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Dynamic Cloth for the Digital Character

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DYNAMIC CLOTH FOR THE DIGITAL CHARACTER

A Thesis
Presented to
the Graduate School of
Clemson University

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

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by
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Accepted by:
Timothy Davis, Committee Chair
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ABSTRACT

Cloth simulation tends to have a lingering reputation for being notoriously complex and
therefore casually avoided. Very few artists are enthusiastic about a cloth simulator's
primary use, and perhaps even fewer would consider cloth simulation for anything other
than clothing. This thesis presents typical practices of cloth simulation based on the
artistic perspective of a Cloth Technical Director (TD) who worked on the animated
feature film and applied case study, *Cloudy with a Chance of Meatballs* (2009). Through
proof of concept using a generic character, simple props, and commercial software, key
techniques are demonstrated to replicate the workflow of clothing the digital character as
performed by artists at Sony Pictures Imageworks. The result is a set of methods aided to
un-complicate the workflow of clothing the digital character.

DEDICATION

This thesis and my education at Clemson University would not have been possible had my stepfather, Russell "Russ" Goucher, not made the difficult choice to move our family from England to the US. I am beholden to him for his courageous choice and for providing me with the many opportunities I would not have had otherwise. Thank you Russ: I dedicate and celebrate this thesis with you.

ACKNOWLEDGMENTS

TABLE OF CONTENTS

Table of Contents (Continued) .... Page

LIST OF FIGURES

List of Figures (Continued)

List of Figures (Continued)

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

Undoubtedly, just as the digital character has become a mainstay of modern digital production, so too has the demand for computer-generated cloth. The clothed digital character is ever present in feature animation and is just as popular in live action film, episodic television, commercials and even music videos. Despite its demand, artists often avoid cloth simulation because of its reputation of being too complicated and tedious. Fortunately, research into cloth simulation has yielded significant improvements to this once slow and burdensome discipline of computer graphics. Each development has expanded the versatility of its use. Already, in recent and current productions, we have witnessed glimpses of alternate uses of cloth that reach beyond the typical norm of clothing the digital character.

This thesis presents typical practices of cloth simulation based on the artistic perspective of a cloth TD who worked on the animated feature film and applied case study, *Cloudy with a Chance of Meatballs* (2009). The work presented is through proof-of-concept using a generic character, simple props and commercial software. In the discussion of clothing the digital character, key techniques are demonstrated to replicate the workflow performed by artists at Sony Pictures Imageworks during shot production. Without the brawn of Sony's full-bodied pipeline and proprietary software, many of the movie's dynamic effects would be impossible to duplicate by the individual artist. Taking full advantage of Maya nCloth's sophisticated toolset, some of the more manageable effects are reproduced.

These concepts will be explored within the context of the toolset offered to the Autodesk Maya user. Maya's new nDynamics module, nCloth, is used to produce the bulk of the work presented in this thesis. Focused on the Maya user, other commercial cloth solvers are introduced such as Maya Cloth, now referred to as Classic Cloth, and the popular third party plugin, Syflex. The purpose of this work is not to produce an award-winning feature animation, but rather, to provide fundamental insight to help alleviate the intricacies of clothing the digital character based on a shared professional experience.

In the next chapter, previous work and relevant background information is discussed. Chapter Three introduces the applied case study, *Cloudy with a Chance of Meatballs* (2009), and presents an in-depth introduction to nCloth through demonstration of workflow techniques in clothing the digital character. Chapter Four documents the results of the implementation. Finally, Chapter Five concludes with reflections.

CHAPTER TWO

BACKGROUND

2.1 A Brief History of Cloth Simulation

The advent of cloth simulation, within the computer graphics community,

bloomed during the 1980s after a series of publications circulated on the subject of

implementing different methods of simulating cloth with computer graphics [Hous00].

However, the study of cloth can be traced back to the 1930s to the textile industry

[Pier37]. Although both the textile and computer graphics industries continue to pursue

the study of cloth today, they do so from different perspectives. While the textile

community adheres rigidly to the physical properties of fabric, the direction of cloth

simulation in the computer graphics community has largely revolved around the

reproduction of believable cloth while maintaining acceptable computation times.

Early applications of cloth simulation appeared in 1987. Such works resulted in

the accurate simulation of a flag blowing in the wind and the draping of rectangular cloth

[Terz87]. Further developments of the same method led to the first approach of animating

cloth on a synthetic actor, or digital character, which arrived in 1991, illustrated by the

works of Lafleur and Magnenat-Thalmann in the "*Flashback*" sequence shown in Figure

2.1 [Lafl91].

Despite several successful achievements, cloth simulation in the mid-1990s was

still too slow and cumbersome to be considered useful in the realm of producing

character animation of any length. Its practical implementation in filmmaking had no

choice but to remain patient until computer resources could catch up. Even the earliest

animated features, such as *Toy Story* (1995), *Antz* (1998), and *A Bug's Life* (1998),

casually, or perhaps strategically, avoided the clothed character, hence opting to produce

"toys and bugs" as digital actors [Hous00].

Figure 2.1 *Flashback* sequence (1991), the first approach of animated cloth on a synthetic actor.

Although the history of cloth simulation in film is relatively adolescent, it has

matured in a short period of time. In 1997 Pixar Animation Studios wowed the CG

community with the animated short film, *Geri's Game* (Figure 2.2). This award-winning

short delivered the first digital character with dynamic clothing to the big screen. More than a decade later, believable cloth simulation has been used in countless productions ranging from feature film to episodic television; many such productions are mentioned throughout the discussion of this chapter.

Figure 2.2 *Geri's Game* © 1997 Pixar Animation Studios. All Rights Reserved.

2.2 Cloth Simulation Today

Now a mainstay of modern digital production, plausible cloth is expected in commercially produced features. Its use in motion pictures has been extensive, varying from billowing ship sails and fluttering flags to highly detailed costumes. Most visual effects studios, if not all, have implemented cloth into their pipelines. With each new development, digital cloth continues to improve and its applications become more

versatile. General knowledge of a cloth solver can make today's aspiring artist a valuable asset in a demanding industry.

2.3 Role of Cloth Technical Director

In the motion picture industry, an artist who works with cloth simulation is often referred to as a Cloth Technical Director (TD). Other titles include: Technical Animator, Character Finishing TD, or Character FX TD. Despite the different titles, the tasks remain the same. For the remainder of this thesis, "Cloth TD" and "Artist" are used interchangeably. The primary role of a Cloth TD is the setup and simulation of digital cloth.

Traditionally a Cloth TD works with either digital characters or creatures, which promotes the use of other exciting applications not discussed here, such as hair, fur and feathers. Each application requires dynamic simulation and is of high demand in feature film and animation. During the production of *Cloudy with a Chance of Meatballs*, upon shot assignment, artists at Sony Pictures Imageworks were expected to simulate clothing on all characters in a given shot as well as hair dynamics if applicable. Figure 2.3 shows a typical shot with multiple characters where cloth and hair simulation were performed.

2.3.1 Cloth Setup

Initially, the task of a cloth TD is to ensure proper cloth setup of assigned characters. Artists working on a film or a project of any length can expect to use the same characters and cloth garments for several scenes [Kund05]. A proper setup is therefore

6

essential for accurate simulation and in alleviating problematic matters that may arise later in the pipeline. The process of cloth setup establishes the overall look of the character's attire. Duties include modeling or tailoring of digital costumes, although depending on the studio, these may be handled by the modeling department. Once the costume rig is complete, experimentation of several software solutions may be carried out in determining a preferred solver. Other duties include: troubleshooting technical problems, running test simulations, defining costume topologies, and establishing default attributes for garments, constraints, and collision geometries such as the character's body.

Figure 2.3 *Cloudy with a Chance of Meatballs* © 2009 Sony Pictures Imageworks

2.3.2 Shot Work

Shot work can be considered the most common and demanding duty of a cloth TD. Bound to a strict timeline, shot work implies that setup is complete, character animation is approved, and any assigned shots are simulation-ready. Here is where cloth TDs apply their artistry to make the cloth behave as needed to convey the story or action

of the shot. After performing initial simulation, observations can be made as to what attributes can be tweaked to aid the aesthetic direction of the shot. Each tweak triggers a new simulation, which is standard practice. Simulations will be run and re-run and combined if necessary via the blending of caches. Other duties include basic modeling of props for collision geometry and inevitably, deformation cleanup.

During production, Cloth TDs typically attend daily review sessions and engage in critique with leads, supervisors and fellow peers. The Artists' responsibility is then to address comments made to bring shots to completion. A great deal of effort goes into creating that extra subtle motion, or that extra wrinkle. Upon approval of a shot, artists can look forward to handing their work downstream to lighters. Ultimately, what is achieved here will be viewed by millions of people in theatres and on television sets around the world.

2.4 Real World Physics vs. Dynamic Simulation

Undoubtedly the best starting point for any CG solution is the real world. Often what is required in CG already has an existing real-world counterpart. Artists working with cloth need not look any further than their own shirtsleeve or trouser leg to observe the scope of chaos exhibited by simple pieces of fabric and therefore the sheer phenomena under consideration. For an animator to animate such chaos by hand to appear natural would be painstakingly slow if at all possible, which is why we turn to dynamic simulation.

Simulation is a broad term but can simply be defined as the imitation of something real based on the principles of physics. Although modern cloth solvers are based on real-world physics, the resulting cloth motion is not a true replication of how physical cloth behaves; moreover, it is approximation, or a sufficient simulation. For now, specifically in CG, sufficient simulation is accepted as long as it is believable; however, with the physics behind these simulations improving every year, unblemished accuracy is possible to achieve.

2.5 The Cloth Solver

Underneath the hood of any cloth simulator is its engine, or solver. Regardless of what simulation package an artist may use, upon converting a mesh into a cloth object, a solver is automatically created. The solver acts as the interpreter, which takes user-defined cloth settings and outputs them to the corresponding geometries before calculating all the attributes together to drive the simulation [Pala08].

Several models for solving cloth dynamics are described in the literature of Ng and Grimsdale [Ng96]. The method most commonly used in the development of cloth in computer graphics is the mass-spring model. This technique was first introduced by Haumann and Parent [Haum88] and was developed further by Provot [Prov95]. Once a mesh becomes cloth, the mass-spring solver generates an array of particles across the surface. These particles are typically positioned at each vertex, and are connected via several different types of springs: shear, stretch and bend springs. The particles are then subjected to forces, while the springs keep the whole system together [Ritch06]. Figure

2.4 illustrates how Syflex distributes the placement of springs on a poly mesh after conversion to cloth. Continued research into mass-spring cloth modeling has resulted in various robust commercial solutions.
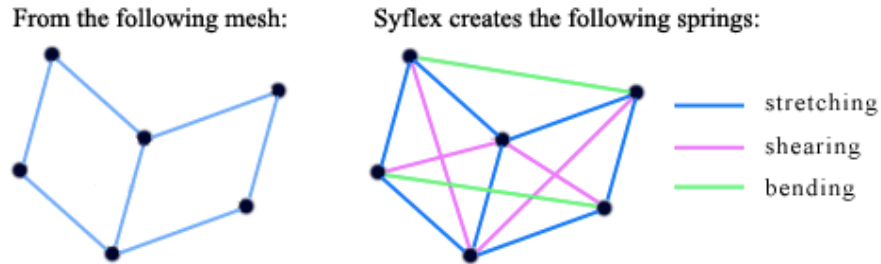
Figure 2.4 Distribution of springs on a polygonal mesh [Syfl09].

2.6 Commercial Cloth Solvers

Many of the larger studios use their own proprietary cloth solvers in conjunction with commercial solutions; others have solely relied on the latter. Many commercial cloth solvers exist today for a variety of 3D packages. Focused on the Maya user, the following are brief introductions to the traditional Maya Cloth module, the popular third party plugin Syflex, as well as an in-depth look at the relatively new Maya nCloth. Each solver has been proven at the professional level and has had a major impact on the visual effects industry.

2.6.1 Maya Classic Cloth

Figure 2.5 Scene from *Stuart Little* © 1999 Sony Pictures Imageworks.

Maya Classic Cloth gained popularity after its first major use in the feature film, *Stuart Little*, in 1999 (see Figure 2.5). Other noteworthy projects that followed include *The Matrix* (1999*)*, *The Lord of the Rings* trilogy (2001-2003) and *Shrek 2* (2004). Still commonly referred to as Maya Cloth, this aging solver is now known as Maya Classic Cloth. Despite its capabilities of creating realistic cloth animation, Classic Cloth is also a cloth modeler that offers traditional workflow techniques in creating garments for simulation. Classic Cloth uses a 2D panel-stitching technique, a method first proposed by Volino and Megnenat-Thalmann [Voli96]. If the objective is to simulate real-world tailoring, then the artist should use a technique similar to that of the real world, which Classic Cloth offers. Using NURBS curves, 2D panels are constructed based on pattern

theories practiced by that of a real-world tailor or seamstress. The panels, when stitched together, compose the individual pieces of a complete garment.

Autodesk no longer supports Classic Cloth. Although this aged solver is quietly less-used today, many studios have adopted its sewing paradigm as part of their costume setups before opting to simulate with either a proprietary or updated commercial solver, such as Syflex or nCloth.

2.6.2 Syflex

Syflex is a speedy, reliable plug-in available for most 3D software packages including Maya. Introduced in 2002, Syflex is the cloth simulator behind many of the realistic cloth animations seen in recent and present-day feature film and animation. Syflex leans away from the sewing archetype employed by Classic Cloth, and NURBS are not supported. Instead, Syflex requires artists to work strictly with polygons. With Syflex, any polygonal mesh can be converted to a cloth object and seamlessly integrated into the Maya workflow with its very own menu of diverse tools. Syflex continues to be a firm favorite amongst professionals and has frequently been used during projects within Clemson University's Digital Production Arts program, such as the stylized animated short, *Tartan Troubles* (2006), illustrated in Figure 2.6.

Figure 2.6 Scene from Clemson University's *Tartan Troubles* (2006).

2.6.3 nCloth Overview

Maya's latest addition to the commercial cloth market is Nucleus Cloth, referred to as nCloth. Added in Maya 8.5, nCloth is the first implementation of Maya Nucleus, which is Autodesk's new simulation framework. nCloth is one of two applications housed within the new nDynamics menu set; the other is Maya's second implementation of Nucleus, nParticles.

nCloth is a fast and stable dynamic cloth solution that uses a system of linked particles to simulate a wide variety of dynamic polygon surfaces, see Figure 2.7 [Auto10]. Similar to Syflex, users can convert any polygonal mesh into a cloth object. In addition, artists can employ the same traditional modeling techniques of Classic Cloth using NURBS, although conversion to polygons is required prior to simulation.

nCloth object components   nCloth particle network components

Face

Edge   Vertex   Tesselation   Cross Links   Particle   Link
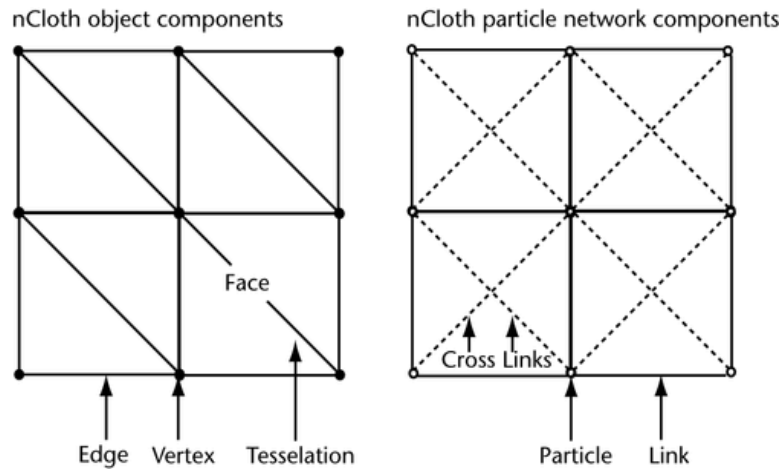
Figure 2.7 The components of a four-faced poly plane of an nCloth simulation [Auto10].

Maya's nCloth simulation environment is an excellent apparatus for discovering new capabilities for fabric and other deformable materials. Beyond fabric, nCloth is capable of, and not limited to, the following simulations: deformable solids, inflatable objects, tearing and shattering of geometries soft and rigid, as well as fluidic-type effects. Additionally, the framework includes a lift model for aerodynamics. nCloth is the preferred solver used as the basis for the work and methods presented in this thesis, and is discussed in depth in the following chapter.

2.7 *Cloudy with a Chance of Meatballs*

The applied case study used in this thesis is Columbia Pictures' and Sony Pictures Animation's *Cloudy with a Chance of Meatballs* (2009). Directed by Christopher Miller and Phil Lord, the 3D animated feature is inspired by the popular children's storybook of the same title written by Judi Barrett and illustrated by Ron Barrett [Barr78]. Sony

14

Pictures Imageworks performed all visual effects including cloth simulation, which was used extensively throughout the movie, most commonly in the simulation of both hero and background characters' clothing. Figure 2.8 shows the movies official movie poster.

Figure 2.8 Official movie poster for *Cloudy with a Chance of Meatballs*

2.8 Alternate Uses

Although this thesis focuses on the typical use of cloth simulation, dynamic cloth has become a major tool in creating believable effects that go beyond clothing the digital character. Future work beyond this thesis will explore alternate uses of cloth simulation. Figures 2.9, 2.10 and 2.11 illustrate a mixture of cloth-driven effects found in feature film, production animation, and commercials that exploit the versatility of modern cloth engines.

Figure 2.9 Kia *Car Cover* commercial produced with Syflex. Animated pin constraints controlled the CG car cover © 2004 Method Studios.

Figure 2.10 *It's Mine* Coke commercial. nCloth provided believable volume preservation to the animated balloon characters © 2008 The Mill.

Figure 2.11 Scene from *Alice In Wonderland.* Cloth simulation drove the bloodhound's floppy ears and jowls © 2010 Disney Enterprises, Inc. All Rights Reserved.

CHAPTER THREE

IMPLEMENTATION

From the perspective of a cloth TD's work experience, this chapter presents

challenges and techniques for creating dynamic cloth for an animated character similar to

techniques used at Sony Pictures Imageworks (SPI) during the production of the

animated feature film, *Cloudy with a Chance of Meatballs* (2009). Although SPI used

their very own robust proprietary cloth engine, the workflow demonstrated in this chapter

is executed with Maya's nCloth, which is one of several commercial solutions available

to artists. In conjunction with the fundamental workflow of clothing the digital character,

this chapter also serves as an introduction to nCloth's abilities to accurately simulate

fabric.

The methodology of this workflow is demonstrative of the setup and shot work

described in Chapter Two. It is assumed that all necessary assets are provided to prepare

a shot for simulation. Cloth TDs typically receive character model and animation, and

modeled clothing complete with UV layout and textures upon shot assignment.

As mentioned in Chapter Two, today's industry demands realistic cloth

simulation. By no means should this imply that dynamic clothing is a simple task.

Clothing the digital character is often dubbed as one of the most difficult effects to

achieve in 3D animation. In the past, the technicalities of cloth have often related to lack

of simulation control and slow computation times. nCloth is fast, responsive, and in many

cases predictable. However, to achieve realistic results requires ample practice, proper

settings and steadfast patience. Once these technicalities are mastered, cloth can be manipulated correctly and expeditiously.

3.1 Generic Character Introduction

The generic digital character used to demonstrate nCloth's character workflow is an Alien, and referred to as either "Alien" or "character" for the remainder of this chapter. Flint Lockwood, the hero character in *Cloudy with a Chance of Meatballs*, and the Alien (pictured in Figures 3.1 and 3.3) share similarities in their physique and clothing. For this reason, the Alien is an ideal candidate for conceptually demonstrating key techniques used in the profession of cloth simulation. Although Flint Lockwood is singled out, all characters from the movie were simulated with the same basic principles.

Figure 3.1 (Left) Flint Lockwood, hero character from *Cloudy with a Chance of Meatballs* © 2009 Sony Pictures Animation. (Right) Generic Alien character used for workflow demonstration.

3.2 Animation and Asset Review

Before beginning any simulation work, it is important to review the action of a shot. The primary action of the Alien is a walk cycle, as seen in Figure 3.2. This pre-animated Alien will be the subject of dynamic cloth. At this point, the Alien is no more than an organic geometric shape with its animation coming in the form of a geometry cache.

The geometry cache starts animation at frame -50. At this point the Alien is in dress pose, commonly referred to as the t-pose. Then from frame -50 to 0, the Alien slowly eases into animation pose and the character begins to walk for 300 frames. These 50 frames serve as buffer frames that will allow dynamic cloth to settle. Working with geometry caches is a good practice to adopt because it saves time by eliminating files from becoming bogged down with memory-eating rigs and other deformations. Saving time and making use of resources is an important objective to a workflow of any kind.
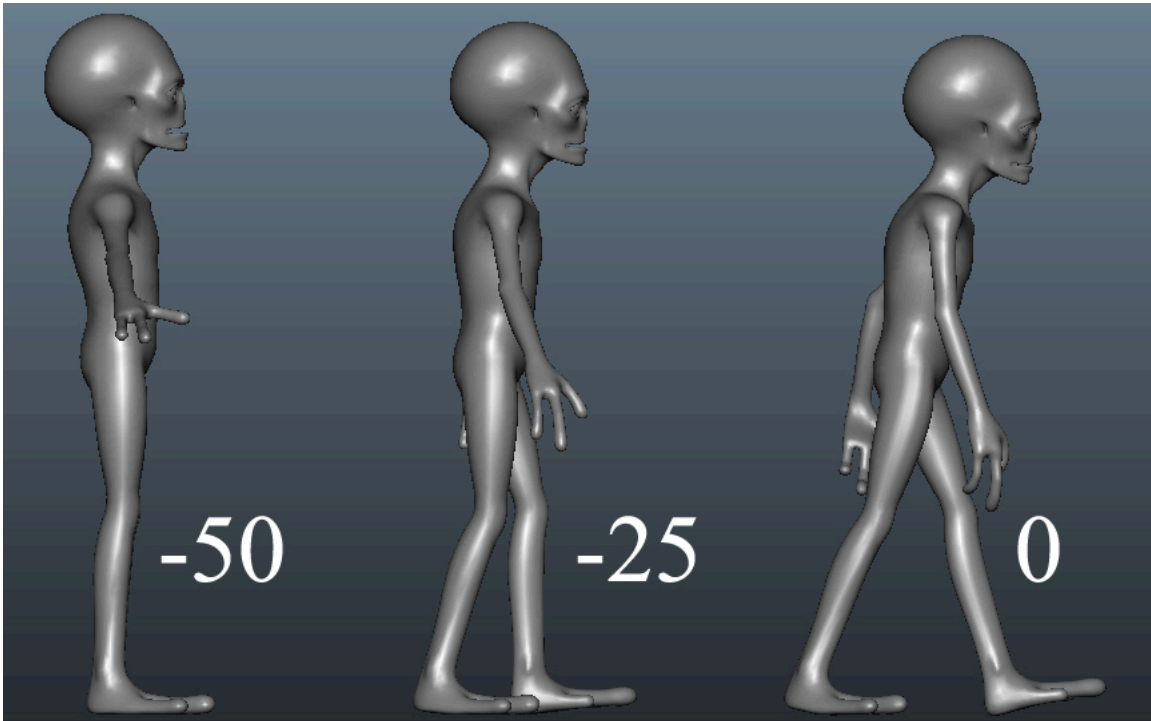
Figure 3.2 Buffer frames from t-pose (frame -50) to animation pose (frame 0).

3.2.1 Costumes

Below are two versions of the character's costume, seen in Figure 3.3. Initially we are only interested in working with the simulation mesh, which is the single-sided and lower resolution version of the garments. Eventually the single-sided geometry will define the more detailed, double-sided geometry, which is known as the "beauty" cloth, or "mesh." The beauty cloth is the final output mesh used for rendering.
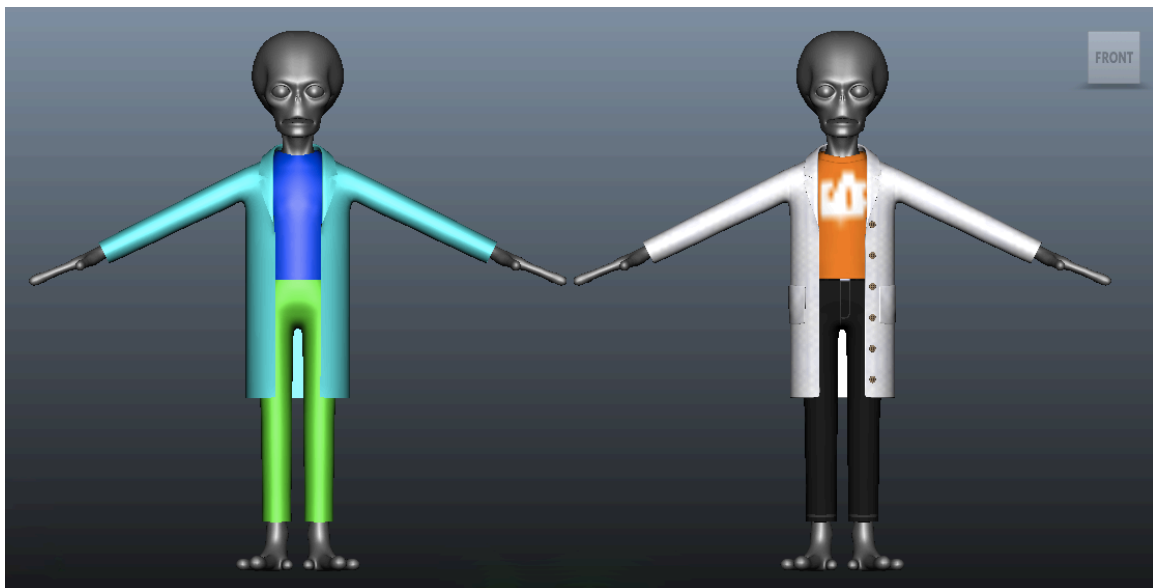
Figure 3.3 Simulation and beauty costumes.

3.3 Dynamic Clothing with nCloth

To begin, an introduction to some essential nCloth properties is required. Throughout the course of this implementation, additional features of nCloth are introduced and explained to help explain the process of dynamic clothing. The scope of attributes that can control the behavior of dynamic cloth within Maya's Nucleus

framework is extensive. For the purpose of this implementation, only pertinent attributes are discussed. Also, at various stages of this implementation, professional relevance is discussed.

3.3.1 Nucleus Solver Properties

Upon creating an nCloth or nRigid object, a Nucleus solver node is also created. The Nucleus solver properties should be adjusted, prior to simulation, to suit the need of the scene. The Maya Nucleus solver properties control internal forces that affect all of the nodes that are members of a particular solver system [Maya10].

One of the most important Nucleus solver attributes is Space Scale. Scale is a simple concept often overlooked, but one that is crucial to simulation. In a production environment, the geometry that is used in nCloth simulation is modeled as life-size; therefore, Space Scale needs to be adjusted to compensate for the difference in scale. For instance, the Alien model uses feet as its unit of measurement. In Maya, the Alien's lab coat is approximately three units tall. The Nucleus reads this as 3 meters or 9.8 feet long, which is inaccurate in the real world. Rather than spend countless time overcompensating with alternate attributes, a simple unit conversion will provide a more responsive solve. One foot converted to meters equals .304, which will represent the Space Scale of simulation work performed in this implementation.

As previously noted, the animation of the Alien begins at frame -50. By default, the Nucleus solver starts simulations at frame 1. In order to begin simulation on the Alien, the Start Frame was adjusted accordingly to frame -50.

3.3.2 Collision Properties

Collisions play a significant role in the behavior of cloth. The Collision Property attributes directly control how collision and self-collision detection is handled. Ultimately, the animation of the Alien drives the cloth simulation. The polygonal mesh of the Alien's body serves as the only passive collider (nRigid) object. All three nCloth objects (pants, t-shirt, lab coat) need to collide with the body for accurate motion. nCloth provides excellent visual feedback for adjusting collision and self-collision thickness, as well as the collision flag. By activating the Solver Display, an nRigid or nCloth thickness and its collision flag are represented by a non-renderable (default yellow) surface that is simply used as a visual aid for controlling Thickness.

Users can control the speed of nCloth collisions with the Collision Flag at the expense of collision accuracy. By default, the Collision Flag is set to Face, which provides the finest and highest accuracy of collisions, but at a slower computation time than that of the Edge and Vertex flags, which are illustrated by the character in Figure 3.4. Other key attributes associated with collision behavior are Bounce, Friction and Stickiness, all of which are keyable and paintable.
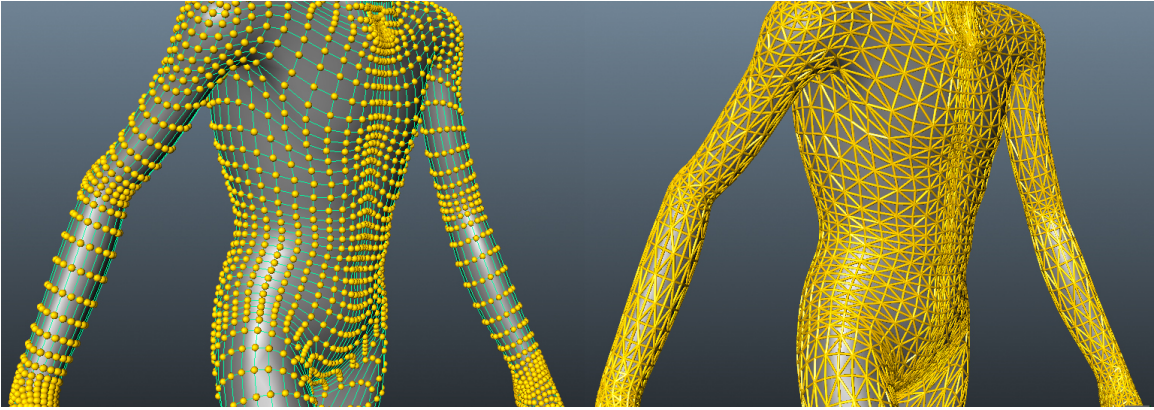
Figure 3.4 Solver Display representing collision thickness and vertex/edge types.

3.3.3 Dynamic Properties

Of the many attributes used to control cloth, artists can expect to spend ample time fine-tuning the Dynamic Property attributes. The options here control how the cloth object will react to stresses, as well as the behavior of nCloth when interacting with other objects as the simulation runs. Figure 3.5 shows the Dynamic Property attributes associated with the nCloth Shape node.
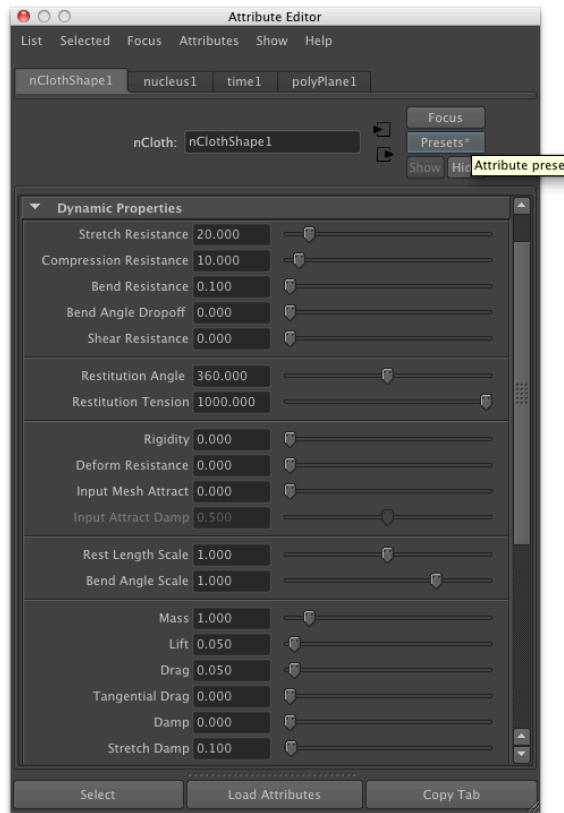
Figure 3.5 Dynamic Properties of the nCloth node.

3.3.4 Caching

By using nCloth caches, cloth simulation only needs to be done once. The caches allow the user to store simulation at each frame to disk, making playback go much more quickly, and allow the artist to access the Timeline at any point without simulating up to that frame. Additionally, portions of nCloth caching allow simulation to be saved as geometry cache clips. If any changes are made to the cloth or solver properties, the cloth will need to be re-simulated and re-cached to produce the correct results.

3.3.5 Paintable Attributes

The following collision and dynamic properties can be painted directly on nCloth using the Paint Properties Tools in the nMesh menu: Thickness, Bounce, Friction, Stickiness, Mass, Stretch, Bend, Wrinkle, Rigidity, Deformability, and Input Attract. There are two ways to achieve this: vertex property maps and texture property maps. When the artist paints vertex maps, the nCloth property values painted are stored per vertex on the nCloth and do not require clean UVs. When the artist paints texture maps, the nCloth property values painted are stored to a texture file, however, nCloth objects need to have clean mapped UVs in order for painted texture properties to have a predictable effect. Painting nCloth property values with the brush tools allows the artist to manipulate the nCloth more artistically, by either creating effects across the entire nCloth area or in isolated areas.

3.3.6 nContraints

Constraints are an integral part of cloth simulation that offer stability, effect and solutions. Without constraints, simulated cloth would be reduced to a weighted geometry [Pala08]. nCloth has several constraints that allow artists to add stability to a simulation without forfeiting deformability. All the constraints have the same attributes, but each has a specific purpose. The Constraint Method and Connection Method located within the Dynamic Constraint attribute editor can control the behavior of an nConstraint.

3.3.7 nCloth Presets

nCloth is complete with a large library of presets. The clothing presets target typical cloth materials such as silk, denim and cotton and provide initial attribute values used to define their distinctive properties and characteristics. Table 3.1 displays the clothing material presets. As with most presets within any Maya module, they exist only as a starting point; users are encouraged to test them all. Converting a simple poly-plane into cloth and letting it drop (collide) onto a poly-sphere or cube should provide enough feedback in deciding upon a preset with which to start.

The more extensively one works with nCloth, the more its attributes become familiar. Artists are encouraged to save their presets once establishing default settings for any particular scenario. Establishing and utilizing presets is not only time-effective, but also a good practice when working at a constant scale or with a consistent fabric type.

nCloth Attribute	Clothing Materials							
	Silk	Chiffon	t-Shirt Cotton	Loose Thick-knit	Heavy Denim	Burlap	Thick Leather	Chain-mail
Friction	0.05	0.9	0.3	1.0	0.8	2.0	0.6	0.3
Stretch Resistance	60.0	40.0	35.0	30.0	50.0	40.0	50.0	50.0
Compression Resistance	10.0	20.0	10.0	5.0	20.0	40.0	50.0	2.0
Bend Resistance	0.05	0.2	0.1	0.5	0.4	3.0	10.0	0.01
Bend Angle Dropoff	0.3	0.6	0.4	0.603	0.603	0.603	0.727	0.818
Mass	0.05	0.15	0.6	0.8	2.0	1.5	3.0	10.0
Tangential Drag	0.05	0.40	0.10	0.40	0.10	0.40	0.20	0.20
Damp	0.20	2.0	0.80	1.0	0.80	4.0	8.0	0.05
Scaling Relation	Object	Object	Object	Object	Object	Object	Object	Object
Max Iterations	1000	1000	1000	1000	1000	1000	1000	1000
Push Out Radius	0.108	0.108	10.0	0.108	0.108	10.0	10.0	10.0

Table 3.1 Maya nCloth Clothing Material presets [Maya10].

3.4 Order of Simulation

When working with a character's multiple garments, the artist must first access the order of simulation, which then defines the collision hierarchy. Although nCloth has the ability to solve multiple garments in one pass by assigning collision layers, for the purpose of this project, we individually approach each garment to ensure better control. The Alien has 3 items of clothing: pants, t-shirt and lab coat.

3.4.1 Pants Workflow

As with all physical simulations in Maya, before any simulation work can begin, animation playback speed should be set to Play Every Frame. We simulate the character's pants first because we need to work from the innermost layer of cloth to the outermost layer of the lab coat. With the character in t-pose, the single-sided pants should be appropriately positioned around the character without contacting the character's body. Upon turning the pants into an nCloth object, they are automatically connected to the existing Nucleus, which was created from converting the Alien's body to an nRigid. Again, this Nucleus acts as the unified solver for the rest of the character's clothing.

Once the Alien and pants are part of the same system they will collide with one another by default. Figure 3.6 demonstrates the collision behavior between the two, as well as the effect of gravity, which is given by the Nucleus. To prevent the pants from falling straight off and to complete the basic setup, they need to be constrained to the character's body. Figure 3.7 illustrates the top three rows of vertices on the pants that are constrained to the Alien's body via a Point to Surface constraint. A Point to Surface

29

constraint pins selected vertices to a target surface. In essence a virtual belt is created for the Alien. Alternatively, if the character's rig were accessible, a Transform constraint could be used instead, which in turn creates a locator that can then be parented to the root joint of the skeleton.
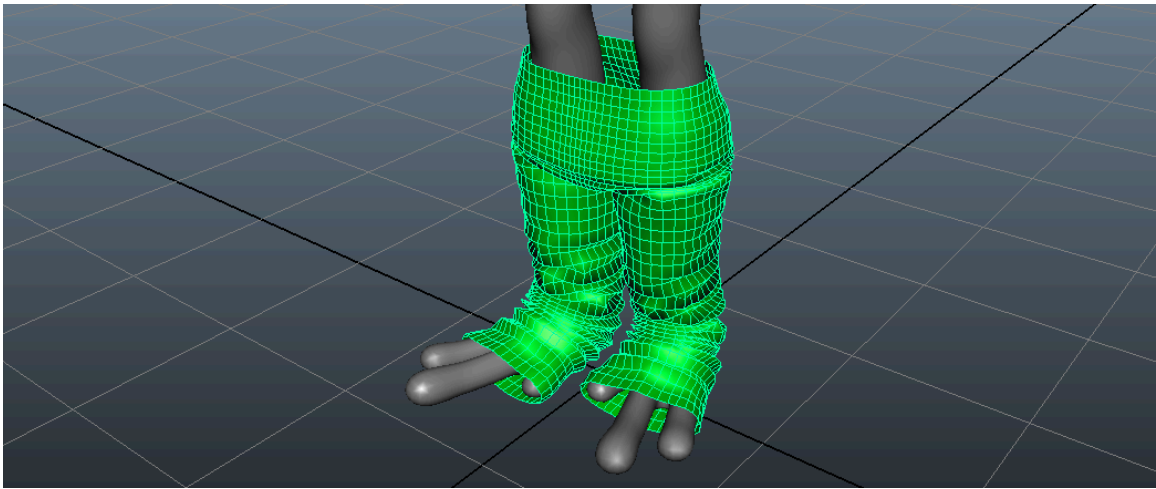
Figure 3.6 The effect of gravity without constraints.
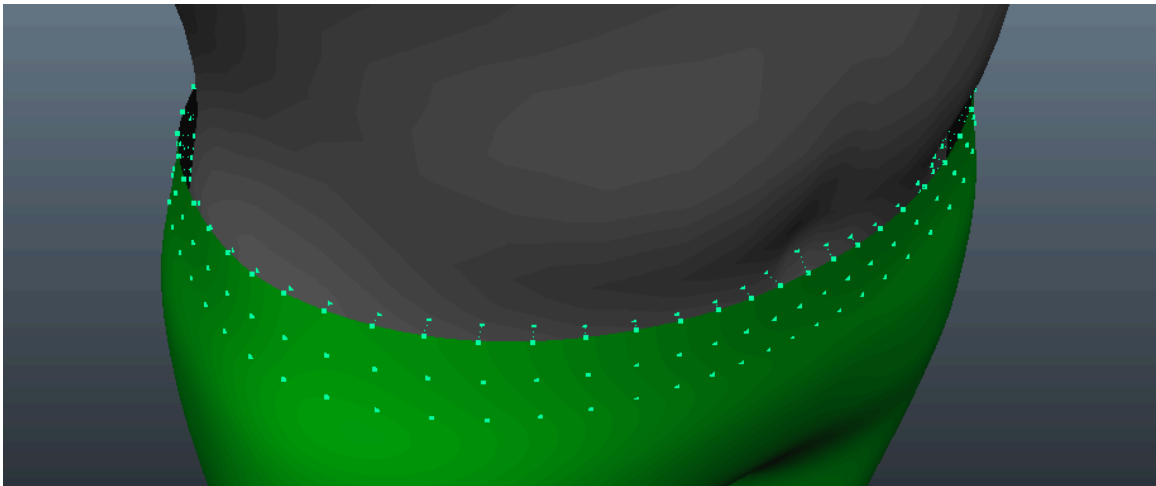
Figure 3.7 A virtual belt, Point to Surface constraint, pins the pants to the body.

Rather than use the default cloth settings, the denim preset is applied as a starting point. To reach the desired motion from the initial simulation of any object is extremely rare. Artists spend most of their time tweaking the dynamic property options of the garment to control the nature of the cloth, in addition to establishing the look and feel of a specific fabric type.

The pants must simulate properly with no artifacts in order for the t-shirt and lab coat to collide successfully. Once desired motion has been achieved and cached, a playblast is required to view the dynamic motion in real-time. Figure 3.8 illustrates the results of the preferred simulation, which are quite acceptable even with very limited control. The limited experimentation time lends testimony to establishing good solver properties.
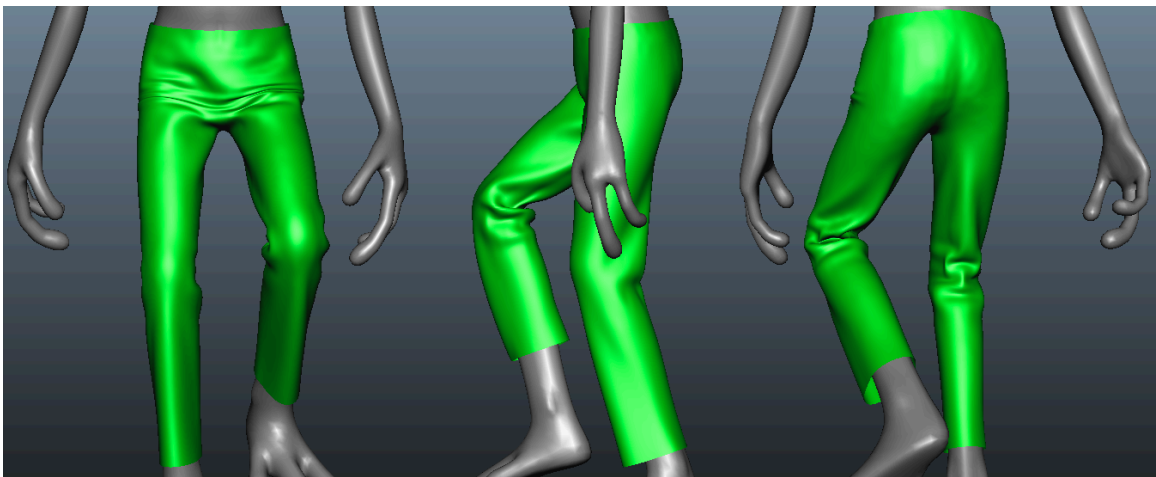
Figure 3.8 Front, Side and Perspective views of the simulated pants.

3.4.2 T-shirt Workflow

After successful simulation of the pants, the next layer of simulation can begin on the t-shirt. For the t-shirt, the timeline was adjusted from -50 to -60; likewise, the Time Frame attribute of the Nucleus was adjusted accordingly. The timeline adjustment was done to provide 10 frames for the t-shirt to settle, or drape, while the character is motionless. Although the pants collide well with the default collision settings of the Alien's body, adjustments are required to the collision thicknesses for the t-shirt (Figure 3.9). The t-shirt is relatively thin and needs to cling to the body firmly since it is essentially "sandwiched" between the characters body and lab coat. For a faster solve, the collision flag of the character's body was changed from Face to Edge.

Just as the pants' initial cloth attributes were derived from the denim preset, for the t-shirt, the "t-shirt" preset is chosen which is based on the characteristics of cotton.
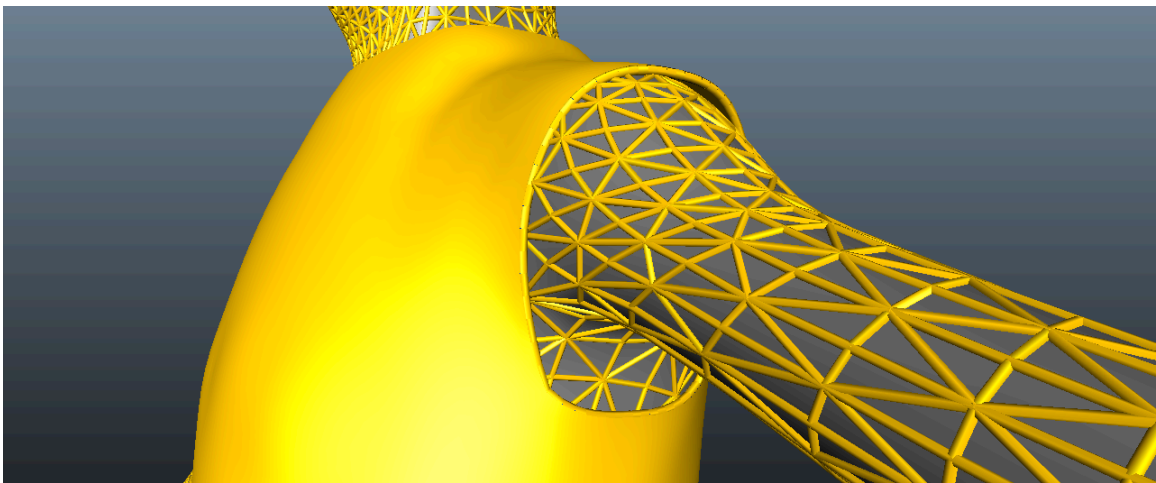
Figure 3.9 Solver Display of t-shirt (face flag) and body (edge flag) collision thickness.

The t-shirt is very tightly modeled around the character, which may not provide a great deal of detail. For a simulation mesh, however, its resolution is relatively dense, which typically encourages detail. Any secondary motion coupled with a wrinkle or two will provide personality to the simulation. Figure 3.10 shows immediate adjustments are necessary to the initial "t-shirt" preset.

In a case such as the t-shirt, many artists would question the worth of simulation as opposed to a geometric bind. For example, Flint Lockwood's t-shirt was only simulated for close-up shots, and shots where he appeared without his lab coat. The time and effort of a cloth simulation may not produce any additional detail than that of non-simulation methods.
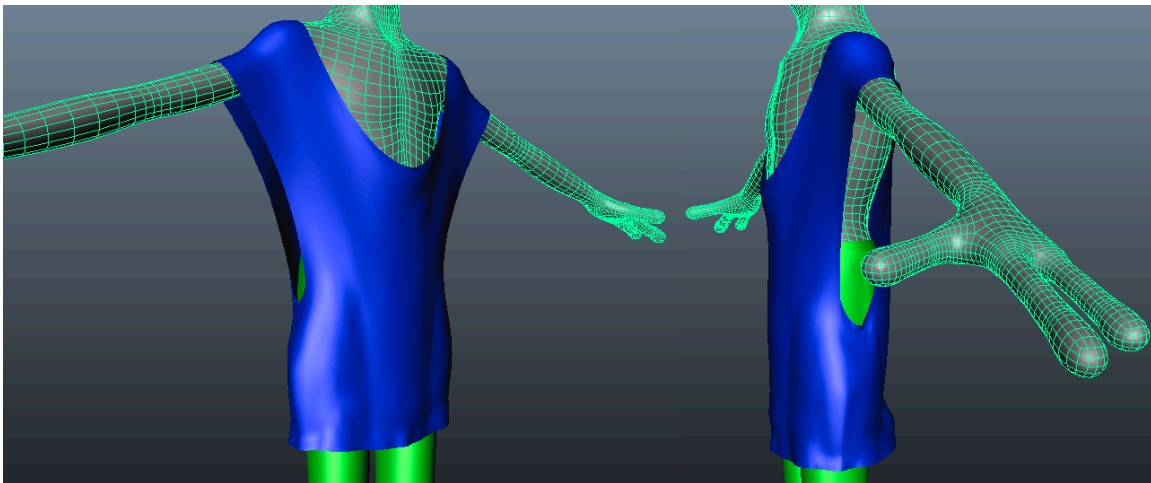
Figure 3.10 Initial t-shirt settings look unnatural and too stretchy.

Recommendations are to fine-tune the cloth attributes one or as little at a time. Changing multiple attributes at one time leads to ambiguity of what attribute provoked

what change in behavior. In a production environment, this process is referred to as "wedging". Using powerful render farms, cloth TDs can "kick-off" several simulations at a time with incremental adjustments made to a specific setting. On completion, artists can review the results and determine which values worked best. For Instance, three different simulations were initially generated on the t-shirt with Stretch Resistance being the only altered attribute from the original settings. Stretch Resistance values of 20, 40, and 60 were tested.

Commonly, constraints are used around the collar, or opening, of a shirt that "pin" selected vertices to the body of the character to help stabilize the shape. Due to the tightness of the Alien's t-shirt adjustments were made to the Friction and Stickiness attributes to achieve the same effect. Furthermore, for a finer level of control, rather than have the increased Friction and Stickiness affect the t-shirt as a whole, we utilized nCloth's paint features to apply a vertex property map for each attribute (Figure 3.11).
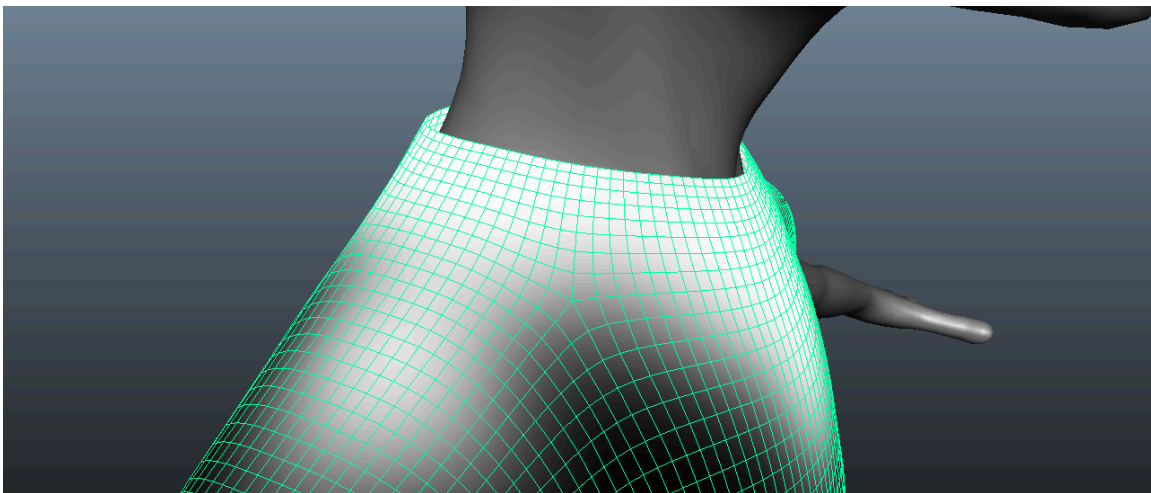
Figure 3.11 Painted vertex map controlling the Friction attribute.

Had the Alien's t-shirt been baggy and more loosely fitted, constraining the collar to the body (or neck) would have been required. After several attempts, Figure 3.12 displays the results of two favored t-shirt simulations that exhibit slight variances in detail, both desirable and undesirable. Rather than spend additional time tweaking settings and running continuous simulations, their caches can be blended together to achieve the desired appearance. Blend caching is discussed in section 3.5.1.
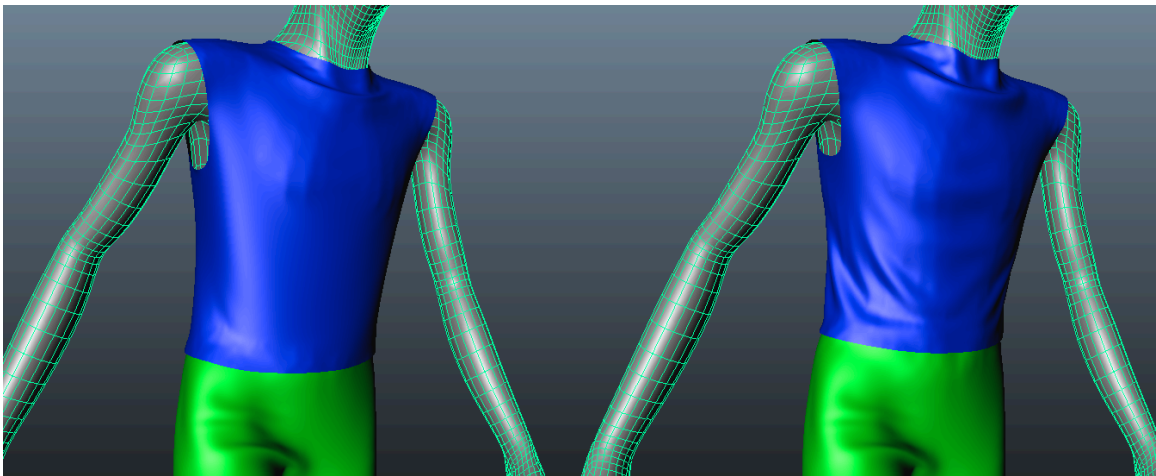
Figure 3.12 Results of two favored simulations to be revisited in post-simulation phase.

3.4.3 Lab Coat Workflow

With working versions of the t-shirt complete, the third and final item of clothing can be simulated to complete the character's dynamic outfit. The lab coat has more of pronounced presence than that of the t-shirt and pants and covers a large percentage of the character's body. In essence, the lab coat acts as the protagonist piece that will add significant life to the character.

The accuracy of the lab coat's motion is largely dependent of the collision behavior of the body animation and the previously simulated garments. Due to the successful performance of the pants and t-shirt, the collision behavior of the lab coat can be expected to collide smoothly with the other geometries. Like the t-shirt, the initial step is to make sure the lab coat drapes appropriately while the Alien is motionless from frames -60 to -50, as illustrated in Figure 3.13.
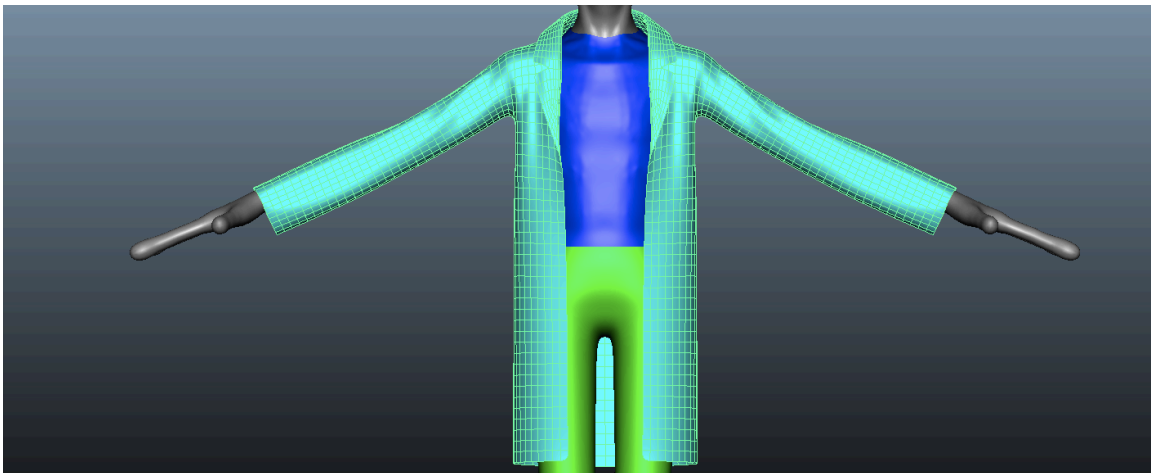
Figure 3.13 Relaxed lab coat at frame -50.

Although the lab coat drapes well on the static character, immediate problems are noticed with the collar, or lapel area of the garment, once the primary animation begins. The collar tends to change shape and slide around the character's shoulder too much (Figure 3.14). To remedy this issue, the general goal is to stiffen the collar region without affecting the rest of the lab coat. We therefore use a combination of the methods used in both the pants and t-shirt workflows.
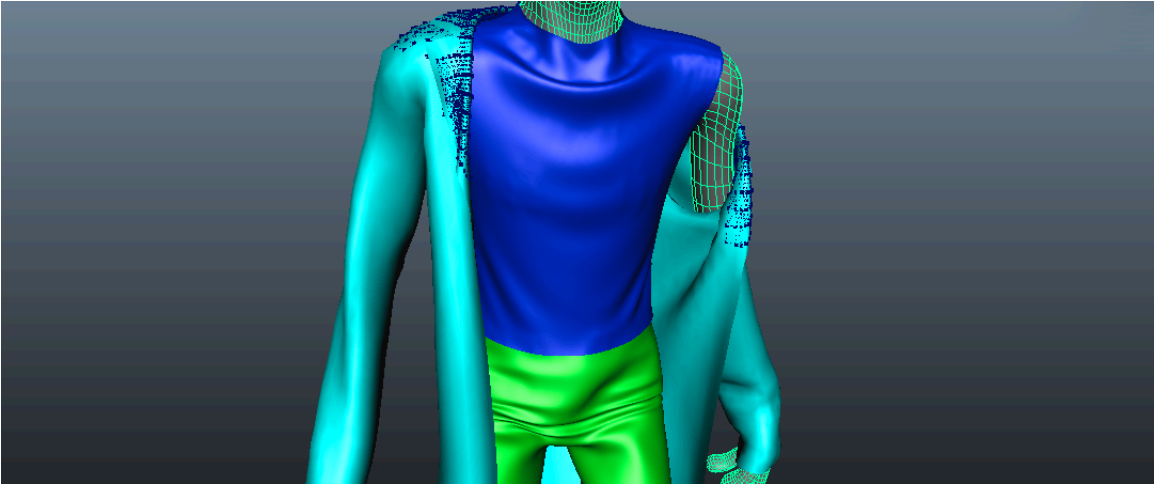
Figure 3.14 Problems with lab coat simulation.

Friction and Thickness were increased on the collar region through vertex property maps (see Figure 3.15). In addition, a Point to Surface constraint was added to pin the inner edge vertices along the edge of the collar's fold.
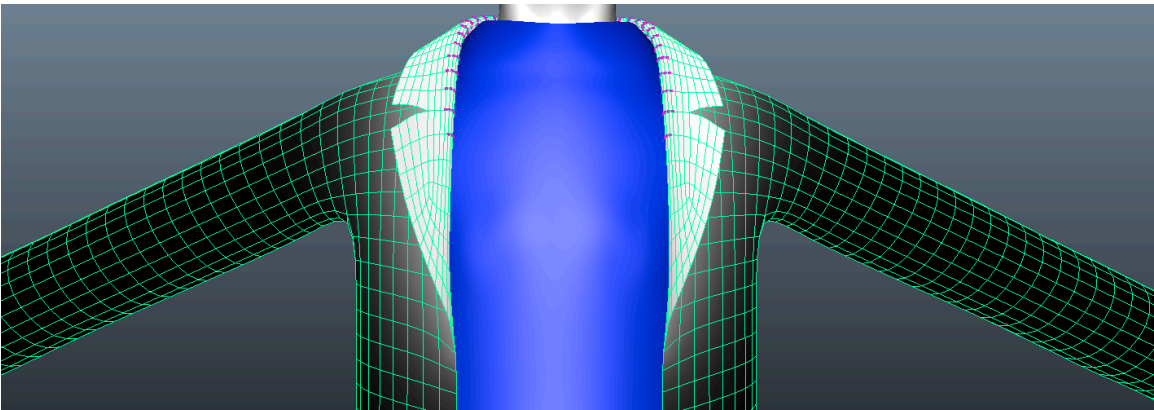
Figure 3.15 Constrained collar with painted vertex maps control Friction and Thickness.

With the collar problems resolved, experimentation of the dynamic properties began to define accurate cloth settings. In regards to the solver attributes, Substeps and Max Collision Iterations were kept at relatively low values throughout the course of simulation for faster solve times. Once the simulation started to appear acceptable, these values were increased to improve the overall quality of the simulation, but at slower, yet sufficient, computation times. Figure 3.16 depicts the progress in reaching the final desired simulation.

Figure 3.16 Successful progression of lab coat simulation.

3.5 Post-Simulation

Ideally, all clean-up work should be performed on the simulation cloth. Once all garments are simulated successfully, artists refine their work in post-simulation. Working only with caches, the process of post-simulation allows artists to sculpt, blend, and deform as necessary to achieve the final appearance before wrapping to the renderable beauty cloth.

3.5.1 Cache Blending

As artists work along, they start to build a library of caches that are indicative of their best cloth simulations. Figure 3.17 illustrates the results of two favored simulations of the character's t-shirt. Both share natural motion but vary in aesthetic characteristics. The overall motion of the purple shirt is very natural and exhibits some desirable wrinkles; however, the upper region of the t-shirt appears baggy and unnatural. The same upper region of the orange shirt is much more fitted to character's body, without the exaggerated wrinkles seen in the purple t-shirt. An appropriate solution is to blend the caches together to achieve the final appearance. The blue shirt depicted in Figure 3.18 illustrates the results of this technique. Artists can blend as many caches as necessary to achieve a desired look or motion, but should do so with caution; too many caches blended into a single garment can cause unnatural results. A blend is not always necessary to last an entire frame range. For further control, caches can be key-framed to vary the amount of blending during the simulation.
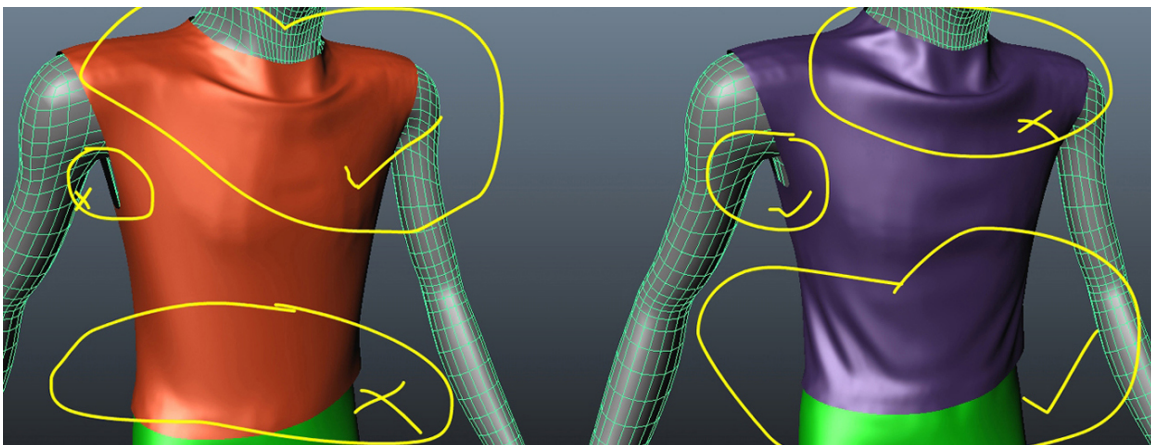
Figure 3.17 Two favored t-shirt caches to be blended.
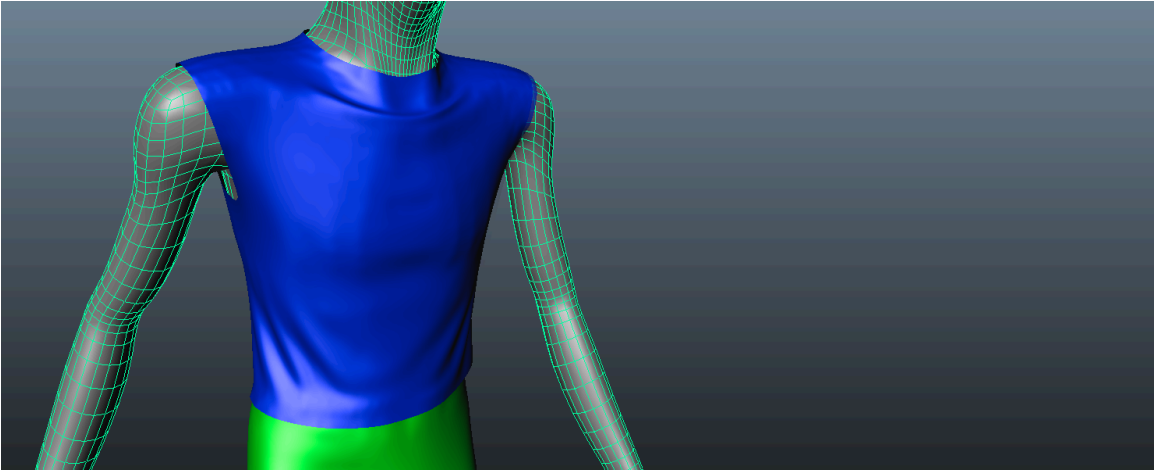
Figure 3.18 The result of blended caches.

3.5.2 Deformation Clean-Up

Striving for perfect simulation is commendable and occasionally possible. More often than not, however, artists will find themselves relying on deformation tools to remedy problem areas of a simulation. Fixing interpenetrations, freezing a pose, sculpting a silhouette or even faking wind are all forms of common clean-up work. Usually, artists will discover more than one way to fix a problem. Knowing various methods helps in developing an artist's individual workflow. Many studios, including Sony, have custom deformation tools that would overwhelm Maya's existing deformer toolset. Popular Maya deformers include: cluster, blend shape and wrap. For our purposes, we will focus on the wrap deformer.

3.5.3 Wrap Deformers

The wrap deformer is a valuable asset, which allows a high-resolution mesh to deform to the dynamics of simulated, lower-resolution mesh. The benefit of wrap deformers is that the artist is free from the struggle of having to simulate dense and complicated topology, saving time and effort. With the Alien, both the character's beauty pants and lab coat are wrapped to the simulation mesh. Additionally, since the pockets were modeled as separate geometries, they too are wrap-deformed to the already influenced lab coat. Once everything is wrap-deformed a playblast will ensure that everything works as predicted.

Alternatively, in the event that beauty geometry is not provided, nCloth allows the artist to add to simulated objects downstream. For example, once simulated, a low resolution, single-sided object can be smoothed and extruded to create a makeshift beauty object that will deform accordingly. Figure 3.19 shows a close-up of the simulation mesh and renderable beauty mesh with its inherited dynamics.
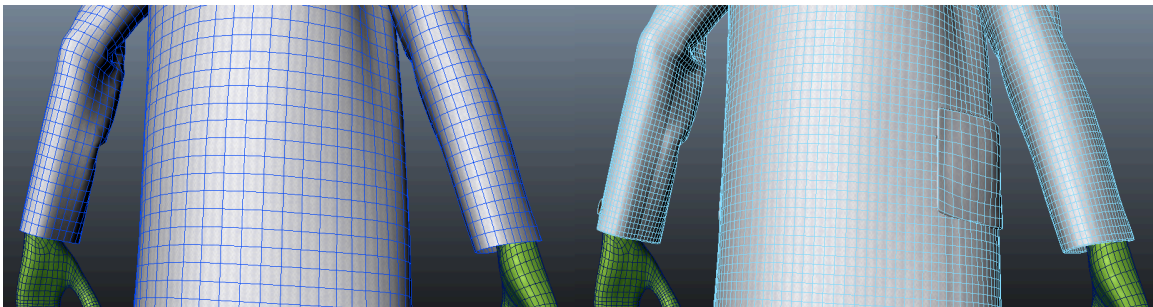
Figure 3.19 The beauty mesh (right) inherits the dynamics of the simulation mesh (left).

3.5.4 Attaching the Buttons

The artist can attach rigid objects several ways, such as buttons to clothing. For the Alien's lab coat, we utilized the Point on Poly constraint, which is new in Maya 2011. Once a button is appropriately positioned, it can be constrained to a vertex of the target surface. Once constrained, the artist can use the Offset fields to fine-tune the rotational position of the button.

3.5.5 Handing Off

Once all problem areas have been fixed and the geometries are wrap-deformed, a playblast is recommended to check that all problems have been resolved. The final step is to create and export a Maya geometry cache for each garment. This step is an extended courtesy that provides lighters a cleaner, lighter scene unburdened with cloth nodes and deformations created by the cloth TDs.

3.6 Summary

When simulating cloth, learning nCloth properly can save considerable time. Although the artist may not take long to become familiar with the software, applying knowledge artistically and technically may take practice and patience. Each change in the Nucleus system has an effect on all other attributes, many times creating a domino affect, which can be frustrating. The remedy is that the artist must truly learn and understand how the interworking of each parameter acts upon another, which comes with experience and experimentation. With each simulation, the artist must rely on troubleshooting to

manipulate the dynamics to their liking. Once these skills are accomplished, the artist will

be able to effectively create realistic cloth.

CHAPTER FOUR

RESULTS

This chapter is dedicated to showcasing the final results of work implemented in Chapter Three and the impact similar techniques have produced in the feature animation, *Cloudy with a Chance of Meatballs*. Both sets of results depict a stylized appearance, but the same principles can be applied to the look of photorealism. Lastly, noteworthy statistics and awards are presented that measure and highlight the film's success.

4.1 Alien Results

The final simulation result of the Alien's clothing is attractive, realistically persuasive and deemed acceptable even by professional standards. Through the use of basic lighting, the following rendered stills add, significantly, to the realism of the clothing and ultimately help to "sell" a shot for approval. With the addition of basic light and shadow, the cloth is punctuated, more realistic; the details unravel with cascading folds and with aesthetic wrinkles, which ultimately help bring the character to life. Moreover, with the use of appropriate textures, the material and fabric type are more accurately represented.

Unlike Flint Lockwood in *Cloudy with a Chance of Meatballs*, the Alien is marginally more detailed than his cartoony conceptual counterpart. Figures 4.1 through 4.4 illustrate various finished stills from the rendered simulation sequence.

Figure 4.1 Rendered still of Alien cloth simulation sequence.

Figure 4.2 Rendered still of Alien cloth simulation sequence.

Figure 4.3 Rendered still of Alien cloth simulation sequence.

Figure 4.4 Rendered still of Alien cloth simulation sequence.

4.2 Feature Animation Showcase

Figures 4.5 through 4.12 showcase selected shots from *Cloudy with a Chance of Meatballs*. These shots, performed at Sony Pictures Imageworks, are representative of the workflow methods discussed in Chapter Three. The selected shots illustrate a variety of characters all clothed with dynamic cloth.

Figure 4.5 *Cloudy with a Chance of Meatballs* © 2009 Sony Pictures Imageworks.

Figure 4.6 *Cloudy with a Chance of Meatballs* © 2009 Sony Pictures Imageworks.

Figure 4.7 *Cloudy with a Chance of Meatballs* © 2009 Sony Pictures Imageworks.

Figure 4.8 *Cloudy with a Chance of Meatballs* © 2009 Sony Pictures Imageworks.

Figure 4.9 *Cloudy with a Chance of Meatballs* © 2009 Sony Pictures Imageworks.

Figure 4.10 *Cloudy with a Chance of Meatballs* © 2009 Sony Pictures Imageworks.

Figure 4.11 *Cloudy with a Chance of Meatballs* © 2009 Sony Pictures Imageworks.
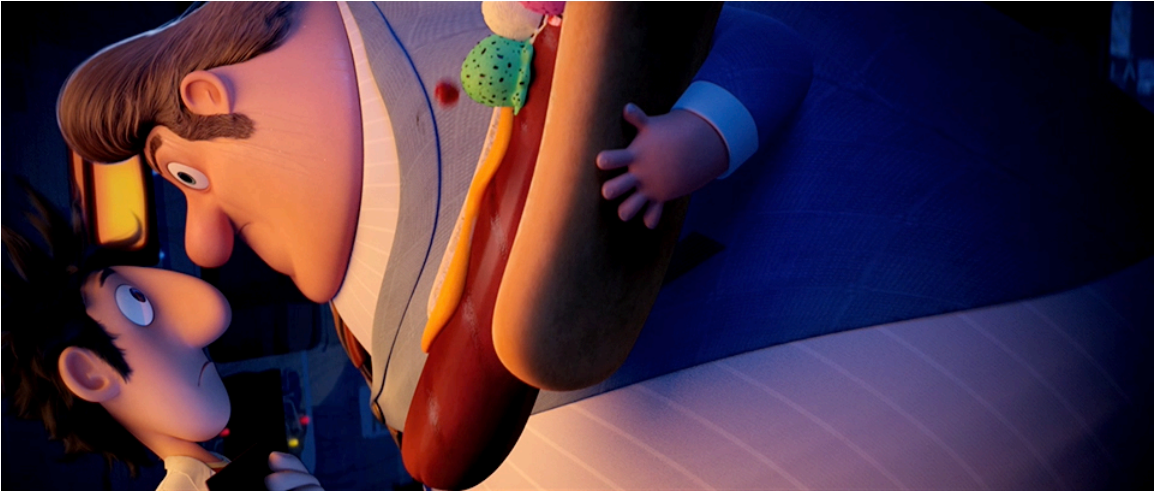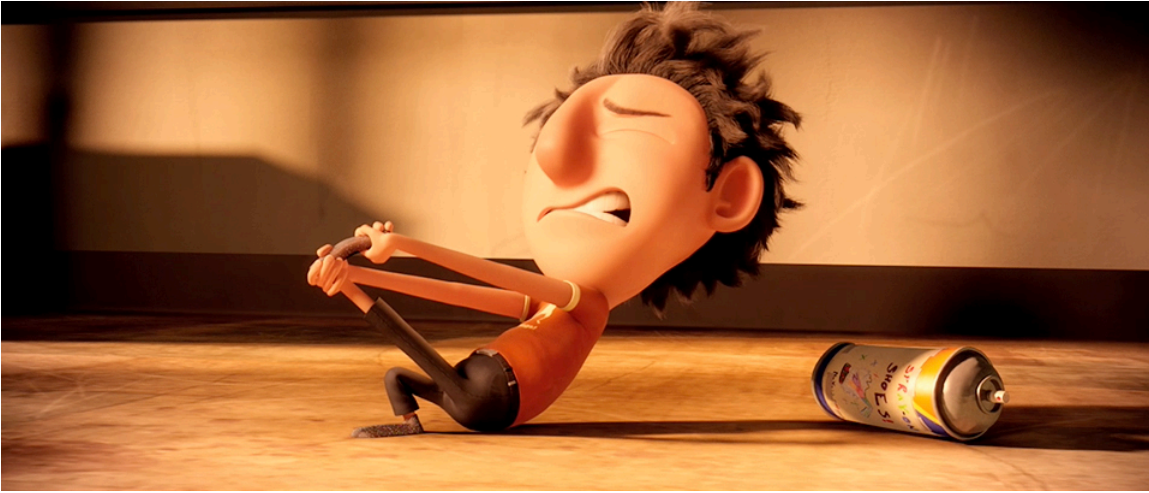
Figure 4.12 *Cloudy with a Chance of Meatballs* © 2009 Sony Pictures Imageworks.

4.3 Measure of Success

Opening at number one in the box office, *Cloudy with a Chance of Meatballs* was, without a doubt, a box office success. With a projected budget of $100 million, the movie earned over $8 million on its opening Friday and a total of over $30 million for its first weekend. *Cloudy with a Chance of Meatballs* holds the record for third-largest opening weekend in the month of September. The worldwide total was over $243 million.

Additionally, *Cloudy with a Chance of Meatballs* received four Annie Award nominations: Best Animated Feature, Animated Effects, Directing in a Feature Production, and Writing in a Feature Production. The film also received a Golden Globe nomination for Best Animated Feature [Answ11].

CHAPTER FIVE

CONCLUSION

This thesis explores techniques of using nCloth to convincingly simulate the dynamic motion of a character's clothing. The workflow is kept relatively simple; however, comparable techniques can be implemented for more complex characters and models. The aforementioned methods used to set up and simulate the Alien are akin to those of setting up the cast of characters in the feature animation, *Cloudy with a Chance of Meatballs*.

Keep in mind that the workflow described is not limited to nCloth; all cloth simulators are based on the same principles regardless of which 3D application an artist may use. Moreover, artists will find more than one way to tackle cloth simulation and must develop individual techniques to ensure proper cloth setup and simulation are achieved. For example, during the production of *Cloudy with a Chance of Meatballs,* the quality of dynamic cloth from shot-to-shot is consistent throughout the movie; however, dozens of Sony's Cloth TDs approached the software and its tools differently.

Since the advent of cloth simulation research, artists and visual effects studios have witnessed significant improvements in cloth simulation software. As a result, digital characters have become increasingly sophisticated, making the skills of a Cloth TD a valuable resource sought out in the field of computer animation. Mastering the art of digital tailoring need not discourage those interested in the field of visual effects. With general knowledge of commercial software, even the novice artist should be able to establish default attributes of garments, constraints and collision geometry to create

plausible cloth. Often artists make the mistake of working with complex characters and complicated models, which ultimately leads to problems that cripple workflow and impede the production timeline. Notably, the simplicity of the clothing and characters in *Cloudy with a Chance of Meatballs* resulted in creative and marvelous effects that would otherwise be difficult, if not impossible, to achieve by any other method. The contribution of cloth simulation in the visual effects world is not invisible. Cloth simulation is a hybrid of technical and artistic techniques that ultimately add to the magic of the audience's experience.

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