A TOOL FOR CREATING EXPRESSIVE CONTROL OVER FUR AND FEATHERS

A Thesis

by

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ABSTRACT

The depiction of body fur and feathers has received relatively abundant focus within the animation production environment and continues to pose significant computational challenges. Tools to control fur and feathers as an expressive characteristic to be used by animators have not been explored as fully as dynamic control systems. This thesis outlines research behind and development of a control system for fur and feathers intended to enable authoring of animation in an interactive software tool common in many animation production environments. The results of this thesis show a control system over fur and feathers as easily used as appendages control to create strong posing, silhouette and timing of animations. The tool created impacts the capacity of more effective and efficient animation of characters that use fur and feathers for expressive communication such as hedgehogs, birds, and cats.

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Contributors

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1. INTRODUCTION

A significant amount of digital characters are animals. Since animals lack the ability to communicate like humans, the majority of their emotions are visible in their body language. Imagine a scared cat or an angry dog, and you can clearly see the cat's tail puffed twice it's normal size or the dog's guard hairs raised. If one was to blacken out this image so only the silhouette was readable, the raised orientation of the hairs are necessary indicators of emotion. When animating, it is necessary to change the orientation of fur and feathers to pose a character so it's silhouette is easily readable. However, a dynamic approach to this problem would be unmanageable and limiting because this takes away control from the animator and does not allow for interactivity.

Most approaches to simulating fur and to a lesser extent feathers rely on dynamic solutions. These dynamics consist of a physically based solver, a deformation solver such as cloth, and a render based mesh generator. These solvers are based on sub steps which calculate in relation to time, so interactivity as well as user control are limited if at all possible. There is a need for simple methods to provide animators to directly control the character's silhouette with expressive fur and feathers. These simple controls allow development of solutions without hindering animators' time and creativity spent by managing the dynamic solvers. In this work, we have developed a control system that is both interactive and expressive.

In an animation production environment, animators use control objects to pose characters in relation to time. For the approach that is illustrated in this thesis, control objects are used to animate the fur or feather geometry. These control objects, called *controllers,* subdivide the density of the hairs so as to separate the large number of hairs into a manageable control interface while also maintaining expressive capabilities for animators. These controllers are bound to guide curves using succinct lines of code and constraints so as to provide interactive control to the user. Each guide curve represents a cluster of generated hair geometry. Dividing the guide curves into control groups allows for timely animation as this gives regional control that manages hundreds of controlled objects through a simple control. Through the implementation of this technique, an animator can express animal emotion easily and effectively.

Changing of orientation of hair at the base of a strand, known as piloerection, is a common reflex that many mammals use to represent strong emotions such as fear, anger, or thermal reactions to cold. Birds also have the capability to lift their feathers when experiencing strong emotions or in response to environmental influences such as heat. In many instances, this behavior is used to change the silhouette of the animal in response to external stimuli such as food or mate competition, or predators. In an animation production, animators use traditional animation principles such as staging and silhouette to create expressive performances. Since many films use animals as characters, the ability to control the silhouette through the fur and feathers is necessary for appealing animation.

The tool described in this thesis, named the AnimFur tool, is used to represent the unique hair or feather characteristics of three different animals. Hedgehogs have stiff modified hairs called *quills* that have the ability to simultaneously interlock and raise along their back. Cats raise their fur to appear larger when afraid or angry, however they retain less control over orientation than hedgehogs due to finer, and more flexible hairs. A fantastical bird-like character has been used to demonstrate the generalization of this tool to feathered creatures. These animals represent a wide range of specific uses for which this method can be applied. Using the method illustrated in this thesis allows for better character performance in film.

2. OTHER WORK

2.1. Motivation

Disney animators Frank Thomas and Ollie Johnston put forth Disney's principles of animation in an attempt to explain the concepts animators need to understand to create compelling animations [1]. These principles included the concept of staging, timing, exaggeration, secondary action, and many others. Some of these concepts are shown in stills from the Disney classic, *The Skeleton Dance* (1929), where the raised feathers and fur contribute to the staging and exaggeration of the performance. In reaction to these principles, John Lasseter of Pixar revised the principles for computer animation [2]. One principle of note is the concept of staging. In a frame of animation, the viewer's eye needs to be directed at the action and able to clearly read the emotions of the character in the scene. Posing, scene layout, as well as simplifying the action present are methods to implement staging. However, in the early years of Disney when animations were in black and white, form and silhouette were vital for delineating subject from background. The effect that hair has on the silhouette of a creature was used as an animated trope in many 2D animations. Several computer-animated films have applied the animation principles to character animation. However, it is apparent that limited attention has been given to the silhouetting capabilities of feathers and fur.

There are many furred creatures in computer graphics films. The first CG furred creature was the in the 1994 live action movie, *The Flinstones.* However, because of the limitations of technology, the character was given limited screen time and screen space.

A 2001 animated film, *Monster's Inc,* provided us with the character of Sulley, a fully furred monster. His fur was revolutionary at the time because it utilized the implementation of key-hairs to interpolate behavior to the rest of the hairs on his body allowing for realistic behavior and appealing results. The 2016 animated film *Zootopia* featured an entire population of furred characters. The fur was created using a Disney proprietary software tool that expands on the principles of key-hairs by allowing easy-to-use grooming and behavior modifiers. Even more recently, in the live action 2018 film *Peter Rabbit* which re-introduced us to the classic Beatrix Potter animal characters, Animal Logic's proprietary software *AnimCFX* allowed for complex simulated interaction between the animal's clothing, the live-action actor's body, and environmental stimuli such as wind and gravity

2.2. Piloerection and Animal Behavior

As illustrated by the examination of these films, the orientation of fur and feathers are an underexplored opportunity for expressing character emotion. There are scenes in *The Secret Life of Pets* where the cat characters are in a stance that is often paired with puffed hair in the natural world. Xiaoyuan Tu proposed a method for creating computer animated animals that advocated in depth analysis of how animals perceive their environment and the effect this has on the animal's physiology and behavior which in turn helps to determine the necessary performance goals of an animal character [3]. When applying Tu's method of animal behavioral analysis to this thesis in regards to fur and feathers, the hedgehog is an example of a furred animal which has above average control over the piloerection of modified hairs called quills which subsequently strongly influences silhouette. The hedgehog's cutaneous muscles along the spine force the base of the quills to erect when rolling into a defensive ball [4]. The hedgehog also has the ability to raise quills regionally and orient the quills into a defensive barrier [5]. The cat retains this ability to orient the fur specifically to communicate when afraid, filled with aggression, or cold [6]. A final example that will be illustrated for the purpose of this thesis is the orientation of feathers in birds, which is not only used as an emotional indicator but also as a necessary element of flight [7]. A Cockatoo with raised feathers can be compared to a Cockatoo with neutral feather placement. This change in orientation of fur and feathers as an emotive reaction by animals is critical when animating the silhouette and posing of digital characters.

2.3. Existing Simulations

The body fur or feathers of a digital character is usually controlled by a dynamic system as the large number of individual strands and complex behavior of the individual components are a challenge to replicate in most animation software. In 1979, Csuri et al. created a technique to graphically display highly detailed three-dimensional models in a brute force method by generating thousands of individual polygons to achieve the look of hair [8]. Since then, extensive work has been done to find the best method of generating and controlling hair. Miller introduced the mass-spring system to dynamically move hair in 1988, which was later expanded on by Haumann, and

Haumann and Parent who applied a physics simulator based on masses, springs, and hinges to fabric [9] [10] [11]. This work was later expanded by Rosenblum et al. who applied this simulation method to hair by modeling each strand as a linear series of masses, rigid springs, and hinges [12].

More refined approaches to the simulation method were implemented leading to the use of guide hairs. This method was developed in 1993 by Daldegan et al. who approached the challenge of simulating long hair by using guide hairs with simulations applied to represent dense regions of rendered hair [13]. Plante et al., Chang et al., Ward et al., and Choe et al. approached these problems by refining the simulation method to create high-quality, accurate physical behavior [14] [15] [16] [17]. Chai et al. proposed a model of hair physics that allowed for real-time simulation; however, the creative capabilities of this method are severely limited as the reduced model relies on simple parameters such as guide hair interpolation and a hair skinning method which interpolates weighted influence from guide hairs, and physics based calculation of a limited number of guide hairs [18].

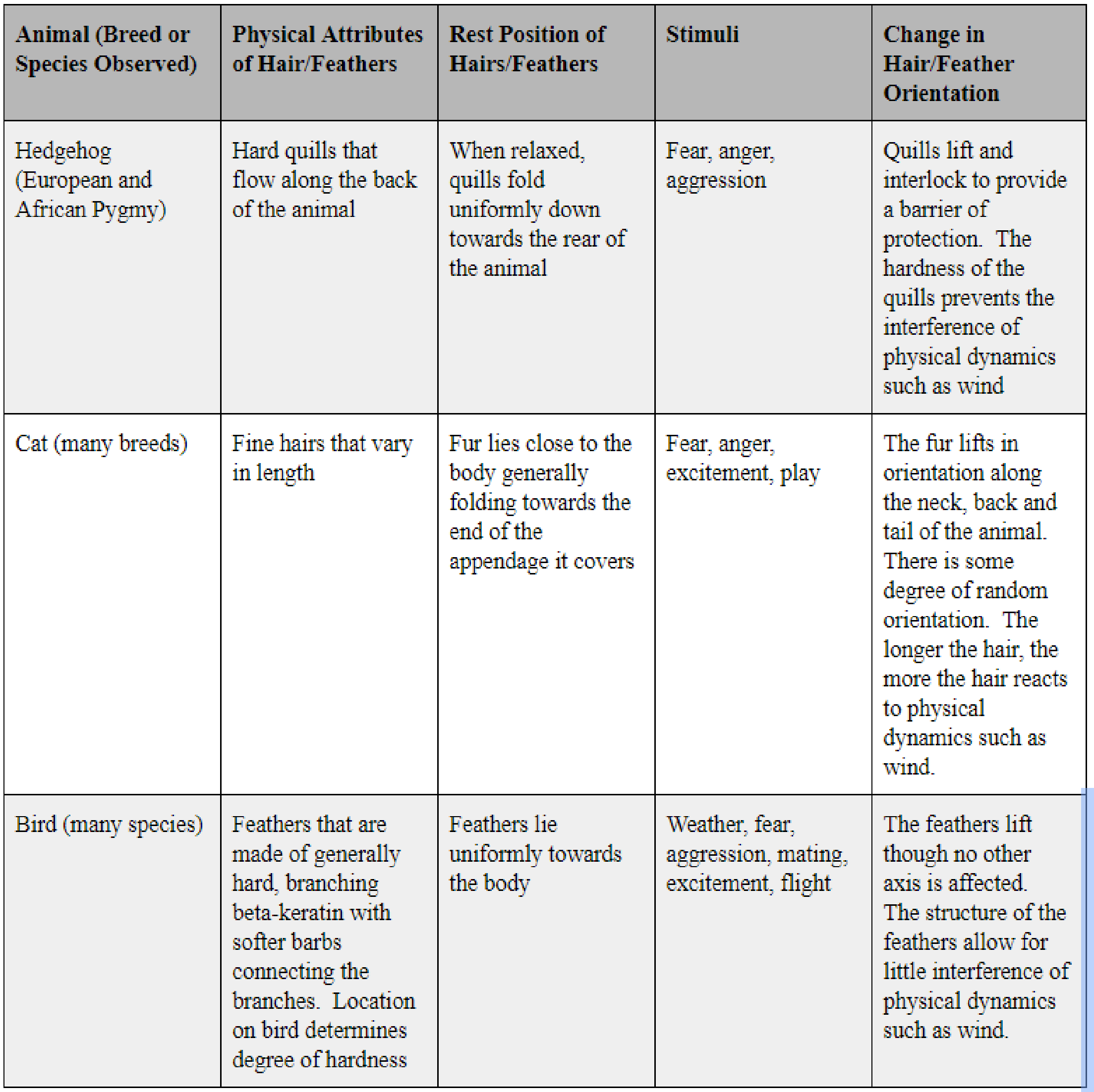
While the results of this research are appealing, these simulations do not have much opportunity for creative motion controls. This limits the animator's capability to use the strands of hair as expressive animation tools. The approach described in this thesis research relies on the use of rigging tools to control the orientation of the root of thousands of guide hairs while maintaining interactivity and refined animator controls to allow for expressive animation.

3. METHOD

3.1. Piloerection in Animals

The range of control needed by the AnimFur tool was determined by observing three animals: hedgehog, cat, and birds. Reference videos of these animals were analyzed to determine the behavior of the fur or feathers and the degree to which the fur and feathers rotate from the relaxed position specific to each animal. These animals represent the limit of hair behavior in a majority of animals and thus encapsulate most performance needs of hair. This range is versatile enough to allow users to create animations that reflect the behavior of piloerection in this set of animals and more. Along with the rig-based control system, there are also dynamics blending components as fine, flexible hairs are best controlled partially through dynamics. The animal's need for piloerection also helped determine the degree of control necessary as the hedgehog weaves the quills together for self-defense while the bird's feathers remain oriented along the follicular tracts when raised as a visual cue.

Review of footage resulted in the following observations in Figure 3.1.



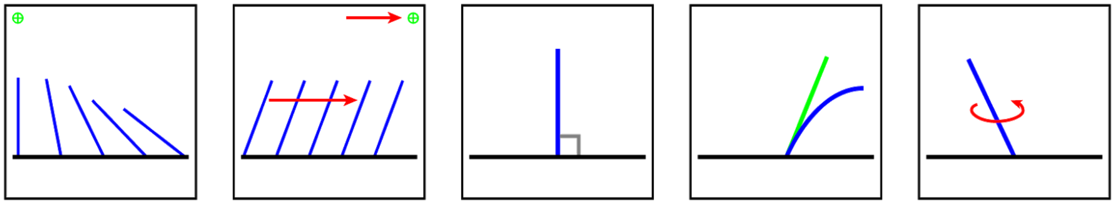
Animal (Breed or Species Observed)	Physical Attributes of Hair/Feathers	Rest Position of Hairs/Feathers	Stimuli	Change in Hair/Feather Orientation
Hedgehog (European and African Pygmy)	Hard quills that flow along the back of the animal	When relaxed, quills fold uniformly down towards the rear of the animal	Fear, anger, aggression	Quills lift and interlock to provide a barrier of protection. The hardness of the quills prevents the interference of physical dynamics such as wind
Cat (many breeds)	Fine hairs that vary in length	Fur lies close to the body generally folding towards the end of the appendage it covers	Fear, anger, excitement, play	The fur lifts in orientation along the neck, back and tail of the animal. There is some degree of random orientation. The longer the hair, the more the hair reacts to physical dynamics such as wind.
Bird (many species)	Feathers that are made of generally hard, branching beta-keratin with softer barbs connecting the branches. Location on bird determines degree of hardness	Feathers lie uniformly towards the body	Weather, fear, aggression, mating, excitement, flight	The feathers lift though no other axis is affected. The structure of the feathers allow for little interference of physical dynamics such as wind.

Figure 3.1 Physical attributes of hair and feathers organized by animal.

3.2. Design for Hair Rig

The hair rig was used to attach the base hair curves to a control system which allows for several different levels of controls. The hairs are attached to the base mesh and then rigged with a sophisticated hierarchy of constraints by influence objects that allow specific controllable behaviors. The first part of this tool is the generation of the rig that controls the hair/feather geometry. Once the rig generation tool is run, a window asks for the bind geometry, hair/feather curve geometry, and inputs the amount, shape, and color of spatial controls. The controls generated by the AnimFur tool can be adjusted to create the desired number of controls, as well as the shape, color, and position of the control. Once the spatial control layout is satisfactory, the rigging script is executed.

The fur or feather rig resulting from the rig script is designed to allow regional control over thousands of instances of geometry. The geometry is created using Nurbs Curves and attached to the bind mesh of the character using a deformer that attaches the base of the hairs to specific coordinates of a 2D projection map of a three-dimensional mesh using “U” and “V” axes, also referred to as UV space. The orientation of the geometry is determined by the animation controls. If the animation control is raised or lowered spatially from the bind geometry, then the curve will orient itself to point in the general direction of the control. Sliders in the control interface will connect to behaviors that reference the curve’s local space. Such behaviors include the ability to lift perpendicular to the bind mesh, to aim directly at the spatial control, to rotate randomly around the follicle, and to blend the result hair, or the hair that is being animated, between the position of the rig and the position of the dynamic calculation. These behaviors are illustrated in Figure 3.2.



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

Figure 3.2 Graphic of hair curve behaviors (a) Hairs (blue) aim towards control object (green). (b) Hairs (blue) move in same direction of control object (green). (c) Hair (blue) lifts ninety degrees from base mesh (black). (d) Dynamic result hair (blue) has base of hair attached to orientation of influence hair (green) and tip of hair driven by a dynamic simulation. (e) Hair (blue) orients randomly based off attribute in control UI

Because of the many different behaviors possible, and to prevent unwanted flipping when transitioning between behaviors, the curve position is based on a result transform of a null object, or object node that simply contains transform data, attached to the base mesh. This null object gets it's transforms from a user-defined bias from many influence transforms. To be lifted perpendicular to the mesh, the orientation of the transform object is aligned to the vector of the surface normal of the nearest face of the base geometry. To match the direction of the curve to the change of position of the spatial control, the out direction of the transform object is connected to the transform of the control. The aim behavior differs from the direction in that the curve is oriented to look directly at the control. To rotate randomly around the local transform, the curve's forward rotational axis is connected to an attribute on the control interface which multiplies the rotation by a number randomly assigned at rig generation so not all hairs in the rig rotate at the same rate allowing for visual variance.

The rig also allows dynamic integration that blends between the more absolute rigging control and less artistically directed hair simulation. This blending capability is utilized in a production project that represents the longer fur of the cat, however is turned off for the hedgehog and bird which require more absolute control.

This rig allows for more control over the final look of fur or feathers in the animating process. It is designed to work within the AnimFur tool, and allow interactive and artistic control for animators.

3.3. Local Software Compatibility

There are several different options for software that can be used to render hair geometry. This tool works best for a software which uses guide curve methodology. With this methodology, the guide curves represent the behavior of clusters of rendered hair. This methodology is currently the most widespread as it allows for faster computation and render time. Thus, the AnimFur tool is compatible with most fur/feather rendering software.

4. IMPLEMENTATION

4.1. Implementation Environment

The 3D software used was Autodesk Maya 2015. Resulting animations were rendered using Pixar's rendering software Renderman 20.9. The hair rig and control system was generated using Maya's scripting language Mel in combination with Python because of the flexibility and customization available with these two languages. Future users can customize the AnimFur tool by loading the scripts into Maya's text editor and modifying scripted functions.

The base hairs were generated two ways. The hedgehog and cat hair curves were made with Xgen, a plug in developed by Disney for creating artistically posed hair, and exported as a Mel script, and the phoenix feathers by creating multiple duplicates of plane geometry, or two dimensional geometry, parented bellow Nurbs curves. Each curve is connected to the mesh using *follicles*, a Maya object which adheres to the UV space of a specified mesh. The locked rotation attributes of the follicles are then unlocked and reattached to attributes of the control system using constraints and expressions.

Finally, the renderable hairs are generated. The phoenix feathers were assigned Renderman shaders to planes because the complex appearance of feathers needed to be simplified into 2D representation. The hedgehog quills were generating using Maya's built-in hair renderer nHair and the resulting shapes assigned Renderman shaders so that the quills could be drawn in the render with density. The cat hairs were attached to an nHair system which was then used as an animation modifier to an Xgen groom and rendered with Renderman shaders because Xgen results in more appealing natural looking hair than geometry or nHair. This workflow is visualized in Figure 4.1.

The rig was applied to three animated characters, each with separate performance needs. The robustness of the AnimFur tool was tested by using different performance goals to ensure that the system could handle various animations and high volumes of hair.

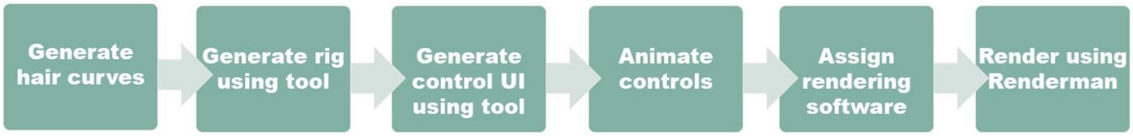


Figure 4.1 A graphic representation of tool's general process to create fur performance

4.2. Preparing the Curves

Nurbs curves were created to be used as a base from which the rendered guide hairs would be generated. The nurbs curves were then attached to Maya's nHair hair system which could be used as a rendering tool or applied to Xgen as an animator modifier. However, Maya's nHair tool is not designed to easily groom the hair direction which is necessary for visual appeal.

To create a set of appealing curves that could eventually be rendered as hair, we utilized Xgen's grooming tools. These tools allowed me to vary length, placement, and orientation of hairs. Once Xgen preview of the groomed "hairs" matched the desired aesthetic direction, we exported the groom as a Mel file which converted the preview into nurbs curves.

The curve pivots were at the Maya scene origin with their rotate orientation matching Maya's origin. This was useless as the purpose of the rig was to create a control system to manipulate the orientation relative to the individual curve. This issue was addressed later after the rig tool was initialized.

This tool asks for the user to input the name of the base mesh to which the hairs would be attached and also for the name of a root group which contained the nurbs curve guide hairs. The tool queries these inputs and then asks the user to generate controls. The controls are generated based on several conditions input by the user using Mel buttons, text fields, and sliders: name, amount, color, and shape type. The controls are then placed along the origin, and the user must position the controls according to their needs. The user can create more controls, delete controls, mirror controls over specified axis, change the color or name using buttons, text fields, and menus on the Mel window. Once the input has been finalized, the user then presses a button to initialize the rig tool.

Figure 4.2 illustrates this workflow.

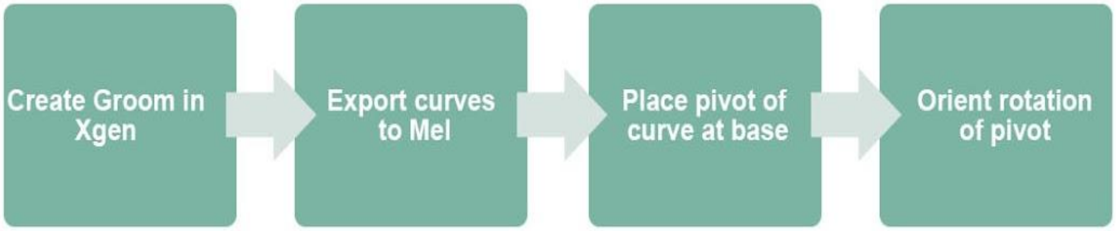


Figure 4.2 A graphic representing the workflow to prepare the curves for the rig

4.3. The Hair Rig

The controls are adhered to the base mesh using a function (discussed later). The controls are then prepared for animation by locking and hiding unused channels such as rotate and scale which prevents confusion for the animator. Ultimately, the transform channels are left open as well as three additional attributes added: lift, aim, and random. These attributes are eventually connected to the curves to modify orientation.

The curves are useless if their pivots and rotation axis do not align with the base mesh and the direction the guide hair is facing. To combat this, the tool first corrects the pivot location by identifying the world location of the base point, or control vertex, of the curve as shown in Figure 4.3. This vector value is then copied to the world space coordinates of the scale and rotate pivots of the curve.

Each curve is composed of line segments connected by control vertices, or CVs. As the rotate orientation of curves cannot be directly manipulated in Maya, a locator was created and placed at the base CV of each curve. A second locator was placed at the second CV of the curve based on the assumption that all curves must have two points: a beginning and an end. The locator at the base of the curve is aim constrained with the y-axis identified as the up axis without maintaining an offset so that the y-axis of the locator points down the curve. With the pivot of the curve matching the pivot of the locator, the curve is parented below the locator so that the rotation axis of the locator is carried down the hierarchy to the curve. These locators are adhered to the mesh input by the user using a function which creates a follicle object at the nearest UV point on the base mesh and then parents the desired object beneath that follicle.

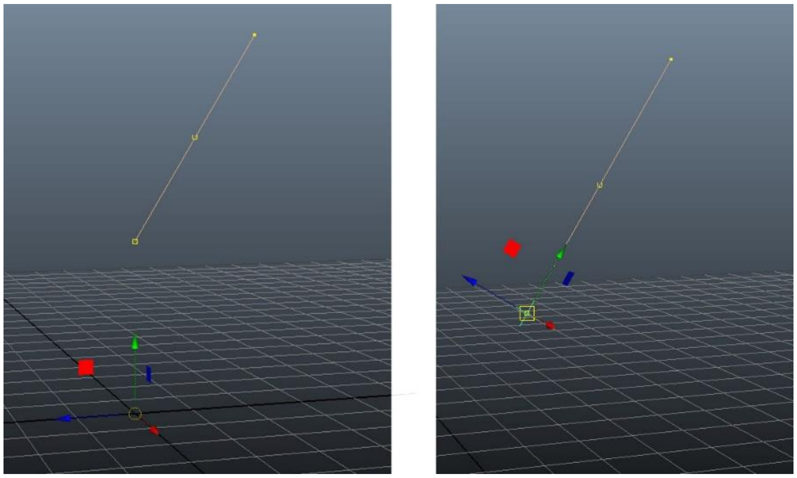


Figure 4.3 Images showing orientation of curves before and after rotate orientation correction

The curves must be assigned to groups divided spatially so that their behavior is linked to the control closest to the curve. Each control is added into a list. Since the controls have their transform channels zeroed out for animation, another locator is created and point constrained to the control's world position. A looping statement checks each curve's world position to the position of each control in the list. Once the control nearest to the curve is found it's name is added to a separate list. Each control has its own curve list.

Each curve must be connected to the control's position and attributes. Because each control has its own list of curves, a looping statement goes through every control and executes a script for each curve that ultimately connects the control's attributes and transform values to the curve's behavior. A curve is connected to it's assigned control through constraints or expressions. Because of the number of desired behaviors, the result guide hair is parented under a result locator, or a locator with the resulting behavior. Each behavior has a locator to influence the result locator. These behaviors are aim, lift, direction, and random orientation . Figure 4.4 is a visualization of this hierarchy.

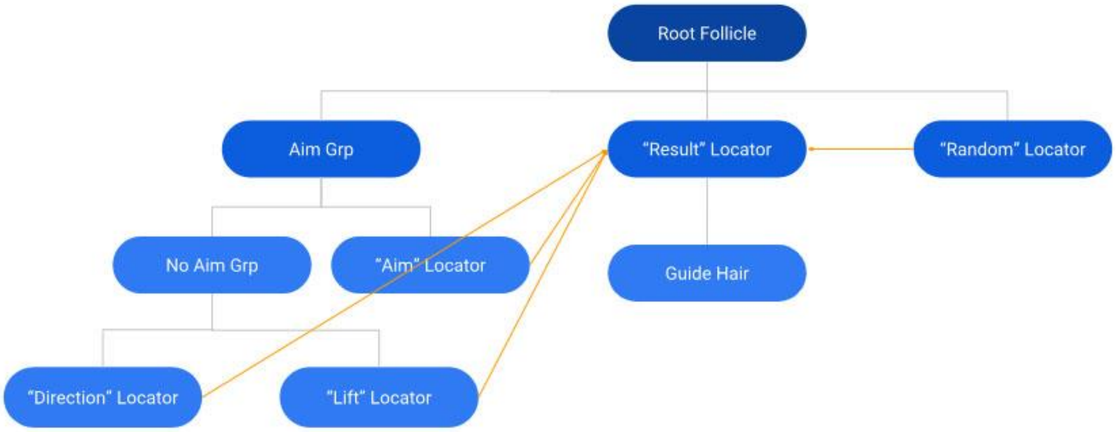


Figure 4.4 Depiction of relationships rig hierarchy and guide hair. Blue lines represent parent-child relationships, and orange arrows represent influence-result relationships.

These behaviors were determined to be necessary for most instances of expressive hair: aim, direction, lift, dynamic blend, and randomized twist. Aim attracts hairs to look at a point in space determined by the position of the corresponding control. Direction shifts the orientation of the result hair based on comparable changes in the control's position. Lift pushes the hair perpendicular from the bind mesh. Dynamic hairs incorporate real world physics into the resulting position which is particularly useful for softer or longer hair. Randomize orients the twist axis of a result hair by a multiplier driven by a value on the control object. Each behavior is visualized by a locator which in turns drives the behavior of the result locator where underneath a guide hair is nested.

Because of the unpredictable flipping and large rotation values that result from Maya's constraint tools, each locator influences the position of the result locator with a safe guard built in place to avoid flipping. For each influencing locator is another locator parented bellow the influencing locator and placed three units along the y-axis of the parent locator. The reason the locator was moved three units was to allow ample scene space for the constraint to calculate accurate values, and the axis it was projected down had to match the axis that pointed down the guide curve. The result locator was then aim constrained to each of these locators that were children of the influencing locators. Blend color nodes allow a smooth transition from orienting between the influencing locators instead of flipping into the base mesh and causing undesirable performances.

The aim behavior was created by aim constraining the influencing locator to look at the control. This is different from non-aiming behavior as with aim turned on, all hairs face the same point in space. With this attribute turned off, the hairs orient in a similar direction, but do not point to the same spot. To do the tracking behavior, locators are created in a bounding box around the base mesh which is broken into eight regions divided by the change in orientation of the normal at the nearest point of the curve to the base mesh. This makes the resulting behavior much less extreme than the aim behavior.

Lift behavior is determined by creating a locator that is perpendicular to the nearest face normal of the base mesh to the curve by use of a ClosestPointonMesh node. The random behavior, which is needed for interlocking hair patterns and visual appeal, is created by assigning a random multiplier to each curve's rotate z axis, and then interpolating the multiplier by the random attribute of the corresponding curve.

This resulted in customizable control which has an added level of control over the resulting behavior because of the layered hierarchy.

5. RESULTS

The hair and feather rigging tool, called AnimFur tool, was developed to be able to control the behavior of fur and feathers on a character to represent the realistic changes in fur/feather orientation that happens as a result of an animal's emotional response. The tool was implemented in various animated pieces to determine how successful the tool is at achieving the look for which it was developed. These pieces include a phoenix-like fantasy bird, a hedgehog, and a cat.

Figure 5.1 Results of phoenix

The phoenix short depicted a bird-like fantasy creature who is hunting a presumed dead beetle. The phoenix approaches the beetle, but is startled into raising its crown feathers when the beetle twitches its legs. When the beetle begins to scurry around the terrain, the phoenix puffs up his chest, lifting his chest feathers, and spits fire at the beetle, scorching it. The short ends after the phoenix lifts it's crown feathers as it tilts its head in curiosity as shown in Figure 5.1.

The phoenix rig implemented the AnimFur tool on both the head and the chest feathers. The animation referenced animals such as Cockatoos and Secretary Birds which lift their exaggerated head feathers to display excitement or aggression. Since the feathers are relatively stiff, and simply lift from their rest position to roughly perpendicular to their skin, the tool was successful for animating this behavior. These feathers are also highly expressive, and show that the AnimFur tool can be successfully implemented to create expressive animation.

Without the AnimFur tool described in this thesis, the approach to rigging feathers with the same expressive needs would be accomplished using the most efficient means provided by the software packet. In the case of Maya and animation software similar to it, this would be a traditional bone-joint rig or hybrid bone-joint rig with simulation. However, bone rigs are computationally heavy, creating large files that hinder production further along the animation pipeline. The simplified mesh attachment and expression and constraint driven behavior has much lighter computation time relative to skinned and joint driven rigs.

Figure 5.2 Results of Hedgehog

The AnimFur tool was also implemented in the creation of a short animated piece featuring a hedgehog, shown in Figure 5.2. The hedgehog short depicts a hedgehog coming across a still roach. The hedgehog approaches the roach, however, when the roach twitches, the hedgehog reacts in fear. The hedgehog tenses and the quills raise, then the hedgehog pulls itself into a ball and the quills randomize into an interlocking pattern.

The AnimFur tool was used to control approximately a thousand quills on the back of the hedgehog. From this animation, it was determined that the tool's control interface was successful at controlling a large number of hairs. Even though there was a thousand hairs attached to the rig, interactivity was preserved. The tool was also successful at representing the complex interlocking behavior of raised hedgehog quills. The controls allowed for expressive timing and posing, and thus demonstrated the AnimFur tool's versatility.

Figure 5.3 Results of Cat

Finally, the AnimFur tool was used in the production of a short depicting a scruffy alley cat with long hairs. The short, shown in Figure 5.3, depicts a cat approaching a dead roach on the sidewalk of a city. When the roach twitches, the cat arches his back and his tail and spine hairs puff up in defense. The short ends with the cat, hairs still raised, backtracking out of the frame.

The challenge of this piece was to implement the dynamic blending capabilities of the rig. Since the fur of the cat is more flexible than the hard quills of the hedgehog, the base of the hair should maintain fidelity to the rig-driven behavior while the tip of the hair should react to a dynamic simulation. Since the dynamic simulation relies on timely calculations, the tool was not directly interactive. However, stiff hairs attached to the rig representing the control-based position of the hairs gave the users a visualization that represented the position of the hairs to create successful animation.

6. CONCLUSION AND FUTURE WORK

The results of this thesis allow for more effective and efficient animator control over the fur or feather orientation of characters to communicate intent and mood as demonstrated through the representation of a bird, a cat, and a hedgehog. This thesis shows that fur or feathers can be controlled more easily by animators to implement the animation principles of timing, posing, and silhouette than is possible through dynamic simulation. The method in this thesis demonstrates a control system for authoring animation of the fur/hair/feathers by an interactive software tool that is easily implemented in an animation production environment as an alternative to the dynamic tools already in place within the wide ranging instances of fur within animation production. The behavior of fur and feathers are put in the animator's hands and can be used as an expressive tool for artistic direction. Because the animator can control the posing, timing, and silhouette of characters, the principles of animation can be implemented easily to allow for appealing and successful performances that were not possible with dynamic simulations.

There are multiple ways in which the work of this thesis can be extended. TheAnimFur tool increases the level of control given to the animator to improve the look and feel of the outcome. This could result in controls that allow for specific, artistically designed and animatable hair grooms. The AnimFur tool could be applied to create additional rigs for animation use and expanding the rig to include deformations of the base mesh the rig is attached to so that more realistic results can be achieved. More dynamic settings could also be included to affect the rig. Further expansion could lead to an AnimFur tool with it's own rendering capabilities such as Xgen or nHair.

Once the AnimFur tool has been placed in the public domain, it will be of use to artists who would like finite control over the expressive qualities of fur and feathers on animal or animal-like characters. The methodology of this tool can also contribute to hair simulation techniques to connect the bridge between artists responsible for animation and character simulation to create more endearing and expressive animations.

6.1. Future Work

Using a combination of Maya nHair and Xgen has drawbacks. It would be ideal for the AnimFur tool to use the same programs throughout for ease of use. Future research could focus on creating a tool that incorporates grooming tools as well as the rigging tool illustrated herein. The controls could also be more intuitive. Future work could focus on creating an interface to allow for more appealing control design.

The purpose of this research was to create a tool for expressive control of hairs using rigging methods. Ideally, this method should be in combination with dynamic simulation so that artistic results can be achieved in combination with the support of physics based behavior.

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