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# Rigging Realistic Skin Deformation with Muscle Systems

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RIGGING REALISTIC SKIN DEFORMATION  
WITH MUSCLE SYSTEMS

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A Thesis  
Presented to  
the Graduate School of  
Clemson University

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In Partial Fulfillment  
of the Requirements for the Degree  
Master of Fine Arts  
Digital Production Arts

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by  
Christian Sharpe  
May 2019

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Accepted by:  
Dr. Sophie Jörg, Committee Chair  
Dr. Eric Patterson  
Dr. Brian Malloy

# Abstract

Realistic skin deformation is one of the major criteria for creating believable, digitally enhanced characters. Muscle simulation is one of the more popular techniques used in filmmaking. It helps bring a sense of realism to the character by adding subtle, secondary motion to the skin. Small features like these make the character appear more lifelike. This thesis focuses on the generation of a character rig and implementation of a digital muscle system for a tiger. The rig is built and animated in Maya and the Maya Muscle tool was used to create the muscle system. The muscle deformations are compared to the standard smooth skinning method in a walk and run animation.

# Acknowledgements

I would like to thank my thesis advisor Sophie Jörg for guiding and providing feedback throughout my research. I would also like to acknowledge Eric Patterson and Brian Malloy who have taught and challenged me throughout my college career.

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# Chapter 1

## Introduction

Digital characters in movies and video games have become more and more life-like over the years. One of the many contributing features toward this realism is muscle simulation. Digital muscles have been developed to act like real muscles and provide that accustomed skin bulging and sliding that sometimes goes unnoticed since we see it in our everyday lives. These subtle details are what make characters seem real and easier to believe when set into a fantastical world.

Muscle simulation is a deformation technique used for rigging a character in feature films or video games. It is a volume-conserving method that effects the surface or skin of a digital model and typically acts as a secondary deformer on the skin during locomotion. Muscles have been used on photo-realistic and stylized characters to make their skin move naturally, simulating how the surface of the skin would look if those digital characters did indeed have a muscle system. Live-action films like *Life of Pi* (2012), animated films like *Shrek* (2001), and games such as *Red Dead Redemption II* (2018) all implemented muscle deformers to simulate realistic skin deformation for animals and humans, increasing the overall immersion of the movie-watching and gaming experience.

In this thesis, I implement a muscle simulation on a tiger rig I built in Autodesk Maya. Tigers and large cats are great examples to utilize muscle deformations due to their well-defined muscle definition. The tool I used to generate the digital muscle objects was a standard plug-in for Maya called *Maya Muscle*. Part of the research and development process was to determine the best way to handle this tool. I was able to shape the muscle objects to fit within the model and create a relative muscular system.



I utilized this tool to give each muscle object their physical properties based on the frame-rate of the animation and directly bound the surface of the model directly to these muscles.

This thesis discusses my approach to create a quadruped muscle rig of a tiger that portrays realistic muscle animation. I furthermore describe the methods and technologies used to produce muscle simulations. To create a life-like muscle system for a tiger, we first need to understand its anatomy, which I present in Chapter 2. The deformation techniques used to build the rig and implement the muscle simulation are described in Chapter 3. My implementation will be discussed further in Chapter 4, while Chapter 5 reviews the motions required of the rig and discusses the visual results of the muscle simulation.

## **1.1 Artist Statement**

My work focuses on building characters that have the capabilities to perform in their designated world and tell a story that is entertaining to the viewer. My goal for this thesis was to create a tiger that exemplifies reality and has the same locomotion capabilities and muscle deformations as seen in the wild. The main sources of inspiration include real-life depictions of tigers, some of which can be seen in Figure 1.1. Tigers have always amazed me with their strong physique and ferocity. Knowing that several different species have become extinct and others are on the verge of extinction, I feel it is important to bring these creatures back into the light.

I attempted to incorporate as much detail as I could, however some aspects had to be altered due to lack of efficiency through the production pipeline. The high cost of using muscle objects required me to structure a muscle system with limited muscle objects. My muscle system was designed to follow the shape and directional flow of the largest and most prominent muscles in a tiger's muscular system. Since the muscles are not locked to their initial modeled shape and change form during motion, they have a high level of sculptability and allowed me to design artistically a muscle setup that keeps the integrity of the anatomical structure of a tiger. Although this muscle setup



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FIGURE 1.1: Photos of tigers.[Flickr, 2012][Anaxibia, 2010]

may differ from reality, this approach I took seeks to convey the strength and graceful movement of the creature.

## Chapter 2

# Tiger Anatomy

Understanding anatomy is important for a rigger. Knowing how the bones in a skeletal system are positioned and connected and how they interact with each other can serve as a basic guideline to build the joint system for a rig. In reality, we use our muscles to move our bones and pose our skeletons and bodies. In a rig however, the joints and bones are what drives the mesh and muscle objects. The muscle objects are connected to the joints, so joint positioning is crucial. I will present the tiger's skeletal structure in Section 2.1. To get the best performance from a tiger muscle rig, it is important to know which muscles are used when tigers perform specific motions so that we can determine the muscles' shape, size, and physiology when building the muscle system. Refer to Section 2.2 for an overview of the tiger's muscular system.

### 2.1 Skeletal Structure

A tiger's skeletal system is composed of more than 200 bones. More than 600 muscles steer its skeleton and tissues. These skeletal features enable tigers to endure the vastly different rigors of both speed and strength [Thapar, 1986]. The skeleton can be broken down into five major areas: the spinal column, skull, ribs, forelegs, and hind legs. The spinal column, or backbone, supports their entire body and begins at the base of the skull and ends at the tip of the tail. It can be broken down further into five regions: the cervical, thoracic, lumbar, sacral, and caudal region. All of the vertebrae in these five spinal regions are identified and numbered in Figure 2.1 except for the sacral vertebrae which are located in the pelvis and contain three vertebrae fused together.

Cats in general probably have the most flexible spine of all mammals as it can arch its back in a "U" shape when feeling threatened [Foss, Stewart, and Swift, 2013].

The thickest and longest bones are located in the forelegs and hind legs, enabling tigers to support the large muscles in these areas. Tigers' hind legs are longer than their forelegs and are designed for power, not endurance. Tigers hunt by stalking their prey, sneaking in close enough to launch an attack. They can spring forward around 10 meters (32.5 feet) and will chase the prey for only a short distance [Thapar, 1986]. The scapula (shoulder blade), located at the top of the foreleg, is unattached to the main skeleton and capable of performing a vast range of complex motions due to the small size of the clavicle bone. The completely free-floating scapula can move backward and forward along the side of the body in a pendular motion, adding to the excursion of the foreleg during locomotion [McLaughlin and Sumida, 2007].

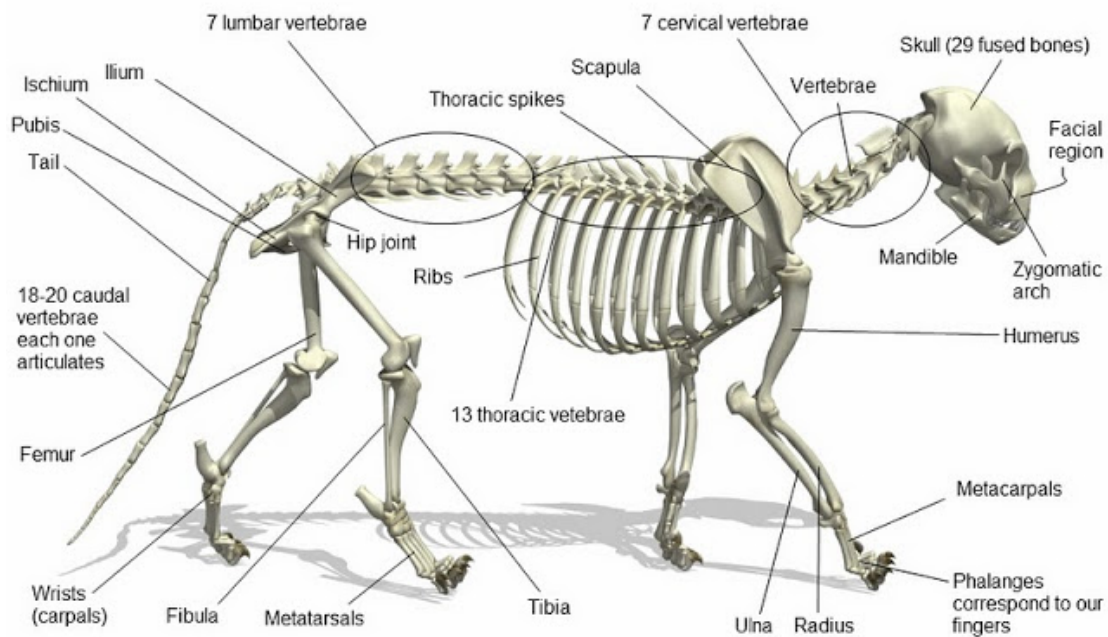


FIGURE 2.1: Tiger Skeletal System [Broad, 2012]

## 2.2 Muscles

Tigers represent efficient muscular machines in their ability to jump, twist, and turn. The ratio of their strength to their size is far superior to humans [Foss, Stewart, and

Swift, 2013]. As for all mammals, there are three muscle types within the body: cardiac muscles, smooth muscles, and striated muscles. The cardiac muscles are found in the heart and contract automatically. Smooth muscles, as the name suggests, have a smooth appearance and control the internal organs. They help move food down the digestive track and, similarly to cardiac muscles, contract without any conscious control. Striated muscles are the flesh of the body and make up the majority of the muscles. They are controlled at will and allow the tiger to move any part of their body. The structure of these muscles can be seen in Figure 2.2. The striated muscles are what will be focused on for building the muscle simulation.

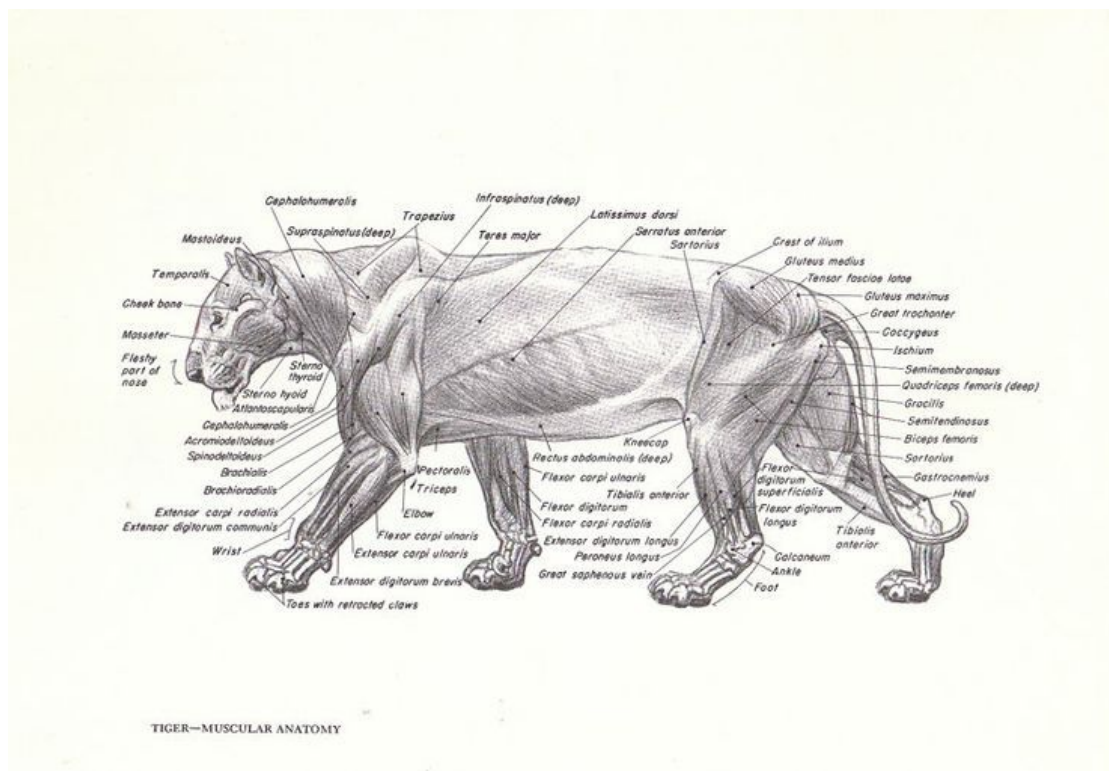


FIGURE 2.2: Drawing of the tiger muscular system. [Knight, 2013]

The dorsal muscles run along the backside of the tiger, right above the spine. These muscles twist and turn the torso. They protect the spinal column and lay on top of the oblique abdominal muscles in the belly which hold in the internal organs. The trapezius muscle covers the scapula and draws the shoulders up, while the deltoid right below pulls the shoulders forwards. The ligaments in the tiger's paws make them strong enough to survive the impact of landing, an important factor in the tiger's

ability to sprint at high speeds.

The most muscular areas of tigers are located at the shoulders and leg regions, which contain the biceps femoris that wrap around the hind legs and the triceps in the forelegs. These muscles bend and extend the legs, giving them the ability to move gracefully and quickly. These muscles provide incredible power, enabling them to chase and bring down large prey. Their neck muscles, or anterior trapesins, are also impressive. They run along the side of the neck and are used for lifting and dragging their prey over vast distances. These muscles are important to note as they are some of the largest in the muscular system and will greatly influence how the skin deforms as tigers move.

## Chapter 3

# Rigging

Rigging is the process of constructing a control system for a digital model to allow animators to move it around and bring it to life. It is one step in a production pipeline which typically follows after the modeling department. For more complex characters, a rig typically involves a skeletal system and a way to bind the mesh to that skeleton. The skeleton for a model is composed of a series of joints and bones that form joint chains. Joints, or pivot points, let you position a skeleton when animating a model, while bones are only visual cues that illustrate the relationships between joints [Alias, 2004]. Determining where these joints are placed within the model and how many are needed to fulfill the required motions are the first step when beginning to rig. Having gone over the skeletal and muscular system of tigers in the previous chapter, designing the rig and skeletal system for a tiger should come naturally.

In order to move the skeleton, controllers are created to manipulate the joints. Other tools such as IK solvers are used to simplify the mechanics of the rig by determining the position of a skeleton of an animated character. IK handles run along a joint chain and calculate the rotation of the associated joints with the IK solver. This reduces the number of controllers needed for a rig, making the rig less cluttered and simpler to animate.

The process of skinning or weight painting attaches the vertices of the model to the skeleton so that the model can be deformed by the skeleton. Skinning is an important step as it determines how the mesh interacts with the skeleton and deformers. The following sections of this chapter, will provide a general overview of deformation techniques used for rigging and how some are used to implement muscle deformations.

## 3.1 Deformation Techniques

Skin deformations can be created in a variety of ways. Each commercial 3D software package has its own tools to perform deformations and many visual effects houses have developed internal proprietary tools that are either stand alone or expand the capabilities of a commercial solution [McLaughlin, Cutler, and Coleman, 2011]. Different deformer can be activated at the same time and layered upon each other on a specific mesh. This topic is quite extensive and new deformation techniques are being researched and developed almost every year. I will cover some of the more common techniques used in films and video games.

### 3.1.1 Skeleton Subspace Deformation

Skeleton Subspace Deformation (SSD), also known as Linear Blend Skinning (LBS) or smooth skinning, is a technique in which weighted vertex values based on skeletal joint influences determine skin motion relative to animation of the performing rig [McLaughlin, Cutler, and Coleman, 2011]. The higher the influence a joint has on a vertex, the more the vertex will translate and rotate with the joint. Influence is determined by a range between 0 and 1. 0 meaning no influence, and 1 being completely controlled by the joint. Multiple joints can effect a single vertex. For each vertex, the joint influences are normalized to add up to 1. This method determines how much the vertex moves with each joint.

This skinning technique is widely used in commercial software and produces acceptable deformations in a good range of situations. It is the most popular skinning model due to its simple implementation and fast performance. It also supports all basic transforms such as translation, rotation, and scaling. The procedure of SSD for a two limb joint is illustrated in Figure 3.1.

There are several drawbacks with using this technique to implement realistic deformations, one of which is mentioned in Figure 3.1 and ties to volume preservation. Volume loss is prominent near strong bends and twists of the joints. The vertices begin to pinch in on themselves causing undesired and unrealistic deformations. Vertices that run along the bones are directly influenced by the parent joint or the base of the



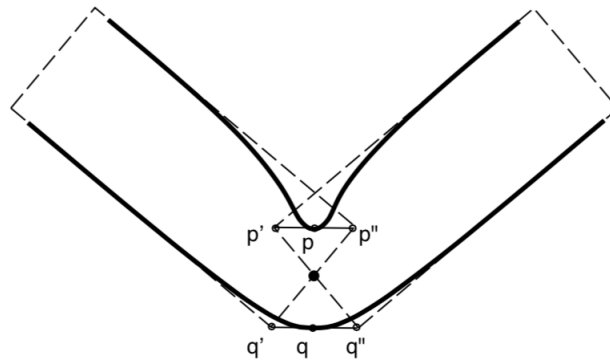


FIGURE 3.1: The deformed position of a point  $p$  lies on the line  $p' p''$  defined by the images of that point rigidly transformed by the neighboring skeletal coordinate frames, resulting in the characteristic 'collapsing elbow' problem (solid line) [Lewis, Cordner, and Fong, 2000].

bone. There are no other incoming influences affecting said vertices. Since the bones of a skeletal rig are only visual cues and do not change shape, there is no secondary motion or reactions on the vertices of the model and the animations could be perceived as rigid.

### 3.1.2 Cage Deformers

Cage deformers are any number of solutions that define how the mesh will behave relative to control objects that are external to the surface of the mesh [Joshi et al., 2007]. Examples include lattices and weighted clusters which are shown in Figure 3.2. A lattice is a structure of points for carrying out free-form deformations. A lattice deformer surrounds a deformable object, such as a character model, with a manipulatable lattice that can change the object's shape. A weighted cluster, identified with the red arrow, affects selected vertices and different portions of the mesh depending how much influence is weighted to the vertices on the mesh.

In order to manipulate the cage deformers, controllers could be created for an animator and be manually animated to match the motions of the character. Another option would be to program the cage deformers to move automatically base on the position of the skeleton. A simple expression could accomplish this and save time during animation. If using clusters to implement muscle deformations, one might position a cluster where the bicep would be on an arm. When the arm is animated to fold inward, the

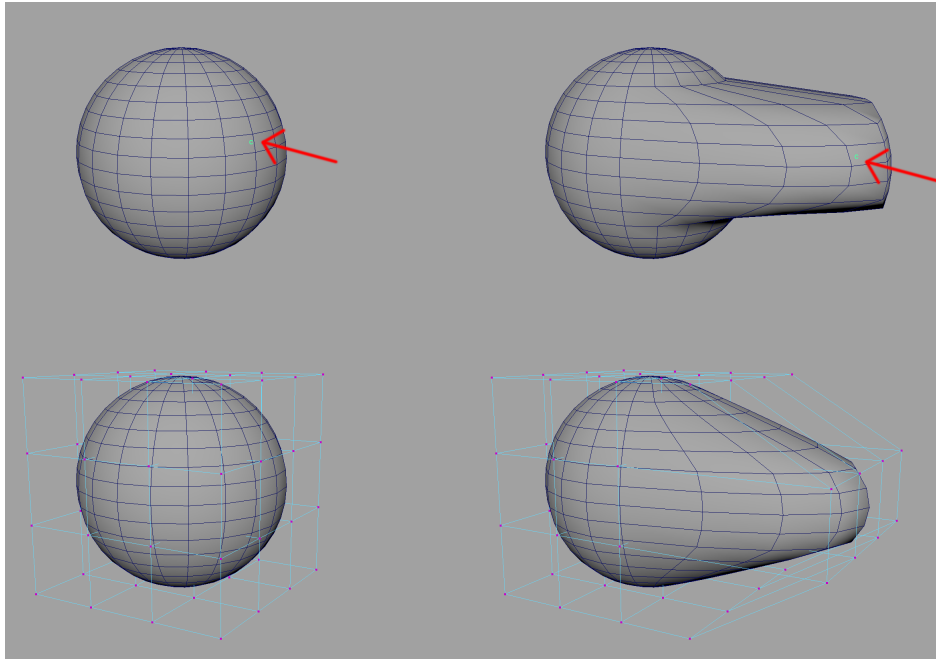


FIGURE 3.2: On top, a cluster deformer a sphere.

cluster should also be animated to move outward causing a larger bulge deformation to occur in the upper arm area.

### 3.1.3 Data-Driven Techniques

A number of data-driven techniques have been created to capture skin deformation by recording the motion of the skin using a large amount of motion capture markers and cameras that emit an inferred light that is reflected off the markers. These approaches have been able to produce realistic and detailed results because they capture directly from the real world. These markers, which can range from 300-450, are placed on an actor and cover their entire body. A marker setup can be seen in Figure 3.3. The cameras record the movement of the actor and their skin by tracking the markers. The motions performed by the actor are stored in a database, which is later used for modeling the body of the actor and creating the skeleton of the rig [Park and Hodgins, 2008].

Data-driven techniques require extensive planning and time to execute correctly. The recorded motions of an actor can be applied to any digital model with a similar anatomical structure, however the same cannot be said when trying to capture realistic



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FIGURE 3.3: Motion capture marker setup on an actor.

skin deformation. Each database of motions is actor specific, meaning the captured skin deformation is applied to a model designed around the physical proportions of the actor.

### 3.1.4 Pose Space Deformation

Pose Space Deformation (PSD) is typically applied on top of SSD. It is a shape interpolation technique that provides direct manipulation of the desired shapes through sculpting, creating an elegant solution to the limitations of SSD. In general terms, it could be described as the desired movement of the surface vertices along the mesh. [Lewis, Cordner, and Fong, 2000]. This method stores sculpted shapes, also known as pose shapes or blend shapes, as offsets and interpolates each shape when the character's joints reach a particular pose.

The algorithm to compute the change in deviation between the re-sculpted vertices and original pose of the model is quite simple and not computationally heavy. Firstly, a pose is defined. The character rig is repositioned and any manipulators affecting the mesh whose movement will cause some deformation, such as a joint, are analyzed to determine if they have changed or moved from their default rest position. New deformations are then sculpted for that pose by moving vertices to the desired position.

The vertices that have moved due to sculpting are found and saved in a database with their corresponding location in pose space. The deformation is then interpolated for each vertex based on the current skeleton pose.

In terms of creating muscle deformations with PSD, a character could be posed to flex their arms. A blend shape is then created for the arm which bulge the vertices along the biceps. This shape would then activate based on how close the joints' are to reaching the defined pose.

### **3.1.5 Muscle Systems**

Muscle systems can be defined as any number of solutions ranging from simple to complex that define how a mesh will behave relative to objects that are internal to the surface of the geometry [McLaughlin, Cutler, and Coleman, 2011]. For character rigging, the muscle deformer are modeled to occupy the appropriate volumes and fit within the digital character. These muscles work as influence and collision objects but with special attributes that precisely simulate the physical properties of muscle interacting with skin [Autodesk Help, 2016]. These muscle objects move with the skeleton and control the surface of the characters' skin as they squash and stretch.

Muscle objects populate the skeletal figure in the same manner that actual muscles are arranged. Anatomy is used as a guide for analysis of the character form. When trying to accurately represent an animal or human in a muscle simulation, an identical representation of the muscular system is best. However, using muscles can be computationally expensive and many of the muscles in smaller areas could cause binding errors [Hiebert et al., 2006]. To reduce the overall number of muscle objects attached to the rig, several muscles are combined into larger muscles.

Advanced techniques for muscle systems involve modeling bones, muscles, tendons, and fatty tissues. To deform the skin according to these structures, implicit functions are defined so that the densities occupy the volume of the corresponding anatomy [Parent, 2012]. These high-detailed muscle systems require stronger physics engines as they perform progressively slower computing collisions with complex shapes.

## Chapter 4

# Methodology

The model used for this thesis was taken from an existing rig created by Truong and distributed on TurboSquid <sup>1</sup>. The existing rig for the model was deleted and a new rig was built for the purpose of this thesis. This chapter will cover the features of the rig as well as the muscle simulation applied to it.

### 4.1 Skeletal Setup and Kinematics

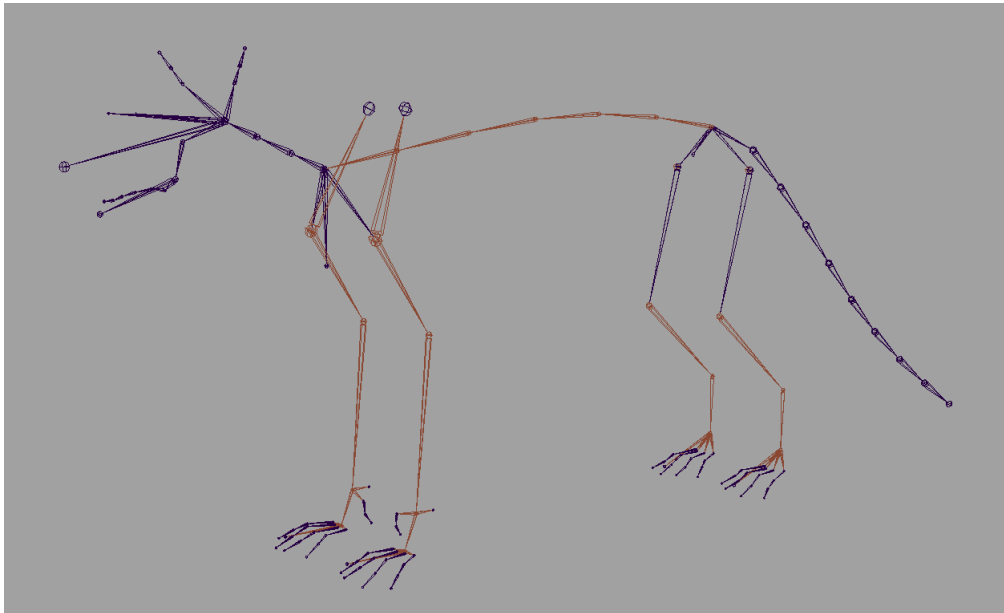
Using 200 bones in a character rig is not desirable in some cases, for example in real-time applications. In many cases it is possible to create the desired range of motion and deformations using fewer bones and joints. The tiger's spine is an obvious case, since it contains around 30 vertebrae. Determining how many joints and bones are needed to achieve the required capabilities for the production is an important step in the rigging process. When building a rig that supports muscle simulation, it is also important to learn where and how the muscles are attached to the skeleton. This information helped guide my decision making when positioning the joints and designing the overall structure of the tiger skeleton.

Each joint in my skeletal setup was positioned to mimic a typical tiger skeletal model, as can be seen in Figure 4.1. The joints that make up the spine run along the upper back of the model. Rather than having a single joint hierarchy throughout the entire model, I divided my skeletal joint system into three sections: the lower hips, the upper torso, and the mid-spine. The joints associated with the lower hips make up the

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<sup>1</sup><https://www.turbosquid.com/FullPreview/Index.cfm/ID/1033448>

hind legs and tail. The upper torso include the fore legs, neck, and head. This allows the lower hips, upper torso, and mid-spine to move independent of each other.



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FIGURE 4.1: Tiger Joint Skeleton

#### 4.1.1 Mid-Spine

Since the spine is the longest skeletal feature in a tiger and contains five sections, I decided to split it up into three sections in my rig. Three joints were used in the upper torso (neck), seven for the mid-spine, and nine for the lower hips (tail). The mid-spine section includes the seven joint chain, which the animator has free range of control over; being able to bend it into any shape. This setup involves an IK Spline Handle and allows these seven joints to squash and stretch. To avoid drastically stretching the spine in an unrealistic manner, I included a switch enabling the animator to toggle this feature on and off.

#### 4.1.2 Hind Legs

For the hind legs, I used an overlaying joint system. Two identical joint chains run down both hind legs and three controllers are used to manipulate these legs. These controls are located at the base of the legs, the upper thigh, and in front of the knees.

See Figure 4.2. The joint chain controlled by the leg controller contains an IK spring solver which causes the associated joints' orientation to be uniformly distributed. This joint chain acts as the main driver for the leg and manipulates the other joint chain which is skinned to the surface mesh. The other joint chain is a child of the spring joint chain and contains an IK rotate plane solver located along the lower leg, beginning at the knees and ending at the base of the metatarsals. This joint chain allows the animator to adjust the "wrist" to point in the direction they desire. The thigh control pivots the hind legs at the hips, allowing for more control over the position of the thighs. The knee controller controls the direction the leg will point and bend towards.

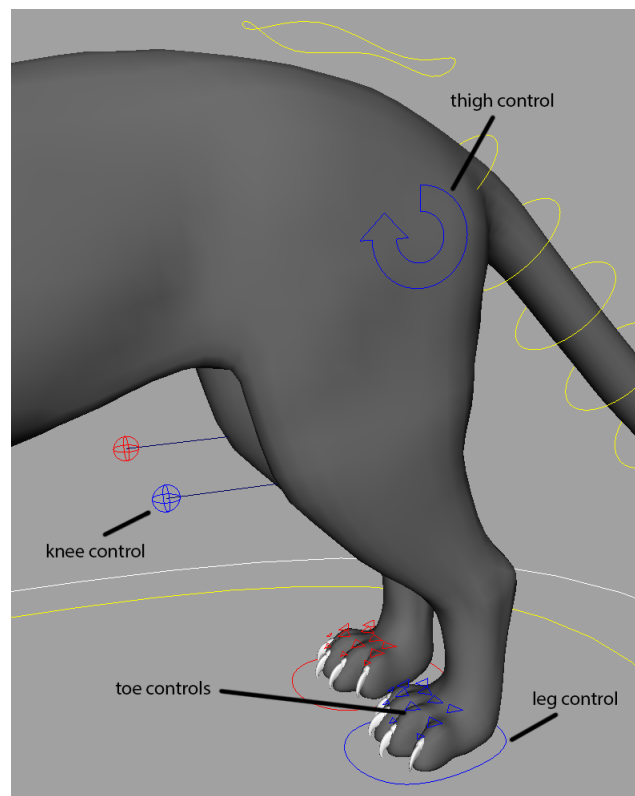


FIGURE 4.2: Controller setup for the hind legs.

### 4.1.3 Forelegs

The forelegs are also made of two separate joint chains. One chain represents the lower leg and runs down to the paw, while the other chain represents the scapula. Both of these chains begin at the shoulder area and have a single controller to translate them

so they move together and stay connected. An IK rotate plane solver is used to rotate the leg joints and pose the foreleg. An elbow control was used to guide the direction of the elbow while the leg is bent. The scapula bone has its own single joint chain that is not effected by the IK handle. It pivots at the shoulders which allows the scapula to rotate in the pendular motion described in Chapter 2. This control setup can be seen in Figure 4.3.

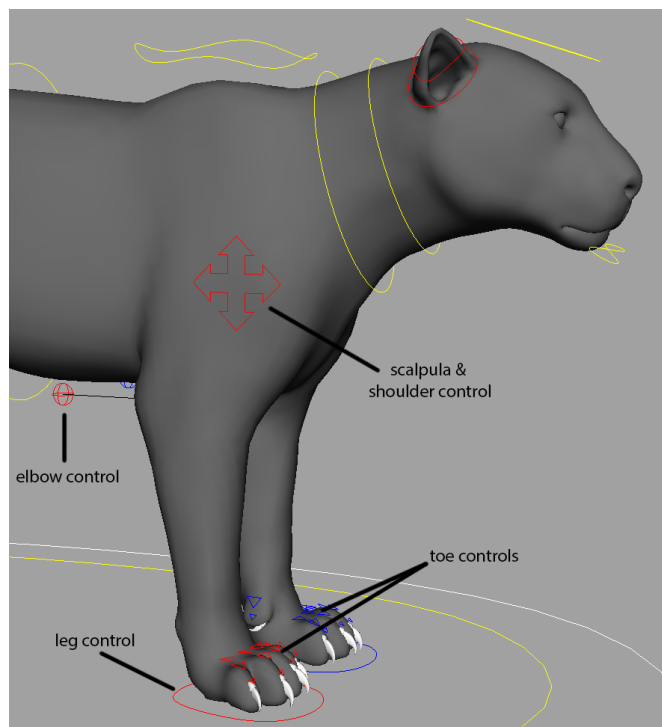


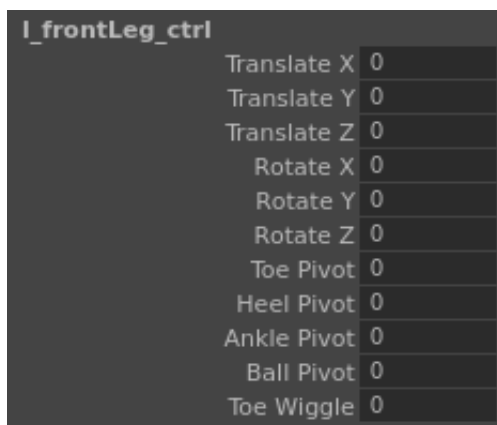
FIGURE 4.3: Control setup for the forelegs.

#### 4.1.4 Paws

The paws have a pivot setup which enables the paws to rotate at the heel, ball joint, and at the ends of the toes. These rotations are controlled by the leg controller and these attributes for the leg controller can be seen in Figure 4.4. Changing the translate values of this controller will move the paw in 3D space as well as change the position of the legs. The remaining attributes affect the orientation and pose of the paw beginning at the ankles. This allows for more precise movements such as rolling the paw when stepping or lifting the leg up while keeping the toes on the ground. Each individual toe has a joint chain containing three joints. One joint is located at the base of the



specific toe, near the heel area, the next joint is in the middle of the toe. The joint at the end moves the claw, allowing it to retract into the mesh. These joint chains have a FK functionality, where the claw translates with the rotations of the toe joints.



l_frontLeg_ctrl	
Translate X	0
Translate Y	0
Translate Z	0
Rotate X	0
Rotate Y	0
Rotate Z	0
Toe Pivot	0
Heel Pivot	0
Ankle Pivot	0
Ball Pivot	0
Toe Wiggle	0

FIGURE 4.4: Extra attributes in the leg controller for the paws.

#### 4.1.5 Head and Tail

Because the muscle deformer were only placed throughout the upper spinal column, the head and tail area have a standard skeletal setup. The tail implements FK due to the fact that the animations require the tail to only hang out and not interact or wrap around other objects. Since facial expressions are not required, all the facial features of the model are bound to a single head joint. However, the ears can rotate back and forth at the base and half way up the ears. The eyes can rotate and aim a specific direction. The jaw can open and close, and the tongue can be animated.

## 4.2 Maya Muscle System

The tool I used to implement the muscle system for my rig is Maya Muscle. It is a skin deformer first released in 2008 that converts any NURBS surface into a muscle object. It also automatically generates NURBS surfaces between two selected joints, making it easy to add muscles to an existing rig. These generated muscles initially take on an ellipsoidal shape whose two end points are bound to their corresponding

joints. Upon generation, a NURBS curve known as the action curve and three controllers shaped as boxes are also created and run along the muscle object. The controllers, which can be seen in Figure 4.5, control the vertices of the action curve. They are typically located at the two end points and center of the muscle object, allowing for manual animated muscle movement. The number of controllers and control vertices for the muscle object can be adjusted before generation if needed.

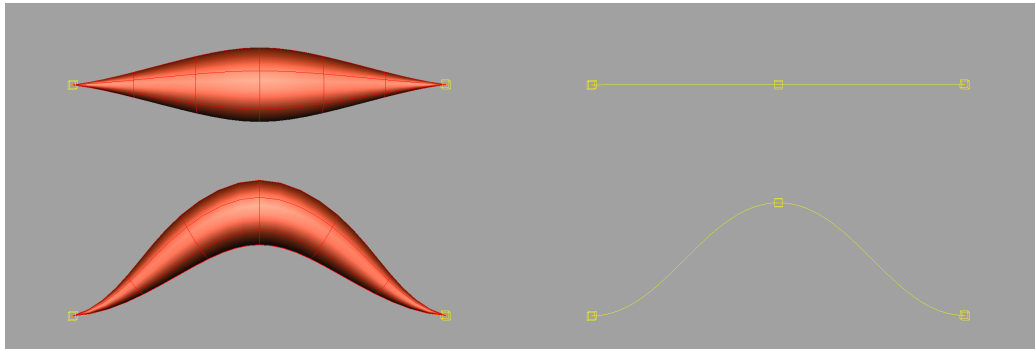


FIGURE 4.5: Boxed-shaped controllers influence the muscle object by manipulating the action curve.

Determining which joints to bind specific muscles to took the longest time to complete. Modeling the muscles to take on the appropriate volume and be visually similar to a tiger's muscular system, all while making sure the muscles deform correctly as the skeleton moves was quite a challenge. The hind legs for example have dynamic range when they are extended or bent. I ran into issues where my muscle objects would collapse on top of each other when the hind legs were fully extended, causing the legs to shrink in size. After many trials, I was able to design several muscle groups that behave correctly and preserve volume in the hind legs. The final muscle setup can be viewed in Figure 4.6.

Maya muscle objects keep their volume reasonably well when squashed and stretched, which can result in over sized muscle shapes while the muscle is flexed. Figure 4.7 shows an example of the tricep muscle group flexing (b) from a rest pose (a). To reduce the squash size during the flex, a blend shape, or new target model, was sculpted. To activate the sculpted shapes, the max squash and stretch must first be defined in the muscle parameters of the muscle object. As the muscles reach these max positions, the sculpted shape activates (c).

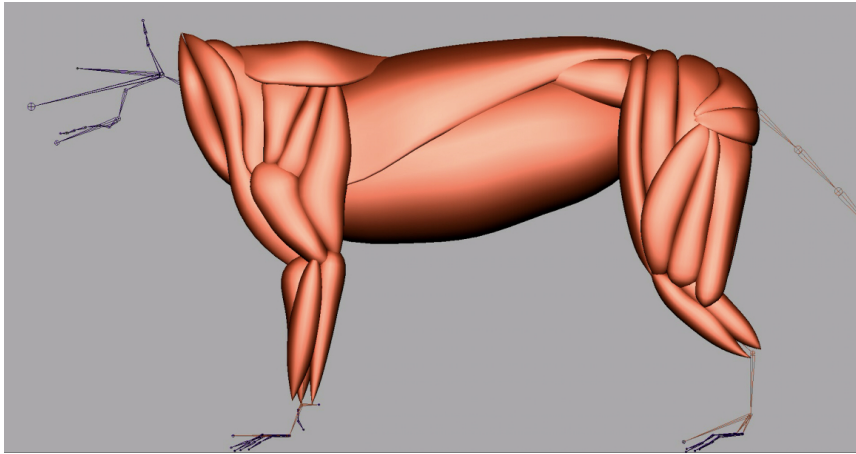


FIGURE 4.6: Tiger Muscle Setup

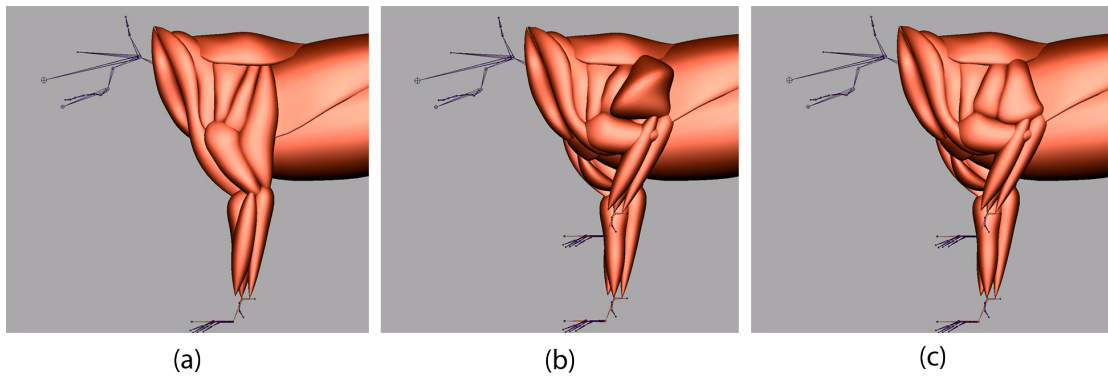


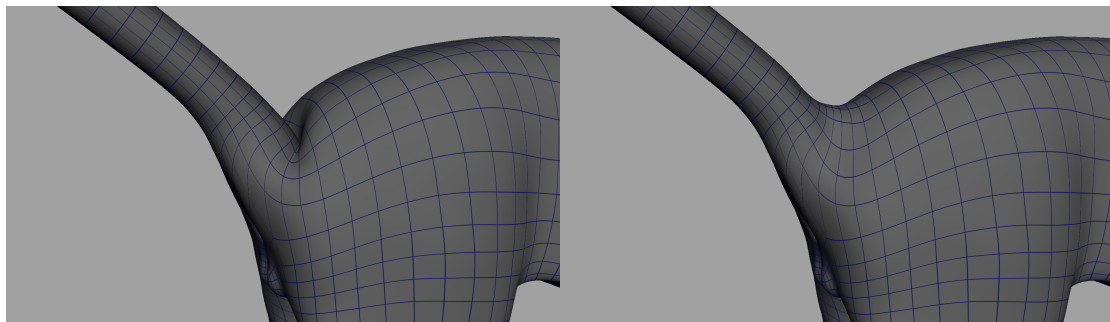
FIGURE 4.7: Image (a) shows muscle objects at rest pose. Image (b) shows the tricep muscle object squash as forearm is bent. Image (c) shows corrected shape of tricep when forearm is bent.

After the muscles were generated and bound to the mesh, the physical attributes for each muscle were modified. Muscle jiggle is a parameter that needs to be adjusted in order to achieve the correct physical behavior of the muscle object. The various attributes to control the properties of the muscles are Jiggle, Cycle, and Rest. These attributes modify the box control curves that manipulate the action curve of each muscle. The Jiggle attribute is a master multiplier for jiggle on the controller. A value of 0 means there is no jiggle and the muscle remains static with the joint system. Raising this value makes the muscle move more based on the movement of the rig. Cycle determines the number of frames it takes for the muscle to bounce back and forth. Rest determines the number of frames the muscle takes to come to rest once forces on it stop

affecting it [Autodesk, 2011].

### 4.3 Skinning

After I finished building the skeletal rig for my tiger, I began skinning the mesh directly to my joint skeleton using SSD. Once completed, I unsurprisingly ran into issues with collapsing vertices near major joints, causing unrealistic shapes once the tiger was animated. This volume loss around the joints were most prominent at the elbows on the forelegs, the knee on the hind legs, and the base of the tail. When the tail of my rig is positioned upward, there was obvious pinching occurring on the geometry near the base of the tail, which can be seen in Figure 4.8. I created a blend shape for this area and sculpted the vertices to rise up and fill in the missing volume. I then set the blend shape to active whenever the joint at the base of the tail rotates upward. The same approach was used for the legs.

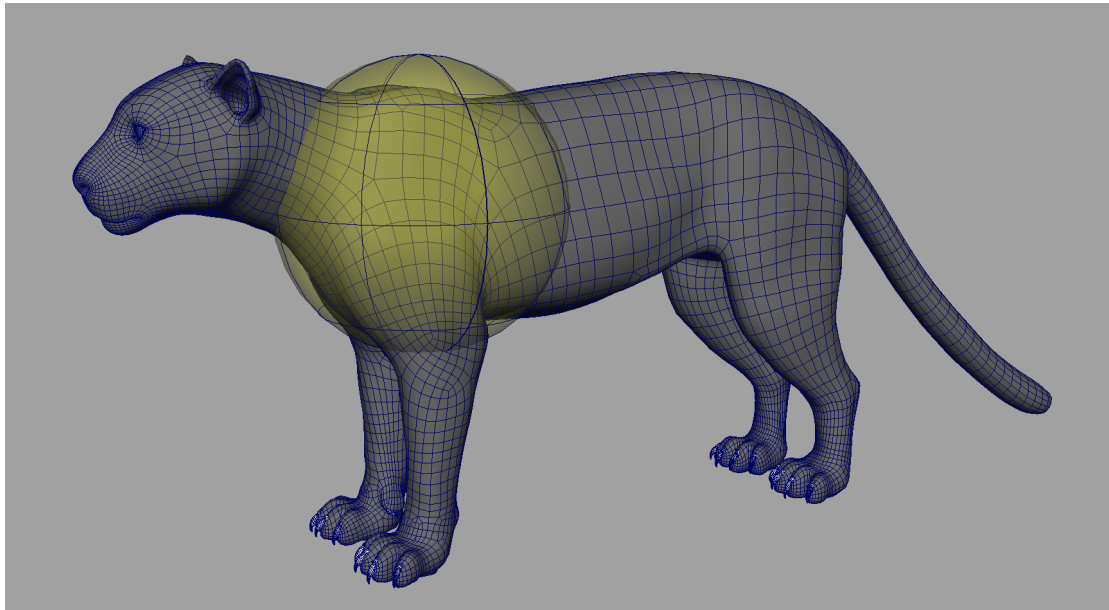


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FIGURE 4.8: Before and after shape deformation was added to base of tail.

To reduce the computation of the muscle deformer on the mesh, a bind distance can be set before applying the deformer to the mesh. Maya Muscle provides a simple tool that generates a visual representation of the bind distance for each muscle object on the mesh, which can be seen in Figure 4.9. A NURBS sphere is generated around the selected muscle. The vertices encompassed by the sphere are enabled to be influenced by the specified muscle. Any vertices outside the sphere will not be influenced, even if muscle skin weights are painted on these vertices. When skin deformation is computed

for each muscle object, vertices outside the bind distance will be skipped, reducing the overall computation at run time.



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FIGURE 4.9: Visual representation of bind distance for muscle object in upper forearm.

After the bind distances were set and the muscle skin deformer was attached to the mesh, I began skinning the muscles to the mesh with the Muscle Paint tool. Sticky weights are painted on the surface of the mesh surrounding the muscle. These weights determine how much the painted vertices on the mesh will stick to the surface of the muscle object. Since the skin mesh is effectively attached to the muscle surface with sticky weights, when the muscle jiggles or bulges, so does the skin that is weighted to it [Autodesk, 2011].

## Chapter 5

# Results

The tiger rig works well with the muscle system for animation. The controllers are animator friendly and effective. Each body part is able to be posed and animated as desired. The muscles interact with the skeletal system correctly and create nice deformations on the surface skin. For comparison purposes, two separate videos were rendered for each animation. One with the muscle deformer on and the other with the muscles turned off. The animations with the muscles turned off displays a smooth bind, SSD deformation.

### 5.1 Deformations

The lower forelegs are rigged with three muscle objects representing the carpi and digitorm muscles used to extend and flex the paw. When the wrist controller for the rig is rotated, these muscle flex or stretch corresponding to the direction and manipulate the vertices along the lower foreleg. When testing for volume preservation, twisting the wrist still keeps nice deformations and very little volume loss. These results can be seen in Figure 5.1 as the tiger's left paw is twisted inward from the rest pose. As for the hind legs, Figure 5.2 displays muscle deformations in the upper thigh area as muscle objects bulge when the leg is bent. These bulging deformations are most prominent in the buttocks region and the front-upper hips.

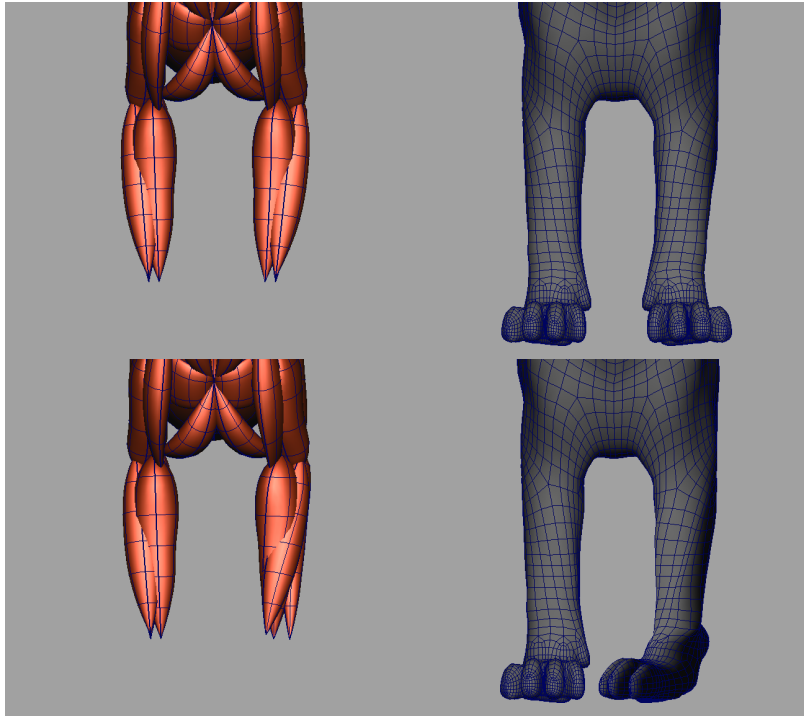


FIGURE 5.1: Twisting deformations in the forelegs.

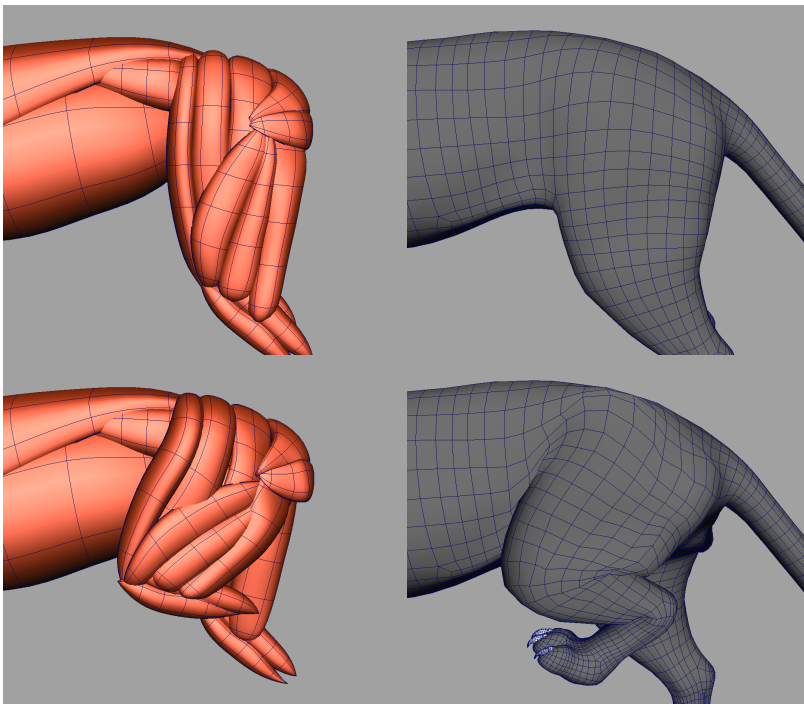


FIGURE 5.2: Bending deformations in the hind legs

## 5.2 Walk Cycle

A walk cycle was rendered out to exhibit subtle muscle deformations of the most common activity in which a tiger engages. Skin deformation caused by the muscle objects are most prominent as the legs are lifted to take a step, and when the tiger brings his legs down and makes contact with the ground. The muscles bulge and flex as the legs collapse in on themselves. Figure 5.3 shows side by side comparison of the reference footage<sup>1</sup> used for the walk animation, the tiger model with muscle deformations, and the tiger model with SSD both performing the same walking motion. It is difficult to express the full impact of muscle deformations in a still image as the physics of the muscles are lost, however volume preservation issues are visible with the SSD model. There is a noticeable pinch in the shoulder area and ankles at this pose. These deformations could be fixed on the SSD model by adding blend shapes to smooth out the vertices in these areas, however the SSD model still lacks the jiggle and bulging of the skin as seen on the other model with muscles in the animation.

## 5.3 Run Cycle

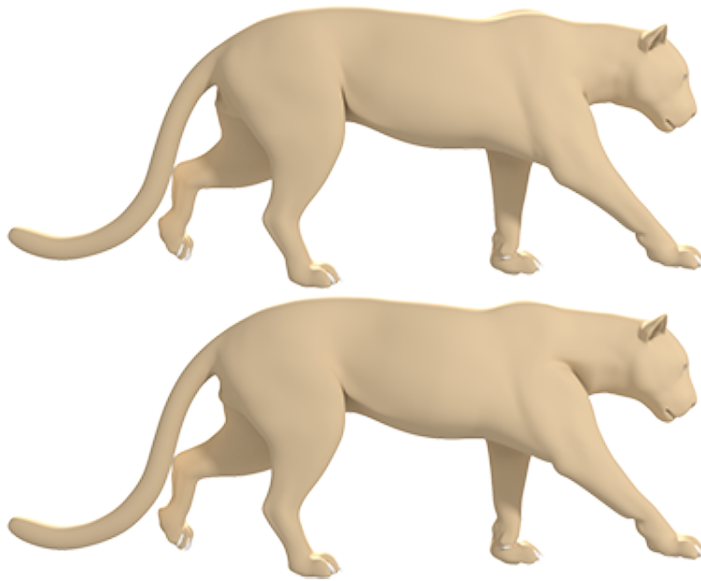
The run cycle achieves more dynamic muscle deformation of the skin. With faster movement, the muscles jiggle more forcefully and the skin deformations are easier to see. The run cycle was based off multiple reference footages and hand-drawn animation. Figure 5.4 includes still frames from the rendered run cycle and a single frame from the reference footage<sup>2</sup>. One key difference between the muscle simulation and SSD can be seen in the forearm. When looking at the still image from the reference footage, one can see the nice curvature in the forearm as the skin pushes against the radius and ulna bones as the forearm begins to swing downward (see Figure 2.1 for a review of the skeletal system). Looking at the middle frame of the tiger with the muscle simulation, a slight curvature can be seen in the forearm as well. This curvature is not present in the tiger model with SSD, as this area only contains a single joint influence.

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<sup>1</sup><https://youtu.be/Tec5bp90C8k>

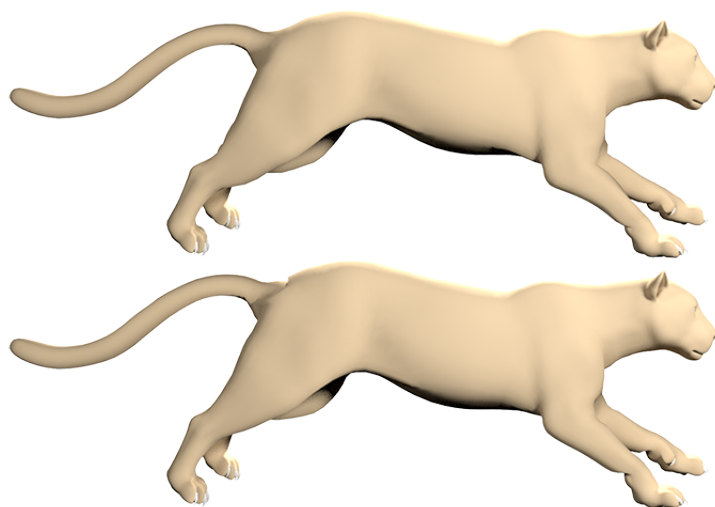
<sup>2</sup><https://youtu.be/qSPYVL0g92c>





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FIGURE 5.3: Still frames of walk cycle. Reference image of tiger walking on top, followed by muscle deformation in the middle, and SSD on the bottom model.



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FIGURE 5.4: Still frames of run cycle. Reference image of tiger running on top, followed by muscle deformation in the middle, and SSD on the bottom model.

## Chapter 6

# Conclusion

Muscle systems are a complex tool used to produce high end effects. Not only are their results suitable for accurate skin deformation, the visual representation of the muscle system simplifies the conception of this deformation technique, making it easy to use. The Maya Muscle tool is intuitive and great for implementing realistic skin deformation. This tool can add muscle deformer on top of existing rigs and does not need to be prearranged before the rigging process begins. Muscle objects have the capability to be modeled in almost any shape and imitate physically correct muscle movement automatically. On top of that, they also allow freedom for the animator to manually animate muscle movement without further training on the toolset.

A basic understanding of the anatomical structure of the character model does help establish where the most visible skin deformation occurs. The most prominent muscle groups should be prioritized, especially when using muscle deformer in real-time applications. The deformations for the tiger were enhanced and weight painting became more intuitive when painting the vertices to the muscle objects.

Automated deformation systems have become the most prevalent for production-quality rigs in animation. Adding a muscle simulation to a character rig does make a positive and visual difference in the final animation. Muscles gives characters more realism and believability, enhancing the immersion experience.

# Bibliography

- Alias (2004). *Character Setup*. Vol. 6. Alias Systems, pp. 33–34.
- Anaxibia (2010). *Siberian Tiger (Panthera Tigris Altaica)*. URL: <https://a-z-animals.com/animals/siberian-tiger/pictures/3884/>.
- Autodesk (2011). *Maya Muscle*. Autodesk, Inc.
- Autodesk Help (2016). “Maya Muscle”. In: *Autodesk Maya User Guide*. URL: <https://knowledge.autodesk.com/support/maya/learn-explore/>.
- Broad, Michael (2012). *Cat Skeleton*. URL: <https://pictures-of-cats.org/cat-skeleton.html>.
- Flickr, Derrick Brutel (2012). *Bengal tiger, India*. URL: <https://pictures-of-cats.org/cat-skeleton.html>.
- Foss, Michael, Nancy Stewart, and Jean Swift (2013). *Cat Anatomy and Physiology*. Washington State University Extension, pp. 4–15.
- Hiebert, Brad et al. (2006). “Session Details: “The Chronicles of Narnia”: The Lion, the Crowds, and Rhythm & Hues”. In: *ACM SIGGRAPH 2006 Courses*. SIGGRAPH ’06. New York, NY, USA: ACM.
- Joshi, Pushkar et al. (2007). “Harmonic Coordinates for Character Articulation”. In: *ACM SIGGRAPH 2007 Papers*. SIGGRAPH ’07. New York, NY, USA: ACM.
- Knight, Charles R. (2013). *Animal Drawing: Anatomy and Action for Artists*. Dover Publications.
- Lewis, J. P., Matt Cordner, and Nickson Fong (2000). “Pose Space Deformation: A Unified Approach to Shape Interpolation and Skeleton-driven Deformation”. In: *Proceedings of the 27th Annual Conference on Computer Graphics and Interactive Techniques*. SIGGRAPH ’00. New York, NY, USA: ACM Press/Addison-Wesley Publishing Co., pp. 165–172.

McLaughlin, Tim, Larry Cutler, and David Coleman (2011). "Character Rigging, Deformations, and Simulations in Film and Game Production". In: *ACM SIGGRAPH 2011 Courses*. SIGGRAPH '11. New York, NY, USA: ACM, 5:1–5:18.

McLaughlin, Tim and Stuart S. Sumida (2007). "The Morphology of Digital Creatures". In: *ACM SIGGRAPH 2007 Courses*. SIGGRAPH '07. New York, NY, USA: ACM.

Parent, Rick (2012). *Computer Animation: Algorithms & Techniques*. Third Edition. Morgan Kaufmann.

Park, Sang Il and Jessica K. Hodgins (2008). "Data-driven Modeling of Skin and Muscle Deformation". In: *ACM SIGGRAPH 2008 Papers*. SIGGRAPH '08. New York, NY, USA: ACM, 96:1–96:6.

Thapar, Valmik (1986). *Tiger : Portrait of a Predator*. Facts On File, Inc.