

FUTURIST SCULPTING:
MODELING MOVEMENT IN 3D

A Thesis

by

PIOTR KRAWCZYK

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

December 2006

Major Subject: Visualization Sciences

FUTURIST SCULPTING:
MODELING MOVEMENT IN 3D

A Thesis

by

PIOTR KRAWCZYK

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

Approved by:

Chair of Committee,	Ergun Akleman
Committee Members,	Richard Davison
	John Keyser
Head of Department,	Mark Clayton

December 2006

Major Subject: Visualization Sciences

ABSTRACT

Futurist Sculpting:

Modeling Movement in 3D. (December 2006)

Piotr Krawczyk, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Ergun Akleman

Futurist Sculpting is a collection of techniques for representing dynamic motion in a static three-dimensional model. These techniques allow digital artists to use animation as a new modeling tool. The idea of Futurist Sculpting is inspired by the works of the Italian Futurist artists and it aims to achieve the same goal as the one described by Umberto Boccioni, “to find a form that would be like a remembered motion, the product of time but permanent in space.” However, Futurist Sculpting extends Boccioni’s idea to the new medium of 3D animation and modeling, introducing the techniques of Motion Snapshot, Surface Differentiation, and Motion Elasticity. Motion Snapshot has evolved from the idea that multiple key poses captured at different stages of motion can successfully portray the idea of movement. Surface Differentiation was developed to remove redundancy of overlapping geometry introduced by snapshots occurring with high spatial frequency. Exploded Snapshot creates a geometric blur effect and extends application of Motion Snapshots to motion of deforming objects. The Motion Elasticity technique stretches the object to represent a partial volume through which it is moving. As a proof of concept all of the Futurist Sculpting techniques were implemented in Maya. The techniques should be viewed as a set of tools for the artists. The user can choose any one of them to apply to any animation, but he needs to understand their applications and limitations too.

To my Mom, my Grandparents and my Friends

ACKNOWLEDGMENTS

I have a whole list of people to thank, starting off with my thesis committee. Ergun Akleman, my committee chair, encouraged my creativity to run free and always listened to my crazy ideas, like modeling with animation. It was also in his modeling class, while working on a “Human in Motion” project, that I got the idea for this thesis. Whenever I talked with Richard Davison, he would unavoidably find connections between my thesis and the work of modern artists. Like him, I still hope that my thesis work can be used to create a real sculpture. John Keyser guided me through research of relevant work in Computer Graphics. His great sense of humor made me laugh even at my own slip ups, like sending a blank attachment.

I must thank Karthik Swaminathan for his unbound curiosity and his interest in other people’s work. Also, I have no proof, but I am almost positive that, while I was in the Viz Lab, Karthik was in some way involved in every single thesis project there. Wonchan Song and Frank Chance may not realize it, but they helped me out a couple of times simply by sparking another idea in my head. Thanks to Ozan Ozeker, we almost had a paper published. I believe that we can still do it.

Thanks to the Viz Lab for providing a great teaching program and learning facilities for me and the rest of my fellow Vizzers. While I was away, Margaret Lomas was the one who helped me take care of all the necessary forms and procedures needed to finish my graduate studies.

I am certain that I would not have been able to finish this thesis without my Mom. She has been the main source of my motivation, pushing me forward with the words of encouragement, “Aren’t you done yet?” Thanks Mom.

TABLE OF CONTENTS

CHAPTER	Page
I INTRODUCTION	1
II PREVIOUS WORK	9
III METHODOLOGY	14
III.1. Motion Snapshot	16
III.1.1. Temporal Motion Snapshot	17
III.1.2. Spatial Motion Snapshot	18
III.2. Surface Differentiation	19
III.3. Exploded Snapshot	20
III.4. Motion Elasticity	20
IV IMPLEMENTATION	23
IV.1. Motion Snapshot	23
IV.2. Surface Differentiation	25
IV.3. Exploded Snapshot	26
IV.4. Motion Elasticity	27
V RESULTS	29
VI CONCLUSION AND FUTURE WORK	36
REFERENCES	38
APPENDIX 1	40
VITA	42

LIST OF FIGURES

FIGURE		Page
1	Representing motion in photography of Eadweard Muybridge, “Descending Stairs.”	1
2	Representing motion in photography of Jules-Etienne Marey: (a) “Running”, (b) “Cyclists.”	2
3	Motion in Futurist art: (a) Marcel Duchamp “Nude Descending a Staircase”, (b) Giacomo Balla “Violinist.”	3
4	Motion in Giacomo Balla’s paintings: (a) “Abstract Speed and Sound”, (b) “Flight of Swifts.”	5
5	Motion in Umberto Boccioni’s art: (a) ”Unique Forms of Continuity in Space” (1913) ,(b) “Elasticity” (1912).	6
6	Representing motion in photography of Anton Giulio Bragaglia, “Change of Position.”	8
7	Motion in CG: Non-photorealistic rendering of Dynamic Motion. . .	10
8	Motion in CG: (a) James Troy “Engineering Swept Volumes, 3 of 3”, (b) Motion Swept Volumes.	12
9	Motion in CG: Nathaniel Jones “geometric motion blur.”	13
10	Motion in CG: Wonchan Song ”Speed-Line for 3D Animation.” . . .	13
11	Comparison of Futurist Sculpting techniques: (a) original motion, (b) Temporal Motion Snapshot, (c) Spatial Motion Snapshot, (d) Motion Snapshot with Surface Differentiation, (e) Exploded Snapshot, (f) Motion Elasticity.	15
12	Comparison of Motion Snapshots: (a) Temporal Motion Snapshot, (b) Spatial Motion Snapshot.	16
13	Diagram of Temporal Motion Snapshot.	17

FIGURE	Page
14	Diagram of Spatial Motion Snapshot. 18
15	Diagram of Surface Differentiation. 19
16	Diagram of Exploded Snapshot. 20
17	Diagram of Motion Elasticity. 21
18	Graph showing stretch function based on facing angle (top) and an image of surface deformed by the stretch function (bottom). 22
19	Maya's Animation Snapshot tool. 24
20	Maya's Boolean difference tool. 25
21	Maya's polygonal face extrude tool. 27
22	Comparison of the Temporal-Frequency and the Spatial Motion Snapshots. 29
23	Exploded Snapshot ball test: (a) uniform spacing, (b) varied tim- ing, (c) varied scale, (d) final version. 30
24	Exploded Snapshot of human model animation: (a) just one leg, (b) one snapshot copy per piece, (c) one arm and a leg. 32
25	Motion Elasticity test on a rigged human model. 33
26	Two examples of Motion Snapshot used on a segmented runner model. 34
27	Motion Snapshot used to create a walking crowd. 35
28	Composition created by applying Motion Snapshot with Surface Differentiation to a walk-cycle animation. 35

CHAPTER I

INTRODUCTION

The idea of capturing motion has intrigued men for ages. The early attempts in the form of paintings on cave walls and on canvas were not very successful, because working in traditional media is a long process. Paintings and sculptures took days or even months to create. The artists were able to focus on the studies of form and light, but not on capturing time. It was the invention of photography that allowed men to carefully study motion. Even the early photographic cameras could record “instances” of time shorter than a second. It was something with which none of the painters could not compete. Instead the artists of the early 1900’s used the photographic studies as reference for their work. This inspired a new art movement called Futurism with its emphasis on dynamism, energy, and speed.

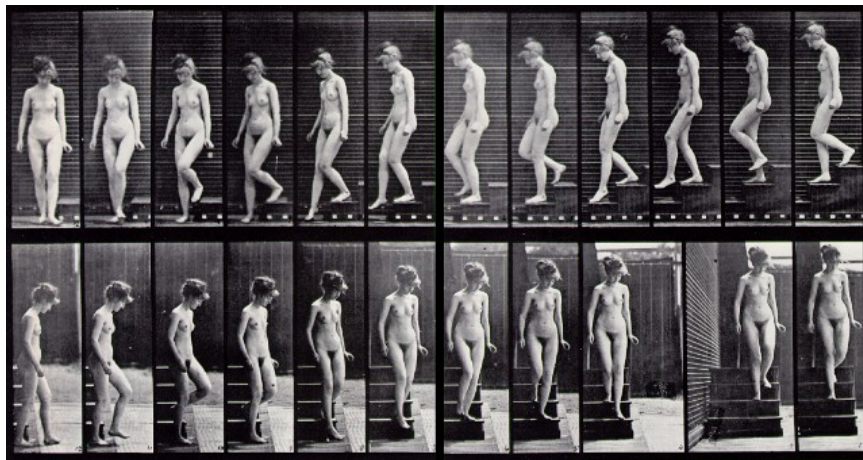


Fig. 1. Representing motion in photography of Eadweard Muybridge, “Descending Stairs.”

The journal model is *IEEE Transactions on Visualization and Computer Graphics*.

Eadweard Muybridge was the first photographic pioneer who focused on representing motion in photographs. His experiments consisted of using multiple cameras to take a series of photographs of a subject in motion, capturing poses of movement at different times. An example of this can be seen in Figure 1, showing a study of a female walking down stairs. Each photograph separately is nothing more than an image of a single pose. However, when displayed as a series in a cohesive order, they reveal motion. Muybridge’s work inspired another pioneer, Jules-Etienne Marey, to use photography as a scientific tool to analyze motion.

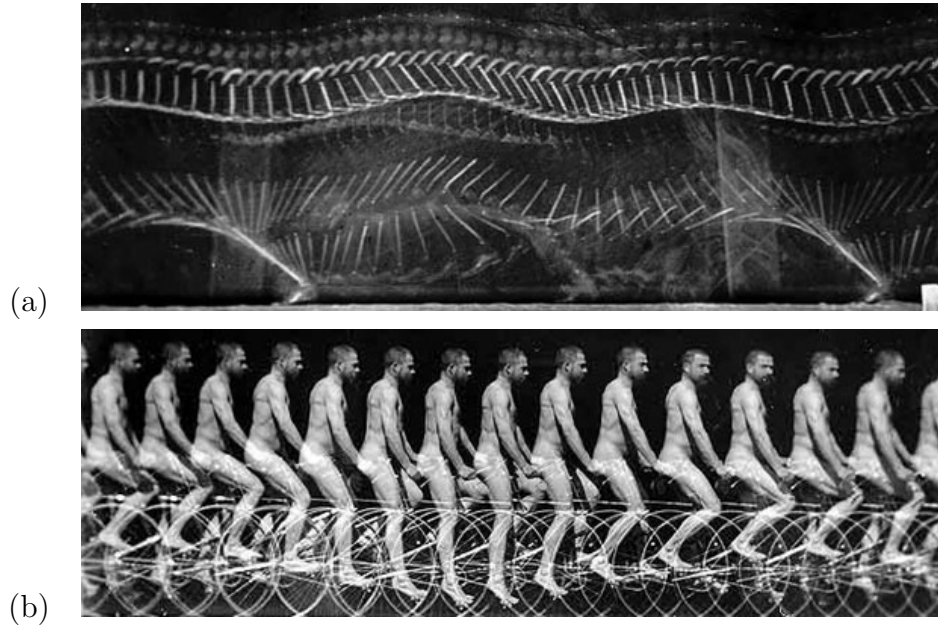


Fig. 2. Representing motion in photography of Jules-Etienne Marey: (a) “Running”, (b) “Cyclists.”

Jules-Etienne Marey was the first man to use photographic analysis as a scientific tool to study human motion. His aim was to produce a single-image representation depicting the “relationship in time and space between various body parts.” [1] For that purpose he invented chronophotography, a technique of recording multiple pho-

tographic exposures on a single glass plate (See Figure 2). However this technique had a significant limitation, “a trade-off between acuity in time and in space. If he increased the number of exposures (number of slots in the shutter), he got more pictures, therefore better temporal resolution, but, due to the superimpositions of the pictures (contour overlap) the spatial resolution was poor, and the images were blurred.”[1] In order to minimize overlapping of exposures, Marey had to emphasize only the lines and points which gave the most information about movement. He accomplished this by obscuring majority of the form and marking only lines and joints of importance for his experiments, as shown in Figure 2(a). By doing this Marey removed all redundancies and was able to successfully produce a single representation in which “the trajectories of the major points could clearly be seen.”[1]

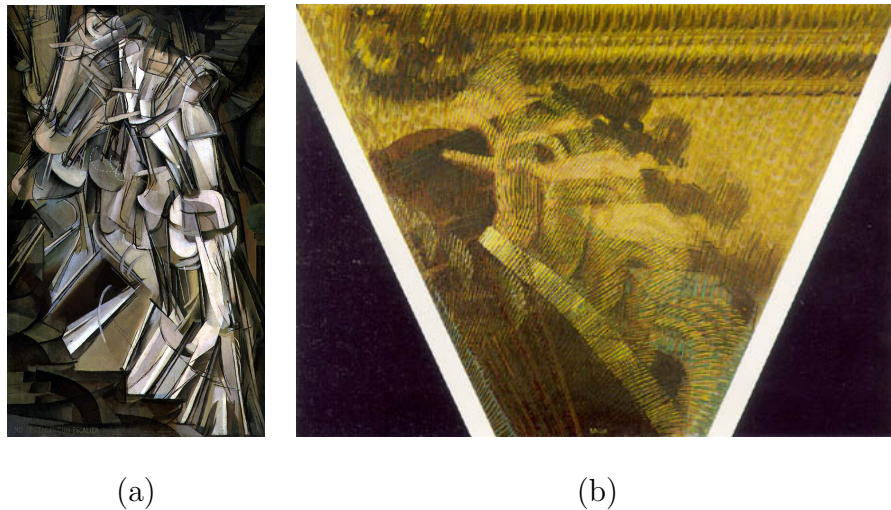


Fig. 3. Motion in Futurist art: (a) Marcel Duchamp “Nude Descending a Staircase”, (b) Giacomo Balla “Violinist.”

Photography captured instances in time, showing people what was not perceptible to the human eye. Photographic studies allowed the artists to understand motion and to represent it more accurately in their work. Especially Muybridge’s and Marey’s

motion studies inspired artists to reference motion in their work. One of the earliest examples of this is *Nude Descending a Staircase*, a painting by Marcel Duchamp (see Figure 3). That painting bears strong resemblance to Marey’s chronophotographic studies (See Figure 2). Marey’s influence is also visible in Giacomo Balla’s “Violinist” (See Figure 3), showing multiple overlapping images of violinist’s hands during a performance.

As the artists used painting, sculpture and photography to describe motion, the Futurist art movement was born. Its focus was on representing speed, dynamism and energy, while the artists experimented with various techniques to show “vitality of matter”[2]. One of the Futurist painters, Giacomo Balla, saw motion as a “sequence of rhythms of movement”[2]. In his earlier works Balla adapted techniques of Divisionism. An example of this is shown in Figure 3, where motion is represented by pieces of disintegrated form following the trajectory of motion. His later work, although more abstract, retained the Divisionism’s segmentation with added fluidity and rhythmic flow of movement (See Figure 4). Another Futurist artist, Umberto Boccioni, pursued a “sense of dynamic activity” in his paintings[3] (See Figure 5(b)). Boccioni, who began working as a painter, later used sculptures “to construct complex forms in space and light.”[4] Figure 5(a) shows one of the best examples of his work, entitled *Unique Forms of Continuity in Space* (1913). As seen in Figure 5 Boccioni’s sculpted a figure of a walking man, whose body is distorted by his movement. It can also be interpreted as a representation of the volume of air surrounding his form displaced by motion. This sculpture and the painting “Elasticity”, both represent Boccioni’s interest in the flow and continuity of motion. Much of his work bears a lot of resemblance to the images produced by a photographic technique called photodynamism.

Unlike chronophotography and cinematography, which separate motion into se-

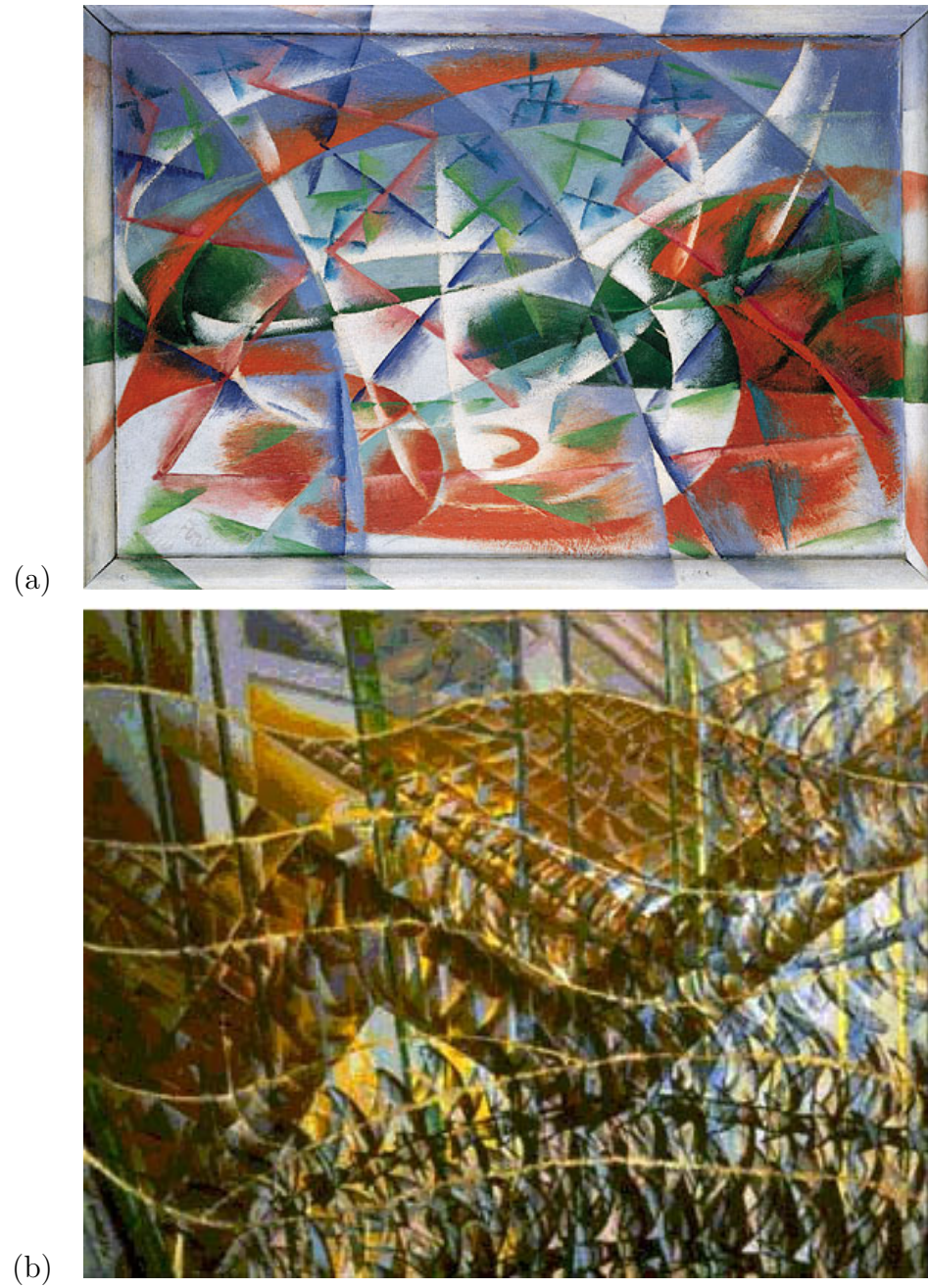


Fig. 4. Motion in Giacomo Balla's paintings: (a) "Abstract Speed and Sound", (b) "Flight of Swifts."



(a)



(b)

Fig. 5. Motion in Umberto Boccioni's art: (a) "Unique Forms of Continuity in Space" (1913), (b) "Elasticity" (1912).

quences of discrete steps, photodynamism shows fluidity and continuity of motion (See Figure 6). It is a photographic technique of using long exposure to visualize movement through motion-blur distorted images. The moving objects appear to have stretched forms and partially blend in with the background, “since images themselves are inevitably transformed in movement”. [5] Photodynamism focuses on continuity of motion and rejects any ideas about discrete characteristics of motion. In the Futurist Photodynamism manifesto Anton Giulio Bragaglia made the following statements: “We are not interested in the precise reconstruction of movement, which has already been broken up and analysed. We are involved only in the area of movement which produces sensation.” [5] He also believed that it was only through photodynamism that it was “possible to obtain a vision that is proportionate, in terms of strength of images, to the very tempo of their existence, and to the speed with which they have lived in a space and in us.” [5] According to Bragaglia’s ideas, this technique provides a true representation of motion, by expressing not form but presence of the moving objects in space. While chronophotography was used for scientific measurements and studies of motion, photodynamism was developed by the artists as one of the techniques of the Futurist art movement.



Fig. 6. Representing motion in photography of Anton Giulio Bragaglia, "Change of Position."

CHAPTER II

PREVIOUS WORK

Representing motion has not found many applications in computer graphics. It is mainly used as a technique of enhancing rendered 2D images and film animation. For instance, motion blur was invented as a way to create a more photorealistic look in computer rendered images. This is simulated in computer graphics by temporal sampling over a time range during the image rendering process. The idea is that “In computer graphics, the simulation of motion blur is useful both in animated sequences where the blurring tends to remove temporal aliasing effects and in static images where it portrays the illusion of speed or movement among the objects in the scene.” [6] This technique mimics the result of a photographic camera shutter being open for a finite fraction of time. If the object is moving fast enough its position will change during the time when the shutter is open and it will appear partially transparent in the recorded photograph. Concurrently to the research of creating more photograph-like images, an area of non-photorealistic rendering evolved. It encompasses research focused on simulating traditional media, as well as incorporating artistic styles into the digital media. At Georgia Tech’s Animation Lab Jessica Hodgins and Alan Chen researched development of techniques for *Non-photorealistic Rendering of Dynamic Motion*[7]. Their work was also based on the analysis of the Futurist art, so it shares many common ideas with my thesis. Even though Hodgins and Chen had focused on rendering 2D images, some of their techniques of layering, deformation and exaggeration of form, shown in Figure 7, can be extended into the domain of 3D modeling.

The idea of using animation to produce a 3D models is familiar to engineers,

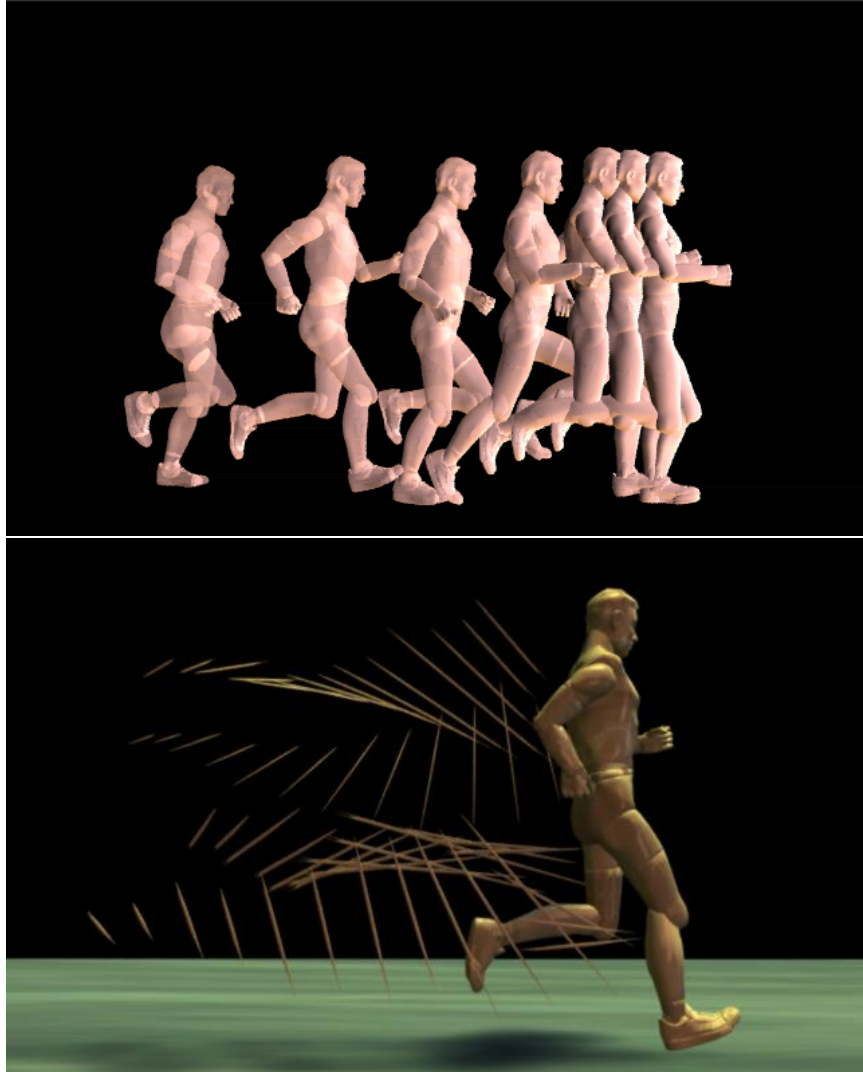


Fig. 7. Motion in CG: Non-photorealistic rendering of Dynamic Motion.

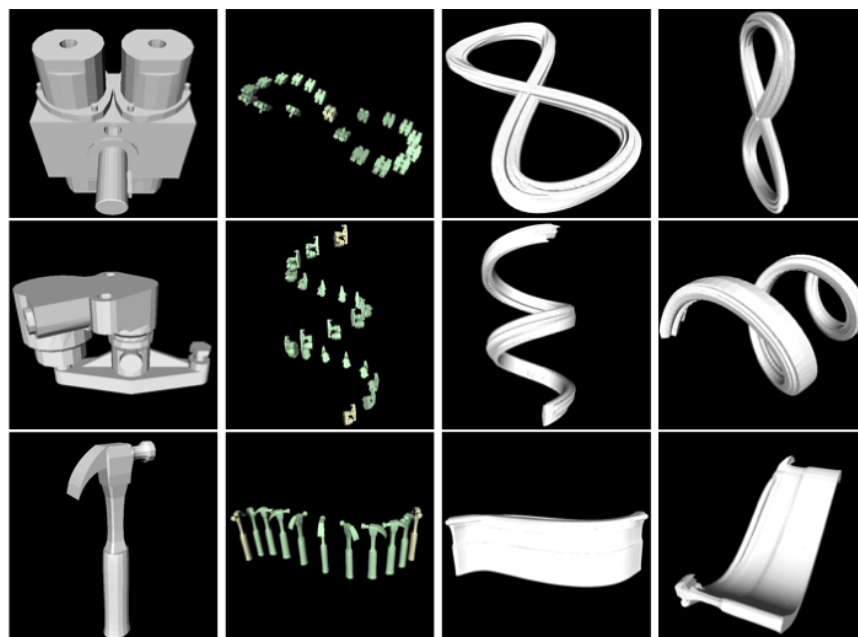
who have used it for decades in the form of motion swept volumes. The motion swept volume technique was proposed by researchers in early 1900s. Decades later it was introduced to computer graphics, mainly as a tool for engineering.[8, 9] Motion swept volume is defined to be “the volume generated by the motion of an arbitrary object along an arbitrary path (or even a surface) possibly with arbitrary rotations.”[10] The digital motion swept volumes are created by using an animated 3D model to shape a bounding volume for the object’s range of motions. Since the engineering focus is on the precision of the representation and completeness of the measurements, generating motion swept volumes is a highly complex process which does not have much room for creativity. They are mainly used for science and rarely for art. Figure 8 shows a rare example of using motion swept volume to create an artistic piece, which was displayed as a part of SIGGRAPH 2003 art gallery.

Recently, in his thesis *Real-time Geometric Motion Blur* [11], Nathaniel Jones applied certain ideas of motion swept volumes to create a motion shell behind a moving object. The effect created by his technique, shown in Figure 9, is a three-dimensional representation of the photographic blur. Jones also describes experimenting with a number of different approaches, including simultaneous display of multiple poses, generation of shell geometry, and stretching of the object’s surface. Since geometric blur is a means of representing motion of a model at each frame, therefore it is very closely related to Futurist Sculpting.

Additionally some research was done on adding visual line effects to enhance the representation of movement in 3D animation. Masuch et al. focused on visualizing motion without blurring the form, by drawing lines trailing behind the moving object and contour lines of its previous positions.[12] Extending the idea of using lines to help visualize motion last year Wonchan Song wrote a thesis on creating three-dimensional motion line effects.[13] Song’s technique works to enhance perception of motion and



(a)



(b)

Fig. 8. Motion in CG: (a) James Troy “Engineering Swept Volumes, 3 of 3”, (b) Motion Swept Volumes.

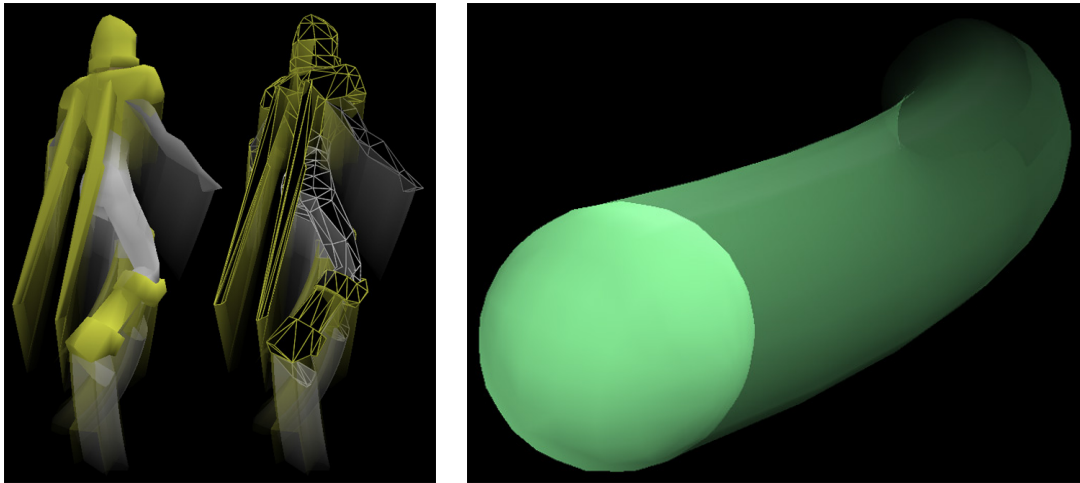


Fig. 9. Motion in CG: Nathaniel Jones “geometric motion blur.”

the style of rendering an animated sequence (see Figure 10). In the process of creating the motion lines, he created three-dimensional tubes following the moving object. Although his final results were rendered image sequences, it is possible to apply his intermediate pipe models as a modeling tool.



Fig. 10. Motion in CG: Wonchan Song “Speed-Line for 3D Animation.”

CHAPTER III

METHODOLOGY

Futurist Sculpting is a collection of techniques for creating a static model representation of dynamic motion. In this chapter I will focus on describing four main techniques: Motion Snapshot, Surface Differentiation, Exploded Snapshot, and Motion Elasticity. Figure 11 shows a comparison of the results of each technique applied to the same motion of a translating sphere. Motion Snapshot duplicates object's geometry at a various instances of time (these copies of the original object's geometry will be referred to as "snapshots" in the rest of the paper). There are two variations of Motion Snapshot: Temporal Motion Snapshot and Spatial Motion Snapshot (See Figure 11b,c). The characteristic of Temporal Motion Snapshot is that the distance between snapshots is proportional to the speed, while keeping equal time intervals between them. Figure 11b shows that the snapshots get more dense on the left side and eventually overlap as the sphere slows down. By comparison Figure 11c visualizes that Spatial Motion Snapshot ensures constant spatial frequency of snapshots. Spatial Motion Snapshot creates evenly spaced snapshots regardless of the relative change in speed. Surface Differentiation, shown in Figure 11d is derived from Motion Snapshot. Instead of complete copies it produces partial ones, by applying difference of consecutive snapshots. Surface Differentiation eliminates overlaps and incorporates repeating lines and shapes to enhance representation of motion. Exploded Snapshot abandons the duplication of form use by previous techniques. Instead it creates a trail of "exploded" pieces along the motion path of the moving object (see Figure 11 e). Unlike the snapshot techniques Motion Elasticity does not create any additional geometry. Instead it distorts the original object as if the motion was stretching it (see

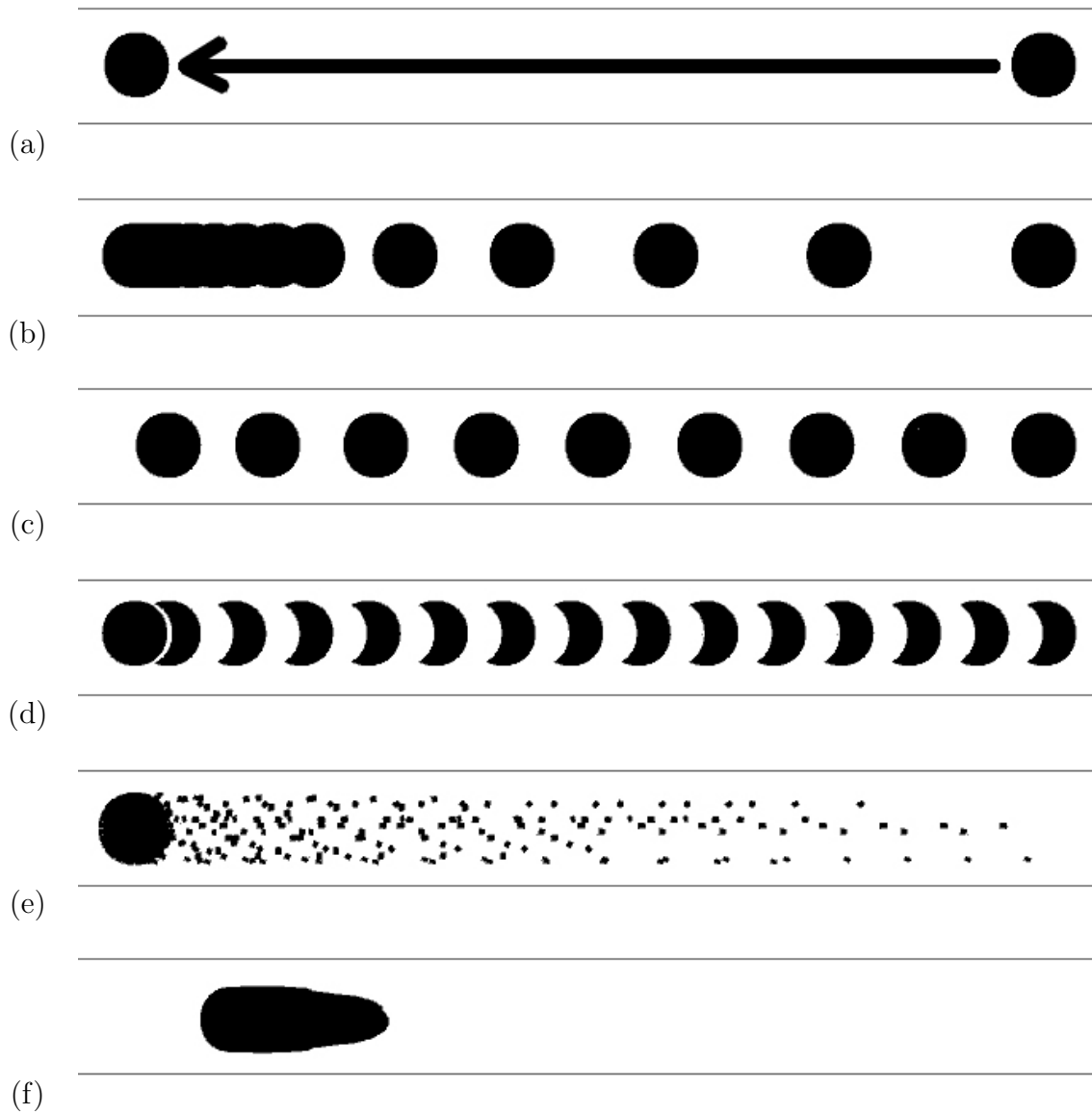


Fig. 11. Comparison of Futurist Sculpting techniques: (a) original motion, (b) Temporal Motion Snapshot, (c) Spatial Motion Snapshot, (d) Motion Snapshot with Surface Differentiation, (e) Exploded Snapshot, (f) Motion Elasticity.

Figure 11f). In the following sections I will explain how each technique of Futurist Sculpting uses a different algorithm and produces an equally different representation of motion.

III.1. Motion Snapshot

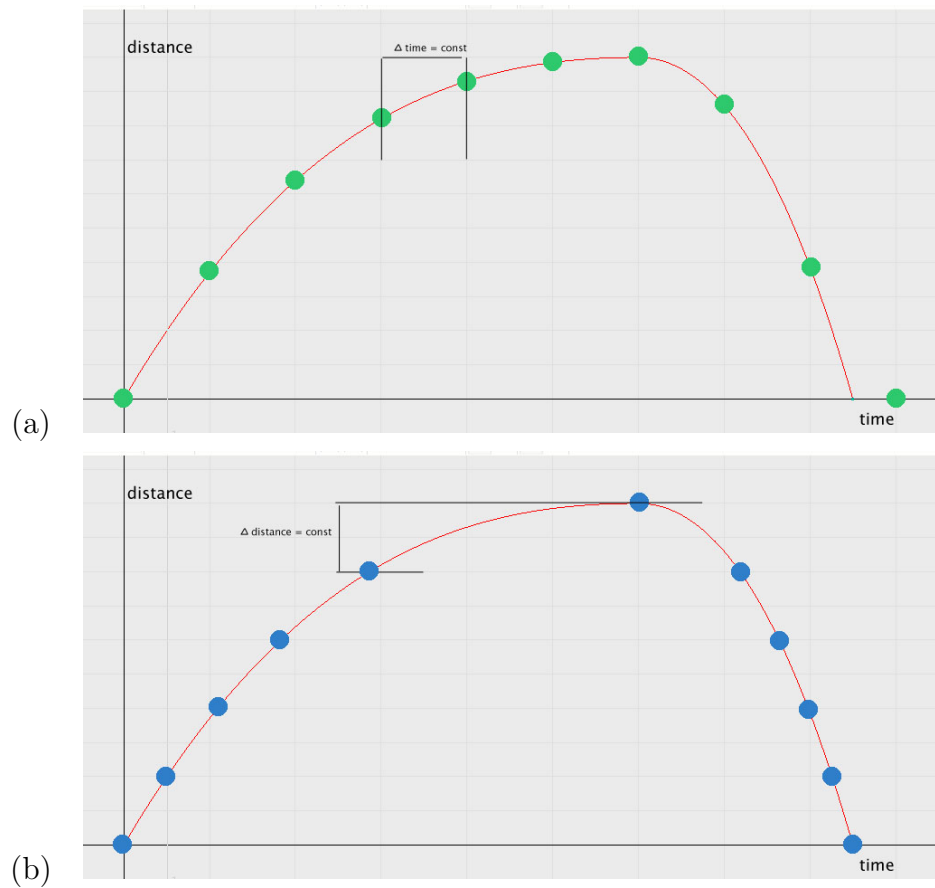


Fig. 12. Comparison of Motion Snapshots: (a) Temporal Motion Snapshot, (b) Spatial Motion Snapshot.

Motion Snapshot is a technique similar to Marey’s chronophotography. It combines several “snapshots” captured at various instances of time to construct a representation of motion as a series of discrete steps. In photography this was done

by Marey, by having multiple exposures on one image. Unlike chronophotography Motion Snapshot combines three-dimensional copies of the moving model's surface. Also two variations of Motion Snapshot have been developed, based on two variables of motion: change in position and change in time. To have a clear representation of motion we need to keep one of the two variables constant. This creates two variations, depending on which variable we want to keep constant, Temporal Motion Snapshot and Spatial Motion Snapshot. Figure 12 compares the two variations of Motion Snapshot by graphing points on a motion graph where snapshots would be created in each case. The graphs plot distance versus time allowing to compare the results of keeping time increment constant (Temporal Motion Snapshot) or the space increment constant (Spatial Motion Snapshot).

III.1.1. Temporal Motion Snapshot



Fig. 13. Diagram of Temporal Motion Snapshot.

Starting with an animated object, Temporal Motion Snapshot iterates through the given time range taking snapshots at equal time increments. The result of this technique gives a clear representation of motion. It also preserves information about relative speed in the form of spatial distance between the consecutive snapshots. If the object moves faster the snapshots will occur less frequently, indicating that the object has traveled a greater distance in the same amount of time. Similarly a slower moving object will produce snapshots occurring more frequently. Graph in Figure 12a visualizes how changes in speed are reflected in spatial frequency of Temporal Motion

Snapshot. The following formula represents relation between distance and speed when time increment is kept constant.

$$\text{since: } s = \frac{d}{t}$$

where: s is speed

d is change in distance

t is change in space

if $s_1 > s_2$ and $t = \text{constant}$

then $s_1 > s_2$

$$\frac{d_1}{t} > \frac{d_2}{t} \text{ where } t > 0$$

$$d_1 > d_2$$

Problem with this approach arises if there is a significant change in speed during the selected time range. This would cause a significant change in the spacing between snapshots, making motion representation less readable. If the snapshots are separated by a distance much greater relative to the size of the object, it is difficult for the viewer to understand the relation between them. Similarly if the snapshots occur too densely they will overlap, obscuring object's shape and motion from the viewer. This can be seen in Figure 13, where on the left side the snapshots are overlapping and blending into a single shape. In such cases where there is a significant change in object's speed the Spatial Motion Snapshot maybe more appropriate alternative.

III.1.2. *Spatial Motion Snapshot*



Fig. 14. Diagram of Spatial Motion Snapshot.

Since Spatial Motion Snapshot, like Temporal Motion Snapshot, is a variation of the Motion Snapshot, it also creates copies of the model's surface. However it is not constrained to keep the time intervals between snapshots constant. In the graph from Figure 12b it is clear that in order to keep equal distance spacing time increments vary between snapshots. Spatial Motion Snapshot produces snapshots at a constant spatial frequency by iterating through the selected time range and creating a snapshot whenever the object has advanced by a certain distance. This technique works especially well with any translational motion, because it always produces evenly spaced snapshots. It also allows the artist to control spacing between snapshots. The trade off is that it does not preserve information about the relative speed changes of the objects in motion (See Figure 14).

III.2. Surface Differentiation



Fig. 15. Diagram of Surface Differentiation.

Surface Differentiation is an auxiliary technique to be combined with either of the Motion Snapshots. Use of Surface Differentiation is most appropriate to clarify the result of Motion Snapshot by eliminating redundancy of surface overlaps, or to enhance the representation of motion by incorporating negative space. Given an array of models created by a Motion Snapshot, this process applies a binary Boolean difference operation on pairs of consecutive snapshot models. This removes the intersections of surfaces by cutting out one out of the other. The result can be seen in Figure 15, where circular snapshots have become half-moon shapes. This method

exaggerates the repetition of shapes, since the result of subtraction reflects the forms in negative space. The need for Surface Differentiation arises in cases where the frequency of snapshots creates overlapping geometry. For instance, when Temporal Motion Snapshot is applied to an object with varied speed motion.

III.3. Exploded Snapshot



Fig. 16. Diagram of Exploded Snapshot.

Exploded Snapshot is an extension of Motion Snapshot, which allows to represent motion of deforming objects. The result is a sampled space of movement similar to the paintings of the Divisionism movement. You can see the similarities between this technique and some of the paintings of Giacomo Balla shown in the Introduction chapter of this thesis. Exploded Snapshot employs a pre-process step. First it splits the original model into elemental non-deforming pieces. From then on each piece is treated as a separate and independent model, however they still retain the animation of the original model. After the object is “exploded” into pieces, then the second step is to apply Motion Snapshot to each individual piece. The resulting model has pieces of the object trailing behind it, as can be seen in Figure 16.

III.4. Motion Elasticity

Unlike the discrete techniques described above, Motion Elasticity represents continuity of motion. The resulting shape is the original surface deformed by its motion



Fig. 17. Diagram of Motion Elasticity.

similar to a photographic image blurred by fast motion. Motion Elasticity exaggerates inertia and elasticity of matter, stretching the surface as if the object were pulled by some invisible force (See Figure 17). It is similar to the “stretch-and-squash” technique used by the traditional and CG animators for years. The animation technique represents a blend of velocity and acceleration. When an object is moving fast it stretches, when it slows down, or changes directions (i.e. bounces) it gets squashed.

Motion Elasticity’s process begins by interpreting motion of the object as motion of its vertices. For each vertex an animation curve is created and stored. Then by accessing animation curves for all vertices the object’s surface is reanimated. At this point the resulting animation remains the same, while the animation process has changed, allowing control of animation of each vertex independently. The vertices are organized into those facing towards and away from the direction of motion, by using surface normals and motion curve information. In the final step, for each vertex position is modulated based on the degree of how much it faces the direction of motion. The vertices facing towards the direction of motion are unchanged, while the ones facing away are pulled back along their motion curves.

Figure 18 shows a graph of the stretch function for Motion Elasticity. Stretch amount is plotted against the value of a facing angle determined by the vectors of direction of motion and the surface normal. The stretch value is zero for all normals facing in the direction of motion. However, as soon as the facing angle is greater than 90 degrees the stretch value increases. The stretch is at maximum when the

facing angle value reaches 180 degrees, at which point the surface normal is pointing in the opposite direction than the direction of motion. Below the graph is a visual representation of the surface deformed by this stretch function. The front-facing half is undeformed, while the back-facing half stretches back. This produces the effect of the back of the surface to be lagging behind due to object's elasticity and inertia.

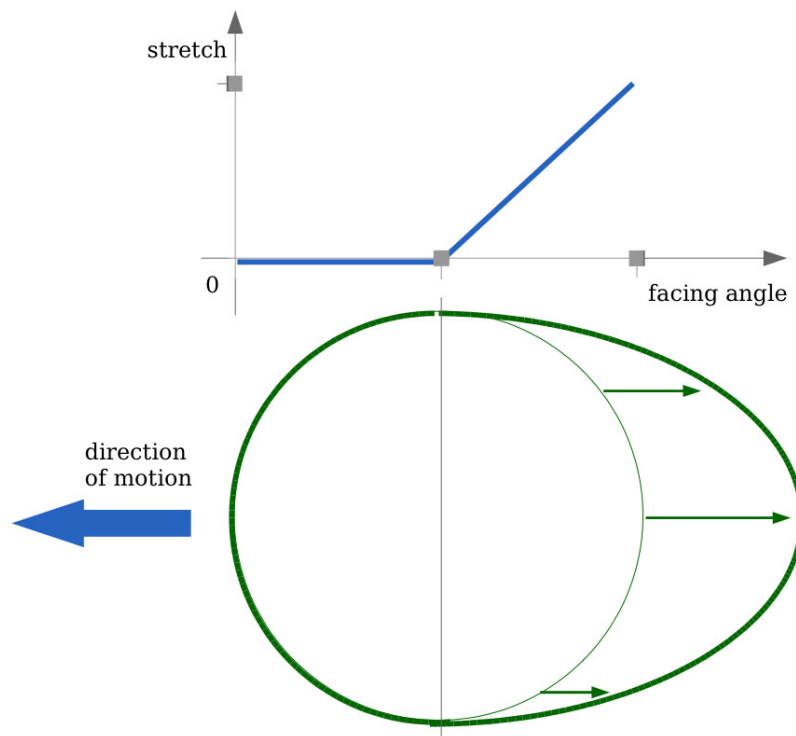


Fig. 18. Graph showing stretch function based on facing angle (top) and an image of surface deformed by the stretch function (bottom).

CHAPTER IV

IMPLEMENTATION

Implementation of this thesis was done in Maya, a software package designed for modeling and animation. The main benefit of using Maya is that it allowed me to focus on the topic of my thesis without having to write tools for modeling and animation. Another benefit is Maya Embedded Language (MEL), Maya's native scripting language. By writing MEL scripts, which executed Maya commands, I was able to automate the steps of the Futurist Sculpting techniques outlined in the Methods chapter. The script writing was an experiment process, during which I found certain limitations of Maya software. I also found out limitations and applications of each technique. For instance I discovered the fact that the Motion Snapshot techniques work best with rigid, non-deforming objects.

IV.1. Motion Snapshot

As described before, there are two variants of Motion Snapshot. Temporal Motion Snapshot is actually already implemented as an Animation Snapshot, one of Maya's built-in tools (See Figure 19). This is not surprising, because in the animation file data is organized and stored in a time-based format. This makes a process of creating Temporal Motion Snapshot straight forward in Maya. Given an animation file with a selected time range, the user just needs to select the animated model and run the Animation Snapshot (See Figure 19).

Spatial Motion Snapshot is more complex to implement. In the time-based approach, of the Temporal Motion Snapshot, all objects share the same time range, since they exist at each time step. In the space-based approach, each object will

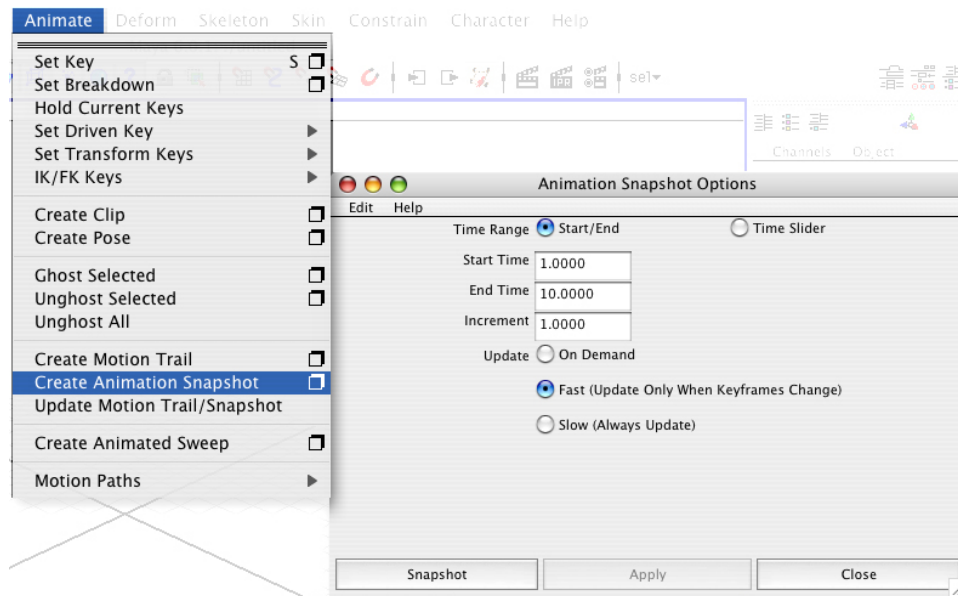


Fig. 19. Maya's Animation Snapshot tool.

start from its own initial position and will move through its unique space range. This means that Spatial Motion Snapshots cannot be executed in world-space, shared by all objects, because the objects do not move in the same space range. Also it is a much more complex problem to have uniform steps in three dimensions of space, compared to only single dimension of time. To address both of these issues I decided to implement the Spatial Motion Snapshot in object-space. The snapshots follow the motion path of each object and are dependent on its position and size.

My implementation of Spatial Motion Snapshot is a script, which takes snapshots with an adaptive time step to approximate constant step in distance. The script tests position of the object at a given time and compares it to its previous position. If the distance between the two positions is the same as the user defined space increment, then a snapshot is taken. If the distance between the two points is too short or too long, then an adjusted time step is calculated and the snapshot is taken at that

time. To find an object's position and bounding box the script calls on Maya's xform function. Bounding box is used in calculations of a distance step to ensure that smaller objects will get more frequent snapshots.

IV.2. Surface Differentiation

Surface Differentiation is an additional step executed after all the snapshots have been taken. It operates on pairs of consecutive snapshot copies and applies Maya's Boolean Difference function (See Figure 20). The result is a newer snapshot with the older one cut out of it. In most cases the trailing side is removed and the shape of the leading side is emphasized by both positive and negative space.

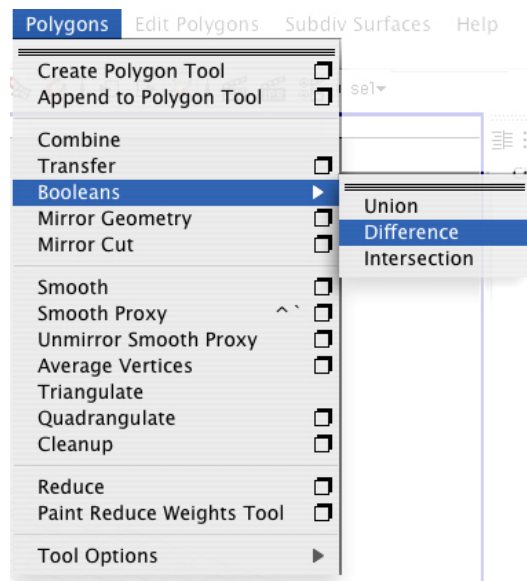


Fig. 20. Maya's Boolean difference tool.

IV.3. Exploded Snapshot

Exploded snapshot was developed as an extension of adaptive snapshot to handle animated deformable objects. Its implementation works in two steps. First, a deformable object is exploded into many smaller, “non-deformable” objects. Second, a Motion Snapshot is applied to each of the exploded pieces. Elements created in the first step retain the original animation. As explained in the Methods chapter Exploded Snapshot is an augmentation of the Motion Snapshots. The first step, to separate the surface into small pieces is implemented by using Maya’s built-in functions: `polyChipOff`, `polySeparate` and `polyExtrudeFacet`. The script uses the `polyChipOff` function to separate all polygonal faces of the surface. Then, by applying `polySeparate` function, each separated face becomes a separate object. In order to better represent a volume of the object and not just a thin surface, `polyExtrudeFacet` function adds thickness to each newly created polygonal face object (See Figure 21). After these three functions are applied the result is a shell of the original object, that’s constructed out of small three-dimensional blocks. This completes the step of “exploding” the surface. Since Maya saves model’s history, each one of the exploded pieces inherits the animation of the original surface. This means that even though they are independent objects, they will move together as if they still were part of the original object. If the Motion Snapshot were to be applied to them without any variation, the result would be the same as one created by a non-exploded snapshot. To create a more randomized look, the start time of Motion Snapshot for each object is modified, picking a time inside of the animation time range. This way the collection of snapshots will appear as discrete steps, but rather as sampling of a continuous volume.

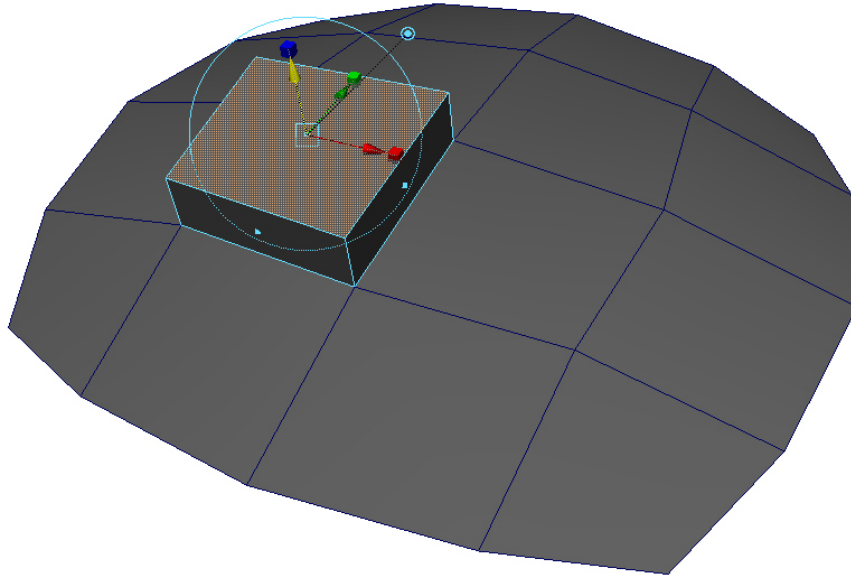


Fig. 21. Maya's polygonal face extrude tool.

IV.4. Motion Elasticity

Implementation of the Motion Elasticity was the most complex, since it was the only one of the Futurist Sculpting techniques not implemented in computer graphics. That is because automating deformations of the model based on its motion is a completely new idea. The complexity of connecting deformations to motion originates from the fact that motion is stored per object, while deformations affect individual surface points. The first step of my implementation is to record motion path for each vertex into a curve. By retrieving data back from the curves and applying it back to the vertices I was able to reanimate the surface. At this point the surface moves and looks the same, but the way of animation has changed completely. It is not animated anymore by the object and its parameters, but by the motion of its vertices. This means that modulating the animation of individual vertices will

distort the surface. The script uses vertex information including its position and surface normal to determine if it is facing towards or away from the direction of motion. The vertices facing away from the direction of motion are slowed down and as a result of it the model's surface gets stretched. The stretch is proportional to the speed of movement and can be controlled by user parameters.

CHAPTER V

RESULTS

Using Maya has made it easier to implement the techniques of Futuristic Modeling, without writing the underlying functionality of animation and modeling tools. However together with benefits I had to accept limitations of Maya's functions, which would not be present in a custom-written program. The biggest problem I had was with Maya's memory usage. This was most apparent in the Exploded Snapshot, which is a memory intensive technique. I found out that its performance was greatly affected by the complexity of the model's skeleton. For an animated human model I was able to get only partial results with the Exploded Snapshot, shown in Figure 24.

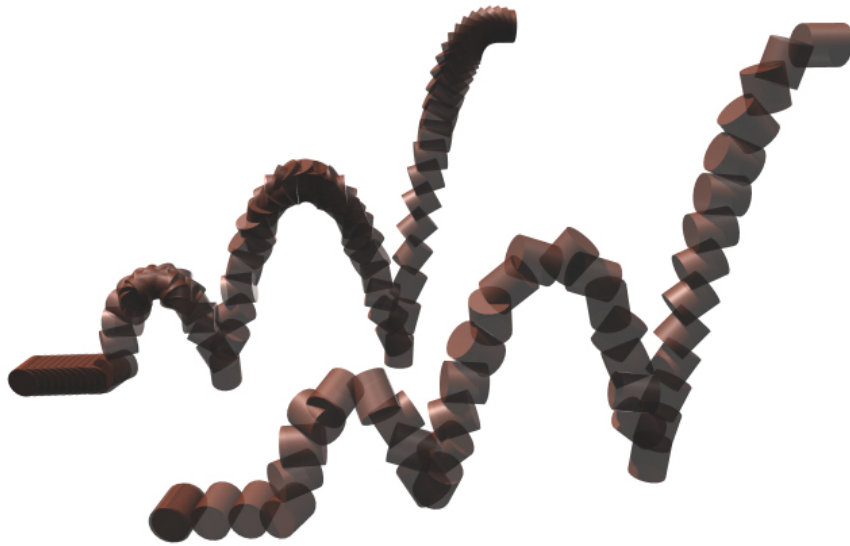


Fig. 22. Comparison of the Temporal-Frequency and the Spatial Motion Snapshots.

Figure 22 compares the results of Temporal-Frequency and Spatial Motion Snap-

shots. The snapshots have been rendered with a semi-transparent shader in order to make the overlaps more apparent. Both of them are applied to the same animation of a bouncing cylinder. Unlike Temporal Motion Snapshot, shown in the back, Spatial Motion Snapshot, which is in the front, preserves the information about the motion path while keeping all poses clearly visible.

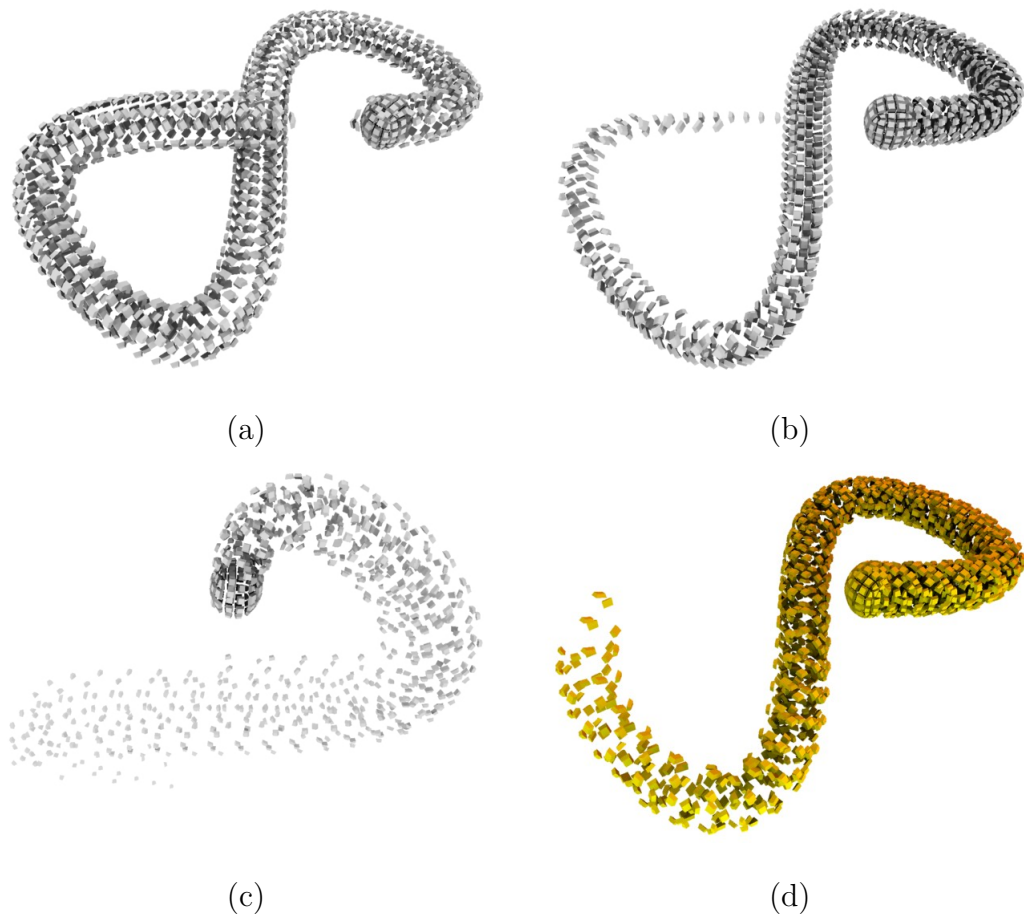


Fig. 23. Exploded Snapshot ball test: (a) uniform spacing, (b) varied timing, (c) varied scale, (d) final version.

Figure 23 shows evolution stages of the Exploded Snapshot. At first all the snapshots of exploded pieces were created with the same parameters. Then I experimented with varying snapshot spacing, time range, and scaling. In the final version I have

been using the Exploded Snapshot with varying start time for each piece.

Figure 24 shows results of applying Exploded Snapshot to an animated human model. Images show partial exploded snapshots, since I was not able to complete a full one. The images show my attempts to create Exploded Snapshots of just parts of the model or to create a single copy of each piece at different animation time.

In Figure 25 is a render of Motion Elasticity results at two different points in the timeline of the same animation. The subject was being translated forward, so a horizontal stretch is visible. Stretch of the leg results from an additional motion of the leg in the same direction as the translational motion. The arm shows problems of turning the geometry inside out when there is a drastic change in the direction of motion.

Figure 26 shows Motion Snapshot applied to the animation of a starting runner. By comparing the two images it is apparent that choosing short and less complicated segments of animation produces more coherent results. In the first image we see a snapshot of starting and running animation. The initial starting motion is too complex to visualize with the same settings as the running motion. In fact most of the snapshots of the body parts are not visible and it is difficult for the viewer to understand the motion. However the second image shows a result of Motion Snapshot applied to a short segment of the running animation.

I have also used Motion Snapshot repeatedly on a walk animation in order to create a model of a crowd, shown in Figure 27. Adjusting the time range for each Motion Snapshot introduced enough variation to disrupt uniformity and to create an appearance of a crowd. Also in a Figure 28 I used Motion Snapshot with Surface Differentiation on the same walk cycle animation. I combined multiple results to compose a result closely resembling Marey's chronophotograph from Figure 2.

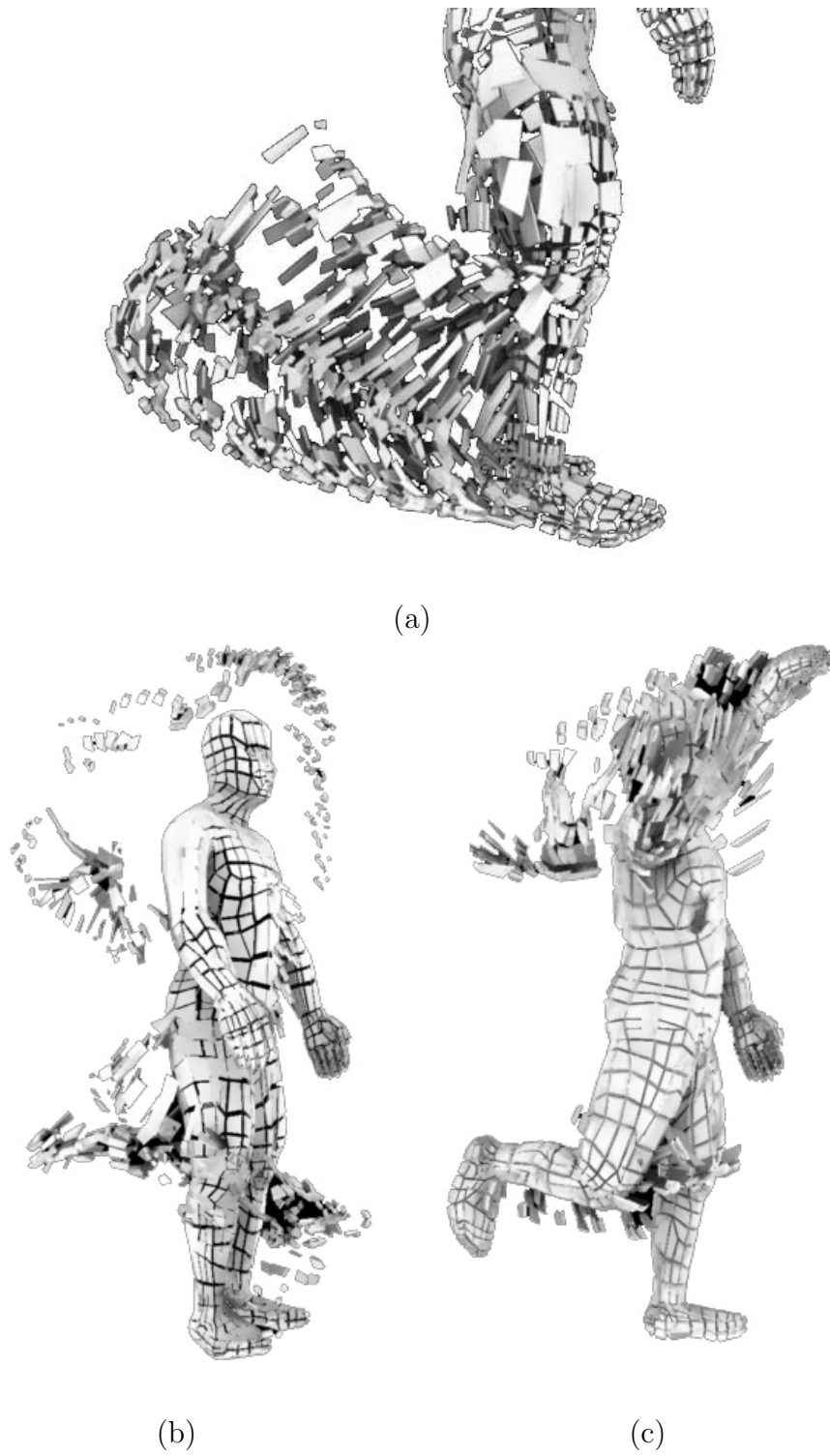


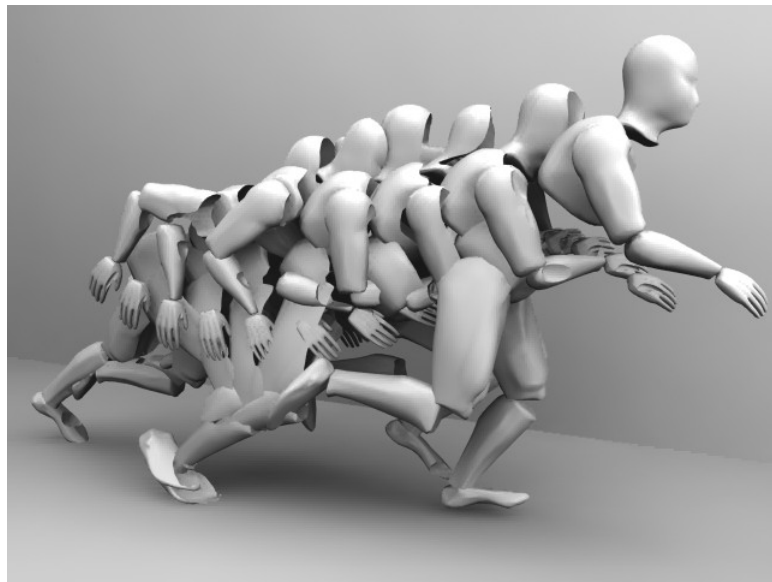
Fig. 24. Exploded Snapshot of human model animation: (a) just one leg, (b) one snapshot copy per piece, (c) one arm and a leg.



Fig. 25. Motion Elasticity test on a rigged human model.



(a)



(b)

Fig. 26. Two examples of Motion Snapshot used on a segmented runner model.



Fig. 27. Motion Snapshot used to create a walking crowd.



Fig. 28. Composition created by applying Motion Snapshot with Surface Differentiation to a walk-cycle animation.

CHAPTER VI

CONCLUSION AND FUTURE WORK

In this thesis I have successfully developed the techniques of Futurist Sculpting and implemented them using MEL scripting language as an extension of Maya's functionality. The techniques should be viewed as a set of tools for the artists. The user can choose any one of them to apply to any animation, but he needs to understand their applications and limitations too.

During the implementation stage I tested the applications of each technique. Since Motion Snapshots are based on changes in position of the object's center, I found them to be most appropriate for larger-scale translational motions. Movements resulting from rotations and deformations were not well represented by these techniques. On the other hand, Exploded Snapshot and Motion Elasticity are more versatile. They can handle both large-scale translational motions and small-scale deformations. Exploded Snapshot does this by focusing on sub-object parts and taking snapshots of small separated pieces. Motion Elasticity takes a different approach, analyzing motion on per vertex basis, and is unaffected by the size of the object. The trade-off of using either the Exploded Snapshot or Motion Elasticity is that they involve more complicated calculations and take longer to complete. Also during their implementation I have found certain limitations of using Maya.

When writing the implementation for Motion Elasticity I also discovered another source of a memory leak. At first I attempted to create each curve using the `curve()` command and at each frame adding a new point to it. In this case Maya was allocating memory for all the temporary curves, instead of having just one curve in memory. I have bypassed this problem, by storing all the point positions in an array and creating

the curve at the end. This way there was only one curve in Maya's memory created for each vertex.

One of the features which I was not able to implement is a way to connect the pieces created by snapshots. This could be accomplished by combining my Motion Snapshot with Wonchan Song's Motion Lines.[13] This solution to automatically create "bridges" connecting pieces of the snapshots together would allow the artist to create a single-surface representation of motion. This means that the animation would be used to build a 3D model, which could be sent to a rapid prototype machine. Using computer animation to create not only a digital 3D model, but a real sculpture would extend this project beyond the field of computer graphics.

REFERENCES

- [1] M. Braun, *Picturing Time: The work of Etienne-Jules Marey (1830-1904)*, Chicago, IL: University of Chicago Press, 1992.
- [2] R. S. Barnes, *Giacomo Balla: Divisionism and Futurism 1871-1912*, Ann Arbor, MI: UMI Research Press, 1981, pp. 89-100.
- [3] R. Rosenblum, *Cubism and the 20th Century Art*, New York: Harry N. Abrams, 2001.
- [4] J. C. Taylor, *Boccioni*, Garden City, NY: Doubleday, 1961.
- [5] A. G. Bragaglia, "Futurist Photodynamism," *Lacerba* (Florence), 1913,
Available: <http://www.futurism.org.uk/manifestos/manifesto33.htm>
Accessed March 2006
- [6] M. Potmesil and I. Chakravaty, "Modeling motion blur in computer-generated images," *Proceedings of the 10th Annual Conference on Computer Graphics and Interactive Techniques*, ACM Press, New York, 1983.
- [7] Graphics, Visualization & Usability Center, "Animation Lab: Non-photorealistic Rendering of Dynamic Motion," Georgia Institute of Technology, 1999, Available:
<http://www-static.cc.gatech.edu/gvu/animation/Areas/nonphotorealistic/>
Accessed March 2006
- [8] G. E. Favalora, "Volumetric 3D Displays and Application Infrastructure," *IEEE Computer* 38 (8), 2005

- [9] Y. J. Kim, G.l Varadham, M. C. Lin, and D. Manocha, "Fast Swept Volume Approximation of Complex Polyhedral Models," *ACM Symposium on Solid Modeling and Applications*, (Session: Motions & transformations), 2003, pp. 11-22.
- [10] K. Abdel-Malek, D. Blackmore, and K. Joy, "Swept volumes: foundations, perspectives, and applications," *International Journal of Shape Modeling*, 2003, Available:
<http://www.engineering.uiowa.edu/~malek/papers/swept-volume-review.pdf>
Accessed March 2006
- [11] N. Jones, "Geometric Motion Blur," M.S. Thesis, Computer Science, Texas A&M University, College Station, 2004.
- [12] M. Masuch, S. Schlechtweg, and R. Schulz, "Speedlines - Depicting Motion in Motionless Pictures," *Proceedings of Computer Graphics (ACM SIGGRAPH, Abstracts and Applications)*, 1999, p. 277.
- [13] W.-C. Song, "3D Speed Lines," M.S. Thesis, Visualization Sciences, Texas A&M University, College Station, 2005.

APPENDIX 1

MOVIES

Together with an electronic copy of this thesis are included five movie files, in Quicktime format. Below is a list and some information about them.

animation_stretch2.mov

This is a video file of Motion Elasticity applied to simple animated sphere moving in a figure eight. In this case Motion Elasticity was used at every frame of animation, showing how it distorts the sphere's shape depending on the motion path and speed. The images were rendered using Maya's software renderer.

runner_only.mov

Here is a video of an animation of a starting runner. The animation shows complex realistic motion of a model built out of separate pieces. It was used as an accurate test case of how Motion Snapshots could be by artists. The images were rendered using Maya's hardware renderer.

runner_snapshot.mov

Using the same animation as in the "runner_only.mov" this video shows an application Temporal Motion Snapshot. For the entire frame range a snapshot of all pieces of the model is generated at each time step. The images were rendered using Maya's hardware renderer.

runner_pieces.mov

This video visualizes the method of creating a model using Surface Differentiation combined with Motion Snapshot. In this example the runner animation was used. Each consecutive frame reveals an additional piece created from animation. Last frame shows a complete Futurist Sculpting model. The images were rendered using Maya's hardware renderer.

walk_cycle.animation_difference1124b.mov

This a turntable of a model created from a human walkcycle animation. The Futurist Sculpting model was created through application of Temporal Motion Snapshot and Surface Differentiation. The images were rendered in Maya using Mental Ray renderer.

VITA

Piotr Krawczyk

663 Washington Blvd
 Marina Del Rey, CA 90292
 piotrek.krawczyk@gmail.com

Education

M.S. in Visualization Sciences	Texas A&M University, December 2006
B.S. in Computer Science	Texas A&M University, August 2002

Employment

Graduate Assistant, Teaching	Texas A&M University, September 2003 - May 2004
TD Intern	Pixar Animation Studios, January 2005 - June 2005
Optimization and Rendering TD	Pixar Animation Studios, June 2005 - April 2006
Look Development TD	Sony Pictures Imageworks, May 2006 - present