SPACIAL GROOM

A Thesis

by

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ABSTRACT

This thesis describes a method for grooming computer generated fur in a 3D production environment. Fur grooming systems that are included with the major commercial 3D software packages link fur grooms to a specific model's topology. This significantly reduces the flexibility to continue development of a model's surface edges, loops, and vertices after fur grooming has started. By using a method that links the groom to the 3D environment rather than the model itself, a groom can be transferred between meshes. This provides increased artistic flexibility within a production pipeline for both modeling and fur grooming.

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1. INTRODUCTION

Computer Generated fur is a technique used in animation and visual effects to add realism and depth to scenes and characters. It can be used to create the hair on a character's head, fur on an animal, grass in a field, or even feathers on a bird. Most large commercial animation and visual effects facilities use CG fur. Fur modeling has become a standard component of the animation pipeline.

When the fur is created for a model it must be adjusted by digital artist into the style that is needed for the project. This process is called grooming and is similar in theory to a haircut. Besides adjustments such as shortening and directing which way the fur flows, the artist also decides where fur will grow on the model and how frizzy, curly, or straight the fur appears to be. Tools that give an artist the ability to groom fur are typically written attachments to the major 3D modeling program, and referred to as plug-ins. The most common way that fur is attached and groomed on a model is through digital texture maps. Each vertex on a model is explicitly assigned coordinates within the UV definition of a 2D texture map. Through this mapping of a 3D model to a 2D image the color or gray-scale values in the image are used to set and modify numerical values that define the visual creation of attributes on the 3D model. The drawback with using 2D mapping to place and style hair is that if the model's topology is changed, the maps are no longer valid. This means if the model is revised or adjusted, the groom work that has already been done is no longer use-able.

This project provides the solution to this problem by linking the development of the groom to the 3D environment rather than the models explicit surface. The approach taken in this thesis is to use the spherical volumes in Cartesian space to

define the groom. This volumetric approach has been used in studios such as Blue Sky Studios[9] but is not available outside of a proprietary system. The solution offered in this thesis is a volumetric approach developed as a plug-in to a commercially available program that is accessible for students and small-scale users.

The use of volumes to create fur grooms results in work that is not directly tied to the topology of a model's mesh. Instead, by surrounding the models mesh the groom creates texture maps based on the topology found inside the volumes. If the topology in the volume is changed, the artist has the ability to recreate the texture maps in relation to the new geometry, rather than recreate the groom entirely. This makes grooms more flexible in handling changes and iterations that occur in the production process. It also means that one groom can be distributed to several similar models. Artist no longer have to repeat several similar grooms. Instead, the volumetric groom can be imported and minor adjustments made, according to need.

This thesis is structured to describe a method for developing a volumetric based fur grooming system that is accessible as a plug-in to commercial software to artist in small-scale production environments. The thesis describes two key questions of the grooming problem:

- *A topologically independent approach to fur grooming:* A generic method for grooming fur is defined that does not directly tie the fur groom to the topology of the model being used.

- *An implementation in Autodesk Maya:* A Maya plug-in is described that allows artists to create use-able fur grooms. The asset should have a GUI that gives the artist the necessary tools to create a groom such as ability to place fur on models, make adjustments to fur attributes, as well as save and load grooms to move between models.

The paper begins by describing the development background of CG fur, and how it has been developed fit within the production pipeline. Then it discusses the method for creating a plug-in that works in a way that will allow for grooming while also not being directly dependent on the topology of the model to be groomed. Finally it will also look at how this will have an impact and what can be done in future works to improve upon the program.

2. RELATED WORKS

CG fur has been around for roughly 35 years and has made many improvements in that time-span. The first work to develop a way to simulate fur was by C. Csuri, R. Hackathorn, R. Parent, W. Carlson, and M. Howard at The Ohio State University[7]. In their 1979 paper, Towards an Interactive High Visual Complexity Animation System, a new algorithm is used that is able to handle millions of faces, lines, and points. The new algorithm "...makes possible a full range of visual cues to simulate fire, smoke, water, and complex 3-D texture such as grass, hair, and bark[7]." William Reeves then took fur to the next step in 1983 by modeling fuzzy objects using particle systems instead of geometry[17]. Reeve's approach was used to simulate a wall of fire in the film *Star Trek II:The Wrath of Khan*(1982). Reeve's research helped lead to James Kajiya and Timothy Kay's 1989 work[14] in which fur on a 3D model was rendered as a texture rather than geometry. By treating the fur as a 3D texture rather than geometry, fur became a more viable tool for production. The amount of geometry that needed to be rendered was reduces and the rendered fur had a more natural look compared to previous methods. There was a rapid growth in CG fur development after this. The first digital fur rendered in a full length film was on the character "Kitty" by Industrial Light & Magic in *The Flintstones*(1994). This was quickly followed by furry and hairy characters in other films such as *Jumanji*(1995) and *Toy Story*(1995).

As the field grew, three main areas evolved for working with computer generated fur: grooming, rendering, and simulation. Grooming, also called styling, is the task of shaping the fur on the model. This involves adjusting attributes such as the length of the fur, where the fur is located on the model, and its shape. Rendering of the

hair deals with how it will look in the final image. How the computer reacts when it encounters fur while creating the image is important in making the fur look realistic. Finally, if the fur is going to move, such as if the character is animated or wind is pushing the fur around, it must go through simulation. Simulation uses physics to determine how the fur moves in reaction to what is going on around it. The complexity of fur styling, rendering, and simulation means that there is a large body of work dealing with the topics and each area could be covered extensively. Since this thesis deals with grooming, it will be looked at more in depth.

When fur is groomed on a model, the artist determines through a software interface where to place the fur and how it looks once there. Placing the fur on the model requires either using a 2D placement method or 3D placement method. 2D uses a mapping function through which the artist paints fur on a 2D surface that is projected, or mapped, onto a 3D object. This link is an explicit connection between the 2D coordinate and the 3D coordinate on the model and with this connection, when a value is looked for at the 3D coordinates, it is given the values of the color at the 2D coordinates. In 3D mapping, the artist selects the areas of the model in a view port that present the model in Cartesian space and the program places fur on the selected areas[13]. Once the fur is placed on the model, it must be shaped to give the desired look. There have been many different methods put forth to solve the problem of shaping the hair into the desired look. Keyser, Schaefer, and Yuksel presented a styling method in their paper Hair Meshes [22]. They created a method which uses geometry shaped to look like the desired hairstyle to sculpt the shape of the groom. Others have used physical simulations to manipulate the styling of the hair. One example is Hadap and Magnenat-Thalmann's Fluid Flow which places areas of forces such as vortexes that hair must flow around [12]. The forces are what is used to direct the hair and can make the hair bend or curl to create the groom.

Using images to style the hair, such as the work done by S. Paris, H. Briceo, and F. Sillion, can create accurate results but gives the artist little control of the final results because it is limited to the image used and cannot be altered[16]. These are just a small sample of the research being done on computer generated fur and hair. For a more complete overview look at A Survey on Hair Modeling: Styling, Simulation, and Rendering by Ward, Bertails, Kim Marschner, Cani, and Lin[13].

Most major animation and visual effects studios have created custom fur grooming tools to handle their production work flow. Disney created a proprietary tool named "Tonic" for the grooming work on *Frozen*(2013) [10]. The tool allows the artist to create hair styles as procedural volumes. Pixar Animation Studio's solution is to use Maya nurbs curves to lay out the flow and length on the model. It is then put through "gofur", their proprietary software, to fill in-between the nurbs with hairs. Pixar used these tools to create the fur and hair in *Ratatouille*(2007)[15]. Blue Sky Studio uses a procedural approach in their proprietary system. It uses tools to create a vector field over the 3D model to describe the fur's direction and flow. They then add in spots in 3D Cartesian space to change attributes such as length and curliness in specific locations on the model[8]. Rhythm and Hues Studios' in house software, "Voodoo", used painted maps and had the ability to adapt to changing topologies [18]. This technology was used in films such as *Life of Pi*(2012).

The animation and visual effects industries have many different tools to solve the problem of grooms on various topologies but outside of the major studios there are few options and the cost for small-scale users and students is usually not within a reasonable budget. The plug-ins for fur grooming that are packaged with current software packages available to students provide the tools needed for artist to style fur on a model, but the topology of the model can not change. Autodesk Maya uses a 2D method for styling hair. The style is dictated by 2D texture maps that determine

attributes of the hair such as length, curliness, and angle. On the maps the alpha value, or transparency, is adjusted and the value that is painted is given to the fur at the matching location mapped on the 3D object [3]. Autodesk 3DS Max uses a similar method for fur grooming with the added combing tool. This allows areas of fur to be adjusted by dragging a mouse in the direction the artist needs the fur to flow [2]. Side Effects Software's Houdini also uses texture maps that artists paint directly onto the geometry to create grooms [19]. The problem with each of these methods is that the fur groom is tied to the topology of the model being groomed. One of the few options available that can handle changes in topology is Joe Alter's "Shave and a Haircut" [1]. This is a web-delivered download-able plug-in that provides useful tools for fur grooming in Maya. It uses a mix of textures and guides to groom the fur and can manage changes to topology. The major drawback of "Shave and a Haircut" is the cost of acquiring. At around $800 it is outside the range of small budgets. This thesis creates a free plug-in that works in commodity software package and enables the creation of grooms that are not directly tied to a model's topology.

3. METHOD OVERVIEW

The current software packages available to students and small-scale users deal with fur grooming by connecting the groom directly to the topology of the model being groomed. This limits the ability to iterate or make changes to the model without having to recreate some, or all, of a groom. The approach this thesis is taking is to create a method that associates the groom with the 3D Cartesian environment instead of the model itself. By having the groom connected to the 3D Cartesian space, changes in the models topology will have little effect on the groom itself. This sections details the process of creating a tool that can create such a groom and implement it in a way that is usable by digital artist.

3.1   Integration with Animation Production Process

The software package the tool is written in is Maya, developed by Autodesk[3]. Maya is commonly used in the animation industry and an educational version can easily by attained by students. Maya also contains an application programming interface(API) that allows for the creation of new tools within the program. Using the API, the tool using the 3D Cartesian space can be created and implemented with other tools that come packaged with Maya. Since the software package is a common tool in the animation industry, has the ability for users to create custom tools, and is easily attained by students it is an ideal program to use for the creation of the spacial grooming tool. The current package, Maya 2014, comes with a fur system that uses 2D textures to place and groom fur.

3.2 Limitations of Map-Based Techniques

A major component of all of 2D fur grooming is UV maps. As described in Maya's User Guide:

> UVs (pronounced U-VEEZ) are two-dimensional texture coordinates that reside with the vertex component information for polygonal and subdivision surface meshes. UVs exist to define a two-dimensional texture coordinate system, called UV texture space. UV texture space uses the letters U and V to indicate the axes in 2D. UV texture space facilitates the placement of image texture maps on a 3D surface.[6]

The UV texture space, or UV map, is basically a way to describe a 3D object in 2D space. A user creates an image with the UV map as a guide and the rendering software looks to the image when deciding what color to use at that particular place on the mesh. Fur grooms use the alpha values of UV maps to set the value of an attribute at a given area on the mesh. This works great for models that do not change but problems can arise if the mesh is changed. The old painted map will no longer connect to the same location on the new UV map created from the modified mesh. In order to remedy this problem, a way to paint UV maps without having the process be directly tied to the mesh is needed. This is done using isospheres which are volumetric sphere packaged with Maya. These transparent spheres can be placed in 3D Cartesian space and from them the spacial grooming tool can check if parts of the geometry fall within the sphere's area.

3.3 Off-line Processing

The spacial Grooming tool is implemented using off-line processing in Maya API. Off-line processing code is run periodically by the user to process large amounts

of data where real time is run continuously. Real time allows the artist to see what the groom looks like continuously since it would be updating itself. Off-line processing allows the artist to process much more complex models without the spacial grooming tool slow down Maya by constantly trying to update. The choices of what programming language it is written in comes down to Python and C++[4]. Tools that deal with larger data amounts and need to compute faster usually are created using C++. Python is better for iterations since it is less complicated and is less likely to crash Maya with memory errors[21]. Maya also has the option to write small scripts in Python which gives the option to test small sections of code before implementing it in the larger program[5]. Initially the tool was began in C++, thinking that it might be fast enough to update itself as the artist works on the groom. After some testing in C++ it was shown to still take too much computational power to run in real time due to the program not being able to keep up with the artist. The decision was made to write the tool in Python. The switch was mainly to be able to work with Python's more intuitive syntax and scripting ability since the speed boost of C++ would not give the tool any great benefit by having the tool try to constantly update the information.

3.4   Method

To create an area to be modified that is not directly tied to the polygonal topology, a way of defining a finite area of the model's geometry is needed. The plug-in needs a way to select the areas of the model where artist want to modify attributes. Blue Sky Studios' proprietary software is described as having "...a 3D compositing setup where we have spots and splines in space to describe different aspects of the hair where its short, where its long, where its curly, where it lies flat[8]." So by using volumes and splines defined by the artist, the hair is placed on the model and manipulated

to the desired look. Disney's proprietary tool Tonic tool uses volumes to define the areas of the groom that then procedurally place the hairs [10]. Using isospheres, the areas of the model to be modified can be selected by a sphere being placed on the geometry. The program is then be able to change the attributes of the hairs within the radius of the isosphere in relation to those outside the radius. For example, if an artist wants to create an area of long fur, they would place the isosphere in that area and set the tool so that the length attributes value inside the sphere is greater than the value outside of the sphere. This can be seen in Figure 3.1. The isospheres work well for this process because it is easy to manipulate both location and size of the area encompassed.
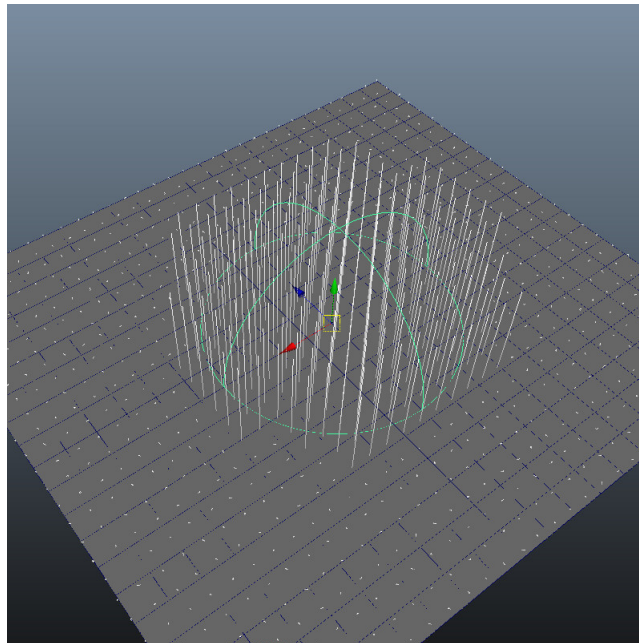

Figure 3.1: Plane with isosphere defining areas of fur to be manipulated

One method to manipulate the fur attributes in Maya uses ray tracing to paint

the surface of the model. This means that the center of the isospheres would act as a point and if geometry was in range of the radius of the sphere it would change the surface texture. This change would influence the fur's characteristics. The issue with this method derives from how Maya's fur is rendered. The Maya Fur Tools sends all data through a fur tools node. This node takes in information such as fur color and styling and modifies it. If the data going into the fur node differs from what the renderer was expecting, the fur will not appear in the final render. The ability to modify the fur node is restricted from the end users so that Autodesk can protect part of its proprietary software. This means that in order to use Maya's rendering tools, the plug-in must manipulate the information going into the original fur grooming tools.

The way Maya's fur grooming tools work is through changes to different attributes over the whole model surface. These changes are done by altering a numerical value or in localized areas by painting texture maps. The fur node reads in the texture files and values. It then creates the rendered fur. To make the spacial grooming tool work, the plug-in needs to paint the texture maps that would then be linked to the Maya's fur node.

The data that Maya uses to create the geometry of the model being groomed needs to be stored to be able to create the texture maps needed. This data is stored as the Cartesian coordinates for each vertex of the model and this location data must be determined and stored for use by the plug-in. To do this the polygonal mesh is selected and the program cycles through the list of all of the vertices that make up the mesh. While cycling through the given mesh, the position of each vertex is stored with the other vertices that make up each individual polygon in the mesh.

Once the location data of the vertices is collected and stored, the program determines if an area of geometry is inside an isosphere that the artist has placed. To

find out which parts of the mesh are inside an isosphere, the program cycles through each vertex it has stored. The location data of the vertex is compared to the location and radius of the isosphere. If the vertex is within the radius of the isosphere the polygon is marked as being within the influence of the isosphere . If all of the vertex fall outside the spheres radius, the program marks the polygon as outside of the isosphere's influence.

The texture maps that are attached to the fur node are created from the polygons and their corresponding UV map location. If the polygon is marked as being inside the influence of the isosphere, its corresponding area in the UV map is filled with an alpha value selected by the artist. Once all the polygons within the isospheres are filled in the areas of the remaining polygons on the UV map are filled with the alpha value selected by the artist for the areas not influenced by isospheres. This process of filling in areas of the UV map that correspond to whether a polygon is inside or outside an isosphere creates a texture map that show what areas of the polygonal model are encompassed by the isospheres. After all of the vertices and polygons of a model have been checked and the texture map has been filled in, the map is attached to the attribute on the fur node that it has been created for.

To make the grooming process and work flow more artist friendly a graphical user interface(GUI) has been developed. The GUI is written in PySide, a python based Qt language that comes integrated in Maya for creating custom GUIs [11], and integrated into the spacial grooming program. The GUI gives the artist the ability to easily create new isospheres, name, and delete them. It also allows for an artist to quickly change the attribute values that the spheres are tied to. The most important part of the GUI for this thesis is that it allows the user to select and change geometry quickly as well as save created grooms and load them into new scenes. The saving of grooms is done by creating a text file that stores the name,

location, radius, and attributes of each isosphere in a groom. The program can then load the groom from the selected text file. By having a GUI, artist can quickly use and manipulate the tools as well as move grooms across model iterations. The GUI can create and delete isospheres as well as link them to the various fur attribute the artist need to manipulate. The artist are given control over the attribute values that will be created on the attribute texture maps and can save grooms to a desired location as well as load files that have been created previously.

4. RESULTS

The spacial fur grooming plug-in is developed to be able to create fur grooms and have that groom be independent of the topology of the model it is groomed on. Various tests were used to determined how successful the tool is at achieving the goals it was developed for. The tests were a groom on a complex organic model, a groom on a hard surface model, and the transferring of the hard surface model groom to other various models.
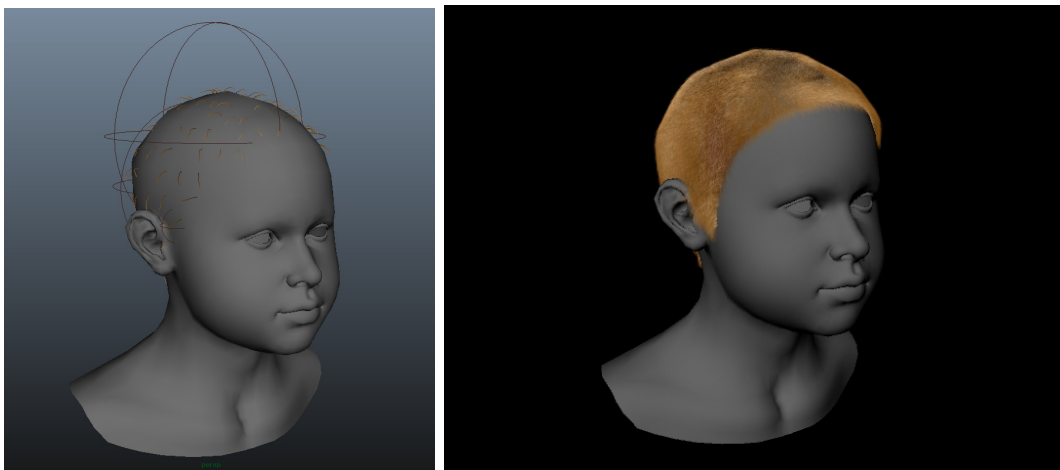

Figure 4.1: Boy's hair volumetric groom. Model by Bitmapworld [20]

The test on the complex organic model as seen in Figure 4.1 shows that the spacial grooming tool can handle complex geometry and creates a fur groom that can be rendered in Maya's rendering software. The test also shows the tool's ability to cover complex shapes by placing several isospheres in a cluster. The time it took the fur grooming tool to calculate the texture maps and attach them to the geometry

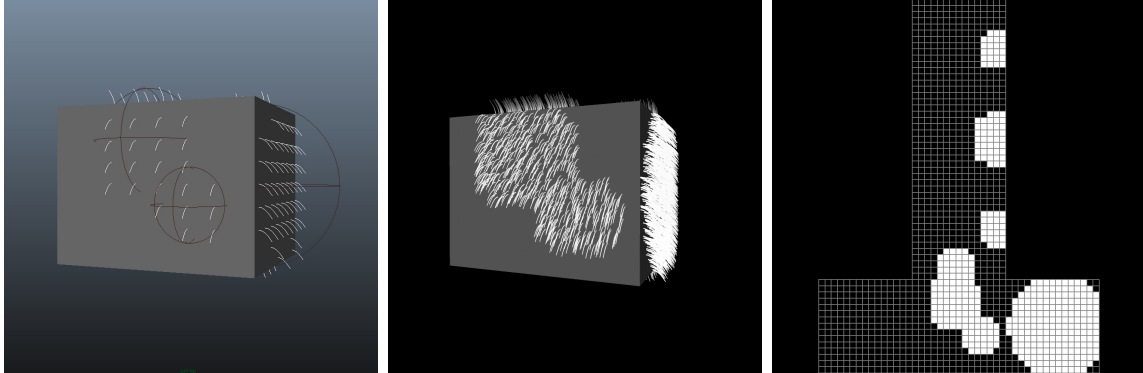was between 5 seconds and 20 seconds depending on the number of isospheres.

Figure 4.2: Volumetric groom on cube, rendered image, and groom texture map

The spacial grooming tool test on the the hard surface model in Figures 4.2, 4.3, and 4.4 looks at how the tool handles problems such as sharp edges. The groom that resulted had fur placed on edges and around corners without any major problems occurring. The one minor issue comes from the polygons normals being drastically different. This causes there to be a defined line in the fur where the normals change direction. This problem can be solved by artist by placing more and smaller isospheres around the edges to reduce the large normal angle difference. The calculation time of the hard surface model was between 3 and 5 seconds depending on the number of isospheres. This is much shorter than the organic model due to the lower number of polygonal information to be calculated.
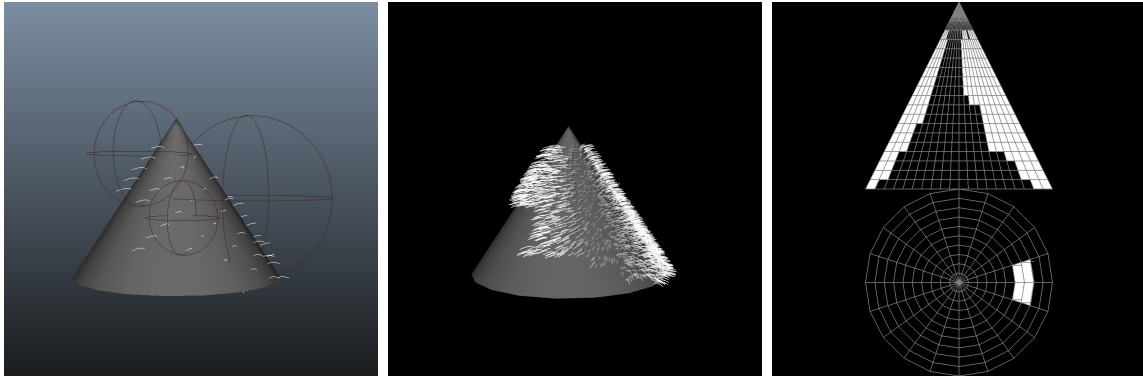
Figure 4.3: Volumetric groom on cone, rendered image, and groom texture map

The groom on the hard surface model was then saved and loaded on to two models with topologies very different from the hard surface model. These two models were a cone and a sphere. By moving the groom on to these models, the concept that the spacial grooming tool can move one groom between various topologies is tested. The grooms that were loaded on to each model calculated new maps and rendered without any issues and took a similar amount of time to calculate, about 3 to 5 seconds.
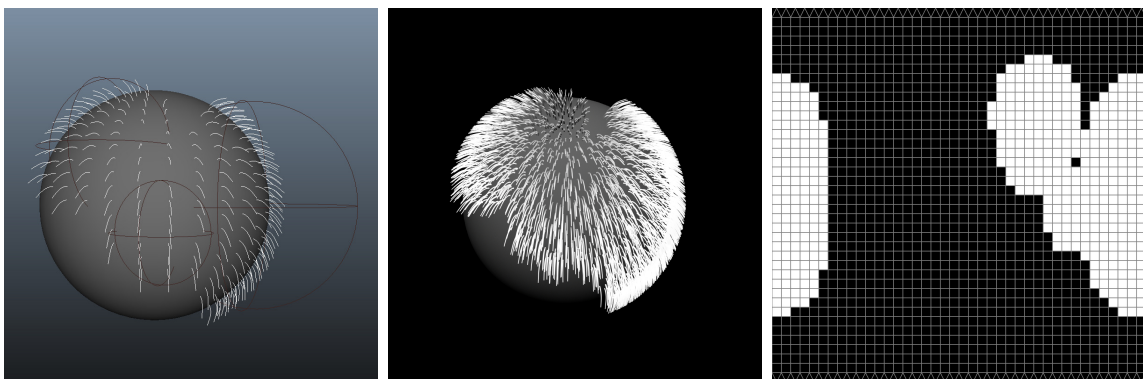

Figure 4.4: Volumetric groom on sphere, rendered image, and groom texture map

5. CONCLUSION AND FUTURE WORK

5.1 Conclusion

The goal in which this thesis set out to accomplish was to develop a tool that gave small-scale users the ability to groom a model and have the resulting groom not directly dependent on the topology of the model. The use of isospheres allows artist to create grooms based on the volume of the geometry rather than the texture maps. The program then creates maps based on the groom created. This way 2D maps can be used without the drawbacks of having to recreate grooms once the topology of a model has been changed. It also means that the grooms can be saved and used on several models. One groom is moved between models that have drastically different topology and UV maps. Each model can use a different UV map and maps created by the program using the same groom. These different maps show how a similar location in cartisian space can be interpreted by Maya as a drastically different location on the 2D maps. The spacial grooming tool uses the location of the geometry in relation to a sphere in cartisian space to create a groom. The result is grooms that works completely independent of topology changes. This gives artist the ability to create grooms and apply them to various iterations of a model or different models.

The place where this method falls short is when there is a drastic change in the shape of the geometry's shell. If the model is scaled or stretched into a different shape the groom will still remain in the original location. This can be fixed by the artist by replacing the groom in the desired location and adjusting the size of the spheres, but the tool does not do so automatically when the model changes. Besides this, if there is a topological change with only small changes in volume or scale, the original groom would remain useable with only minor adjustments.
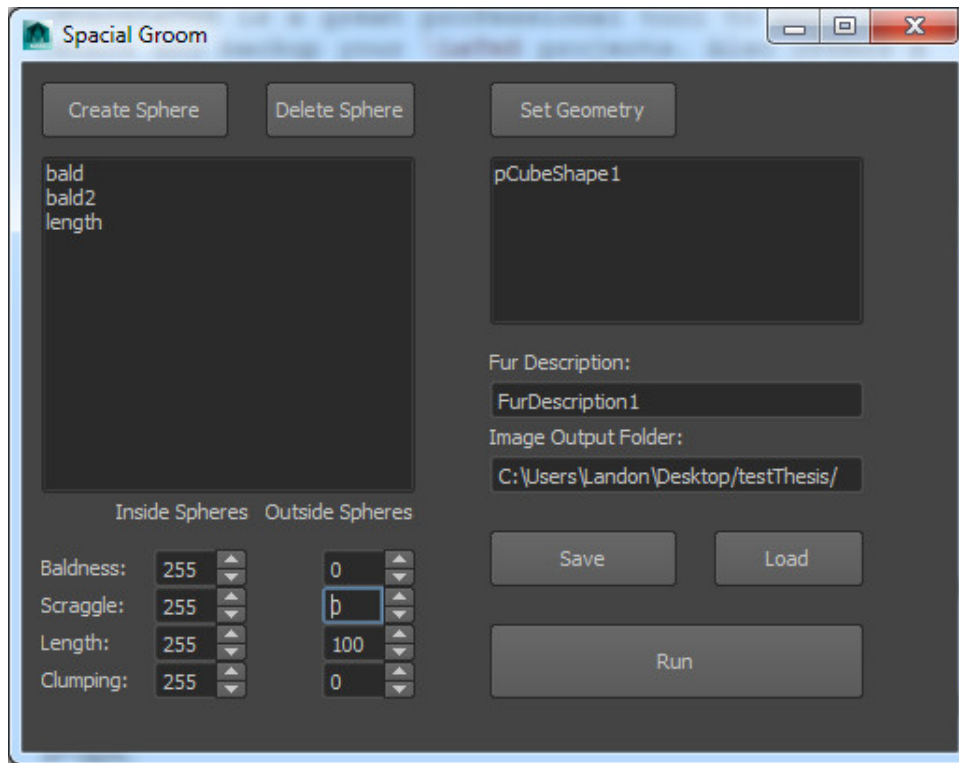
Figure 5.1: Spacial groom tool GUI

The plug-in was further developed to integrate with Maya. The GUI seen in Figure 5.1 and parts of the program such as the ability to save and load grooms give users the added benefit of using the tool in a production level work environment. By working on top of Maya's existing fur tools, the ability to use Maya's rendering tool was also retained. This allows an artist to use a volumetric grooming approach in software that is easily attainable for students and small-scale users.

This work looked into the development and creation of a volume based grooming tool. The idea of a grooming system to create topologically independent fur grooms is not new and has been pursued by several animation production companies. Where this work differs is in the creation of a non-proprietary tool that can be easily at-

tainable by small-scale users such as students. By creating the tool to work within commercial animation production software, the ability to use the plug-ins and tools already available helps users get the most of the created plug-in.

5.2 Future Work

The creation of this plug-in has shown several areas in which further study and work could be done. The fields painted within and outside of the isospheres could be taken beyond solid fields of black, white, and gray. One way to do this would be using procedural textures and maps to vary the colors within fields painted. This variaty could greatly improve the functionality and complexity of fur grooms being created with this plug-in. The spacial grooming tool could also be adjusted to allow a single groom be multiplied across a single model. This would be especially useful in the development of scenery. Beyond fur grooming, the process of using volume to define texture maps could be used to shade models or paint joint weights on animation rigs.

The area of fur grooming has been researched and developed at many animation and visual effects studios but the tools have not filtered down to small-scale users. This thesis looked at one way that could be developed to create the tools needed for artist to groom fur styles on models. With this method the ability to easily iterate work could improve the final output rather than artist spending time recreating what they have already done.

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