

PERFORMANCE-GUIDED
CHARACTER BIND POSE FOR DEFORMATIONS

A Thesis
by
BENITO ADÁN PEÑA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

May 2011

Major Subject: Visualization

PERFORMANCE-GUIDED
CHARACTER BIND POSE FOR DEFORMATIONS

A Thesis

by

BENITO ADÁN PEÑA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Tim McLaughlin
Committee Members,	Ann McNamara
	Jinxiang Chai
Head of Department,	Tim McLaughlin

May 2011

Major Subject: Visualization

ABSTRACT

Performance-Guided Character Bind Pose for Deformations. (May 2011)

Benito Adán Peña, B.E.D, Texas A&M University

Chair of Advisory Committee: Prof. Tim McLaughlin

Current production methods for creating a motion system for a deformable digital character model involve providing an underlying joint structure based off of a T-Pose, A-Pose or another arbitrary bind pose of the character. A bind pose is required to establish the skeleton-to-geometry spatial relationship that will be used as a mathematical reference to determine geometry deformations in animated poses. Using a set of human motion capture performances as input animation, the impact of the standard T-Pose and A-Pose on the stretching and compression of human character model geometry is compared relative to novel mean poses derived from each performance. Results demonstrate that using an averaged joint position of each specific performance as the bind pose for the performance reduces the overall deformation of the model. Appropriate applications of the mean pose as a bind pose could impact the resources required to repair deformation artifacts in animated deformable digital characters.

To My Family.

ACKNOWLEDGMENTS

I would like to thank my committee chair, Tim McLaughlin, committee members Dr. Ann McNamara and Dr. Jinxiang Chai, for all of their help and encouragement throughout this thesis. Special thanks to Megha Davalath, Jose Guinea Montalvo, Eric Landreneau, and Xiaolin (Kevin) Wei for their help and insight on various topics within this thesis.

I would also like to thank my parents, Ben and Yolanda Peña, sister and brother-in-law, Elena and Mark Chinn, and fiancée, Marian Kreis, for their support throughout my academic career. Without their encouragement I would not have been able to achieve my goals.

Finally, I would like to thank all of the faculty, staff, and students of the Visualization Department who also encouraged my efforts and created a fun learning environment over the years.

TABLE OF CONTENTS

CHAPTER		Page
I	INTRODUCTION	1
II	BACKGROUND AND PREVIOUS WORK	2
	A. Common Practices in the Management of Deforming Character in Animation Production	2
	1. Character Setup	3
	a. Evaluation of Character from Production	4
	b. Scope of Use	4
	c. Joint Placement and Number	5
	d. Deformation Systems and Tools	6
	e. Bind Poses	7
	B. Overview of Deformation Methods	10
	1. Surface Deformations	10
	2. Multi-Layered and Physically Inspired Models	10
	3. Shape Interpolation	11
	4. Skeleton-Subspace Deformation	11
	5. Pose Space Deformation	12
	C. Methods for Averaging Joint Movement Over a Performance	12
	1. Motion Capture Range of Motion (ROM)	12
	2. Eigenpostures	12
	3. Principal Component Analysis in Facial Animation . .	13
III	METHODOLOGY	14
	A. Use of T-Pose and A-Pose	14
	B. Identification of a Wide Range of Performances	14
	C. Evaluate Suitability of Model to Deformation Issues	14
	1. Appropriate Topology	14
	2. Use of Humanoid Model	15
	D. Value of Using Motion Capture	15
	E. Character Setup	15
	1. Procedural Bone Placement	16
	F. Establish Deformations for Each Pose	16
	G. Application of Motion Capture to Motion System	16

CHAPTER	Page
H. Results of Tension and Compression Across Surfaces for T- and A-Poses	17
I. Creation of Mean Pose	17
1. Joint Rotation Data	17
J. Re-bind Geometry to Motion System in Mean Pose	17
K. Application and Results for the New Model	18
L. Analyze Visual and Numeric Data from T-Pose, A-Pose and Mean Pose Models	18
IV IMPLEMENTATION	19
A. T-Pose and A-Pose Configuration	19
B. Overview of Software and Plug-ins Used	20
1. Animation Software	20
2. Plug-ins and Scripts	21
a. SOuP Plugin	21
b. HumanIK	21
c. Chalana	22
d. Scripts	22
C. Selection of Motion Data	23
1. Source: Carnegie Mellon University Online Database	23
2. Quality of Data	24
3. Performance Types	24
D. Selection of Model	24
1. MakeHuman Model	24
2. Topology Considerations	25
E. Rigging Model	25
1. Procedural Rigging	26
F. Setting Up Deformations	26
G. Application of Motion Capture Data	27
1. ASF/AMC File Format	27
2. HumanIK Retargeting	27
3. Re-targeting Issues	28
H. Determination of Mean Pose	28
V RESULTS AND CONCLUSIONS	30
A. Mean Pose Results	30
B. Side-By-Side Comparison using RGB Colors	31
C. Collected Data	32

CHAPTER	Page
D. Differences Between the Bind Poses	33
1. Distribution of Stretching and Compression Occurrences	33
2. Extreme Stretching and Compression	34
E. Practicality of Results Used in Production Environment . .	35
VI FUTURE WORK	39
A. Statistical Analysis of Motion Data	39
B. Other Human Body Types	39
C. Non-human Characters	39
REFERENCES	40
VITA	43

LIST OF FIGURES

FIGURE		Page
1	Examples of a T-Pose and A-Pose, Respectively [12].	7
2	T-Pose Used for this Thesis.	19
3	A-Pose Used for this Thesis.	20
4	Screenshot of the Chalana Interface.	23
5	Screenshot of the MakeHuman GUI.	25
6	Screenshot of the Characterize Tab in the HumanIK Dialogue.	29
7	Mean Pose for the Walking Animation Sequence.	30
8	Mean Pose for the Running Animation Sequence.	31
9	Mean Pose for the Dancing Animation Sequence.	32
10	Side-By-Side Comparison of Walking Sequence Using RGB Colors.	33
11	Side-By-Side Comparison of Running Sequence Using RGB Colors.	34
12	Side-By-Side Comparison of Dancing Sequence Using RGB Colors.	35
13	Distribution of Occurrences from the Bind Pose for the Walking Animation Sequence.	36
14	Distribution of Occurrences from the Bind Pose for the Running Animation Sequence.	36
15	Distribution of Occurrences from the Bind Pose for the Dancing Animation Sequence.	37
16	Occurrences of Extreme Deformations for the Walking Animation Sequence.	37

FIGURE		Page
17	Occurrences of Extreme Deformations for the Running Animation Sequence.	38
18	Occurrences of Extreme Deformations for the Dancing Animation Sequence.	38

CHAPTER I

INTRODUCTION

Believable character motion is dependent upon geometry deformations that visually mimic the behavior of organic skin. Deformations are the output of a character model that is driven by a motion or skeletal system. Maintaining the form of a character through an animated sequence plays a large role in facilitating expressiveness through the preservation of silhouette and posing.

In character setup, an arbitrary bind pose that is used over an entire range of performances results in varying degrees of shape maintenance problems that can be costly to production resources. These arbitrary poses, including the T-Pose and A-Pose, are used as a standard basis for character deformations that cover a wide spectrum of performances, often encompassing a multitude of shots. The varied deformation results are based upon how extreme the performance, with regard to range of motion, is in each shot relative to the bind pose. In order to maintain the correct character shape and form, resources are expended per shot to fix the deformations through geometry corrections in the rigging and deformation systems.

This thesis describes the use of a performance-based bind pose and examines its impact on the deformation of a character model relative to the use of industry standard T-Pose or A-Pose setups. This thesis shows that a bind pose that more closely represents the midpoint of the range of motion in a performance will provide fewer compression and stretching deformation artifacts.

A bind pose of this kind is not currently used in production and may be a valid addition or alternative to methods used.

This thesis follows the style of *IEEE Transactions on Automatic Control*.

CHAPTER II

BACKGROUND AND PREVIOUS WORK

The following fields were investigated relative to this problem: common practices in the management of deforming characters in animation production, surface deformation methods for character animation, and methods for averaging joint movement for an animation sequence.

A. Common Practices in the Management of Deforming Character in Animation Production

Character deformation has its roots in both mimicking real organic creatures and pose exaggeration from 2D drawing sequences. The believability of current 3D animated characters is heavily dependent on those two factors due to perceptual knowledge of living creatures and animation standards and practices.

The first use of a deforming character on film can be found in 2D animated drawing sequences, notably *Humorous Phases of Funny Faces* (1906) [1]. The use of 3D Computer animation did not enter into the film world until the 1976 movie, *Futureworld*, which featured a computer-generated face and hand [2]. *The Adventures of André and Wally B.* introduced the first CG animation with squash and stretch in 1984 [3]. The first articulated CG character in a feature film appeared in *Young Sherlock Holmes* (1985) as the ‘stained glass knight’ [1]. However, this character’s deforming surfaces were limited to bending legs. Realistic human movements were introduced with the T-1000 character in *Terminator 2: Judgement Day* (1991) [1]. In this case, deformations were limited to maintaining the continuity between surfaces attached to articulating joints such as the elbows and knees. *Jurassic Park* (1993) featured the first photorealistic CG creatures exhibiting more complex deformations in

which multiple skeletal bones could effect a single surface [1]. Gollum, from *The Lord of the Rings Trilogy* (2003), was the first photorealistic motion captured character for a film. Currently, it is common for feature films to include many different types of complex deforming characters.

Aesthetically, well achieved deformations are important to an animation because they allow the viewer to remain connected to the character. This links to the animation principle of appeal [4, 5]. For example, the movement and deformations of the dinosaurs in the live action movie *Jurassic Park* allowed moviegoers to believe them to be real and could therefore exhibit genuine reactions to their role in the movie. If the dinosaurs moved and deformed in a manner that did not fit their role or environment, they would not be aesthetically pleasing to the viewer and would likely be labeled as fake. This is because any gaps in believability lead the viewer to question what they are seeing.

1. Character Setup

Creating a deformable character involves creating a motion, deformation and control system that is ready for an animator to create a performance with it. This is referred to as the Character Setup Pipeline. It is an early stage of the production pipeline and involves interdepartmental collaboration to create a product. It occurs after character modeling and before performance animation.

In an animated film, a character is animated per shot. A shot is measured in frames, typically at the rate of 24 to 30 frames per second. A series of shots linked together comprise a scene, however, each shot is an individual piece of performance and therefore has its own ramifications on the model. Currently, a character is set up to handle the full range of performances for the entire film. This is not necessarily a good fit because each performance is produced per shot.

a. Evaluation of Character from Production

Character setup also includes the decisions that are needed to be made by the rigger regarding how the character is to move and what its role is in the production. Concept drawings and production artwork are assessed to determine the form of the character [6]. The artwork will show how the character looks in various poses, as well as details of particular deformations that should occur. It will also provide silhouette information which is key for character animation and identification.

Along with form information, a rigger needs to evaluate the performance requirements of the character. This is achieved by studying the storyboards, animatics and artwork [7]. These resources will also determine how much of the character is to be seen in frame which will in turn provide level-of-detail information for deformations. For example, if a character's legs are never to be in frame, then creating a muscle system for them is not necessary. Also, if a character is to always be far away from the camera, certain deformation measures can be limited to save time.

In animation production, a character can perform a wide range of performances. In the movie *Kung Fu Panda*, the main character, Po, is a panda who becomes a kung fu master [8]. His character exhibits a wide range of performance and wide range of motion, from walking around to performing martial arts kicks, punches and maneuvers. In contrast, the character of Po's father, Mr. Ping, spends most of his performances walking around and cooking in his restaurant. The range of performances needed by a character is defined by the needs of the story.

b. Scope of Use

Studying storyboards and animatics will also let the rigger know how many shots a character is going to be in [9]. If the character is in just a few shots, it might not

be very important to the overall story and will probably not be carrying out a lot of actions. The attention needed toward its deformations in this case are going to be lessened than for a character that appears in many shots. This is because a character that is in only one or a few shots is more easily forgettable. A character that appears in many shots will give the viewer time to pick up on subtleties of its motion and deformations, especially if it is exhibiting a wide range of performances.

c. Joint Placement and Number

After these decisions are made for a particular character, a rigger can begin the rigging process. This starts with creating a motion system comprised of a skeleton. A skeleton is a hierarchical, articulated structure that allows a bound model to be posed and animated. It is comparable to a real skeleton, which gives underlying structure to a body. In a 3D software package, the individual components of a skeleton are called joints. The number and placement of joints in a skeleton is dependent upon the types of deformations needed. If rigging a humanoid character, biological accuracy of joint number is not required, but is instead used as a reference for the joint placement [10]. Biological accuracy is not needed for the form to look correct. For example, only one joint is needed for the upper leg, mimicking the femur bone. However, there is not a one-to-one ratio for the amount of joints needed to mimic a spine. This is because a character can exhibit similar spinal deformations with far fewer joints due to falloff influences between the joints and bound vertices. In an organic creature, the bone can only affect the muscles that are attached to it which drives the outlying skin. On a CG character, a joint can affect anything that is assigned to it; it is not distance limited. It is the rigger's choice as to what is influenced by the joint.

The joint location within the geometry impacts its deformation [6]. A joint that is centered within its surrounding geometry will have an even impact on its deformation.

A joint that is closer to one side of a deforming limb is going to impact the geometry on the opposite side in a different manner than on the adjacent side. Regarding range of motion, a CG character does not have the same performance rotation limits that a real body has. In keyframe animation, an animator might animate a character way beyond a typical biological range of motion in order to abide with the principles of animation, such as exaggeration. This impacts deformations. The goal is for there to be enough joints to demonstrate the articulation and range of motion desired for the character. If wanting to imitate a human arm, using a single joint for the entire arm will not present the articulation desired.

d. Deformation Systems and Tools

Deformations on a character model can be created through different methods depending on the need. Each 3D software package has its own methods to perform deformations, but most of them at least include the following: joint based, deformers, dynamics and muscle systems. The origins of these methods are further discussed in the section “Overview of Deformation Methods.” Joint based deformations commonly use the Skeleton-Subspace Deformation (SSD) technique. SSD uses weighted vertex values based on skeletal joint influences to determine skin motion relative to animation. The deformation method known as deformers are “high-level tools that are used to manipulate (when modeling) or drive (when animating) the low-level components of a target geometry or model” [11]. These are also known as modifiers or space warps and consist of lattices, clusters, jiggle and many other tools that perform specific types of deformations to a model. Dynamics are another way to deform a model through soft body and rigid body simulations. Muscle systems are used to deform a model in the same manner that muscles deform real skin. Underlying muscle objects are created and set up so that when certain movements are made, the muscles

either bulge, relax or jiggle.

Even though there are many types of deformation methods, all of them have the same purpose: to manipulate a mesh or model. When this occurs, the geometry of the mesh changes. The positions of vertices are changed and therefore polygonal faces can increase or decrease in size. This causes the mesh to compress, stretch and/or shear. Depending on the desired look of the deformation, these changes can be beneficial or hindrances to the aesthetics of the model. Unwanted shearing, twisting, creasing, pinching or nonuniform stretching needs to be addressed and corrected to maintain the look of the character based upon its design and concept.

e. Bind Poses

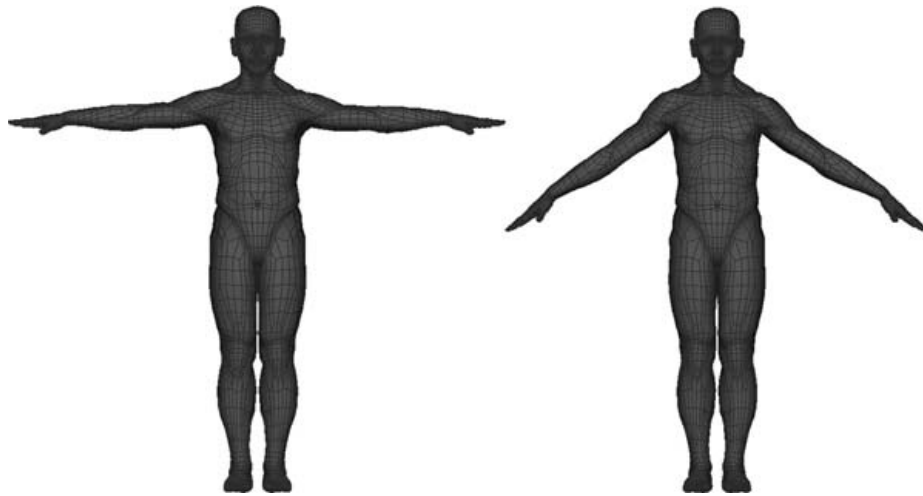


Fig. 1.: Examples of a T-Pose and A-Pose, Respectively [12].

When setting up a character to apply a deformation system, the geometry of the model and the motion system, or joints/bones, need a common state defining their spatial relationship to one another. This is commonly called the bind pose because it is the act of binding the skin of the character to the movement of its skeleton. This

pose is also known as a default, neutral or rest pose. Its purpose is to be a starting point from whence all deformations begin; it is the only pose that does not cause deformations to the model. The bind pose can be any configuration of the model, but the animation industry standards on what is called the ‘T-Pose’ and ‘A-Pose’ (See Fig. 1). When modeled in the T-Pose, a character’s arms are straight out to the sides [12], away from the body and parallel to the ground plane. The feet are close together, pointing forward, and the body resembles the shape of a T when viewed from the front. This pose is also known as the da Vinci pose, making reference to the famous Vitruvian Man drawing.

One benefit of the T-Pose is that allows joint placement for the motion system to occur along orthogonal planes of the coordinate system in the animation software [13]. This also makes it easier to create controls for the motion system that occur along axial planes. The T-Pose is also preferred for use in creating a cloth system for the character, in which the cloth can be easily tailored and draped on the character through simulations before character motion is provided by animation. When surfacing a character, the T-Pose is also preferred because it provides easy access to high deformation areas of the model such as the armpits, knees and waist.

The A-Pose differs from the T-Pose in that the arms are angled down to the side, about 45 degrees away from the body and the legs are either together or shoulder-width apart [12, 14]. Both of these poses are not well documented and are subject to the preference of the rigger or the common practices of the animation studio. For example, the palms of a character can be facing forward or facing the ground plane in the T-Pose. The A-Pose can have the arms at 45 degrees away from the body, or at some other arbitrary angle. The A-Pose can also introduce slight bends in the elbows and knees, which is contrasting to the stiff-looking positions of the T-Pose. Some riggers prefer to have the model in a ‘relaxed stance’ where the hands are slightly

cupped with fingers curved, the arms bent down and slightly away from the body, and the legs slightly bent.

The A-Pose and its variations are often preferred due to the nature of the model being in the middle of a typical range of motion. For example, the position of the arms in the T-Pose are in the middle of the arms being raised straight up from the body and down by its side. However, that is not the most common range of motion for a humanoid character. Instead, the arms are more often down, closer to the body. With the arms modeled closer to the body, they are less likely to have extreme deformations for common activities. From the T-Pose, if the arm was to be placed alongside the character's body, areas of the shoulder will need to handle deformations for up to 90 degrees of rotation from the corresponding joints. If it had instead started from the A-Pose, the shoulder would only need to handle less than 45 degrees of rotation from joint based deformations. This same idea is often carried to other deforming areas of the model, such as the elbows and knees as mentioned above.

The shoulder area is often what drives which pose is used. The shoulder is a complex connection because of its range of motion and anatomy. Deformations of the shoulder are influenced by the joints of the upper arm, clavicle, chest or spine, and scapula. Each of these joints pulls on the same area of the model and it is difficult to maintain a natural form when testing the deformation system. If modeled in the T-Pose, the shoulder is flexed and the clavicle is slightly raised. Areas of the chest are also needed to be modeled in a way that show the stretching of the pectoral muscle toward the armpit and deltoid. In general, it is easier to stretch geometry in a believable way than it is to compress/crease it. Because of this, the T-Pose makes the area of the shoulder harder to control in terms of deformations. An A-Pose positions the shoulder geometry in a more relaxed form that is easier to maintain.

Another pose that is modeled for a character in an animation pipeline is a hero

pose, or action pose [14]. This pose presents the model in a way that most describes the character. If the character is a superhero, the pose would most likely be of it standing proud, chest puffed, fists on its hips with its head and gaze looking up and away. While this pose is not directly used for setting up the character, it is used as a reference for deformations and is a 3D product of the concept art and look development for the character. A director likes to see the character in this pose in order to see how the character will look in the movie. It can also be used for marketing purposes for the film.

B. Overview of Deformation Methods

1. Surface Deformations

One of the first uses of surface deformations was in Parke’s facial animation work [15, 16]. This work used high-level parameters to deform control vertices of a facial model. The parameters were custom algorithmic implementations that linked a wide range of facial vertex positions based on a small set of input control parameters. This was used to reduce the amount of time needed in animation. An example of one of these parameters is ‘raise-upper-lip.’

2. Multi-Layered and Physically Inspired Models

Some deformation models were inspired by realistic physical models and anatomy, such as the movement of skin over muscles. Wilhelms and Van Gelder [17] used many classes of deformed cylinders to represent muscles. Volume preservation of these muscles is maintained by scaling the muscle thickness and width. The overlying skin is a spring mesh that is anchored to the underlying muscle or bone in appropriate areas.

3. Shape Interpolation

Interpolation is a widely used technique involving the determination of an intermediate value between two given values [16]. Shape interpolation takes the same idea and applies it to vertices of a mesh to define new surface mesh shapes. This is also known as shape blending, multi-target morphing, or blend shapes and is commonly used in facial animation. Two or more shapes are used, one of which being defined as the base shape and the others are target shapes. The differences between these shapes are represented as vector sets. These sets are used to move the vertices between the base and target shapes. One drawback to this method is that the movement is linear and therefore not a natural representation of skin deformation.

4. Skeleton-Subspace Deformation

As previously mentioned, skeleton-subspace deformation (SSD) relies on weighted control vertices to an underlying structure. SSD appears in commercial software packages under the names ‘skinning,’ ‘enveloping,’ etc [18]. The algorithm is unpublished, but is widely used. “The position of a control vertex ... on the deforming surface of an articulated object lies in the subspace defined by the rigid transformations of that point by some number of relevant skeletal coordinate frames” [18]. A limitation of SSD stems from the deformations being restricted to the skeleton subspace. In the case of a shoulder or elbow, the desired deformation as the joints bend is difficult to achieve purely as an adjustment of vertex weight values. This results in what is called a ‘collapsing joint’ defect or a ‘candy wrapper twist’ when the joint is rotated.

5. Pose Space Deformation

Pose space deformation tries to improve upon both shape interpolation and SSD [18]. When applied, poses are stored as offsets rather than actual geometry and are sorted in transform and joint space instead of object space. This is called ‘pose space.’ This deformation is applied on top of an underlying skinned skeleton. An advantage of this method is the direct manipulation of the desired shapes through sculpting, creating an elegant solution to the limitations of SSD.

C. Methods for Averaging Joint Movement Over a Performance

1. Motion Capture Range of Motion (ROM)

In motion capture, a range of motion (ROM) test is performed by the actor and is used to set up their digital counterpart. The actor will move and twist their body and this action is recorded by motion capture cameras. In order to create a digital skeleton to match the actor, the size and position of joints is needed. These positions are derived from the ROM data by finding the center of rotation from the movements captured. There are different methods to achieve this [19], but attention is made to account for noise in the data and small ROM [20].

2. Eigenpostures

Pattern recognition was used analyze and synthesize human gaits based on gender [21]. Principal component analysis (PCA) was applied to a collection of averaged individual walks from motion capture data to reduce the dimensionality of the space. This set, called ‘eigenpostures’ is directly related to the eigenvalues with the largest variance from PCA. A discriminant function analysis was then used to create an axis that closely captured gender-specific differences. This data could then be applied to

a new model to produce a novel animation with the desired gender level.

3. Principal Component Analysis in Facial Animation

A similar PCA approach was used to model facial models [22]. Exemplar facial sculptures were collected and PCA was applied to reduce the multi-dimensional space. A graphical user interface was used to apply the principal components to new faces to modify its facial feature, gender and expression.

CHAPTER III

METHODOLOGY

A. Use of T-Pose and A-Pose

The T-Pose and A-Pose are industry standards for character modeling and setup. However, there is little documentation regarding their benefits. There is even less information about how each pose is literally defined. Using what is known about these poses in this thesis provides a point of comparison against any new poses created as well as testing the poses themselves.

B. Identification of a Wide Range of Performances

In an animation production, a character can exhibit a wide range of performances. These performances each have their own set of motion ranges. A walk cycle has a different range of motion than a cartwheel. However, these performances are performed per shot in production. The use of a single deformation setup for a character is not necessarily a good choice for this type of production.

C. Evaluate Suitability of Model to Deformation Issues

1. Appropriate Topology

A good character model has a well thought out topology which is critical for character deformations. There must be an even distribution of polygons with areas of higher resolution around areas of extreme deformation. “The topology of the model surface should reflect the understanding of how this region articulates” [12].

2. Use of Humanoid Model

The use of a human model is commonly used in production. Using a human model is beneficial due to the familiarity of forms. Humans are cognitive beings that can easily detect when something aiming to imitate biological forms and movement is expressed incorrectly. There are also plenty of reference subjects available for comparison. Because of this, it is easier for a rigger to set up a motion system for a human model or known species versus something based in fantasy. Regarding motion capture, the human subject has been widely used. Many of the online motion capture databases focus on the collection of data from human subjects. Application of motion capture to a human model is also available as a standard in 3D software packages such as Autodesk Maya and Motion Builder.

D. Value of Using Motion Capture

Motion capture is an accurate method to collecting motion data from a subject. Motion data is recorded by multiple cameras that are sampling the movements of markers on a subject at a high frequency. This data must be processed to account for movement introduced by camera wobble and markers on the performer. The amount of processing is determined by the motion capture artist to maintain the fidelity of the performance. If it is processed too much, it can become soft and lose fidelity. If it is not processed enough, the data will be noisy and unappealing. This thesis will use motion capture as an animation input to provide deformations to the model.

E. Character Setup

The character model needs to be setup in a similar method to production animation. This includes a motion, deformation, and control system. The placement of joints

for the motion system needs to be adequate to provide realistic deformations to the model when posed.

1. Procedural Bone Placement

A procedural system is an automatic or guided process as opposed to manually placing each bone. Procedural bone placement can involve placing locators within a model and then running a script to build the skeleton and motion system, placing a joint at the position of each locator. Another method uses a dummy skeleton that can be positioned within the model and then a motion system then applied. A procedural system for creating a skeleton and control system is useful because it allows for the rig to be recreated without much time loss.

F. Establish Deformations for Each Pose

Each pose will need to have a deformation system applied to it. This can be achieved using the industry standard SSD system. In 3D software packages, this is referred to as painting skin weights or skinning. Weight values are given to the vertices of a model that express the amount of influence applied to each joint in the motion system.

Once the character model is skinned, the weight values need to be exported for later use. This allows the same weights to be applied to other models with a similar motion system.

G. Application of Motion Capture to Motion System

The motion capture data will need to be applied to the motion system of each pose being tested. The motion capture data is not necessarily taken from a performer that

is the same dimensions as the character model, so the data needs to be transformed to fit accordingly. This process is referred to as retargeting.

H. Results of Tension and Compression Across Surfaces for T- and A-Poses

The amount of stretching and compression that occurs at the vertex level over the course of the animation sequence needs to be recorded. This will be recorded for each bind pose and each animation. The data collected should be transformed into a range that is easily understandable, such as 0 to 1 where 0 is full compression, 0.5 is no change, and 1 is full stretching. Once the data is in this form, it can be viewed as a graph of Keyframes vs. Deformation Range. The data can also be applied to the model in the form of vertex colors in the grayscale range of 0 to 1, where 0 is black and 1 is white.

I. Creation of Mean Pose

1. Joint Rotation Data

For each sequence of animation, a mean pose will be calculated. This position is derived from the rotation values for each rotation axis over the course of the animation. This new mean pose can be applied to a copy of the skeleton from which it was calculated or to the same skeleton by setting each value to a keyframe outside the range of the animation sequence.

J. Re-bind Geometry to Motion System in Mean Pose

In order to test the amount of deformations that occur on this new mean pose, a model will need to be positioned in a manner that matches the pose. This can be accomplished by using an already skinned model, such as the one used for the T-

or A-Pose and rotating the joints to match the mean pose. Once this is completed, the skinned model will need to be released from the motion system and re-bound in this new position. Before re-binding the model, sculptural modifications to the model might need to be made in order to maintain the form of the human figure and reduce any artifacts that occurred. Once this is completed, the model will need to be bound to the motion system for application to the animation sequence.

K. Application and Results for the New Model

The process of retargeting motion capture data to a motion system will be applied in the same manner as the T- and A-Pose. Recording and viewing the amount of compression and stretching will occur in the same manner as well.

L. Analyze Visual and Numeric Data from T-Pose, A-Pose and Mean Pose Models

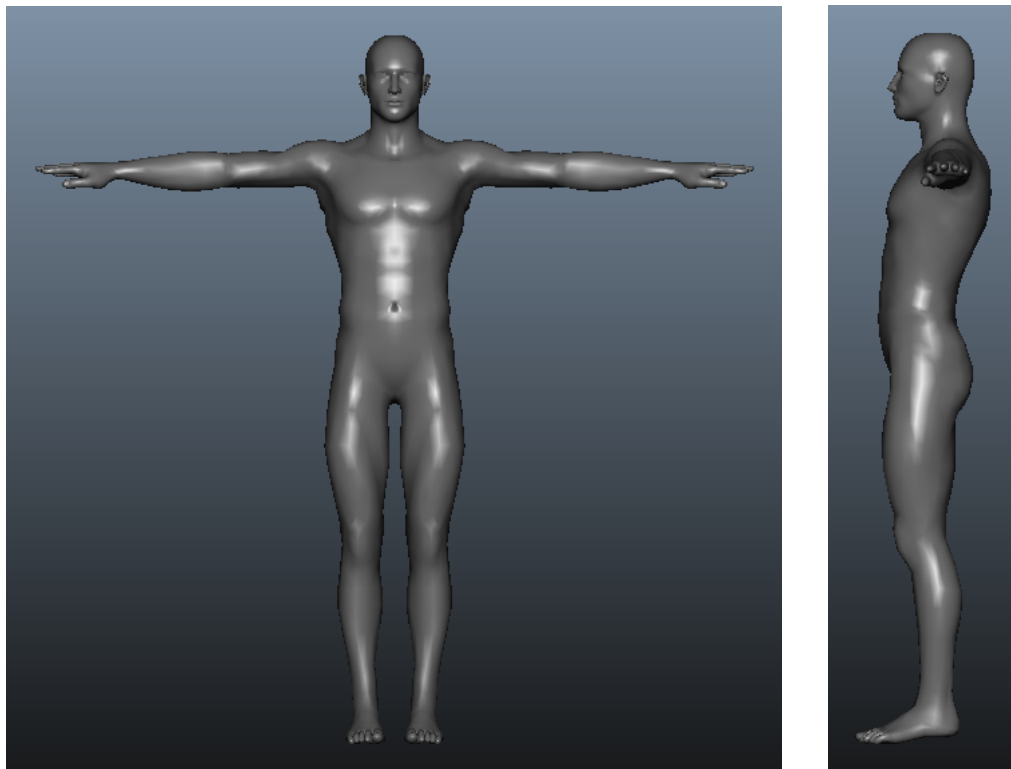
For each bind pose for each animation sequence, the amount of stretching and compression will be visible as a grayscale value applied to the vertex on the model. The data can also be compared graphically to find similarities and differences in the compression and stretching values for each vertex or range of vertices in the model.

CHAPTER IV

IMPLEMENTATION

A. T-Pose and A-Pose Configuration

Due to the lack of industry consensus on the definition of the T-Pose and A-Pose, this thesis used a combination of cited examples [12, 14]. An example of the T-Pose and A-Pose used in this thesis can be found in Figures 2 and 3, respectively.



(a) Front View

(b) Side View

Fig. 2.: T-Pose Used for this Thesis.

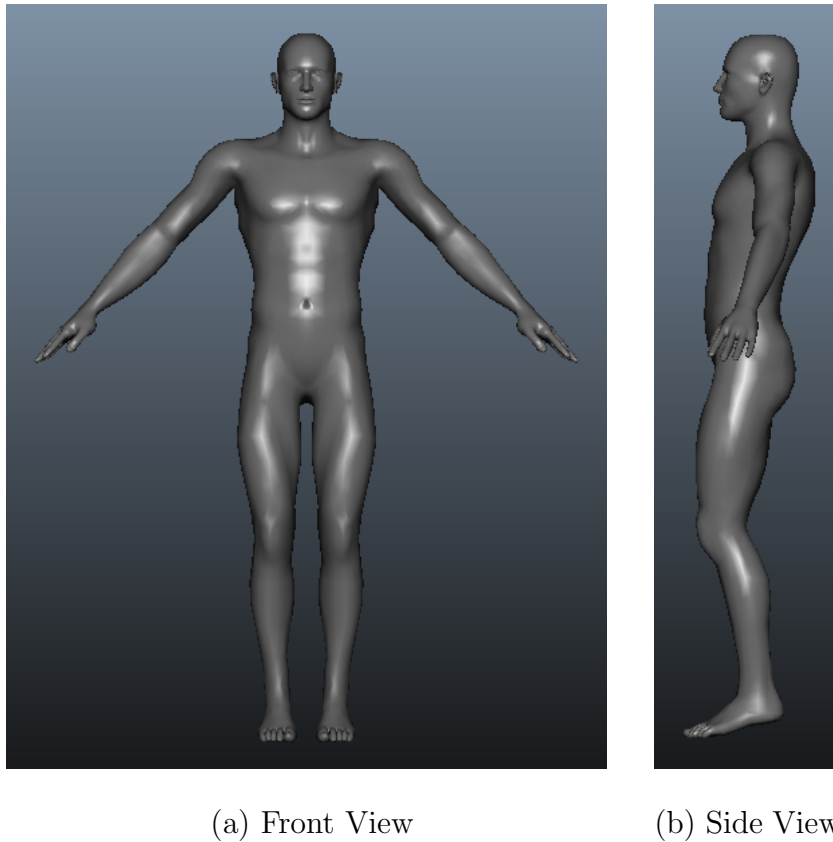


Fig. 3.: A-Pose Used for this Thesis.

B. Overview of Software and Plug-ins Used

1. Animation Software

Autodesk®Maya®2011 is a fully featured and industry standard 3D animation software. Maya includes its own scripting language, Maya Embedded Language (MEL), which gives users the ability to have access to the core functionality of the software. In recent versions of Maya, the software has integrated the Python scripting language. With that, users can have the same accessibility as MEL, but with the added benefit of the Python syntax and libraries. Version 2.6.4 of Python is included in Maya 2011 and is what is used for this thesis.

2. Plug-ins and Scripts

a. SOuP Plugin

“SOuP is a collection of nodes for Maya that are based on the principles of building a flexible, non-destructive procedural pipeline” [23]. It is a freely available plugin that is downloadable from the development website. It has a core team of developers under the direction of Peter Shipkov, a digital artist, programmer and CG hobbyist.

There are many nodes in the SOuP plugin, but the one specifically used in this implementation is the tensionMap node. It measures the amount of stretching or contraction a mesh endures from the bind pose and outputs the data as a color map. With the default setting, RGB, red represents compression, green for neutral, and blue for stretching. These color maps can be used to drive other maps if desired. The node has two modes, distance-based and in-between angle-based. Distance-based measures the distances between points (edge lengths) and angle-based measures the angles between edges. The second method is useful to represent deformations without stretching or contraction such as the bending of an elbow in which the points get closer but their associated edge lengths remain the same.

b. HumanIK

“Autodesk®HumanIK®(HIK) animation middleware is a full-body inverse kinematics (IK) solver and retargeter. HumanIK is included in Maya as a retargeting engine that lets you retarget animation between characters of differing size, proportions and skeletal hierarchy” [11].

c. Chalana

Chalana is a freeware program for Windows that converts motion capture data from AMC and ASF files into MEL scripts for importing into Maya [24]. It includes a standalone program and a Maya Shelf.

To use Chalana, the user needs to have both Maya and Chalana open. After supplying Chalana with the paths to the AMC and ASF files, the user can supply any unit conversions from the associated drop-down menu and then click the button labeled ‘Convert to MEL + MOV’ (See Fig. 4). Once the data has been converted, it can either be copied and pasted into the Script Editor in Maya and executed there, or the data can be sent to Maya for execution using the Shelf items. If choosing the latter method, the user will click ‘Convert and send to Maya’ and then move to the Maya Chalana Shelf icons. Click on the skeleton icon to generate the ASF skeleton and then click on the key icon to apply the AMC motion to the skeleton. The Maya scene will now have keyframes applied to the skeleton for the duration of the motion sequence.

d. Scripts

Scripts that were used were written in Python and MEL and executed in Maya. One MEL script was used to set up the tensionMap node and was written by Einar Magnus Næss, a poster on the SOuP development forum [23]. Two Python scripts were written by the author of this thesis, *exportVertColors.py* and *calcMeanPose.py*. *exportVertColors.py* was used to analyze and export the vertex color information from the tensionMap node and *calcMeanPose.py* was used to calculate the mean rotation angle from each axis of each joint in an animation sequence.

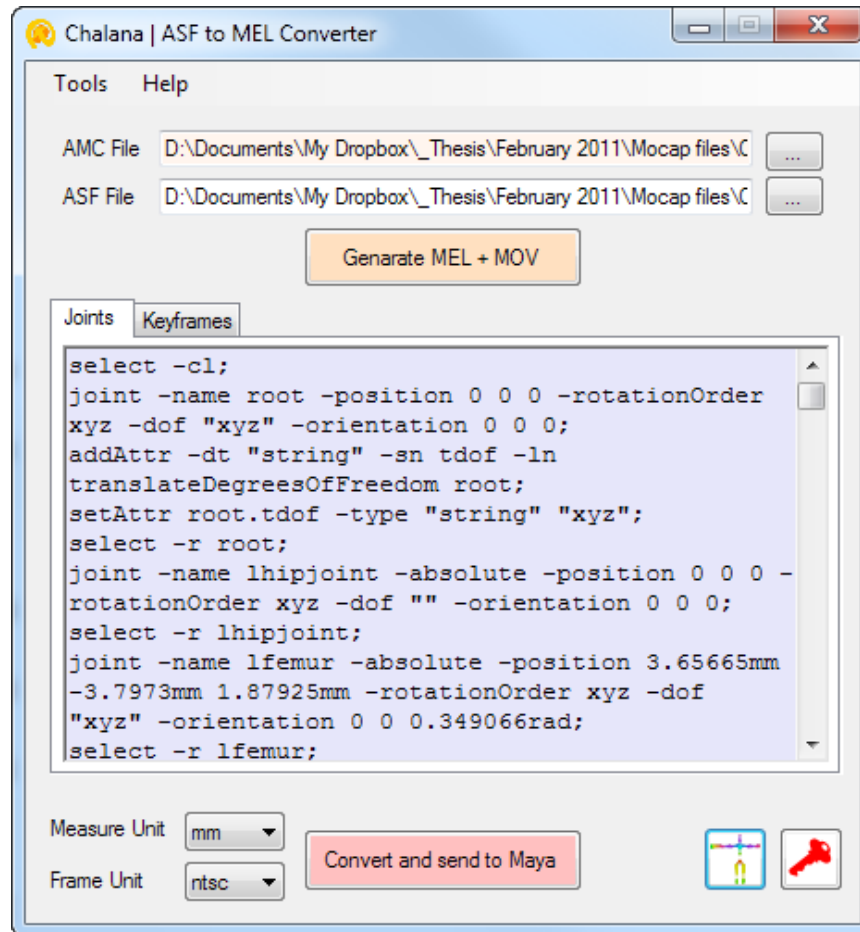


Fig. 4.: Screenshot of the Chalana Interface.

C. Selection of Motion Data

1. Source: Carnegie Mellon University Online Database

Motion data was used from motion capture database found at the Carnegie Mellon University (CMU) Graphics Lab motion capture library [25]. This library contains 2605 trials in 6 categories and 23 subcategories. These trials range from subjects walking in a straight line to navigating an obstacle course to acting like a chicken.

2. Quality of Data

The data was captured using a Vicon motion capture system consisting of 12 infrared MX-40 cameras. The database website has documentation of the marker placement used on the performer. The data from this library is available in many different formats depending on usage. Also included with each trial is a video file of the motion applied to a skeleton for comparison. All motion data is presented in as is condition with no guarantees to the quality. However, with the abundance of trials, each with its own feedback section and example videos, the quality can be easily determined from the user of the database.

3. Performance Types

As mentioned, there is a large amount of performances included in the CMU database. For this thesis, three trials will be utilized: walking, running and dancing. More specifically, walk trial 2 from subject 7, run trial 3 from subject 9, and dance trial 4 from subject 5.

D. Selection of Model

A humanoid model was used to test the various bind poses. This was due to familiarity in form, common rigging setup methods, and use in the retargeting system.

1. MakeHuman Model

MakeHumanTM is an open-source software for the modeling of 3D humanoid characters [26]. It includes a high quality mesh that is easily manipulated by the user through an intuitive Graphical User Interface (GUI) (See Fig. 5). A user can transform the mesh into a desired shape using a multitude of sliders. Examples of these sliders

include the following: gender, age, muscle tone, weight and height.



Fig. 5.: Screenshot of the MakeHuman GUI.

2. Topology Considerations

The MakeHuman model is based “on a single, highly optimized, light and professional mesh” [26]. The developers of MakeHuman have continually updated the model so that there was a maximization of both maintaining low polygon count and improving the structure for deformations.

E. Rigging Model

In order for the model to be able to deform and move, the creation of a motion system is necessary.

1. Procedural Rigging

The method used for this thesis involves using the HumanIK system in Maya 2011. It allows a user to set up and create a motion system with the use of a GUI and export/import features. Using this system also aids in the motion capture retargeting setup, another feature within the HumanIK system. The placement of the joints is dependent on the rigger's skill.

To use HumanIK procedural system for joint placement, the user will open the HumanIK dialogue from the Skeleton menu in Maya. The Skeleton Generator tab will be used to generate the skeleton. From there, the user has options to customize the skeleton by using sliders and check boxes to choose the number of joints for each part of the body. For this thesis, a minimal amount of joints was used. For example, only one joint was used to represent the whole hand instead of having joints for each finger and each finger segment. This minimal amount was chosen in order to closely match the amount of joints in the motion capture skeleton file. After choosing the number of joints, the user can then move them into place using the model as a reference.

The export/import feature of this tool allows the user to easily save their joint number and configuration for multiple uses.

F. Setting Up Deformations

After the creation of a skeleton, the model needs to be bound to it in order for deformations to occur. One standard way of doing this in Maya is to Smooth Bind the model. This is accomplished by selecting the joint hierarchy and the model and applying the bind. After this, the model will move with the skeleton, but the deformations are inadequate. To fix this, skin weights must be painted on the vertices to apply influences to adjacent joints. This process involves bending each joint and

using the Paint Skin Weights tool in Maya to change the vertex-to-joint influence in a graphical way. Another method involves using the Component Editor to change the numerical weighting for each vertex or set of vertices in the model. When the model has been weighted in a manner that demonstrates the desired deformations, these weights can be exported as luminance maps, one for each joint, through the Export Skin Weights dialogue. This allows the same skin weights to be imported for later uses.

G. Application of Motion Capture Data

1. ASF/AMC File Format

This format was developed by the video game company Acclaim [27]. After the company went bankrupt, the format entered into the public domain and is now used as an export format by Oxford Metrics (Vicon Motion Capture Systems). The motion capture data in this format is comprised by two ASCII-coded files. The ASF (Acclaim Skeleton File) file contains the skeleton description and the AMC (Acclaim Motion Capture data) file contains the motion data. This file format, along with the Chalana MEL converter provided an easy way to import motion capture data into Maya.

2. HumanIK Retargeting

The HumanIK system is used to retarget a character rig to a motion capture sequence. The process involves associating a label in the system to a corresponding joint in the character rig and motion capture skeleton. For example, selecting the head joint from the motion capture skeleton and giving it the label ‘head.’ This procedure is located in the Characterize tab of the HumanIK dialogue (See 6). Once this is completed for both skeletons, the user can apply the HumanIK retargeting procedure by selecting

‘Apply Retargeting’ from the Character Pipe tab and the character rig will then be processed to copy the movement of the motion capture sequence.

3. Re-targeting Issues

One issue in retargeting a character rig to a motion capture sequence is character dimension differences. If the character skeleton is not exactly the same as the motion capture skeleton, the applied motion will not be one-to-one. Instead, the HumanIK system matches the motion as closely as possible.

H. Determination of Mean Pose

The mean rotation angle from each axis of each joint in an animation sequence is calculated using the script *calcMeanPose.py*. It then applies each of the mean values to a copy of the skeleton from which they were calculated. This new *mean pose* skeleton is used as a reference for the analogous bind pose.

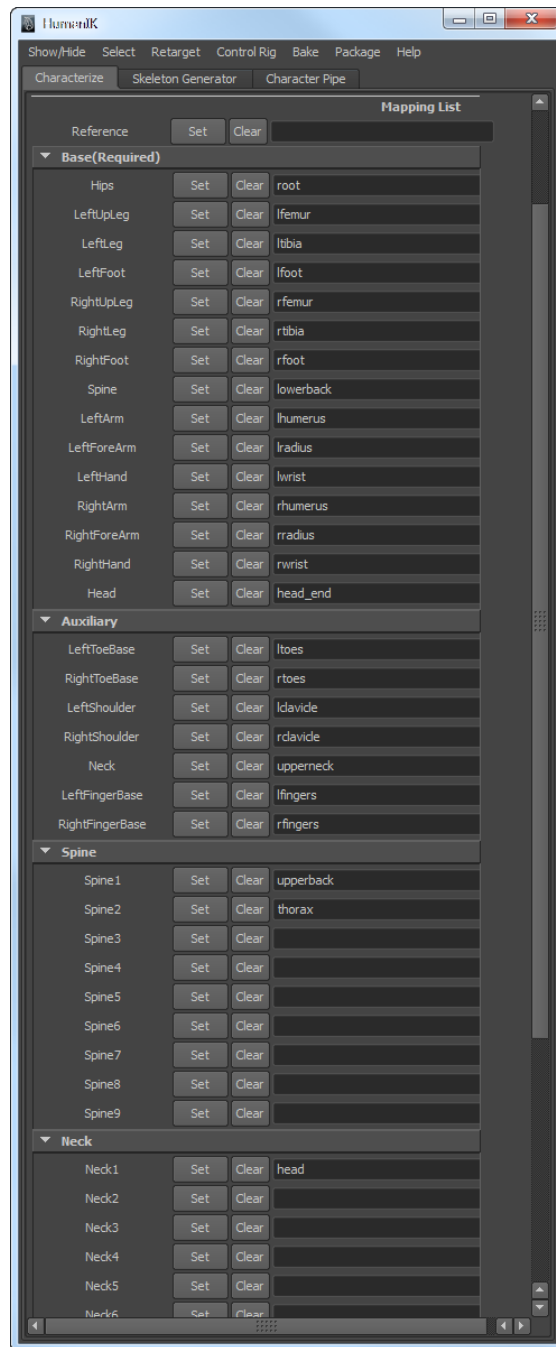


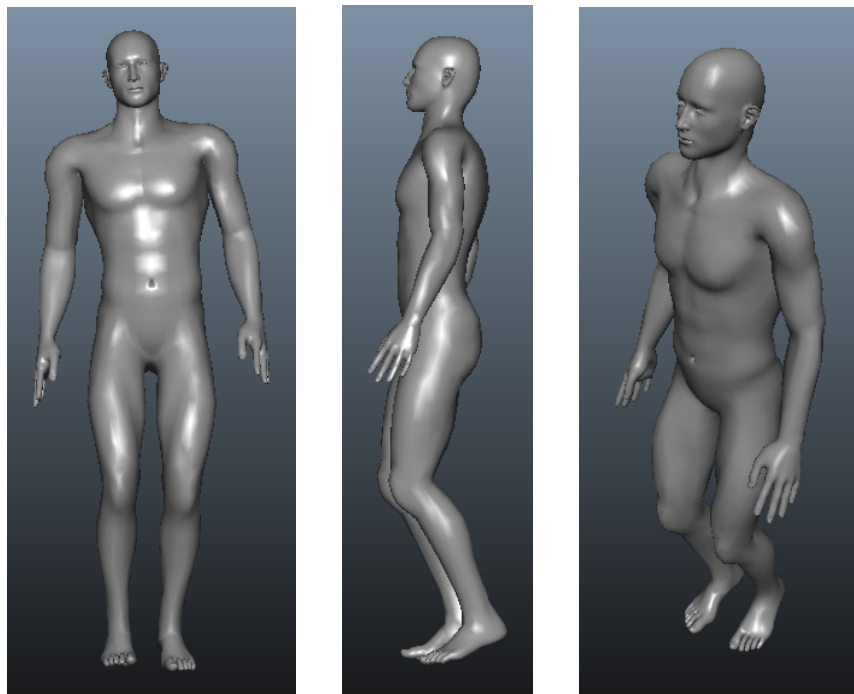
Fig. 6.: Screenshot of the Characterize Tab in the HumanIK Dialogue.

CHAPTER V

RESULTS AND CONCLUSIONS

A. Mean Pose Results

Three trials were completed, each consisting of an animation sequence and three bind poses: T-Pose, A-Pose and calculated mean pose. These mean poses were achieved by using the python script *calcMeanPose.py*. Figures 7, 8 and 9 show the calculated mean poses for each animation sequence used.



(a) Front View (b) Side View (c) Perspective View

Fig. 7.: Mean Pose for the Walking Animation Sequence.

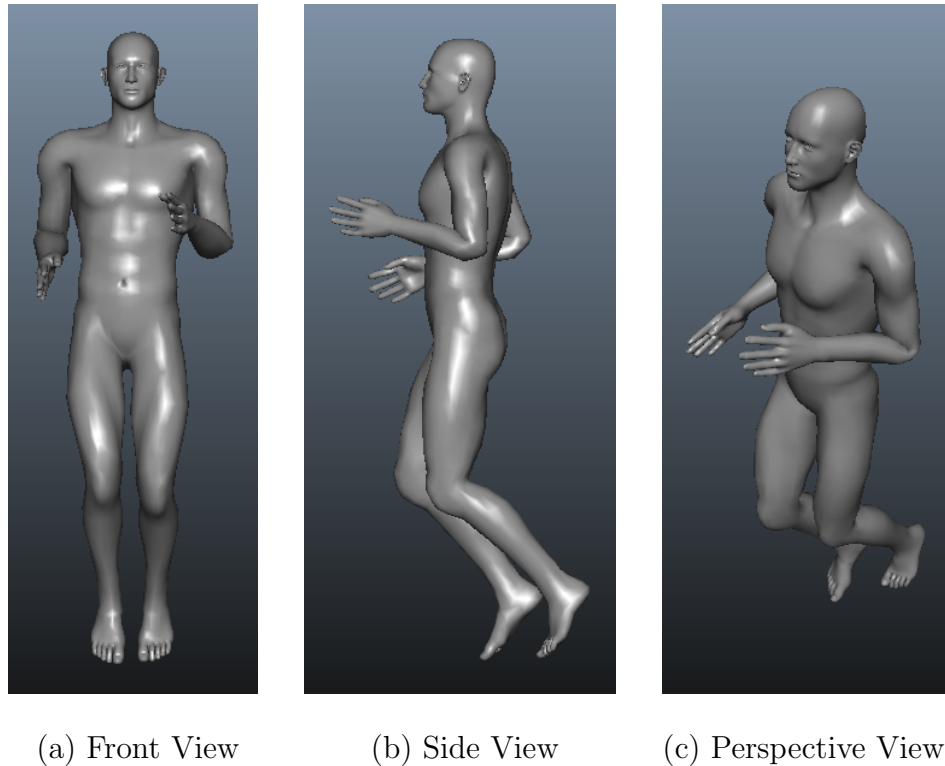


Fig. 8.: Mean Pose for the Running Animation Sequence.

B. Side-By-Side Comparison using RGB Colors

Using the RGB color representation from the tensionMap node gives a viewer an easier depiction of the amount of stretching and compression with regard to the bind pose instead of a grayscale representation. Red represents compression, green represents the bind pose and blue represents stretching. Figures 10, 11 and 12 are examples of this color scheme. This can also be viewed in the supplemental videos provided with this thesis. The goal is for there to be minimal amounts of red and blue (compression and stretching, respectively) and more green (vertices at or close to the bind pose).

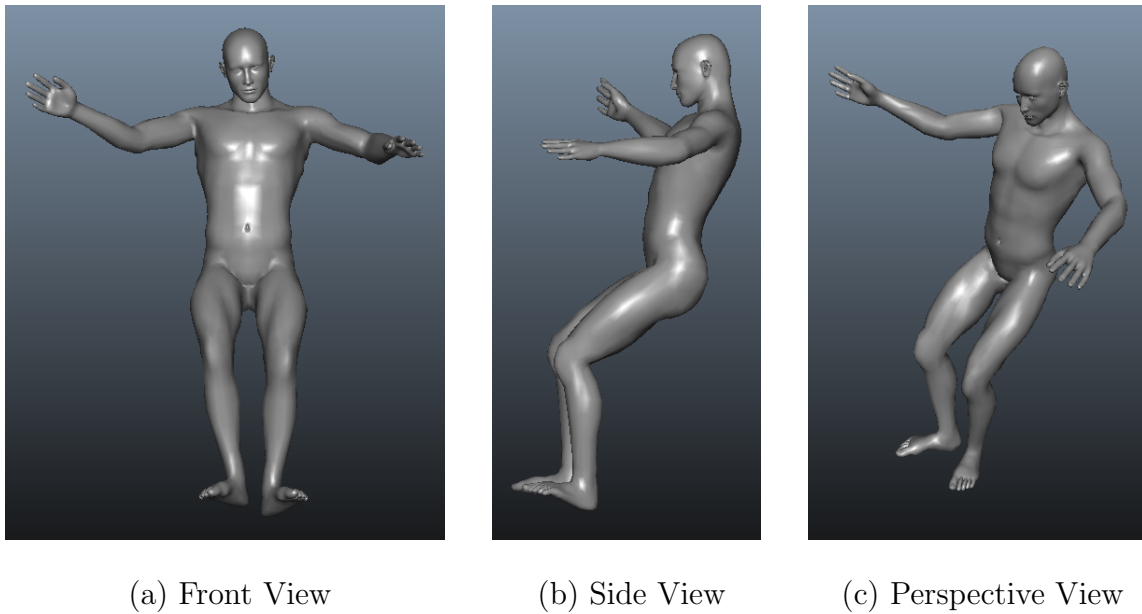


Fig. 9.: Mean Pose for the Dancing Animation Sequence.

C. Collected Data

The animation sequences used were walking, running and dancing. For each bind pose, tension values as vertex grayscale color information was output to a CSV file using *exportVertColors.py*. The resulting CSV files contained thousands to millions of values due to the values of the 9,358 vertices of the model for each of the frames in the animation sequence: 165 for walking, 64 for running, and 266 for dancing. These values ranged from 0 to 1, with 0 equalling full stretching, 0.5 for the bind pose, and 1 for full compression.

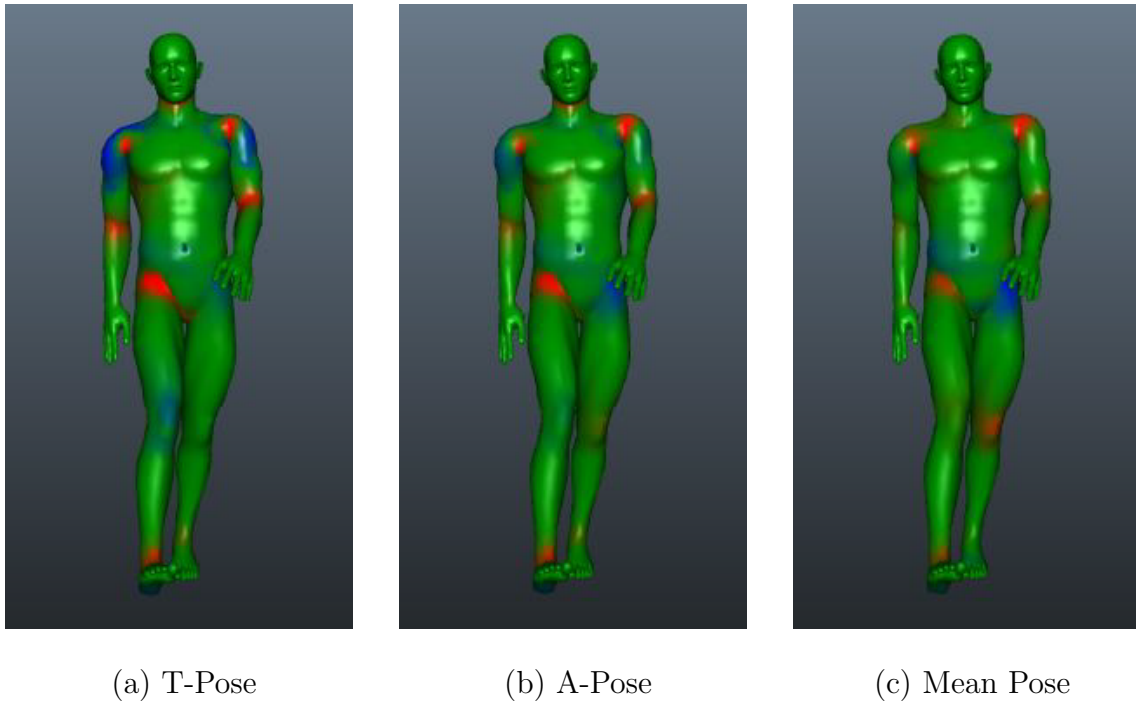


Fig. 10.: Side-By-Side Comparison of Walking Sequence Using RGB Colors.

D. Differences Between the Bind Poses

1. Distribution of Stretching and Compression Occurrences

Each of the bind poses had interesting results for each animation sequence. The values were compared as stretching and compression ranges from the bind pose, where $0.0 \leq \text{stretching} < 0.5$ and $0.5 < \text{compression} \leq 1.0$. The number of occurrences for these values was calculated for each pose and animation sequence (See Figures 13, 14, 15). As expected, the T-Pose had a higher amount of overall stretching and compressing. This was followed by the A-Pose and then the mean pose. The mean pose has more equally distributed occurrences of stretching and compression, which is ideal for minimal deformation artifacts. It is also important to note that similar results occur for all three animation sequences. The dancing sequence has a much larger and

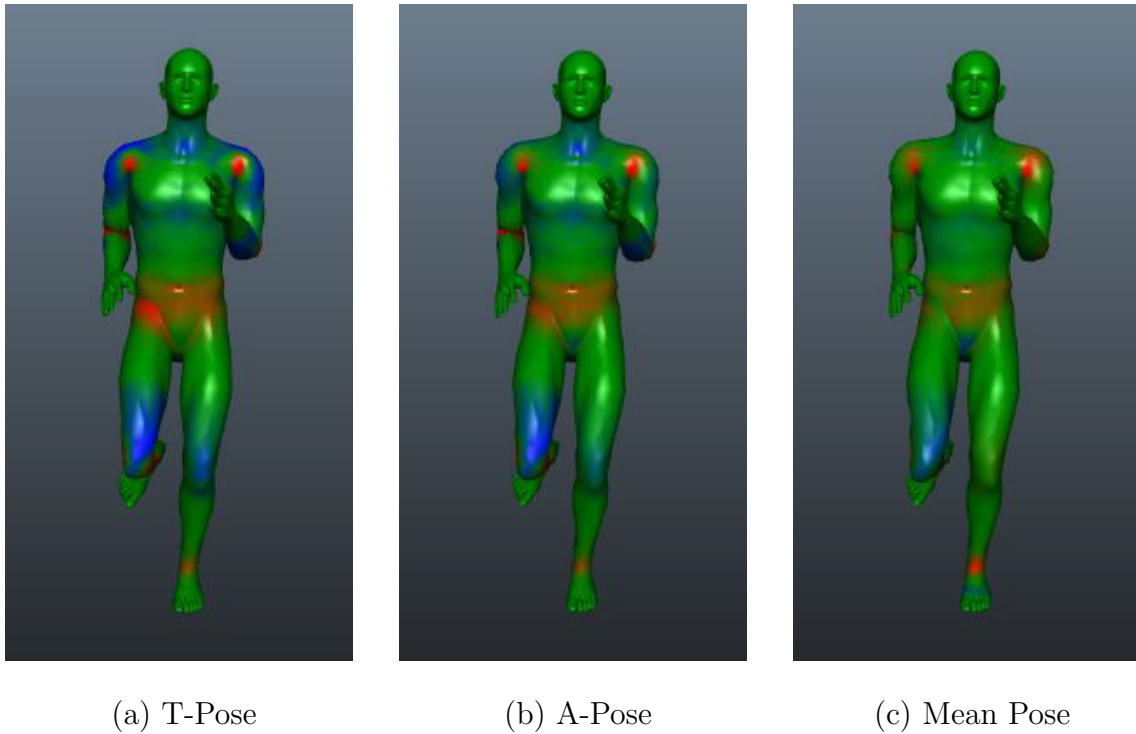


Fig. 11.: Side-By-Side Comparison of Running Sequence Using RGB Colors.

asymmetrical range of motion compared to the walking and running sequences and yet the results for dancing are similar to the others.

2. Extreme Stretching and Compression

In order to determine an amount of extreme deformation on the model, the lower half values of stretching (0.0 - 0.25) and the upper half values of compression (0.75 - 1.0) were examined. The number of occurrences for these values was calculated for each pose and animation sequence (See Figures 16, 17, 18,). The mean pose has fewer occurrences for all three cases. For walking, there was a 55.218% decrease in occurrences from T-Pose to mean pose and a 19.789% decrease from A-Pose to mean pose. For running, there was a 62.698% decrease in occurrences from T-Pose to mean

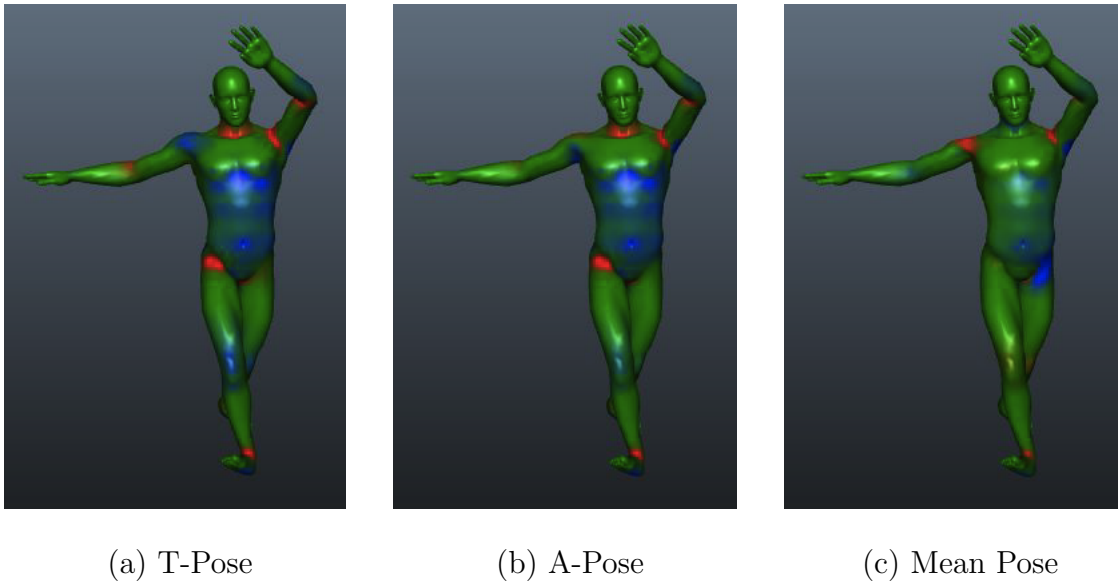


Fig. 12.: Side-By-Side Comparison of Dancing Sequence Using RGB Colors.

pose and a 49.543% decrease from A-Pose to mean pose. For dancing, there was a 32.084% decrease in occurrences from T-Pose to mean pose and a 23.680% decrease from A-Pose to mean pose. These results clearly show that the mean pose, a pose that represents the average position of the range of motion of a skeleton in a performance, provides fewer deformation artifacts.

E. Practicality of Results Used in Production Environment

The resulting bind pose comparisons are significant, but a per shot bind pose is not something that can be easily integrated into an existing production pipeline. A modified pipeline and a new set of tools will need to be developed in order to streamline the process of analyzing animation input and transforming a model into a new bind pose. One option for this animation input is from animatics and/or test animations during the Evaluation of Performance process in the Character Setup Pipeline.

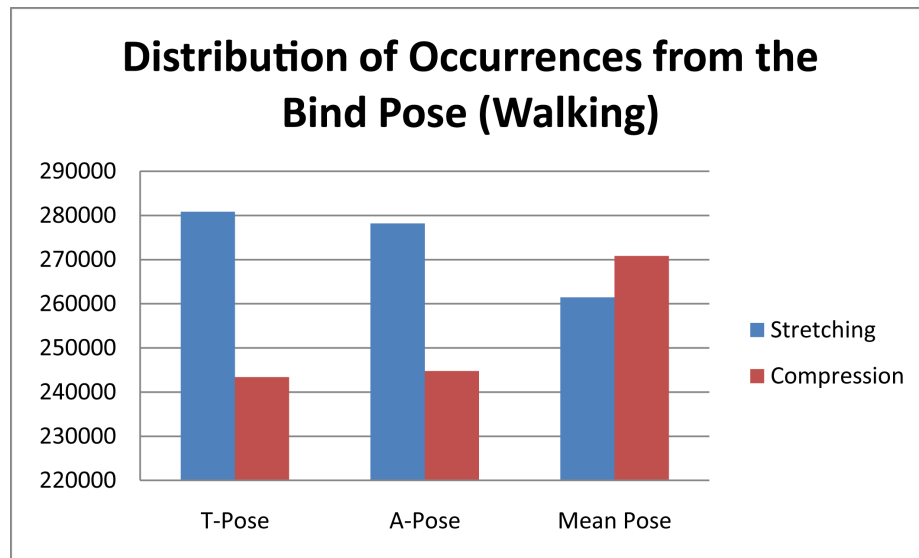


Fig. 13.: Distribution of Occurrences from the Bind Pose for the Walking Animation Sequence.

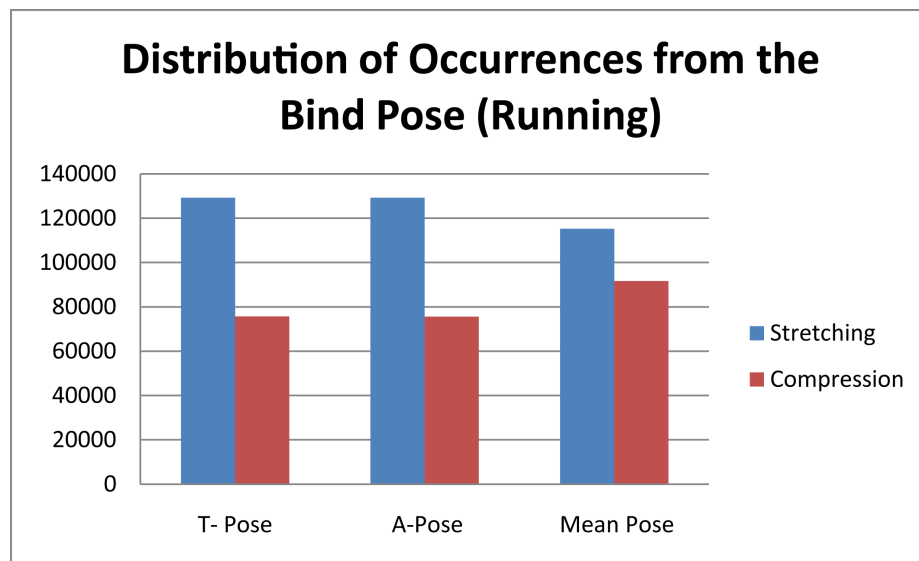


Fig. 14.: Distribution of Occurrences from the Bind Pose for the Running Animation Sequence.

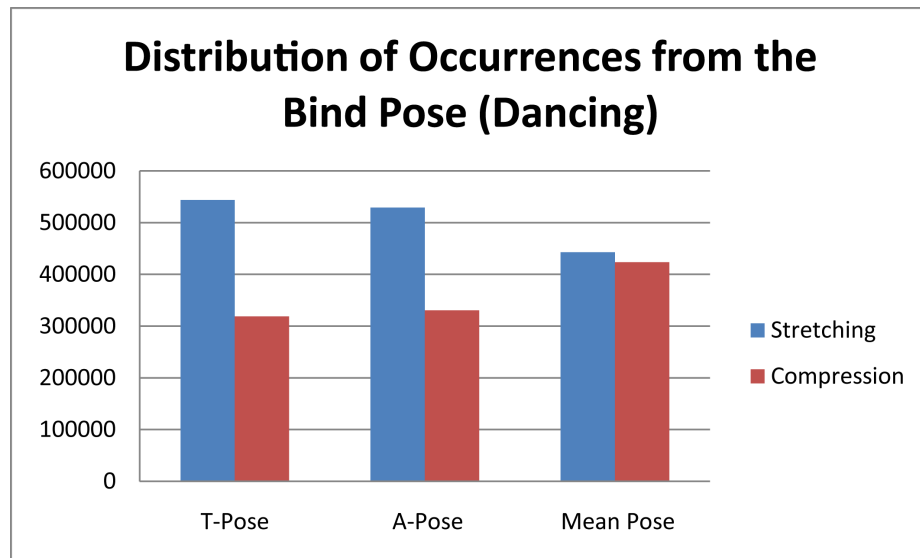


Fig. 15.: Distribution of Occurrences from the Bind Pose for the Dancing Animation Sequence.

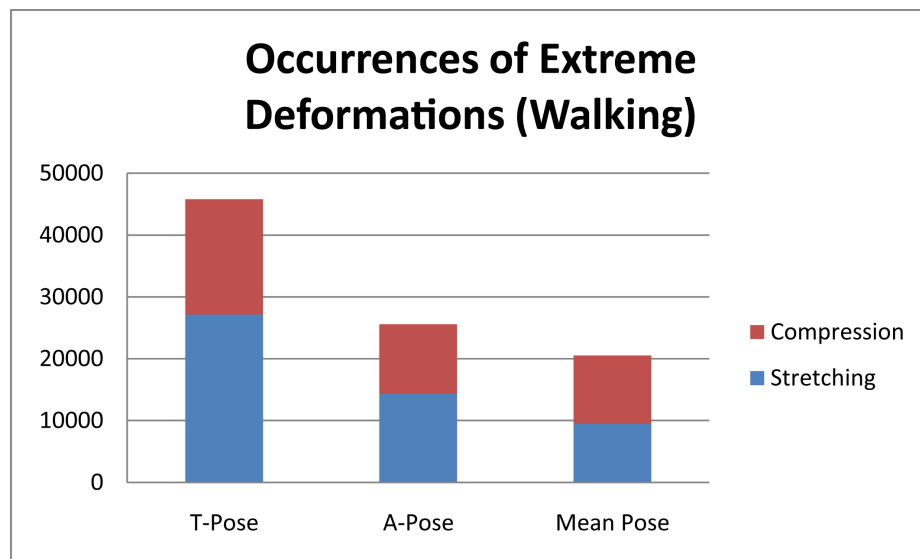


Fig. 16.: Occurrences of Extreme Deformations for the Walking Animation Sequence.

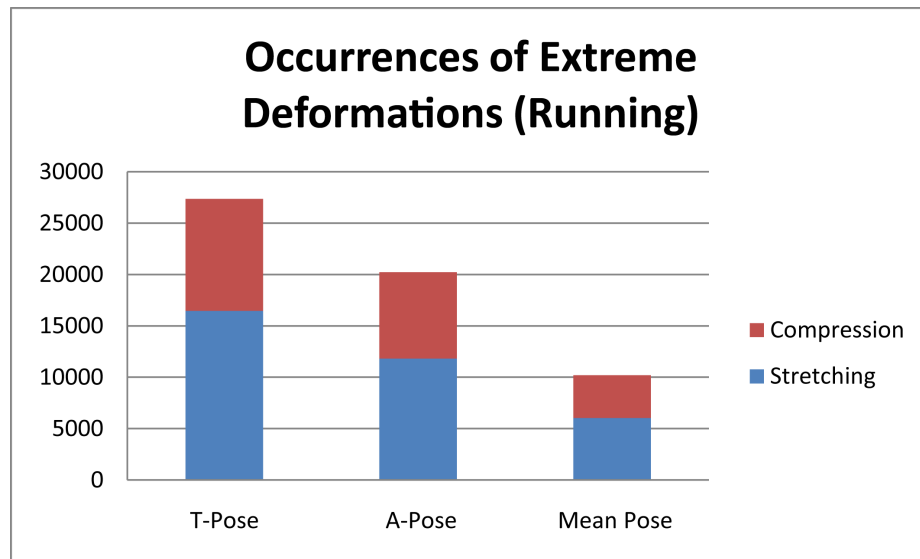


Fig. 17.: Occurrences of Extreme Deformations for the Running Animation Sequence.

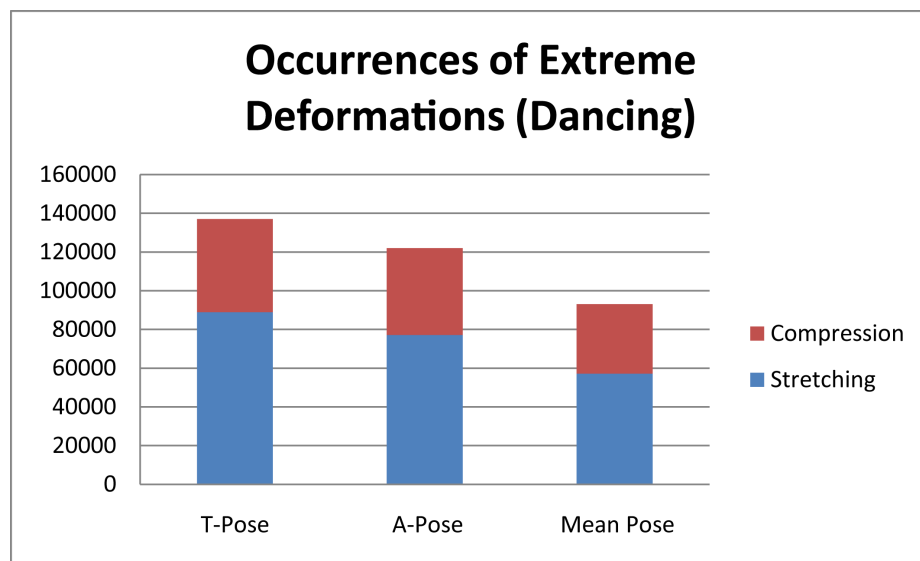


Fig. 18.: Occurrences of Extreme Deformations for the Dancing Animation Sequence.

CHAPTER VI

FUTURE WORK

Topics stemming from this research could change the way bind poses are handled in a production environment. The following topics were out of the scope of this thesis but are valuable to pursue.

A. Statistical Analysis of Motion Data

Aside from a mean calculation, other analysis can be performed on either motion capture data or on the rotation values of the joints. This can include analysis on outliers in the data and discover what types of motions directly affect the data set. Principal component analysis can be performed on a large data set in order to find the positions of the joints that most represent the highest variance. There are many different options available which could introduce a bind pose library for reference.

B. Other Human Body Types

The model used for this this was that of a muscular male. The same analysis applied to other body types will produce different results that could prove useful to a character setup artist. A large woman or a skinny boy might have special bind pose considerations based on the body type of the model.

C. Non-human Characters

An animation production may have the need for a character that is non-human, such as an animal or alien. Similar methods from this thesis can be applied to these characters as well.

REFERENCES

- [1] R. Rickitt, *Special Effects: The History and Technique*. New York: Billboard Books, 2000.
- [2] A. A. Apodaca and L. Gritz, *Advanced RenderMan: Creating CGI for Motion Pictures*. San Francisco: Morgan Kaufmann Publishers, 1999.
- [3] D. A. Price, *The Pixar Touch: The Making of a Company*. New York: Knopf, 2008.
- [4] J. Lasseter, “Principles of traditional animation applied to 3d computer animation,” in *Proc. 14th Annual Conference on Computer Graphics and Interactive Techniques*, 1987, pp. 35–44.
- [5] O. Johnson and F. Thomas, *The Illusion of Life: Disney Animation*. New York: Hyperion Books, 1995.
- [6] T. McLaughlin and S. S. Sumida, “The morphology of digital creatures,” in *ACM SIGGRAPH 2007 Courses*, 2007, pp. 2–6.
- [7] T. McLaughlin, “Taxonomy of digital creatures: Interpreting character designs as computer graphics techniques,” in *ACM SIGGRAPH 2005 Courses*, 2005, pp. 3–10.
- [8] J. W. Stevenson and M. Osborne, *Kung Fu Panda*. Paramount Pictures, 2008.
- [9] T. McLaughlin, “Taxonomy of digital creatures: Defining character development techniques based upon scope of use,” in *ACM SIGGRAPH 2006 Courses*, 2006, pp. 3–10.

- [10] N. I. Badler, C. B. Phillips, and B. L. Webber, *Simulating Humans: Computer Graphics Animation and Control*. New York: Oxford University Press, 1993.
- [11] Autodesk, “Autodesk Maya Online Help,” 2011. [Online]. Available: <http://download.autodesk.com/us/maya/2011help/index.html>
- [12] R. O’Neill, *Digital Character Development: Theory and Practice*. Burlington, MA: Morgan Kaufmann Publishers, 2008.
- [13] N. I. Badler, B. A. Barsky, and D. Zeltzer, *Making Them Move: Mechanics, Control and Animation of Articulated Figures*. San Mateo, CA: Morgan Kaufmann Publishers, 1991.
- [14] M. Ford and A. Lehman, *Inspired 3D Character Setup*. Cincinnati, OH: Premier Press, 2002.
- [15] F. I. Parke, “Parameterized models for facial animation,” *IEEE Comput. Graph. Appl.*, vol. 2, pp. 61–68, Sept. 1982.
- [16] F. I. Parke and K. Waters, *Computer Facial Animation*, 2nd ed. Wellesley, MA: AK Peters Ltd, 2008.
- [17] J. Wilhelms and A. Van Gelder, “Anatomically based modeling,” in *Proc. 24th Annual Conference on Computer Graphics and Interactive Techniques*, 1997, pp. 173–180.
- [18] J. P. Lewis, M. Cordner, and N. Fong, “Pose space deformation: A unified approach to shape interpolation and skeleton-driven deformation,” in *Proc. 27th Annual Conference on Computer Graphics and Interactive Techniques*, 2000, pp. 165–172.

- [19] H. Yasuda, S. Saito, and M. Nakajima, “Range of motion estimation from Mocap data,” in *Proc. 2005 International Conference on Cyberworlds*, 2005, pp. 483–489.
- [20] L. Y. Chang and N. S. Pollard, “Constrained least-squares optimization for robust estimation of center of rotation,” *Journal of Biomechanics*, vol. 40, no. 6, pp. 1392–1400, 2007.
- [21] N. F. Troje, “Decomposing biological motion: A framework for analysis and synthesis of human gait patterns,” *Journal of Vision*, vol. 2, no. 5, pp. 371–387, September 2002.
- [22] J. L. Riewe, “A virtual sculpture based morphable face model,” M.S. thesis, Texas A&M University, May 2007.
- [23] P. Shipkov, “SOuP,” 2011. [Online]. Available: <http://www.soup-dev.com/>
- [24] A. Jayathilaka, “Chalana - ASF to MEL Converter,” 2011. [Online]. Available: <http://code.google.com/p/chalana/>
- [25] Carnegie Mellon University, “CMU Graphics Lab Motion Capture Database,” 2011. [Online]. Available: <http://mocap.cs.cmu.edu/>
- [26] “MakeHuman,” 2011. [Online]. Available: <http://www.makehuman.org/>
- [27] M. Müller, T. Röder, M. Clausen, B. Eberhardt, B. Krüger, and A. Weber, “Documentation mocap database hdm05,” Universität Bonn, Tech. Rep. CG-2007-2, June 2007. [Online]. Available: <http://www.mpi-inf.mpg.de/resources/HDM05/>

VITA

Benito Adán Peña

Dept. of Visualization

c/o Tim McLaughlin

3137 TAMU

College Station, Texas 77843-3137

adanpena@gmail.com

Education

M.S. in Visualization, Texas A&M University, May 2011

B.E.D., Texas A&M University, Dec 2006

Interests

Character Rigging

Forensic Animation

3D Computer Graphics

The typist for this thesis was Benito Adán Peña.