# Adding Cartoon-Like Motion to Realistic Animations

By

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# Abstract

In comparison to traditional animation techniques, motion capture allows animators to obtain a large amount of realistic data in little time. The motivation behind our research is to try to fill the gap that separates realistic motion from cartoon animation. With this, classical animators can produce high quality animated movies (such as Frozen, Toy Story, etc.) and non-realistic video games in a significantly shorter amount of time.

To add cartoon-like qualities to realistic animations, we suggest an algorithm that changes the animation curves of motion capture data by modifying local minima and maxima.

We also propose a curve-based interface that allows users to quickly edit and visualize the changes applied to the animation. Finally, we present the results of two user studies that evaluate both the overall user satisfaction with the system's functionality, interactivity and learning curve, and the animation quality.

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# List of Acronyms

| Acronyms | Definition |
|---|---|
| **IK** | Inverse Kinematics |
| **FK** | Forward Kinematics |
| **SISO [1]** | Slow-in, Slow Out |
| **DoF** | Degrees of Freedom |
| **FBX** | Film Box |

# 1 Chapter: Introduction & Background

## 1.1 Animation

Animation, both as a discipline and as a medium, is ubiquitous in today's society. Both realistic and cartoon animation are frequently used in the entertainment industry for advertisements, cartoons, live action movies, animated movies, and video games.

Realistic animation focuses on re-creating lifelike motion and applying it to highly-detailed digital characters. Its main goals are to blend fantasy with reality, to create the illusion of realism, and to immerse viewers in a believable setting. In contrast, cartoon animation often ignores realism and prides itself on having characters that squish, squash, stretch and jump in inhuman ways. As shown in Illustration 1, a cartoon character's limbs are not constrained by the laws of physics, but by the animator's artistic decisions. Exaggerated movements put an emphasis on the animated actions to convey emotions (such as fear, anger, or happiness) or to produce a comedic/dramatic effect.

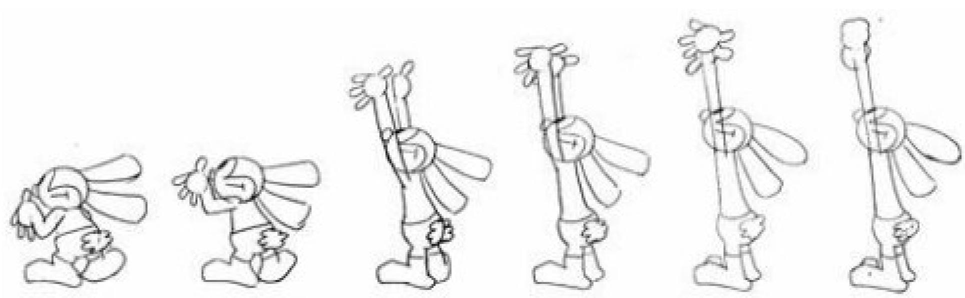

**Illustration 1.1 - Oswald reaching upwards, stretching arms and torso [2]**

Originally, animations were created from several drawings or paintings on paper. An artist would draw dozens of drawings that depicted the minute changes of the characters over time [3]. When combined, these drawings would only create a few seconds of animation. Though these animations were relatively short when they first emerged, the public was delighted and their popularity grew. As the demand for animated media increased, the industry turned towards less costly methods of production with the goal of increasing the overall volume and quality of their final work [4].

## 1.2 Current Animation Systems

Animation, particularly human body animation, is a challenging and time consuming task. To address this, a plethora of different computer-aided or computer-generated systems have been developed that simplify the process and increase production speeds. In the sections below, we present a sample of the most commonly used animation methodologies.

### 1.2.1 Computer-Aided Tweening

Tweening (also called inbetweening) is a procedure in which intermediate frames are created between two different user-defined key poses (manual keyframing) [5]. This can be done based on various parameters, such as position, rotation, and scale. Figure 1.1 shows an example of computer-aided tweening based on character position. The animator placed a rabbit at two different locations, and the computer created the frames necessary to complete the motion. This allows an animator to focus on the crucial elements of an animation and thus saves a significant amount of time.

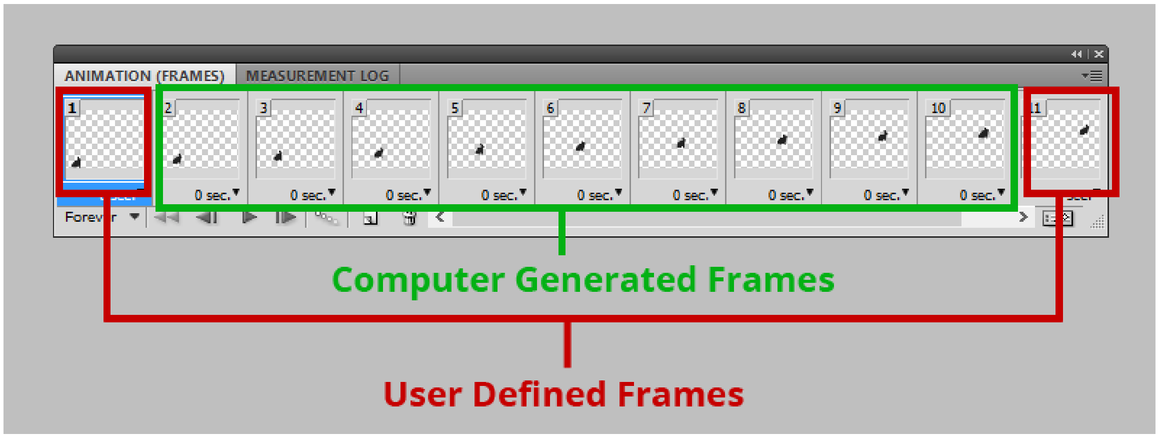


**Figure 1.1 - Tweening process in Adobe Photoshop**

### 1.2.2 3D Meshes, Skeletons and Skinning

3D digital characters are made of a static, yet complex mesh of polygonal shapes [6]. To allow animators to manipulate them in real time, character riggers create a skeletal figure and attach polygonal surfaces to it in a process called skinning [7]. Controlling the skeletal movement directly can be a difficult task, so animators connect the importanwwwt points of movement, such as hands, legs and hips, to an array of 2D control shapes. Animators can translate and rotate these control shapes to place the character's limbs in appropriate poses at each keyframe. Then the computer can generate (aka tween) the necessary intermediary positions to create a complete animation. This process is reminiscent of a puppet master controlling a puppet with multiple strings. To constrain a character's skeleton to the realm of human motion, each joint has defined degrees of freedom (DoF) that determine in which axes a joint can rotate. For example, a knee can only rotate on one axis, whereas an elbow or a hip can rotate on all three.

Figure 1.2 shows Norman, a puppet built for the Academy of Art University Pixar classes, at two different frames of an animation. Comparing the two images at the top left and right shows how the animation controls are scattered around the character and how moving them affects the position of the limbs, mouth, eyelids, etc. The two bottom images show how Norman is constructed; the character's polygonal mesh is shown in black and the joints are shown in various other colours.

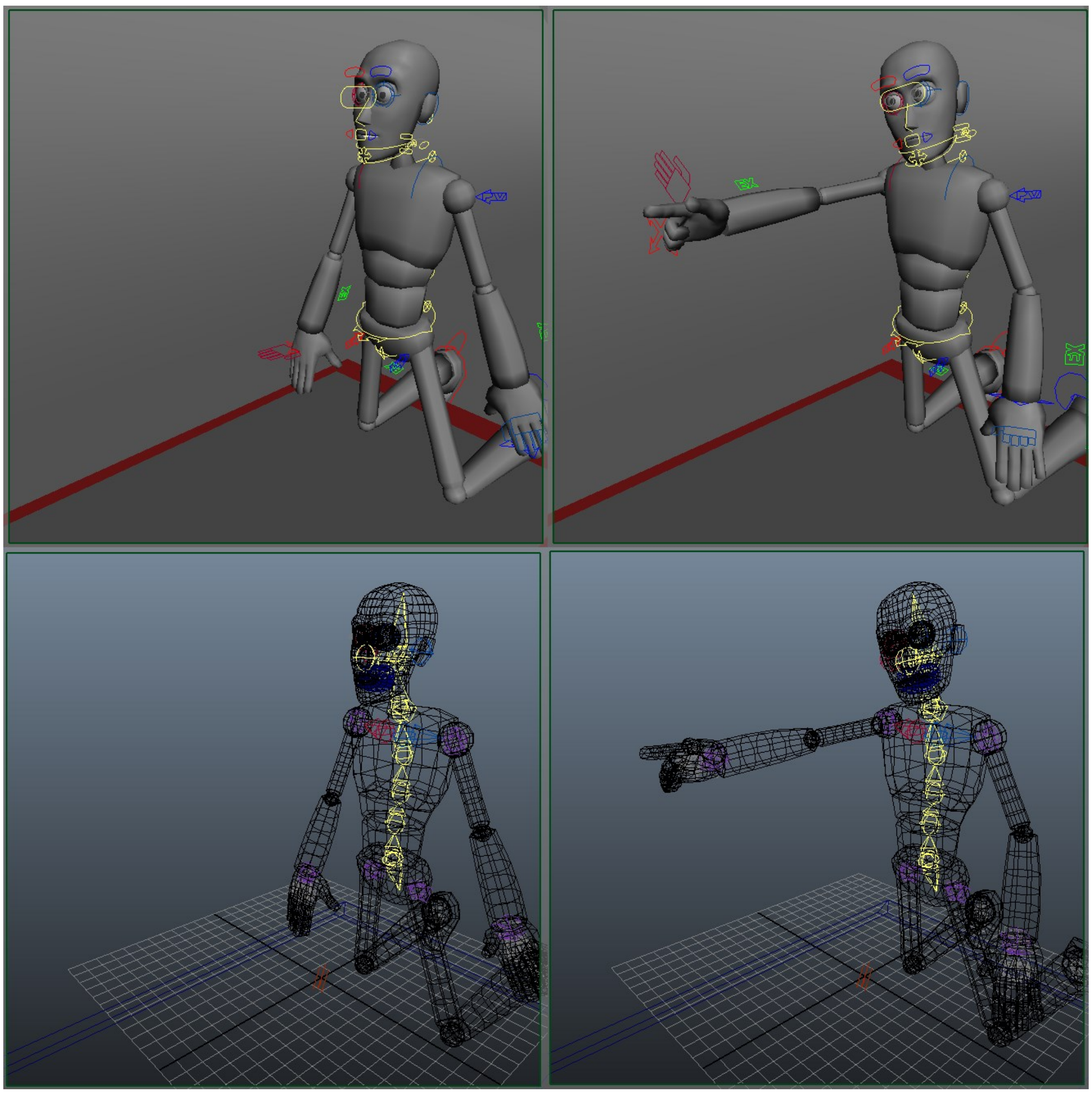

**Figure 1.2 - Norman at two different frames on an animation. Top images show the character and the associated controls. Bottom images show the polygonal mesh and skeleton.**

### 1.2.3 Inverse Kinematics

While originally developed for the field of robotics [8], Inverse Kinematics (IK) has been found to be a useful tool in animation. In this process, IK handles are attached to the end of limbs, and then the IK algorithm calculates the appropriate positions of the intermediate joints along the limb. For example, an IK handle attached to an arm would predict the location of the elbow when the wrist is moved in space. This is in contrast to Forward Kinematics (FKs), where animators must rotate each joint individually to reach the intended destination of the limb. IK allows animators to focus on overall limb placement without having to worry about the location of the intermediary joints.

## 1.3 Animation Visualization

In everyday life it is easy to forget that something as simple as walking is a complex sequence of skeletal movement. An animator studies the different ways a person swings their arms or sways their hips as they walk, and tries to recreate those movements. This section presents the various ways of viewing or conceptualizing these rotational values.

### 1.3.1 Animation Curves

The most widespread way to visualize joint rotation data is to graph the translation and rotation values of moving joints over time. This allows a more detailed analysis of each axis of animation as well as editing individual frames. Figure 1.3 shows an example of an animation graph that plots the X, Y and Z rotations of a character's spine during a walk animation.

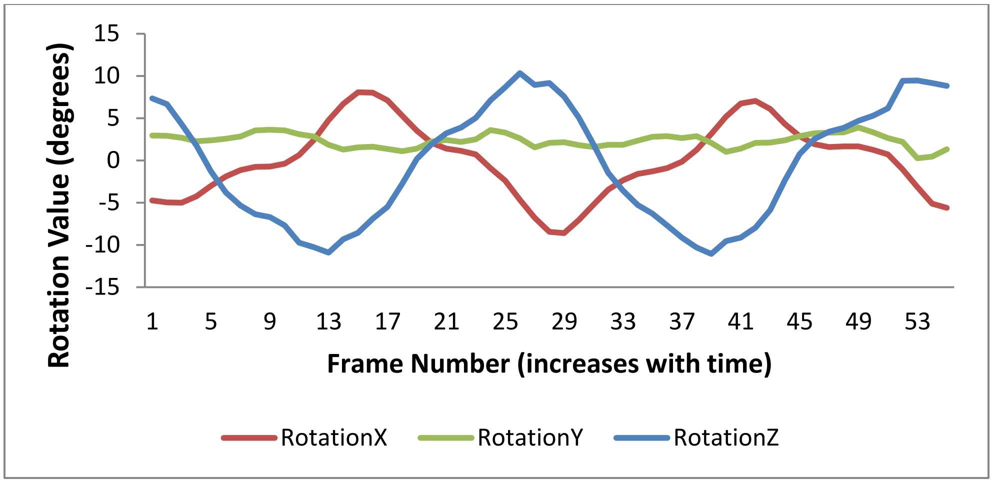


**Figure 1.3 - Spine Rotation of a Walk Animation**

A substantial portion of previous work in this area has focused on editing motion curves like those shown in Figure 1.3 for different purposes, such as motion warping [9], motion blending [10] and motion exaggeration [1], [11].

### 1.3.2 Rotation Matrices

There are various ways of representing a rotation value in 2D or 3D space. One of the most common ways is rotation matrices, which are commonly used in linear algebra. Rotation matrices are used to rotate objects in Euclidean space. Figure 1.4 shows both 2D (90 degree rotation) and 3D rotation matrices.

$$\begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \quad \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix}$$

**Figure 1.4 - 2D (left) and 3D (right) Rotation Matrices**

The main limitation of a rotation matrix is that is difficult to visualize the actual rotation by reading the matrix. This becomes even more difficult with 3D matrices.

### 1.3.3 Euler Angles

Euler angles, introduced by Leonhard Euler, are another method of describing the rotation of an object. According to this theorem, any rotation can be broken down into three consecutive 1-dimensional rotations (x,y,z), as shown in Figure 1.5.

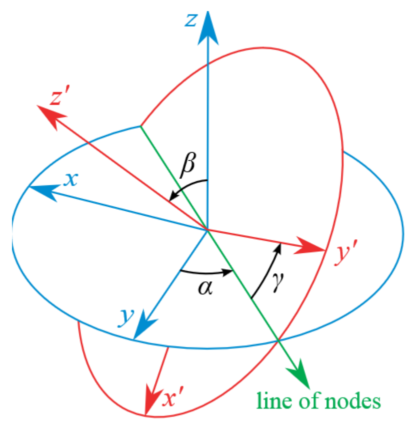


**Figure 1.5 - Euler Angles**

While Euler angles are easy to visualize, they have significant disadvantages. A combination of x, y, z rotations can cause gimbal lock [12] when a second angle becomes 90 degrees. The result is that the object is “locked” in a 2D rotation, ignoring the third dimension. In addition, any given rotation in space can have multiple solutions. For example, a rotation of 90° is equivalent to a rotation of -270°, and as is 180° and -180°. This phenomenon can be observed when recordings of similar actions in the same motion capture session have wholly different Euler angle values. This is demonstrated by

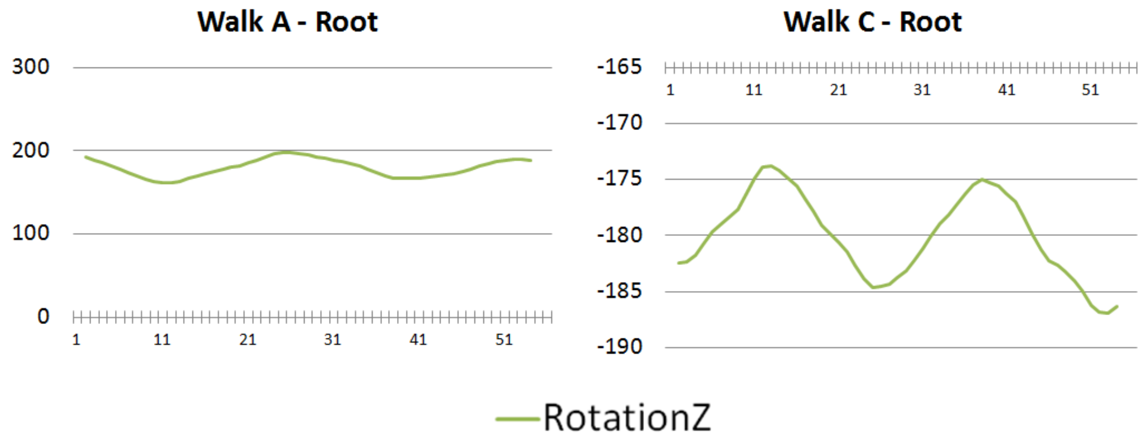


Figure 1.6, where two similar walking animations have their Z-Axis rotations of the root joint start at vastly different values and their amplitudes are inverted.

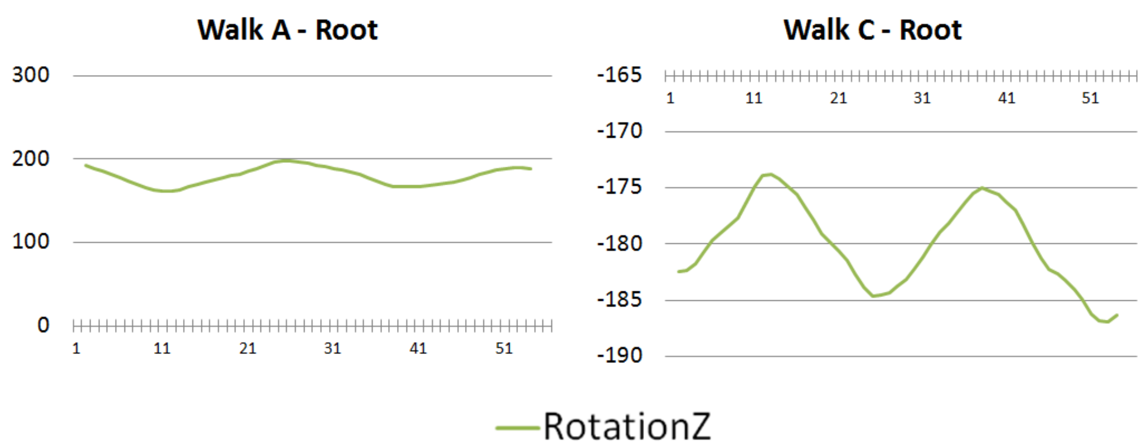


**Figure 1.6 - Z Rotations of the Root Joint**

This discrepancy makes it difficult to create a homogenized algorithm that targets Euler angles, since such an algorithm would have to account for the multiple solution exceptions.

### 1.3.4 Quaternions

A third notation method for rotations is quaternions. Quaternions were originally introduced by William Hamilton in 1843 and are described by the equation below:

$$q = (x, y, z\, w) \tag{1}$$

The x, y and z components describe the axis in which the rotation will occur, and the w component denotes the amount of rotation around it. Although quaternions, much like rotation matrices, can be difficult to visualize , they provide one unique solution for each specific rotation in space [13]. As a result, there are never two quaternion values that define the same rotation value. This characteristic creates more consistent data in animations.

## 1.4 Motion Capture Systems

Most people are highly attuned to realistic human motion because they are surrounded by people every day. As shown by the existence of the uncanny valley effect [14], people easily notice minute mistakes in character animation, particularly when the animation is intended to be realistic. This can make animating with the methods described above not only a time consuming task, but also one that requires the animator to have a significant amount of training and expertise in their craft as well as very high attention to detail.

In contrast, despite the technical knowledge needed to setup the system, motion capture allows an animator to record the detailed elements of an actor’s movements without the need of a profound knowledge of human kinematics. As a result, motion capture is now widely used when realistic animation is required. Once a motion capture system has been set up, the time required to record an animation is only the time it takes for an actor to act out the needed animations.

### 1.4.1 Mechanical, Inertial and Magnetic Motion Capture

There are many methods of obtaining high quality motion capture data. While mechanical (Gypsy [15], ShapeWrap [16]), inertial (MVN [17]) and magnetic (trackSTAR [18]) motion capture are adequate solutions, vision-based systems [19] have become the standard in both the movie and game industry.

### 1.4.2 Optical Motion Capture

Vision-based, or optical, motion capture systems consist of a collection of cameras that record the 2D positions of reflective markers placed on the object of capture. As shown in Figure 1.7, the motion capture system then uses the position of each camera to triangulate the position of the markers in 3D space [20] and create a virtual mannequin of the actor. The main disadvantage of optical motion capture is that it requires a controlled environment that exhibits a low amount of reflection.

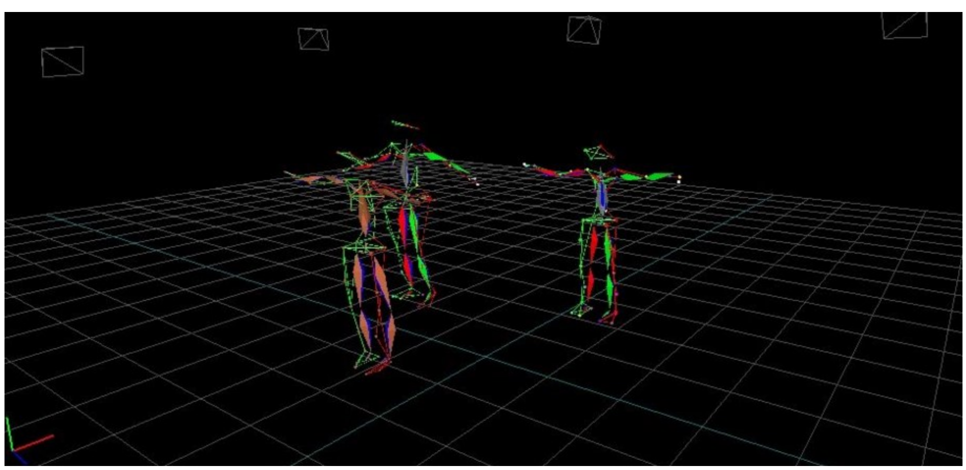

**Figure 1.7 – Three actors as seen through the Vicon Blade system**

## 1.5 Cartoon Animation and Motion Capture

Since the release of *Toy Story*, the first full-length computer-animated cartoon movie, cartoon animation has slowly transitioned from 2D to 3D animation methods. Studios like *Pixar* and *DreamWorks* use methods described in section 1.2 to animate their movies. While these methods give the animator full control over the final animation, they also involve significant manual labour, as animators must manipulate all of the character's limbs with often hundreds of controls.

Motion capture is significantly less time consuming than manual animation, and its emergence has revolutionized computer animation. This success is apparent in the dominance of realistic animations in movies such as *Lord of the Rings*, *Avatar*, and *Planet of the Apes*, and in games such as *Final Fantasy*, *Grand Theft Auto*, *Call of Duty*, and *Halo*.

However, despite the quality of the animations produced, motion capture is seldom, if ever, used by 3D animation studios like Pixar and DreamWorks. These studios adhere to the principles of animation that are now considered an industry standard [2]. Many of these principles are elements of movement that are not found in real life, such as squash and stretch, and thus, motion capture on its own cannot acquire these movements.

## 1.6 Motivation and Problem Description

In contrast with traditional animation techniques, such as manual key framing, motion capture allows animators to obtain a large amount of realistic data in very little time. The motivation behind our research is to fill the gap that separates realistic motion from cartoon animation, and allow classical animators to produce high quality animated movies (such as *Frozen*, *Toy Story*) in a shorter amount of time. Our goal is to automate as much of the process to modify animations quickly and to let animators tweak the final result with less control points than they would have to use if they were manipulating each limb separately. This will simplify the animator's work without limiting their overall control.

The current literature mostly focuses on morphing motion capture data into different types of realistic motion, or blending multiple motion capture animations seamlessly. Physics systems [21] and space-time solutions [22] have been created to generate and modify animations, but this can take considerable computer processing power and time to create the desired animations.

There has been very little work on turning realistic motion into cartoon motion, and when researchers have attempted this transformation it is often added to their work as an afterthought. Furthermore, according to the conclusions drawn in various research papers, the work that has been done on transforming motion capture animation into cartoon animation has produced results that can be used in pre-visualization of movies, but are not of production quality.

## 1.7 Proposed Method

We propose an algorithm that changes animation curves by modifying the local peaks and troughs. We focus on exaggerating angular and positional motion to produce more animated results and explore the ability to change an animation's style through this method.

Once we determine the new points that describe the modified peaks and troughs we use cubic interpolation to connect them together and form a new, modified curve.

Figure 1.8 loosely illustrates our method, with the blue line representing the original data and the red line representing a final modified curve.

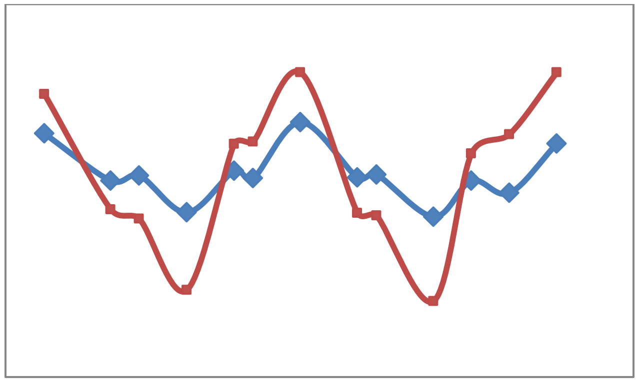

**Figure 1.8 - Proposed Curve Modification Method**

The first use of our algorithm allows us to increase (or dampen) a curve's magnitude to exaggerate a character's joint rotations. While this is useful, we also ventured in motion morphing. Using neutral walks and exaggerated female walks, we compare the inherent differences between the animation curves and apply appropriate time-shifts and magnitude exaggeration/dampening to morph one style of animation into the other.

We also propose a simple curve-based user interface that allows users to visualize potential changes and apply them to the animation. Finally, we test the user experience and the quality of the resulting animation with two different user studies and present those results.

## 1.8 Research Contributions

To transform realistic motion capture into cartoon motion, we suggest a simple method that exaggerates motion by increasing animation curves that differs from previous work, and through cubic interpolation, produces less noise. We also propose a simple yet innovative curve interface as a means of interaction with the system.

Additionally, our system is embedded directly into an already existing animation software package of professional grade (*Autodesk Maya*) and thus, provides a familiar environment for current animators.

## 1.9 Thesis Organization

The following document is laid out as follows: Chapter 1 of this thesis introduces the topic and goes over the background knowledge necessary to understand the direction and motivation of our research. Chapter 2 is a detailed literature review of previous works in motion editing, synthesis, filters and cartoon animation. In Chapter 3, we describe our overall research method. This includes a description of the motion capture system we use, an overview of our development environment, and a theoretical breakdown of our algorithm. Chapter 4 describes the user interface of our system, our user studies and our observations. Chapter 5 is a discussion of our results and findings. Finally, Chapter 6 concludes the thesis with a summary of our contributions and a discussion about potential future work.

# 2 Chapter: Related Works

With the rise of computer animation, the necessity to create high quality animations within an optimal timeframe has been an important focus for researchers across the world. This ever-growing demand has led them to look for innovative ways to either synthesize or modify already existing 3D human motion [23].

In this chapter, we cover a few animation synthesis papers, since the idea and many editing motion capture methods stem from this field. We also discuss the topic of animation blending, as much of the previous work focuses on synthesizing transitions between different animation clips. Beyond that, as Motion Capture allows us to gather a large amount of high-quality data in a short time, we focus on work that presents ways to edit motion capture data with the goal of producing interesting derivatives that can be recycled from production to production. As a direct link to our research goals, we end the chapter by discussing motion capture editing with the explicit goal of creating cartoon characters and provide a brief overview of different interactive features of the various systems presented.

## 2.1 Motion Synthesis

An animator's main concern is the re-production of movement, realistic or non-realistic, onto fictional characters and objects. The following section describes different research projects whose goals were to synthesize motion through the use of various innovative systems.

### 2.1.1 Motion Synthesis through Kinematics and Space-Time Constraints and Manipulation.

One of the earlier and most famous academic works on motion generation is Witkin and Kass' Spacetime constraints [22]. They present a new method for the synthesis of character animation. Their system allows an animator to create 2D or 3D content by specifying the following criteria.

1. What does the character need to accomplish?
2. How should the motion be performed? Should it be sad, angry, loud, etc?
3. What is the overall physical structure of the character in question? What is the polygonal mesh like? What are the joints?
4. What physical resources does the character have at its disposal? Muscles? Is it in free fall? Is it on a hill?

With these user-defined properties, Witkin and Kass' algorithm determines the necessary constraints of the animation and generates a result that fits within these restrictions. In short, they give the limits of what a motion needs to be, and any motion within those constraints is a possible solution.

In order to illustrate their results, they use Luxor Jr (Pixar's lamp mascot) and have him perform a series of space-time generated jumps (normal jump, jump over an obstacle, ski jump). They specify the starting and ending positions of the character through kinematic constraints and use linear interpolation (tween) to generate the movement between the pre-specified start and end of the jump. Then, their space-time formulation adds constraints through the course of the motion to ensure that the original animation parameters are maintained.

In their result section, Witkin and Kass discuss that their space-time method can produce realistic, complex animations with minimal kinematic constraints and also show cartoon properties such as follow-through, squash-and-stretch, and timing [2]. The main advantage of their technique is that it reduces the amount of work that the animator needs to do. However, they note that it might difficult to extend the system into free-form movement the because of how vague specifying a characters' goals can be. They also determine that the addition of more and more constraints, specifically in 3D space, causes significant setbacks and forces an animator to debug for long periods of time.

Along the same lines as Witkin and Kass' work, Rose et al. present an application of space-time constraints that generates transitions between animations [24]. Their goal is to blend different snippets of realistic human animation seamlessly. As previously discussed, animating realistic human motion is a tedious and arduous task – this is also the case when animating transitions between different realistic motion-captured clips. This is because the juxtaposition of hyper-realistic motion with hand animated animation requires a high level of artistic skill.

Rose et al.'s work generates transitions by combining kinematic constraints [25] and space-time constraints [22] to result in higher realism. They use this to lower the amount torque required to transition from one animation to another. To allow for user interaction with the software, they also developed a motion expression language that allows a user to manipulate motion data. Using this system, they successfully generated basic motions, cyclic data and motion transitions.

Through their method, they successfully blended a cyclical walk by having the user select a marker and having the system find the time point in which the difference between position, velocity and acceleration are minimal. To reduce the inevitable time mismatch issue, they add a linear offset and use a least-squares cyclic B-Spline to approximate the modified motion.

Additionally, they successfully applied their algorithm on a variety of gestures and generate successful 0.3 and 0.6 seconds of transitional animations between them. Despite their success, they suggest the usage of a biomechanical model to sample from and guide the resulting animation to increase the realism of the final results. Additionally, although space-time methods provide controlled realistic motion in comparison to various interpolation methods, they are computationally expensive and cannot be used in real time. Similarly to Witkin and Kass' research, Rose et al. also found that their method did not work well for unrestrained body motions, as those require a significant amount of rules to look realistic while creating the desired result.

In 2002, Lui and Popovic present Synthesis of complex dynamic character motion for simple animations. In this research paper, they devise a method for the rapid prototyping of realistic character animation. In contrast with many motion editing methodologies, Lui and Popovic's procedure takes a simple animation sketch and produces a realistic result. Effectively, their system takes in a low-quality and unrealistic animation and outputs a high quality realistic animation. They accomplish this by automatically defining constraints from the inputted sketch.

To create an optimal result that doesn't require a significant amount of processing power, they use simple dynamic constraints. These constraints are determined by the usage of the laws of physics as well as with the overall knowledge gathered by the human biometrics domain. An example of an important constraint the system might enforce would be the implementation of footsteps.

Lui and Popovic's algorithm is broken into the following steps: It initializes the user-intended animations and generates appropriate environmental limits. With those, it creates a constrained and unconstrained animation and then creates intermediary poses between them. From that point on, it determines new physics-based constraints using the laws of physics as well as the rules outlined by biometrics knowledge. Finally, it generates the final animation and presents it to the user.

Beyond the algorithm development, they also implement a pose-suggestion feature into their software. They accomplished this thanks to machine-learning [26] technology: through the input of a large amount of user-created and motion captured animations, their animation editing software successfully prompts the user with suitable pose-suggestions.

Their results show that their system produces complex realistic motion with a low level of involvement and effort from a user. However, not only do they run into problems when the system has a difficulty decoding an animated sketch, they found that detailed editing can involve a significant amount of keyframe input. They also note that there can be a substantial amount of difficulty in controlling what the system doing with the inputted sketch.

### 2.1.2 Motion Synthesis through Motion Databases and Machine Learning

Machine learning uses concepts found in nature to give computer systems the ability to learn and adapt themselves to various situations. A large amount of current work in the field of machine learning has borrowed concepts from the cognitive science field, turning to genetically-inspired algorithms and complex neural networks, with growing success [27]. Consequently, it is not surprising that researchers in animation have attempted the application of artificial intelligence (statistical models, motion databases and predictive/adaptive systems) to the field of animation synthesis [28] and animation editing (see Section 2.2) . The following works have used data-driven methods to generate interesting and compelling animations.

Liu and Popovic initially explore this field through the pose suggestion feature of their system [21], but their application of machine learning is not used to create animations, but to aid a user in their editing process. The following section presents papers that use various methods of machine learning to teach computer different aspects of human motion and use that pre-gathered information to generate new, user-selected animations.

Brand and Hertzmann present Style Machines, a system that permits the stylistic synthesis of animation. The focal point of their research is the development of a statistical model that allows a user to generate an array of different animations through the use of different control knobs. They accomplish this through a hidden markov machine that learns the motion patterns of the inputted set of animations and identifies the similarities between them and allows a user to meld them together.

The inputted motion capture data consists of an array of different marker placements. Because of this, they use a reduced 20 marker schema from which they generate the joint rotations**.** One of the advantages of this methodology is that it allows the generation of longer animations. However, as it is with every machine-learning system, Style Machines**'** success rate suffers when the solutions required are significantly different from the original training data.

Kuznetsova et al. present an innovative technique where the mesh and the motion are combined, synthesizing both human appearance and human motion [29]. They attempt to generate both because data-driven approaches have been shown to produce physically incorrect animations and the transfer of motion data from characters that have different body proportions can produce unrealistic results. They use two sets of databases to match animations along with body mass, and use the resulting animation in a crowd generation demonstration. They evaluate their system with the help of human participants by having them review various videos on a scale of 1 to 4: visually plausible to completely unrealistic. The data gathered through this study shows that their model generates completely new models appropriately and produces overall realistic animations.

In Motion Synthesis from Annotations [30], Arikan & al combine constraint-based animations with data-driven methods to present a framework uses a motion database to generate user-specified animations. Users accomplish this by adding free form annotations (walk, run, jump, pickup, carry, crouch, etc) onto the animation time line. Their results show that their system is not only interactive; it is easy for users to improve their animations through an iterative process.

Other work in motion synthesis through machine learning includes the combination of IK solvers and a database of motion to create human manipulation tasks (pick-up, place) [31], the use of parametric synthesis and parametric motion graphs to produce realistic character animation [32], and the generation of two-character martial art animations [33].

## 2.2 Motion Editing

While the field of motion synthesis is growing, the reality is that a large majority of the motions in movies and video games are differently styled versions of different very similar actions (walks, runs, jumps, etc). Because of this, there's a growing body of work focused on changing already existing animations to suit new production needs.

### 2.2.1 Motion Editing through Physics, Space-Time Methods, Motion Databases and Machine Learning

This section presents work that creates new motion from pre-existing animations through the use of space-time constraints, through the application of real-life physical rules and through machine learning.

In "Physically based motion transformation" [34], Popovic and Witkin suggest an extension of their previous work [22] in an algorithm that implements dynamics when modifying captured data. Their method can be broken down into four major steps: Character Simplification, Space-time Motion Fitting, Space-time edit and Motion Reconstruction. They begin by simplifying the inputted character animation, solving the best space-time motion solutions, adding new kinematic constraints and rules and re-applying the animation to obtain a final result.

Popovic & Witkin's method focuses on producing high quality realistic animations. Their results show that they accomplish this appropriately when it comes to high energy movements, as these specific actions benefit significantly from the dynamic simulations. However, they suggest that low energy animations, such as walking or sitting down do not gain much from the algorithm's process, as high realism (muscle contractions) is rarely needed to make these motions look believable.

In "Motion Editing with Spacetime Constraints", Gleicher presents a method that allows an animator to edit an already existing animation while preserving the inherent quality of the original motion [35]. The main goal of this research is to modify high-quality animations that are already fundamentally good but require tweaking, such as making a character jump higher, avoid an obstacle, crouch, etc. He accomplishes this with an interactive system that allows for the editing of 2D and 3D characters. The common method of interacting with an animated character, as mentioned previously, is through IK handles. While they're generally useful, Gleicher argues that they provide no control of what is happening with the animation between keyframes. When manipulating a characters' IK, an animator can only control one keyframe at the time. Because of this, they developed their algorithm that determines the best movements that satisfies the animator's new positioning while maintaining the spacetime constraints set by the initial motion. This is an improvement from the original paper that implemented spacetime [22] constraints, but did not allow for any interactivity. However, they did not implement any dynamic constraints. They tested their results over a series of 2D and 3D animations and proved that their methodology works. However, they discovered that their system allows an animator to accidentally destroy the physicality of the original motion. They also realized that they did not add sufficient control points.

In “Style-Based Inverse Kinematics”, Grochow et al build a system that produces poses using a set of constraints and a probability distribution over the space of possible poses [36]. This allows them to create multiple animations through one pose combined with a different set of constraints. They successfully interpolate between animation styles (with the use of a motion database) and test the performance of their system through trajectory keyframing and motion capture editing. Because a leading video game developer licensed their product to speed up rapid content development, they argue that their system can replace traditional IK systems. However, they admit that their system does not compute dynamics, and their results would strongly benefit from their implementation.

In “Classification and translation of style and affect in human motion using RBF neural networks”, Etemad & Arya extend their previous work in action recognition and style transformation [37] to present a system that extracts and classifies stylistic qualities from motion capture data by training a group of radial basis functions (RBF) neural networks [38]. With the different classifications, the system can then translate one type of animation into various different versions of stylistic motion. For example, a user can input a neutral walk and output a happy walk. Beyond the RBF neural networks, they found that time warping is necessary. They do so successfully by applying correlation optimization as well as reference data.

An interesting quality of human motion is that it contains a significant amount of redundant data. Because of this, Etemad and Arya use Principal Component Analysis

(PCA) [39] to categorize the data in a more optimal fashion. However, as the motion translation requires the entirety of the animation to change, they only use PCA when classifying the data. The successfully generated animations are shown to be highly accurate through a set of numerical and perceptual tests.

Petre & Laumond present a motion capture-based control-space approach for morphing animation speeds in a virtual environment [15]. Their methodology implements various methodologies: they use a motion library that is used to compute quantitative characteristics (linear and angular velocities) and blend the selected samples (from the library) in the frequency domain (section 2.2.2). Their work allows for real-time editing of a mannequin's displacement. However, they note that their system is restricted to a limited amount of cases and is only applicable to flat surfaces.

Other work in the area includes Min et al.'s use of human motion databases and multilinear analysis to synthesize, edit and transpose motion to and from a large variety of actors [40] as well as Tak and Ko's physically-based motion retargeting filter, that presents a per-frame kinematic and dynamic constraint based system [41].

### 2.2.2 Motion Editing through Warping of Realistic Animation

Motion warping and editing consists of taking pre-existing motion and editing it to clean it up or modify it to get an array of different derivative animations from one source motion. A classical application of this is a method that fits a curve over the raw animation data and allows the editing of the curve's control points. However, while a curve effectively reduces the amount of data points, the number is similar to keyframing an animation by hand. Another way of editing both manually key framed animations and motion capture animations is through the use of different algorithms that act as modifiers or filters on the raw animation data, such as joint position, rotations or degrees of freedom.

Witkin and Popovic's [9] research objectives stem from these goals. They propose a function that takes the original curve values and allow a user to manipulate the scale and the scalar addition of the values, using an interpolation curve (cardinal in his case) to achieve a smooth curve. They highlight two main issues with their solution: The difficulty of applying any geometric constraint on the warping process as well as the fact that their algorithm does not take in consideration the original or the warped motion's structure.

Bruderlin and Williams [42], introduce techniques from the image and signal processing field for motion editing. They collect all motion parameters from the animation curve of a pre-determined keyframe and convert this into a signal. Until now, the large majority of the papers this thesis discusses focus on the joint and angle positions of the human hierarchical representation. In their work, Bruderlin and Williams apply signal-processing techniques and modify an animation's trajectory or speed. The different methods they discuss are Multiresolution Filtering, Waveshaping, Multitarget Interpolation and Motion Displacement Mapping.

They apply multiresolution filtering on a walk animation by increasing the different sub-sections of the different frequencies collected from the original motion signal. Their results show that when they increase the middle frequencies, they obtain a walk-cycle that's both smooth and exaggerated. However, when they choose to only increase the high frequencies, they cause unnecessary twitching of the character.

Although they do not explain the reason, we believe that by increasing those high frequencies, they are dramatizing the effect of the noise in the original data. Finally, when increasing the low frequencies, they resulted in a constrained walk with reduced movement.

Bruderlin and Williams also explore Multitarget Interpolation to attempt animation blending. Their test-trials took multiple animations and blended the animation curves at different percentages. For example, they used two samples: an angry walk and a sad walk, and asked for user input when blending the different frequencies together, thus resulting in an animation that exhibits both anger and sadness. While this is interesting, it requires the system to have both animations to produce results.

### 2.2.3 Editing Realistic Motion into Cartoon Motion

Wang et al. present a method called "The Cartoon Animation Filter" that takes arbitrary input motion and outputs a more animated version of it. By subtracting a smoothed version of the second derivative of the original curve to the original curve itself, they are able to add anticipation/follow-through and squash & stretch to a variety of input data. Their method is the equivalent of applying an inverted Laplacian of Gaussian filter on the animation curve data. This algorithm can be expressed mathematically as:

$$x^{*}(t) = x(t) - x''(t)$$

They automatically generate good default values for their algorithm and apply it to a large variety of motion signals, such as hand drawn motion, trajectory-based animations, video objects and motion capture data.

When filtering Motion Capture data, Wang et al. ran into the recurring problem of foot-sliding/skating [43]. Foot-sliding happens when one edits the leg movements of a hierarchical skeleton structure. This can cause the foot to move when one would expect it to stay immobile. To attempt to remediate this, they recorded the times where the foot was on the ground and adjusted the root translation accordingly. They also apply other types of constraints, such as fixing the feet on a skateboard to prevent the character from floating above of it.

In their conclusion, they acknowledge that the resulting animations do not satisfy the expected quality of hand-crafted animations and are more suited for quick, preview-quality animations.

White et al. build on Wang's work by creating a SISO (slow in, slow out) out filter [1] that, when used correctly, can "add energy and spirit" to an animation. They accomplish this by identifying eligible key frames using Kinematic Centroid segmentation [44] and then applying a time-warp function to obtain the desired result. They demonstrated the effectiveness of their algorithm with a few motion-capture animations, but their paper shows little description of their final result.

Kim et al. attempt to generate cartoon-like anticipation effects by reversing joint rotation and joint position values. Anticipation in animation describes the phase in which the character prepares itself for a subsequent action [45]. For example, as shown in Figure 2.1, a character might bend his knees significantly before performing a large jump.

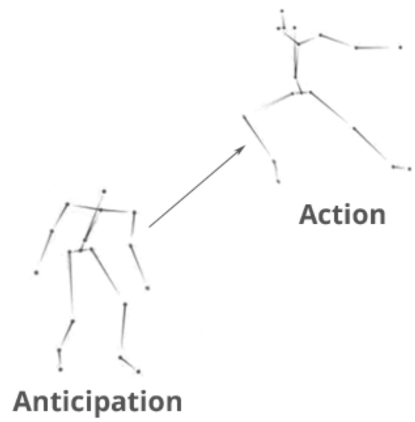


**Figure 2.1 – Anticipation**

They successfully add or exaggerate the anticipation effect of an animation by taking the joint rotations of the character during the action, and applying the reverse value to the anticipatory pose. To dramatize the effect, they also pull the characters' center of mass in the anticipation stage backwards (in relation to the action). They determine the amount of anticipation needed by the relation of how long the actions in in comparison to the anticipatory pose. In short, the longer the action, the longer and the more dramatic the anticipation phase must be.

Kim et al.'s results show that their anticipation generation produces more expressive animations and that it's an efficient tool for amateur animators. However, the main drawback of their system is that it heavily relies on user input to define the anticipation stage and the action stage, a task that proved to be time consuming for some users.

Along the same lines, Kwon and Lee presented a bilateral filter for slow-in and slow-out effect [46] that can be applied to any motion signal. Their method uses a modified version of the bilateral filter introduced by Tomasi and Manduchi, normally used for image processing [47]. Previous methods focus on animations where the keyframe information is available and easy to access. As mentioned previously, some animation methods involve the generation of movement by using laws of physics (rigidbodies). These do not possess any keyframes, and using methods that solely rely on keyframes would be impossible in this case. Kwon and Lee's method only needs the trajectory to modify it. The algorithm focuses on the extreme poses on an inputted motion signal and extends their length to enhance the inherent SISO properties of the original animation.

Savoye [48] presents a method that uses Wang et al.'s cartoon filter to allow an animator to modify a pre-existing realistic animation with a single editing point. For example, a user can move an ankle and Savoye's algorithm estimates the global position of all the other joints in the skeletal hierarchy. He achieves this by minimizing the sum of squared difference between the original motion capture data and the animator-edited animation data. However, Savoye's results suffer from the same issues as the cartoon animation filter. While the resulting animations do provide adequate cartoon characteristics, the overall quality is lackluster when compared to key framed animation.

## 2.3 Other methods

In "Turning to the Masters: Motion Capturing Cartoons", Bregler et al. present new techniques to extract motion data from two-dimensional animated clips [49] (from both cartoon contours and unlabeled videos). They accomplish this by tracking affine motion and interpolation-based weights. They effectively retarget this data to new 2D and 3D characters. Despite their success, their system suffers from a few issues: while 2D to 3D mapping is possible, it is a complex procedure that is taxing to the user. Furthermore, the complexity of the key-shapes is directly tied with the complexity of the animation. This means that in certain cases, it can be more time consuming to extract the data using Bregler et al.'s system than to re-animate the whole sequence by hand.

In contrast, Kwon and Lee developed a system that allows animators to add squash and stretch effects (akin to rubber) to existing motion capture data [50]. They accomplish this by exaggerating joint-trajectories and modifying the inherent skeleton-structure of the character to allow for cartoon-like limb squishing and stretching. They attempt this method because an animator cannot go beyond the limits posed by a character's skeleton. Previous work in the field focuses on the exaggeration of a character's joint angles, both in the Euler and the Quaternion domains [11], [42], [51], [52]. In contrast, they focus on exaggerating joint trajectories.

Kwon and Lee's algorithm modifies motion capture animations in two phases. At first, they compute the trajectory-based exaggeration by stretching the pre-existing joints. Once that's completed, they divide the hierarchy into sub-joints (as shown in Figure 2.2) to allow for the generation of animations that exhibit a rubber-like effect. Finally, as an added step, they augment the exaggeration by applying a mass-spring simulator to the sub-joint hierarchy. This is done to add more visually appealing motion and enhance the follow-through of the animation.

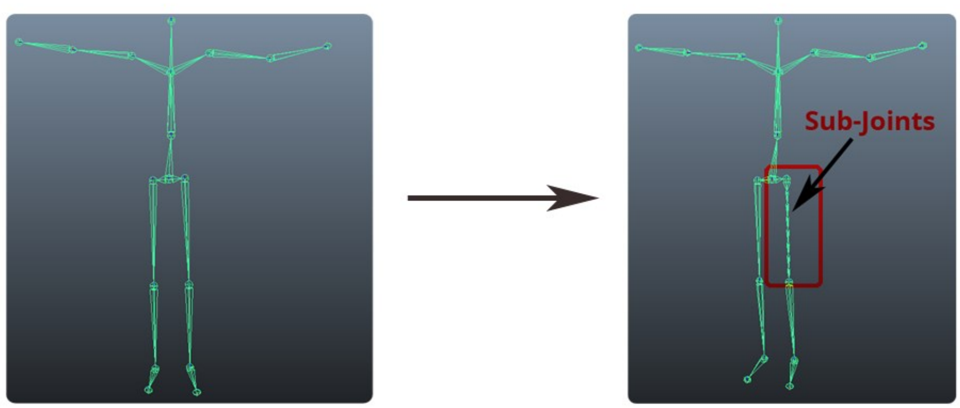


**Figure 2.2 - The Creation of Sub-Joints**

To test the effectiveness of their results, they applied their algorithm on multiple recordings of motion capture data. While they were able to overcome the traditional constraint of bone-based animation, especially when trying to stretch joints, they noted the following limitations:

When editing the data, they realized that it was easy for an animator to accidentally overextend the joints and give the effect of “a broken joint”. They also acknowledge that for their algorithm to work, they require a significant amount of data (six degrees of freedom). They also suggest the further work on their algorithm take into account the possible collisions between joints and avoid overlap between joints. Because of this, their current implementation cannot guarantee that the final mesh of a character won’t be negatively affected by the exaggeration.

## 2.4 Animation Editing Systems and User Interaction

While the algorithms behind systems are paramount for the quality of the resulting animations, the human factor is equally important. A system that provides excellent results but is impossible to use is, despite all of its qualities, unsuccessful. [53]. In the following section, we will present a short overview of the state of usability considerations in the field of motion synthesis and editing.

Many of the research projects presented above focus on the system functionality and performance without any mention of the human factor involved [9], [50]. For example, the cartoon animation filter [11] does not describe any method of system interaction. Various other works, such as space-time constraints, and others [21], [22], [40], [54] consider usability issues, but do not formally test for them. Despite this, there’s a considerable amount of interesting interaction systems that have been developed. For instance, Style Machines [54] uses a series of control knobs to manipulate the difference stylistic changes to the animation, and Gleicher' work allows for direct manipulation in 2D and 3D space. In contrast, Rose et al. allows human users to generate motion transitions through the a motion expression language [24].

# 3 Chapter: Proposed Method

This chapter describes in detail the specifics of our motion capture system, the overall procedure for our recording sessions, as well as the different elements of our animation editing algorithm and the curve-based user interface that accompanies it. Figure 3.1 shows an overview of our methodology. We begin by collecting realistic data from participants, and then we develop both the front-end (user interface) and the back-end (algorithm) of the system. Following this, in part A of our user studies, we ask participants to edit the data collected in our first motion capture data collection step, and in part B, a different set of users evaluate the results produced by participants in part A of the studies.

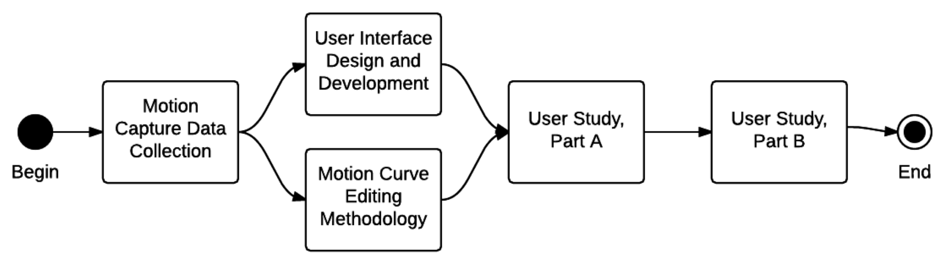


**Figure 3.1 - Methodology Overview**

Our method differentiates itself from previous work because:

- We propose an algorithm that modifies animation curves by manipulating the local maxima and minima and interpolating the remaining points.
- Our software is directly embedded in already existing professional animation software.

- Through our curve-deformation based interface, amateur users can easily edit motion capture data (see Chapter 4:User Studies)

# 3.1 Motion Capture System

In this section, we describe the various specifications of our motion capture system and our recording methodology. We discuss the hardware and software used, our pipeline and our specific recording procedure with our actors.

## 3.1.1 Hardware

As briefly covered in our introduction, we use an optical motion capture system to record all of the animation data in our research (Figure 3.2). This system contains, in total, ten cameras. Each one has its own onboard processor that allows them to pre-process the data before sending it to the main console to be processed into three-dimensional positions. To improve the visibility of the markers, each camera has a ring of reds strobing lights that illuminates them.


**Figure 3.2 - Motion Capture Room and Vicon Cameras**

In order to track human motion, we attach reflective markers to participants. We avoid gluing them on the body by having them wear a tight, black Velcro suit that prevents unnecessary reflections that might be caused by skin (Figure 3.3).

**Figure 3.3 - Two Participants in the Motion Capture Suits and Markers**

We use in total, forty-five 18mm markers (polystyrene spheres covered in a retro-reflective material) placed on different locations on the body. Figure 3.4 shows the overall placement of the markers on the suit, as required by our default human template. To optimize the capture results, we place the markers as close to the joints as possible (such as the elbow) and bones (such as the tibia in the leg, the radius in the arm).

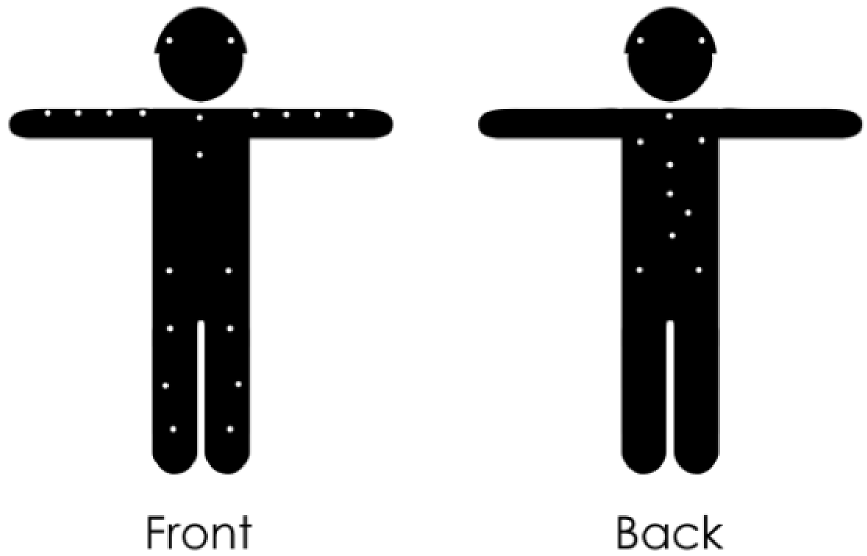


**Figure 3.4 – Overall Marker Placement on the Motion Capture Suit**

### 3.1.2 Software

We use Vicon Blade 1.7 from Oxford Metrics [55] to record all of our data. The main advantage in using Blade is that, unlike previous software (eg: Vicon IQ), it directly retargets the marker motion onto a skeleton that's easily exported into the Filmbox (.FBX) format. The FBX format is a flexible file type that allows animations to be imported in various content-creation applications (such as Autodesk Maya, Unity3D, Quicktime, etc) [20]. However, because of the large amount of keyframes that are exported by the Vicon Blade system (one keyframe per frame, 120 frames per second), we import the data into Autodesk Maya and reduce the keyframes within that system.

### 3.1.3 Pipeline

Our motion capture system requires a very rigid pipeline in order to record animation effectively. We followed the procedure (Figure 3.5) outlined on Carleton University's School of Information Technology's Vicon Blade online guide, which contains detailed information about project creation, system setup and calibration as well as the recording and exporting process [56].

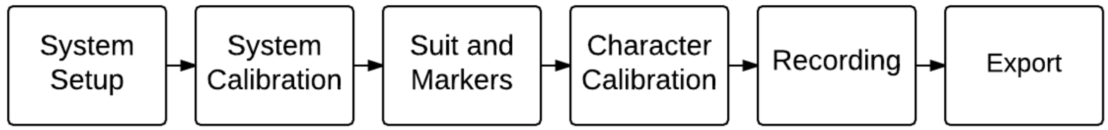


**Figure 3.5 - Overview of the Motion Capture Process**

## 3.2 Data Collection

In order to provide a large variety of input data for our system, we collected several animation clips from a total of 15 participants (8 male, 7 female) in 2 hour motion capture sessions. As shown in Table 3.1, we had originally planned for eight categories of physically/impossible plausible animations. These motions are actions that are impossible for a human actor to re-enact, yet are omnipresent in cartoon movies; making them a perfect input for our work. However, since we wanted to create a curve-modification algorithm that could be applied relatively uniformly to all of our collected data, we decided to focus on exaggerations, large jumps, and gait editing.

**Table 3.1 - Animation Types**

| Animation Type | Definition |
|---|---|
| **Exaggerations** | Movement is physically plausible but difficult to re-enact by a regular actor. |
| **Ignoring Physics (Momentum/Gravity)** | Character moves in a fashion that ignores the rules of physics. |
| **Speed (very fast, very slow)** | Character moves at an abnormal speed. |
| **Joint Disconnection** | Character's joints disconnect and reconnect at will |
| **Joint Stretching and Bending** | Character's bones stretch and bend at inhuman proportions |
| **Acrobatics: Large Jumps** | Characters can jump very high. |
| **Acrobatics: Flips** | Characters can perform impossible flips. |
| **Acrobatics: Sliding** | Characters slide around as if on wheels/ice. |

### 3.2.1 Source Clips

Due to the nature of our research goals, our motion capture animations are inspired from a collection of different animated movies. Of course, because they are re-enacted by real human beings with real human-proportions, we do not expect the motion capture recordings to be 100% faithful to the animated movie clip. Instead, we use it as a base for interesting recordings that can be both re-enacted by motion capture actors and edited by our users. Because of these constraints, we chose snippets of animations from movies that had a large variety of bipedal characters, such as Toy Story, Rise of the

Guardians, Frozen, Despicable Me, The Croods and Hotel Transylvania (Table 3.2, Figure 3.6 and Figure 3.7 ).

**Table 3.2 - Source Animations**

| Exaggerations | | Jumps | |
|---|---|---|---|
| Movie | Animation | Movie | Animation |
| *Disney's Frozen* | Elsa's Exaggerated Walk | *The Croods* | Guy Jump |
| *Toy Story 3* | Woody Run Cycle | *Despicable Me* | Gru's Jump |
| *Disney's Frozen* | Duke of Weselton's Quirky Bow | *Despicable Me* | Gru's Jump Kick |
| *Hotel Transylvania* | Dracula's Dance | *Rise of the Guardians* | Jack Frost's Jump |
| *Hotel Transylvania* | Monster Dance | | |

**Figure 3.6 – Elsa from *Frozen* walking across her ice palace** [57]

**Figure 3.7 – Dracula from *Hotel Transylvania* dancing [58]**

### 3.2.2 Recording Procedure

For each participant, data collection process followed the following procedure,

1. Before the participant's arrival, the researcher calibrates the room to ensure optimal data quality.
2. User arrives at the motion capture room (Azrieli Pavilion, room 134). Before the data collection can begin, participants are asked to sign a consent form (Appendix B).
3. Researcher gives the participant a few size choices for the motion capture suit and asks them to get changed in the nearby bathrooms.
4. After their return to the motion capture room, the researcher places all forty-five markers on the participants body as shown in Figure 3.3 and Figure 3.4.
5. Participants are encouraged to stretch before the recording session. Once ready, researcher calibrates the system with the participant's individual

marker configuration and recording begins. Before each recording, the researcher shows a clip of the example animation and allows participants to practice until they are ready to record (for a maximum of 5 minutes).

6. All participants re-enact all clips three times and each session follows the same order of animations.
7. Participants are encouraged to take breaks for rest or water, as some of the recordings can be physically tiring (jumps, runs, etc).
8. After all recordings have been completed, participants are asked to get changed back into their everyday clothes and are given $20 as a compensation for their time.

### 3.2.3 Data Exporting

The Vicon Blade system provides us with 3D position data for each marker. In the interest of our research goals, we transfer the positional animation onto a hierarchical based skeleton. This effectively changes seemingly unrelated marker positions onto one unified character whose motion is achieved through joint rotations.

## 3.3 Plugin Development

### 3.3.1 Development Platform

We use Autodesk Maya's IDE, Python 2.7 and various libraries (PyMel, OpenMaya) to develop a plugin that allows a user to edit animation data from an imported Vicon Blade skeleton (in .fbx format).

### 3.3.2 Exaggerated Animation Curves

We use a method that's reminiscent of Wang and Drucker's work [11], which exaggerates the peaks and troughs of a curve to add cartoon-like motion to an animation curve. However, instead of using a Laplacian Gaussian curve function to dramatize the peaks, we define an exaggerated point (x') as the addition (when greater than the median) or subtraction (when smaller than the median) of a user specified coefficient C. This coefficient is scaled in to take the relationship between the original point x, the median (m) and the global maximum or minimum values of the overall animation (M).

$$x' = x \pm (C * ((x - m) / (M - m))) \quad (1)$$

As motion capture data has a high frame density, we simplify the animation curve by determining where the local minima and local maxima of a curve are located. To reduce the processing power required, we only apply the exaggeration formula above to the pre-determined points (shown in Figure 3.8) and use cubic interpolation to determine the points in between.

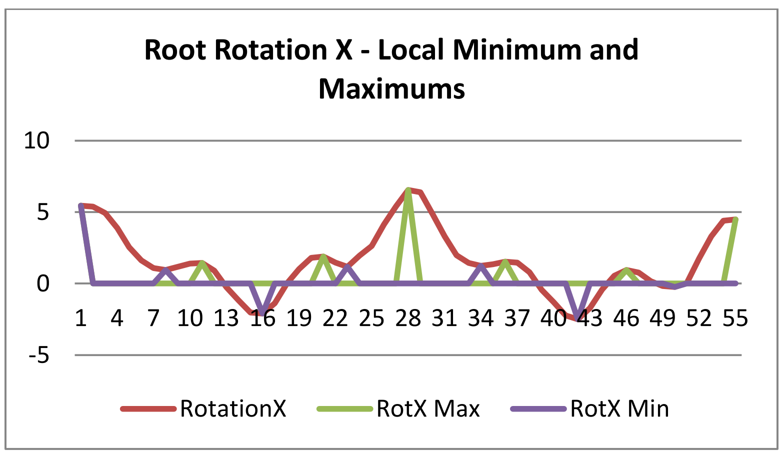


**Figure 3.8 - Local Maximum and Minimum of the Root Joint (X)**

Figure 3.9 shows a comparison between the original data and the result of interpolating between the pre-determined local minimums and local maximums. While there is a slight amount of motion detail that's lost around frames 1-7 and frames 51-55, the overall nature of the curve is maintained.

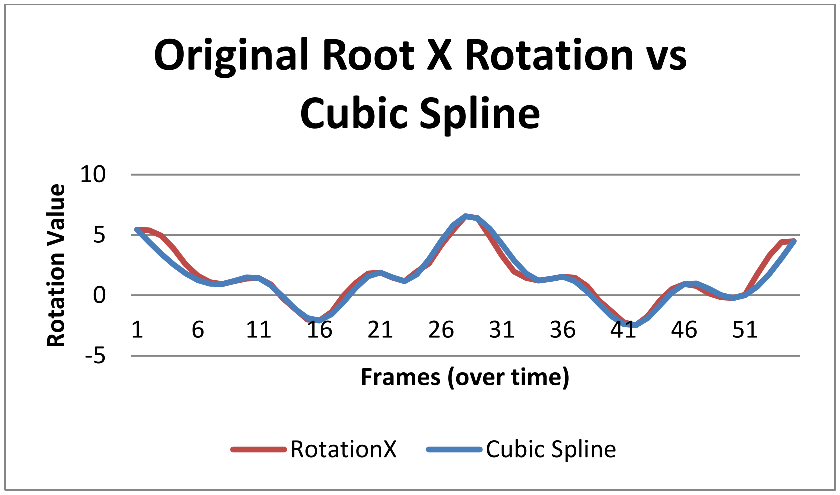


**Figure 3.9 - Original rotation vs cubic interpolation**

Using the equation 1 in Section 3.3.2, we exaggerate the peaks and troughs of the original curve to obtain an overall exaggerated curve (Figure 3.10).

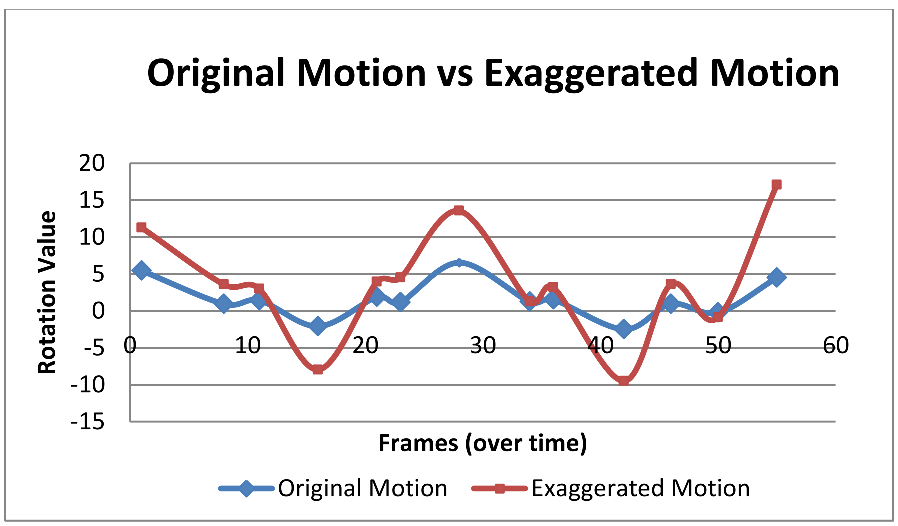


**Figure 3.10 - Original and Exaggerated Curve**

Finally, to summarize our overall process, the flow chart in Figure 3.11 gives a visual overview of our algorithmic process.

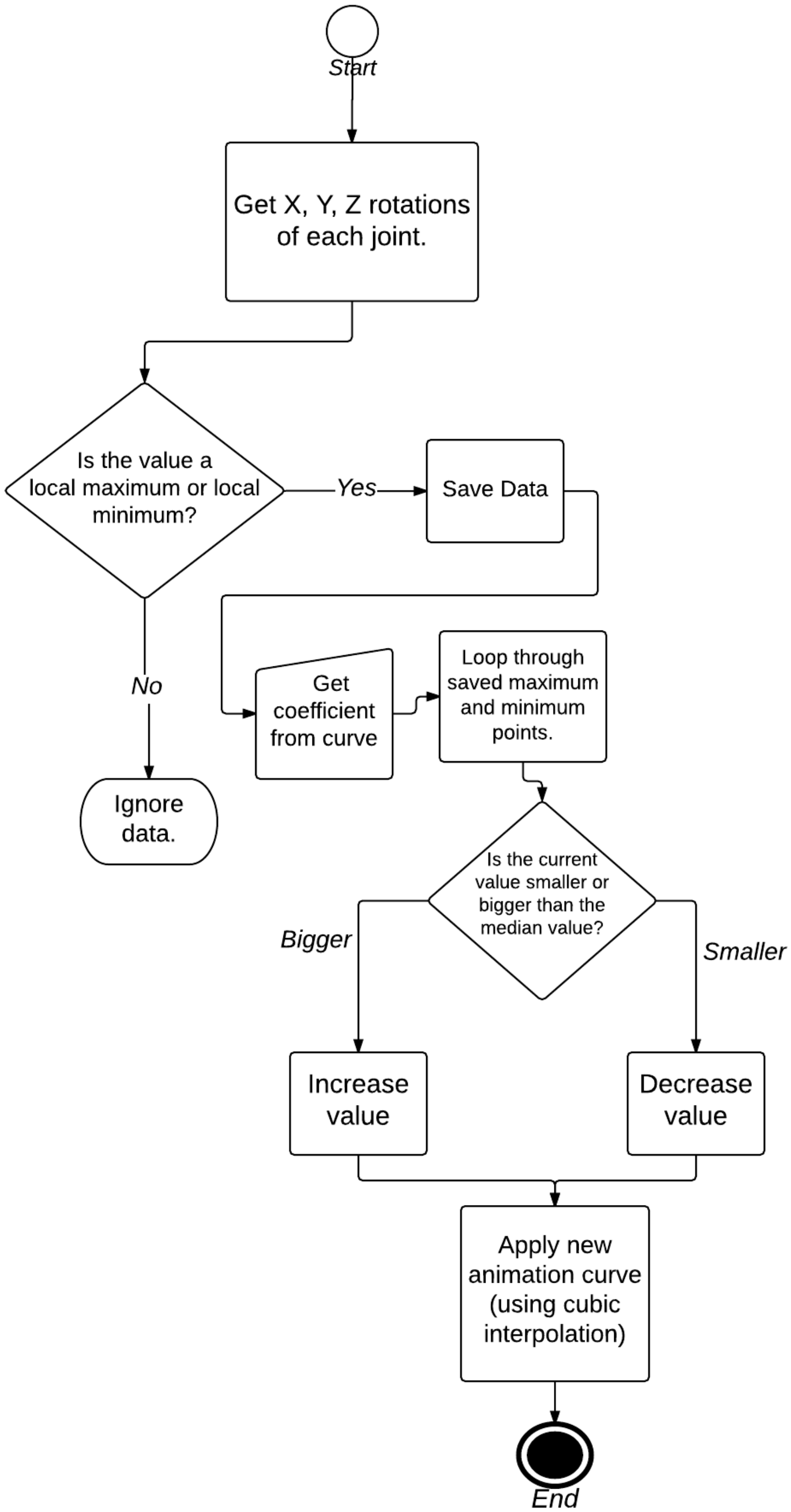


**Figure 3.11 - Exaggeration Process**

### 3.3.3 Foot Sliding

A ubiquitous problem with editing human motion through joint rotation values is that, because all the joints are organized in a hierarchy, exaggerating the rotation values of the parent joints can cause unexpected results further down the hierarchy. While this doesn't affect the upper body negatively, it causes something called foot sliding or foot skating, and is generally a problem that still hasn't been completely solved [43]. Because this affects the appeal of our animations significantly, we implemented a fix that uses inverse kinematic handles to anchor the feet on the floor. To determine when the foot is bearing weight (and thus, immobile), we find the local minimums of the Y position of the ankle and key-frame the IK handles to those positions. This process prevents the feet sliding effect from happening. While this effectively reduces the overall exaggeration of the lower body, it allows us to avoid awkward animations where character's legs seem to be sliding erratically on the floor.

### 3.3.4 Jump Trajectory Exaggeration

Our jump trajectory exaggeration feature is similar to our previous section (3.3.2). The main difference is that instead of exaggerating the rotation values of all the joints, we specifically target the Y translation value and apply our algorithm on that specific axis. This results in jumps with higher amplitude and an added bouncing motion to the landing sequence (more detail in Section 5.1, Algorithm Results). Furthermore, to avoid an over-simplification of the jump trajectory, we maintain more than simply the maximum/minimum keyframes.

### 3.3.5 Neutral Walk to Exaggerated Feminine Walk

Animated movies often exaggerate movement based on stereotypes; an example of this is the fashion in which most female characters walk. These characters can exhibit physically impossible movement of the spine, hips and legs. We use the peak and through modification algorithm once more to modify a neutral walk into a stylized female walk akin to characters such as *Jessica Rabbit*, *Elsa* from *Frozen*, etc. However, instead of arbitrarily increasing the maximum and minimum values uniformly, we target the main features of the walk and modify them accordingly.

In order to determine how to change a neutral walk into a feminine-stylized walk, we collected samples of a neutral walk and of exaggerated female walks. To compare them accurately, we determined the beginning of each walk cycle by looking at the Z position of the foot joint.

With the cycles lined up, we looked at the difference in amplitudes between our neutral walks versus our exaggerated walks. Using a combination of the data points collected, we determine the coefficients portrayed in Table 3.3.

**Table 3.3 - Stylized Female Gait, Joint Coefficients**

| Joint | X | Y | Z |
|---|---|---|---|
| **Root** | 7.0 | -1.5 | 10.0 |
| **Spine** | 2.5 | 0.7 | 6.0 |
| **Shoulders** | -0.5 | -1.5 | -0.5 |
| **Arms** | -3.0 | -15.0 | 0.5 |
| **Hips** | 10.0 | -5.0 | -X *2 |

By adding scaled versions of these values to the stylized walk, we approximate the actual rotation values of the exaggerated female walk. Figure 3.12 shows the X rotation of the root joint for three animations: the original (neutral) walk is in blue, the actual feminine exaggerated walk is in green, and the edited version is in red.

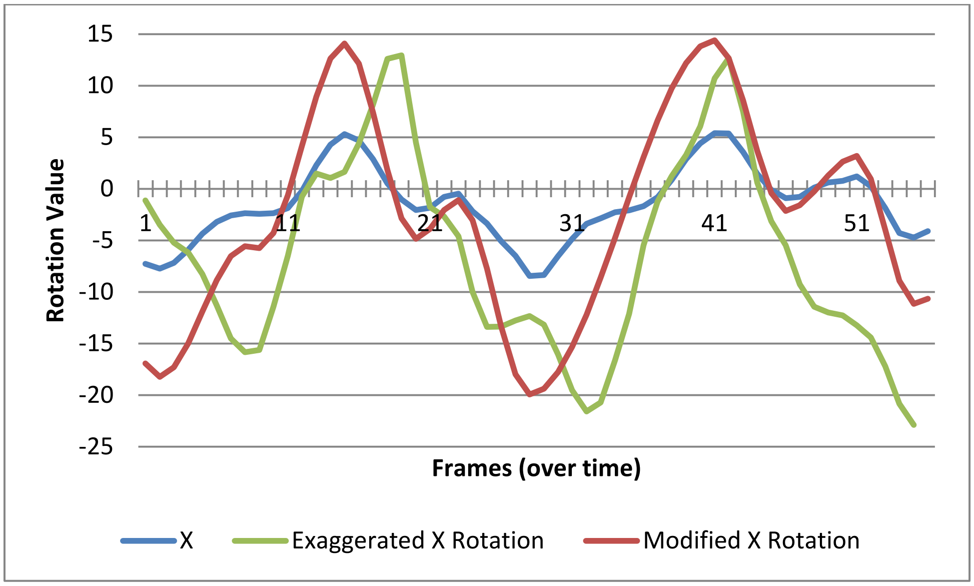


**Figure 3.12 - Comparison between original (blue), edited (red) and actual exaggerated (green) rotation curves of the spine Z rotation**

Additionally, as mentioned in Section 3.3.3, Foot Sliding, exaggerating the hip and root joint rotations caused a significant amount of feet sliding. As a consequence, we opted to anchor the feet with IK handles and bring them closer together to give the illusion of an exaggerated hip motion. While this reduces significantly the direct rotational exaggeration of the hip, it allows us to avoid the very distracting artefact of feet sliding.

### 3.3.6 Time-shifting the Animation

To emphasize the extreme motions of the animations, we allow users to slow-down the local minimum and maximums. To maintain the homogeneity of the algorithm, we use the root joint as the reference joint to base when to slowdown the animation. We chose this specific joint for its relative position (at the character's center of gravity).

## 3.4 The Curve Interface

We created a curve interface to give users an easy and straightforward way to edit motion capture clips while providing a visual metaphor for the changes that will be applied on the animation. This is a simplified version of how animators currently edit animation curves. However, instead of potentially hundreds of control points (x,y,z coordinates, hundreds of keyframes, etc), we reduce the interactions to three arrow controls. Figure 3.13 shows two curves: the first curve, in grey, denotes the default position of the curve. The red curve shows an attempted user edit. The X axis denotes time and the Y axis denotes "amount of change". If users try to apply the default curve to the animation, there is almost no change. In such case, the system finds the local maximum and minimum and re-creates the curves using cubic interpolation, but without changing the peaks or troughs. Conversely, any change in the Y axis will increase the local maximums and decrease the local minimums.

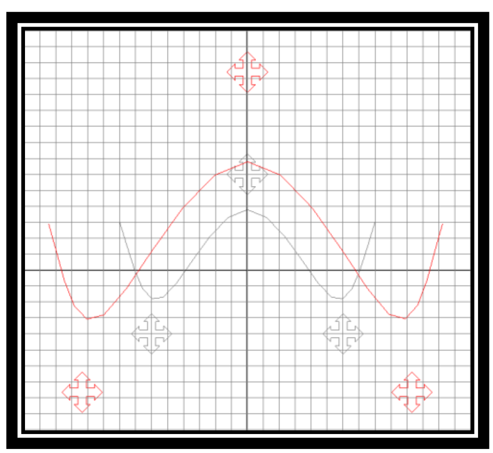

**Figure 3.13 - Curve User Interface, grey curve shows the default curve setup, the red curve shows a user modification.**

Users manipulate the curve by translating (with the default Maya interface) the arrow controls. These shapes are constrained to deformer clusters that move the curve's control points. This effectively morphs the curve depending on how the user pulls the curve. Figure 3.14 illustrates four different edited curve configurations (in red) in comparison to the original input (in grey) along with the deformer positions (shown as the letter c).

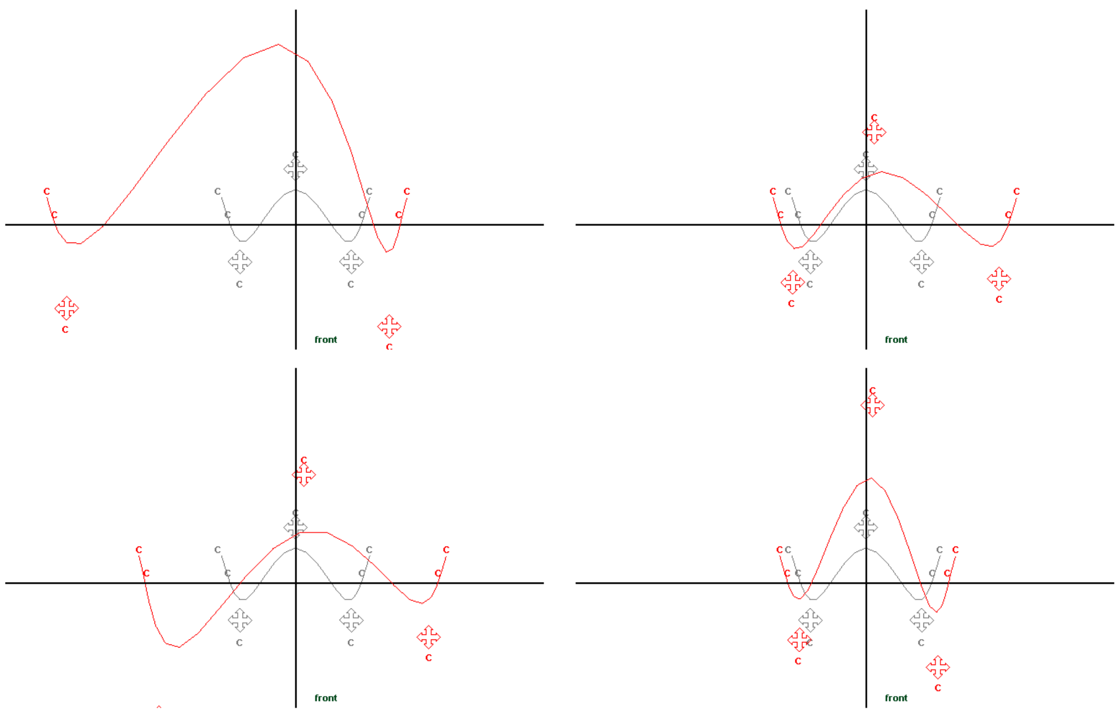


**Figure 3.14 - Curve Manipulation of the edited curve (red) in comparison with the original curve (grey) along with cluster deformers (shown as the letter C). 4**

In order to determine how to modify the animation in relation to the user-inputted curve, we calculate the distance between the clusters and create three different coefficients: One to determine the amount of change in the pre-determined local maximums and minimums of the curve (Y axis) and two to determine how to slow down the animation (the farther the cluster is from the center point, the slower the animation). The X axis relationship between the center control and the right control slows down the whole animation in relation to the local peaks of the root joint, whereas the relationship between the center point and the left control slows down the whole animation in relation to the local troughs of the root joint.

To initiate the modification process, users select how they wish to change the animation in a separate dialog window (

Figure 3.15 - Cartoon Animation Editor, Dialog Window).

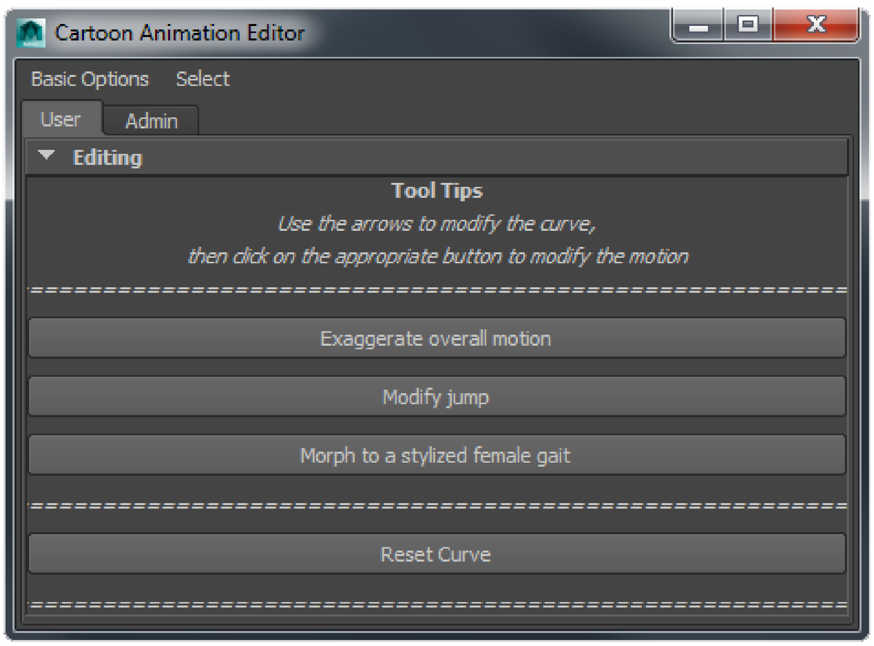


**Figure 3.15 - Cartoon Animation Editor, Dialog Window**

The complete system interface is illustrated in Figure 3.16. The curve based interface is on the left side of the window, the animation preview window on the center and the dialog window (on the right side) is mobile and can be moved around to a user's preference.

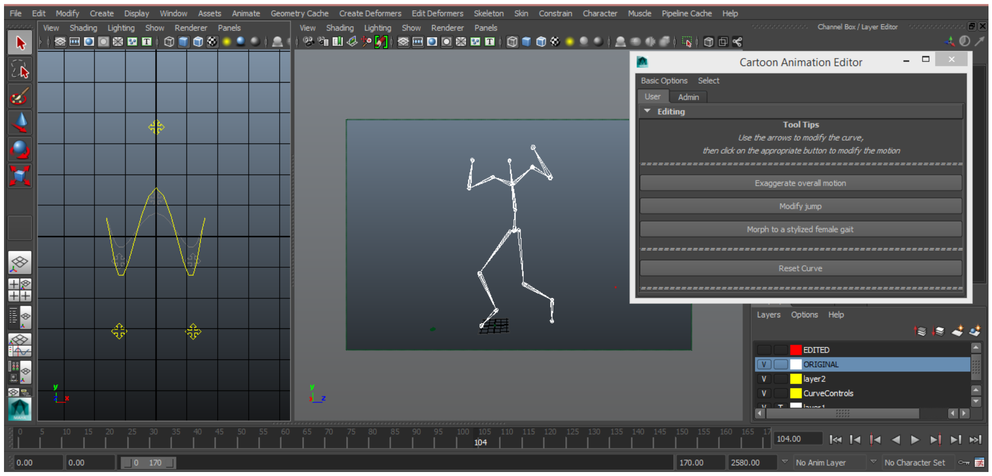


**Figure 3.16 - Complete System Overview: Curve Interface (right), Animation Preview Window (middle), Cartoon Animation Editor Dialog Box (right)**

# 4 Chapter: User Studies

This chapter explains the setup, the tasks and the goals of the two different phases of our user studies (A and B).

## 4.1 Part A – Editing Animations with our Curve Interface

In Part A of our user studies, we asked participants to edit a random selection of ten motion capture animation clips we recorded in our data collection phase. This includes one practice run and three animations per category (as explained Section 3.3). All outputted animations were saved along with the curve used to edit them, as well as a reference to their original clip. Our goal was to evaluate the system performance as well as the system's usability. We accomplished this by asking a series of questions related to the animation quality and the user interactions. The participants filled out a demographics questionnaire before the study began, an animation data sheet after each edited clip, and a final questionnaire at the end of the study to collect their overall opinion of the session (Appendix B ).

### 4.1.1 Goals

The two main goals of this first part of the study were as follows:

- Determine the overall usability of our animation editing system. Will people understand how to edit the animations? Will they grasp the dimensionality of the curve control? Will they find it easy or frustrating?
- Evaluate the visual results produced by the users and verify whether the curve input illustrates the changes in motion effectively. How do they feel about the original animation in comparison with the edited animation? Do

they understand the motion change? Which do they prefer? Do they see the relationship between the edited animation and inputted curve?

### 4.1.2 User Tasks

Because participants were recruited on campus without filtering for proficiency in animation or Autodesk Maya, we split our user tasks into two phases: basic tasks and animation editing tasks. We did this to establish a baseline of what an easy and what a difficult task is across participants. The basic tasks consisted of manipulating the character, the camera and the animation timeline. The animation editing tasks required users to exaggerate the movement, change a neutral gait into a stylized female gait and finally, exaggerate the jump trajectory. The time shifting functionality was available across all three tasks. A detailed overview of these user actions are shown in Table 4.1.

**Table 4.1 - User Tasks (Part A)**

| Basic Tasks (Skill evaluation tasks) | Animation Editing Tasks |
|---|---|
| Move the Character<br>• Translate<br>• Rotate<br>• Scale | Exaggerate Movement<br>• Amount of change<br>• Time Shift |
| Move the Camera<br>• Rotate<br>• Pan<br>• Zoom | Change neutral gait to stylized female gait<br>• Amount of change<br>• Time Shift |
| Manipulate the Timeline<br>• Play/Stop<br>• Preview the animation<br>• Change start/end of timeline | Exaggerate jump trajectory<br>• Amount of change<br>• Time Shift |

We also asked participants to fill out different parts of a questionnaire (B.1) at various points in the study in order to try to quantify the animation quality and their overall user experience (see 4.2.3 for more detail on the user study procedure).

### 4.1.3 Data Collected

During the study, we collected three types of data. As explained previously, we collected a variety of questionnaire data. We also saved all of the participants' resulting animation data along with the curve input used to modify it.

### 4.1.4 User Study Outline

For each participant, our user studies followed the following procedure.

1. User arrives at the study location (HCI Building, room 2111) and the researcher leads them to the work station. Before the study can continue, participants are asked to sign a consent form (A.2).
2. Participant is shown a quick demo of Autodesk Maya. This includes instructions on how to:
    a. Translate, rotate and scale the character.
    b. Rotate, pan and zoom the camera.
    c. Play the animation and change the timeline preferences.
3. Participant completes the actions mentioned above and answers the first part of the questionnaire (B.1)
4. Researcher explains the user interface and allows the participant to experiment with a test animation.
5. Once the user feels comfortable, they are asked to edit animations by using the curve and the box user interface. They exaggerate three clips; they turn three

neutral walks into stylized cartoon-feminine walks and increase the jumping motion of three jumps (eg, walk -> jump -> exaggerate -> walk -> jump -> exaggerate). The clips are randomly chosen from a library of various animations recorded during our motion capture sessions (Section 3.2, Data Collection). After each edited clip, the participant completes an animation data sheet (B.1).

6. After the participant has completed all the editing, they are asked to fill out the final part of the questionnaire (B.1).

## 4.2 Part B – Animation Review

In this second user study, we had participants watch fifteen animations that were created by participants in part A (three of each category) and collected their opinion through Likert-scale questions as well short and long form questions. Our goal was to evaluate the animation results and examine the relationship between the animation changes and the previously determined user input. The participants filled out a demographics questionnaire before the study began, an animation data sheet after each clip they watched, and a final questionnaire at the end of the study to collect their overall opinion of the session (Appendix B ).

### 4.2.1 Goals

Similar to our previous user study (Section 4.1), our goals were as follows:

- Compare and evaluate the animation quality by users who were not involved in the creation process and have no emotional attachment to the final product.

- Evaluate the user input as well as the relation of the curve in relation to the animation change.

### 4.2.2 User Tasks and Data Collected

We asked participants to watch and review a total of 15 animations, 3 for each category (5 jumps, 5 walks, 5 exaggerations). Users watched and compared animations and filled out the appropriate questionnaire (B.2). For this part of the study, we only collect user opinions through the questionnaire.

### 4.2.3 User Study Outline

For each participant, our user studies followed the following procedure.

1. User arrives at the study location (HCI Building, room 2111) and the researcher leads them to the work station. Before the study can continue, participants are asked to sign a consent form (Appendix A.3).
2. Participant answers the demographics section of the questionnaire (B.2).
3. Researcher explains the user study and shows participant how to:
    a. Play the animation
    b. Show/hide the original and the edited animation.
4. Participant watches animations and answers the corresponding animation data sheet. When finished, participant notifies the researcher, who sets up a new animation (with a random number generator). This is repeated until fifteen animations have been watched and reviewed.
5. After the participant has completed all the editing, they are asked to fill out the final part of the questionnaire.

# 5 Chapter: Results

This section presents the results related to the animations obtained from our algorithm as well as an in-depth analysis of the data collected in both parts of our user studies.

## 5.1 Algorithm Results

The following chapter shows examples of how our algorithm changes all three animation categories. A quantitative analysis of the participant user experience and rating of the animations is detailed in section 5.2.

### 5.1.1 Joint Rotation Exaggeration

Our method of exaggerating animation curves is as discussed in Section 3.3.2. This method is effective at intensifying the maximum and minimum rotational values of the character's joints (namely the root, spine, shoulders, arms, hips, ankles) without over-dramatizing smaller motions. During Part A of our user study, participants exaggerated the overall rotation of a total of 48 dances, walks or runs selected in a randomized order. Our algorithm successfully amplifies the range of motion of the characters to produce new, more cartoon-like animations. Figure 5.1 shows the motion graph of one of the dance animations, with the original curve in blue and the time-shifted, exaggerated curve in red. It also shows the user input used to determine the intensity of the animation change. Figure 5.2 is a visual comparison of the original animation and the edited animation. The main features to note in Figure 5.1 are the increased rotation values, the reduced number of keyframes (obtained through the interpolation between the maxima and minima) and a uniform slowdown caused by the X-axis modification of the user input. This exaggeration effect is also seen in Figure 5.2. Furthermore, it's important to note that the key-frame reduction obtained through the interpolation between local minimum or maximum, does not considerably change the nature of the motion.

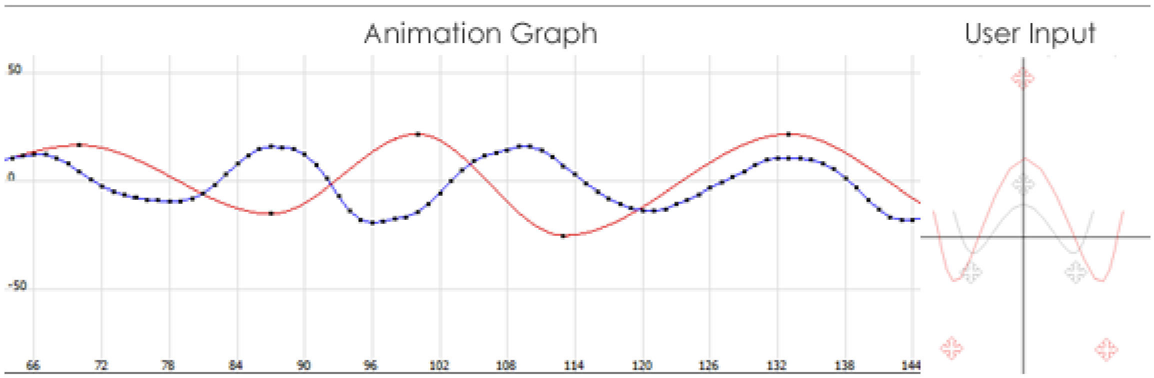


**Figure 5.1 - Original and Exaggerated Motion Graphs (Root Rotation X)**

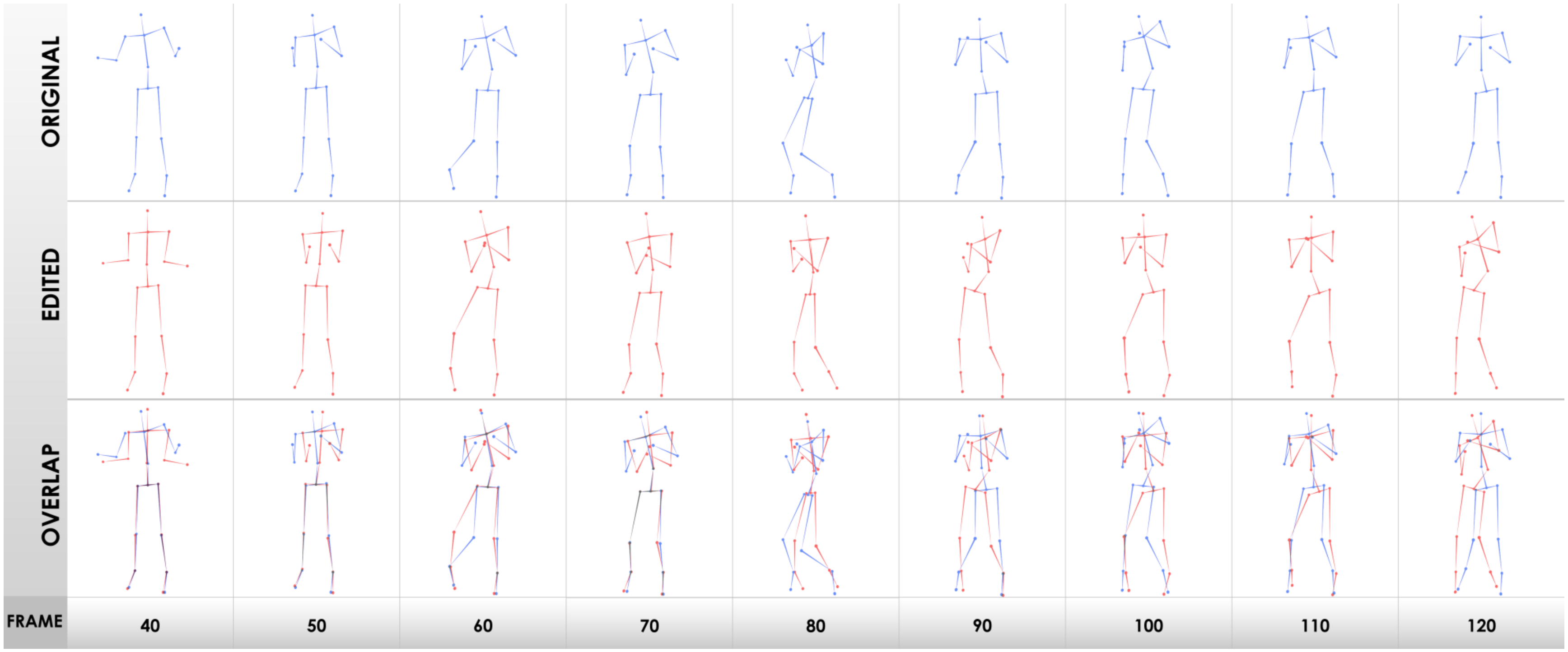


**Figure 5.2 - Original and Exaggerated Dance**

### 5.1.2 Jump Trajectory Exaggeration

As can be seen in Figure 5.3, our method of jump trajectory modification effectively increases the jump height and the anticipatory motion in an aesthetically pleasing fashion. The results related to participants' experience of the resulting animations can be found in Section 5.2. We asked participants to exaggerate the jump trajectory of three clips, chosen randomly from 48 different animation sources. Figure 5.4 shows the result of a single jump kick animation edit: the original animation is shown in blue and the edited version in red. The graphic in the top-right corner of Figure 5.3 illustrates the user input used to modify the animation. The corresponding graph illustrates the actual Y translation difference between the two animations (Figure 5.3).

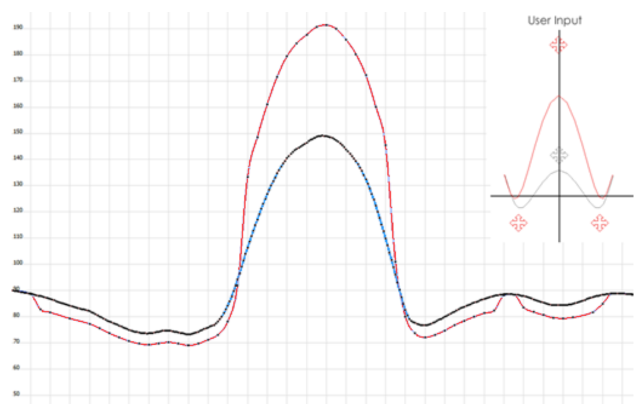


**Figure 5.3 –Original (blue) and Edited (red) animation curves for the animations in Figure 5.4 (Translation Y).**

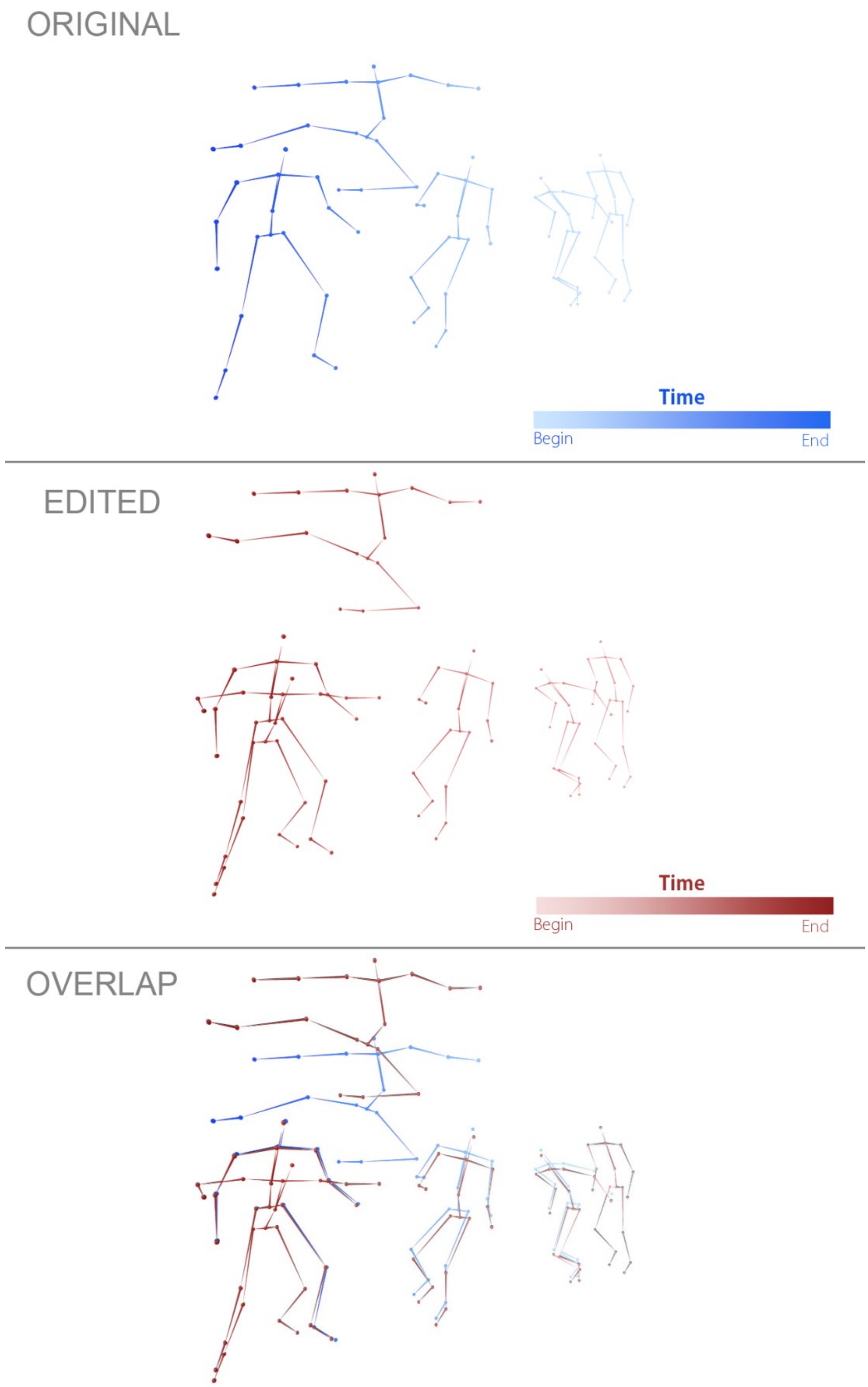


**Figure 5.4 - Comparison between an original jump and an edited jump**

Figure 5.5 and Figure 5.6 show another example of the results produced by our jump exaggeration algorithm, both in animation and final animation curve form. Note the increase in jump height and in landing blowback, as well as the reduced key-frames.

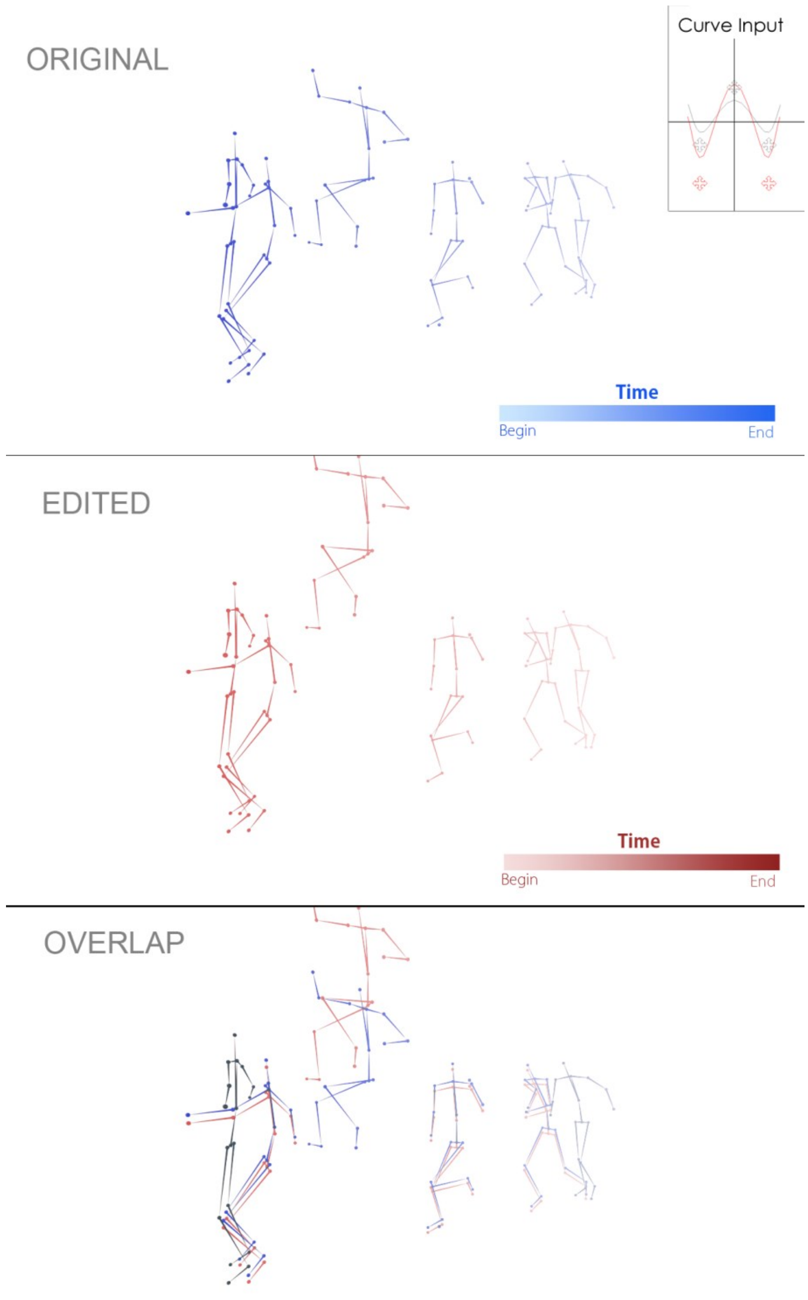


**Figure 5.5 - Original (blue) and Edited (red) jump animations**

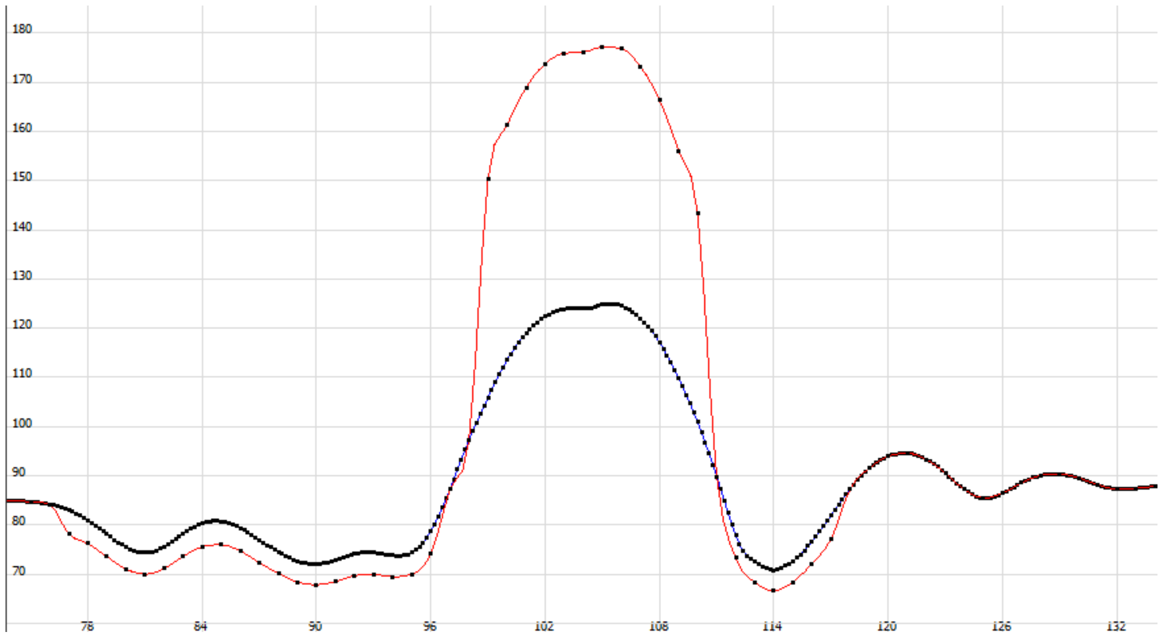

Figure 5.6 - Original (blue) and Edited (red) animation curves for the animations in Figure 5.5 (Translate Y)

### 5.1.3 Neutral Walk to Stylized Walk (Feminine)

Our final application of our algorithm is the stylistic change between a neutral, gender-ambiguous walk to a stylized cartoon female walk. Figure 5.7 and Figure 5.8 show an example of the change in animation curve and actual animations resulting from the algorithm as applied to a neutral walk. Figure 5.7 also shows the user input to the algorithm that created these changes.

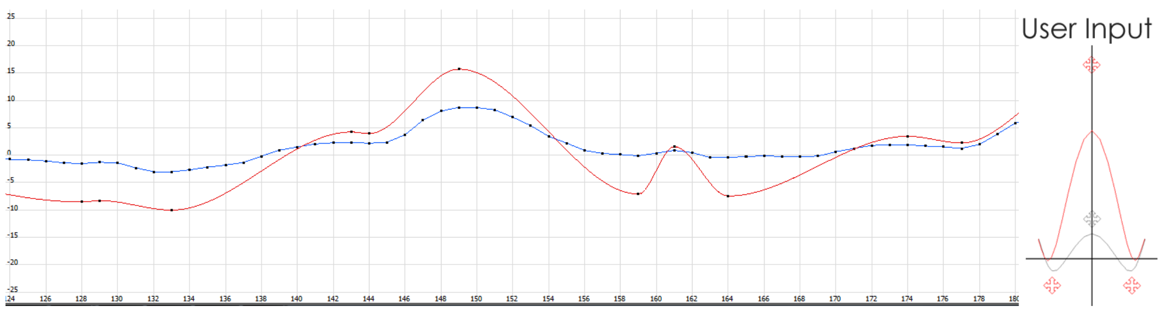


Figure 5.7 - - Original (blue) and Edited (red) Y Rotations of the Root Joint

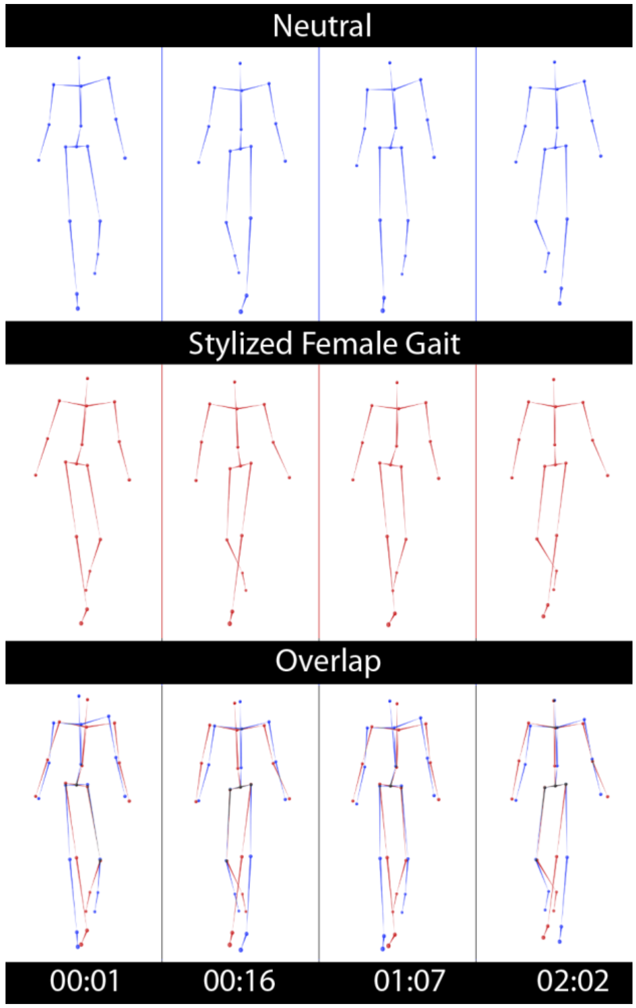


**Figure 5.8 - Example of a neutral walk (blue) modified into a stylized female (red) walk**

The edited animation has more dramatic spine movements and the reduced arm/shoulder movements when compared to the original animation. The hip motion is constrained because of the foot slide issue, as described in Section 3, which led us to anchor the character's feet. This in turn restricted the rotation of the root and hip joints. However, the results of our user study (Section 5.2) show that bringing the feet closer together gave participants the illusion of more strongly pronounced hip motion.

## 5.2 User Study Results

### 5.2.1 Part A – Animation Editing with Curve Interface

In this section we present the results of the questionnaire administered during Part A of our user studies (outlined in Section 4.1). We also provide an in-depth statistical analysis of the questionnaire responses.

#### 5.2.1.1 Overview

In total, we conducted sixteen one-hour user studies with 16 participants (14 male, 2 female). Each individual edited nine animations (three walks, three jumps, and three miscellaneous clips, chosen at random). The resulting edited animations were used in Part B of the user study.

Participants included Carleton University undergraduate and graduate students, as well as a few staff. As shown in Figure 5.9, a large majority of our users were between 18 and 34 years old, with only 4 participants over age 35. Because participants were predominantly male, we will not discuss gender as a part of our results analysis.

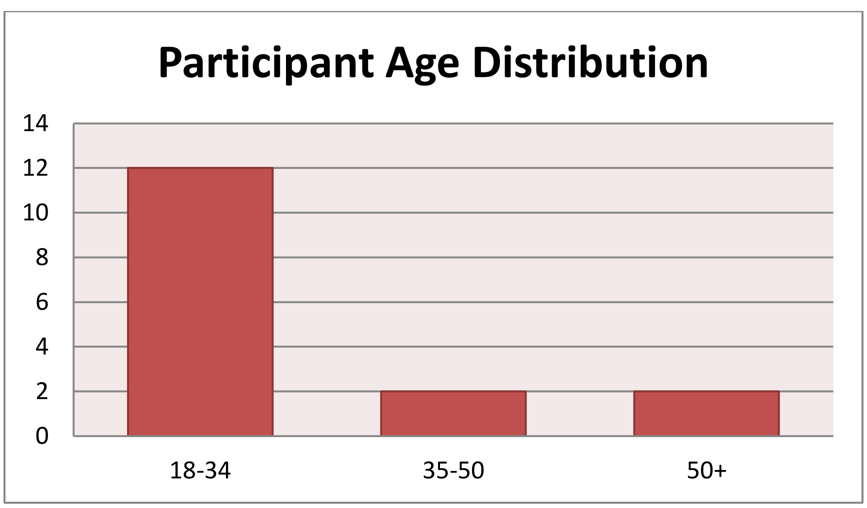


**Figure 5.9 - Participant Age Distribution**

A majority of participants, 58%, had not done any animation before participating in our study. The remaining participants had experimented with animation in undergraduate courses or through self-learning of various animation methods, such as cell-shading animation, motion capture with Microsoft's Kinect or video editing. Twelve of our sixteen participants (75%) rated their familiarity with Autodesk Maya as very low.

In our post-study questionnaire, we evaluated the overall satisfaction level of participants in terms of functionality, interactivity and learning curve of our animation editing system. The results shown in Figure 5.10 demonstrate that over 80% of participants had a high or very high satisfaction level in all three of our usability criteria.

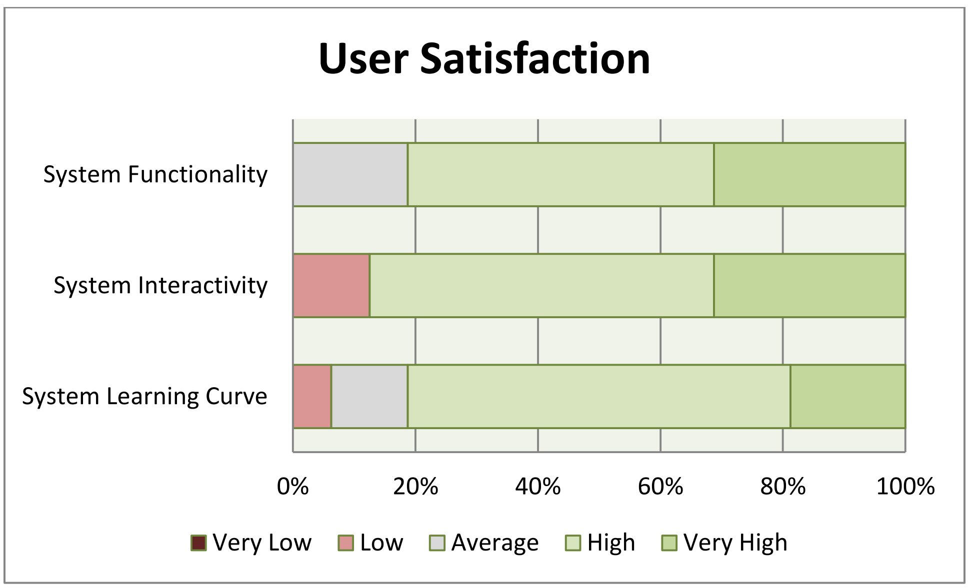


**Figure 5.10 - User Satisfaction with the System Functionality, Interactivity and Learning Curve**

To evaluate the usability of our system, we compared the overall difficulty of our four interaction tasks with the difficulty of three of Autodesk Maya's basic functions (Figure 5.11). To do this, we compared participants' average rating of our interaction tasks with their average rating of the Autodesk Maya tasks. Both the average ratings of our interaction tasks, $D(16) = 0.197$, $p = .097$, and the average ratings of the Autodesk

Maya tasks, $D(16) = 0.313$, $p = .000$, are significantly different from a normal distribution, as shown by the K-S test. As a result, we compare the two averages using the non-parametric Wilcoxon test. 11 participants rated our interaction tasks as more difficult than the Autodesk Maya tasks, 4 participants rated the Autodesk Maya tasks as more difficult, and 1 participant found them to be equally difficult. However, no statistical difference was found between the average difficult rating of the basic Autodesk Maya tasks and our animation editing tasks, $Z = -1.936$, $p = .053$. While this suggests that our animation tasks are equal in difficulty to basic tasks in Autodesk Maya, we do not have enough participants in our sample to state this outright. However, 75% of our users had no previous experience using Autodesk Maya and yet the average difficulty rating for our interaction tasks was 1.17 (0-4 scale), which is quite low. This leads us to believe that our curve interface is simple and amateur-friendly, especially compared to the more traditional animation methods discussed in Section 1.2.

Interestingly, even though all three animation editing tasks use the same control scheme, participants rated them differently in terms of difficulty, as shown in Figure 5.11. Table 5.1 shows that all of the task ratings were significantly different from a normal distribution. As a result, we use Friedman's test to determine that there is a significant effect of the type of animation editing task on the difficulty rating, $\chi^2(16) = 8.417$, $p = .034$. Wilcoxon post-hoc tests (Table 5.2) with the Bonferri correction applied (.05/6) show that the only significant difference between two tasks is the "increase jump height" and "time-shift the animation" tasks, $Z = -2.743$, $p = .008$).

**Table 5.1 – KS, *D*(16) Test Statistics to Determine Normality**

| | *Kolmogorov-Smirnov*[a] | | |
|---|---|---|---|
| | Statistic | Median | Sig. |
| Move the character skeleton around (rotate, translate, resize) | .307 | .50 | .000 |
| Move the camera | .308 | .50 | .000 |
| Manipulate the timeline | .378 | .00 | .000 |
| Exaggerate Difficulty | .227 | 1.00 | .027 |
| Change Gait Difficulty | .286 | 1.00 | .001 |
| Increase Jump Difficulty | .318 | .00 | .000 |
| Time Shift the Animation | .238 | 2.00 | .016 |

*a. Lilliefors Significance Correction*

**Table 5.2 - Wilcoxon Signed Ranked Post-Hoc Results**

| | **Exaggerate Difficulty - TimeShift the Animation** | **Change Gait Difficulty - TimeShift the Animation** | **Increase Jump Difficulty - TimeShift the Animation** | **Change Gait Difficulty - Exaggerate Difficulty** | **Increase Jump Difficulty - Exaggerate Difficulty** | **Change Gait Difficulty - Increase Jump Difficulty** |
|---|---|---|---|---|---|---|
| ***Z*** | -.921[b] | -.525[b] | -2.743[b] | -.312[c] | -2.326[b] | -1.834[c] |
| ***P*** | .480 | .697 | .006 | .836 | .027 | .078 |

b. Based on positive ranks.

c. Based on negative ranks.

From our observations during the user study, participants seemed to find the jump editing to be the most intuitive task, as the arc of the jump visually resembled the amplitude change in the user input. The time-shift task proved slightly more difficult because our implementation (outlined in Section 3.3.6) didn't allow users fine control over what parts of the animation were slowed down.

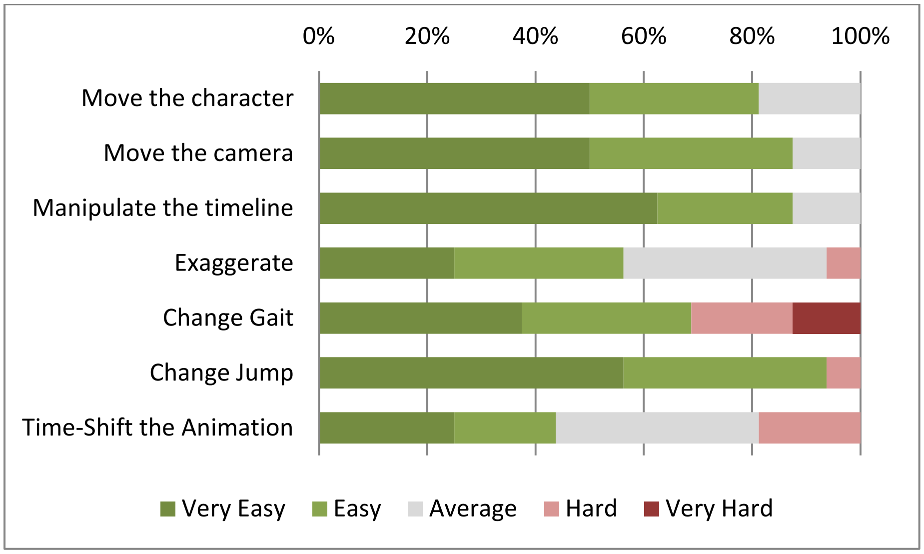


**Figure 5.11 – User ratings of task difficulty**

Figure 5.12 shows overall participant satisfaction levels of the animation quality with using our curve-based interface. 81% of participants agreed to some extent that the animations they created were visually pleasing, 75% agreed that the edited versions were more interesting than the original animation and 56% thought the curve was a good illustration of the changes done to the animation. It also interesting to note that none of the participants disagreed with the statement "Overall, the resulting animations I created were more interesting than the original motion". This suggests that our system provides both high functionality and high usability.

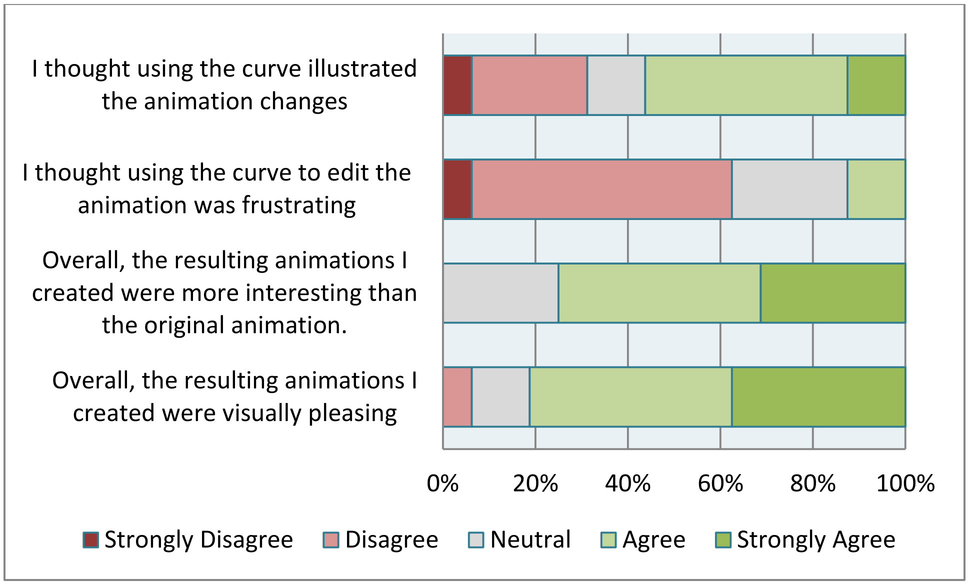


**Figure 5.12 – User agreement with statements relating to interface ease of use and animation aesthetics**

#### 5.2.1.2 Comparing Animation Types

This Section examines user preferences (e.g. which animation do you think is more visually appealing?) among the three animation categories. Figure 5.13 shows the participants' preference between the original animation and the edited animations, by animation type. At least 54% of participants preferred the edited animations in each animation type, with 77% preferring the edited jump over the original jump. These results, coupled with the ones in Figure 5.12 suggest that, overall; both the user interface and the animation results produced by our system are satisfactory.

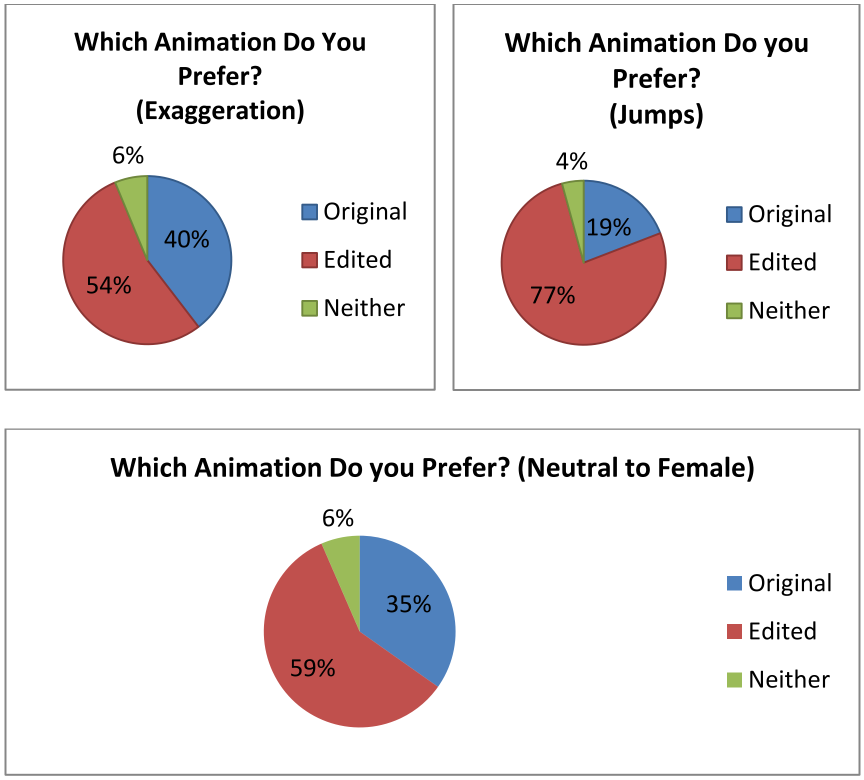


**Figure 5.13 - Individual Cases, Animation Preferences**

We also asked for participants' opinions on the recognizability, realism and visual appeal of both original and edited animations. The results of these questions are reflected in Figures 37 to 39. We compare all data points (exaggerations, jumps and female walks together) using the Wilcoxon signed ranked test, as none of the variables follow a normal distribution (Table 5.3).

**Table 5.3 - KS, D(144) Test Statistics to Determine Normality**

| | Kolmogorov-Smirnov[a] | | |
|---|---|---|---|
| | Statistic | Median | Sig. |
| Recognizability (Original) | .411 | 4.00 | .000 |
| Recognizability (Edited) | .339 | 4.00 | .000 |
| Realism (Original) | .351 | 4.00 | .000 |
| Realism (Edited) | .155 | 2.00 | .000 |
| Visual Appeal (Original) | .226 | 3.00 | .000 |
| Visual Appeal (Edited) | .243 | 3.00 | .000 |

In all three cases, in a sample size of 144 data points (9 categories x 16 participants), we found a significant change of median ratings between the original and edited animations. In the case of the visual appeal, the original animation has a higher score, despite the fact that many people still preferred the edited version (Figure 5.13). However, the difference was found to be non-significant, $Z = -1.467$, $p = .146$. The recognizability yielded a higher difference in medians, $Z = 4.275$, $p = .00$. Finally, as expected from our research goals, the realism of the animations was considerably reduced. This is shown both by Figure 5.13, as well as the results of the Wilcoxon test, $Z = -8.394$, $p = .00$

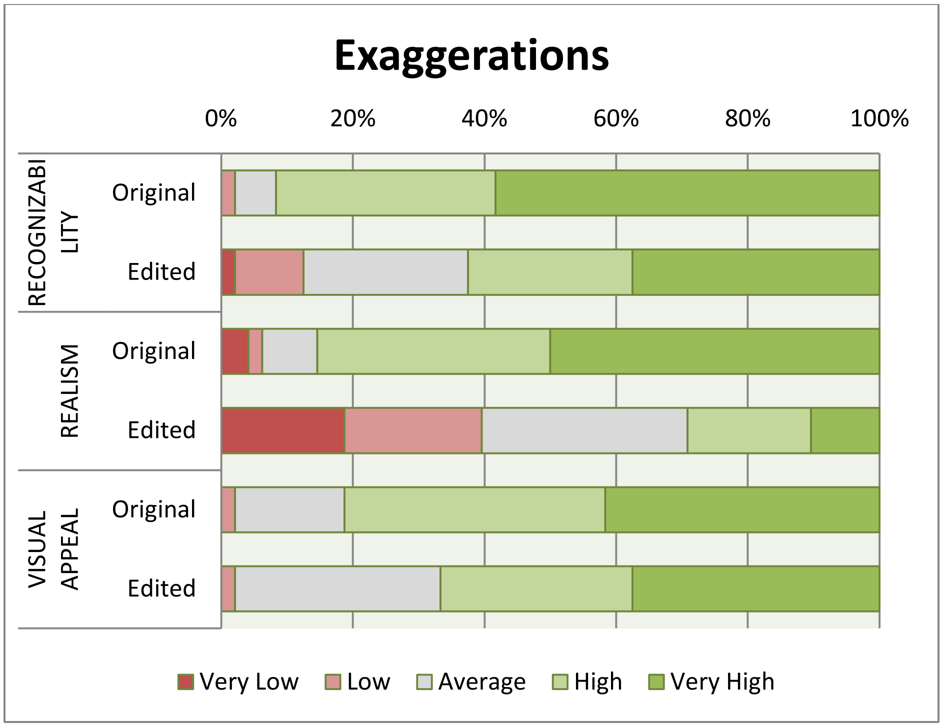


**Figure 5.14 - Recognizability, Visual Appeal and Realism of Exaggerations**

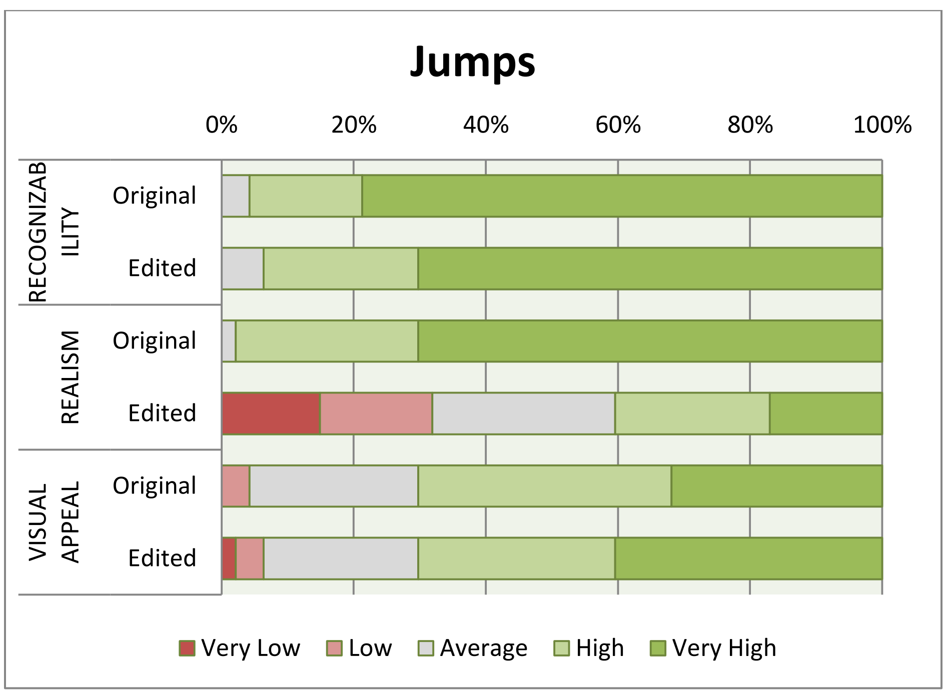


**Figure 5.15 - Recognizability, Visual Appeal and Realism of Jump Animations**

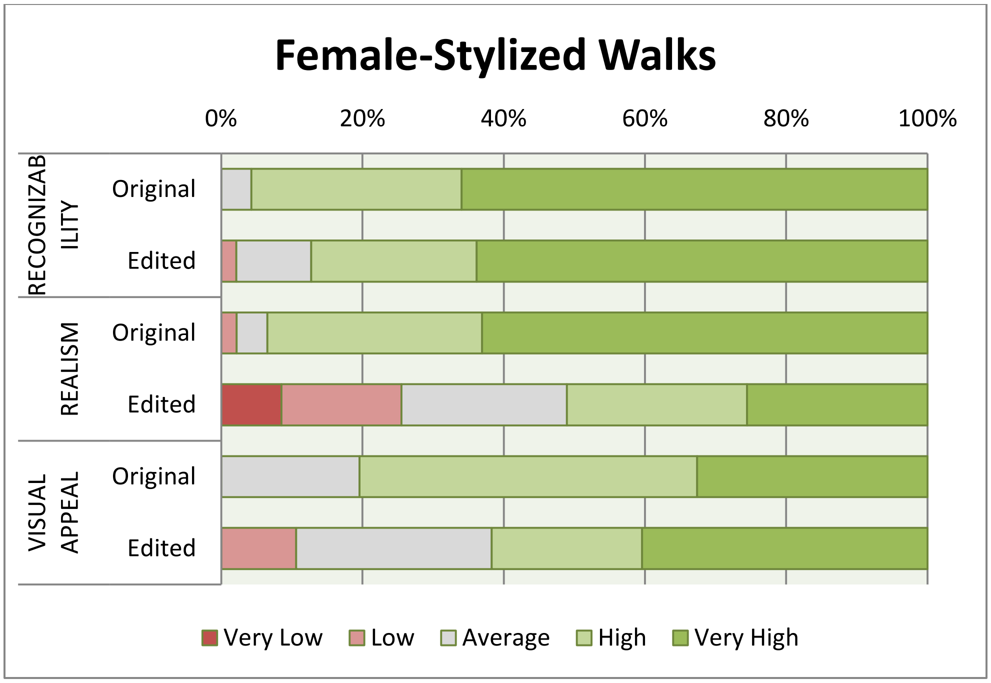


**Figure 5.16 - Recognizability, Visual Appeal and Realism of Female-Stylized Walks**

These results tell us that our algorithm successfully added cartoon elements to the original, realistic animations, but impacted the visual appeal (non-significant) and recognizability negatively. However, despite this, participants still preferred the edited animations across all three categories.

#### 5.2.1.3 Animation Results

The participants in part A of our study used our curve base system to generate a total of 144 animations. We've compiled a modest sample of animation results in Appendix E .

### 5.2.2 Part B – Animation Review

In Part B of our user study, we conducted fifteen one-hour sessions with 15 new participants (9 male, 6 female). None of the participants from Part A participated in Part

B of the user study. In each session, the participant watched fifteen animations (five jumps, five exaggerations, five walks) and completed a questionnaire, giving us a total of 225 data points. These animations were randomized from the pool of animations generated during Part A of our user study (as described in Section 4.1). Of these participants, 50% had done some kind of animation, mostly in Adobe Flash. Only one participant had any motion capture editing experience (Figure 5.17).

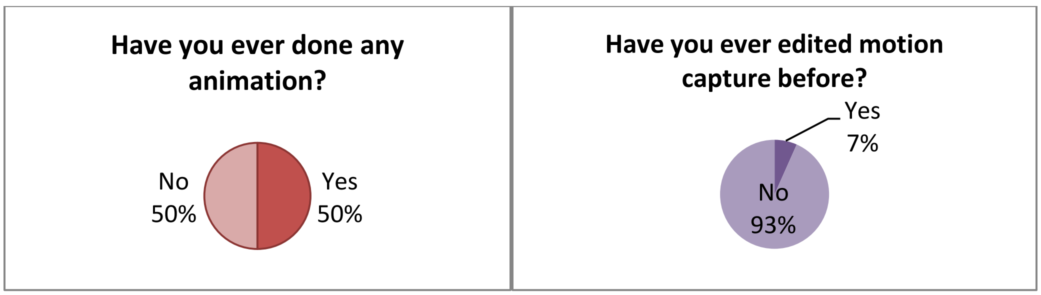


**Figure 5.17 - User Experience with Animation and Motion Capture**

#### 5.2.2.1 Animation Results

As in Part A of the study, participants in Part B were asked to evaluate how well the edited curve input illustrates the changes made to the animation. Interestingly, the results from these participants, who never used the curve input themselves, were more favorable than those from the users who edited the motion capture clips. As shown in Figure 5.18, Part B participants agreed to some extent that the curve input was a good illustration of changes made to the animation in 63% of the exaggerated clips, 66% of feminized walks and 95% of the jumps. These results lead us to believe that using a simple curve to illustrate animation changes was a success, particularly when it comes to translation values, as in our jump animations. The jump trajectory exaggeration matches directly with the amplitude increase, likely leading to a strong affordance between the curve input and the jump animation.

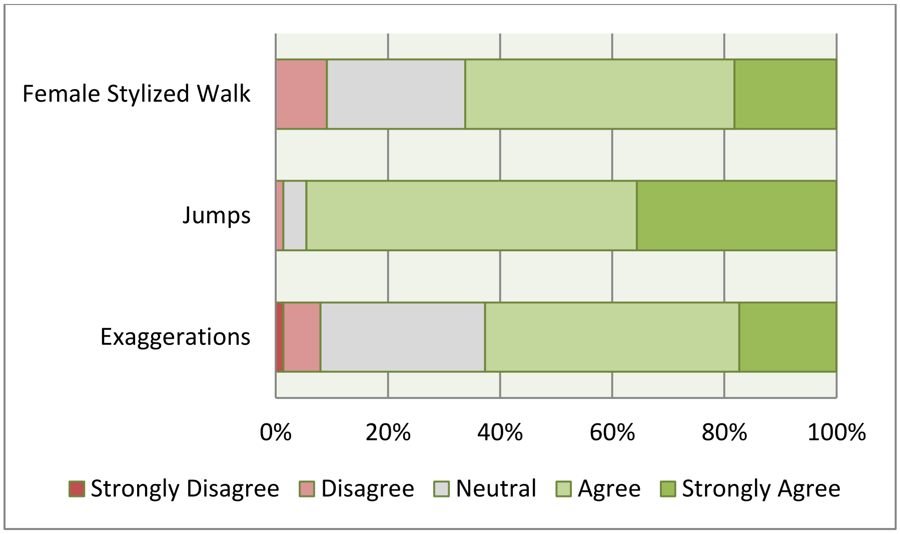


**Figure 5.18 - User agreement with the statement "The edited curve position illustrates the changes made to the animation" by animation type**

Despite these results, user preferences for the edited and original animations are less promising. Participants indicated that they preferred only 37% of the edited exaggerated animations over the corresponding original clips, 34% of the feminine-stylized walks, and 59% of the edited jumps. All three animation types had lower preferences for the edited animations in this part of the study than in Part A. We can explore the reasons for these results by examining the answers to the short and long answer questions from the Part B questionnaire. Participants who liked the animations explained that they found the edited animations "funny", "entertaining", and "unattainable through real motion". Some comments focused on how they preferred animations with less extreme animation edits. Conversely, participants who disliked the edited animations stated that they were "over exaggerated", "unpolished and jerky" or "unrealistic". While the jerkiness of the movement is caused by the algorithm itself, over exaggeration is mostly the result of purposeful user input. The lack of realism was the direct object of the interface and the study overall. We believe that perhaps the unrealistic motion would be more appealing to users if the character in the animation were an identifiable cartoon, rather than a bare skeleton; however this must be left for future work to determine.

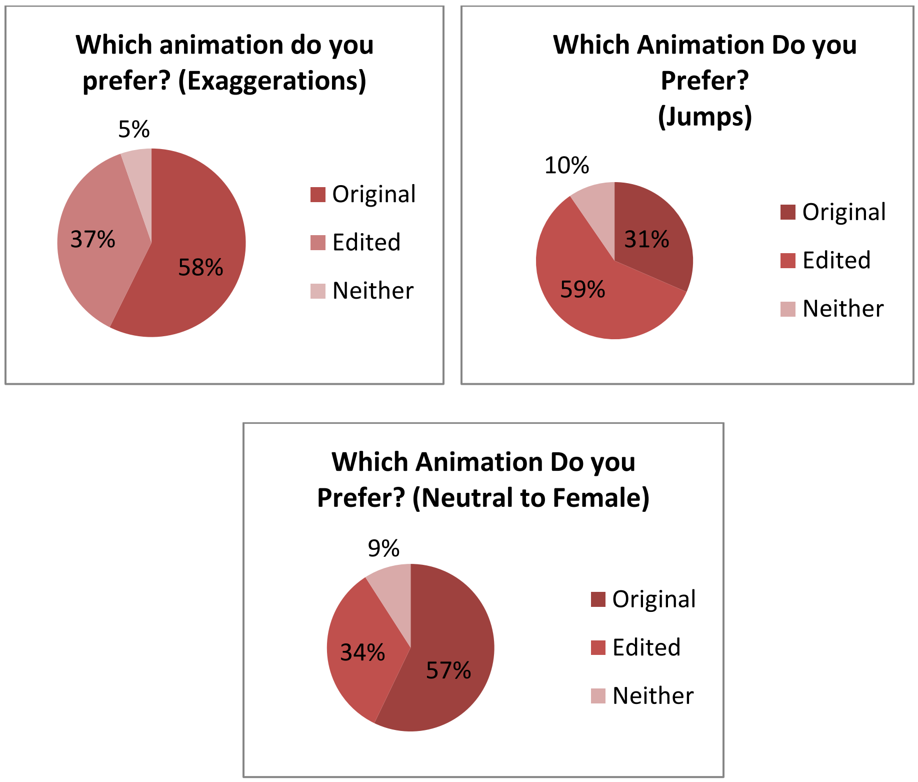


**Figure 5.19 - User Preference of Original vs Edited Animation, by Animation Type (Part B)**

#### 5.2.2.2 Evaluating Curve Input

These less encouraging preference results led us to examine the correlation between the participants' preferences for the original vs edited animations with their agreement that sensible curve input was used to change the animations. Figure 5.20 shows the user opinions of the curve by animation type and original vs edited animation. To simplify this graph, the "Strongly Disagree", "Disagree" and "Neutral" ratings for whether the curve input was sensible are combined into one category "Disapproved of the user input", and the "Strongly Agree" and "Agree" ratings are combined into one

“Approved of the user input” category. This was done only for the visual presentation of the graph, and for statistical purposes all individual Likert ratings were maintained.

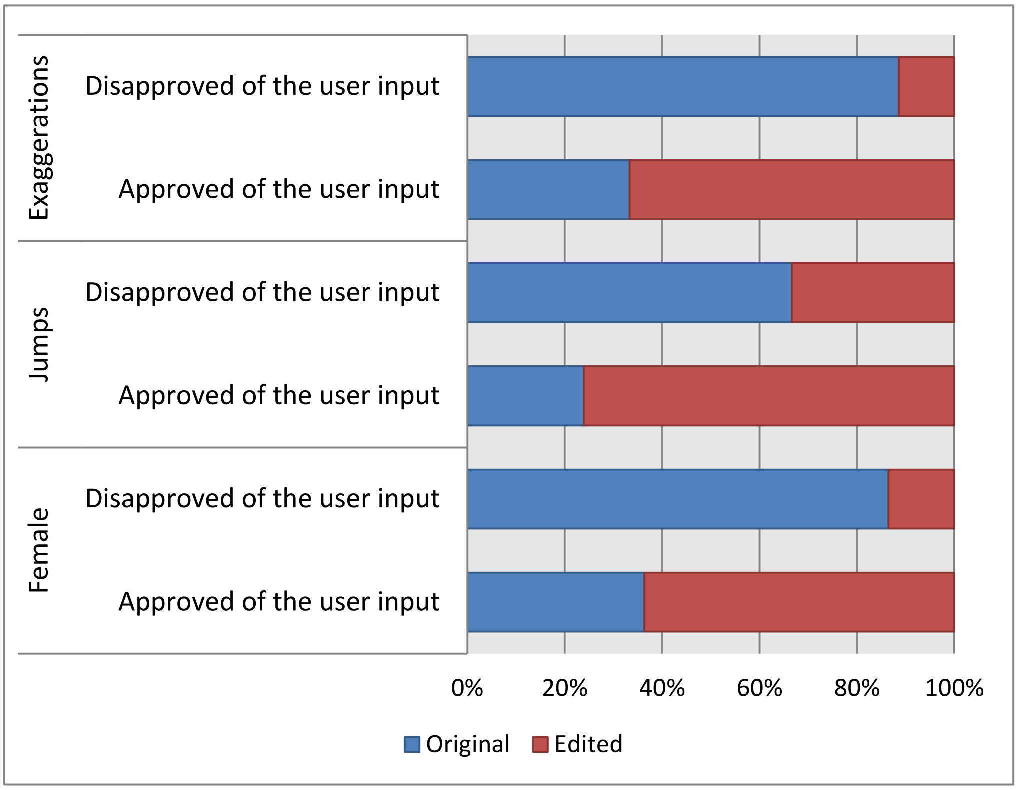


**Figure 5.20 - User Preference of Original vs Edited Animation compared to User Opinion of Curve Input**

By the results of the K-S test, the user opinion of the curve input, regardless of animation type or original vs edited animation, was found to be significantly different from a normal distribution, $D(225) = 0.232$, $p = .000$. Thus the non-parametric Spearman’s rho can be used to correlate this data. 15 participants rated a total of 225 animations, and a significant correlation was found between their agreement that the curve input was sensible and whether they preferred the original over the edited animation, $r_S = .336$, $p = .000$. This correlation indicates that users who preferred the original animation were more likely to disapprove of the curve input used by a previous participant to edit that animation.

When examining the short and long answer results, we did find a few cases where the animation algorithm didn't work as intended. Appendix D contains word clouds that reflect the most commonly used terms in these results. Some participants described the final result of the feminized walk algorithm as feminine, female, or sassy, however a subset found it to be more reminiscent of a drunken person walking, or someone trying to walk on a tight-rope. These impressions can be explained by an over-exaggeration of the spine joint, which makes the character appear unstable. This was exacerbated by the over-tightening of the feet position described in Section 3. For the two other categories, most criticisms came from frame-skips in the jump animations, and the aggressive use of the time-shift function. Despite this, considering the skill level of participants in Part A of the study, the average preference results are acceptable (43%). Furthermore, we successfully show that the curve interface is a good interaction method that's easy to use for amateur users.

# 6 Chapter: Conclusion

## 6.1 Thesis Findings

In this thesis, we presented an animation editing algorithm coupled with a new curve-based interface with the goal of adding cartoon-like qualities to realistic motion. The animation algorithm was based around the idea of interpolating between modified local minimum and maximum values. Our curve interface provides a 2D metaphor to the animation modification process.

The algorithm proved efficient at reducing the realism of the motion across all three animation types, and users found the curve interface easy to use and understand.

## 6.2 Limitations

Despite the success, our work has a few limitations. Our algorithm does not function very well at extreme data points (large slowdowns, large exaggerations) and can produce very unappealing results when the editing coefficients are too large. Additionally, we do not empirically study the source of good and bad animations (are the results user-dependent or system-dependent?).

In terms of the animation time-shift, our method only allows for the systematic slow-down of the selected clips. To allow for more functionality and a better metaphor between our user interface (the curve) and the result, the ability to speed-up as well the animation is lacking.

For various reasons discussed in chapter 5, our edited animations were not always preferred to the original animations. These results can be explained by a combination of algorithmic quirks, user inexperience (at animation) and a lack of context (human skeleton instead of a cartoon character, blank setting instead of a cartoon environment).

Furthermore, our user studies, particularly for Part A, pose a few issues. The question “Which animation do you prefer” is vague and subjective and thus gives us scattered results. We suggest changing this to “Which animation is more suitable for cartoon movies?” or another similar question that connects more appropriately to our study goals. In terms of the participant pool, a better balance between genders (a minimal ratio of 40% - 60%) would reduce bias, particularly when it comes to the visual appeal of the exaggerated feminine walk. Finally, to better tie in with our system goals, the participants should have been 3D animators, or at least have had some experience with current cartoon animation methods.

## 6.3 Future Work

As future work, we’d like to point the research topics in this direction:

- **Real-time editing**: To make the editing process more streamlined, we suggest the implementation of the curve editing system in real-time. This would allow users to make more “on the fly” editing changes and fine tune the results.
- **Motion filtering on raw motion capture data:** While editing the animation curves allowed us to get decent results, we believe that the editing process would benefit from being done before retargeting the linear marker motion onto our human skeleton.
- **Less restrictive foot constraints:** Our feet constraints reduced the amount of exaggeration in joints below the hip. While this was necessary to maintain an appropriate level of animation quality, we suggest exploring the ways one can

couple the feet planting process with the exaggeration algorithm to allow interesting modifications of the lower body animations.

- **Use cartoon-like character models and setting when editing motion:** The usage of humanoid skeletons with realistic proportions poses a few cognitive issues, as certain cartoon motions can look awkward when applied to a realistic human skeleton. This might not be because the animation itself is inherently bad, but rather because it looked out of place. We suggest further research to skin a cartoon-like character to the skeleton to further explore this issue.
- **More variety of cartoon motion:** The cartoon elements implemented in our research are limited to three static categories. We recommend the exploration of other categories of cartoon motion detailed in Section 3.3, such as physically-impossible joint deformations and disconnection.

# Appendices

## Appendix A - Consent Forms

### A.1 Motion Capture Data Collection

Carleton UNIVERSITY
Canada's Capital University

**Consent Form: Cartoon Character Motion from Motion Capture**

**Title**: Cartoon Character Animation from Motion Capture
**Date of ethics clearance**: To be determined by the REB (as indicated on the clearance form)
**Ethics Clearance for the Collection of Data Expires**: To be determined by the REB (as indicated on the clearance form)

I ________________________________________, choose to participate in a study on Cartoon Character Animation from Motion Capture. This study aims to develop a set of tools to modify realistic motion into cartoon motion. This includes an in-depth analysis of the differences between realistic motion and cartoon motion. **The researcher for this study is Rufino Ricardo Ansara, a Master's Student in the School of Information Technology.** He is working under the supervision of Professor Chris Joslin in the School of Information Technology.

---

This study involves one 120 minute motion capture session. With your consent, your motion data will be recorded. This data only consists of the position in space of different markers (no images or actual video are recorded) reconstructed in a virtual 3D Environment. Your identity will be kept confidential.

Because you will be asked to wear a tight Velcro suit and the researcher will place 45 Velcro markers on the suit, the study can pose some mild physical discomfort. However, should you experience any distress; you have the right to end your participation in the study at any time, for any reason, up until April 30th 2015. You can withdraw in person, or by phoning or emailing the researcher or the research supervisor. If you withdraw from the study, all information you have provided will be immediately destroyed.

As a token of appreciation, you will receive a $20 gift card. This is yours to keep, even if you withdraw from the study.

All research data, including recordings and any notes will be password-protected and stored on a Google Drive Shared folder. Research data will only be accessible by the researcher and the research supervisor. However, this data may be subject to the US Patriot Act and could be accessed by US officials if they see it fit.

Once the project is completed, all research data will be kept for five years and potentially used for other research projects on this same topic. At the end of five years, all research data will be securely destroyed. (Electronic data will be erased and hard copies will be shredded.)

If you would like a copy of the finished research project, you are invited to contact the researcher to request an electronic copy which will be provided to you.

The ethics for this project were reviewed by the Carleton University Research Ethics Board, which provided clearance to carry out the research. Should you have questions or concerns related to your involvement in this research, please contact:

**REB contact information:**
Professor Louise Heslop, Chair
Professor Andy Adler, Vice-Chair
Research Ethics Board
Carleton University
511 Tory
1125 Colonel By Drive
Ottawa, ON K1S 5B6
Tel: 613-520-2517
ethics@carleton.ca

**Researcher contact information:**
Rufino Ricardo Ansara
Master's Student
School of Information Technology
Carleton University
Tel: [redacted]
Email: ransara@connect.carleton.ca

**Supervisor contact information:**
Professor Chris Joslin
School of Information Technology
Carleton University
1125 Colonel By Drive
Azrieli Pavilion, Room 230L
Tel: 613-520-2600 ext. 1889
Email: chris_joslin@carleton.ca

Do you agree for your motion to be recorded? ☐ Yes ☐ No

Do you agree to wear a motion capture suit (tight Velcro) for the duration of the study? ☐ Yes ☐ No

Do you consent to having the researcher respectfully place 45 reflective markers on the motion capture suit? ☐ Yes ☐ No

_________________________ _______________
Signature of participant Date

_________________________ _______________
Signature of researcher Date

## A.2 Part A, Animation Editing

Carleton UNIVERSITY
Canada's Capital University

**Consent Form: Cartoon Character Motion from Motion Capture (PHASE A)**

**Title**: Cartoon Character Animation from Motion Capture
**Protocol #:** 15-163
**Date of ethics clearance**: 09/23/2015)
**Ethics Clearance for the Collection of Data Expires**: 08/31/2016
**Funders**: SSHRC Partnership Grant, IMMERSe Network (http://immerse-network.com/research-sites/)

I ________________________________________, choose to participate in a study on Cartoon Character Animation from Motion Capture. This study aims to develop a set of tools to modify realistic motion into cartoon motion. This includes an in-depth analysis of the differences between realistic motion and cartoon motion. **The researcher for this study is Rufino Ricardo Ansara, a Master's Student in the School of Information Technology.** He is working under the supervision of Professor Chris Joslin in the School of Information Technology.

---

This study involves one 60 minute user study where you will be editing various animation clips using an innovative user interface. With your consent, your resulting animations will be saved and analyzed. Your identity will be kept confidential. Because of the nature of the study, participants with severe visual handicaps will be excluded.

Because you will only be using a computer for a short period amount of time, the study should not pose some any physical discomfort. However, should you experience any issues; you have the right to end your participation in the study at any time, for any reason, up until October 1st 2015. You can withdraw in person, or by phoning or emailing the researcher or the research supervisor. If you withdraw from the study, all information you have provided will be immediately destroyed.

All research data, including recordings and any notes will be password-protected and stored on a Google Drive Shared folder. Research data will only be accessible by the researcher and the research supervisor. However, this data may be subject to the US Patriot Act and could be accessed by US officials if they see it fit. Because the data collected digitally consists of animation data (3D Position Coordinates) that have no personal or identifiable links to the user, we will not use any encryption.

Once the project is completed, identifying data will be kept until January 1st 2016, and the un-identified data will be kept for 5 years (to be used in future work).

If you would like a copy of the finished research project, you are invited to contact the researcher to request an electronic copy which will be provided to you.

The ethics for this project were reviewed by the Carleton University Research Ethics Board B, which provided clearance to carry out the research. Should you have questions or concerns related to your involvement in this research, please contact:

**REB B contact information:**
Dr. Shelley Brown, Chair, CUREB B
Professor Andy Adler, Vice-Chair
Carleton University Research Office
511 Tory
1125 Colonel By Drive
Ottawa, ON K1S 5B6
Tel: 613-520-251
ethics@carleton.ca

**Researcher contact information:**
Rufino Ricardo Ansara
Master's Student
School of Information Technology
Carleton University
Email: ransara@connect.carleton.ca

**Supervisor contact information:**
Professor Chris Joslin
School of Information Technology
Carleton University
1125 Colonel By Drive
Azrieli Pavilion, Room 230L
Tel: 613-520-2600 ext. 1889
Email: chris_joslin@carleton.ca

Do you agree to edit various animation clips and allow them to be compared to others? ☐ Yes ☐ No

__________________________ _______________
Signature of participant Date

__________________________ _______________
Signature of researcher Date

## A.3 Part B, Animation Review

Carleton UNIVERSITY
Canada's Capital University

# Consent Form: Cartoon Character Motion from Motion Capture (PHASE B)

**Title**: Cartoon Character Animation from Motion Capture
**Protocol #:** 15-163
**Date of ethics clearance**: 09/23/2015
**Ethics Clearance for the Collection of Data Expires**: 08/31/2016
**Funders**: SSHRC Partnership Grant, IMMERSe Network (http://immerse-network.com/research-sites/)

I ________________________________________, choose to participate in a study on Cartoon Character Animation from Motion Capture. This study aims to develop a set of tools to modify realistic motion into cartoon motion. This includes an in-depth analysis of the differences between realistic motion and cartoon motion. **The researcher for this study is Rufino Ricardo Ansara, a Master's Student in the School of Information Technology.** He is working under the supervision of Professor Chris Joslin in the School of Information Technology.

---

This study involves one 60 minute user study where you will watch various animation clips and answer a questionnaire. With your consent, your responses will be saved and analyzed. Your identity will be kept confidential. Because of the nature of the study, participants with severe visual handicaps will be excluded.

Because you will only be using a computer for a short period amount of time, the study should not pose some any physical discomfort. However, should you experience any issues; you have the right to end your participation in the study at any time, for any reason, up until October 1st 2015. You can withdraw in person, or by phoning or emailing the researcher or the research supervisor. If you withdraw from the study, all information you have provided will be immediately destroyed.

All research data, including recordings and any notes will be password-protected and stored on a Google Drive Shared folder. Research data will only be accessible by the researcher and the research supervisor. However, this data may be subject to the US Patriot Act and could be accessed by US officials if they see it fit. Because the data collected digitally consists of animation data (3D Position Coordinates) that have no personal or identifiable links to the user, we will not use any encryption.

Once the project is completed, identifying data will be kept until January 1st 2016, and the un-identified data will be kept for 5 years (to be used in future work).

If you would like a copy of the finished research project, you are invited to contact the researcher to request an electronic copy which will be provided to you.

The ethics for this project were reviewed by the Carleton University Research Ethics Board B, which provided clearance to carry out the research. Should you have questions or concerns related to your involvement in this research, please contact:

**REB B contact information:**
Dr. Shelley Brown, Chair, CUREB B
Professor Andy Adler, Vice-Chair
Carleton University Research Office
511 Tory
1125 Colonel By Drive
Ottawa, ON K1S 5B6
Tel: 613-520-251
ethics@carleton.ca

**Researcher contact information:**
Rufino Ricardo Ansara
Master's Student
School of Information Technology
Carleton University
Tel: [redacted]
Email: ransara@connect.carleton.ca

**Supervisor contact information:**
Professor Chris Joslin
School of Information Technology
Carleton University
1125 Colonel By Drive
Azrieli Pavilion, Room 230L
Tel: 613-520-2600 ext. 1889
Email: chris_joslin@carleton.ca

Do you agree to watch and comment on various animation clips? ☐ Yes ☐ No

__________________________ _______________
Signature of participant Date

__________________________ _______________
Signature of researcher Date

# Appendix B  Questionnaires

## B.1 Questionnaire – Phase A

### Part 1 – Before the Study

1. Participant

2. Gender:

☐ Male ☐ Female ☐ Other ☐ Rather Not Say

3. How old are you? Click here to enter text.

4. Have you ever done any animation?

☐ Yes ☐ No

If so, in where/in what context? Click here to enter text.

5. Have you ever edited Motion Capture data before?

☐ Yes ☐ No

If so, in where/in what context? Click here to enter text.

6. Rate your familiarity with Autodesk Maya?

☐ Very low ☐ Low ☐ Average ☐ High ☐ Very High

7. Please rate how difficult the following tasks were.

Move the character skeleton around (rotate, translate, resize)

☐ Very Easy ☐ Easy ☐ Average ☐ Hard ☐ Very Hard

Move the camera (rotate, translate, zoom)

☐ Very Easy ☐ Easy ☐ Average ☐ Hard ☐ Very Hard

Manipulate the animation timeline (play, pause)

☐ Very Easy ☐ Easy ☐ Average ☐ Hard ☐ Very Hard

**Part 2 - After the Study**

8. Please rate how difficult the following tasks were.

Exaggerate the motion

☐ Very Easy ☐ Easy ☐ Average ☐ Hard ☐ Very Hard

Change gait from male to female

☐ Very Easy ☐ Easy ☐ Average ☐ Hard ☐ Very Hard

Increase Jump

☐ Very Easy ☐ Easy ☐ Average ☐ Hard ☐ Very Hard

Time Shift the animation

☐ Very Easy ☐ Easy ☐ Average ☐ Hard ☐ Very Hard

In the following section, please choose one choice between Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree.

9. Overall, the resulting animations I created were visually pleasing

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree

☐ Strongly Agree

10. Overall, the resulting animations I created were more interesting than the original animation.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree

☐ Strongly Agree

11. I thought using the curve to edit the animation was frustrating

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree

☐ Strongly Agree

12. Why?

10. I thought the curve illustrated well the changes I wanted to make to the animation.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree

☐ Strongly Agree

11. Why?

12. Rate your overall satisfaction with the following elements

System Learning Curve ☐ Very low ☐ Low ☐ Average ☐ High ☐ Very High

System Interactivity ☐ Very low ☐ Low ☐ Average ☐ High ☐ Very High

System Functionality ☐ Very low ☐ Low ☐ Average ☐ High ☐ Very High

13. How do you think the system should be improved?

Click here to enter text.

14. Do you have any other comments or suggestions?

Click here to enter text.

**Animation Data Sheet**

*Participant ID: Click here to enter text.*

*Animation ID: Click here to enter text.*

In the following section, please choose one choice between Very low, Low, Average, High or Very high.

1. Rate the overall recognizability of the animations

Note: Can you easily understand what the character is doing?

| | | | | | |
|---|---|---|---|---|---|
| Original | ☐ Very low | ☐ Low | ☐ Average | ☐ High | ☐ Very High |
| Edited | ☐ Very low | ☐ Low | ☐ Average | ☐ High | ☐ Very High |

2. Rate the overall realism of the animations

Note: Is the motion grounded in the real world?

| | | | | | |
|---|---|---|---|---|---|
| Original | ☐ Very low | ☐ Low | ☐ Average | ☐ High | ☐ Very High |
| Edited | ☐ Very low | ☐ Low | ☐ Average | ☐ High | ☐ Very High |

3. Rate the overall visual appeal of the animations

Note: Do you think the animation looks good?

| | | | | | |
|---|---|---|---|---|---|
| Original | ☐ Very low | ☐ Low | ☐ Average | ☐ High | ☐ Very High |
| Edited | ☐ Very low | ☐ Low | ☐ Average | ☐ High | ☐ Very High |

4. Which animation do you prefer?

☐ Original ☐ Edited ☐ Neither

## B.2 Questionnaire – Phase B

### Demographics

1. Participant ID: Click here to enter text.

2. Gender:

☐ Male ☐ Female ☐ Other ☐ Rather Not Say

3. How old are you? Click here to enter text.

4. Have you ever done any animation?

☐ Yes ☐ No

If so, in where/in what context? Click here to enter text.

5. Have you ever edited Motion Capture data before?

☐ Yes ☐ No

If so, in where/in what context? Click here to enter text.

**<u>End of Study Questionnaire</u>**
**<u>In the following section, please choose one choice and circle it.</u>**
1. Overall, the animations I watched were **visually pleasing**

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree
☐ Strongly Agree

2. My favourite animations were

☐ Very “Cartoony” ☐ “Cartoony” ☐ Neutral ☐ Realistic ☐ Very Realistic

3. Which animation category yielded the best results? Give points from 3 (best) to 1 (worst).

Exaggerations: Click here to enter text.

Jumps: Click here to enter text.

Stylized Female Gait: Click here to enter text.

**<u>Open Ended Questions</u>**

3. Can you tell us a few things you **liked** about the animations?

Click here to enter text.

4. Can you tell us a few things you **didn’t like** about the animations?

Click here to enter text.

5. Any other comments?

Click here to enter text.

## Individual Data Sheet

Please fill one of these per animation watched.

Animation ID Click here to enter text.

1. Rate the overall **recognizability** of the animation

*Note: Can you easily understand what the character is doing?*

Original ☐ Very low ☐ Low ☐ Average ☐ High ☐ Very High

Edited ` ☐ Very low ☐ Low ☐ Average ☐ High ☐ Very High

2. Rate the overall **realism** of the animation

*Note: Is the motion grounded in the real world?*

Original ☐ Very low ☐ Low ☐ Average ☐ High ☐ Very High

Edited ☐ Very low ☐ Low ☐ Average ☐ High ☐ Very High

3. Rate the overall **visual appeal** of the animation

Original ☐ Very low ☐ Low ☐ Average ☐ High ☐ Very High

Edited ☐ Very low ☐ Low ☐ Average ☐ High ☐ Very High

4. What is the first thing you noticed about the animation?

5. The curve input selected by the user is a sensible input.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

6. The edited curve position illustrates the changes made to the animation.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

7. If you had to describe this animation with one word, what would it be?

Click here to enter text.

8. Which animation do **you prefer?**

☐ Original ☐ Edited ☐ Neither

# Appendix C Participant Recruitment Notices

## C.1 Poster, Motion Capture

Carleton UNIVERSITY

Call For Participants

**Experiment Title:** Cartoon Character Animation from Motion Capture

**Experimenters**: Rufino R. Ansara and Dr. Chris Joslin

**Location of Experiment:** Azrieli Pavilion, Room #234.

### Description

Optical Motion Capture is a process where motion is recorded and then reconstructed in a virtual 3D environment. Our study analyzes realistic human movement in comparison with cartoon movement in order to develop software that can bridge the gap between the two.

During a 120-minute long session, participants wear a Motion Capture suit and re-enact different scenes from different animated movies. After that, they will fill a short survey that will record their reactions and opinions. Participants will receive a $20 gift card.

### Eligibility

Participants must:

- Be over 18 years old.
- Be able to spend an extended time in a tight motion capture suit.
- Not have epilepsy

Participants who have mobility impairments or movement restrictions/difficulties (in any joint) will be excluded from the study.

**Ethical Review:** This research has been reviewed and approved by the Carleton University Research Ethics Board at 613-520-2517 or ethics@carleton.ca.

**Cartoon Character Animation from Motion Capture**
**E-mail:** ransara@connect.carleton.ca
**Subject:** "Motion Capture"


**Cartoon Character Animation from Motion Capture**
**E-mail:** ransara@connect.carleton.ca
**Subject:** "Motion Capture"

**Cartoon Character Animation from Motion Capture**
**E-mail:** ransara@connect.carleton.ca
**Subject:** "Motion Capture"

**Cartoon Character Animation from Motion Capture**
**E-mail:** ransara@connect.carleton.ca
**Subject:** "Motion Capture"

**Cartoon Character Animation from Motion Capture**
**E-mail:** ransara@connect.carleton.ca
**Subject:** "Motion Capture"

**Cartoon Character Animation from Motion Capture**
**E-mail:** ransara@connect.carleton.ca
**Subject:** "Motion Capture"

**Cartoon Character Animation from Motion Capture**
**E-mail:** ransara@connect.carleton.ca
**Subject:** "Motion Capture"

**Cartoon Character Animation from Motion Capture**
**E-mail:** ransara@connect.carleton.ca
**Subject:** "Motion Capture"

## C.2 Poster, Animation Editing and Animation Review

Carleton UNIVERSITY

Call For Participants

**Experiment Title, Protocol #:** Cartoon Character Animation from Motion Capture, 15-163

**Experimenters:** Rufino R. Ansara (Masters' Candidate) and Dr. Chris Joslin (Faculty Member). School of Information Technology

**Location of Experiment:** HCI 2111

**Ethics Clearance for the Collection of Data Expires:** 08/31/2016

### Description

Optical Motion Capture is a process where motion is recorded and then reconstructed in a virtual 3D environment. Our study analyzes realistic human movement in comparison with cartoon movement in order to develop software that can bridge the gap between the two.

During a 60-minute long session, participants will be asked to either edit various motion capture generated animations using an innovative interface, or watch a series of clips. After that, they will fill a short survey that will record their reactions and opinions.

### Eligibility

Participants must:

- Be over 18 years old.
- Be able to use a keyboard and mouse

**Participants who have eyesight impairments or restrictions/difficulties will be excluded from the study.**

**Ethical Review:** This research has been reviewed and approved by the Carleton University Research Ethics B Board at ethics@carleton.ca.

**Cartoon Character Animation from Motion Capture**
E-mail: ransara@connect.carleton.ca
Subject: "Motion Capture"

**Cartoon Character Animation from Motion Capture**
E-mail: ransara@connect.carleton.ca
Subject: "Motion Capture"

**Cartoon Character Animation from Motion Capture**
E-mail: ransara@connect.carleton.ca
Subject: "Motion Capture"

**Cartoon Character Animation from Motion Capture**
E-mail: ransara@connect.carleton.ca
Subject: "Motion Capture"

**Cartoon Character Animation from Motion Capture**
E-mail: ransara@connect.carleton.ca
Subject: "Motion Capture"

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E-mail: ransara@connect.carleton.ca
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E-mail: ransara@connect.carleton.ca
Subject: "Motion Capture"

**Cartoon Character Animation from Motion Capture**
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Subject: "Motion Capture"

**Cartoon Character Animation from Motion Capture**
E-mail: ransara@connect.carleton.ca
Subject: "Motion Capture"

## C.3 Social Media Post, Motion Capture

Carleton UNIVERSITY

Call For Participants

### Call For Participants!

We are currently looking for volunteers who would like to participate in a motion capture session at Carleton University. You will wear a motion capture suit with 45 markers and will re-enact scenes from popular animated movies. Sessions are on average 120 minutes long and participants will receive a compensation for their time. Please contact me for more information.

**Email**: ransara@connect.carleton.ca

## C.4 Social Media Post, Animation Editing and Animation Review

Carleton UNIVERSITY

Call For Participants

### Call For Participants!

We are currently looking for volunteers who would like to participate in a user study at Carleton University. During a 60-minute long session, participants will be asked to either edit various motion capture generated animations using an innovative interface, or watch a series of clips. After that, they will fill a short survey that will record their reactions and opinions.

**Experimenters**: Rufino R. Ansara (Masters' Candidate) and Dr. Chris Joslin (Faculty Member). School of Information Technology

**Email**: ransara@connect.carleton.ca

**Notes: Participants who have eyesight impairments or restrictions/difficulties will be excluded from the study.**

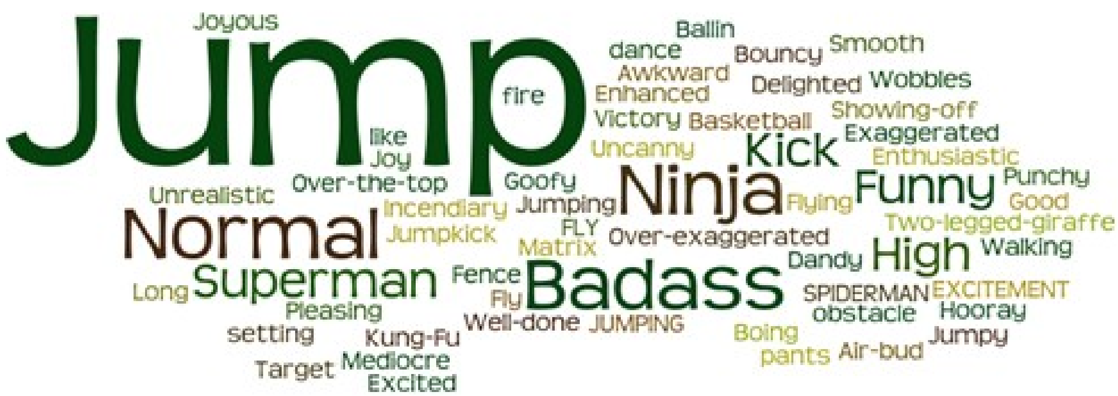
This study has been approved by Carleton University Research Ethics Board B (Protocol #15-163).

Ethics Clearance for the Collection of Data Expires: 09/23/2015

## Appendix D  User Study, Part B - Word Clouds

### D.1 Exaggerations

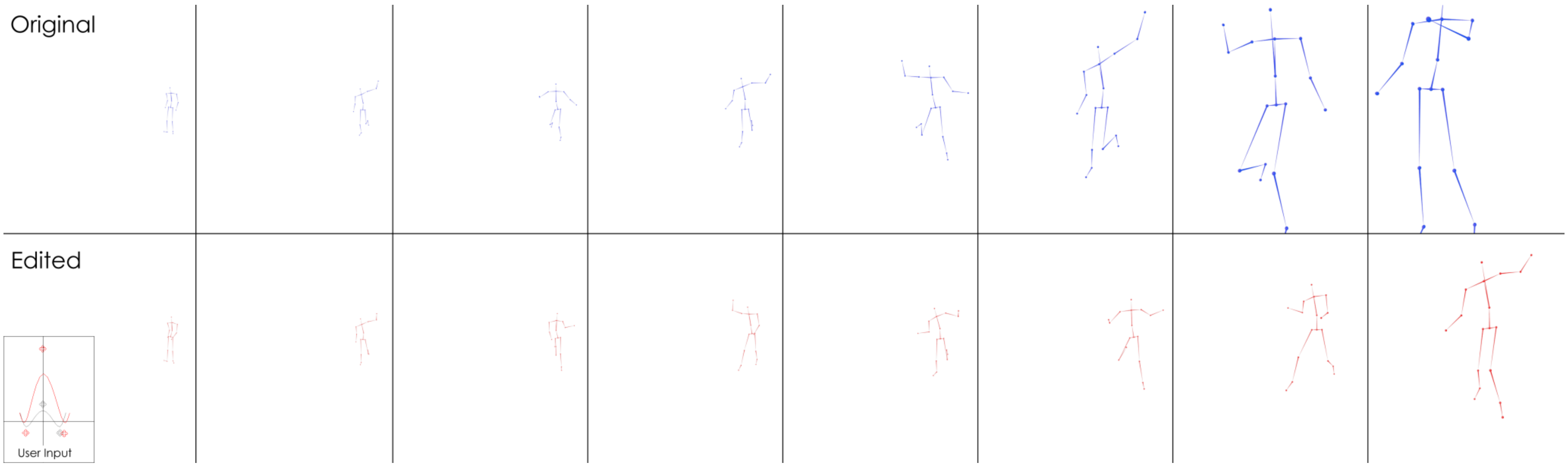

### D.2 Jumps



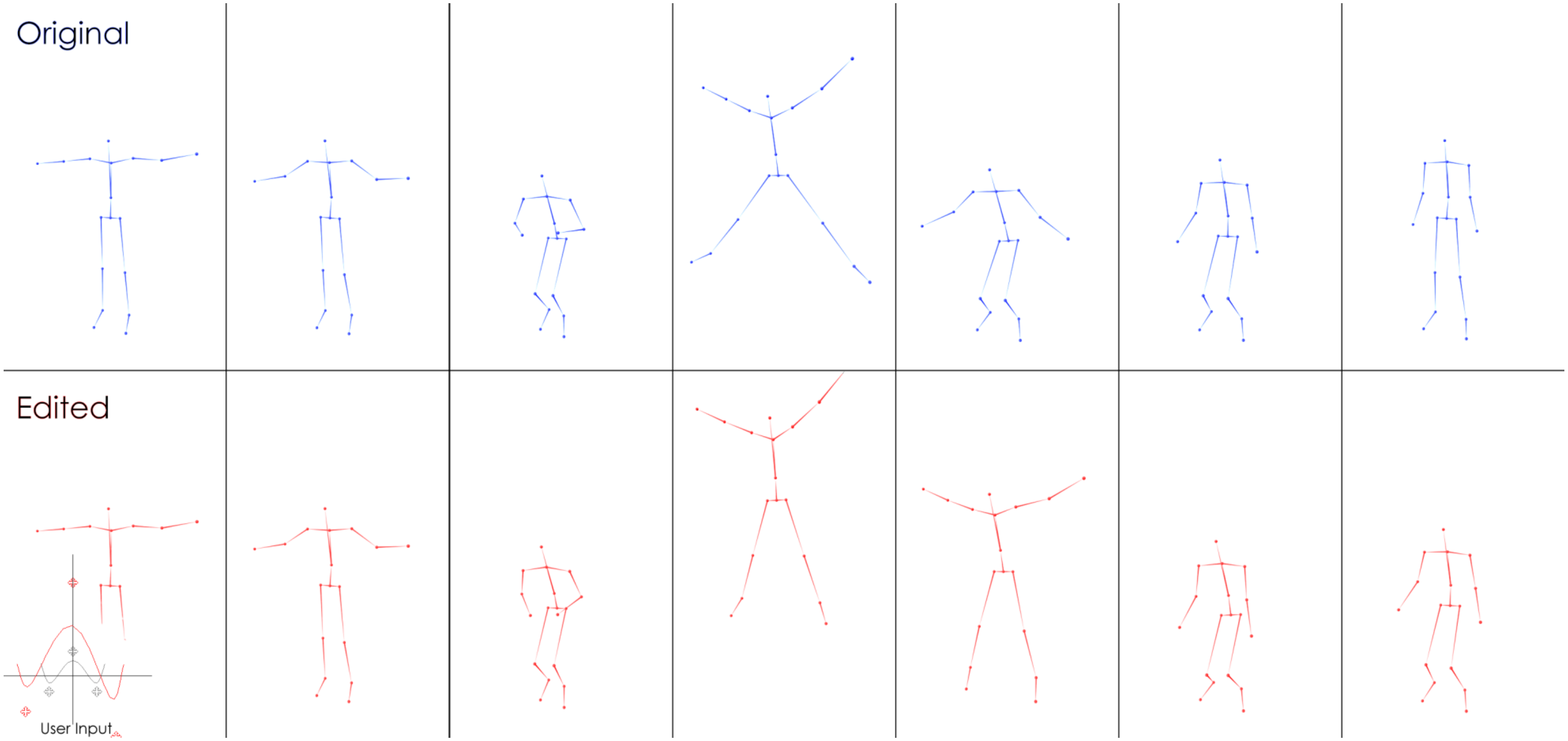
## D.3 Feminine Walks

## Appendix E User Study, Animation Results

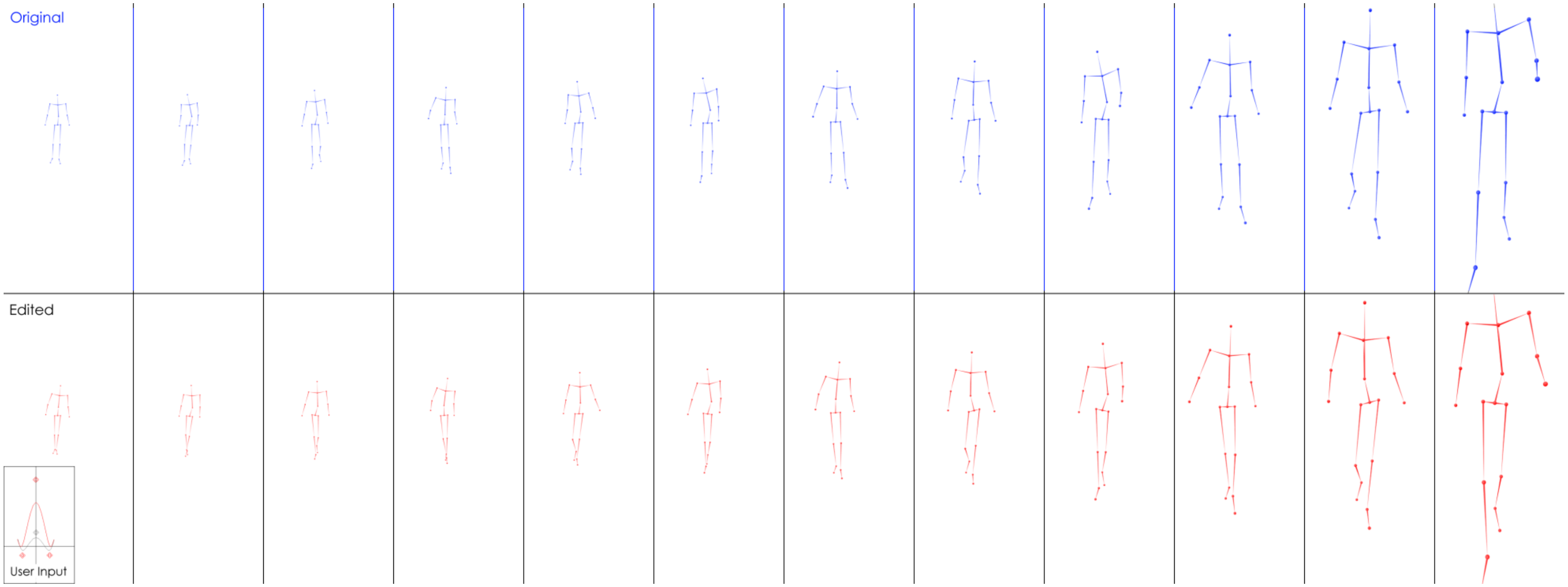
### E.1 Exaggeration



### E.2 Jump



## E.3 Stylized Feminine Walk



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