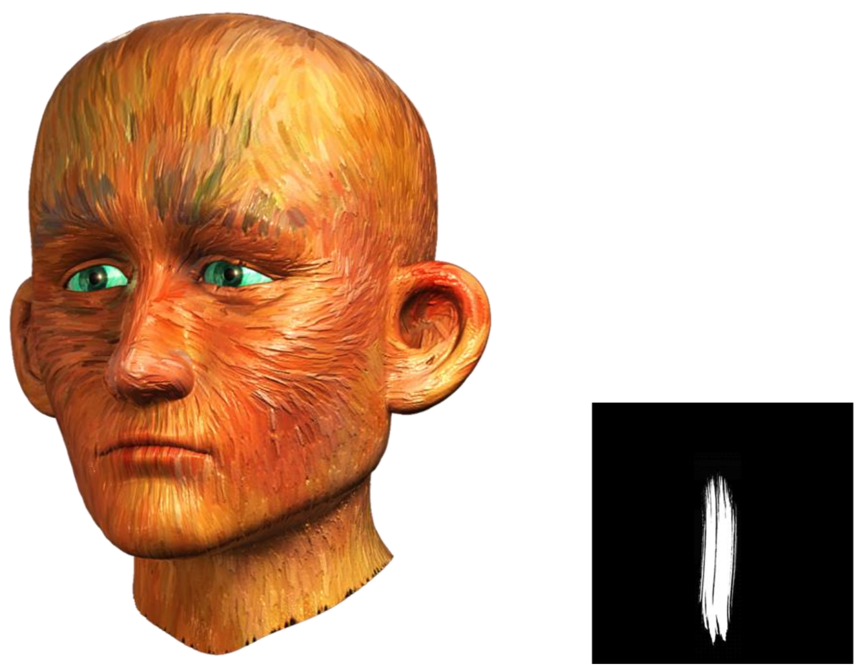


(a)

Figure 55. Varying brushstroke profile shape in (a), (b) and (c). (Left) 3D render of the generic head. (Right) Brushstroke profile used



(b)

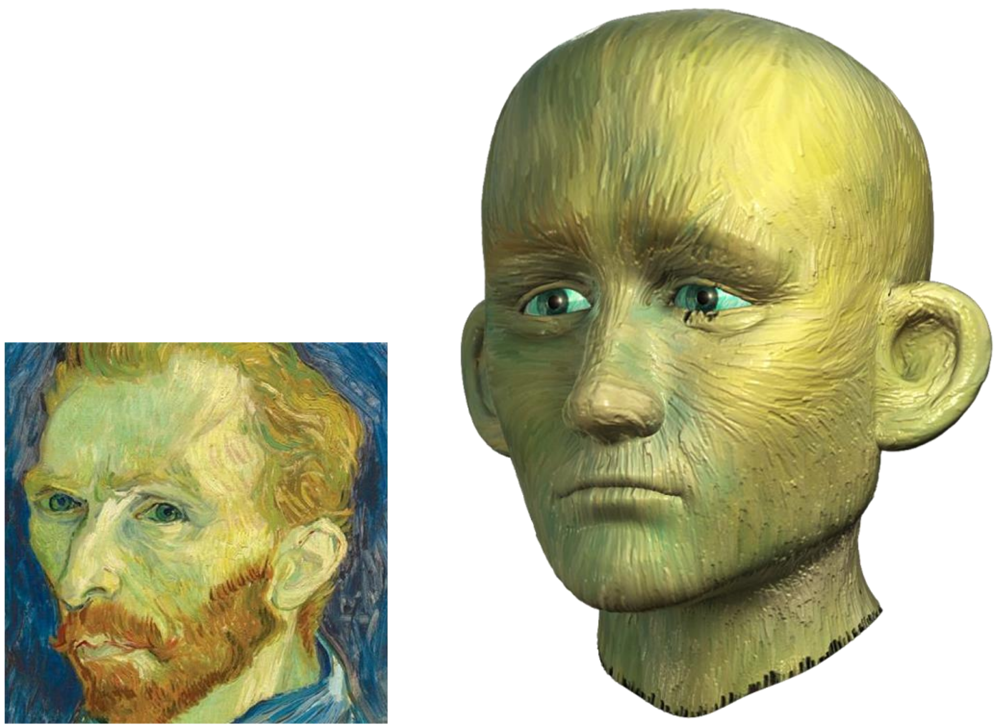


(c)

Figure 55. Continued

Variability in the Use of Color for a Given Brushstroke Pattern

Modifying the input color map created variability in the color of the procedural brushstroke patterns. This was helpful since Van Gogh's self-portraits exhibit a wide range in the use of colors. Figure 56 shows color variability applied to the generic 3D model. This variation is informed from two of Van Gogh's portrait paintings; one is composed of pale hues while the other uses a myriad of colors.



(a)

Figure 56. Variability in the use of color in (a) and (b). (Left) Self-portrait painting by Van Gogh, 1888 - 1889 [20, 44] used as reference. (Right) 3D render of the generic head

(b)

Figure 56. Continued

Variability in the Stroke Size for a Given Brushstroke Pattern

The *Stroke_size_variation* parameter controlled variability in the sizes of the brushstrokes for a given brushstroke pattern. Figure 57 shows results achieved using this setting. The results from this setting were subtle; however, it was useful in creating variations in the output brushstroke patterns.

Figure 57. Varying the brushstroke size. (Left) Size variability set to 0. (Right) Size variability set to 1

Layering Multiple Brushstrokes Patterns

The examples above illustrate the variability achieved using a single brushstroke pattern layer. More complex variability was achieved by layering multiple brushstroke patterns. The composite brushstroke patterns were then used in the shader. The left image in Figure 58 illustrates the use of a single layer while the right image is the render produced using multiple layers of brushstroke patterns. To create this render, three layers of brushstroke patterns were used to compose the final skin texture. Separate brushstroke patterns provided the hair and eyebrows.

Figure 58. (Left) Using a single layer of brushstroke pattern. (Right) Layering multiple brushstroke patterns

Lighting Studies

To augment the essence of the thick oil painterly effects applied to a generic 3D model, three characteristic lighting studies were conducted. These studies were also useful in capturing the variability in the quality of the surface reflecting light under different lighting conditions. These lighting setups were based on the lighting observed in Van Gogh's portrait paintings. The three lighting studies included: short lighting, broad lighting and back lighting. The results of applying these lighting setups are illustrated below.

Study 1: Short Lighting

To create short lighting as seen in the reference painting shown in Figure 59, a large area light was placed above and to the right side of the face, which is facing away from the viewer. Additional area light was added on the same side of the face, but lower, to augment the main source of light. These lights act as key lights that simulate a strong natural light source that illuminates the right side of the face.

As seen in the painting, the observed left side of the face is not in complete darkness. Therefore, a lower intensity area light was used as a fill light to illuminate the left side of the face. An environment light was used to simulate the ambient reflected light that falls on the areas that are not directly illuminated. Figure 60 illustrates the result of applying this lighting setup to the generic head model.

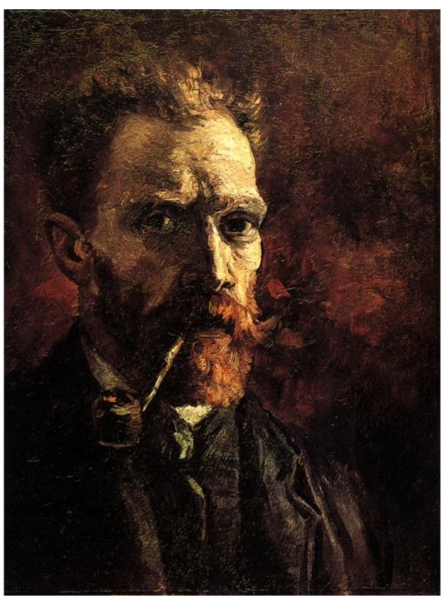


Figure 59. Self-portrait painting by Van Gogh, 1886 [48] used as a reference for short lighting

Figure 60. Short lighting the generic head

Study 2: Broad Lighting

Broad lighting is the most common lighting type observed in Van Gogh's self-portraits. To simulate the effect of broad lighting, four area lights were placed on the right side of the face, which is facing directly towards the viewer (or camera). These lights function as a natural key light. The intensities of these area lights were adjusted to approximately match the illumination observed on the right side of the reference portrait. Another area light was used to create the reflected fill light seen on the left side of the face. Finally, an environment light was used for the overall ambient illumination. Figure 61 shows the reference painting used to inform the broad lighting setup. Figure 62 illustrates the corresponding rendered 3D head model.

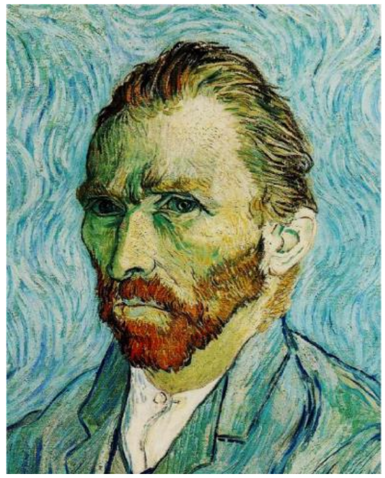


Figure 61. Self-portrait painting by Van Gogh, 1889 [45] used as a reference for broad lighting

Figure 62. Broad lighting the generic head

Study 3: Back Lighting

The illumination setup seen in Van Gogh's self-portrait in Figure 63 is an example of backlighting, where most of the front face is in shadow. Simulation of this lighting setup starts by adding two large area lights on the left side of the face, directly illuminating the back of the head. These are regarded as key lights for this study. The intensities of these backlights were adjusted to match the illumination seen in the painting. Further, a low intensity fill area light was added directly in front of the face, followed by an environment light to capture an overall illumination of the head model. The resulting back lighting is shown in Figure 64.

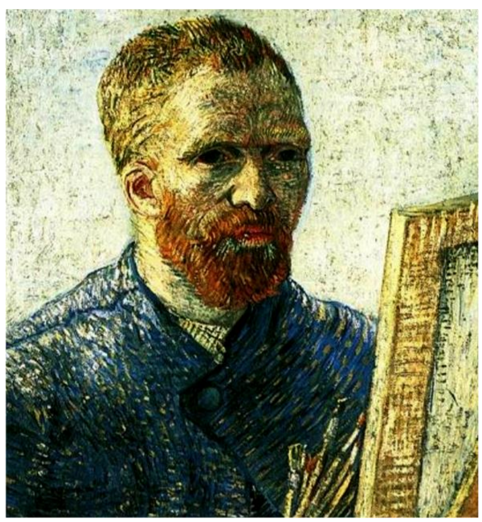


Figure 63. Self-portrait painting by Van Gogh, 1888 [49] used as a reference for back lighting

Figure 64. Backlighting the generic model

Shaded 3D Van Gogh Head Model

The broad lighting setup was used to illuminate the 3D Van Gogh head model since it is the most common lighting condition observed in Van Gogh's self-portraits. Figure 65 and 66 shows the results achieved after color correcting the 3D rendered images.

Figure 65. Front view render of the Van Gogh head model

Figure 66. Three-quarter view render of the Van Gogh head model

Shaded 3D Generic Head Model

The result of applying the Van Gogh inspired shading methodology to a generic 3D model is shown in Figures 67 and 68. The skin was made using three brushstroke pattern layers. I started with the base skin color as the first layer. Two additional layers of brushstroke patterns with slightly different hues were added. The transparency of these additional pattern layers was controlled using mask maps. The hair and eyebrows were added using a separate brushstroke pattern layer.

Composite color and displacement maps were produced based on the combined brushstroke layers. Specular and reflection properties were adjusted for the overall surface shader to synthesize the shininess of the simulated wet oil paint surface. Subsurface scattering property was also included in the shader. Subsurface scattering contributed to the translucent appearance of the oil paint surface as well as enhanced the effect of light diffusion through the surface.

Figure 67. Van Gogh inspired rendering applied to a generic 3D head model

Figure 68. Van Gogh inspired rendering applied to a generic 3D head model

CHAPTER IX

CONCLUSIONS AND LESSONS LEARNED

Conclusions

This shading technique developed defines an additional approach to achieving stylized surface qualities in a virtual 3D environment. The technique and the results achieved were useful in gaining an understanding of an existing painting style. The results produced were useful in creating an artistic experience beneficial for both the audience and the developer. This research helped me understand the salient features that characterize a specific 2D painting style and to design methods to recreate the identified features using 3D digital techniques.

The primary goal of this research was to render 3D portraits surfaces with a visual aesthetic informed from Van Gogh’s portrait painting techniques. I feel that the designed shading methodology was effective in capturing an aesthetic informed by Van Gogh's rendering style. The results achieved were successful in creating a thick oil painting style similar to Van Gogh’s. While these results show one approach to Van Gogh's style, there are many possibilities for further explorations and experimentation.

The developed shading methodology uses a tedious and labor-intensive method to create the flow maps that determine direction in the procedural brushstrokes. This tedious process encourages the development of a more automated approach that can facilitate the generation of flow maps. Moreover, the designed methodology depends on separate sets separate software tools. This inhibits a streamlined workflow in creating the painterly renderings. Creating more integrated tools that can support the shading process is an important area for future work.

The variations allowed in the rendering procedures produced a range of plausible results. These results were effective in demonstrating a range of variability similar to that observed in Van Gogh's paintings. The viewer can experience a connection between Van Gogh's style and created digital renderings.

In the course of this research I needed to align and reconcile my initial intentions with an understanding of the possibilities provided by existing tools. This enabled my wider appreciation of classical aesthetics in a new contemporary setting. My thesis process also enabled me to experience and understand the importance of experimentation.

It is important to acknowledge that this work exists in an area with immense scope and potential development. I hope to continue working in this area with newfound understanding.

Lessons Learned

This thesis is an example of an exploratory research. There were several trial and error based approaches conducted during the course of the project. A completely painted approach was used at the onset of the project, which gave unsatisfactory results in terms of achieving thick oil paint effects or in capturing the essence of individual brushstrokes.

Moreover, painted methods were labor-intensive. Gradually, in order to reduce the amount of manual work involved in the painting process, and also to achieve parameterization, procedural methods were incorporated in the shading methodology. Eventually, the overall process created was a balance between procedural and painted approaches that worked in unison to achieve the desired result.

Painted Approaches

The painterly methods that were initially tried made use of 3D painting techniques to achieve the desired brushstroke effects. 3D painting methods allow painting directly on the 3D model. Figure 69 below shows a 3D painted head model of Van Gogh.

Figure 69. 3D painting on the head model

The 3D painting software allowed exporting the painted color information as UV map images. Color and displacement maps were exported and used to control surface shader properties. Figure 70 shows the render of the Van Gogh head model achieved using this painted approach.

Figure 70. Head render using the painted approach

Benefits of the Painted Approach

The painted approach was beneficial in terms of capturing the high degree of variability observed in Van Gogh's self-portrait paintings. Moreover, transferring the painted color information on the UV map image also retained the appropriate size of the brushstrokes in dense regions of UV points. Therefore, the rendered 3D surface effectively captured the 3D painted brushstroke information even though it lacked the distinctive surface quality of impasto oil painted surface.

Drawbacks of the Painted Approach

There were several drawbacks using the painted approach. This method involved a significant amount of manual work. This method was also unsuccessful in achieving the impasto oil paint stroke effect. Moreover, all the strokes were painted directly on the geometry and exported onto a single map. Having all the stroke information on one map does not allow layering techniques to be applied. Therefore, there was not enough control achieved using the painted methods. This approach also depends on how skilled the user is with the 3D painting software.

One of the critical observations of Van Gogh's style is the number of brushstrokes in the renderings and the distinctiveness of each stroke. The painted method used proved significantly labor intensive in capturing the visual complexity seen in Van Gogh's renderings. Furthermore, the painted method did not allow for any parametric controls. Therefore, better ways to emulate the desired painterly rendering style were explored.

Procedural Approaches

Using the procedural pattern generation process was more successful in terms of capturing the essence of individual thick oil paint strokes than the painted approach.

Figure 71 shows an example of an intermediary result achieved by incorporating procedural brushstroke pattern generation techniques within the shading methodology.

Figure 71. First attempt using procedural patterns

This result captures the essence of Van Gogh's style even though the facial features are not clearly articulated. This result reads as an abstract version of the 3D Van Gogh head model. It was achieved using a single brushstroke pattern layer that defines the stroke color, orientation and displacement properties. All the brush strokes that form the skin and beard are on a single brushstroke pattern map that controls the surface properties. With this intermediate step, I was successful in achieving a thick oil paint effect.

Another intermediate result is shown in Figure 72. To create this particular render, a single procedural brushstroke pattern layer was used; however, the intensity of the displacement was reduced. This resulted in a texture-wrapped appearance to the surface.

Figure 72. Texture-wrapped appearances using a single brushstroke pattern layer

Benefits of the Procedural Approach

Using procedural methods allowed me to control the color and direction of the strokes as well as to select the type of brushstroke for a given pattern. By changing inputs and adjusting the settings to the procedural system, it became easier to generate variability in brushstroke patterns. Further, the procedural methods became useful in incorporating layering techniques within the shading methodology.

Drawbacks of the Procedural Approach

The first attempt at using the procedural method yielded a texture-wrapped appearance of the 3D rendered surface. The variability achieved using the painting methods was compromised in the procedural methods.

Hybrid Shading Approach

The designed shading approach combined painted and procedural methods. The painted methods were used to create the input maps for controlling the brushstroke color and direction information required by the procedural system. The system generated pattern maps containing procedural brushstrokes. These procedurally generated pattern maps further controlled the surface properties of the shader to create the desired look.

The hybrid method was successful in capturing the essence of *thick* oil paint strokes while preserving the individualistic quality of each brushstroke. The generic head model rendered using a single layer of procedural brushstroke pattern produced a uniform look in the directional patterns of the brushstrokes. This issue of uniformity was resolved by breaking the surface into multiple layers of procedural brushstroke patterns. Overall, the results achieved by combining painted and procedural methods in the hybrid approach were useful in emulating the style on the 3D surfaces.

CHAPTER X

FUTURE WORK

The following discussion is a reflection on my research and possible future areas of development based on this work.

As observed in Van Gogh's portrait paintings there are no distinct boundaries defining the facial features. Rather, the strokes used to paint the hair are blended with the ones used to define the face. My current methodology works only for single pieces of 3D geometry. To maintain the cohesiveness seen in Van Gogh's work, the shading methodology needs to be modified to address the issues of integrating models with separate pieces of geometry.

Some of Van Gogh's paintings suggest a strong understanding of the underlying facial muscle and tissue structure. Van Gogh uses his brushstrokes to enhance the quality of the observed facial features by consciously emphasizing this aspect in some places while de-emphasizing them in others. To incorporate this feature into the design methodology, better solutions to control brushstroke flow patterns could be explored for future work.

The current shading methodology uses several different software packages. For future implementations, it would be convenient to have everything consolidated within a single software domain. Further, there is an opportunity to explore and develop a fully customized impasto oil paint shader with parametric controls that give artists a wide range of rendered results.

Manifesting a virtual 3D environment rendered using only brushstrokes, as inspired from Van Gogh's work, suggests another area for future research. This could also be expanded into the realms of interactive visualizations to create immersive experiences using Van Gogh inspired rendering approaches.

Studying and applying the salient features of Van Gogh's work in 3D rendering style also opens up paths to study and replicate some of the effects produced in works by other impressionist and post-impressionist artists such as Georges Seurat, Claude Monet, Edgar Degas and Paul Cézanne and apply the lessons learned to other rendering approaches.

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