SHADING WITH PAINTERLY FILTERED LAYERS: A PROCESS TO OBTAIN PAINTERLY PORTRAITS

A Thesis

by

SAIF AYMEN CASTANEDA

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Chairs of Committee,	Ergun Akleman
Co-Chair of Committee,	Felice House
Committee Member,	Russell Reid
Head of Department,	Timothy McLaughlin

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ABSTRACT

In this thesis, I study how color data from different styles of paintings can be extracted from photography with the end result maintaining the artistic integrity of the art style and having the look and feel of skin. My inspiration for this work came from the impasto style portraitures of painters such as Rembrandt and Greg Cartmell. I analyzed and studied the important visual characteristics of both Rembrandt's and Cartmell's styles of painting. These include how the artist develops shadow and shading, creates the illusion of subsurface scattering, and applies color to the canvas, which will be used as references to help develop the final renders in computer graphics. I also examined how color information can be extracted from portrait photography in order to gather accurate dark, medium, and light skin shades.

Based on this analysis, I have developed a process for creating portrait paintings from 3D facial models. My process consists of four stages: (1) Modeling a 3D portrait of the subject, (2) data collection by photographing the subjects, (3) Barycentric shader development using photographs, and (4) Compositing with filtered layers. My contributions has been in stages (3) and (4) as follows: Development of an impasto-style Barycentric shader by extracting color information from gathered photographic images. This shader can result in realistic looking skin rendering. Development of a compositing technique that involves filtering layers of images that correspond to different effects such as diffuse, specular and ambient.

To demonstrate proof-of-concept, I have created a few animations of the impasto style portrait painting for a single subject. For these animations, I have also sculpted high polygon count 3D model of the torso and head of my subject. Using my shading and com-

positing techniques, I have created rigid body animations that demonstrate the power of my techniques to obtain impasto style portraiture during animation under different lighting conditions.

ACKNOWLEDGMENTS

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NOMENCLATURE

2D	Two Dimensional
3D	Three Dimensional
CG	Computer Graphics
NPR	Non-Photorealistic Rendering
RGB	Red, Green, and Blue

CONTRIBUTORS AND FUNDING SOURCES

Contributors

With the exception of my own personal funding, no additional funding or contributions were necessary in order to complete this thesis.

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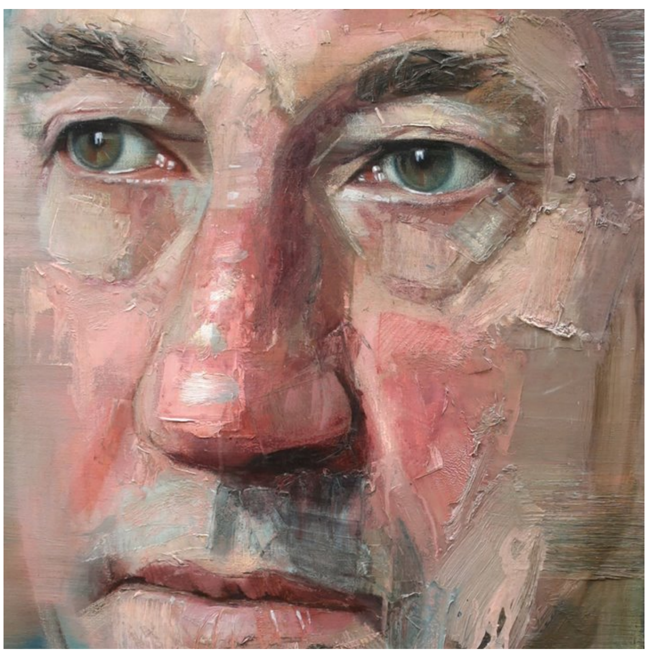
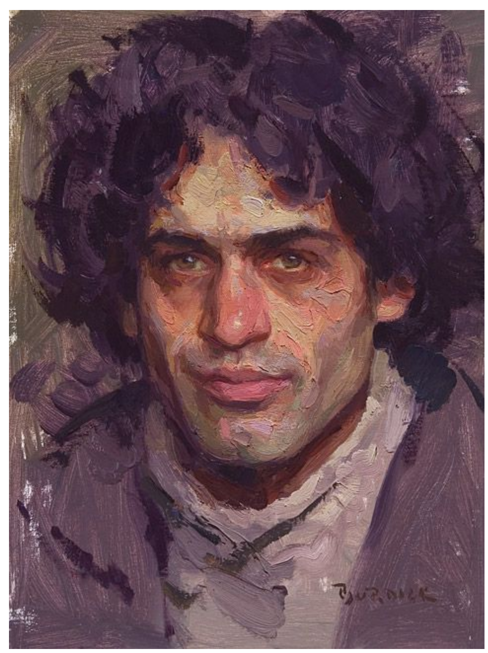
1. INTRODUCTION

1.1 Motivation and Inspiration

Impasto is a technique used in painting, where paint is laid on the canvas very thickly, usually thick enough that the brush or painting-knife strokes are visible. When dry, impasto provides texture, the paint appears to be coming out of the canvas as shown in two examples given in Figure 1.1. Figure 1.1a visually demonstrates that a major component of the visual characteristics of impasto painting is the bas-relief type effect you get on the canvas from the over application of paint [2]. Figure 1.1b shows how all elements in an impasto painting works together to create a unique looking image [3].



(a) A close up example of an impasto style portrait painting demonstrating underlying texture.

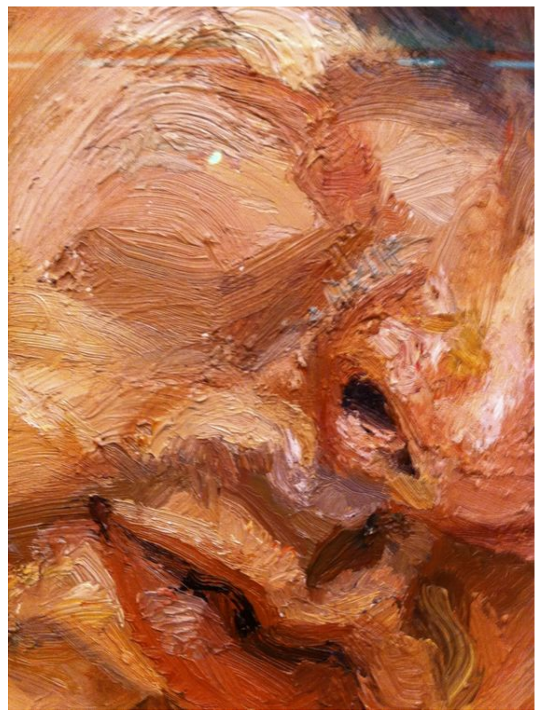


(b) An impasto portrait painting in its entirety from distance.

Figure 1.1: Examples of impasto style paintings that demonstrate how realism can be achieved using this technique.

The impasto style serves several purposes. First, it makes the light reflect in a particular way, giving the artist additional control over the play of light on the painting. Second, it can add expressiveness to the painting, the viewer being able to notice the strength and speed applied by the artist. Third, impasto can push a painting into a three-dimensional sculptural rendering.

(a) A Portrait painting by Rembrandt Van Rijn.



(b) Closeup of an impasto painting by Connie Zammett.

Figure 1.2: Two examples of impasto portrait painting that demonstrate the importance interpreting accurate color values in order to convey the appearance of skin.

It would be interesting to explore how the varying color distribution of impasto style portrait paintings can be translated to 3D computer graphics using color extraction from photography. The inspiration behind this idea comes from the fact that traditional portrait painters were producing realistic looking images long before 3D computer graphics came along. 3-D artists have become so accustomed to generating everything in a realistic way based on physically accurate numbers that we have lost sight on how artists used to generate realism, through painting. Traditional artists are masters of interpreting color values just by using their eyes, not by using a computer to dictate the most accurate numerical value as shown Figure 1.2a. Moreover, such a style provides a rendering of the skin using moody and contrasting tone (For a discussion see [4]). The contemporary impasto portrait painting by Connie Zammett in in Figure 1.2b shows how the overlay of color and texture on the canvas helps convey the look of skin [5]. As demonstrated by example in Figure 1.2b, giving the impression of skin in a realistic manner can be more effective than rendering out extraneous physical details such as pores, veins and blemishes.

Instead of working with a traditional medium, like oil paint, our process utilizes the capabilities of both portrait photography and 3D computer graphics. In recent years, there have been many attempts at recreating a painterly rendering style in live action and in both 2D and 3D computer graphics. Non-Photorealistic Rendering (NPR), an area of computer graphics that focuses on creating a wide variety of expressive styles for digital art, has been used in numerous productions in past years. A few examples of this are "What Dreams May Come" (1998), a live action film that contained many sequences that were meant to appear as impressionist paintings, and most recently "Loving Vincent" (2017), a 2D animated film made entirely with paintings inspired by Vincent van Gogh. Both works use the Non-Photorealistic painterly style to enhance the ability to tell their stories. They also provide for us a platform to further push this idea of incorporating Non-Photorealistic painterly styles using 3D computer graphics and compositing software.

In computer graphics, skin is still one of the most difficult and time consuming assets to render. It has many subtle visual characteristics, and human beings are acutely sensitive to the appearances of skin and faces in particular. The sheer amount of detail in skin presents a barrier in of itself. A realistic model of skin must include wrinkles, ports, freckles hair follicles, scars and so on. This is all very computationally heavy and a lot of times does not lend to satisfying results.

1.2 Introduction

The goal of this research is to explore the artistic possibility of rendering realistic "appearing" skin in a painterly style, using traditional painting techniques and portrait photography. Traditional artists use their eyes to dictate which colors to apply to their palate, so we will use portrait photography as our method of simulating color extraction in traditional painting.

This research will focus on (1) How to create a light, middle, and dark tone map from photography references. (2) How to create stroke like transitions in color that react to adjusting location and intensity of the light source, in order to match the look of portrait paintings. (3) How to properly illustrate the illusion of accurate subsurface scattering and specularity. Traditional portrait painters fake attributes like these with layers of color. (4) How to capture the irregularity in shapes and forms in computer graphics, which is commonly seen in traditional portrait paintings. The research will be focusing on the rendering aspect of 3D animation. Such aspects as animation will not be explored in this project as they exceed the scope of the study.

We begin by breaking down the important aspects of portrait paintings. The analyzing process will be primarily based on four aspects: (1) shape and form, (2) color value and tone, (3) lighting and shadow, (4) composition. Then several non-photorealistic shading methods are developed to replicate the visual characteristics from the selected art style in computer graphics. The methods developed here are intended to give the user enough creative control to generate onto their scene any artistic style they want. To implement the methods, we designed and sculpted a high polygon count 3D model to represent our subject in our 3D portrait painting. Then with a combination of 3D rendering and 2D image processing, we generate the look of style portrait painting as well as the impression of accurate looking skin. Finally, a short animation is developed to demonstrate color interpolation as the light in the scene changes position and intensity. This research uses existing 3D software and image processing software to develop our work. High polygon sculpts are modeled using Zbrush and Autodesk Maya, shader development and rendering use Mental Ray in Autodesk Maya. Image processing is done using Adobe Photoshop.

The rest of the thesis is organized as follows. Chapter 2 discusses the history and techniques of select portrait paintings and painters, and then it summarizes previous researches related to non-photorealistic rendering as it pertains to skin. Chapter 3 presents an artistic analysis of some portrait painters, followed by discussing the NPR shading methods that are used to match the intended visual style in computer graphics. Chapter 4 provides the process of creation of a portrait paintings from designing and building the 3D scene to rendering and shading. Chapter 4 provides implementation and results. Finally, Chapter 5 presents our conclusions and discusses future works.

2. BACKGROUND AND LITERATURE REVIEW

In this chapter, we will talk about the background information for our research. First, we will discuss the history of portrait paintings and how techniques have evolved into the of 17th century. The impasto painting technique will be discussed and how it affects the overall look and feel and portrait paintings. Secondly, we will review some of the previous works in non-photorealistic rendering relating to artistic and painterly looking images within computer graphics. We will break up our previous works into two categories: still image manipulation and 3D animation NPR. Painterly rendering has been a well-researched area in computer graphics. To review all the work is beyond the scope of this paper. We will review some of the relevant works starting from Egyptian tomb portrait paintings from Ancient Roman times shown in Figure 2.1.

(a) (b) (c) (d)

Figure 2.1: Examples of ancient Egyptian portraits that were painted on wooden boards attached to mummy tombs.

2.1 History and Techniques of Portrait Painting

A well defined portrait painting has the ability to express more than just what is on the surface. Many portraitists were commissioned by very wealthy, high standing figures but history shows us that it became very common for lower and middle class patrons to be depicted in portrait paintings. No matter the economic status of the subject, many painters throughout history have demonstrated the ability to illuminate the inner workings of their subjects. Which, according to Aristotle 'the aim of art is to present not the outward appearance of things, but their inner significance; for this, not the external manner and detail, constitutes true reality.' [6] is the most important aspect of portrait painting.

In ancient civilizations; such as early Egypt, Rome and Greece, portrait painting was more of public art, rather than a private one. This means that most paintings were designed to decorate public areas and reflect the morals and religious values of the day. Portraits were not only represented through painting, but also through sculpture. As shown in Figure 2.1, the Fayum portraits, painted portraits that were attached to Egyptian mummies, are some of the only remaining examples of portraiture from acient civilizations [7]

Moving into the Middle ages, from the 5th century until the early parts of the 15th century, portrait art was dominated by the Byzantine art style. A more symbolic approach to portrait art was favored in contrast to the more realistic style of mid 15th century and forward portrait art. Much of the art during this period were located primarily in churches and monasteries, in the form of murals, panel paintings or stained glass. Much of the work during this period of time were very flat in comparison to later artists that captured more realistic emotion and form in their artworks. Byzantine art is much more focused on conveying messages through symbolism

A significant shift happened in the late 14th century when Giotto di Bondone introduced his unique style. Giotto wanted to deviate from the abstract and symbolic style of religious Byzantine art, and instead introduced a realism to religious paintings that was brand new and unique for its time. His paintings conveyed more life like interpretations and more realistic form than previously displayed prior to his work. Giotto's revolutionary methods paved the way for further progress to be made to more realistic paintings. Jan van Eyck was one of the foremost painters of the Northern Renaissance. Van Eyck continued Giotto's realistic techniques that he introduced by creating realistic oil paintings, usually of religious subjects. His trademark three-quarter pose combined with his expertise with oil paints created even more life like and realistic results than previously seen before as shown in Figure 2.2.

(a) 'Portrait of a Man in a Red Turban' by Jan van Eyck

(b) 'Portrait of a Man with a Blue Chaperon' by Jan van Eyck

Figure 2.2: Examples of portrait paintings by Jan van Eyck. These paintings demonstrates the progress towards more realistic portrait paintings since the beginning of the 5th century.

Towards the end of the 16th and beginning of the 17th century, some of our most influential portrait painters would surface. Caravaggio was a pioneer of the Italian Baroque style that grew out of the Mannerist era. Italian Baroque art was not widely different to Italian Renaissance painting but the color palette was richer and darker and the theme of religion was more popular. As show in in figure 3a, the intense, dramatic contrasts of light and dark, resolute realism, meticulous attention to naturalistic detail and approachable, life-like subjects set Caravaggio's paintings apart from all the masters that preceded him [8]. His methodology consisted of chiaroscuro, which is an Italian term meaning referring to the contrast of light (chiar) and dark (oscuro) in an artwork.

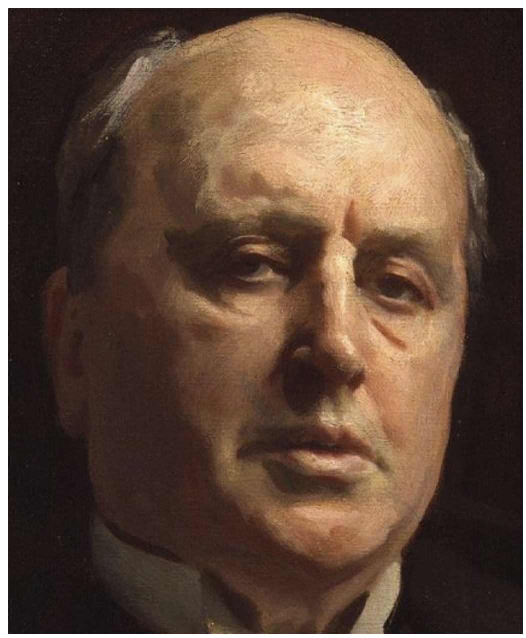
(a) 'The Gypsy Girl' by Frans Hals.

(b) A self-portrait by Rembrant Van Rijn.

Figure 2.3: These examples from 17th centry Holland illustrates a further progress towards more realistic portraits.

Frans Hals and Rembrandt Van Rijn were mid 17th century painters that were masters were masters of interpreting color values just by observing subjects with their eyes (See examples in Figure 2.3). Rembrandt Van Rijn would utilize a small palette of colors dominated by dark earth tones and golden highlights and used a particularly thick consistency of oil colors and applied several layers of paint to the canvas (See Figure 2.3b). Rembrandt's use of combination of light and space to influence the complexity of his composition. He alternates between hard and faded lines, and light and dark tonal values that enhances the realism and grunginess of the composition.

(a) ''Seft Portrait' by Benjamin West



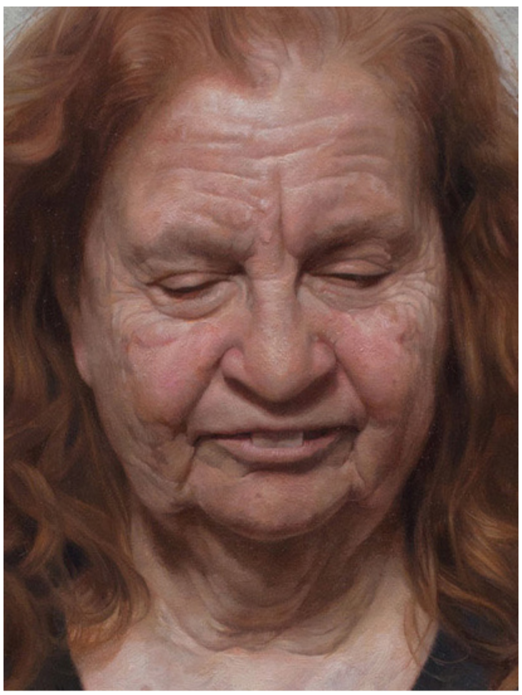
(b) 'Henry James' by John Singer Sargent.

Figure 2.4: Examples of portrait paintings by American painters.

In the early parts of Frans Hal's career, his work was dominated by sharp and vivid colors (See Figure 2.3a). He used warm tones mainly for his subjects' flushed faces and his various multi-layering techniques. As time went on, his colors were less bold and had a less vibrant presence than in earlier works where they had more volume and luster. It is during this century that the impasto style began to grow in frequency.

A progression of Hals's and Rembrandt's style is John Singer Sargent. John Singer Sargent spent a lot of time on the basic structure of the head before he moved on to any of the finer details. In someways he would draw and paint like a sculptor. He would use a lot of paint for large thick brushes and worked mostly in half tones before finishing a painting with the dark tones and highlights. The dark tones and highlights are to act just as accents [9].

The last two examples I'd like to show are of modern day portrait artists that have commercialized and adapted the styles of the famous artists listed above. Greg Cartmell is a 21st century portrait painter that utilizes oil paint to create a combination of abstract and realistic appearing images. In terms of his portrait paintings, he is much more abstract and utilizes surface irregularities much more frequently to enhance his composition. Figure 2.5b shows a portrait painting by him that demonstrates how he captures a tricky balance of abstraction and realism. The intense use of light and shadow emphasize the idea of lost and found edges, this engages the viewer more than a photographic image that spells out everything for you. [3]. He generally is more varied and vibrant in terms of his color palette choices. His use of impasto is much less subtle than what was demonstrated by 17th century painters. As shown in Figure 2.5a, David Kassan very subtly conveys the look and feel of realistic skin, but still retains the characteristics of a painting. He starts by applying a thin layer of Liquin to the painting surface to make it slightly wet and to bring the darks up to where they were the day before. On the palette he mixes small quantities of colors in what he calls puddles. As he adds pigment, he pulls adjacent puddles out from a center point, one lighter or darker, on warmer or cooler. Working dark to light, he loads only the tip of his brush, which he then draws very lightly on the slightly tacky surface in a series of hatches that follows the form. By pulling soft brushes lightly along or across the hatch direction, he very gently blends some areas. Both David Kassan and Greg Cartmell are good examples of how well known techniques have evolved and continue to be interpreted in different ways.



(a) Portrait Painting by David Kassan

(b) 'The Old Man' by Greg Cartmell.

Figure 2.5: Examples of portrait paintings by contemporary painters.

2.1.1 Impasto History and Description

Like many other celebrated painting techniques, the use of impasto evolved from artists' exploration of the qualities of oil paint, which had become the standard medium in western painting during the Renaissance [10]. Oil paint dries slowly, allowing painters to build it up thickly, or in layers. To create especially thick and dramatic impasto, the paint may be applied with a palette knife instead of a brush.

Little is known for sure about how the artists of the Baroque period, who pioneered impasto technique, mixed their paints, but some speculate that they may have added varnish, or that the coarse texture of the white lead used as a coloring agent enhanced the texture. Master painters of the Baroque era often used impasto in conjunction with other techniques, creating a wide range of textures and effects in a single work [11]. Thick, bright oils, still showing the marks of the brush, gave their work the desired air of spontaneity, and captured the intensity of natural light and shadow [12].

Impasto creates a richly textured, three-dimensional surface that can catch the light or create tiny areas of shadow, enhancing the drama of a painting. Earlier painters often used areas of impasto to suggest complicated textures, such as lace, hair, wrinkled skin, or carved stone without copying exact details, or to enhance atmospheric effects. Another aspect of impasto paintings is by under painting certain details, to depict them as less precise. Another way this is achieved is by allowing parts of the painting to remain in shadow. The basic fundamentals of impasto, and all painting in general, are [13].

- Color and Value. Value within color is important because it can alone create illusion of form.

- Light and Shadow. In impasto painting, shadows are used to not only hide form and add a mystery to the subject, but it is also used to hide edge and manipulate the way the view registers the depth of the painting.

- Depth and Composition. Impasto painters are notorious for using layers of color to produce depth and translate that richness of color into accuracy of form [14].

To achieve these goals, artists are always creating and recreating their craft to more closely achieve their artistic goals.

2.2 NPR Techniques

2.2.1 Still Image Manipulation

Kun, Mingtian, Caiming, and Song-Chun [15] used a semantics based approach for stroked influenced painterly rendering, which was based on previous image parsing techniques. Image parsing integrates segmentation for regions, sketching for curves, and recognition for object categories. In an interactive manner, they decomposed the input image into a hierarchy of its constituent components in a parse tree representation with occlusion relations among the nodes in the tree. They created a database of brushes, which were collected by experienced painters, which were used to influence the new look of the source images. Zao et al. created painterly portraits using semantics-driven approach for stroke-based painterly rendering, also based on image parsing techniques by taking into account facial structure [16]. Their work can also be included in our process since these are also painterly filtering methods

To combine painterly knowledge and technology together, Steve DiPaola's [17] system uses a multi-layer stroke analyzer/renderer which perceives and lays strokes down in large masses first, progressively using smaller strokes and more detailed analysis. This approximates how painters squint at first to read large tonal masses and progressively adds greater levels of detail on top of exposed paint from the layer before. Rather than use progressive difference grid techniques to move through a source image, the system progressively iterates over tonal masses, beginning with major tonal areas of the face: body tone, half-tone and shadow by calculating a gross tone map.

DeCarlo [18] developed a method of Non-Photoreal Rendering (NPR) by using a computational approach to stylizing and abstracting photographs that explicitly respond to the goal of non photorealistic rendering. His system transforms images into a line-drawing style using bold edges and large regions of constant color. To do this, his system represents images as a hierarchical structure of parts and boundaries computed using eye tracking.

Haeberli first introduced the concept of painterly filters to obtain painterly images from photographs with an ordered collection of strokes described by size, shape, colour, and orientation [19]. In early 2000's several methods have been developed to obtain various painting effects such as watercolor or oil painting [20, 21, 22]. For instance, Hertzman applied filters to new target images to develop analogous filtered images [21] and DeCarlo developed another transformation method to turn photographs into stylized line drawings using bold edges and large regions of constant color [18]. All of these methods can be incorporated in our process.

J.P. Collomosse and P.M. Hall [23] presented an automatic NPR technique capable of rendering 2D images in a painterly style, using three-dimensional conic strokes of super-quadric cross section. The implicit ordering of cones is governed by a statistical measure of salience, which mitigates against low salience strokes encroaching upon high salience areas. This approach increases the conservation of detail within the painted image.

2.2.2 3D Animation NPR

Shading languages have been developed to provide efficient ways for rendering, illumination and shading of 3D scenes [24, 25]. All shading languages are based on shade trees concept that offers a way to specify shading properties quickly and easily [24]. His model separates conceptually independent tasks such as light source specification, surface reflectance and atmospheric effects, which is crucial for our paper.

In our work, we develop our shaders using Barycentric operations to have artistic control [26]. Barycentric shaders are used before to include global illumination effects into charcoal drawings and Chinese paintings [27, 28].

Realistic skin rendering has been an important research topic. Mertens developed an approach of rendering subsurface scattering using an algorithm that operates in image-space in GPU [29]. The dipole and multi-pole models allow for efficiently solving challenging diffusion-theory equations. By using texture-space diffusion, a Gaussian-based approximation, and programmable graphics hardware, developers can create real-time, photo-realistic skin renderings [30]. Jimenez uses diffusion theory to produce realistic skin renderings [31].

An interactive system that stylizes an input video into a painterly animation was originally proposed by Lin, et al [32]. The system consists of two phases. The first is a Video Parsing phase that extracts and labels semantic objects with different material properties (skin, hair, cloth, and so on) in the video, and then establishes robust correspondence between frames for discriminative image features inside each object. The second Painterly Rendering phase performs the stylization based on the video semantics and feature correspondence.

Mizuki Kagaya, et al., described a video painting framework in which style parameters as well as brush stroke orientations can be specified individually for each region (object or background) in some keyframes and propagated to other frames in a temporally coherent fashion. They referred to this as the problem of multi-style painterly rendering, or simply multi-style painting. The user can specify style parameters, such as stroke color, size, and opacity for each target object in some keyframes [33].

As you can see, there have been many works done that address the need to render "images" in a painterly way, but they are just single images. They don't address the need for rendering these filters in an entire animation sequence. This is another motivation for this thesis, because I would like to move past the single image processing phase, and apply this painterly affect to many images in sequence, not just one.

3. ARTISTIC ANALYSIS

In this chapter, we propose the impasto-style shader approach for creating our final rigid animation. First, we present an artistic analysis on our visual references to extract the essential characteristics of impasto-style portrait paintings for us to match in 3D. And then, based on the result of our analysis, we will discuss, in detail, the process that was taken to develop our shader based on the discussed characteristics of of impasto portrait paintings in the following chapters.

3.1 Artistic Analysis

In this research, we use a combination of one historical (Rembrandt Van Rijn) and one contemporary (Greg Cartmell) portrait painters's styles as the primary visual reference. Both Rembrandt Van Rijn and Greg Cartmell exhibit many of the common qualities that help identify their works as 'impasto' style; even though Rembrandt Van Rijn was a 17th century painter compared to Greg Cartmell being a modern day artist. For example, when studying many impasto paintings, the paint is laid on a canvas or panel in quantities that make it stand out from the surface and is usually thick enough that the brush or knife strokes are visible. The heavy use of paint can amplify the complexities of the paintings in multiple ways. One added complexity is how the relief can intensify the highlights by increasing the light-reflecting properties of the paint. This effect extends the tonal range of the painting by making highlights appear more brilliant. The relief can also give a more three-dimensional and almost life like feel to the depiction of wrinkled skin or the texture of intricately crafted surfaces of jewelry and fabrics. Also the dramatic use of shadows adds to the drama and depth of the composition. Both Rembrandt and Cartmell tend to increase the illumination of what is facing the light source and exaggerate the shadows of what is facing away. Rembrandt and Cartmell, in some of his less abstract works, both utilize these basic fundamentals that have been consistent for over three centuries years. The integration of their complex use of color and shadow; plus the added dimension of the 'relief' effect of the large quantities of paint on the canvas, are all essential to creating an impasto looking portrait in 3D computer graphics. It should be noted that the goal for this research is neither to copy the visual references into 3D computer graphics, nor to simulate real world behaviors or visual accuracy of oil paint, which are commonly used in impasto paintings, but to use his paintings as primary visual reference for studying and resembling the style and aesthetics of impasto-style oil paintings.

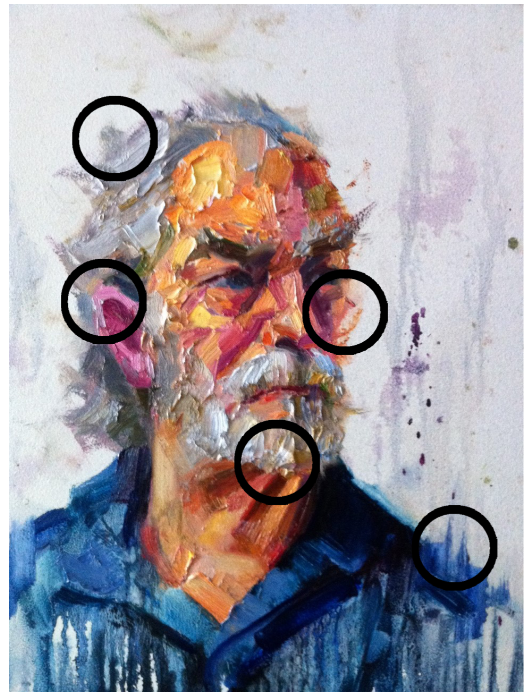
Here we choose some of the Rembrandt's more well known portrait paintings and we use a mixture of final and sketch work from Greg Cartmell for artistic analysis. The purpose of the analysis is to provide a breakdown of the important artistic characteristics and aesthetics of impasto style portrait painting in order to create accurate digital work in CG. The results of this analysis yield a list of essential characteristics and artistic aspects derived impasto portrait painting, which can be categorized as follows:

- shape and form
- color value and tone
- lighting and shadow
- composition

Based on the analysis, specific solutions will be presented, which are suited to recreate these visual characteristics in computer graphics.

And for each aspect, we alternate between Rembrandt and Greg Cartmell portrait paintings to demonstrate the different characteristics of impasto paintings for this analysis. The goal is to try to find out the universal visual aesthetics shared by the art works. And it

(a) Old Man Color Study by Greg Cartmell.



(b) Old Man Color Study with markers to visualize border and surface irregularities.

Figure 3.1: An oil painting by Greg Cartmell: ‘Old Man’.

should be noted that the visual characteristics from each analysis is not just specific for a particular painting.

3.1.1 Shape and Form

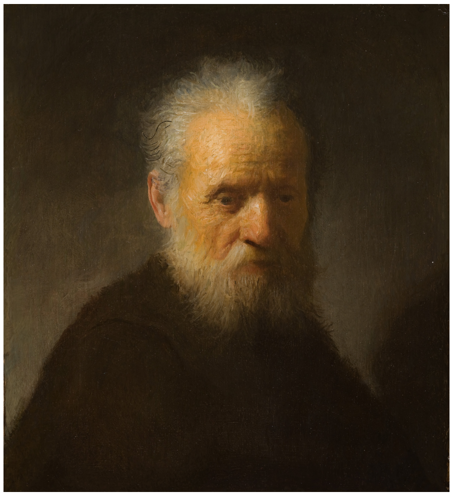
This subsection addresses the artistic irregularities in the shape and form of the subject in the paintings. This includes how the application of paint and brushwork are used to create irregularities in the shape and form of the main subject in the portrait paintings. In impasto style portrait paintings, it is very common for the edges and borders of the subject to be rendered in a nonlinear and abstract way. Figure 3.1 shows a close-up image of a head study done by Greg Cartmell, in which we can see imperfections along the edges in the form of added noise textures or color smear. The image shown in Figure 3.1a is the original impasto painting, and The image shown in Figure 3.1b is the same painting that has markers in place to help visualize the different border and surface irregularities that are common with impasto paintings.An element of the shape and form that is affected by the paint application is the amount of paint that is used during the painting process. As you can see along the facial structure, the paint appears to 'clump' and pull away from the canvas. This not only affects the surface look of the painting, but it can also help with the depiction of wrinkles, which in the case of this old man study, it does. Also, it is worth mentioning that the irregular patterns sometimes are carefully controlled by the artist and painted differently from the foreground and background elements. For instance in Figure 3.1, the irregularities are used in such a way that it draws the viewers eye directly at the subject.

3.1.2 Color Value and Tone

In this subsection, the analysis is based on color value and tone. Color value and tone refer to how different shades of color, from like to dark, and how different shades of black and white, also including grey, help convey the form and depth of the artwork. Lighting and shadows are also affected by color value and tone, so we will mention that as well in this subsection.

In impasto-style paintings, Rembrandt created his distinctive portraits with a small palette of colors dominated by dark earth tones and golden highlights and using a particularly thick consistency of oil colors and applying several layers of paint to the canvas. Which is in contrast to most of Greg Cartmell's portraits, who uses a much more elaborate and vibrant color palette. Cool greys are used for the mid-tones between the lights and shadows. To create different color values and tones, they use the paint brush to load the oil paint in different ratios to achieve different shades of paint [34].

Figure 3.2 shows two impasto-style portrait paintings, one by Rembrandt and the other



(a) An example of the color palette that was used by Rembrandt: 'Old Man with a Beard'

(b) An example of the color palette that was used by Cartmell: 'Old Man Impasto Color Study'

Figure 3.2: Side-by-side comparison of color pallets of Rembrandt and Cartmell.

by Greg Cartmell. Both paintings show how color can achieve multiple objectives. In the painting shown in Figure 3.2a, Rembrandt Van Rijn utilizes earth tones and greys to achieve his grungy and dirty look that is apparent in many of his paintings [35]. The painting shown in Figure 3.2b is an old man impasto study by Greg Cartmell demonstrating how, even with a different color palette and more abstract style at his disposal, Cartmell can still achieve the same visual consistencies as Rembrandt. These examples show how different shades can help render light and shadow. Not only do they utilize different levels of blackness and colors to adjust the highlights on the surface of the subject, but they also very skillfully draw the eye to towards the important aspects of the painting by playing with areas of high contrast. The transfer of light foreground to dark background creates a focus and center to the artworks.Impasto paintings have a waxworks quality, with evenly lit, colourful figures acting in a clearly organized space. The revolutionary change that took place in Rembrandt's style between about 1627 and 1629 [36] involved the role of light.

By concentrating the light and by exaggerating the concentration of the force of light in relation to the distance from the light source, Rembrandt arrived at what could crudely be termed 'spotlight effects'. In order to create convincing light effects, Rembrandt adjusted by leaving large areas shrouded in shadow.

3.1.3 Composition

In this section, we analyze the painting references based on the artistic aspect of layout and composition, which refers to how the artist arranges composition of foreground, midground and background elements harmoniously in the aesthetics of impasto-style portrait painting.

One of the major characteristics of any Rembrandt painting, either portrait or non portrait, was his ability to tell a story with his composition. This stemmed from his experiences in narrative painting, and it served as a prominent aspect of all his compositions [37]. He was very skilled at creating a strategic focal points around which the entire composition is about. Everything within that focal point is important because it all serves to tell the story of what Rembrandt was trying to tell within that painting. Every expression, posture, or body placement served to tell his story and was key to the composition of his pieces. The 'relief' aspect of impasto-style paintings also add the complexity of the composition. When you apply the many layers of paint, and it dries away from the canvas, the subject in the painting come away from the canvas.

The lost and found aspect in respect to the edges of the painting also manipulates the composition. Rembrandt and Greg Cartmell skillfully fade the edges into shadow and will abruptly bring edges back into the light, sometimes in a very non realistic way. This allows the composition to have a lot of depth going into the background instead of making the subject appear flat. In Figure 3.3, we have 'St. Bartholomew' by Rembrandt. In this painting alone we have multiple examples of how Rembrandt was able to affect the

Figure 3.3: An oil painting by Rembrandt: 'St. Bartholomew'.

composition to fit his narrative storytelling style. This painting demonstrates some subtle approaches that enhanced his composition; the lost and found edges, moody lighting, and texture of the paint and canvas. The unsettling angle of his pose and expressions convey a lot of about what his subject is going through at this particular time [38]. Also the dramatic lighting creates that focal point that we talked about earlier; the viewer eyes go directly to St. Bartholomew's face. The loose brush work and textures of the paint and canvas also add to the overall shape and form of the composition.

4. PROCESS

In this section, we present a process for creating impasto portrait paintings from 3D facial models. The characteristics of impasto-style portrait paintings that our shader will try to generate in our renders are organized into four categories: (1) Color Value and Tone, (2) Shape and Form, (3) Lighting and Shadow, (4) Composition. These are the same attributes that were identified in our analysis that we will implement into our shader. Our shader gives users an easy to follow methodology that enables them to generate impasto-style renders.

To begin, first a 3D scene is designed and modeled to represent the objects that are necessary for a portrait painting. This includes a high detail sculpt of the subject, lights, and a simple plane representing the canvas of the painting. Then, custom NPR surface shaders, which are comprised of paintings and custom filters developed in Adobe Photoshop, are attached to the 3D meshes from within the custom shader in AutoDesk Maya. Virtual CG lights will also be created and used to illuminate the surfaces. The user is able to artistically control the 3D rendering results by adjusting the parameters linked to the custom filters. Then, by using different render passes that will eventually be composited from within Adobe Photoshop, beauty and ambient occlusion passes, the user will be able to have full control over the final results. and assemble them together by using 2D image processing operations Figure 4.1 gives a brief breakdown of the process used to develop the final animation.

4.1 3D Modeling and Scene Development

4.1.1 Low Polygon Model

In order to create a believable replication of portrait painting composition, we begin by developing a low polygon model from our photography references. We chose this method

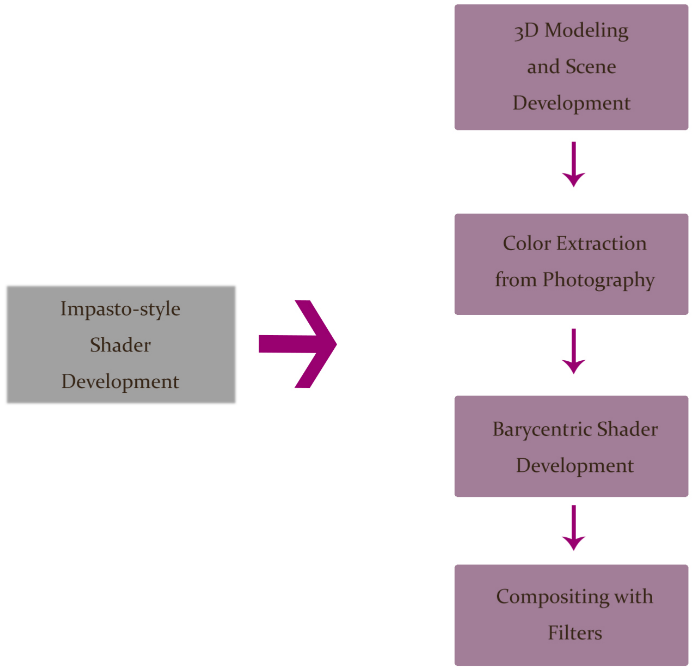
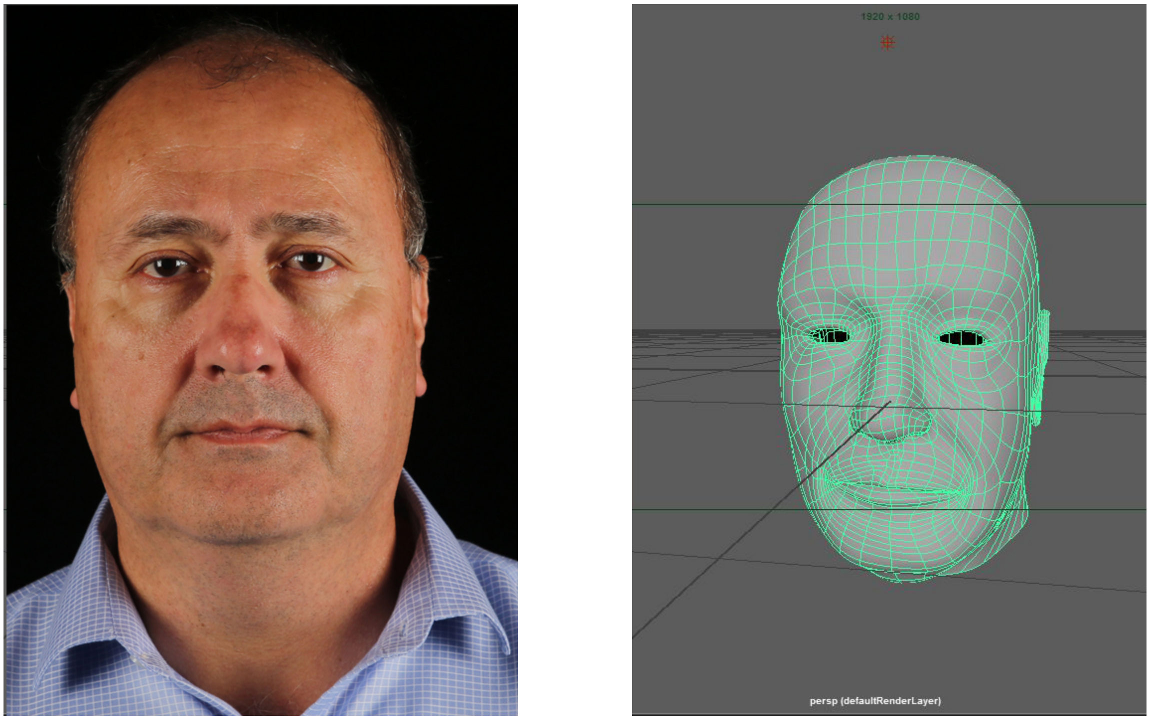


Figure 4.1: This flowchart illustrates the general process that we take to develop our impasto-style shader.

because generating our images from tangible sources is how painters paint on a canvas.

Our 3D meshes are then modeled in Autodesk Maya using our photograph as visual reference. We started with a cube and blocked out the important visual aspects of the face, like the nose and mouth. We then focus on creating proper typology and curvature of the face. Figure 4.2 shows the beginning of the modeling process as compared to our reference. Adding features such as hair are not included in the parameters of this thesis. We start with a low polygon model for several reasons:

- A low polygon model provides a low vertex count which yield faster render and computation times.



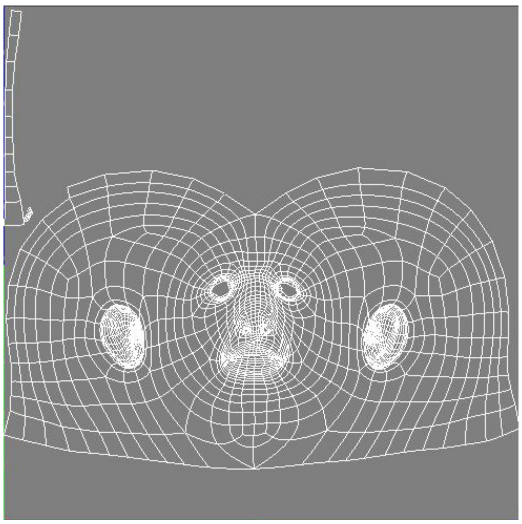
(a) Our initial photography reference captured in a studio

(b) Our finished low polygon model based on photograph reference

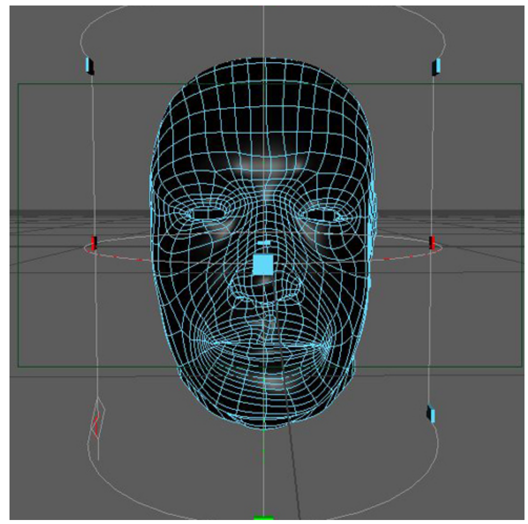
Figure 4.2: Our initial composition is consistent with traditional portrait photography, in that we crop our from just below the shoulders and have a slight amount of headroom to keep the focus of the subject in the center of the frame.

- UV unwrapping is much easier on a low vertex count model, as opposed to a model with many vertices.
- All the information from the low polygon model can be transferred to a high polygon count model.

After creating a low polygon model, the next step is to generate a usable UV unwrap. Unwrapping is important because it allows us to take our 2D textures, which we will create, and place them onto the surface of our 3D model. UVs are two-dimensional texture coordinates that correspond with the vertex information for your geometry. UVs are vital because they provide the link between a surface mesh and how an image texture gets applied onto that surface. They are basically marker points that control which pixels on the texture corresponds to which vertex on the 3D mesh.



(a) UV unwrap 2D



(b) UV unwrap model view

Figure 4.3: Figure 4.3a is a screenshot from Maya showing the UV layout of the low polygon face model. As you can see, the UV'S are well organized and the faces are not overlapping on top of each other. Figure 4.3b shows the cylindrical unwrap of the head mesh. These images show the relationship between the 2D UV unwrap and the 3D model. As you can see the UV unwrap is a flat 1 to 1 representation of the 3D model. All the faces translate uniformly from one to the other.

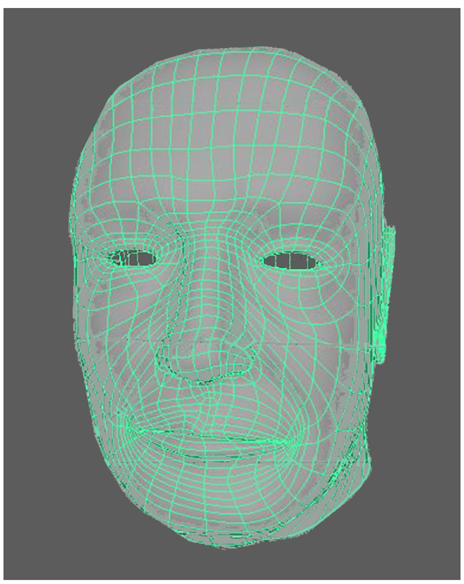
The three main unwrapping methods are:

- Planar mapping projects UVs onto a mesh through a plane. This projection is best for objects that are relatively flat, or at least are completely visible from one camera angle.

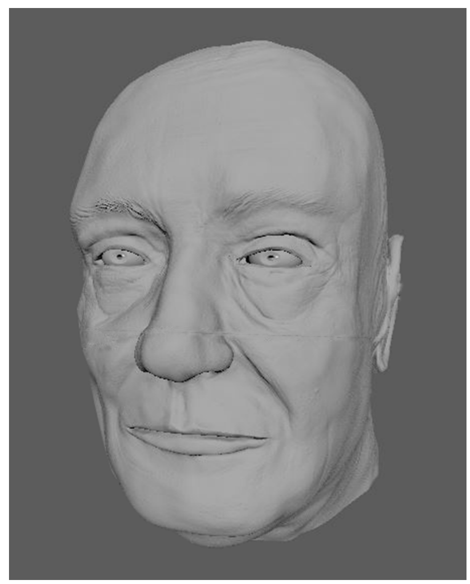
- Cylindrical mapping creates UVs for an object based on a cylindrical projection shape that gets wrapped around the mesh. This projection is best for shapes that are both vertical and round in nature.

- Spherical mapping create UVs using a projection that is based on a spherical shape wrapped around the mesh. The main difference between spherical and cylindrical mapping is cylindrical mapping has a vertical component that spherical mapping doesn't necessary have.

For this thesis we used cylindrical mapping. The reason for this decision is because even though the head is circular by design, it unwraps much cleaner using cylindrical mapping because of the vertical stretch that heads have. Using spherical mapping on the head would lead to a very squashed unwrap. Figure 4.3 shows the results of the unwrap utilizing the cylindrical unwrap.



(a) Wireframe of the model.



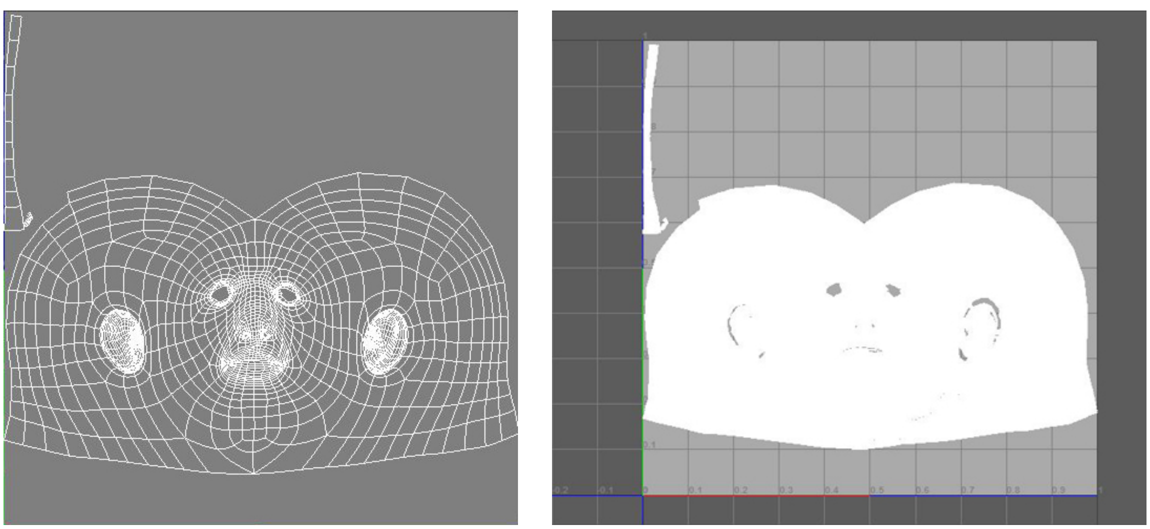
(b) Simple rendering of the model.

Figure 4.4: Our low polygon and high polygon sculpt that we created based on our photographic references in Figure 4.8

4.1.2 High Polygon Sculpt

Portrait painters are extremely skilled at subtely suggesting details in their paintings; ie. wrinkles, creases, pores, etc. In the case of impasto portrait paintings, they not only physically painted in extra details, but they used layers of color and the canvas texture itself to amplify the effects of these details on their subjects. We simulate this by doing a high detail polygon sculpt of our low polygon model.

The high polygon sculpt was made in ZBrush, and it has added details such as wrinkles in the skin, more detailed curvature to more accurately match the photographic reference, and also has about 1 million more polygons than the original low polygon mesh. Figure 4.4 shows a visual comparison of the low and high polygon meshes.



(a) low poly uv (b) high poly uv

Figure 4.5: Figure 4.5a is a screenshot from Maya showing the UV layout of the low polygon mesh. Figure 4.5b shows the result of the transfer attributes command on the high polygon sculpt UV layout. When we compare the two unwraps, you can see how the vertices are located in the same position.

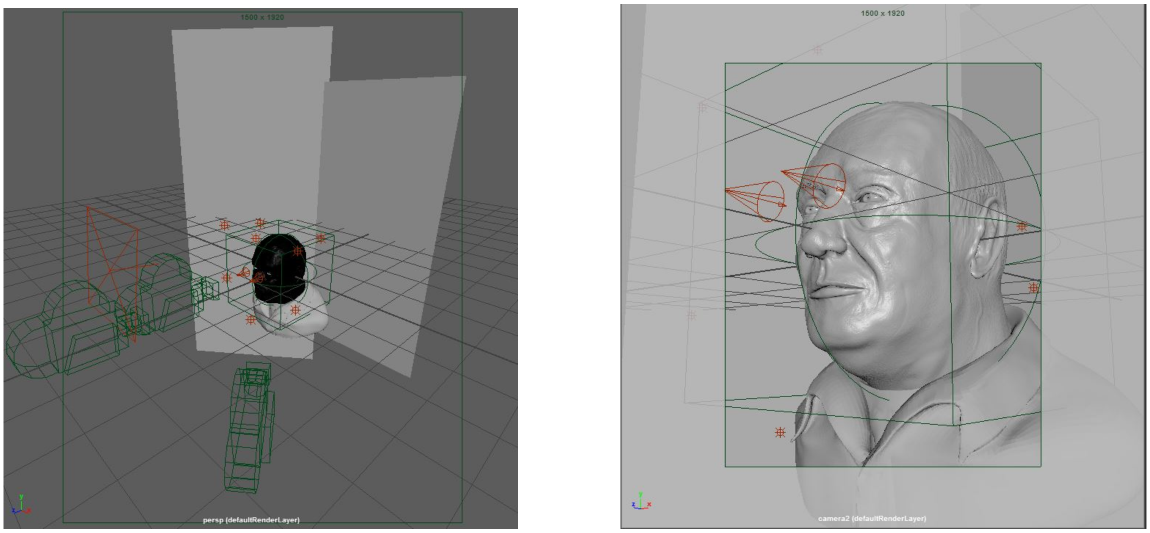
The added density creates a challenge to the unwrapping process. Attempting to accurately and meticulously unwrap one million vertices is near impossible. To solve this issue we use a feature in Autodesk Maya called Transfer Attributes. Transfer Attributes transfers vertex data by sampling the vertex information on the source mesh, the low polygon mesh, and then transferring the information to the specified target mesh, the high polygon sculpted mesh, based on a comparison that is spatially based. The target mesh gets modified as a result. Figure 4.5 shows the results of the transfer attributes method.

4.1.3 Scene Development

In our compositional setup, the main driving force behind the design was we wanted to tell a story with our composition, just like impasto paintings do. In order to do that we need to establish a focal point not only with the 3D camera, but also with lighting. We wanted it to be more dynamic than just a standard front shot perspective. All the models and 3D cameras are then created in Autodesk Maya to try and match the desired compositional requirements. We used a single source light to not only illuminate the entire face, but to also cast dramatic shadows. There are back lights and lights that are strictly responsible for lighting the background. Figure 4.6 shows the final scene layout.

4.2 Color Extraction from Photography

In this section we discuss the process of extracting color information from photography to assist us in developing our painterly shader. Artists collect all of their color information directly from observing their subjects. We start with photographs because we are trying to simulate the process that artists use when they are painting their subjects. We then discuss how we extract necessary color and shadow information in Photoshop



(a) Scene layout

(b) 3D camera viewport

Figure 4.6: Figure 4.6a is a screenshot from Maya showing the scene layout from a top angle. From here we can see the lighting and model placements in respect to one another. Figure 4.6b shows the final animation layout from the 3D camera.

(a) Photography errors 1

(b) Photography errors 2

Figure 4.7: Figure 4.7 shows two examples of early errors during the photographic process. Figure 4.7a shows the harsh lighting on one half of the face, the over exposed left side, and the hard shadows on the right. There is no gradual falloff. Figure 4.7b the light falloff end in the middle of the face, around the nose, and then becomes slightly brighter on the right.

4.2.1 Image Collection Process

Our goal from taking these photographs is we want to capture the average dark and light values across the face from different light angles. In order to collect this information, we took still frame images of our subject with a mobile light rig. We used a wide soft light in order to evenly illuminate the entire face. We wanted to try and eliminate any harsh lights and shadows across the face. Having an uneven distribution of light and color would give us inaccurate results.

Figure 4.7 shows a couple early samples of the photographic process. A few errors are immediately apparent from these images. Since our goal is to find the average light and dark values from a variety of angles, our initial setup was fundamentally flawed. In Figure 4.7a, notice the long hard shadow along the right side of the face and the over exposed left side. This will not give us any sort of average values because it goes from 0 to 1 with nothing in between. Figure 4.7b has slightly different results, but nonetheless it still gives us faulty data. The left side is overexposed with a value of 1, the middle of the face shifts to a value of 0, and then shifts to a value of 0.5 on the right side of the face. This will not give us reliable average color data because the values oscillate too abruptly and don't give us an even distribution across the face.

We eventually developed a method that addressed these issues. We started by using a very soft light that evenly illuminated the entire face. The reason for this soft light is so we can avoid the harsh shadows and such sudden falloff like we find in Figure 4.7. In order to determine an accurate enough average dark and light color value, we need to have a large amount of sample images to pull from. In Figure 4.8(a-l), you can see how our method was finalized. In addition to the soft light, we used only a single source light to illuminate the face. The single source light has three different heights:

- 0°in the y direction: Light shifts from 0°to 45°, to 90°, to 135°, and finishes at

180°along the x direction.

- 90°in the y direction: Light shifts from 90°to 45°, to 90°, to 135°, and finishes at 180°along the x direction.

- 180°in the y direction: Light shifts from 180°to 45°, to 90°, to 135°, and finishes at 180°along the x direction.

Using this setup, as you can see in Figure 4.8, we achieved a more gradual transition of light to dark color value across the face.

4.2.2 Dark, Midtone and Light Map Influence from Photography

We will be using our photographic images from Figure 4.8(a-l) as our source images to help us create our light and dark maps for our shader. Currently, with every image, we have an individual example with how the light falls off on the face from one specific angle. What is important for us to understand is how color is distributed from all angles at any given time. In our to do this, we will be utilizing Photoshop's blending modes. For this specific project, the Lighten and Darken blending modes worked best for achieving our desired results.

- Lighten looks at the color information in each channel and selects the base or blend color; whichever is lighter, and assigns this as the result color. Pixels darker than the blend color are replaced, and pixels lighter than the blend color do not change.

- Darken looks at the color information in each channel and selects the base or blend color; whichever is darker, and assigns this as the result color. Pixels lighter than the blend color are replaced, and pixels darker than the blend color do not change.

We stack the images on top of each other and apply the two blending modes on the images. We know that Photoshop is looking at either the darkest or lightest pixel, depending

Figure 4.8: Figure 4.8(a-l) are portrait pictures captured in a studio with a single light source. The single light source was placed at three different heights and moved in increments of 45 degrees across the face. Figure 4.8(a-d) have the single light source at the highest point on the face, (e-h) shifted to the middle of the face, and (i-l) moved to the lowest point of the face.

on which blending mode we are using, so the specific order that the images are layered does not affect the final image.

(a) (b)

Figure 4.9: Figure 4.9 shows the results of using the darken blending mode. Figure 4.9a shows the original photograph of the subject with even lighting. Figure 4.9b shows the effects of the darken blending mode. The dark color values from Figure 4.8(a-l) have been averaged and combined into one image.

From Figure 4.9 and Figure 4.10, you can see how we were able to achieve an even distribution in our light and dark maps. Figure 4.9 will be used as our mid tone shadow map, or our C_1 color value. However, if you look at Figure 4.10, you will notice an overabundance of overexposed regions along the face. This information is valuable when we create our specular map, or our C_3 color value, but for our light map, this information needs to have more of an even 'matte' tonal value across the face. To fix this issue, we sampled the color values just outside of the overexposed 'hotspot' regions in order to soften the effects of the lighten blending mode. The results arent perfect, but it definitely results in a much smoother overall color tone. Figure 4.11 shows a close up of the sampled areas for part of the face, and Figure 4.12 shows a comparison of the edited and non edited lighten blend mode images.

(a) (b)

Figure 4.10: Figure 4.10 shows the results of using the lighten blending mode. Figure 4.9a shows the original photograph of the subject with even lighting. Figure 4.10b shows the effects of the lighten blending mode. The light color values from Figure 4.8 have been averaged and combined into one image.

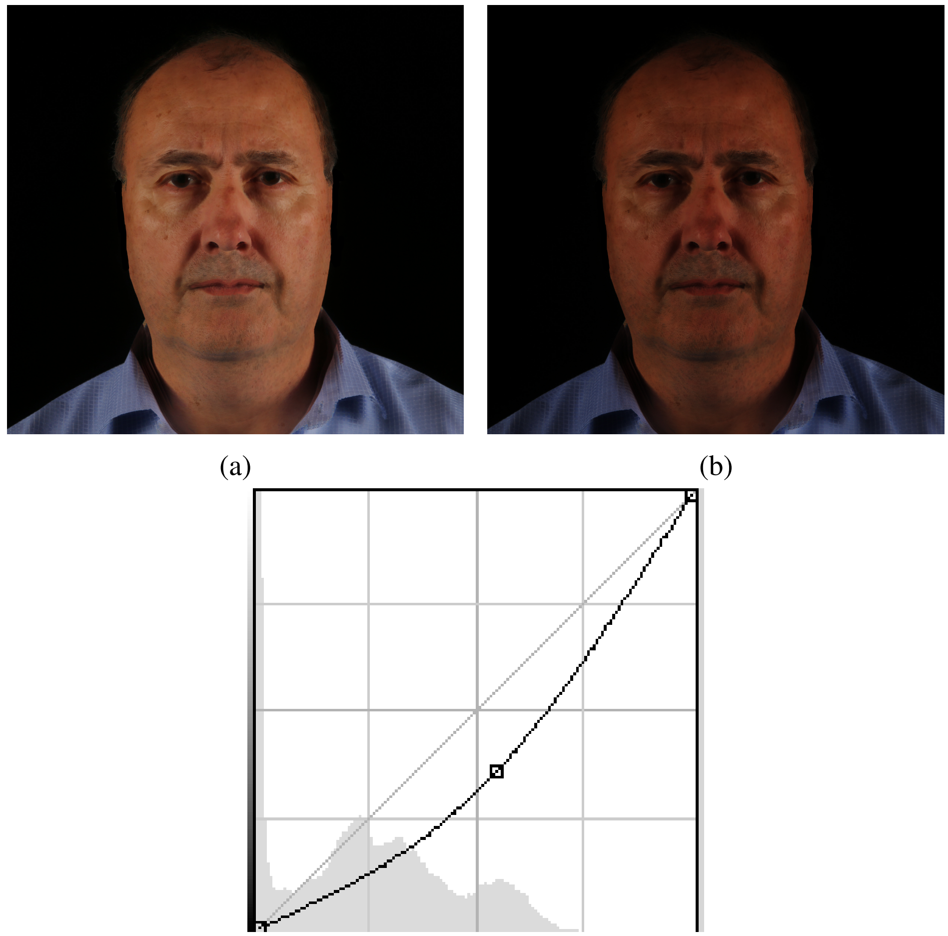
(a) (b)

Figure 4.12: Figure 4.12a shows the original results of the lighten blending mode. Figure 4.12b shows the results of touching up the overexposed regions by sampling neighboring color regions.

(a) (b)

Figure 4.11: Inside the red circle on Figure 4.11a shows an example of a region that was used to correct the overexposed regions as a result of the lighten blending mode. Figure 4.11b shows the result the color samples had on the overexposed regions.

Figure 4.12b will be known as our diffuse illumination map, or our C_2 color value. Now we need to create our final map, our shadow map. This map will represent the dark values that are not being illuminated by any light source. In order to do this, we take our C_1 color map and adjust the RGB curves of our image, adding more dark reds and darkening the original image. Figure 4.13 shows the result of this adjustment. This new image because our shadow map, or our C_0 color value.



(a) (b)

(c)

Figure 4.13: Figure 4.13a shows the orginial C_1 color map before the curves adjustment. Figure 4.13b is our C_0 map after the curves adjustment. Figure 4.13(c) shows the curves adjustment that was used to modify the original C_1 image

4.3 Barycentric Shader Development

The fundamental approach to creating our shader consists of multiple steps:

- Using the the color maps that we created in the section above as the groundwork to paint our texture maps.

- Create a shading network within Autodesk Maya that gives the user the ability to oscilate between their color maps smoothly based on light positioning and intensity

- Using Photoshop as our main compositing software, we generate our painterly filter by combining already known filters and brushes from within Photoshop to create our final look

- We then batch render our final style to create our final animation

4.3.1 Custom Tone Map Generation based on Photographic Editing

We begin our shader development process by creating our color maps from our photographs. We created four maps that our shader is based on, our diffuse color map, midtone shadow map, dark shadow map, and our specular map. These maps are going to govern the tonal range of our renders. Figure 4.14 shows our color palette that we extracted from our photographs in our earlier section.

(a) (b) (c)

Figure 4.14: Figure 4.14a is our diffuse color palette, Figure 4.14b is our midtone color palette, and Figure 4.14c is our dark shadow color palette.

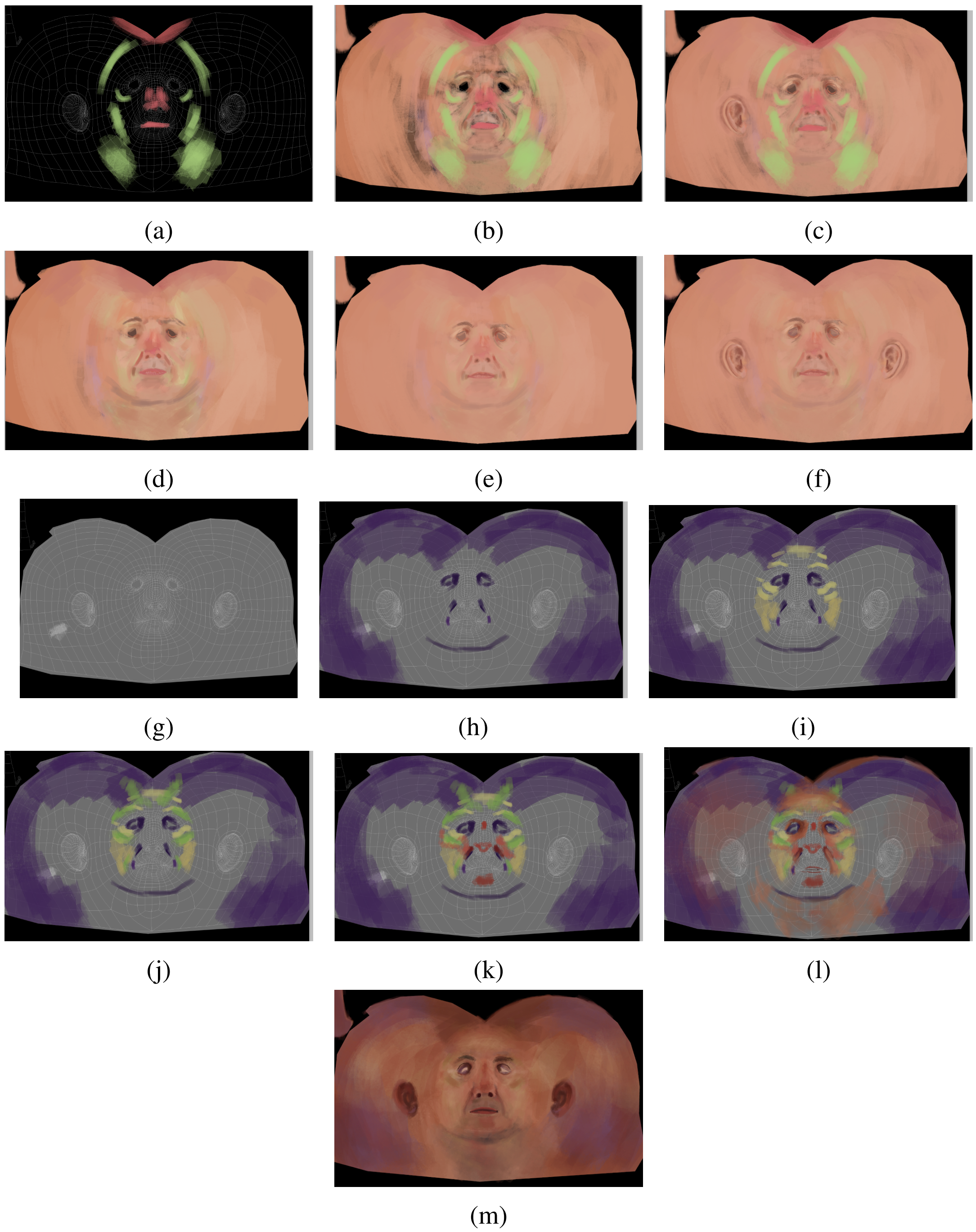
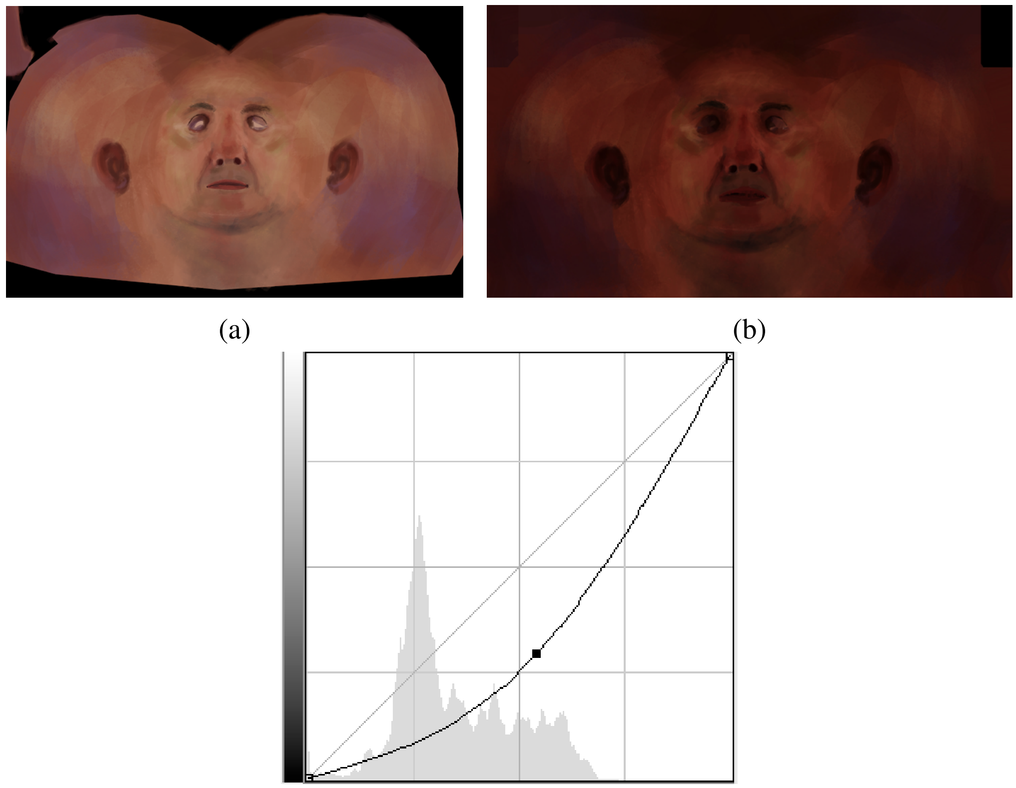


Figure 4.15: Figure 4.15(a-f) shows the painting process of generating our diffuse color map. Figure 4.15f is the final result. Figure 4.15(g-m) shows the painting process of generating the midtone shadow color map. Figure 4.15m is the final result.



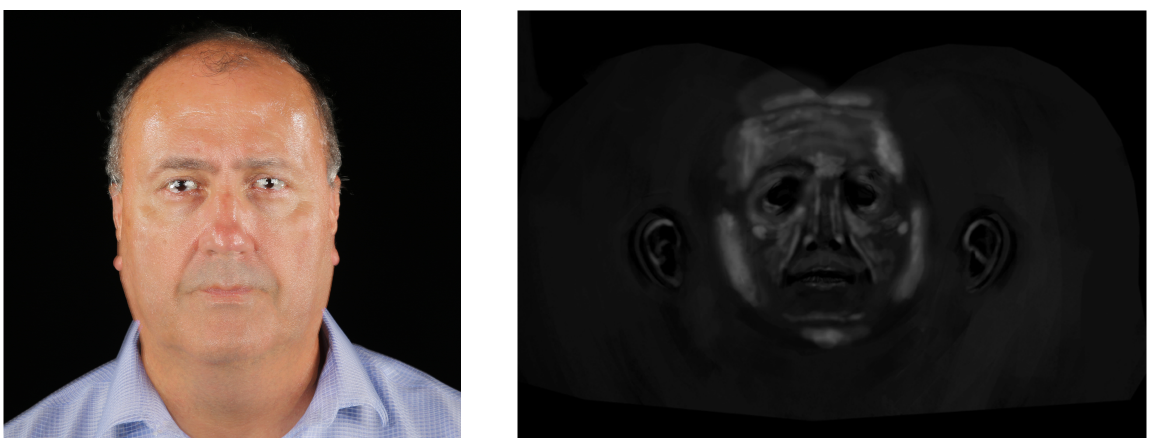
(a) (b) (c)

Figure 4.16: Figure 4.16a shows the orginial C_1 color map before the curves adjustment. Figure 4.16b is our C_0 map after the curves adjustment. Figure 4.16c shows the curves adjustment that was used to modify the original C_1 image

In Figure 4.5, we showed the UV layout of our 3D model. This UV layout will be our guidebook to paint on for our color maps. When we paint on the UV map, each of the faces corresponds to a face on the 3D model. Painting directly on the UV map will have a 1 to 1 effect on the 3D model. Figure 4.15 shows the process we took to paint our light and midtone maps in Photoshop. To generate our dark shadow map painting, we take the same approach as in Figure 4.13; adjusting the curves to slighting darken the RGB values. Figure 4.16 demonstrates the results of this process.

One of the important aspects of our projects is to not only develop a rigid animation in the style of impasto portrait paintings, but it is also to replicate the physical and visual characteristics of the skin on the subject. When our light source changes position, we want our skin to react not only with adjusting color tones, but we also want the specular highlights to react in response to the light. So we will create another parameter, C_3 which will act as our specular reflection parameter.

Specularity is a term used to define the surface's shininess and highlight color. Specular strength is defined in between the values of 0 to 1; 0 meaning no specularity, 1 meaning completely specular. When we talk about specular maps, which are maps that define where the specularity is on the face, 0 also means completely black and 1 means completely white. We use our photographic reference from Figure 4.12 as visual reference for our specular map. Figure 4.17 shows our specular map as compare to our photographic reference.



(a) (b)

Figure 4.17: Figure 4.17 shows the creation specular map influenced by our photographic reference. The closer the values in the specular map are to 0, or black, the less specular those regions will be in the renders. The closer the values in the specular map are to 1, or white, the more specular those regions will be in the renders.

4.3.2 Barycentric Shader Creation

To combine texture images for shading we use barycentric shaders. Using barycentric shaders, we must only restrict shader operators to be of the form

$$c = \sum_{i=0}^{M} \omega_i C_i \quad \text{where} \quad \sum_{i=0}^{M} \omega_i = 1 \quad \text{and} \quad \forall \omega_i \geq 0$$

where the C_i's are colors, i.e. n-tuples of positive real numbers. The restriction that the weights ω_i are all positive and sum to 1 is called the partition of unity property, which guarantees that solutions c stay inside of the convex hull defined by the colors C_i. This restriction does not impose any limit over the polynomials we can use. In fact, basis functions of most widely used parametric polynomials in geometric modeling, such as Bezier, B-splines or β-splines, satisfy this property. For instance, if we choose $\omega_0 = (1-t)$ and $\omega_1 = t$ with $0 \leq t \leq 1$, we obtain the mix operator, which utilizes basis functions of first degree Bezier curves. Similarly, it is easy to see that the degree zero B-spline basis functions, namely,

$$N_{i,0}(t) = \begin{cases} 1 & \text{if } t_i \leq t < t_{i+1} \\ 0 & \text{otherwise.} \end{cases}$$

satisfy partition of unity and each t_i is called a knot. Moreover, higher degree B-spline basis functions

$$N_{i,p}(t) = \frac{t - t_i}{t_{i+p} - t_i} N_{i,p-1}(t) + \frac{t_{i+p+1} - t}{t_{i+p+1} - t_{i+1}} N_{i+1,p-1}(t),$$

that are obtained by the Cox-de Boor formulation also satisfy partition of unity. More importantly, any parametric rational or irrational polynomial or piecewise polynomial can be converted to a form that satisfies the partition of unity property [39]. In addition, the convex hull property, which comes with partition of unity, is particularly useful in practical shader development applications, since it provides an intuitive control mechanism for obtaining desired results.

Let us now demonstrate Baycentric shaders in a very simple example that is shown in Figure 4.18. Let w_1 denote illumination function that is by a lump sum value that include illumination coming from ligits and ambient occlusion for a given pixel. If we mix only two images, then w_0 is simply computed as $w_0 = 1 - w_1$, which represents areas that are not illuminated for given pixel. Note that since both w_0 and w_1 are given for all pixels of a rendered images, we can represent them as images $W_0 = w_0(u, v)$ and $W_1 = w_1(u, v)$, as shown in Figure 4.18. The rendering then can be represented as a simple compositing operation as follows:

$$I_{final} = I_0 W_o + I_1 W_1$$

where I_0 and I_1 two images that are obtained by projected texture mapped shape into image space as shown in Figure 4.18. As shown in this example, the resulting rendering becomes very close photographic results since we obtain both dark image I_0 and light image I_1 from actual photographs.

In our implementation, instead of two, we use three images to obtain diffuse illumination. The third texture image is simply obtained by interpolating and slightly changing the original images. To interpolate three images, we use a first degree B-spline functions [39]. This operation can be implemented either in post-production or during rendering. In our current implementation, we use mental ray Plug-in for Autodesk Maya to obtain results directly from rendering.

We chose to implement our Barycentric methodology using a Ramp Shader, provided by Autodesk Maya. We chose to use a Ramp Shader because it allows us to have extra control over the way color changes with light and the view angle. All the color-related attributes in the Ramp Shader are controlled by ramps (gradients). Many of the controls

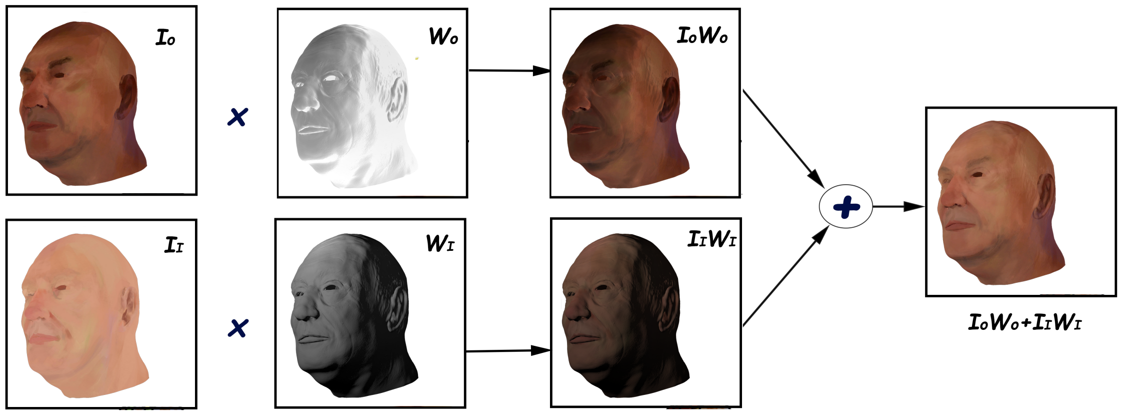


Figure 4.18: Barycentric mixing of the two images using two weigh functions that adds up to 1.

within the shader have graph attached to them, which helps keep the shader clean and non congested. The controls that we will be manipulating from within the shader are:

- Color and Color Input. Color is manipulated on a ramp. Colors interpolate between each other in the form of a gradient. Color Input is how the colors the colors interpolate along the surface of the mesh. For this thesis, normalized brightness worked best for our needs. On the color ramp, The right side of the ramp is the output color where the brightness of the diffuse and translucent lighting is 1.0 or greater. The left side is the output color where the brightness is zero. This is where our C_0, C_1, and C_2 are defined.

- Specularity and Specular Roll off. This modulates or scales the intensity of the specular highlight. The facing ratio is the input to the graph. This is where our C_3 is defined.

- Shadow Shaded Color controls. We use this because we want to specify a particular shadow color that has gradients based on the background or objects that the shadow is cast on. This is where our C_0 is defined.

To test our shader, we create an initial setup that demonstrates the capabilities of the ramp. For our initial test, we use our photographic color maps as our C_0, C_1, and C_2 inputs.

(a) C_1 (b) C_0 (c) C_2

Figure 4.19: Figure 4.19 shows three initial test images for our ramp shader. Figure 4.19a is our C_1 component, or our midtone shadow influence, Figure 4.19b is our C_0 component, or our dark shadow component, and Figure 4.19c is our C_2 component, or our diffuse component.

Figure 4.20 shows the initial results of our shader configuration. The only influence on these images are shadow and diffuse components. There is no specular influence at this stage. For this scene, we are using a single point light that we move to a few different locations to evaluate the effectiveness of the shader. As you can see, the most illuminated sections are displaying our C_2 component, which is on the far right of the ramp. As the light falls off, C_0 and C_1 are blended for a seamless transition.

(a) (b)

(c) (d)

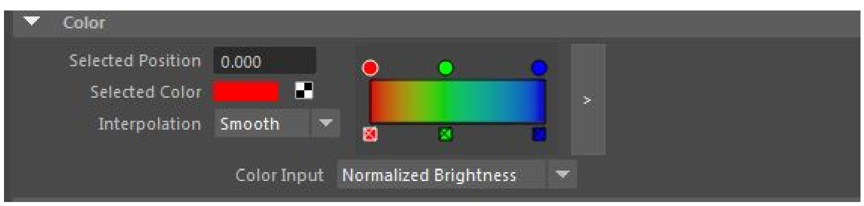
Figure 4.20: Figure 4.20 shows initial test results of our ramp shader.

In the next chapter, we talk about how we implement our Barycentric shading and filter method by using an educational version of Maya 2016, which is an existing 3D software, and Adobe Photoshop CS5 for all of our image compositing needs. We talk about the process of creating our final 3D portrait animation scene. Figure 4.1 shows the basic process of developing the final animation.

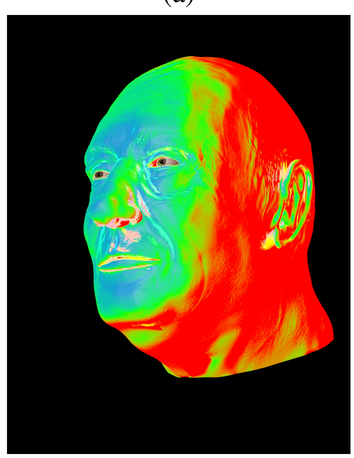
5. IMPLEMENTATION AND RESULTS

5.1 Barycentric Shader Implementation in 3D Software

In order to visualize how the light is affecting the interpolation of our texture maps, we apply red, green, and blue to our ramp. Red will act as our C_0 component, green will act as our C_1 component, and blue will act as our C_2 component. This will give us a clear indication of the light falloff and where the transitions of color are occurring. Figure 5.1 shows the ramp color settings as well as the rendering results that correspond to those settings.



(a)

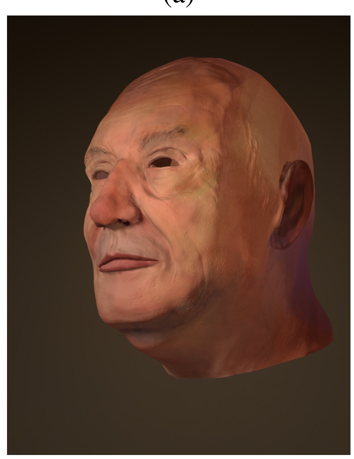


(b)

Figure 5.1: Shows how the ramp shader interprets the color information based on the light information.

In our test scene of our ramp in Figure 5.1, we have a single point light in front of the face that is influencing the render results. In Figure 5.1a, the left side of the ramp is 0, i.e. where the light has severely fallen off. The right side of the ramp has brightness of 1, i.e. where the light is directly hitting the surface of the object. The middle of the ramp is at a value of 0.5, i.e. where the light has fallen off halfway. Based on this information, we can see how the light is affecting the initial placement and interpolation of the color information. Since the right side of the ramp is blue and left side of the ramp is red, it makes sense that our render appears the way it does. If we now replace the RGB color values on our ramp with our painted textures from Figures 4.15 and Figures 4.16, this will result in our model more resembling skin with interpolating tonal ranges based on our ramp shader. Figure 5.2 shows the result of this render.

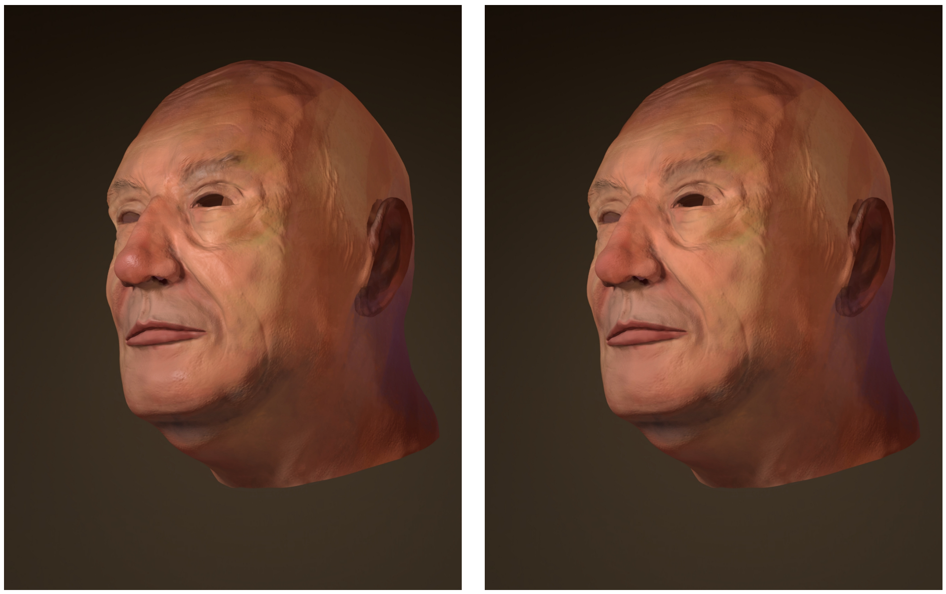
(a)



(b)

Figure 5.2: Shows the results of applying our painted maps into our ramp shader.

If you look at Figure 5.2b, you will notice there is no specular component influencing the specularity of the skin; we dont not currently have a C_3 component in our shader. Figure 5.3 shows a side by side comparison of the results with and without the C_3 component.



(a) with specular component C_3 (b) without specular component C_3

Figure 5.3: Figure 5.3 shows the effect the specular component has on the resulting render.

As you can see above, the ramp shader is giving us the artistic control to interpolate between any number of color maps based on the light position and intensity.

5.1.1 Ambient Occlusion Compositing

The next component of our final image is to address is the need for ambient occlusion. Ambient occlusion allows us to simulate the soft shadows that occur in the cracks and crevices of our model when indirect lighting is cast out onto our scene, such as around the mouth and eyes. The soft shadows that are created from ambient occlusion can help define the separation between the different objects in our scene, such as separation between the head and clothing around the necks. Figure 5.4 shows a visual concept for how ambient occlusion is working in a 3D scene.

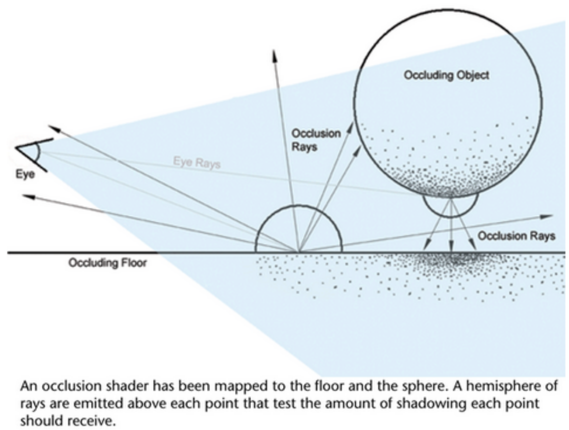
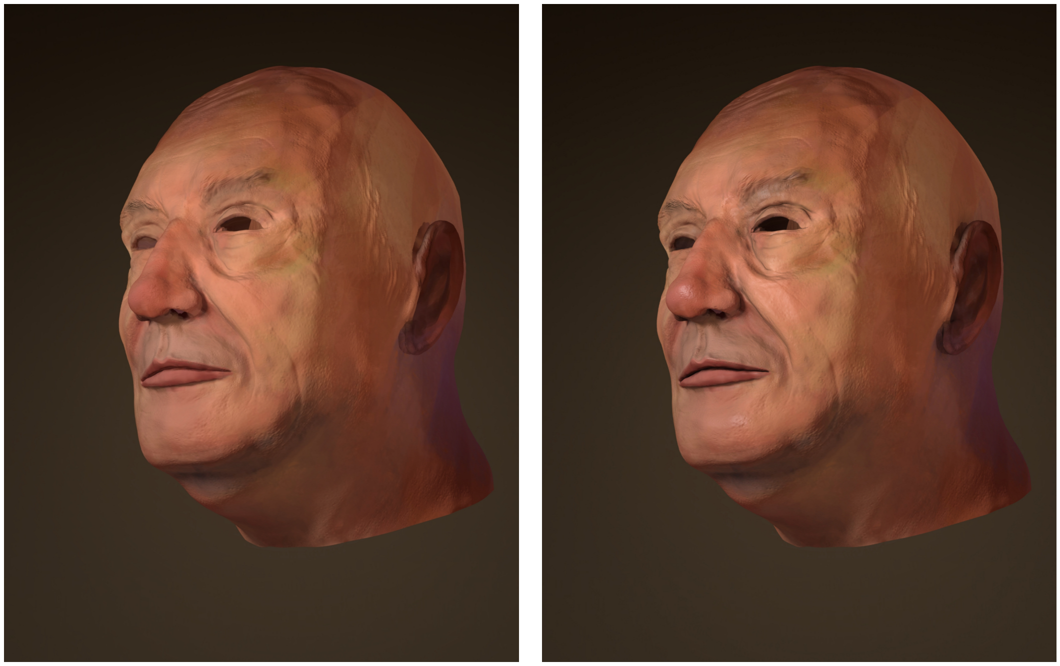


Figure 5.4: Screenshot demonstrating how ambient occlusion functions in a scene [1].

We generate our ambient occlusion pass in Autodesk Maya and composite our beauty pass and occlusion pass together in Adobe Photoshop using a multiply blend option.. As you can see in Figure 5.5, there are many added shadows that were originally affected by the indirect light's inability to bounce around and illuminate areas that are blocked by a nearby object that absorbs the light rays.

(a)

Figure 5.5: A render of our ambient occlusion pass



(a) render without occlusion (b) render with occlusion

Figure 5.6: Figure 5.6 demonstrates the impact that ambient occlusion has on the over render, especially around the neck, mouth, and ears. The ambient occlusion pass gives much needed separation between several of the geometry pieces.

As stated above, we used a Multiply blending mode in Photoshop to composite our occlusion pass from Figure 5.5 and our diffuse pass in Figure 5.6a. For this particular example, our application is done in post production. This method can be visualized in the following equation:

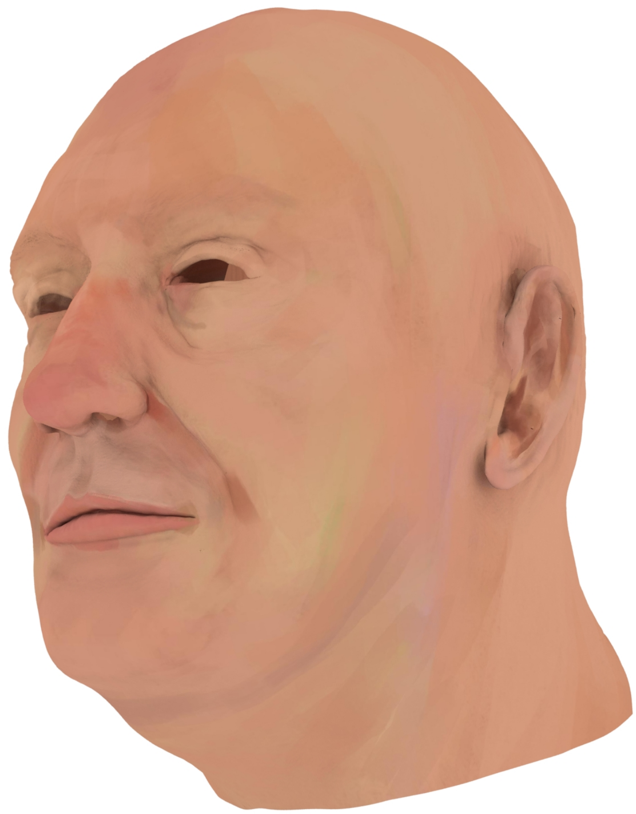
$$(C_0(1-t) + C_1(t)a)$$

where a is our occlusion component. This method of applying our occlusion pass to our final rendering does not give full artistic control to the artist when they are creating their images. If you reference back to the Rembrandt paintings in the earlier sections, you will notice that traditional painters do not paint with solid black and white. Everything is applied with varying values of color. If a is a value of 0 or 1, the entire equation will equalize at a value of 0 or 1. This will result in shadows or highlights that are a completely black or white. This does not give the artist any control in creating painterly looking images.

We adjust our methodology by applying our ambient occlusion directly to our Barycentric shader that we developed within Maya, compared to our original post production methodology. Applying our occlusion directly to our shader can be described as:

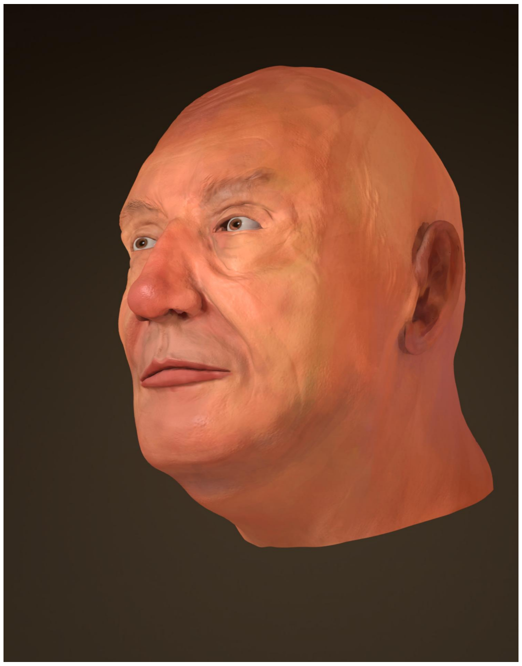
$$(C_0(1 - ta) + C_1(ta))$$

The benefit of our new method is the fact that our occlusion now is completely controlled by our texture maps. Even when a is equal to 0, which would equate to black, C_0 will have direct influence the occlusion map has on our final render. Our occlusion pass will be influenced by our texture maps, C_0 and C_1, as opposed to being influenced by simple black and white values. Figure 5.7 shows a render of our new occlusion map, as compared to Figure 5.5.

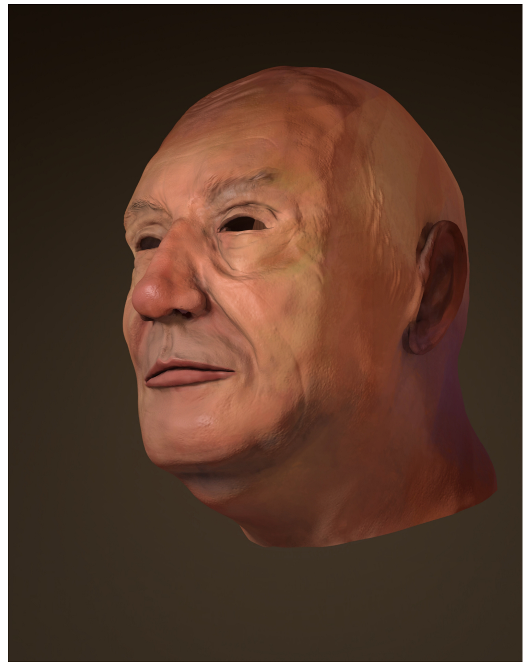


(a)

Figure 5.7: A render of our updated occlusion pass driven by our texture maps C_0 and C_1

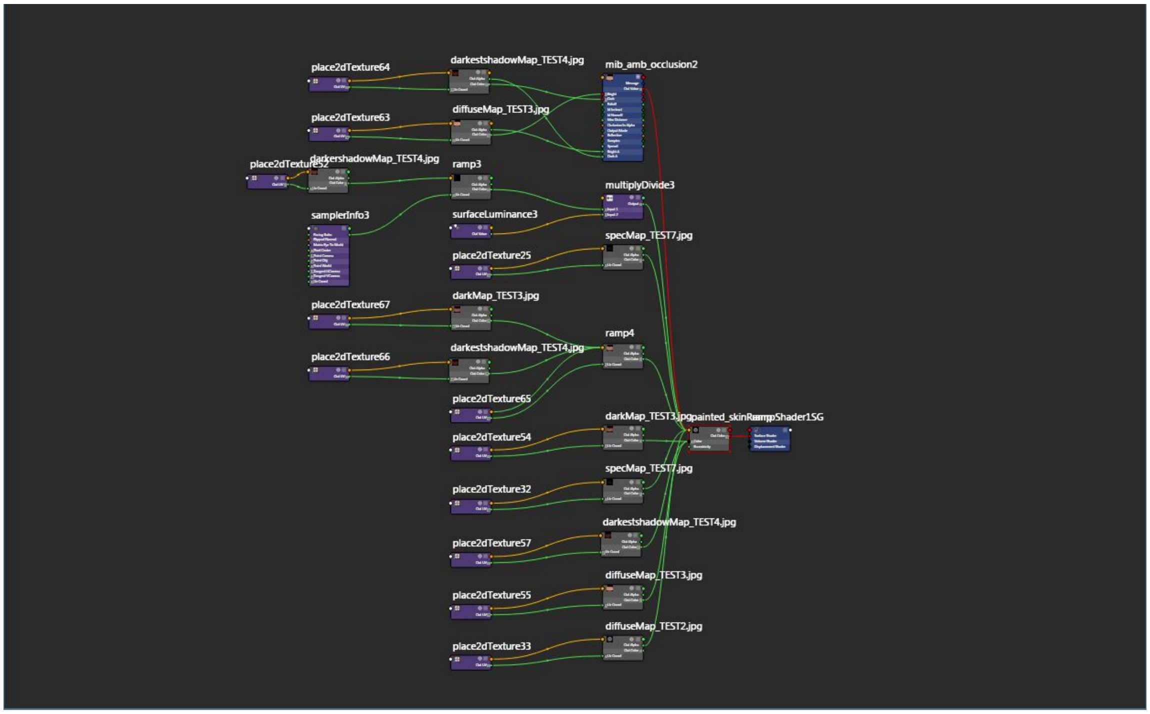


(a) render with color occlusion directly in the shader



(b) render with occlusion with black and whitel influence

Figure 5.8: Demonstrates the difference between the two methods of rendering occlusion. As you can see in Figure 5.8a, our color maps are influencing the ambient color and shadows which will enable much more artistic control. As opposed to Figure 5.8b, where the entire artistic control is dictated by the Multiply blending mode within Photoshop.



(a)

Figure 5.9: A screenshot showing the final Barycentric shader layout from within Maya

5.1.2 Final Scene Creation

To complete the scene, we added components that are commonly found in impasto portrait paintings, a background or canvas texture, clothing, and some resemblance of a shoulder line that tapers off towards the bottom of the page. Figure 5.10 shows a visual representation of the different objects and lights in the scene. Figure 5.11 shows the final scene render displaying the final lighting setup, compositional layout, and the final settings associated with the ramp shader.

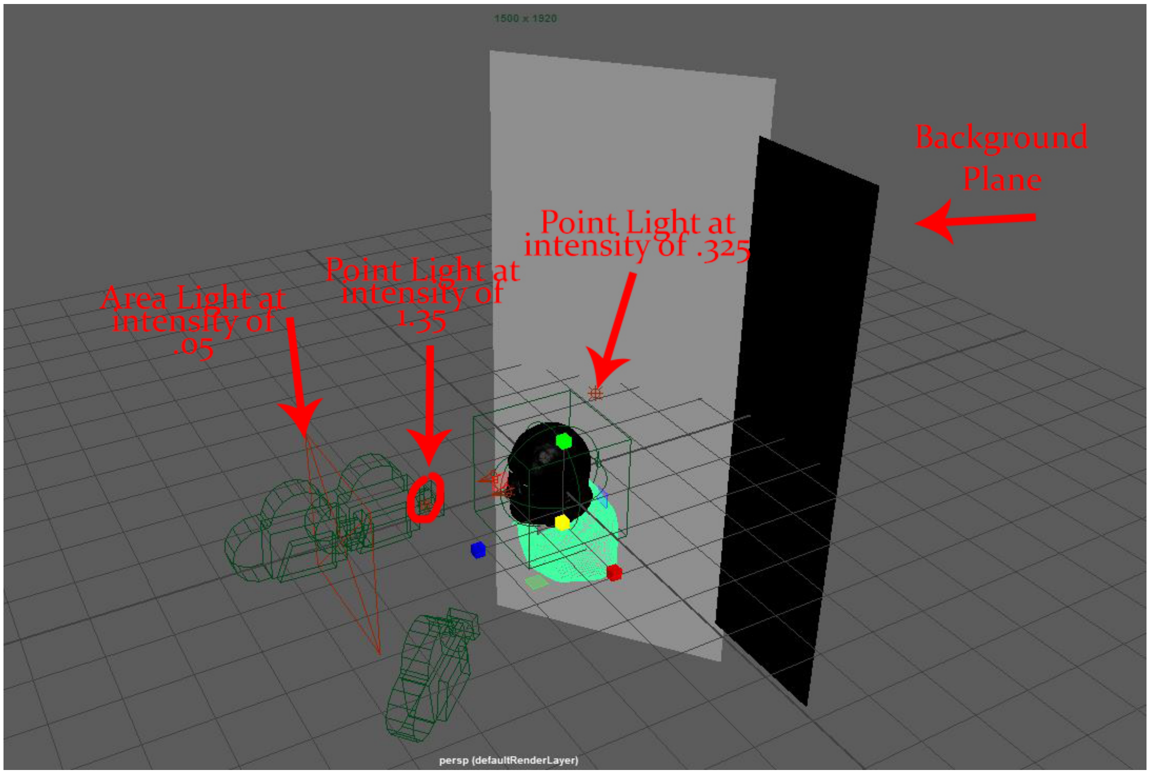


Figure 5.10: Screenshot from Maya of the light and background placement in respect to the subject.

Figure 5.11: Screenshot from Maya showcasing the combination of our C_0, C_1, C_2, and C_3 components. No filters have been added to this image.

5.1.3 Filter Creation and Final Image Composite

The final components of our thesis are to create filters that give our renders a portrait painting visual aesthetic, and to composite all the aspects of our images together. We will generate our filters in Adobe Photoshop, using existing filters from within the software. Since Photoshop does not have a node editor from within the software, we will be using Photodonut, a free Photoshop plugin to do our image compositing.

5.1.3.1 Photoshop Filter Compositing

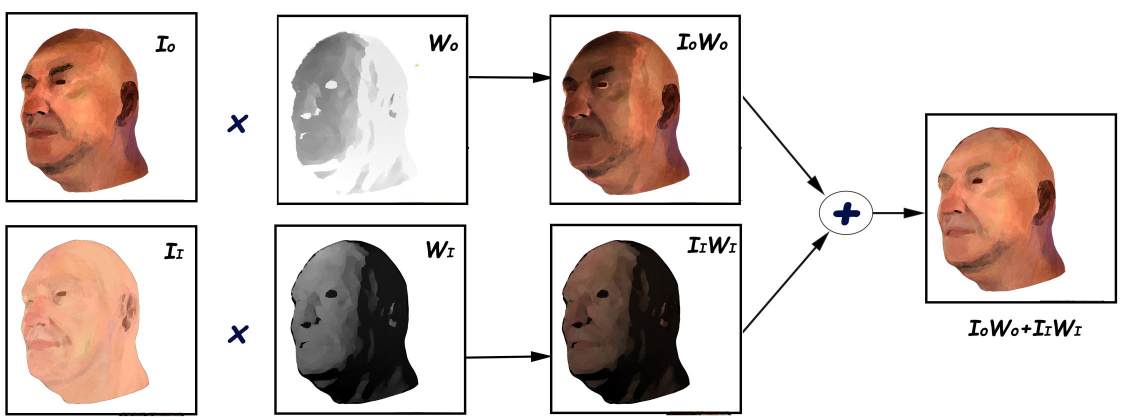


Figure 5.12: Barycentric mixing of the filtered layers in Figure 4.18 to obtain painterly portraits.

Figure 5.12 shows an example of Barycentric mixing of filtered images. Each layer is treated individually with a unique Photoshop filter. Note that we can use any painterly filter to obtain results from Haeberli's paint-by-number filters [19] to Zhao's statistical filters [16]. Another important issue is that the filters have to be applied to rendered layers not to textures. Filters applied to rendered layers creates imperfect boundaries as shown in Figure 5.12. The main advantage of this approach over filtering images is that each layer is filtered independently exactly like painters. For instance, dark colors can be filtered different than light colors. These choices are essential to obtain results similar to painters' work. When we apply filters directly to images, we do not have the option to filter different effects independently.

To composite all our filters together into an animated sequence, we use a Photoshop plug-in, Photodonunt. Photodonut allows us to batch render our created filters onto our renders using a source image. Figure 5.13 is an example of one of our source images that demonstrates a finished rendering of our painterly filter methodology.

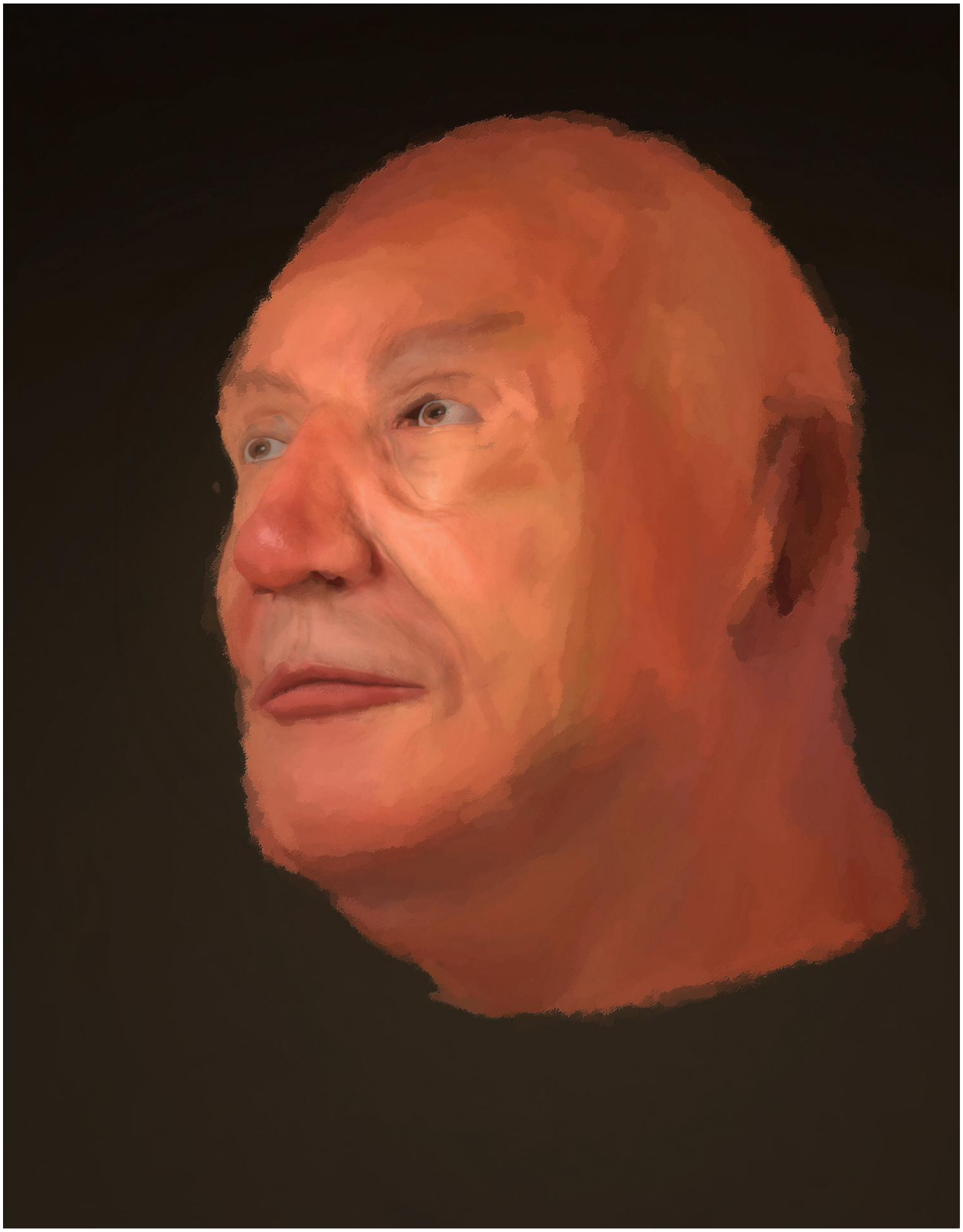


Figure 5.13: Rendering of our final composited filter methodology

This process can be implemented in post-production during compositing to obtain better control over results. However, current compositing software do not really provide the kind of the control that is needed for implementation of these Barycentric operations. For instance, we need W_0 automatically computed from W_1. Otherwise, the whole operation becomes very time intensive for users. Therefore, we also implement this in shader level. During the rendering we simply apply a sequence of photoshop filters. One disadvantage of our approach, if we do not like the results, we need to re-render again.

5.2 Results

Our final examples demonstrating the effectiveness of our method are shown in Figures 5.14. These images were generated as a result of combining the methodology in Figure 4.18 and Figure 5.12, using our barycentric shaders and textures shown in Figure 4.15.

Using the methodology presented in Figure5.12, we have created a workflow that allows the artist to have total control over the outcome of their images. Having the ability to adjust and manipulate every layer leading up to the final image will result in no two images looking the same.

Another accomplishment of our methodology is the ability to generate animations utilizing our painterly filters. Our textures and filters are mapped directly to the surface of our 3D model, so they react to changing light positions and movement of the 3D model.

Both Photoshop and Photodonut, a Photoshop image compositing plug-in, were utilized to generate the painterly effect our final images. All of our images used a combination of watercolor and oil painting filters as well as emboss filters to give our images a bas-relief effect, in that the paint appears to be coming off the surface of the canvas.

Figure 5.14: Examples of renderings obtained by our layer filtering method.

6. CONCLUSION AND FUTURE WORKS

In this research, we explored the method to transfer the unique visual characteristics of traditional portrait paintings into 3D computer graphics, through the use of barycentric shader development and 2D artistic filter creation in Photoshop. Through the use of combining barycentric shader development and 3D modeling, we have developed a variety of images that attempt to achieve a painterly portrait style. We were able to generate images that have similar color interpolation and stroke like application of color as found in traditional portrait paintings.

Potential further improvements to our work include utilizing shading language to apply our filters to all frames. This would negate much of the man power necessary during the compositing stages. Creation of artistic filters that render specific styles and eras of portrait painting utilizing our barycentric methodology is another future iteration of our work.

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