

LANDSCAPES OF COLOR

A Thesis

by

CHARLES BARRETT DAVIS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

December 2011

Major Subject: Visualization

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Approved by:

Chair of Committee,	Ergun Akleman
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ABSTRACT

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In this work, I propose a digital painting process to create virtual paintings that can be created with paint layers. The process enables the artists to manipulate the look of the painting by placing lights in the three-dimensional environment, changing the surface properties of the geometry, and changing the camera angle that the audience views the work.

The initial step is the development of a digital paint system for use with a tablet device. Artist's decisions such as pen pressure, color choice, and brush placement are recorded and exported to a RenderMan scene file. A height parameter is incremented on a per-pixel basis each time the artist draws over a portion of the digital painting. Once the digital painting is complete, the artist may then render the scene file to reveal the build-up of paint layers.

This approach aims to merge ideas from the field of digital painting with those of non-photorealistic rendering. The digital painting interface builds on previous research and should be familiar to the artists using the system. I have addressed the need for more research in terms of the build-up of digital paint layers based on an artist's decisions.

To my family, Scott, Ivan, and Carol

ACKNOWLEDGMENTS

There was a lot of support from both faculty and students in the Visualization Lab. Thank you to everyone who helped me along the way. Your support through these past few years has meant everything to me, and I hope that my support in return will help you achieve your goals as well.

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CHAPTER I

INTRODUCTION

I have developed an approach that will allow a painter to create a two-dimensional digital painting that can be translated to a three-dimensional scene for greater flexibility in the image-making process. The painter will be able to use my program as it records his or her decisions for color, position, brush width, and pressure in real-time. My approach will then use a commercial package, RenderMan Pro Server 15.0 [20], to render the brush strokes as geometry in a three-dimensional scene. The painter will then be able to place lights and cameras to expose the three-dimensional aspects of the scene.

I.1. Introduction

In traditional painting, painters cover physical surfaces with materials such as dyes, paints and any assortment of dry or wet media using tools such as brushes and palette knives. Physical paintings should not be considered an image. They are complex landscapes that consist of layers of materials that may be seen from different viewpoints. Thomas Hess [15] in discussion with Willem de Kooning wrote, “[de Kooning] suggests a further complication of meaning, and points out that his ‘idolized’ *Woman* reminds him strongly of a landscape - with arms like lanes and a body of hills and fields, all brought up close to the surface, like a panorama squeezed together (or like Cezanne),” see Figure 1. More so, much like landscapes they do not look the same under different lighting conditions.

This thesis follows the style of *IEEE Transactions on Visualization and Computer Graphics*.



Fig. 1. Willem de Kooning, *Woman I*, 1950-1952, 6' 3 7/8" x 58".

Digital painting, on the other hand, provides better user interfaces by allowing much more freedom to the artist. However, digital painters create single images at the expense of many of the attributes that traditional methods guarantee, such as interaction with light, build-up of paint layers, and the ability to look at the object from multiple angles.

I think that digital painting systems should allow artists to create virtual paintings that may consist of paint layers, interact with light, and be viewed from multiple angles. Therefore, I developed an approach to create such virtual paintings. My approach is a process that includes a system that is rooted in the traditional methods of image-making by allowing build-up of paint layers. The process also enables the artists to manipulate the look of the painting by placing lights in the three-dimensional environment, changing the surface properties of the geometry, and changing the camera angle that the audience views the work.

I have assembled a system that can provide a proof-of-concept for this approach. My software development is based on a virtual brush behavior that I have created. The aesthetic for the final look of the paintings has been mainly influenced by my physical non-representational painting style and the style of abstract expressionism movement. Note that I consider the resulting virtual three-dimensional scenes as paintings not sculptures.

My aim is to create an approach that combines a number of different procedures and steps. One of the initial steps requires that I create a painting program. Alvy Ray Smith [26] defines a digital paint program as a program that “essentially does no more than simulate painting of a brush on a canvas.” It is not my intention to create a physically accurate simulation of paint. My approach may be considered a painting system because it integrates a number of programs. Furthermore, Smith [26] divides the realm of computer-assisted picture creation in two distinctive realms:

The world of computer-assisted picture making can be divided cleanly and simply into two distinct worlds: geometry-based graphics and pixel-based graphics (also known as imaging), depending on how the original data is stored. Standard computer-generated imagery - as in Pixar’s *Toy Story*, for example - is geometry-based. The digital paint system captures the pixel-based half of graphics.

My approach includes aspects of both pixel-based graphics and geometry-based imagery. The initial portion will require the manipulation of pixels and the latter portion will require the creation of geometry. However, the final product will still be pixel-based for presentation purposes.

I.1.1. Definitions

There will be considerable overlap in terminology since we are moving between traditional and digital media that both deal with painting.

A virtual or digital painting is a raster image that only contains color data and must be displayed using a digital device such as a computer monitor. These paintings are created during the digital painting portion of this project. All of the color data is generated by the program and exists completely in the virtual environment.

The three-dimensional scene is defined as any digital file that contains virtual geometry, lights, and cameras. This file may be rendered as a two-dimensional digital image using RenderMan Pro Server. It may be displayed on any digital device such as a computer monitor.

A Processing [7] sketch is a program developed in the Processing programming language that contains code and may be compiled to accomplish a task. Each sketch contains a virtual canvas for the artists to create their digital paintings. A physical painting may use a canvas that is comprised of materials such as linen, cotton, or other materials such as polyester [27]. However, I will make use of the term for both the physical and digital painting environments. A digital canvas may be thought of as a plane in the virtual space where the colors will be layered.

I.2. Motivation

My foundation in the visual arts started with drawing and eventually moved to painting using traditional media such as tempera, watercolor, acrylic, and oil paints. When I moved to the digital arts I found considerably more freedom with the image-making process since I was not concerned with physical properties. However, the limitations imposed by physical properties also meant that by moving to the digital realm I lost

some of the beautiful interactions between the physical media and lights. It has been my goal for a number of years to bridge the gap between both of these methods by exploring the possibilities of the digital realm as I adapt my knowledge of the traditional forms.

I.2.1. Physical Painting

Physical painting has a certain materiality that draws me to it. I have felt increasingly aware of the brush strokes on a canvas and at the same time dismissed the colors and compositions of the colors that the artist may have intended the viewer to witness. Through the combination of the canvas material, the physical properties of the paint, and the interaction with light our eyes dance upon a carefully crafted landscape of colors. An artist does not always have complete control over the creation of the peaks and valleys as the paint may settle and the lights may change depending on the location of display.

A painting is the result of a process. It requires a number of steps and considerations to fully develop before it may be shown to an audience. Among the first of these considerations is the general scale of the canvas. Will it be a painting that takes the form of a human scale, may it take over the side of a building, or will it be a masterfully crafted miniature painting? There is a give and take in terms of the size, but more often than not the artist has a fairly realized range that they decide to work within. Arts and crafts stores offer the opportunity to buy pre-framed canvases for artists to expedite the process of selecting a size. For example, I went to purchase a few canvases that were 10" square, see Figure 2 for one of the completed paintings. I knew that I wanted a small painting and so I simply purchased a pre-defined size from the store. This size limited my working space given that the canvas was already

framed and had only enough canvas to be attached to the frame securely. I could have always torn the frame apart and trimmed the canvas down to make it smaller, but I could not make it any larger without sewing or otherwise appending more material that may interfere with the painting process.



Fig. 2. A painting by the author, *Cosine*.

Each painting is unique in part because there are a number of decisions made by the artist for the given dimensions of a painting. If the gestures of color are recorded initially, then he or she may be able to enlarge that painting without the loss of gesture or color. I have had a number of people tell me over the years that they would like to see some of the smaller paintings that I have created at a much larger scale. This would require the acquisition of a larger quantity of canvas and a lot more paint and effort. Furthermore, my arm may only produce a given gesture at a relatively human scale. The shoulder can move in a limited arc and the wrist has a certain range of

motion as well. These will not translate to the scale of say a building facade. That sort of scale would require a number of smaller strokes that would have to be translated all across the building whereas I might be able to make one or two sweeping gestures on a smaller scale and indicate a gesture much more effectively. Figure 3 shows Robert Motherwell in an attempt to make a larger scale painting using a smaller one for reference.

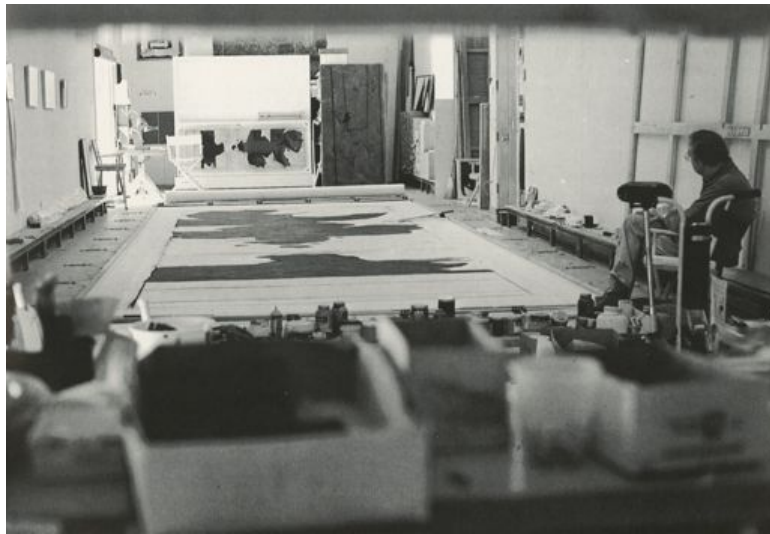


Fig. 3. Motherwell in the studio translating a sketch to a larger painting [18].

It has often been argued that one must see a physical painting in person because there is a loss of information when it is translated to a photographic capture. The lighting that was used to photograph the painting may flatten the dimensions or alter the colors. A painting may be photographed, see Figure 4, for a number of reasons. For instance, it may be to allow greater accessibility to the public through the use of an online portal. Otherwise one may wish to investigate the painting at a finer level

of detail than the museums allow. This photographic capture is further manipulated through the hardware of the camera, the processing of the image through physical or digital means, and the final display element.



Fig. 4. Willem de Kooning, detail of *White Nude*, 1967. 18 1/2" x 24 1/8" [35].

1.2.2. Digital Platform

The history of digital painting has been primarily focused around two ideas: have the computer give the appearance of digital images as if they had been hand-painted or allow an artist to create a digital painting using the concepts of physical painting. My approach is much more concerned with the latter. However, I feel as though it is necessary to research both fields of research because they are both informed by physical painting and aim to create some form of painterly image in the digital realm.

A number of development teams have done research that paved the way for the commercial packages that we use today such as Adobe Photoshop [31] and Corel Painter [6], see Figure 5. These packages aim to provide the artist an interface to

create a digital painting with both ease and flexibility. However, the shortcoming that I have found over the years is that the painting remains a flattened virtual object. This means that a painting is limited in terms of depth beyond the illusion of space created with the conventions of painterly techniques.



Fig. 5. The interface and an example work from Corel Painter 11.

Other packages such as Adobe Illustrator [30] allow the artist to create vector-based images. This method allows for greater manipulation of an image in terms of scale; however, the image is still inherently a two-dimensional image consisting of flat layers. The artist is confined to having layers of points that overlay one another without any sort of geometry or ability to rotate the object in space. Although the artist may enlarge the vectors while retaining the original directions and proportions, he or she is still confined to having discrete layers of color that do not surface properties..

Autodesk Maya [3] allows for the artist to create virtual three-dimensional brush strokes that may rendered as a two-dimensional image, see Figure 6. The painting package also allows for two-dimensional brush strokes. It is possible to strokes on

three-dimensional forms; however, the documentation for Maya indicates that when painting across multiple surfaces with a single stroke it may not operate appropriately.

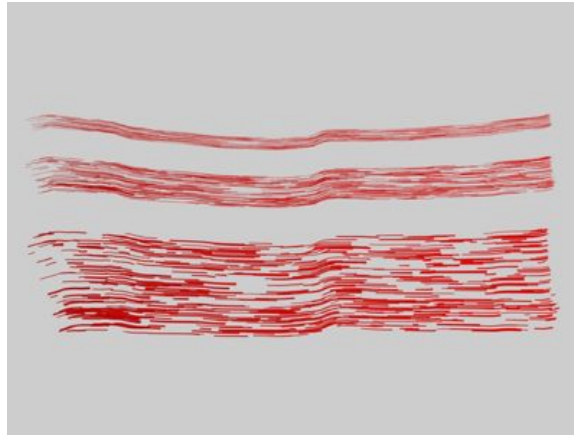


Fig. 6. Example brushes using the Maya 3D brush system.

It is my goal to take the best strengths from each of the commercial packages and combine them in an approach that may offer new possibilities. I like the look of the brushes that Photoshop/Painter is able to produce, the flexibility that Illustrator allows with vectors, and the rendering of curves like Maya's 3D Paint system. Much of the data that I need to gather are hidden in the two-dimensional packages. I am able to explore the data in Maya; however, I found that the initial creation of the brush strokes was not intuitive enough for a traditionally trained artist. So, I have developed a virtual painting system to balance out that portion.

CHAPTER II

PRESENT STATUS

II.1. Physical Painting

II.1.1. *Historical Background*

The history of painting has been marked by a number of different styles, but it has overwhelmingly been tasked with creating the illusion of a three-dimensional space on a somewhat flattened viewing plane or window. Many of the subjects leading up to modern day consisted of religious ideology, portraits of well-established figures and events. As the 19th century drew to a close, artists found a new freedom to explore personal experience, everyday life and the changing urban landscape. My particular interest in painting has been the development of impressionism and abstract art, both of which originated during this period.

It was at this time that the naturalistic representation and symbolism that had dominated painting practice began to give way to an increasing consciousness of painting as a process. This led to the examination of the physical make-up of the strokes that the artists created. A particular technique that marks a number of impressionist artists is impasto. As defined by Ray Smith [27], “Impasto is the technique of applying paint thickly, so that the brushstrokes are plainly visible and create a textured effect.” Artists such as Vincent van Gogh made use of this technique. As can be seen in Figure 7, the build-up of paint allows for more interaction with light. It may be argued that the large clumps of paint detract from the image itself. However, it is my belief that these marks of the artists actually emphasize the image-making process and perhaps are more interesting than the actual image intended for depiction.

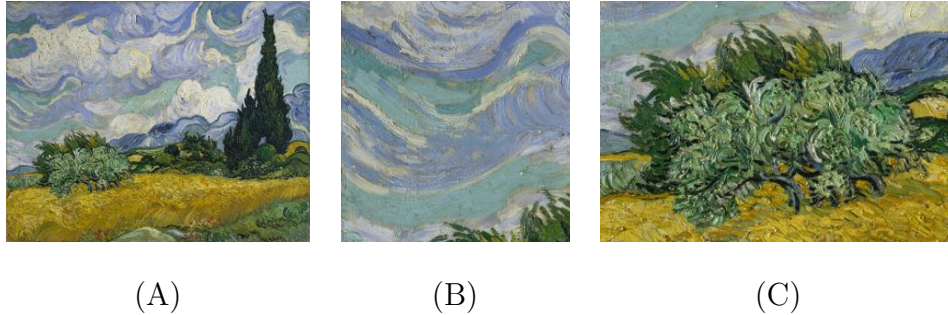


Fig. 7. (A) Vincent van Gogh, *Wheat Field with Cypresses*, 1889. 28 3/4" x 36 3/4",
 (B) detail of the clouds and (C) detail of the bushes.

The painting process for this project may be considered virtual impasto because the artist is constantly having to apply paint until the painting session is done. There is not a mixture of paint as there is with the wet media such as oil paints. However, every paint stroke that the artist lays down will always be visible until they are covered up by other paint strokes, as can be seen in the work by Edouard Manet [24] in Figure 8:

As is unmistakable in *Asparagus Still Life*, the colours were also no longer carefully mixed on the palette as before, but often first sculpted into each other on the canvas. A visible example of this is the use of thin to thick (also known as *impasto*) applications of paint in a manner as free as it was targeted. The asparagus tips are almost tangibly emulated by *impasto* dabs of paint, whose shimmering colorfulness could only be created through the impromptu mixture of different paints. The consistently wet-in-wet applications of paint in *Asparagus Still Life* suggest that this

painting was created in a single session. The fact that all of the evidence of the work process remains visible and that not even all of the areas of the canvas were covered, were both the hallmarks of Impressionist art and the primary reason for all of the criticism they received.

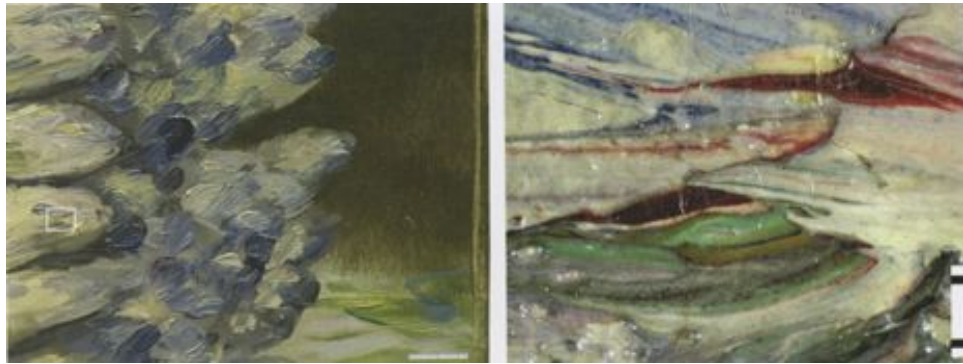


Fig. 8. A painting by Edouard Manet, *Asparagus Still Life*, 1880. 46 x 55 cm. Scale = 1mm.

The art movement known as Abstract Expressionism came about in the 20th century and includes artists such as Robert Jay Wolff, Franz Kline, Willem de Kooning, Larry Rivers, and Robert Motherwell. According to the Oxford Dictionary of Art [19], “the works of the generation of artists active in New York from the 1940s and regarded as Abstract Expressionists resist definition as a cohesive style; they range from Barnett Newmans unbroken fields of colour to Willem de Koonings violent handling of the figure.” Furthermore, the movement is marked for “its attention to the physical immediacy of paint.”

Many of the abstract expressionists painted layers upon layers of paint until they were satisfied with a result. This methodology was not as straight-forward as going

to a landscape and painting a visual representation of trees and clouds that may have been in front of the artist. As can be seen in the work *Woman* by Willem de Kooning, see Figure 1, he had painted a woman. We may make sense of a set of eyes and a mouth and perhaps the rest of a human form, but it is really through the name of the painting that we associate a human form with the image. Willem de Kooning also made use of the impasto technique [15]:

The physical appearance of *Woman*, as has been mentioned, gives no clue to the length of its history. Paint is applied in consistent impastos which thin out to the canvas in a few places and rise elsewhere to heavy ridges.

Perhaps the largest inspiration for this project comes from another abstract expressionist named Franz Kline. His body of work includes paintings that seem to create enlarged brush strokes that overlap one another, see Figure 9. The strokes almost take on a human-sized scale. The artist also made an emphasis of the strokes rather than trying to obscure them by blending the paints. His works were sometimes sketched at a smaller scale and later enlarged to a canvas when the artist was happy with the look of the sketch [22]:

When I work with preliminary sketches, I don't just enlarge these drawings, but plan my areas in a large painting by using small drawings for separate areas. I combine them in a final painting, often adding to or subtracting from the original sketches.

An illusion of depth is not as readily available since the traditional scheme of shading from light to darker brightness values is not evident. I aim to give more definition and dimension to the objects by allowing each of the strokes to interact with light. Furthermore, the user will be able to navigate through the strokes thereby giving them even more dimensional cues.



Fig. 9. Franz Kline, *Lehigh*, 1956. 80" x 112". [5]

Judy Pfaff is also an inspiration for this project. She was trained in the traditional painting style, but has done a great number of installation pieces since graduating from the academic setting. Her installations almost seem to be paintings that are extruded in space, see Figure 10. This allows the audience to move through the space and become completely immersed in the installation. It is my goal to allow the audience the ability to explore my paintings in much the same way. However, it will be in the digital realm. Discussion of physical painting versus three-dimensional ‘painting’ in Pfaff’s work [23].

Compared to Action Painting on a two-dimensional surface, “painting” in a three-dimensional space revealed the process of art-making from an infinite number of angles. Pfaff was free to move through a work, this way and that, thinking her way through physically and mentally - in a kind of hyperactive stream of consciousness.

Traditional painting has the dilemma of confining an artist to a finite space of



Fig. 10. Judy Pfaff, *all of the above*, 2007. 40' x 44'.

canvas or other painting space. Once those dimensions have been chosen the artist must stick with the designated space. For example, Larry Rivers, a painter from the abstract expressionist movement in the 20th century, painted a number of different sized canvases throughout his career. *Portrait of Berdie No. 1*, see Figure 11, painted in 1953 depicts a woman seated in a chair. We, the viewers, are aware that the woman should be of relatively normal height and stature not measuring more than a few feet at a sitting position. However, Mr. Rivers chose to enlarge the scene that he saw to be at least double the accurate size of a normal portrait. The final painting stands roughly 7' tall depicting the woman seated in a chair with her head and feet converging on the top and bottom of the canvas, respectively.

One may not be aware of why he might have chosen to enlarge the size of the woman; we may only assume that the final dimensions present on the canvas are the ones that he chose to settle the final image. It may be that he would have desired the woman to be a much grander scale. If this were the case, then he would have had to



Fig. 11. Larry Rivers, *Portrait of Berdie No. 1*, 1953. Approx. 5' x 7'.

create a larger canvas and start anew. There is the belief that the enlargement may have been due to design considerations [1]:

Portrait of Berdie, Number II is based on a photograph he took of the model. [...] The changes that Rivers made when translating the photograph into a painted image reveal his awareness in the dynamics of pictorial composition. In the painting he smudged Berdie's features and moved the black triangle of her sweater down and expanded it to transform it into a simplified abstract element. He enlarged the figure to fill the painted field in a knowing manner, rendering it monumental, and altered the position of the model's foot so that it touches the bottom edge of the canvas.

Further, the transition and planning was done as according to the article in ArtNews [21].

Rivers planned a large painting of his mother-in-law, whom everyone calls Berdie, to be painted on a piece of canvas about 5 feet wide by 7 feet high, thumbtacked to the Homasote-covered wall. He started first with a complete pencil sketch of Berdie posing in a wicker chair on the lawn. This was then freely transferred to the canvas, without the model, by drawing with sign-painter's charcoal.

Display of traditional paintings requires that the painting be hung in some area with light sources that illuminate the painting. An artist may choose a light setup when initially creating the work of art, but more than likely the curator of a gallery will set up the final lights when displaying the work. Therefore, the artist may have worked in a certain light condition but when it comes to viewing the work in public the lighting has changed beyond the control of the artist.

Otherwise, a physical painting may be turned into a digital image through the use of photography. A photograph may be taken - whether using traditional film and a scanner, or more directly using a digital camera - which flattens the painting into a two-dimensional image. This flattening of the image makes the lighting interaction with the painting constant and does not allow for the viewer to move around the canvas and fully realize the dimensions that the paint has on the surface of the canvas. Some recent developments of higher resolution images captured using digital photography have led to greater detail to be shown to the public in terms of traditional painting. Initiatives online such as Google's Art Project [9], see Figures 12 and 13, present art work at an extremely high resolution that allows for a greater illusion of getting close to the painting object.

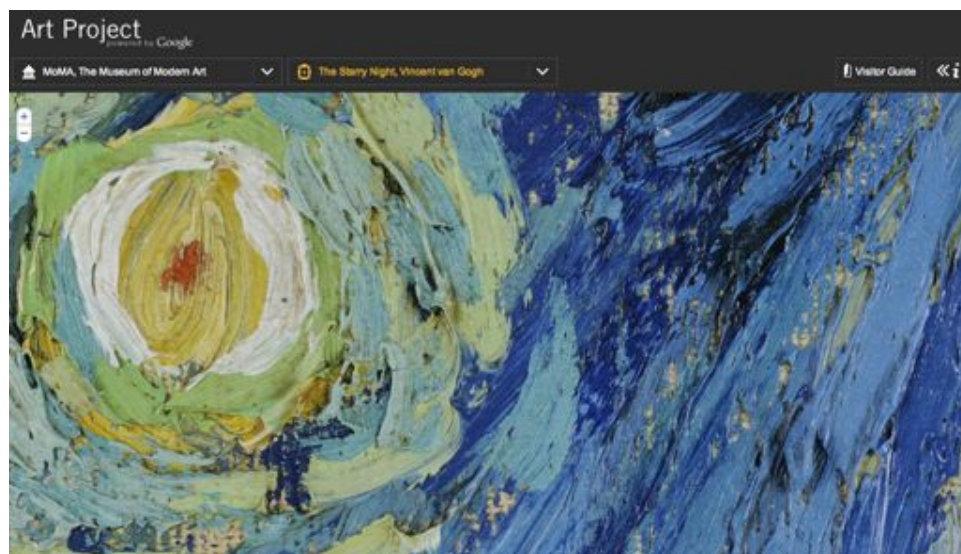


Fig. 12. Google's Art Project detail of *The Starry Night* by Vincent van Gogh.



Fig. 13. Google's Art Project detail of *Farmhouse in a Wheat Field* by Vincent van Gogh.

II.2. Digital Painting

Painting in the virtual environment is a rather recent development in the history of visual arts. Alvy Ray Smith [26] documented a history of digital paint programs in the year 2001. He marks the time frame of 1969-1970 as the first development of a paint program by Joan Miller at Bells Labs. Since then a number of more robust systems and techniques have developed. However, the basic principle of painting still remains the same: an artist must apply a paint media with any sort of tool, a brush for example, to another media such as a canvas.

There are many ways to divide the fields of digital painting and image-making, but I have decided that the work may be divided as follows:

- Classic Paint Programs
- Image Processing
- Three-Dimensional Painting

As discussed earlier by Alvy Ray Smith, graphics may be split into those that handle pixel-based concerns and others that handle geometry-based. The first portion of this project handles the pixel-based graphics. This category must be divided further to address different concerns as defined by Bruce Gooch [8]:

There are two main tasks involved in the creation of a digital painting. First is the creation of brushstroke positions. The second is the ‘rendering’ of brushstrokes into pixel values. If the brushstroke positions are manually created by a user, the software is a classic ‘paint’ program. [...] If the brushstroke positions are computed algorithmically, then this is an ‘automatic’ painting.

My program deals primarily with the classic paint program methods. However, I was influenced by the automatic painting approaches, so it is necessary to include them here. When the artist has completed the painting process he or she will move to geometry-based graphics processing. Therefore, I have decided to include research of three-dimensional painting methods to compensate for the latter portion of this project.

II.2.1. Classic Paint Programs

The generation of digital paint systems is rooted in the desire to match traditional painting. Although the degree to which the digital painting style matches the physical attributes of an actual painting varies, the basic concept of painting remains the same. Smith described the process of a general digital painting program as follows [25]:

Painting a color, say red, into a framebuffer is the simple process of writing red into each pixel which falls under a 1 in a rectangular bitmask. A pixel

under a 0 is not changed. The bitmask is called a brush and is translated over a frame-buffer by a user who moves a stylus over a tablet surface.

Digital painting was developed on existing computer technologies but required new software and hardware to accomplish the goals of the artist. Alvy Ray Smith expanded on the existing tablet technologies with an approach to generate a brush in real-time using a stylus [25], see Figure 14.

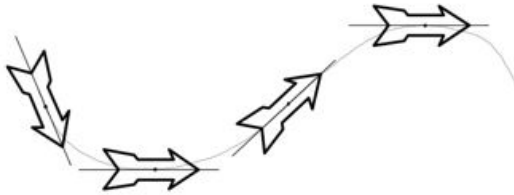


Fig. 14. An input device being tracked using Smith's program.

The development of a real-time tracking tablet was extremely important to the development of the digital painting era. More so, the correct tracking of the brush was necessary as well. When an artist uses a physical brush the bristles follow the movement of the artist's movements. Digital painting was, and is still largely, based on a stamping process. As an artist moves the cursor across the canvas, a brush will leave a single or array of pixels based on the size and color of the brush. Strassmann [28] talks about the stamping process:

The "brushes" used in conventional computer painting systems are far simpler than real paint brushes. Usually no more than automated rubber stamps, they build up images by placing repeated copies of some static or

simply derived pattern. Some systems offer “airbrushes” which simulate a spray of ink by painting pixels in a circular region around the brush.

Artists such as Strassmann [28] worked to break away from the stamping brush methodology in an attempt to “allow computers to *suggest* scenes with artistic abstraction.” Some common goals for these systems included brushes containing a certain number of bristles, a given width, and a color associated with the brush as it moves across the canvas. Strassmann was concerned with mimicking the Sumi-e approach of painting [28], see Figure 15.

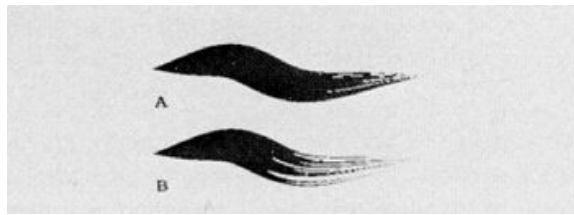


Fig. 15. An example of Strassmann’s brushes.

Haptic interfaces have been developed to give physical feedback to the artist as if he or she is applying paint to a physical surface. Artists such as those at The University of North Carolina at Chapel Hill [4] have developed such systems. This approach requires the development of a more advanced hardware than the acquisition of a tablet device such as a Wacom device, see Figure 16.

II.2.2. Image Processing

The field of image processing allows for more automation in terms of rendering a more painterly image. Some of the techniques require an artist to move a cursor across an



Fig. 16. An in-process haptic device painting.

image to reveal strokes while others only require the push of a button to make an image appear painterly.

Haeberli [10] was interested in the manipulation of two-dimensional image data to make it appear more painterly, see Figure 17. His approach requires a series of overlapping paint strokes generated by the artist to reveal the original image. The colors are driven primarily by sampling the original image. An artist may choose to use a number of pre-defined brushes or create his or her own. The pre-defined brushes consist of various shapes such as circles, rectangles, and lines.



Fig. 17. An example of Haeberli's stroke algorithm.

Hertzmann [12] used a similar approach as Haeberli where the artist may render a source image as if it were painted using strokes of varying size, see Figure 18. However, Hertzmann’s approach has limited interaction with an artist. The final image is primarily derived from an automated process of the program drawing brush strokes of varied sizes. His approach allows for a number of styles which he describes “as an intuitive set of parameters to the painting algorithm that a designer can adjust to vary the style of painting.”



Fig. 18. An example of Hertzmann’s work.

There are a number of other approaches to image processing that extend beyond painterly rendering. *Non-Photorealistic Rendering* [8] and *Non-Photorealistic Computer Graphics* [29] provide an excellent base for the far-reaching scope and history of non-photorealistic rendering. Hertzmann has also written brief surveys on the field both in 2003 [13] and 2010 [14].

One of the more recent papers that influenced my project was the work of Kun Zeng and others [34], see Figure 19. They took the image processing approach to another level by moving beyond only sampling the colors of an image. An image is parsed into different sections based on both color and line continuities. This allowed for a deeper level of image processing that would allow for different sections of detail and varied treatment with the dictionary of strokes that they had accumulated from

various artists. It was their goal to capture more of the “object-oriented techniques of painting” [34].

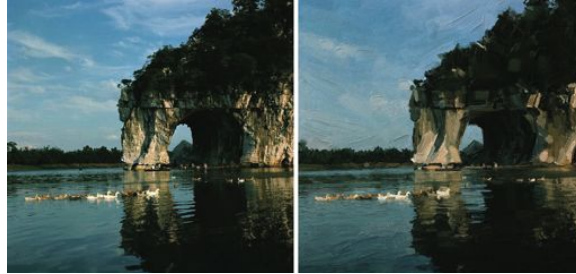


Fig. 19. Zeng and others.

II.2.3. Three-Dimensional Painting

There are yet other implementations that paint directly on virtual objects or create their own virtual objects from the painting process. The resultant images are still two-dimensional and must be displayed on display devices such as monitors or projections onto screens.

Hanrahan [11] was able to paint on surfaces and create an appearance of light calculations with a “what you see is what you get” (WYSISWYG) approach. Meier [17] was focused on painterly rendering for animation, see Figure 20. Her approach was not an interactive system. It required that a surface in a three-dimensional scene be populated with particles. Bitmap images are later attached to the particles that represent brush strokes. The bitmaps are oriented to the surface to give an impression that the objects were painted by hand.

Cave Painting was a technique employed by Keefe [16], see Figure 21. An artist

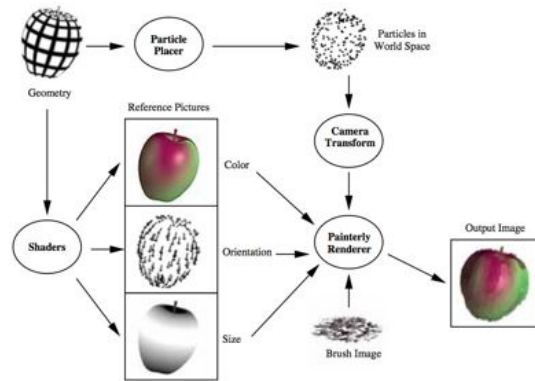


Fig. 20. An example of Meier's pipeline.

still paints on a two-dimensional plane. However, this approach requires an artist to be in a physical space rather than sitting at a station with a tablet device. The artist is given the ability to rotate these images to reveal the three-dimensionality of the scene. Movement through the space was done through the artist's interaction with his or her hands and feet and the various tools in the physical space.

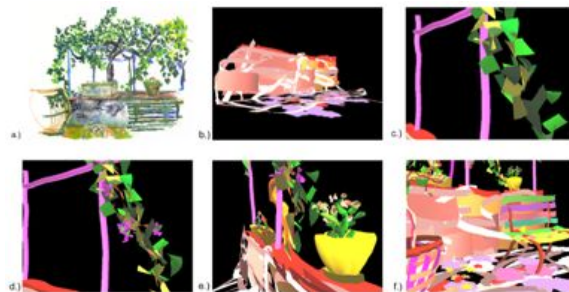


Fig. 21. An example of the Cave Painting process.

II.3. Previous Attempts by the Author

This project has been an ongoing concept that I have developed over a number of years in different forms. The initial idea was to have an animation that would have a character walking through a space with paint strokes that form an environment. At the time, I had not seen “What Dreams May Come”, see Figure 22, but that is a rough idea of what the project was designed to be. The project did not aim to be representation which detracts greatly from the movie where the characters almost lived inside a landscape painting filled with flowers and trees.



Fig. 22. An image from the film, “What Dreams May Come”.

The first iteration of the project was created using Photoshop and Adobe After Effects in the fall of 2007, see Figure 23. I first created the paint strokes in various layers within Photoshop and then created key frames to move the layers through space in After Effects. The only attribute of a layer was that it had some number of strokes with the same color. There was not a consideration to have each of the hundreds of strokes on their own layer as it would prove too great an effort for the limited amount of time I was allowed for the project.

The final dimensions of the strokes were limited in a number of ways. First, the images were painted as raster layers at a certain resolution using Photoshop. Furthermore, since the brushes were only raster images they were transported to the After Effects file to be represented as flat planes of color. This of course resulted in the planes of color disappearing if the camera ever became perpendicular to a given stroke. This proved problematic because I had the desire to create a sort of forest or landscape of paint brushes.

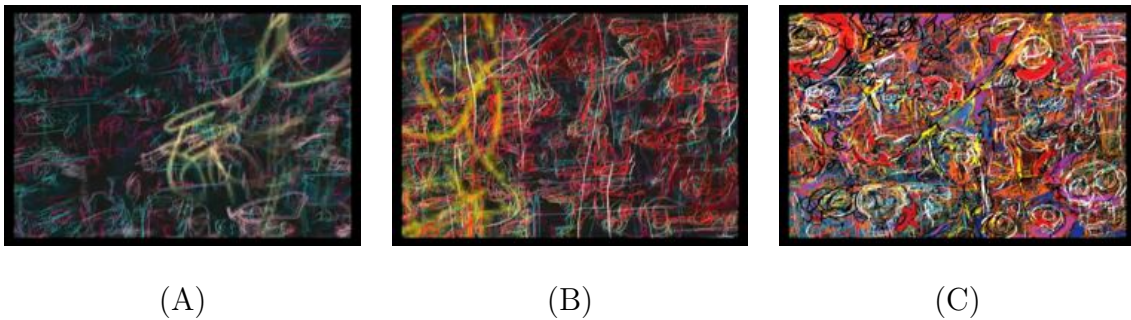


Fig. 23. (A) early still from the animation, (B) progression of animation and (C) final shot of the animation.

A more in-depth of analysis of how a two-dimensional painting could be translated to the three-dimensional realm took place in the fall of 2008. The first step in this process required physical creation of how a paint stroke might take form given if it were floating in space or otherwise extracted from a canvas, see Figure 24. It was my intention once again to create a scene that a given user or audience would be able to navigate through and explore this “painting.” Ultimately, although the objects had three-dimensional form in a volume, the primary output for this project was a single view that was printed on textured paper to give the illusion of a painted image, see

Figure 25.



Fig. 24. An attempt at interpreting a brushstroke as a three-dimensional form.

Given some limitations of the software I did not pursue this project any further and decided to wait until I had more control over the computer environment before I continued this concept. The main drawbacks of the software implementation and methodology included that the resolution was capped at a few thousand pixels by a few thousand pixels. Anything beyond the given resolution and the program refused to render the scene. I also did not understand completely how to control the strokes of paint. The manner in which the strokes were manipulated came in the form of layered displacement being applied to the objects. A lot of the calculations behind this were accepted as a mystery and added to the intrigue of the project.

As I have moved further into my studies I have decided to take a more ground-up approach and take complete control of the programs. Where I have found limitations in the past I am attempting to remove all of them by building my system from scratch rather than relying entirely on the developed commercial softwares. This involves the creation of brushes that can be drawn to the screen and how I move those brushes around in the three-dimensional space.



Fig. 25. An attempt to create 3D brushstrokes using Blender.

CHAPTER III

OBSERVATIONS

The bulk of the work will be completed in the digital environment. However, it is first necessary to examine the actual process of painting using physical media. This will help us transition the concept and the visuals that are produced from the physical standpoint to the digital platform. It has been my experience that having reference to follow, in this case having the output of a physical painting method, is much more valuable than relying on one's memory.

III.1. Gathering Physical Data

I am not concerned with a physically accurate depiction of how paint is applied from a brush to a canvas; however, it is necessary to do some investigation to understand how painting takes place. The primary focus is how pressure applied to the brush influences the spread of paint, the typical length of a given brush stroke, and how paint media interacts with light.

First, I gathered data from a series of paint strokes including both acrylic and oil paints, see Figure 26. Both media included a series of short and long strokes, varied movement, and varied pressure using both a flat and round brush. I only used one color for the paint and the background of the canvas for each of the tests. It was determined to be an ivory black paint for both the acrylic and the oil media. This allowed the highlights from the lights to contrast well with the body of paint. The background is a beige piece of paper from a Moleskine journal that measures roughly 10" x 7.5". I chose to use a very low-relief textured paper because I did not want the texture that is typically associated with canvas to influence the tests of

strokes. After testing both acrylic and oil media, I chose to approach the look of the oil paints because of the media's interaction with light. It is most noticeable when the oils become more clumped together and rise off the surface of the paper and catch reflections from the light sources.

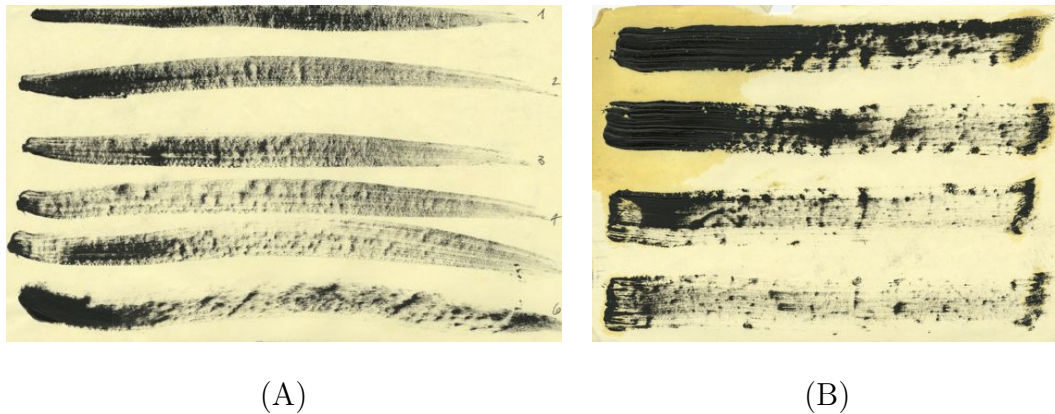


Fig. 26. (A) example of acrylic brushes, (B) example of oil brushes.

III.2. Virtual Paint System

The initial step of the implementation requires the creation of a digital paint program. This includes the development of a set of virtual brushes and a color system for the artist to create a digital painting on a virtual canvas. During this process we must track the artist's movements as he or she moves the brush across a Wacom tablet.¹ A continuous stream of paint is laid down at each bristle point as the artist moves

¹Any given pressure sensitive tablet may be used, but we used a Wacom tablet for this implementation.

the brush across the canvas. If the artist stops applying pressure and lifts the pen from the tablet then the paint will stop being applied to the canvas until pressure is applied again. The artist is only viewing a flat plane of color at this stage much like a typical paint package. Therefore, the only consideration that the artist needs to make at this stage is the creation of a desired image.

It is not my concern to have a robust painting system like that of Photoshop or GIMP [32] that allows for a number of image processing routines and hosts a number of brush tools. This may require more time and effort to produce a painting. I make use of one or two brushes in my collection of physical painting tools so I gather that an artist may be able to produce satisfying results through these restrictions. My primary concern is to have a brush with a certain number of bristles that may interact with the pressure from the artist such as Strassmann's [28] painting system, see Figure 27. The artist will have the ability to alter the brushes to have a varied number of bristles, varied width, and draw as if it is a calligraphy brush or a flat-headed brush, see Figure 28.

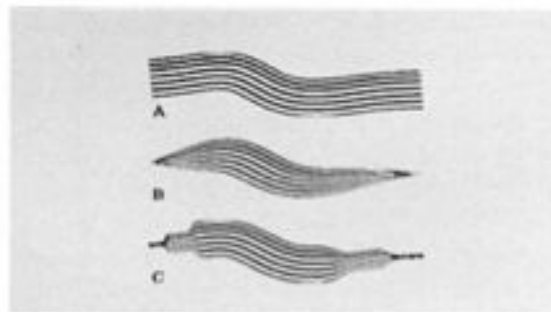


Fig. 27. An example of Strassmann's brushes.

I have examined drawing different shapes as the bristles move across the canvas.

Amongst these considerations were ellipses, diamonds, and bitmap images. Photoshop stamps bitmap images to the canvas that follows the artist's movements. These bitmap images may contain color and opacity, see Figure 29. Furthermore, the artist has a variety of tools to alter the look and spacing as well as combine bitmap images to create a brush template. Some of the tests that I have done along the way have included various shapes and bitmap images as well as changes in opacity. One of the problems that I encountered with having semi-transparent objects is that the specular calculation is done without regards for opacity. Therefore, it was possible to have an object that was somewhat transparent but did not disappear due to a highlight being placed over the transparent portions.

An artist must use a stylus tablet to draw to the program. The majority of my paintings have been created using a tablet that is attached to the computer rather than drawing directly on the screen. This may not seem very intuitive for artists trained in physical media, but I found that I became rather accustomed to it after a few minutes of painting.

All of the decisions made by the artist such as the pressure, movement, color, length and width of the brushes are recorded and exported to a text file. All of the data is stored behind the scenes so it will not impede the creation of the digital painting. As the artist continues to work inside the painting package, he or she may begin to think about what is actually being written to the file. It is possible to print these values to the screen. I have printed values such as the height, the previous color, and the current color to the screen during the creation of a painting. However, I have tried to eliminate such distractions from the artist and only have the focus on the creation of the colors in coordination with the brush design.

I have experimented with using two different color systems during the painting process: hue, saturation & value (HSV), and red, green, & blue (RGB). I've seen a

number of claims that the HSV model is much more intuitive for the artist, but I have found that it is better to keep the system in the RGB color space since both the Processing and RenderMan store the values in RGB. Once the artist moves to the RIB (.rib) and RenderMan shader files (.sl) he or she will be faced with RGB values. I have come to the conclusion that it is better to become acclimated using RGB in the initial steps of the process so that the artist does not have to custom-fit every shader that he or she decides to use with an RGB-to-HSV conversion formula. All of the values will already be in RGB for the artist which transfers rather nicely to the shader files.

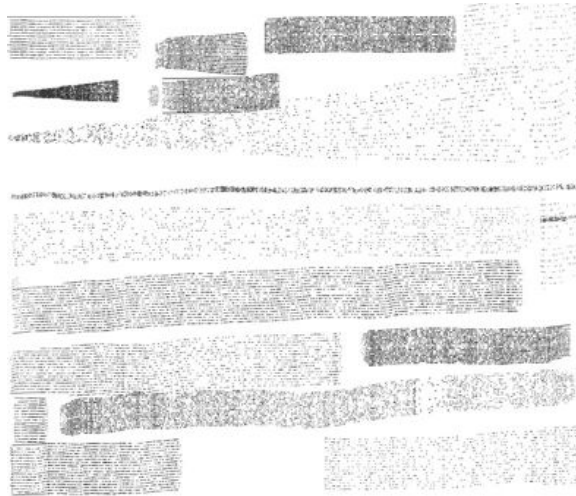


Fig. 28. Some early brush examples using our system.

Once the artist is satisfied with the two-dimensional image he or she must close the session. This will allow the program to write the final data to the output file. A two-dimensional rasterized image will also be created. This rendering will match the

exact canvas, in terms of size and color, that the artist viewed when the program exited. The user will now have in their possession a text file with the initial scene and an image of the virtual painting canvas to compare once he or she renders the three-dimensional scene.



Fig. 29. A painting done with an earlier prototype of the system.

III.3. Three-Dimensional Scene

The latter portion of my approach requires the interpretation of the data gathered from the virtual painting process. An initial scene is written to the file that includes the placement of the bristle locations, shaders attached to the objects, a single light source and a camera placed overhead to match the two-dimensional painting. However, further exploration of the scene requires the artists to manipulate the look of the shaders as well as the attributes of both the lights and cameras.

The final image sizes are dependent on the artist. If he or she chooses to render the scene without modification then it will be a direct correspondence to the canvas size painted originally. Virtually any image size may be used to render the scene. The creation of a larger image will allow for the artist to zoom in and out of the painting with relative ease. As with any painting, there are finer details that may only be viewed when arriving close to the surface.

The camera in the three-dimensional scene is initialized as a telephoto lens placed above the strokes that may measure a field of view as low as ten or fifteen degrees. This is necessary to match the original two-dimensional painting and the render from the three-dimensional scene. The artist is encouraged to rotate the camera so that it is not completely overhead. Doing so will reveal the true build-up of paint that is present in the scene.

Interpretation of the brush strokes from the virtual painting to the three-dimensional scene is not a perfect one-to-one match. If an artist paints a single line in the virtual painting, then a curve is represented in the three-dimensional scene. The curve is given three-dimensional form by producing a shading calculation which makes it appear as though it is a cylinder.

CHAPTER IV

PROCESS AND METHODOLOGY

In this chapter, I will present the process and methodology to obtain a three-dimensional scene from two-dimension drawings.

The process I have developed based on my observations is discussed in chapter III and consists of four steps:

1. Collecting physical data with a virtual 2D painting system
2. Converting the data to 3D
3. Exporting 3D data
4. Rendering 3D data

In the next section, I will discuss the virtual painting that is used to collect physical data.

IV.1. Virtual Paint System

In my virtual paint system, I use a stylus pen to collect data about brush motion and pressure. The interface allow to change brush type, color of the paint, the number of bristles, and spacing between the bristles.

IV.1.1. *Brush Motion*

Here we denote $p = (x, y)$ as a point in screen space, where x and y are horizontal and vertical coordinates respectively. Now, let $p_{i-1} = (x_{i-1}, y_{i-1})$, $p_i = (x_i, y_i)$, $p_{i+1} = (x_{i+1}, y_{i+1})$ denote the three consecutive positions of the tablet stylus pen where i is a

non-negative integer that represents discrete time steps. These positions are sampled if the pen moves more than an ϵ distance where ϵ is a user-defined parameter. In other words, we do not accept p_{i+1} as a sample point until $|p_{i+1} - p_i| < \epsilon$. This guarantees we do not take more samples than necessary.

For every time step, we also assign the pressure of brush as a positive real number a_i . The pressure of the brush can directly be obtained from the pressure of stylus pen when using a pressure sensitive tablet.

IV.1.2. Brush Type

The interface allows artists to choose a calligraphic or non-calligraphic brush, see Figures 30 and 31. Mathematically speaking, the main difference between them is how we compute bristle positions. Bristle positions are computed from brush position p_i , a unit vector n_i and pressure parameter a_i . Let $p_{i,j}$ denote bristle position for time step i where j is a non-negative integer smaller than M where M is the number of bristle. We compute $p_{i,j}$ as follows:

$$p_{i,j} = p_i + a_i n_i \left(\frac{j}{M-1} - 0.5 \right)$$

In calligraphic brush, the direction of n_i is constant, on the other hand in non-calligraphic brush the vector n_i is computed as a perpendicular vector to the brush motion.

In calligraphic brush, the vector orientation for the brush will be constant as defined by the artist, such as $n_i = (\sqrt{2}, -\sqrt{2})$. In practice, when they draw with calligraphic pens artists constantly rotate the pen obtain interesting effects. Current stylus pens do not provide such a control. Therefore, to obtain this effect we add a random noise vector to n_i such as $r_i = (0.01 * \text{random}(-1, 1))$. The new vector is

computed as

$$n_i = \frac{n_{i-1} + r_i}{|n_{i-1} + r_i|}$$

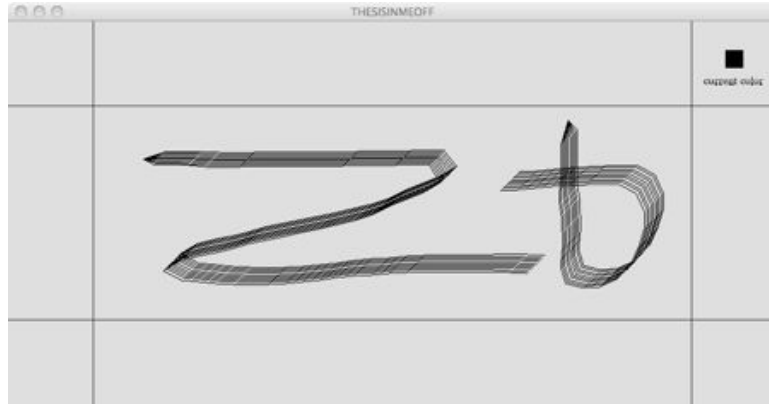


Fig. 30. A calligraphic brush.

For non-calligraphic brush, we compute n_i as a vector that is perpendicular to the movement of the brush as

$$n_i = \frac{z \times (p_{i+1} - p_{i-1})}{|z \times (p_{i+1} - p_{i-1})|}$$

where $z = (0, 0, 1)$ is a unit vector perpendicular to drawing plane and \times is cross product.

IV.2. Converting Data to 3D

Although our input curves are 2D, our goal is to convert them into 3D. In order to that we obtain an additional z_i value to brush position for any given time step. To obtain this z_i , we treat canvas as a dynamic 3D landscape. This landscape is represented as

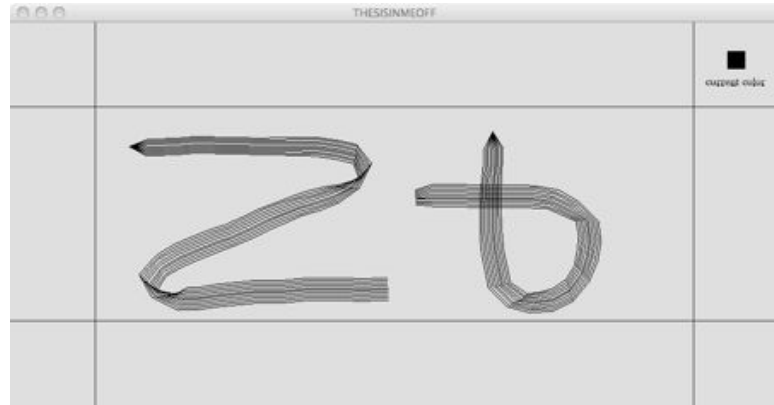


Fig. 31. A non-calligraphic brush.

an image, which we continuously update while we draw.

Each time the artist draws over a point in the screen space we increment the value for that pixel as a position, z_i . We are not concerned with any falloff or softness to the bristles. This approach is following a straight line left by a bristle.

IV.3. Exporting 3D Data

The artist's decisions are captured in real-time and written to a text document when the artist exits the program.

IV.4. Rendering 3D Data

Each curve represented in the 3D scene is an interpolation of points for each set of the artist's gestures. A curve begins when the pressure is first applied and stops when the pen is lifted from the tablet. The width of a bristle is derived from the pressure applied from the pen.

CHAPTER V

IMPLEMENTATION

The tools used for the implementation of this project are as follow:

- Processing API
- Wacom Tablet
- RenderMan Pro Server 13.0
- A word-editor, such as GEdit

V.1. Processing IDE

I've decided to use the Processing IDE because I am most familiar with the environment and because of its cross-platform capabilities. I have found myself working on Macintosh, Windows, and Linux operating systems. The Processing IDE has been able to work seamlessly on all of the systems without any need for a different distribution for each of the respective platforms. Furthermore, the user-base of the software has created a number of libraries that I found accessible and extensible. This allowed for me to test a number of different approaches on the project and move to another with great ease.

I am using a number of libraries that were developed by other people for use with the Processing API. These libraries enabled me such freedoms as allowing me to track the Wacom data, create a GUI for accessibility, and the ability to record a movie of the painting process. All of the libraries may be found through the primary Processing website with all of the necessary documentation to install the software.

The library to access the Wacom [33] tablet is found through the ProTablet library created by Andres Colubri. This allows for me to record the attributes of the Wacom data such as the pressure, the tilt, and the movement of the artist. The library appears to work with other tablet models, but I have not made any extensive testing with anything other than Wacom tablets.

I am making use of the ControlP5 library created by Areas Schlegel because I wanted to include GUI elements for the brush attributes. This was a necessary step to make the painting process more accessible for the artist. Early implementations of the painting program required keystrokes and the relative position of screen space to alter such attributes as color and the size of the brush. Although I adjusted to this method rather quickly, it was not very extensible. I only had a certain number of colors that I could fit to the respective keys on the keyboard. More so, the change in brush width required that pressure be applied to the canvas thereby producing a mark that he or she may not have wanted to be placed on the canvas.

Lastly, the MovieMaker library is included because of the ability to record a movie of the painting process. This option is not enabled by default. However, the code is embedded in the sketch as a set of comments so the artist needs to only uncomment the lines of code associated. There are a few reasons that I do not have it enabled by default. The most important reason is that it hampers the run-time efficiency of the program. This means that the artist will notice some lag in their decisions. It should not impede the artist too greatly and the data is still written appropriately to both the output text file and the video file seamlessly. Another consideration is that the output movie file takes up more space on the artist's computer. The creation of the text files, large rendered three-dimensional scenes, and movie files begins to take an increasing toll on the artist's hard drive space. I have been working on multiple computers with varied hard drive space so I have opted to not have the movies created.

V.2. Virtual Painting Creation

The process begins in the Processing sketch where the virtual painting is created, see Figure 32. Artists only need to worry about creating a beautiful image at this stage.

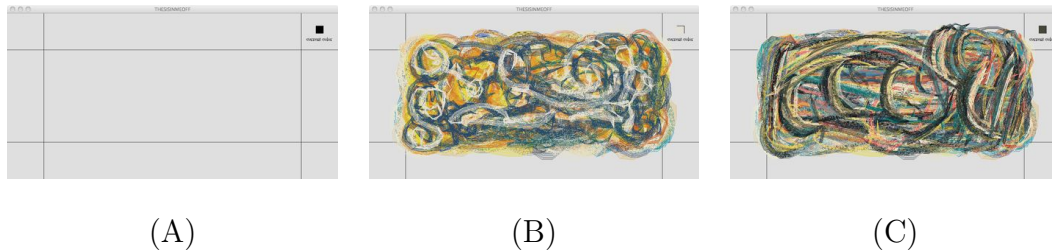


Fig. 32. (A) the initial canvas, (B) work in progress and (C) final painting when exported.

The color of the GUI is initialized to a dark grey by default with a bristle count of twenty-five and a pressure scale of one, see Figure 33. An artist must choose how the pressure influences the brush and how the brush should be drawn before he or she may begin the painting. I have not enabled these by default because I appreciate the notion that the artist needs to make sure that all of the brush parameters are set before he or she may begin to paint.

The size of the virtual canvas is limited by the monitor resolution where the canvas will be displayed. A majority of my tests renders were made using an eight-hundred by six-hundred pixel window for the canvas. This also allowed room for the GUI as well as the Processing environment to run on my computer which has a fourteen-hundred and forty by nine-hundred pixel resolution.

A bounding box is drawn to the screen so that the artists may draw within a



Fig. 33. (A) color selection GUI and (B) initial blank canvas.

safe drawing area. I have not found a solution to the program crashing if the artist draws inside the canvas and moves the cursor outside of the canvas while pressure is still being applied. This is a problem that I hope to fix in a later implementation. The measurements are always one-hundred pixels inside the parameter of the canvas. This seemed like enough room for me to draw within the area of the canvas and not be too concerned with sweeping gestures as I moved closer to the edges. The camera in the three-dimensional scene is centered above this bounding box.

Each of the bristles is comprised of a set of dots that are drawn to the screen as the artists move the pen across the tablet. The Processing sketch samples at a spaced interval based on how fast the artists move the pen. I had previously used the built-in line drawing function of Processing that connects a solid line between the previous point and the current point being sampled. However, there were artifacts that would arise when a line might be drawn from off-screen to the point being drawn. This caused unwanted color data in the virtual painting.

The default background color is close to a pure white. I decided to have the

canvas a near-white color because a common method of painting on canvas is with a white primer. The artist may choose to use any sort of background color for their painting process. However, when they move to render the scene in RenderMan it will be a black background.¹

V.2.1. GUI Manipulation

The GUI may be manipulated to fit the needs of the artist. I have included a number of parameters that I feel will help suit the basic needs of the artist. These include the color, brush type, spacing of the bristles, and number of bristles for a brush.

Each of the RGB values shows a float value that corresponds to the given color at the time. It will remain that color until the artists decide to move the color sliders again. There are no limitations to how much or how little the colors may change before the changes will be represented in the brush.

I have considered adding pre-defined colors to the sketch. This would allow for a more painterly palette instead of having to remember what a given color number combination may have been. A series of colors may be setup by the artist before he or she runs a given sketch. I have not included the parameters in the sketch, but documentation is easily accessible for the controlP5 libraries that would enable such settings.

V.2.2. Brush Creation

I initialize the brush to have a certain number of bristles, spacing, and color. The artist must choose how the spacing of the bristles should be influenced and what type

¹A different color for the background may be created by placing an imager shader in the RenderMan scene file.

of brush, whether a calligraphy or flat, they wish to implement. These are not enabled by default. Therefore, the artist is not able to immediately begin painting once the program is initialized. I believe it is necessary for the artist to choose what type of digital brush to use much like he or she would have to choose a physical brush.

A point will not be sampled more than once if the brush does not move after being sampled. This check is in place because the height would continue to increment otherwise. Previous iterations did not have this check and it caused extreme spikes in height even when the brush was continually moving across the canvas. There has been consideration to remove this cap and allow for paint to flow out and build-up on the layers surrounding as if one had allowed paint to drip or applied a large glob of paint to the canvas. However, I have not made any considerations to allow for this sort of behavior.

Each point drawn to the screen in the two-dimensional painting is exactly a pixel. I have considered implementing larger brushes that sample a group of pixels. However, I felt as though it would be better suited for a later implementation. It is possible to force the bristles to overlap either by moving the brush quickly or lowering the pressure scalar to a small enough number. This will not cause any errors by the program but may produce strange results in the three-dimensional scene.

A curve is completed when the artist lifts the brush from the tablet. RenderMan requires four segments to interpolate a cubic spline using a basis of 1. I remove the initial two points drawn for a given curve in Processing because they are primarily there to interpolate beyond the third point. Therefore, each of the curves needs to have 6 segments before the pen is lifted or else the curve will not be rendered in the RenderMan file.

V.2.3. *Movie Creation*

The artists must choose if they want to create a video of the painting before the virtual painting process is launched. There is a snippet of code that is not turned on by default but resides in the virtual painting program. The comments on the code only need to be removed so that the video can be captured. Once the code is uncommented the artists may go about the painting process as per usual. The code will exit in the same manner when the artist shuts down the program and a movie file will be located in the folder along with the sketch.

Once the image is done the user exits the program and a text document will be exported with the necessary data for creation of the 3-dimensional scene.

V.3. **Three-Dimensional Scene Creation**

The final RIB final file is generated in the same folder as the Processing sketch. My implementation is ready to render assuming the compiled shader is in the same folder. It is possible to reference the shader from a different directory; however, my files are not structured for that at the current time.

I am making use of only one shader for the curves. The shading algorithm is a simple displacement on the curves that gives it the appearance of a cylinder. An ambient, diffuse, and specular term are all included in the lighting calculation. Surface properties of the bristles should hold more importance than I have presented here.² As Smith [27] wrote about surface properties, “painting is the art of disturbing pigment over the surface of a support and, as such, the particles of pigment are the single most important component in any consideration of the painting process.” The artist’s only

²There is plethora of documentation on shaders. I found my shaders using the book *Advanced RenderMan* [2] and some of the other shaders that Pixar developed for use with *RenderMan Pro Server*.

interaction with the shader when using the painting program is the color. He or she may include other parameters in the shader file and include these parameters in the painting program as well.

The scene needs to be setup properly to display the curves. All of the necessary data is written to the file as soon as the Processing sketch is run.

- Create an image buffer to display the image.
- Determine the size of the window to show the image.
- Initialize the camera as perspective with a low field of view.
- Translate the camera plane outwards so we may view the scene.

A camera is placed directly above the painting with a very low field of view. All of my scenes are rendered using a field of view at the value of 15 in the RenderMan environment. It is my choice to have a very low field of view so the perspective matches relatively close to the virtual painting. All of the strokes are incremented so they move towards the camera. This allows for the illusion of the paint layers building towards the artists. I attempted to make the field of view as low as possible to match the orthographic view enabled in the digital painting program. However, objects in the RenderMan scene begin to clip one another as the field of view approaches zero.

There is only one light in the scene that is located overhead and slightly off-center casting a white color. I have chosen to use a distant-light because of the flexibility with moving the canvas about the scene. It is also casting ray-traced shadows to get around having to alter the depth-map shadow map size.

The points are interpolated as cubic curves in RenderMan. This implementation requires that the artist provides at least four points to be interpolated. I acknowledge this is not a direct match with the digital painting program which linearly interpolates

the points. I have decided to use cubic interpolation as opposed to linear interpolation in the three-dimensional scene because it looks more elegant.

My program will continue to add segments to a line as long as pressure is applied to the pen and reset when the pen is lifted. ³ I have tested enforcing the brushes to stop drawing after the number of samples was retrieved even with pressure still applied. Since there was no visual feedback for the paint running dry, it felt very unnatural to continually remove the pen from the tablet. Therefore, until there is some visual indication for the amount of paint remaining on a brush the paint strokes will be continuous as long as pressure is being applied by the artist.

Each of the bristle positions are based on the decisions made by the artists in the virtual painting process. However, once we move to the three-dimensional scene we are confronted with the third-dimension as the bristles begin to overlap one another. A bristle will not arbitrarily go beneath a previously drawn layer of paint. This leads to the potential of having a continuous brush stroke that has the same color but may rise and fall based on the layers that are already in place. For example, when the painting process begins all of the bristles will be of the same height value since there are no previous layers of paint applied to the canvas. If the artist chooses to paint over one of the previously laid paint layers, then the strokes will be incremented.

³There is a limit of 9999 segments for a given bristle. If this limit is reached it will automatically export the brush even if pressure is still applied. This number may be changed to be a lower or higher number. I have not surpassed a few hundred segments sampled.

CHAPTER VI

RESULTS

All of the images contained within this section were produced by myself. Therefore, many of the aesthetic considerations may be similar.¹ I was not concerned with how the painting may look from different perspectives other than the top of the canvas. Furthermore, I was not able to view the painting from any different zoom level. Both of these limitations run counter to my approach with physical painting where I am able to rotate the canvas and view it from multiple distances to consider all sorts of perspectives. However, I believe that since most paintings are viewed from the front perspective at a reasonable distance that it is not too detrimental that I was limited to one point of view.

The final renders show a rather close match to the original painting in terms of the overall color placement. Figures 34 and 35 show the original painting created in the digital painting program and the render that was sent to RenderMan without changing the lighting, cameras, or shading in the scene, respectively. Figure 35 is cropped to fit within the area of the bounding box, as seen in Figure 34.

There are a number of different ways to view the three-dimensional scene. I have played around with changing the widths of the strokes, viewing and the object from different angles, and placing lights in all sorts of directions. However, I have found that a lot of interest may be generated by simply zooming very close to the surface of the canvas as may be seen in Figure 36. This type of render details how the painting

¹The shaders and lighting setups are the same for all of the rendered images. The camera may rotate for a respective image and will be indicated as if moving from a position perpendicular to the center point on the canvas.



Fig. 34. The original painting, *7-22-2011-22*.



Fig. 35. A top view of the three-dimensional scene, *7-22-2011-22*.

has occurred over time in much the same way paint may have been applied and dried on a physical painting.



Fig. 36. A detail of the three-dimensional scene, *7-28-2011-19*.

The development of my approach has required me to form a new process of painting. There are no physical limitations that force the brush to stop applying paint to the canvas aside from lifting the pen from the tablet. Therefore, it is rather enticing to continue painting without stopping for a long period of time. This is a common attribute with digital painting since there is not a considerable cost to applying a gratuitous amount of paint. However, since the artist may be attempting to mimic the painting process it is necessary to think about where a brush stroke will end.

The top of the painting in the three-dimensional scene will not be a flat, uniform surface like the digital painting from which it was derived as seen in Figure 37.

However, I have found that the majority of my paintings end up rather uniform in terms of height across the top portion of the canvas because I am applying paint equally. The areas around the bounding box ramp upwards from the beginning surface of the virtual canvas and plateau when inside the bounding box. Figure 38 depicts a side view at the left-most side of the drawing canvas. I have cropped the image as it begins to plateau and continue across the rest of the canvas.



Fig. 37. The original painting, *7-27-2011-23*.

There is the potential to create more representational landscapes using the program, see Figure 39. As you may notice in the image I have forced my hand at creating a more typical landscape. The green represents a plain or pasture and the raised white hills represent mountains.²

²This may be the best depiction of the default light position. Notice the darker areas on the left side of each of the mountains to determine the positioning of the light.

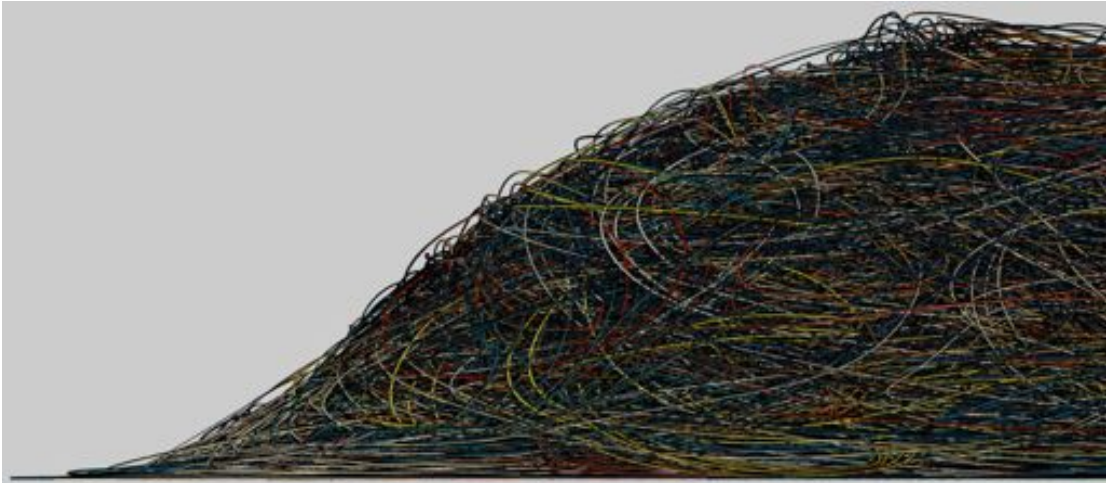


Fig. 38. A side view at the edge of a canvas, *7-27-2011-23*.

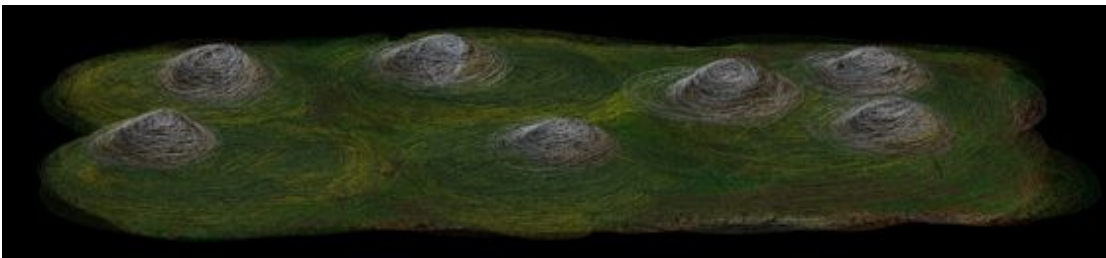


Fig. 39. A side view of an attempt at a landscape with mountains and a field.

CHAPTER VII

CONCLUSIONS

It is my goal that this approach may further the understanding of painting as a process for artists familiar with physical and digital realms as well as the audiences for both media. Furthermore, it should invite all of them to explore the potential of the interaction between the physical and digital environments. I had a faint clue of how complex this approach may become, but actually going through the process has made me understand that there is much more to explore. The venues of exploration are not limited to only expanding the code to enable more functionality but extend to researching methods of artists both past and present.

When I began this project I had considered a physical painting as a two-dimensional image. The conversations I have had with my committee members over the last year, the research done on previous artists, and the in-depth analysis of physical paintings has transformed this idea to something more. It is now my belief that paintings are a three-dimensional object that interacts with light to create a form that has many layers of detail from standing distance all the way to microscopic analysis. Each layer of detail has not only the decisions made by the artist but also the physical attributes of the physical media and the interaction with the light and shadows that illuminate the work of art.

I have found that people are fascinated by the painting process and are almost hypnotized by a painting that develops in front of them. The ability to record the painting process is a venue that needs to be explored more. It is certainly not an innovation that I have stumbled across by myself as there are other artists that have recorded their paintings using digital media. However, I have taken it a step

further and included all of the positions and decisions made by the artist. Other software packages such as Corel Painter and Autodesk Maya are able to record the decisions made by the artist. My program is hopefully more straight-forward than the commercial packages and allows for an easy extension to output the interpretation of these decisions.

VII.1. Further Implementation

VII.1.1. Digital Paint System Extension

A number of different tests have been done for the two-dimensional system that include having the paint drop-off when an actual paint brush would have run out of paint. Also, there has been discussion of having the spacing of the bristles as they are caught either on the surface of the canvas or become clumped together. Both of these are items that may be addressed in later implementations of this project. However, it is my main concern at this stage to have the paint rendered accurately in the three-dimensional scene before I move to a more robust system of mimicking physical attributes of painting.

A method to test the height of the given pixel while drawing the two-dimensional data should be implemented at a later time. The current development of this project does not allow for the artist to actualize how much he has painted over a given area without painting new data. Another window that has a depth value could be created that dynamically changes while the artist is painting. Otherwise, some sort of sampling could be implemented where the artist is able to click on a given pixel and retrieve the height data without actually drawing a color to the screen. This could be done with a toggle switch.

VII.1.2. *Other Approaches to Rendering*

I am able to capture the video of the digital painting process, but animating the creation of the three-dimensional scene has proven too difficult for my current implementation. However, an animation of the three-dimensional scene being generated would be a great extension of this project. An implementation in Maya was able to capture the creation of cubes (see Figure 40), but when I moved to RenderMan it was not so simple to animate the curves being generated. Many people have remarked that they are fascinated with the animation of the painting process. Therefore, it is a rather high priority for me to implement the three-dimensional scene creation.

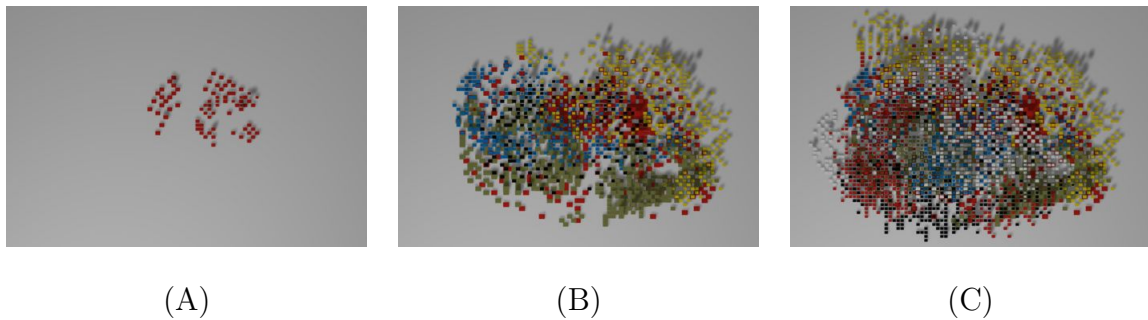


Fig. 40. (A) early still from the animation, (B) progression of animation and (C) final shot of the animation.

There has been discussion of sending this data to a three-dimensional printer or using fabric assembled by hand to generate a physical object from the painting data. The renderings found in Figure 41 were a few of the images that really sparked this conversation. Any material may be used to generate the three-dimensional object, but my first considerations have been to use metal strips or strands of yarn. The process

might prove to be rather laborious, but the result may be rather fantastic.

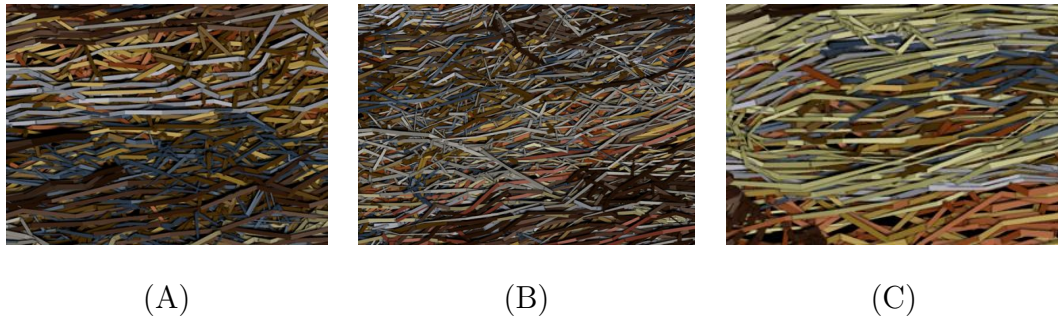


Fig. 41. (A) detail, (B) detail and (C) detail.

The shaders may be manipulated to explore different aspects of the painting. Figure 42 shows the spatial relationship of the points in space. The darker values are furthest from the camera and the brighter are closest to the camera. Those that are completely black are actually on the surface of the virtual canvas. This mimics the use of an X-ray version of a painting to see some of the lower layers of paint [24], see Figure 43.

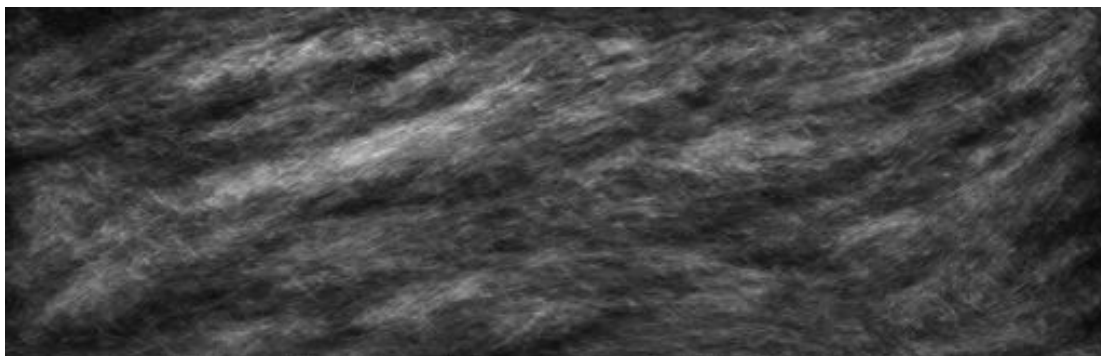


Fig. 42. A view of the spatial relationships.



Fig. 43. Camille Pissarro, *The Route d'Ennery at Pontoise*, 1874, 55 x 92cm. X-Ray on the top portion and actual painting on the bottom.

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