The Chronicles of Narnia:
The Lion, The Crowds and Rhythm and Hues

Course 11
Siggraph 2006

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Introduction

For almost 2 decades Rhythm and Hues Studios has been using its proprietary software pipeline to create photo real characters for films and commercials. However, the demands of "The Chronicles of Narnia" forced a fundamental reevaluation of the studio's existing pipeline and procedures. The requirements of Aslan and the thousands of mythological creatures presented a variety of technical issues that necessitated new solutions and changes in the work flow of almost every department in the studio. This course will explore the studio's new work flow and latest technical solutions by taking a look at several case examples from the production.

The evolution of Aslan will be explored in detail from initial models through rendering. Detail will be paid to the rigging process, muscle systems, a new approach to facial setup, R&H's proprietary fur solution as it was used on Aslan, as well as dynamics on both muscles and fur.

Elements of other creatures offered their own set of technical challenges. The fully articulate wing solution for gryphons will be explored, as well as challenges associated with combining live actors with cg to create centaurs, minotaurs and fauns.

Creating the final battle presented the challenge of creating large crowds composed of many different, non-human character types with cloth and fur. This course will explore several aspects and issues involved in this process including, pipeline considerations, motion transfer between hero and crowd rig, motion generation, skinning, level of detail, lighting, rendering and flexible body dynamics

Prerequisites

Topics will range from intermediate to advanced. An intermediate knowledge of 3D workflow, procedures and terminology is helpful but not required.

Presenter Biographies

Jubin Dave
Lead Lighting TD, Rhythm and Hues Studios

Jubin got his Bachelor's degree in Electrical Engineering from the University of Bombay and his Master's in Computer Science from the University of New Hampshire. He has been with Rhythm and Hues for almost 8 years. He initially worked as a Software Engineer on the proprietary renderer. He is currently a Lead Lighting TD. His partial list of credits include Garfield, Elektra, and The Chronicles of Narnia: The Lion, The Witch and The Wardrobe.

Brad Hiebert
Senior Character Rigger, Rhythm and Hues Studios

Brad Hiebert is currently a senior character rigger at R&H. He was lead rigger on The Chronicles of Narnia where he rigged Aslan and supported all rigs through out the production.

He is self taught and started in the 3D industry as a demo artist for SoftImage where he tested software and created demo material for Siggraph and other presentations. After SoftImage, Brad worked for several of commercial production companies around the country, including Big Idea Productions, before coming to R&H 3 years ago

Tae-Yong Kim
Software Engineer, Rhythm and Hues Studios

Tae-Yong Kim is currently a software engineer in Rhythm and Hues Studios. His primary responsibility at R&H includes development of simulation tools such as cloth, hair, and other types of softbody. For the Chronicles of Narnia, he developed a new hair simulation technique
that was used to simulate aslan's fur as well as fur and hair of other creatures. He holds a Ph.D degree in computer science from the University of Southern California where he did researches on hair

modeling and rendering techniques. His work was published in SIGGRAPH 2002 as well as other conferences. He has taught a SIGGRAPH course on hair simulation in 2003 and 2004.

Ivan Neulander
Principal Software Engineer, Rhythm and Hues Studios

Ivan has been with R&H for over 8 years and presently leads the Rendering Software team. He is a graduate of the University of Toronto, from which he holds a Masters degree in Computer Science. He has made contributions to the photorealistic rendering of CG fur in a number of recent films, including: The Chronicles of Narnia, Garfield, Scooby Doo, Cats & Dogs. He has also made a number of SIGGRAPH presentations on the efficient rendering of realistic fur and hair.

Hans Rijpkema
Character Technology Lead, Rhythm and Hues Studios

Hans has a masters degree in Computer Science. He worked at SCAN in Groningen (The Netherlands) for five years as head of R&D and as a teacher of a computer graphics masters degree program. He came to Rhythm and Hues in 1996 to start up the rigging department and is currently in the software department responsible for character development, like rigging, skinning, fur grooming and animation and model creation and deformation. He has worked on over 30 feature films like Mousehunt, Babe: Pig in the City, Frequency, Harry Potter I, Cats and Dogs, Elf, Scooby Doo, Riddick, Garfield and Narnia.

Will Telford
Creature Supervisor, Rhythm and Hues Studios

As Creature Supervisor on "The Lion, the Witch and the Wardrobe," Will Telford participated in defining and creating look development for more than 60 characters. He co-supervised modeling, texture painting, rigging and lighting.

In addition Will served as Rigging Supervisor on projects including "Scooby-Doo 2," "Garfield" and "Cat in the Hat." He served as

Character Rigging Lead on "Harry Potter and the Sorcerer?s Stone" and "Elf," and as technical director on "Scooby Doo," "Men in Black 2," "The Ring" and "Daredevil," as well as for commercials Coca Cola Polar Bears, Geicko, Advantix and Cheetohs.

Will holds a a Bachelor of Environmental Design Degree from Texas A&M University

Course Outline

1) Introduction
    1. Welcome, introduction of speakers, short overview - 5 min

2) Pipeline overview - 10 minutes
    1. R&Hs proprietary software philosophy
    2. Lite Comps
    3. Construction Kits
    4. Multi-Character pipeline - sharing many characters in one scene between many depts.

3) Aslan: From Model to Render - 75 minutes
    1. Modeling - 5 min.
    2. Body Rigging - 10 minutes
        a - construction kits
        b - binding dynamically
        c - muscle systems
        d- secondary motions
    3. Facial rigging - 15 min
        a - goals and production requirements of facial rig
        b - driven Poses - 2 animator inputs, many complex outputs
        c- final technique - minimal shapes with muscles working together
    4. Animation Testing - 5 min
        a- making it move like a lion
        b- finding human personality in photo real lion
    5. Fur - 25 min
        a - overview of proprietary fur system - guides, pelts
        b- evolution of Aslan's fur - examples of process
        c- lighting & rendering - HDRI, dual highlight specular model
    6 Dynamics - 15 min
        a. Simulating jiggles and body masses with harmonics
        b. Animating Aslan's mane with fur dynamics

4) Q&A 10 min.

Break 15 min

5) Mythological Characters - issues and solutions - 20 minutes

1. Gryphon - 10 min
   - a- model, rigging, render - details behind a fully articulated (folded to open) wing
2. Centaurs - 10 min
   - a- overview problems with actor movements and proportions
   - b- solutions with before and after examples

6) Battlefield 75 min

1) Introduction - 5 min
   - a - the challenge- large crowds on different character types with cloth and fur
   - b - pipeline consideration- crowd preview, independent stages
2) Rigging considerations - 15 min
   - a - hero rigs vs. crowd rigs- differences. similarities and motion transfer
   - b - skinning the crowd- stored in cached character rig model format
3) Motion generation - 10 min
   - a - Joint motion- crowd simulation and key frame animation
   - b - Crowd motion files: efficiently recover subsets of individuals
4) Skinning of a crowd - 15 min
   - a - View port clipping- only process that which is visible
   - b - Automatic Level of Detail selection
   - c - Variation control geometry and materials
5) Lighting and rendering - 15 min
   - a - Prelighting: Levels of Detail and flavors
   - b -Shadows, Tiling, Ambient occlusion, compositing
6) Flexible body dynamics - 15 min
   - a- Dynamics relative to camera: Simulation level of detail and view port clipping
   - b- Feeling the wind -simulating wind effects in cloth and hair simulation for crowds.
   - c - Parallel dynamics computation

7) Q&A 10 min

2. 1 Pipeline overview

The Lion, The Witch, and The Wardrobe is the largest character show Rhythm & Hues has ever done. With an 18 month production schedule and over 67 unique characters to build, the entire production pipeline had to be revisited. Rhythm and Hues primarily uses proprietary software. This approach leads to a much greater flexibility when approaching the challenges of a production. It reduces the need for a dependency on resources external to the studio. The following is a summary of software primarily used for this production:

- Modeling: Maya and And
- Rigging: Voodoo
- Texture Painting: Photoshop and Deep Paint
- Animation: Voodoo
- Renderer: Wren
- Compositing: Icy
- Particle Effects: Houdini
- Crowd Simulation: Massive

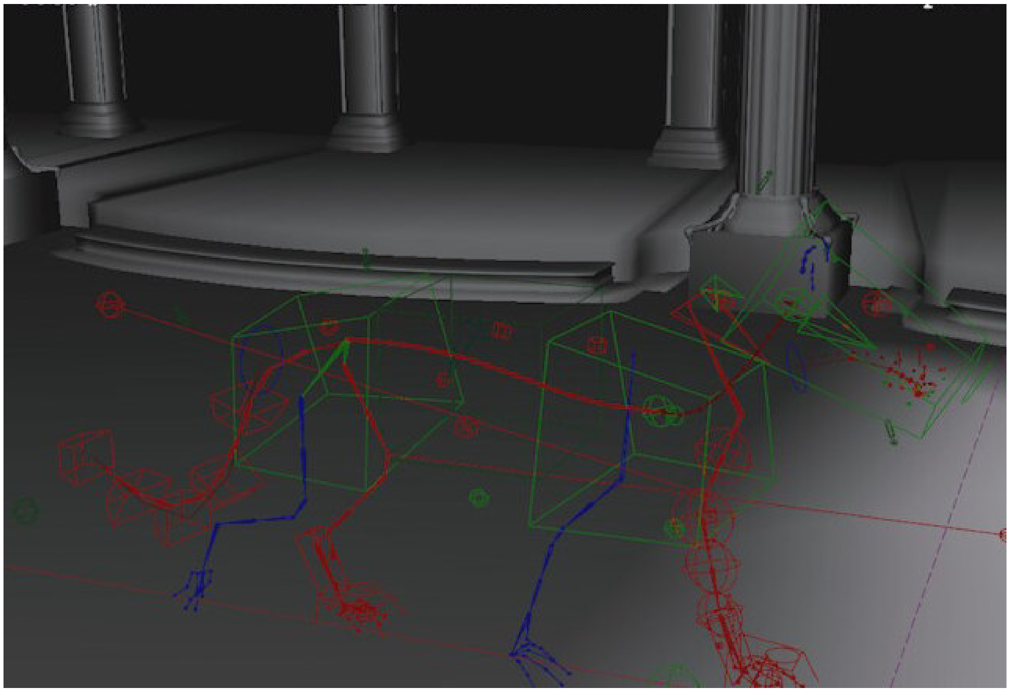
To successfully address the challenges of the production, Rhythm and Hues needed to create and refine several new pipeline processes. It was clear very early on that the production would stretch every resource in the studio very thin. As such we needed to improve the efficiency of the studio. Many processes in the studio worked well for single character shows. A whole new set of challenges arose with so many characters.

LiteCmps

Rendering resources were a primary concern for the production. As such we needed to be more efficient during shot production with our renders. To solve this problem we created LiteCmps. The philosophy behind a LiteCmp is to move as much computation from the render and allow it to happen in the composite. In order to do this it is necessary to generate many additional layers. This is done to the extent that the only changes that require a re-render are animation, light position, and the creation of new lights. On average each new light added roughly six layers. At render times all lights are pure white. Intensity and color are entirely controlled in the comp.

Construction Kits

Another major concern was rigging and animation time of so many characters. It was necessary to create a system that kept the character rigs consistent. Our first approach was to group similar characters. For example, a big cat rig could be re-used for Aslan, the leopard, the cheetah, and the white tiger.



This level of granularity addressed our concerns, but we determined that it didn’t go far enough. Our next step was to further break down our characters by the components that they were constructed of. In doing this, we could create one global spine structure for quadrupeds. In the end we found 13 basic modules that we used to construct every character on the show.

- BipedArm
- HoofedArm
- PawedArm
- BipedLeg
- HoofedLeg
- PawedLeg
- BipedNeck
- QuadNeck
- BipedSpine
- FkBipedSpine
- QuadSpine
- MultiResTail
- Wing

This approach guaranteed consistency between the characters and allowed riggers to easily construct and support rigs. As an added benefit, animation ramp-up time was drastically reduced. For example, if an animator had already animated a centaur, they only needed to learn how the neck controls work if they were moved onto a horse. If an animator already had experience with a faun arm, they new that the minotaur arm would be identical. Another bi-product of this system was the ability to more easily retarget and share motions from one character to the next.

Multi-char pipeline

Another challenge for this production due to the shear volume of characters was the management of multiple characters in one scene. When anticipating the needs of the show it was determined that we would need the ability to combine upwards of 30 hero animated characters in a single animation file, with the possibility of multiple animators working on the same shot.

This presented two main challenges. One, with that many characters in a shot we new we would be pushing the software's threshold for memory and maintaining file speeds. Two, we needed animators to be able to collaborate and share animation and characters between files.

To solve the memory issue the first step was to create less computationally expensive characters for the shots. This was done by allowing animators to publish a character, which would bake out the animation into two resolutions of cached geometry files. This gave an animator three choices when working with characters. They could have the live rig in the file, a lo-res cached geometry, and a hi-res cached geometry. The system allowed them to swap these in and out on the fly.

As the animators published their characters as opposed to publishing their entire animation file, other animators were given the ability to check them out. Any newly published character changes were reflected immediately in the files of animators using a cached geometry.

3 Aslan Rigging

3.2 Body Rigging

There were 3 primary elements in the rigging process that made rigging Aslan and the dozens of other hero characters possible and manageable.

Cks

As mentioned earlier, the standardization of the underlying rigs was key to allowing the production of rigs quickly and to allow changes to happen quickly and seamlessly.

Dynamic Binds

Rather than ever having a baked in weighting, All verts in our rigs are bound dynamically when the scenes are loaded. There are many advantages to the fact that there is rarely the need to have a fixed vert to bone relationship. Joint position, control placement and fall off change can be adjusted at any time in the production process.

Muscle Systems

Another change to our workflow was the creation of an entirely new muscle system. The system was simple in design, volume-preserving shapes, controlled by muscles that the skin would bind directly to. Secondary deform issues like kin slide were not addressed with this tool, however, harmonics and dynamics could be added to the muscles.

Part of the R&D process was to determine the best way to handle the new tools. Initially we tried building a very accurate setup, with as many as 30 muscles per side of the body with 100% biological accuracy. However, that proved to be computationally expensive and many muscles in a small area could cause binding errors. In the end, we determined that less was more. We combined many muscles into larger single muscles. In the end we had about 10 major muscles per side of the body.

Subtle secondary motions

To achieve the subtle effects like loose skin and muscle flexing, we relied on two main approaches, harmonics and shapes. Harmonics is a cycle-based system that mimics dynamics but is much faster and less computationally demanding. The results are not as accurate as a simulation, but adding a simple "jiggle" cycle on a muscle mass was very convincing.

Subtle secondary shapes added an important degree of realism in the torso and legs. These shapes could be animated by hand when needed, or automated for repetitive cycles or at time when the character was far enough back in the frame that it wasn't to noticeable.

3.3 Aslan Facial Rigging

Initial requirements

In addition to all of the issues related to the body, the facial rig had its own set of concerns and problems. Bill Westenhoffer, the Visual Effects Supervisor and Richie Baneham, the Animation Director both had a number of issues that they wanted addressed as we began any development on the face

1) 100% biological accuracy
This issue proved to be tricky. Given our history of cartoony characters, Bill insisted that every movement of the face be muscle based and that the rig not be able to hit ANY pose that a lion couldn't hit. However, Aslan needed to speak. In addition, Richie wanted a lot of random sculpting control that didn't necessarily fit into the rigid system of control that Bill wanted....... there were a lot of meetings on this one!

2) Concerns about too many shapes
We had several animators and leads that had worked on other high profile characters where the face rigs were based upon thousands and thousands of modeled shapes. They found those rigs overly complex and difficult to use. Also, the addition of other shapes during production might conflict with existing animation and require reworking of finaled shots. They wanted to avoid this situation if possible.

3) Concerns with muscles
Muscles could provide realistic movement, but not being locked to modeled shapes gave a high level of sculptabilty that could lead to different looks between artists. The production wanted consistent, easily repeatable poses that would guarantee a consistent look through out the production.

4)Concerns about UI
Animation had concerns that the level of subtle control required would result in a cumbersome, overly complex UI. They wanted something that was as simple and as intuitive as possible.

Working with Shapes

Although we didn't rely completely on shapes, they still played a very important roll in the facial rig. By the time we were done we were using about 75 shapes in the face. These shapes fell into 2 categories, deforming shapes and corrective shapes used to fix deformations in certain situations. The deforming shapes were based (and named) on isolated facial muscle movements rather than poses like "Brow Up" or "Lip Corner Angry". We then combined these isolated muscle based shapes into recognizable "poses" that animators would be more familiar with.

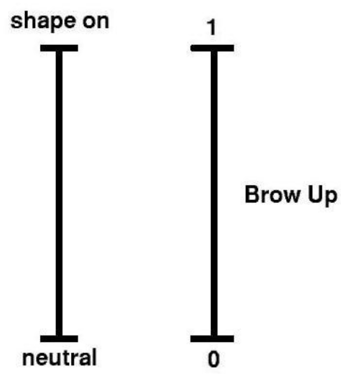
For example, a pose of "Brow Up and In" might be a combination of the externus, temporo, auricularis and palpeb modeled shapes. This helped us to create human like expressions that we were confident were biologically accurate since they were created from accurate muscle movements that a lion could make.

In the past, R&H favored "traditional deforms" over shape based controls. In the end Narnia definitely made more use of shapes than anything we had done in the past. Because of this new emphasis on shapes we were able to create some new tools for working with shape based deforms.

Dpose, a radial basis function

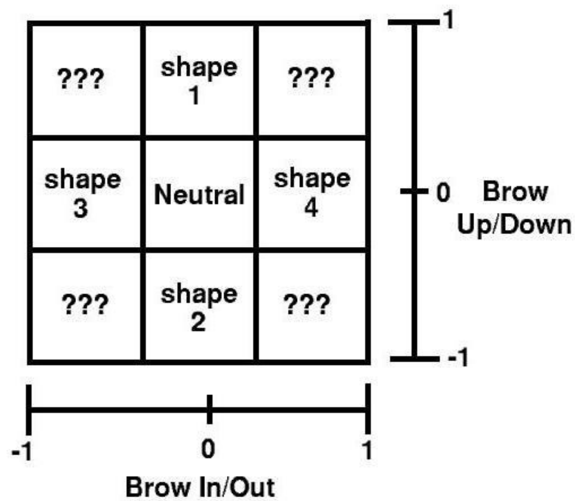
Dpose, or drivenPose, is a tool that was created to allow us to mix multiple shapes and create a wide variety of poses with a minimum number of controls exposed to the animator. Our tool allows for a few inputs, usually 2, to generate any number and variety of outputs. To explain.....

Example 1- basic blend

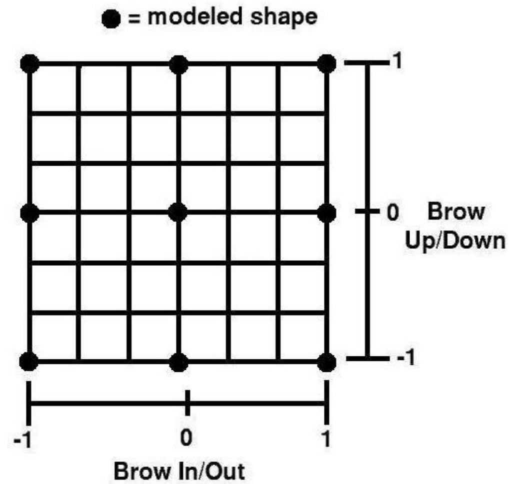


First consider how a basic blend shape works in its simplest form...... One control drives the addition of one shape to a model. Four controls drive 4 blend shapes which are mixed together according to a preset algorithm such as average or additive. You can mix different shapes together, but if you don't like the results you get, you will need to create another shape and use another control.

Example 2 – adding expressions to control more shapes



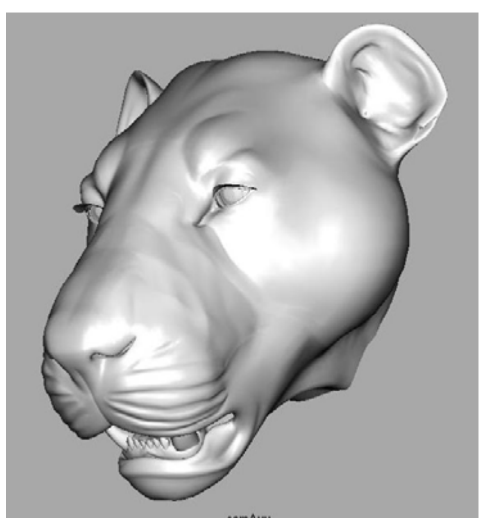
Using separate controls and some expressions on the blend shape sliders, you can have two controls (ex. BrowUp/Down and BrowIn/Out) that drive 4 blend shapes. However, you are still limited in how you chose to mix those shapes. If BrowUp (shape1) and BrowIn (shape3) don't combine nicely with any of your mix mode choices you have a problem to sort out.



Using Dpose we are able to assign any number of shapes to the result of two slider combinations. If you don't like the results of combining Shape1 (Brow Up +1) and Shape3 (BrowIn -1), we can simply create a new shape that is used instead of shapes 1 & 3 when "BrowUp" =1 and "BrowIn" = -1

The final facial approach

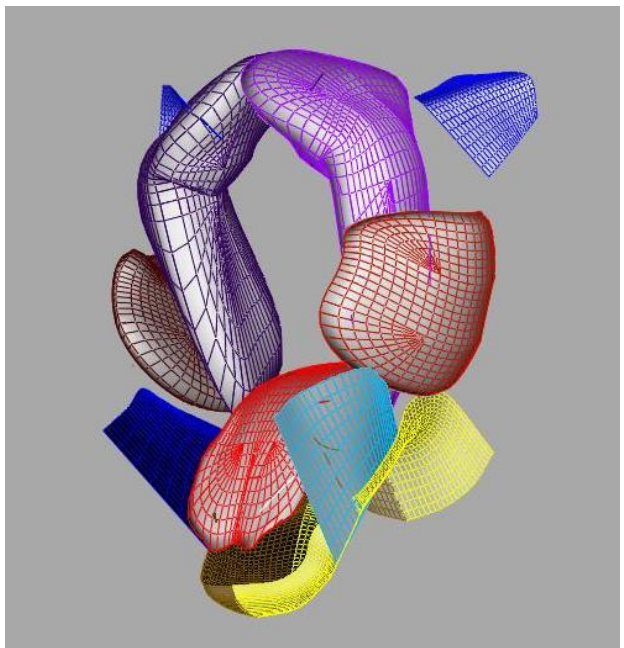
After much experimenting, we ended up with a multi-tiered rig that combined shapes, 2 layers of muscles and traditional deforms.

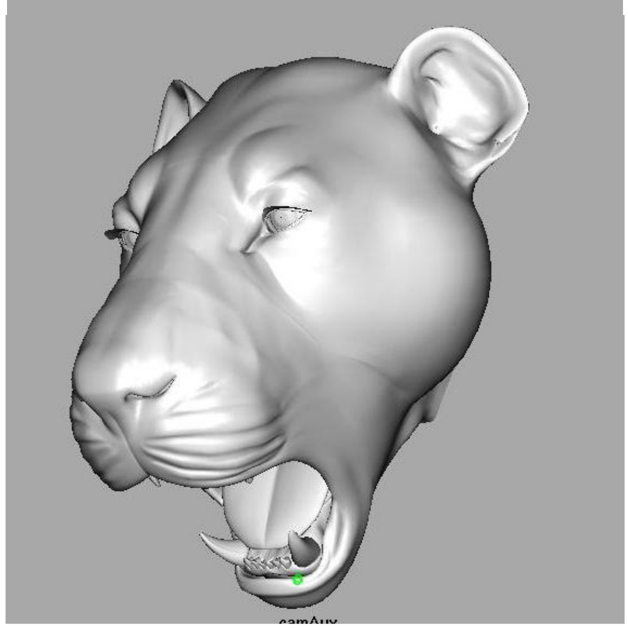


Starting Model

The final model existed in a number of resolutions that were used at various stages depending upon the need of that stage. Usually a very low res model was used.

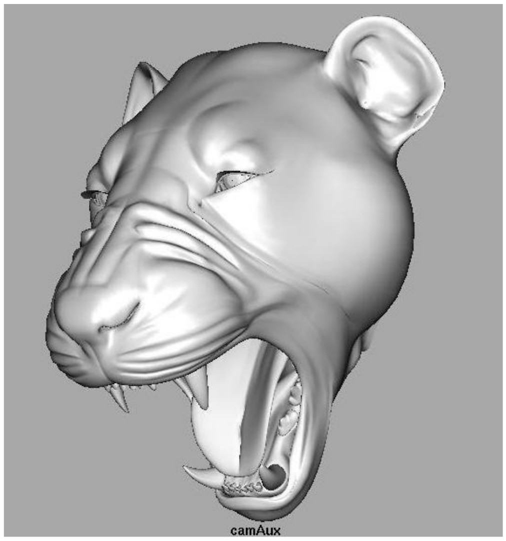
Step 1 - deforming muscles





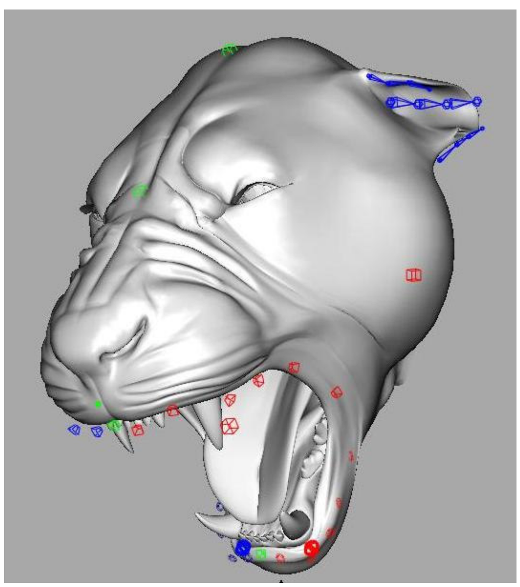
First we created a few muscles that were needed to handle major movements and deformations such as rotations and skin stretch from jaw, ears and tongue. In general these deforms were still fairly rough and not all vertices were distributed in a pleasing manner.

Step 2 – shapes



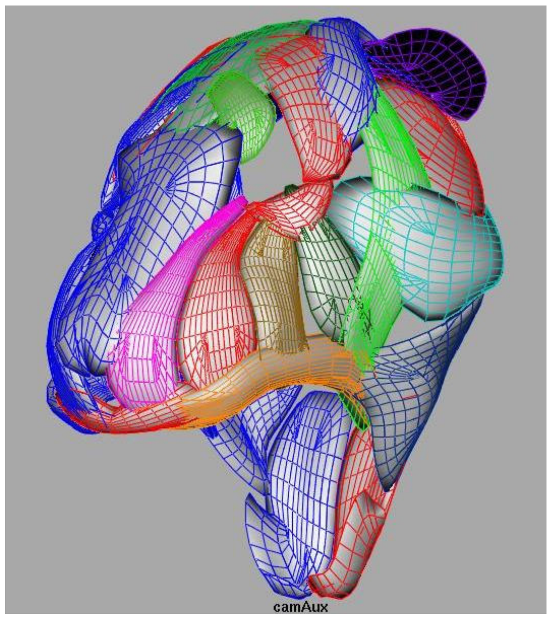
On top of these muscle deforms we mixed in the shape based deformations. These handled many key expressive muscle poses and wrinkles as well as subtle corrections to the previous muscle based movements.

Step 3 - traditional deforms



The next step involved adding many layers of deforms that built on top of the accumulated muscle and shape based deforms. Although many of these controls were for tweaking subtle areas, many had much broader effects such has sculpting the shape of the lips, moving the eyeballs and creating complex ear movements and poses

Step 4 – skin slide muscles



Finally, a set of detailed muscles that represented the muscles on a lion's face that lay just under the surface were added to calculate subtle skin slide that would result from all of the various deformations that have accumulated to this point.

These were then mixed in on top of all of the other deforms at various levels . These provided a subtle movement that really sold the face.

UI - make it simple and clear

Finally, it was very important to the rigging team to have a user interface that made accessing the controls as easy and as intuitive as possible. In addition, we wanted to help standardize the look of Aslan by creating tool sets that lead the animator to use the broader tools first before resorting to low level sculpting tools that a rig this flexible needs.

R&H uses a tool called "CharVui" which is a standardized UI for controlling all characters. It groups all tools into layers that can then be called up into the control window.

Per a suggestion by Erik De Boer, one of the animation supervisors, we grouped all of the controls in 3 major layers.

<u>1) faceMajor Controls</u>

This is where every animator should spend the majority of their time. Controls here were designed to give consistent, repeatable results. It was our hope that 90% of the animation could be done with the faceMajor tools.

This layer included things like eye controls, jaw, complex (Dpose) shape controls and other high level functionality.

<u>2) faceMinor Controls</u>

This was the next tier down of controllability. This layer consisted primarily of access to the individual modeled shapes, not their complex combinations in the faceMajor layer.

In the end these were rarely used, if at all. In retrospect, this was partially due to the fact that we named the shapes after the facial muscles they were based on. As it turns out, calling a shape "mentalis" or "orbicLevator" is not terribly intuative to ,well. anyone!..... who knew?

3) face tweaker

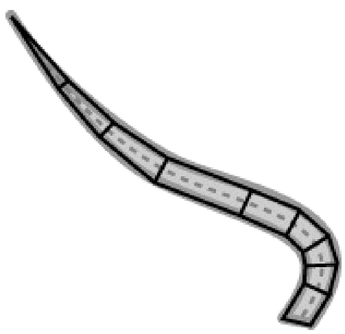
This was the lowest level of control and it contained controls for sculpting the lip shape spline, ears, loose skin around the face and more.

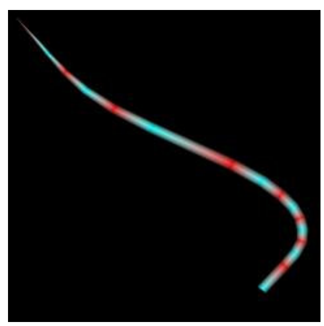
Most animators spent some time with these controls. It was probably inevitable, but grouping these controls on this level helped insure that an animator didn't do an entire scene's lip sync by brute forcing it with sculpting control. The rig was certainly capable of performing in that manor, but it wasn't an efficient use of an animator's time nor did it give the consistent results we wanted.

3. 5 Hair Lighting and Rendering

Hair Representation

Each strand of hair is rendered as a closed generalized cylinder: a tube of varying thickness following a given path through space and tapered at the tip. Hair strands are passed to the renderer in patches that have precomputed bounding boxes for fast clipping. Each strand consists of two or more control points that define (*x,y,z*) position, as well as some extra information used for texture lookups and for approximating self-shadowing. Also, each strand has a *hairType* that defines its shading attributes.





Within the renderer, each strand is tessellated into a polygonal ribbon that follows the Catmull-Rom spline defined by the positional control points. The ribbon is oriented to face the camera, which entails rendering fewer polygons than would tessellating a true generalized cylinder. Even though the ribbon thus constructed is valid only from the camera's view, this is not a problem for us because we assume the hair deforms from one frame to the next and we therefore need to re-tessellate it on a per-frame basis anyway.

In the few scenes where we used ray tracing (mainly for shadows), we used an additional hair representation within the ray tracer: Each hair segment was decomposed into a ball and cone, which are primitives that our ray tracer can natively ray-intersect.

Hair Shading Overview

The shading parameters of hairs are fully scriptable and exist independently of the geometric representation discussed above. Each hair strand is associated with a *hairType*, which is a label that associates it with a particular hair shader. Our hair shader contains the following attributes, of which many are self-explanatory but others are quite complex.

Ka	Color	Ambient color for local illumination
Kd	*Color*	Diffuse color for local illumination
Ks / **Ks2**	*Color*	Specular color for local illumination (individual control for dual highlights)
Kr	*Color*	Specular color for reflections
Kdr	*Color*	Diffuse color for reflections
Kt	*Color*	Transmissive color
Kx$_n$	*Color*	Arbitrary color channel, e.g. Kx1, Kx2, etc.
Ko	*Scalar*	Opacity
Ns / **Ns2**	*Scalar*	Specular exponent for local illumination (individual control for dual highlights)
Bs / **Bs2**	*Scalar*	Broadness of specular highlights under local illumination (individual control for dual highlights)
Thickness	*Scalar*	Strand thickness (more than a shading parameter)
EdgeFade	*Scalar*	Rate of opacity fade from edge to center of strand. This causes a breadthwise blurring of each strand.
Kambert	*Scalar*	Controls blend between Kajiya and Lambert shading
TanShift / **TanShift2**	*Scalar*	Moves primary (**tanShift**) or secondary (**tanShift2**) up or down the hair based on given parametric offset value
ColShift	*Scalar*	Alters color lookups of **Ka, Kd, Ks, Kr, Kdr** by altering their spline lookup parameters
Nt	*Scalar*	Exponent for transmissive falloff
Bt	*Scalar*	Alters broadness of transmissive hotspots

Each of these shading parameters can vary over the length of a hair. We support this variation by allowing each parameter's values to be specified multiple times, with each specification representing a control point of a one-dimensional (for scalars) or three-dimensional (for colors) Catmull-Rom spline. By default, the control points are spaced evenly, but the spacing can be adjusted arbitrarily per-hairType.

Even though **thickness** is more than just a shading parameter (in that it affects the geometry of the hair ribbon) we include it in the above chart because it is controllable within the hair shader and uses the same syntax as the other parameters.

Texture-Based Shading Parameters

An additional level of flexibility comes from allowing any shading parameter specification to come from a texture. Each hair has a single pair of texture coordinates (*u,v*), which match the (*u,v*) of the skin position (follicle) from which it originates. When a texture is used as a shader parameter specification, the texture is sampled at the hair's (*u,v*) coordinates and the resulting color or scalar is used as a control point in the shading spline.

Jittered Shading Parameters

Another useful shading control we implement is the ability to randomly perturb or jitter each shading parameter at each control point of its specification spline in a user-specified way. In addition to purely random additive and multiplicative jitter, we support *jitter palettes*. These allow the artist to specify, using an image, an allowable palette of colors or scalar values which to apply as jitter. This provides control over not only the range of possible jitter values but also the relative probability of each, which is controlled by varying the number of pixels allocated to each color in the palette.

Dual Highlights

Although we make no attempt to accurately model the dual highlights observed in real hair as discussed in Marschner et al. [SIGGRAPH '03], we make it easy to achieve a similar look in a much less expensive and more art-directable fashion: We allow two sets of highlight parameters to exist on each strand (**Ks, Ns, Bs and Ks2, Ns2, Bs2**). Moreover, we allow the user to effectively move each set of highlights along the hair strand by altering the spline parameter used to compute the shading tangent for each shading point. The latter is accomplished using the **TanShift[2]** parameter. The following images illustrate this technique, along with the use of additive jitter in the **TanShift**.

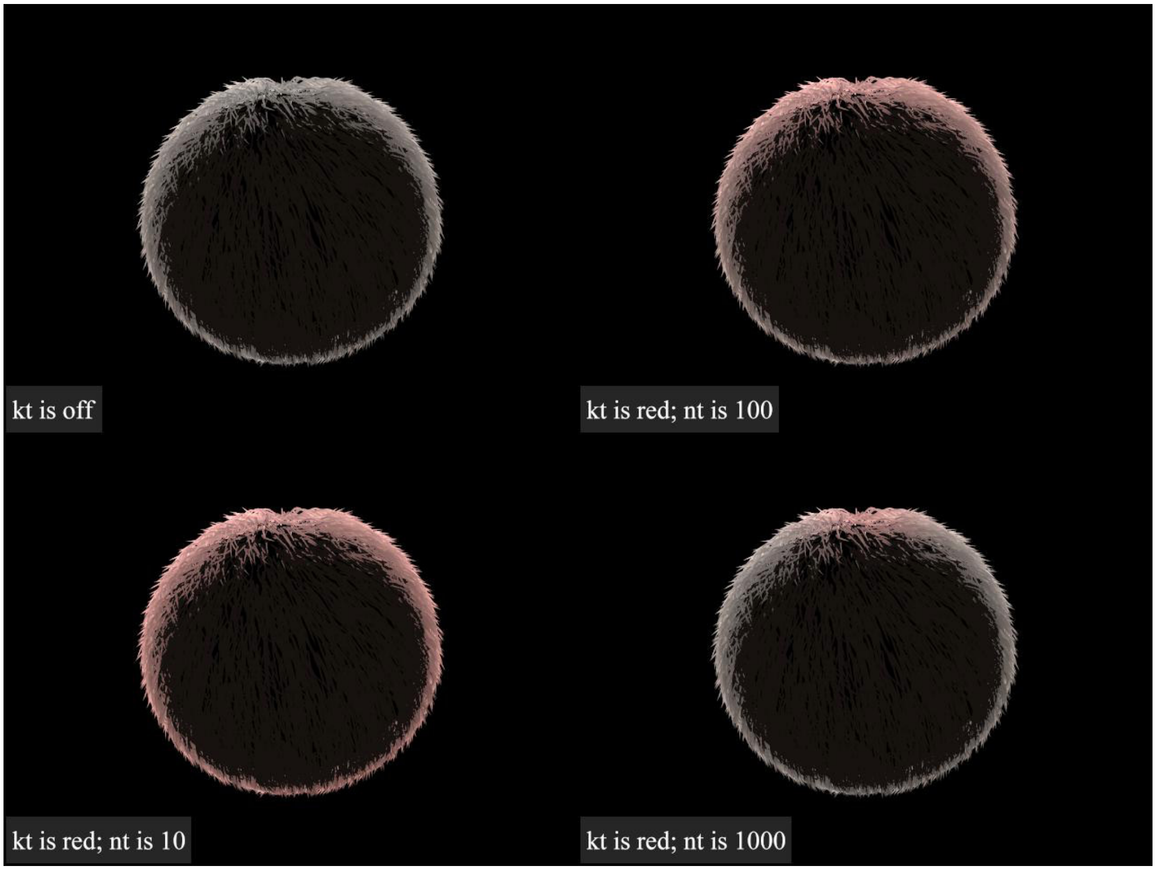
			
Single highlight, no jitter	Single highlight, with jitter	Dual highlights, no jitter	Dual highlights, with jitter

Transmissive Lighting

We model transmissive lighting for traditional local illumination by considering the dot product between the view vector (from camera to shading point) and the light vector (from shading point to light), raised to the power **nt** and scaled by the color paramter **kt**. Although the original Kajiya model does a good job of making backlit hair shine, our transmissive lighting component allows this effect to be accentuated and the backlight to be colored differently from regular illumination.

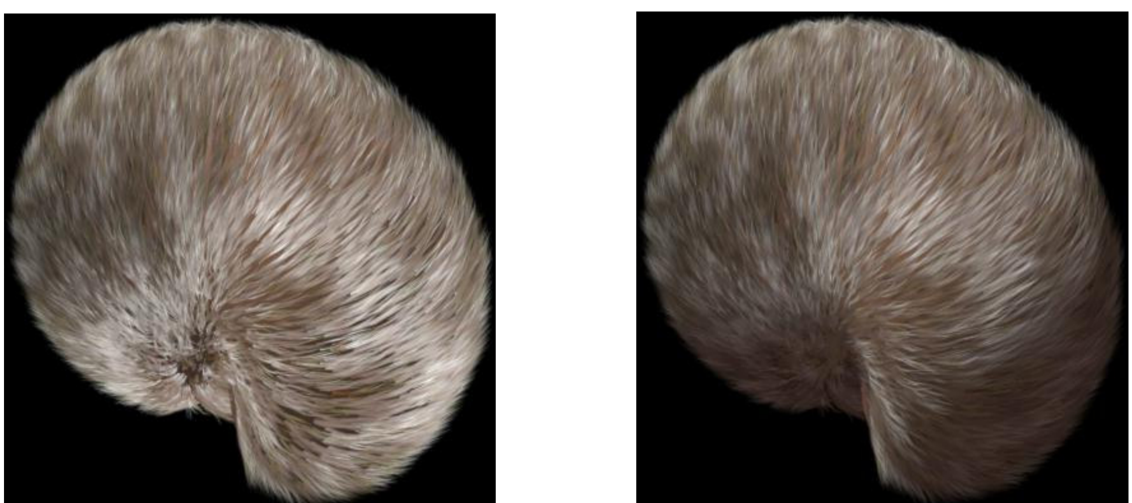
Transmissive lighting proved very valuable in several shots featuring Aslan standing in front of a low, late-afternoon sun. Lighters were able to use this feature to highlight backlit hairs without altering the desired look of the frontlit fur or introducing additional light sources.

We illustrate the effect below:



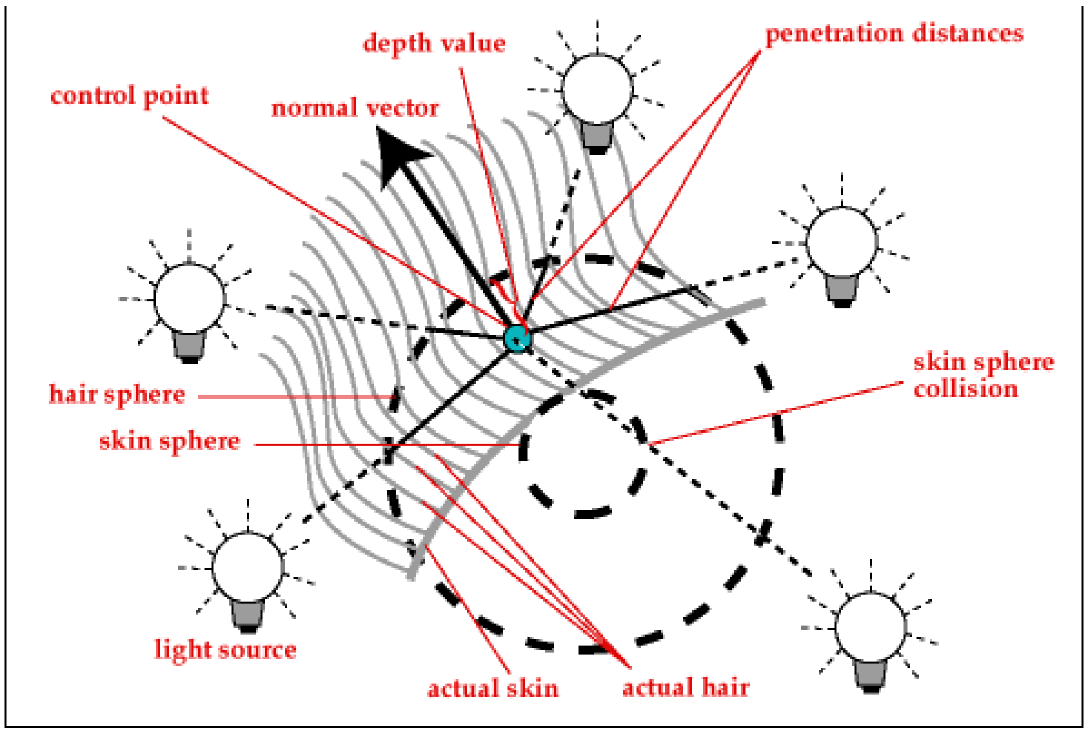
Local Self-Shadowing Model

In addition to depth-map-based shadows, we use a local self-shadowing model that darkens hair using information gathered from the underlying skin. The following renderings illustrate the effect, the left image rendered without local self-shadowing and the right one with. Neither image uses any type of global shadowing (e.g. depth maps)



Left: No local self-shadowing; Right: with local self-shadowing. Neither image uses any true (e.g. depth map or ray-traced) shadowing.

Our self-shadowing model is based on a Graphics Interface '98 paper by Neulander and Van de Panne (http://www.rhythm.com/~ivan/pdfs/gi98.pdf). In short: As part of each hair's geometry, we store at each control point a vector (the *self-shadowing normal*) and a scalar (the *self-shadowing depth*). The combination of these values place the control point within a virtual sphere, as illustrated below.



The sphere is assumed to consist of a homogeneous semitransparent material. Given the position of the point, we can compute for any light direction the relative distance that light must penetrate through the sphere to reach the point. We attenuate the lighting of this point based on this distance, through the following exponential formula:

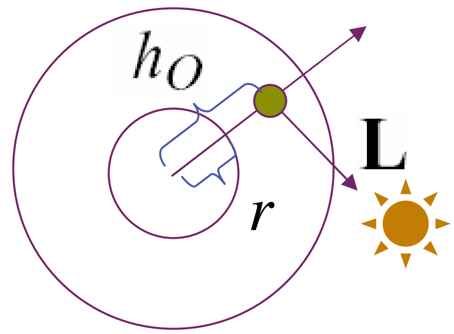
$$e^{-\rho\left(-h_O \mathbf{N_O}\cdot\mathbf{L} + \sqrt{1-h_O^2(1-\mathbf{N_O}\cdot\mathbf{L}^2)}\right)}$$

h_O Self-shadowing height = 1 – *s**depth (*s* varies per hairType)

$\mathbf{N_O}$ Self-shadowing normal vector

$\mathbf{L}$ Unit vector from shading point to light

ρ Hair density constant (varies per hairType)



We also model a separate opaque skin sphere within the semitransparent hair sphere. The relative size of the skin sphere is based on the hairType parameter *s*. We can determine which light directions are occluded by the skin sphere by evaluating the conditional

$$h_O^2(1-\mathbf{N_O}\cdot\mathbf{L}^2) < r^2$$

where $r = 1 - s$.

Although local self-shadowing does not capture distantly cast shadows (e.g. from an animal's paw onto its belly), it is nevertheless useful in providing subtle shading hints as to a pelt's shape. We found it most useful in conjunction with depth-map-based shadowing, which by itself would often fail to pick up very subtle self-shadowing without introducing bias artifacts.

Image-Based Lighting

Image-based lighting was essential to our goal of rendering photorealistic fur that blended seamlessly with live environments. We applied a two-pronged strategy in rendering image-based lighting of hair:

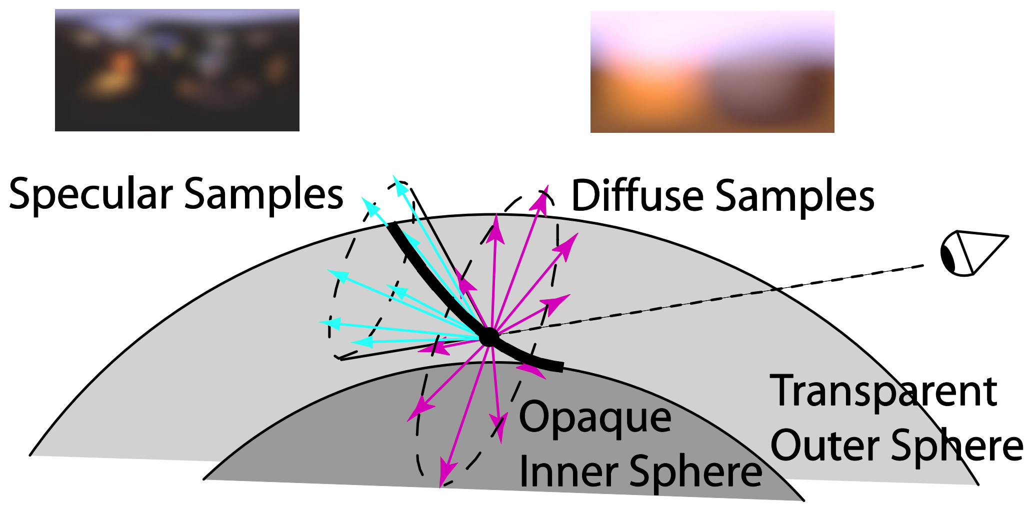
1) We decomposed the environment map into a 16-20 colored directional lights, each with a moderately blurred shadow map. We used an image processing tool, similar to HDRShop's *LightGen* plugin, to extract a small set (1-3) of bright pixel

clusters as key lights. After removing the light contribution of these bright clusters, we then extracted 16 evenly spaced fill lights from the residual environment map. The fill lights used a lower resolution depth map, applied with greater blur.

Even though subsequent shading required a large number of depth map lookups, the result was a smooth and relatively efficient way to capture IBL and properly take occlusion into account.

Left: Sample arrangement of colored directional lights derived from HDRI environment map.
Right: Final rendered image using these lights with depth-map shadows.

2) A less expensive alternative used in some shots was to sample diffuse and specular reflection rays around each strand into pre-filtered diffuse and specular environment maps, using the local self-shadowing model to approximate occlusion. This technique is described in more detail in a 2004 SIGGRAPH sketch by Neulander (http://www.rhythm.com/~ivan/pdfs/sketch2004.pdf). Note that even though this approach sounds like a ray-traced one, it does not use ray tracing. Map lookups are computed purely based on ray directions, and the occlusion term for each lookup is computed using the local self-shadowing formula. As a result, the shading is relatively inexpensive and can even be computed in real time as was demonstrated during the 2004 sketch.



The following illustrate the second IBL approach without (left half) and with (right half) the use of local self-shadowing for occlusion approximation. Clearly, taking occlusion into account, whether by depth maps or otherwise, is very important with IBL.

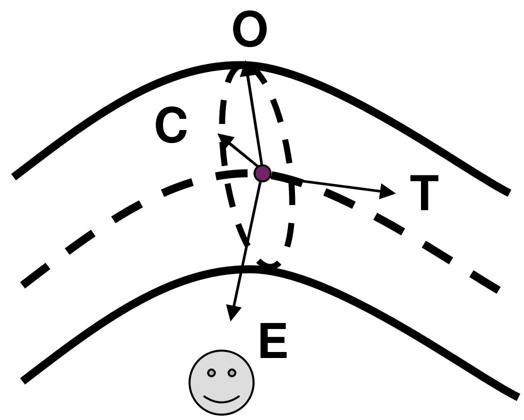
The left side of each image uses unoccluded IBR sampling. The right side of each uses the "fake" self-shadowing model to approximate occlusion.

Kambert Shading Model

The Kajiya shading model nicely captures the look of thin strands of hair (infinitesimal cylinders). However, for thicker clumps, it is desirable to see a distinct lambertian falloff across the width of the clump. To facilitate this, we allow the artist to blend between lambertian and Kajiya shading using the **kambert** hairType paramter.

In order to apply lambertian shading to hair, we first need to compute a shading normal based on a given shading position and tangent vector. We do so by interpolating between a pair of view-dependent vectors **C** and **E**, based on the distance of the shading point from the edge of the hair ribbon. Vector **E** is the view vector and vector **C** is based on **E** and the hair tangent **T** as per the following formula:

O = **E** x **T** and **C** = **T** x **O**

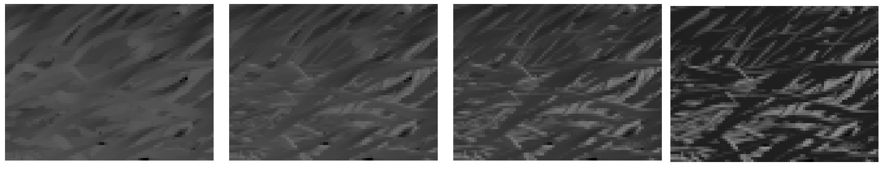


We blend the diffuse components of Kajiya and Lambert shading as follows:

Diffuse = $(1-\alpha)\ D_{kajiya} + \alpha\pi\ D_{lambert}$

The factor of π accounts for the fact that the Kajiya model, applied to a thin cylinder, on average yields brighter illumination than the Lambert model by a factor of π.

To avoid aliasing problems, we always use the Kajiya model for specular shading.
The following renderings illustrate the results with several values for α:



α = 0 0.3 0.6 1.0

3.6 Simulating the world of talking animals

Simulating Hair, Fur, and others

The movie had many talking animal characters, including the majestic lion - aslan. Dealing with fur of each character presented enormous challenges on every side of pipeline. Animating fur - especially longer hairs like the mane of a lion - presented a challenge that the studio had not dealt with before. A new hair dynamics solution as well as many other tools had to be developed and the tools were extensively used to simulate motion of the hair of many such mythological characters.

When the crew had a change to see and interact with wild animals (such as a real lion!), two observations came out.

- Most animal fur is very stiff.
- Animal fur almost always move in clumps, apparently due to hair-hair interaction

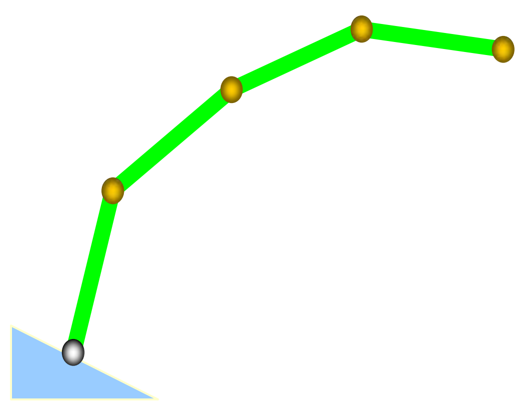
This meant that we needed to have a stiff hair dynamics system with full control over hair-hair interaction. As any experienced simulation software developer would find, this is not a particularly pleasant situation to be in – to hear something is **stiff** in a simulation.

1.1 The hair simulator

From the literature, one would find a number of choices for dealing with hair-like objects. Among those are articulated rigid body method, mass-spring (lumped particle), and continuum approach. Each method has pros and cons and one could argue one method's advantages over others. We decided to start with the mass-spring system since we had a working code from the in-house cloth simulator. Thereby we started by adapting the existing particle-based simulator to hair.

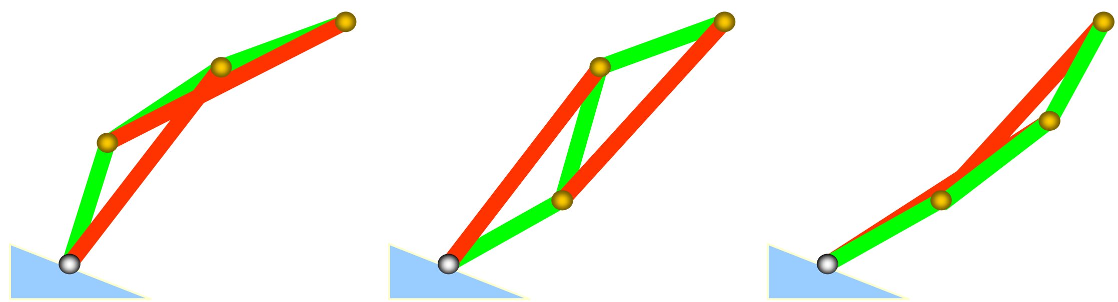
1.2 mass-spring structure for hair

In our simulator, each hair would be represented by a number of nodes, each node representing the (lumped) mass of certain portion of hair. In practice, each CV of guide hairs (created at the grooming stage) was used as the mass node. Such nodes are connected by two types of springs – linear and angular springs. Linear springs maintain the length of each hair segment and angular springs maintain the relative orientation between hair segments.



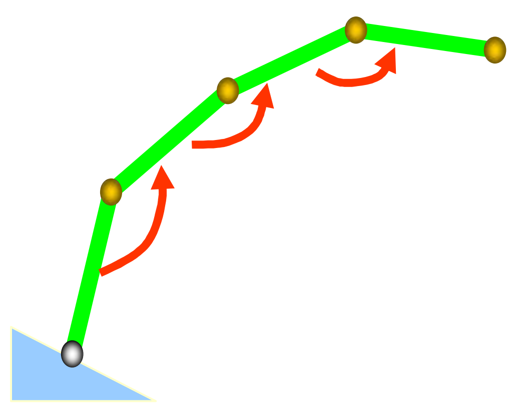
Linear spring was simply taken from the standard model used for cloth simulator, but a new spring force had to be developed for the angular springs. We considered the use of so-called 'flexion' springs that are widely used in cloth simulation. With this scheme, each spring connects nodes that are two (or more) nodes apart. However, after initial tests, it was apparent that this spring would not serve our purpose since there are a lot of ambiguities in this model and angles are not always preserved.

This ambiguity would result in some unwanted 'wrinkles' in the results (in the figure below, all three configurations are considered the same from linear spring's point of view).



ventually, the hair angle preservation had to be modeled directly from angles. We derived the angle preservation force by first defining an energy term defined on two relative angles between hair segments, and then by taking variational derivatives to derive forces. A matching damping force was added as well.

Derivation on angles are usually far more difficult than working on positions, and it would also require additional data such as anchor points attached to the root such that angles could be computed at the root point as well. To compute a full angle around each node, each node would have an attached axis that was generated at the root and propagated to each node.



We simulated the motion of each hair along with external forces such as gravity, wind forces. The time integration was performed with a full implicit integration scheme. As a consequence, the simulator was very stable, elegantly dealing with the stiff hair problem. Extremely stiff hairs (such as wire) needed some numerical treatment such as modification of jacobian matrices, etc., but in general, this new approach could handle very stiff hairs in a fixed time stepping scheme.

In the absence of collision and hair- hair interaction, each hair could be solved independently, and solved very fast if a direct numerical method was employed (thousands of guide hairs could be simulated in a second per frame). In practice, the simulation time was dominated by collision detection and hair-hair interaction. Overall integrator time was only a small fraction (< 5%).

This CG lion test was performed before the production started, as verification on many aspects such as simulation of hair-hair interaction, collision handling, grooming of hair, rendering, and compositing.

1.3 Collision Handling

There are two types of collision in hair simulation – hair would collide against the character body, but would also collide against other hairs. These two cases were separately handled, and each case presented challenges and issues.

1.2.1 Collision handling between hairs and characters.

For collision handling, each character was assigned as a collision object and collision of each hair against the collision object was performed using the standard collision detection techniques (such as AABB, Hashing, OBB, etc.) with some speed optimizations (e.g. limiting distance query to the length of hair.) added.

If a CV was found to be penetrating the collision object, it was pushed out by a projection scheme that was tied to our implicit integrator. For most cases, the simple scheme worked very well, even in some situations where collision objects are pinched between themselves.

However, in character animation, some amount of pinching is unavoidable (especially when characters are rolling or being dragged on the ground), and the simulator had to be constantly augmented and modified to handle such special case of 'user error' in collision handling.

For example, in some scenes, hair roots often lie deep under the ground. In such cases, applying standard collision handler would push things out to the collision surface, but hair had to be pulled back since the root had to lie under the ground. This would eventually result in oscillations and jumps in the simulation. Our simulator had additional routines to detect such cases and provided options to freeze the simulation for the spot or to blend in simulation results. In addition, animations were adjusted (mostly for aesthetical reasons) and other deformation tools were also employed to sculpt out the problem area in collision.

1.3.2 Hair-hair interaction

Early on, it was determined that the ability to simulate hair-hair interaction was a key feature that we wanted to have. Without hair-hair interaction, hairs would simply penetrate through each other, and one would lose the sense of 'volume' in hair simulation. This was especially important since our hair simulation was run on guide hairs, and each guide hair could represent a certain amount of volumes around it. So, the sense of two volumes interacting with each other was as important as simulating each guide hair accurately.

Simulating interactions between a mermaid's hair

Having based our simulator on a mass-spring model, we added the hair interaction effect as additional spring force acting on hair segments. Whenever a hair is close to another hair, a spring force was temporarily added to prevent nearby hairs from further approaching each other, and also to repel too close ones away from each other. The amount of spring force was scaled by such factors as distance, relative velocity, and user-specified strength of hair interaction.

1.3 Adding wind effect

In the movie, many scenes were shot in extremely windy environment. There was almost always some amount of wind in the scene, whether it was a mild breeze or a gusty wind. Once we had a working simulator, the next challenge was to add these wind effects with full control.

In general, hair simulation was first run on (only) thousands of guide hairs and then the guide hairs would drive motion of millions of hairs that were finally rendered. Correspondingly, there were two controls over the wind effects.

First, dynamics had a wind force that applied random and directional noise-driven force that would move around guide hairs. Second, a tool called 'pelt wind' was developed and added on top of the dynamics motion, providing subtle control over motion in every rendered hair.

1.5 Bad inputs / user errors

We would battle issues with ‘bad inputs’ to the simulator. In practice, inputs to simulation are never perfect – sometimes there would be two hairs stemming from exactly the same position, sometimes hair shape was too crooked. In some cases, hairs were too ‘tangled’ to begin with, and hair interaction alone couldn’t handle the situation. Additional hair model processing tools were then used to tame the input – such as untangling hair orientation more evenly or straightening out crooked hairs. In the end, the simulator was also used as a ‘draping tool’ that users could use to process and clean up some of the hand modeled hair geometry.

2. Layering and mixing simulations

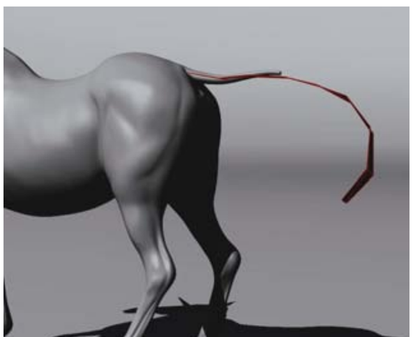
In this scene, three types of simulations were used. Hair simulation for aslan’s mane, cloth simulation for the curtain, and simulation of grass with hair dynamics. Moreover, hair for the mane and cloth simulation had to interact with each other.

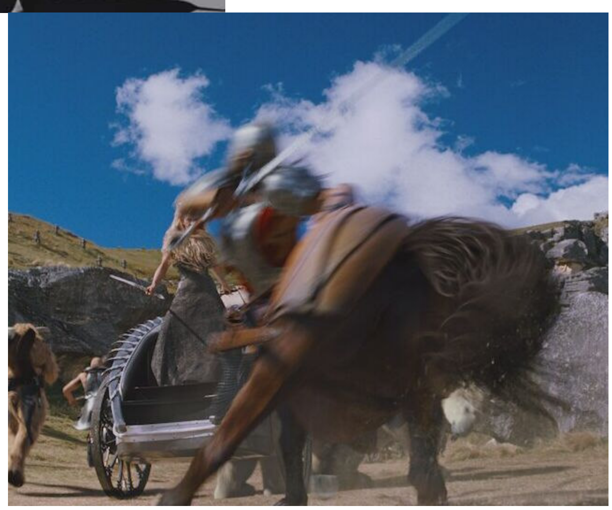
Often, digital counterpart of real actors were used and mixed into the real scenes. Simulations were also used for clothing of such characters (such as cape, skirt, etc.) and even skins of winged characters. At times, cloth simulation and hair simulation had to work together. Cloth would collide against hairs, but hair would in turn collide with cloth.   In such cases, 'proxy' geometry was built to represent the outer surface of hair volume. Cloth would then collide against the proxy geometry and then served as collision object for hair simulation.

This concept of 'simulation layering' was used all over. For some hair simulation, cloth was first simulated as the proxy geometry for hair, and then hair simulation was run, roughly following the overall motion driven by the proxy geometry, and then individual hair motion and hair interaction was added.

Interaction between hair and cloth.

Layering cloth simulation and interaction between [illegible]s.





Layering hair simulation with cloth simulation.

5 Mythological Characters

Among the many characters that Rhythm & Hues created for the film were several mythologically creatures. Below we cover some of the more complex.

5.1 Centaurs

The centaurs for the show were some of the most challenging characters. We had to create three different techniques to be mixed and matched throughout the film: fully CG, CG horse body with live action human, and CG human body with live action horse. The latter two obviously presented the most challenges.

The first step was coordinating with KNB, responsible for building prosthetics, to determine the overall proportions. How large were the horse bodies? How large were the human bodies? At what point should we join the human and the horse? In the end we determined that the horses would be 15 hand horses based off the stunt horses that were cast for the film. It was also determined that we didn't want to deal with any forced perspective shots necessary to cheat the size of the human torso. In the end, the only decision to make was how to join the two together. The positioning settled on was with the human torso slightly cantilevered in front of the horse body. This design decision helped insure the horses front legs didn't read as a human wearing a costume.

Given the connection point it was then necessary to determine how they would move, both for the performance of the centaur and for the direction of the actors on set. For animation the centaurs had to behave as if one brain was controlling all limbs, as opposed to the motion you would get from a rider controlling a horse. To determine how the actors should move on set our animation director took a walk cycle of a horse, parented a human to its shoulders, and then animated a walk cycle for the person that followed the motion of the horse's structure. To our surprise, we found that a normal human walk cycle replicated the motion a centaur's upper body would inherit.

To integrate CG and practical elements for the centaur it required very accurate matchmove. The actors on set wore green pants with tracking markers so that they could be tracked and painted out. They were then placed on a platform roughly 14 inches tall. Due to different shooting conditions and the actors', safety the platform height could vary. A CG centaur was then imported into the scene with its movement constrained to the track at the horse shoulder. From there our animators would drive the motion of the horse. In cases where the platforms on set were not exactly 14 inches, it was necessary to sometimes cheat the size of the horse to allow him to properly fit the distance from the actor's hips to the ground.

5.2 Gryphon

One of the most technically challenging characters was the gryphon. Originally the gryphon did not have such a prominent role. Early versions of the script had a hawk flying in and landing on Peter's arm prior to the battle. After our animation team did a test showing the gryphon coming in for a landing, the director quickly changed his mind and gave the gryphon the part instead.

The gryphons shoulders are constructed of two real world systems that could not reasonably exist together in nature, the shoulder of a lion and the wing of a bird. Joining these structures at the same point on the torso created further complications. The shoulder of a lion involves a very unique structure. Unlike humans, there is no bone that physically connects the bones of the arm to the bones in the torso. Straps of muscle run from the scapula to the chest allowing the rib cage to hang in them like a basket. This allows the entire shoulder structure to slide fore and aft, up and down, as well as rotation about any axis.

The shoulder of a bird is controlled through a very unique mechanism as well. The chest muscles drive both the downward and upward flapping motion of the wing, unlike humans which use their chest muscles to pull their arms forward and their back muscles to pull their arms back. This is done by using a pulley like system of tendons. By doing this it keeps the birds mass on the underside of its body allowing it more stability in flight, as well as plenty of power.

For our CG gryphon we needed to have shoulders with the range of motion of the lion's, but with the mass and muscle structure that he would need to support his wings. This was difficult to achieve due to the fact that sliding the arm resulted in the shoulder needing to occupy the same space as the mass of the wing. This was solved by creating a false lat muscle that ran vertically behind the shoulder. As the wing flapped, we would flex the false lat to give the feeling of power.

Another challenge of the gryphon was creating his fur and feathers. The gryphon required a transition from real fur, to fur-like downy feathers, to small feathers, and finally to large flight feathers.

With the exception of three rows of flight feathers, everything else was done using our in house fur software. The fur and downy feathers were both strands of hair with varying densities and thickness, while the small feathers were simply instanced geometry controlled by guide hairs. We were then able to apply dynamics to the guide hairs to create wind effects that rippled through all of the fur and feathers. Our fur uses slightly different illumination models than those available to geometry. This required our look development team to resolve those differences in order to smoothly transition through the different feather types as we moved from fur-base to geometry-based solutions.

The gryphon's performance also required him to fold his wings. Folding a photo-real bird wing in CG is a problem that has largely been avoided in film. Research into the problem presented many different cheats from not showing the entire wing in frame, to strategically placed cuts, to render tricks that try to account for feather interpenetration. After early tests we came to realize that the smaller fur based feathers behaved rather well with our default set of tools. Most interpenetrations were imperceptible. The challenge became controlling the major flight feathers.

Our prior flight feather solutions involved using a spline that trails the wing that each feather points at. This method allows an animator to use a relatively small number of controls to control a large number of feathers. This method works very well for flight motion., however employing this method for folding the wing causes the feathers to stack up unrealistically. To fold the wing we combined this method with the ability to break the primary and secondary feathers onto separate spline controls to allow the primary feathers to slide over the secondary feathers when closing. One additional layer of control was added in to allow each feather to be animated individually to cleanup any unavoidable interpenetration.

6. The Battlefield: the Crowd Pipeline

6.1 Introduction

The task of being able to model, light, simulate and render armies made out of about four dozen different types of characters for "*The Lion, the Witch and the Wardrobe*" seemed daunting at first. At Rhythm and Hues we had done some minor crowd like work before, for example the army of mice in "*Cats and Dogs*", a space ship full of Gazoos in "*Flintstones II: Viva Rock Vegas*", and streets of background characters in "*Around the World in 80 days*". However, none of these previous productions came near the scope and complexity of what was required for "*The Lion, the Witch and the Wardrobe*".

Since the crowd characters could end up very close to camera (sometimes running next to hero characters) it was necessary to produce relatively high quality skinnings of these characters, as well as the ability to put simulated cloth and fur on them. These requirements logically lead to repercussions on the renderability of the crowds since it could mean large amounts of geometry and hair could be generated at any give time.
Another main requirement was the capability to vary many aspects of the characters' geometry, material and motions. The ability to change these attributes had to be relatively easy and manageable.

And last but not least, the pipeline dealing with the hundreds of models, materials, textures, render scripts and motions would have to be as flexible and transparent as possible. Although there would be many inter dependencies between different parts of the pipeline, we knew that the pipeline should be designed in such a way to allow each component of it to work as independently as possible.

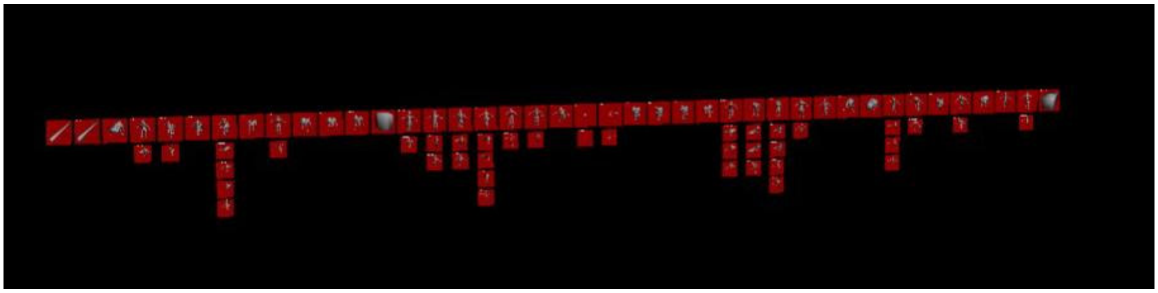
We investigated a number of different commercial packages in order to determine how and to what extent they would be able to solve or help with some of these issues. We finally decided to use Massive as the tool to generate the basic crowd motions but to rely on our proprietary tools to deal with most other aspects, like rigging, skin binding, fur, cloth simulation and variation control of geometry and materials.

In this way we combine the strong point of Massive, which is the ability to build agent brains to generate motion, with the strong points of Voodoo (our proprietary rigging and simulation tool) and Wren (our proprietary renderer).

6.2 Modeling

The crowds consists of about four dozen distinct character types, like fauns, centaurs, cheetahs, minotaurs, horses, boars, ankle slicers, werewolves, etc. Each of these characters can hold or wear a number of different accessories like helmets, swords, shields, scabbards, flails, etc. For these there can be different variations in terms of geometry (for example helmets with different horns). Finally most of these models exist at three levels of detail (LOD), which we call “lo”, “xlo” and “xxlo”.

All characters, accessories, variations and resolutions resulted into a set of approximately 800 individual models.

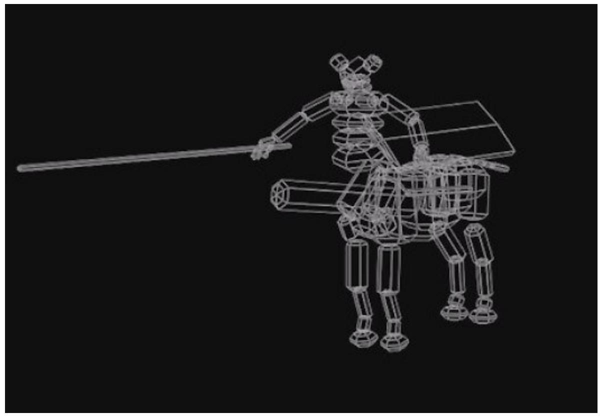


6.3 Rigging

The rigging for a crowd character is different from rigging for a hero character. A hero character normally has many more sophisticated controls and structures than are practically possible for a character that has to be instantiated hundreds or thousands of times.
A crowd rig or **mrig** (the name can be interpreted either as mocap rig, massive rig or medium rig) has just a very simple straightforward hierarchy. We allow for some basic joint dependencies (f.e. for finger controls) as well as a number of sizing controls which can be used to resize specific body parts.

These **mrigs** are rigged in Voodoo and can to some degree be derived from the hero rig (**hrig**), which helps enormously in keeping them both in sync. The resulting rig is then exported from Voodoo as an ASF file which then is used in the motion capture sessions and as a CDL file (an internal Massive character description format), for use as the foundation for the agent building in Massive.

It is vital to keep the rigs which are used during motion capture, motion simulation and rendering the same. The mrig from Voodoo serves as the ground truth and the exported rigs are derived as a subset from this one.

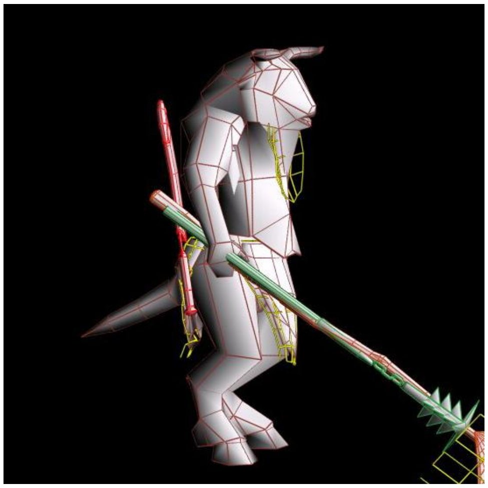


6.4 Skinning

Voodoo contains a large number of deformation tools, which are used for skinning our hero characters. Since we want to be able to deform thousands of characters on the fly at render time, we use a subset of these deformation tools that are needed for the required skinning quality, while being practical in terms of efficiency at the same time. Deformations based on bone weighting and blend shapes are among these fundamental deformation tools. On top of that we did build more efficient versions of tools for hair instantiation and flexible body dynamics to deal specifically with crowd characters (mor eont his later).

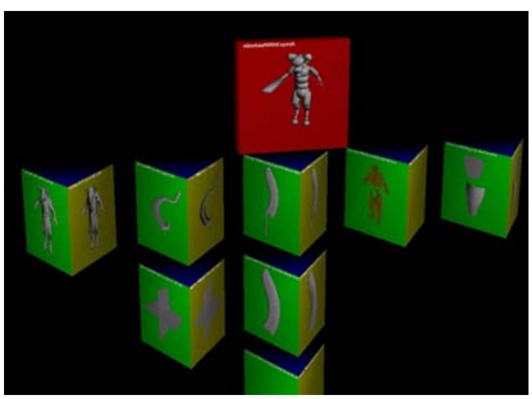
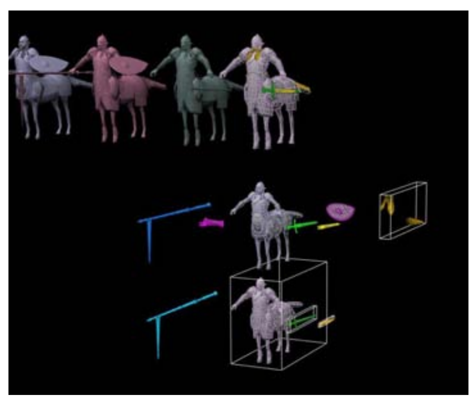
Since the characters are skinned using the same tools (albeit a simpler subset) which are used for hero characters, they are relatively easy for the rigging department to generate. However, there is some added complexity since all different geometry variations and levels of detail must be rigged as well.

A big difference from hero character skinning is that the resulting skin binds for the crowd characters can be exported to a completely stand alone model which not only contains the geometry but also all the skinning data.

Geometry creation

The actual geometry for a specific individual is determined on the fly at render time. First a determination is made which level of detail must be used (more on this later). Then a selection from the applicable geometry variations and accessories is made and finally some material and uv variations are applied to the model. In this way a large set of different looking versions of the same character can be generated from the model data base.

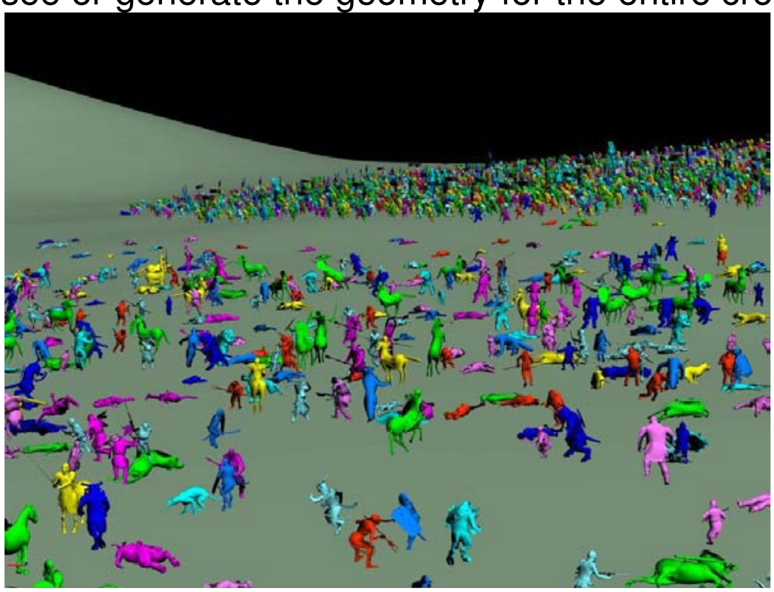
 

Crowd Files

The result from crowd simulations in Massive results in a series of APF files (which is a format very similar to AMC files). These files (one for each frame) contain all the simulated joint angles and positions of each individual in the scene.
In our pipeline we convert this sequence of files into a single crowd motion file. This proprietary file format allows us to easily and quickly

read subsections from the file, for example all data for a specific frame or all data over the frame range for a specific individual or character type. The crowd motion file can be read by a number of tools, like a stand alone crowd viewer, a command line tool to process and query certain aspect of the crowd, a plugin to Houdini for adding effects to the crowds, a module in Voodoo for combination with hand animated characters and cloth simulation, and as a render plugin Wren.

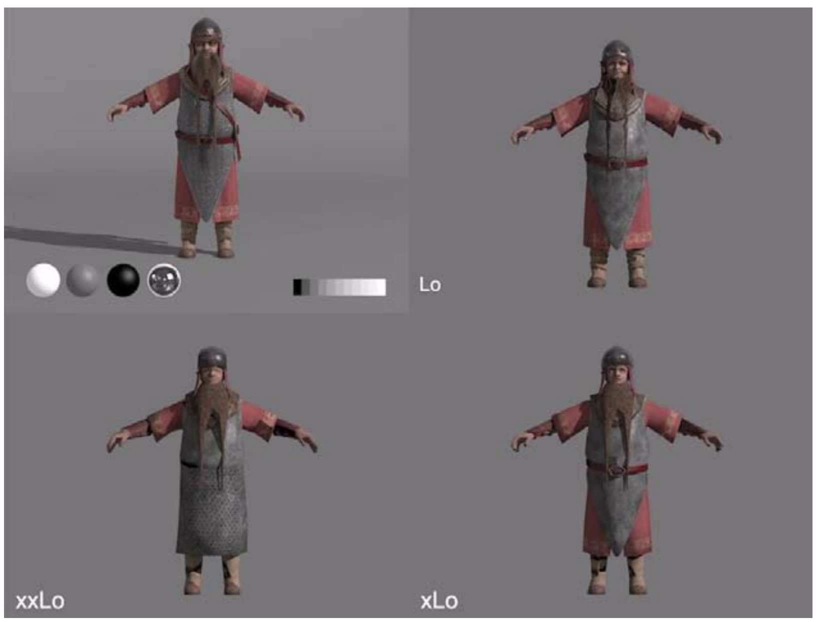
For example inside Voodoo the crowd file can be viewed in a number of different modes, from bounding boxes or stick figures to primitive bone shapes or actual deforming geometry. It uses active viewport clipping and level of detail selection to make sure that only the parts of the crowd which are visible are actually read in from the crowd motion file and processed. Together with the models with skinning data for each character (as described in the skinning section) it is possible to see or generate the geometry for the entire crowd.



Note that the connection of Massive into this pipeline has one main input and one main output. The main input is the mrig from Voodoo which is exported as a CDL. The main output is the APF file which is converted to the crowd motion file. This construction enables us to easily integrate crowds which are generated from other sources into the pipeline as well. On other productions we have generated some simple crowds from key framed motions in Voodoo (the stadium in "*The Longest Yard*") or from simple simulations in Houdini (the flying snakes in "*Elektra*"). This gives us great flexibility in the pipeline described here: the work for a rigger, FX person or lighter is the same regardless of the source of the crowd motion.

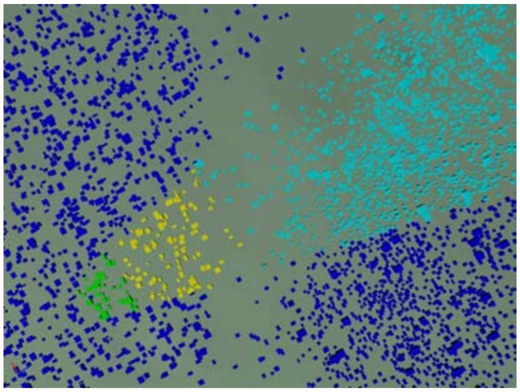
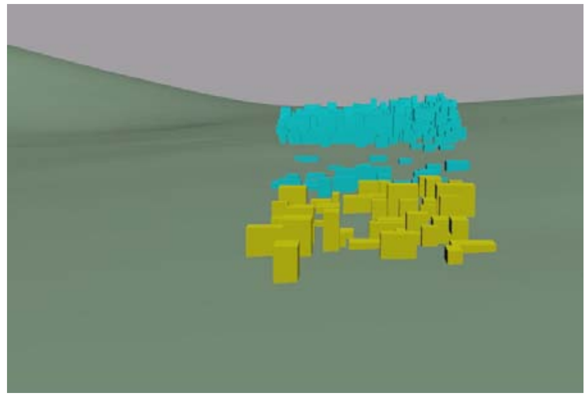
Lighting

The character lighter is responsible for making sure that all different variations and flavors of a character can render, as well as to make sure that there is consistency between the different level of details. Fur or hair can normally be taken from a lower density version of the hero version of the character.
Material and uv variations can be made on the fly, which means they do not have to be built beforehand into the models or rigs. This greatly improves the independency of the lighter from the steps before in the pipeline.



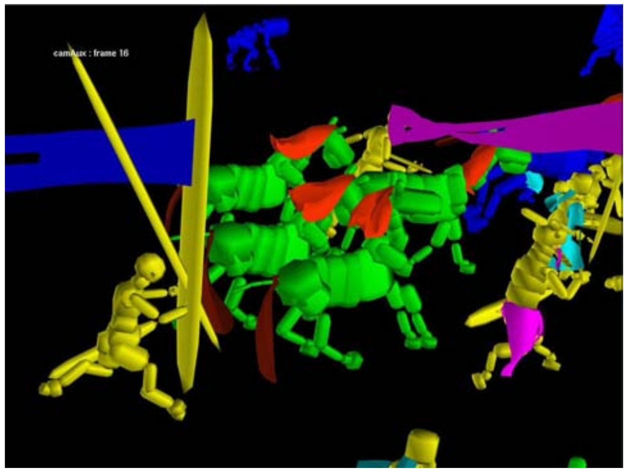
When lighting a specific scene the lighter has control over the distribution and assignment of geometry, material and uv variations. For example the lighter can specify that half of all fauns should wear a certain type of helmet, or that one specific individual should have a beard or that every fifth character should have a green shirt. The scene lighter can also hide or show specific characters. A final important aspect that the scene lighter can control is the distribution of the levels of details, i.e. at what distances each resolution becomes visible. All these settings are applied at render time so there is no need to resimulate or regenerate a crowd when some of these aspects change.

Geometry Management

The amount of geometry that is generated at render time can be enormous for large crowds. There are a couple of methods that help in reducing the amount of geometry that has to be in memory at once. The first method is the use of level of detail. As mentioned before, the scene lighter can control the distance ranges at which each resolution is visible and also has some controls on how transitions happen.
The second method uses view port clipping. Which character are visible from the camera or a light can be determined very efficiently from the crowd motion file before any geometry has been generated or processed. Therefore only the individuals that are going to be visible (this included shadow casting) will be turned into geometry at the appropriate resolution.
Even with the previous two methods the amount of geometry can still be pretty large. In those cases the renders can be tiled. This can happen either in screen space and/or based on distance from the camera.

Flexible Body Dynamics



Many of the characters in the crowd wear robes, have beards, carry banners, or have long tails and manes. Since the battle sequence was filmed on a very windy location in New Zealand it was obvious that flexible body dynamics had to be added, Running simulations like these can be computationally expensive for hero characters and therefore applying this to many more characters would be prohibitive. However, cloth simulations for crowds can be made more efficient by acknowledging that they do not have to be of the same quality as hero cloth dynamics: the cloth does not have to collide with everything in the scene and it does not have to be of the same resolution. Also, normally only a small portion of a crowd is visible and large sections of it are far away.

We derived a simpler solver version from our proprietary hero flexible body dynamics solver for the use on crowds. In the same way as before use view port clipping to make sure we only simulate individuals whenever they are visible (with some ramp up time of course). On top of that we enable the use of level of detail changes on dynamic objects. So a piece of cloth can be simulated at one resolution for the first part of the frame range and then can change into a higher or lower resolution during the scond part of the frame range. The crowd cloth simulation can be run interactively from within Voodoo.

6. 5 Crowd Rendering for Narnia

Prologue

Rhythm and Hues, Inc. has a long history of rendering crowds. Some of the feature film work includes Cats and Dogs (mice), Chronicles of Riddick (prison sequence), Longest Yard (stadium), Ring 2 (deer), Elektra (snakes). Most of our earlier work was based on rendering multiple instances of hero geometry using scripts created for hero rendering (along with some clustering techniques).

These methods did not scale well. They were also not adapted for using multiple levels of detail. About 70 different characters along with props were part of the crowds rendered for Narnia. All of these characters had look variations, some also had geometric variations. A whole new paradigm was required for handling the scope and complexity needed for rendering crowds in Narnia. A few elements of this pipeline were tried out for Elektra. Adjustments were made for Narnia based on that experience.

Requirements

Crowds are integral part of the story of Narnia. Their depiction had to match their importance in Narnia's mythology. Tools were needed that provided artists with the controls they needed to quickly create iterations of varying visual complexity. These loose initial guidelines led to the following requirements:

- Match hero look development as well as live action.
- Integration into hero lighting pipeline.
- Ability to render fur.
- Full featured control over myriad shading properties.
- Easy specification of material and geometrical variations.
- Control over quality versus resource trade offs.

Crowd Look Development

The look development for crowd rendering was dependent on hero look development. It had to closely match hero rendered characters. However, the renders had to be simpler as more time consuming algorithms could not be applied for rendering simulations with thousands of agents.

These dual and sometimes conflicting requirements posed their own set of challenges. For example, the skin of the various agents rendered through the crowd pipeline had to feel translucent without the use of sub surface scattering employed by hero characters.

HDRI maps were used for placement of 'key' lights and for computing environmental contribution, for both hero and crowd renders. Ambient occlusion is needed to attenuate this environmental contribution. For hero renders, this occlusion was computed per frame. For crowd renders, ambient occlusion had to be precooked for static poses and then used as an occlusion matte.

The number of fur strands per agent were fixed to a maximum of ~20000 (as opposed to hundreds of thousands used for hero characters), with a corresponding increase in width to maintain similar coverage over the body of the character.

We had three distinct levels of detail for each and every character and prop. The same set of textures and shaders were used for all levels of detail. Fur was used only on the highest level of detail. This meant that for lower levels, the 'volume' of fur was built into the model. The 'skin' under the hair had to have the same look as the hair found on higher levels.

The lower resolution models had fewer material groups, higher resolution details (e.g. clothing) got collapsed into base geometry like body parts. This meant that textures for higher resolution details had to be collapsed onto base geometry.

Crowd Rendering Pipeline

On Narnia, every character and prop had a set of layers that a lighter was responsible for. These layers included diffuse, specular, sub surface, environment, reflections, per light layers, gobos, and sundry mattes. Macros written for the compositors expected these layers. Crowd renders also had to provide the same set of layers to integrate them into the lighting pipeline.

Crowd simulations were different from hero animated characters. Unlike hero animation, crowd simulations were stored as 'skeleton' streams. These streams did not have any geometry. These skeletons were 'skinned' at render time. This skinning was accomplished by a plugin that created geometry in the render. This run time geometry creation had a couple of benefits:

- It allowed for geometry variations.
- It reduced disc space requirements.
- It allowed for dynamic level of detail changes at render time.

This geometry creation process was compute intensive. To minimize the impact on the render farm, we had to come up techniques and scripts that would do a lot more in one swoop. Hero lighting was broken down into multiple scripts, one for depth maps, one for environment occlusion, one for beauty render, one for fur render, etc.

Crowd rendering integrated all of this into just one script. All the shadows were ray traced, which obviated the need to create depth shadow maps in a separate render. It also reduced the amount of disc space needed. The script also took into account environmental contribution, based on the precomputed ambient occlusion pass and a convolved HDRI map. The same script also rendered all the default mattes, like skin mattes, hair mattes, mattes for each agent type in the simulation, etc.

Support passes like cast shadows and contact shadows were rendered separately. By default, these support scripts always sourced the lowest level of detail to reduce the burden on the render farm.

As each simulation had a varying set of agents, the script was structured such that it polled the skeleton stream to get the list of all agents and then dynamically source all the relevant textures and materials needed for that particular render. This obviated the need of having a really heavy script and also made the process of adding more agent types easier.

Most of this complexity was hidden from the scene lighters. They were all presented with higher level controls to adjust material properties globally, per agent type, and per variation. Quality controls were also provided.

Variations

There were two very different armies in Narnia, there was a regimented, uniformed Aslan army and a loose, unstructured White witch army. Both sets were made up of a host of characters. A lot of these characters had variations, e.g. brown, dark bears.

These variations were used in the hero lighting pipeline as well, although due to continuity reasons these could not be changed ad hoc. For crowd rendering, such variations were critical to add visual interest. In fact, more variations were created just for the crowd rendering pipeline.

Variations came in different flavors, which are listed below:

Geometry variations: These were employed to change the silhouette of various characters. These changes were broader than just changing the scale of various agents. Scale changes were actually done in the simulation as they affected gait and velocity. Examples of geometry variations for rendering include regular versus heavy chain mail for the centaurs, different clothing for the minotaurs, changing rock shapes for the hawks, and replacing torches for banners.

Major texture variations: Texture variations were used to offer completely different looks for the same models. Examples include various breeds of horses, different sashes for the centaurs, different textiles for giant clothing, brown or blond or dark minotaur, weathered versus new leather for the faun armor, etc.

Subtle color variations: Due to its regimented nature, the texture variations for Aslan's army were more nuanced as opposed to the White witch's army. To break up this regularity, another level of variation was added. Each agent (based on its index) was assigned an unique uv pair. This uv pair was used as a lookup into an user defined map. The color returned from this map was applied as a color multiplier to the base texture color of that agent. Usually, the user defined map was some sort of a color wash. This color wash when multiplied with the base texture resulted in subtle variations of color across the crowd. This was used mostly to affect the skin tones of all the agents, e.g. change the faun skin from alabaster to slightly dusky.

Taken together, all of these variation techniques were a very powerful tool. They gave scene lighters tremendous control over the final look of their renders.

Crowd Lighting Workflow

A lot of thought went to the crowd lighting workflow. We wanted something that was responsive, allowed for quick feedback, multiple iterations, and afforded a high degree of customization based on art direction. As mentioned earlier, there was only one script that was used to render crowds. This made the task of managing crowd lighting easier.

All shots were defaulted to the lowest level of detail when they were handed over to scene lighters. These settings resulted in the most efficient renders. Scene lighters used these settings for blocking in their light rigs. Once the light positions were approved, then the lighter would move onto modulating the variations.

By default, all the texture variations for every agent had equal weightage. All texture flavors were randomly distributed over the crowd. Scene lighters had controls to favor one set of flavors over others. The distribution was still random, just with different weights.

It was sometimes necessary to assign a specific variation (be it geometric or texture) to a specific agent in the crowd. This was required when the random distribution placed a few of the agents with the same variation next to each other. This was achieved by identifying that particular agent's index and then manually assigning the desired variation to it. Such functionality allowed the artist to sculpt the crowd to achieve the right combination that they were after.

Finally, the scene lighter could paint a color variation map and get the subtle variation working to add another layer of visual interest.

Special Cases

Most of the setup and most of the shots followed the pipeline and workflow described earlier. However there were a few significant deviations from the norm.

There were a few characters and props which were hard coded to always render at the highest level of detail. These were the giants, the flags and banners. The giants were taller than all their peers in the White witch army. As they stood out, they were always made high resolution.

The flags and banners had to respond the wind and other dynamics. There were not enough polygons in the lower levels of detail to accurately depict the dynamics, therefore all flags and banners were always at the highest level of detail.

There were a few cases where hero animated geometry was rendered through the crowd pipeline, e.g. Peter and Oreius at the head of the Aslan army in the establishing shots. The reason for doing this was that there were quite a few cases where the hero animation was small on screen and there was a crowd render in the scene anyway, so it made sense to simplify the lighting load. These transfers were achieved by re targeting the hero rigs to the crowd rigs. For all these transfers, crowd specific look development for that character had to be accomplished before rendering could begin.

Although most of the attention for crowd rendering has focused on the battle sequence, it was used else where in the film as well. The

Aslan Dying sequence is a prime example. This somber sequence is the emotional core of the film. To add more heft to the moment, the hero as well as animated characters were supplemented with crowd simulations to fill the frame. These simulations had to be of the highest quality to be seamlessly integrated with the rest of the action in the frame.

These shots were different from the battle sequences in that they were not just lit by one light source (the sun), but had a few bonfires and a whole bunch of torches. Even the crowd simulations had agents carrying torches. To achieve this, we had to replace banners with torches. We had to parent light sources to the tips of these banners/torches. We had to create flicker curves to animate the intensity and the fall off of all these torches. Finally we had to create multiple filesets of actual flames to replace the existing banner textures.

Further Enhancements

Narnia was our first major foray into full featured, multi character crowd rendering. All in all, the crowd rendering pipeline worked well. We were able to deliver some beautiful imagery. There are a few things that we would definitely like to look at before we undertake another project of this magnitude.

Look development for crowd rendering is dependent on hero look development. The highest level of detail has to match the hero look as much as possible. The same assets have to translate to the lower levels as well. Getting this to work was cumbersome. It involved close interaction between a lot of departments (e.g. modeling, rigging, etc.). It was also not an easily scalable process as each agent presented its own unique challenges.

As an offshoot to this, the transitions from one level of detail to another were not always smooth. Levels of detail were dependent on distance from camera. Thus for a shot with a great degree of motion there was the possibility of certain agents changing resolution mid scene. It worked better for certain classes of agents as opposed to others. To alleviate this, we had to lock off the resolution for specific agents for the duration of the shot to prevent popping from frame to frame. A better, smoother transition would definitely help out much better.

Better tools to interact with agent selection and modification of their properties would help as well. In general, the system was supple enough to get the show done, but a better interface for handling all these different types of data would certainly be helpful.

6.6. Simulating flexible objects for crowd characters

In addition to hero characters that had 2-3 hair / cloth simulations per character, the whole army of characters had to be animated, and consequently their cloth, hair, and anything soft had to be simulated (the detail of crowd system is described in more detail in later part of this note). As an example, the scene in the figure below shows 20+ hero characters, and all the background (crowd) characters were given another pass of simulation, to give their banner, armor, flag, and hair flowing looks.

The simulator used for crowd characters was adapted from our in-house cloth simulator, and modified to meet some new requirements. For distance characters, geometry used for crowd simulation was of relatively low resolution (<200 polys). The simulator had to not only run fast, but also had to give convincing results on such low resolution geometry.

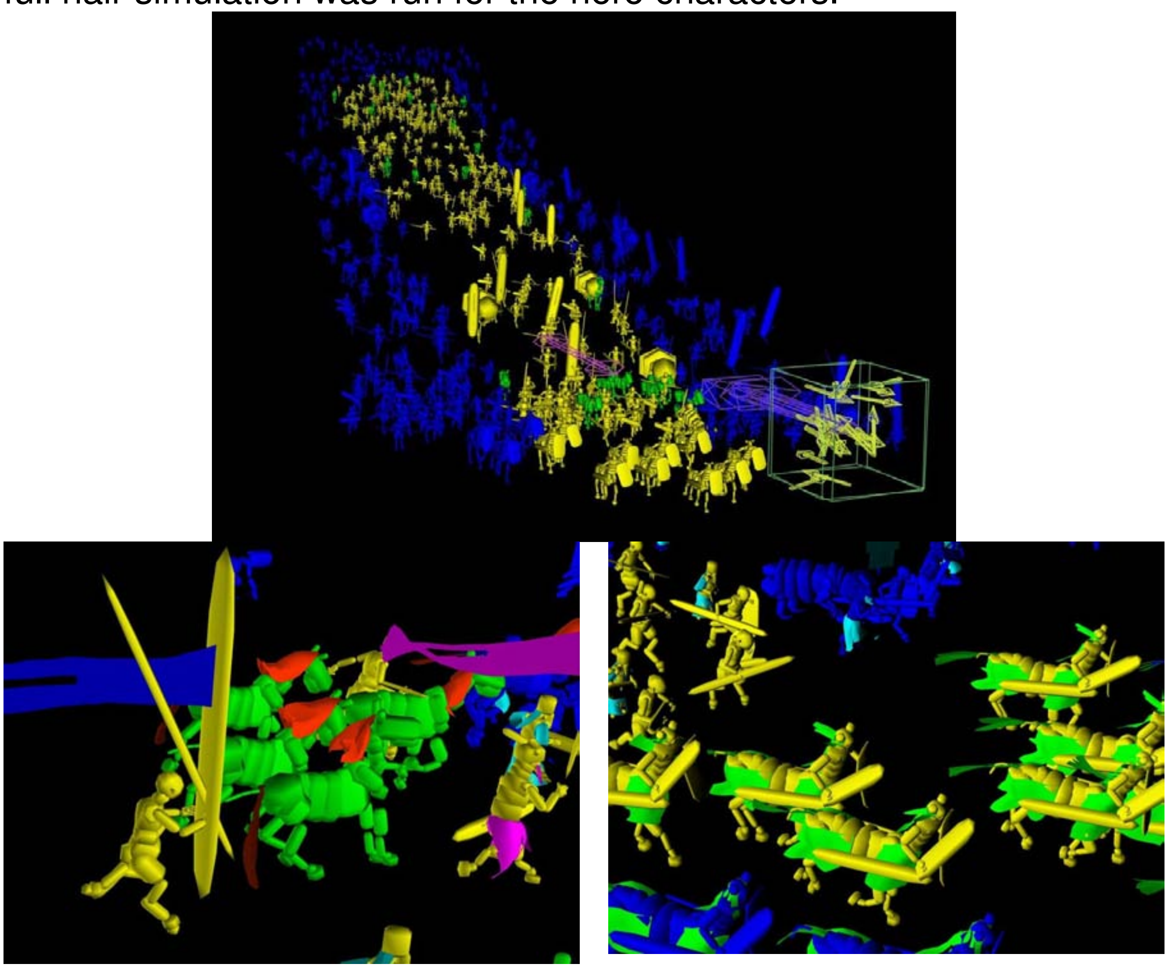
Many characters in crowd shots are not visible until certain moments in frames, and also change its visual importance as they move in and out of the camera. This fact was extensively exploited in our '*simulation level of detail'* system. Contrary to conventional simulation system where a simulator computes an 'end-to end' frame calculation, we simulated all the characters at each frame, and constantly examined whether some characters were moving out of the camera. For such invisible characters, the lowest level of detail of was used in simulation. On the other hand, as characters move closer to the camera, the detail was promoted and more time was spent on simulating higher resolution version of the geometry. This

Simulating cloth and hair of crowd characters. Close-by characters were individually simulated for their cloth and hair, and distant (crowd) characters were given another pass of simulation with level of detail control.

way, we could keep the desired fidelity in motion, while minimizing the requirements for computational resources.

The framework required that simulation had to be interchangeable between different resolutions, so special attention and care was paid to ensure that the simulator's state carries over from lower resolution to higher resolution without noticeable jump or discontinuity in motion.

Typically, several cloth simulations were run per each character, some cloth patches representing a strip of hair that actual hair geometry would be attached at the render time. About 3 to 4 different resolutions were used and switched during simulation. For example, a character's hair would be simulated as a simple polygon strip at the lowest level, and then refined all the way up to 20-100 strips representing the same geometry in much higher detail. At close-up, full hair simulation was run for the hero characters.



A level of detail system was used for simulating capes, flags, and hair of crowd characters. Each character would switch the resolution during simulation, based on distance and visibility. Colors on the characters denote the level of detail per character and per simulated object.