THE EXPRESSION OF GENDER IN SYNTHETIC ACTORS: MODELING AND MOTION CONTROL OVER INVARIANT PERCEPTUAL CUES LEADING TO GENDER RECOGNITION

A Thesis

by

TIMOTHY DAVID MCLAUGHLIN

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

MASTER OF SCIENCE

May 1994

Major Subject: Visualization Sciences

THE EXPRESSION OF GENDER IN SYNTHETIC ACTORS:

MODELING AND MOTION CONTROL OVER INVARIANT PERCEPTUAL

CUES LEADING TO GENDER RECOGNITION

A Thesis

by

TIMOTHY DAVID MCLAUGHLIN

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

MASTER OF SCIENCE

Approved as to style and content by:

Louis G. Tassinary
(Co-Chair of Committee)

Susan Van Baerle
(Co-Chair of Committee)

Tarek Alameldin
(Member)

Wayne L. Shebilske
(Member)

Julius M. Gribou
(Head of Department)

May 1994

Major Subject: Visualization Sciences

ABSTRACT

The Expression of Gender in Synthetic Actors: Modeling and Motion Control Over Invariant Perceptual Cues Leading to Gender Recognition. (May 1994)

Timothy David McLaughlin, B.E.D., Texas A&M University
M.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. Louis G. Tassinary
Asst. Prof. Susan L. Van Baerle

A perception based strategy for communicating the gender of computer animated characters is evaluated. Motivated by the idea that effective character animation involves the expression of character traits through motion, this study builds upon previous work in the areas of computer animation and ecological psychology in an effort to more fully characterize the dynamic information which leads to the perception of gender. Information specifying the masculinity or femininity of a walking figure is considered in relation to the range across which the indexes may be exaggerated and applied to objects not normally considered male or female.

This thesis is dedicated to my parents, James McLaughlin and Darlene Warrick, M.D. My greatest admiration, love and appreciation goes to you for your unfailing support and for showing me by example how to live life and take hold of dreams.

ACKNOWLEDGMENTS

I am thankful to the students and faculty of the Texas A&M University College of Architecture Visualization Laboratory for their encouragement and dedication to the creation of an environment which fosters the marriage of art and science. Special among these people are Peggy Swinney, who never failed to provide assistance with a smile, and Amanda Ronai and Melissa Saul for providing company down the long road toward graduation, beginning to end.

I am indebted to Steve Rikli and Kevin Reuter without whose technical expertise this process would have been much more difficult, and to Jay Davis for his skill in modeling the human figure used in several of the animated sequences of this study. I would also like to acknowledge my indebtedness to researcher James Cutting and his colleagues for providing the basis for this work.

I would like to thank the members of my advisory committee, most notably Susan Van Baerle for being unable to contain the excitement that character animation generates, and to Louis Tassinary for showing the way to the marriage of this art with analytical thought.

To Valerie Aasterud I would like to say thank you for patient listening, and infectious happiness.

TABLE OF CONTENTS

Page

LISTS OF TABLES AND FIGURES

INTRODUCTION

The motion of persons in action contains a wealth of information to which the human visual system is highly attuned. An actor's expressed gender is one trait which has shown to be quickly and accurately discernible by observers. The task of communicating actor gender in computer generated human models ("synthetic actors") requires control over the modeling and motion factors which define the trait. When these elements are controlled, apparent gender can be varied within as well as across a variety of model structures, human and non-human.

Observers are adept at detecting information about actors through the observation of the actor's movements. Performers such as dancers and actors have long used motion to communicate emotion, character, and the situation to the audience. Their work and work in character animation is an extension of the processes by which people communicate non-verbally everyday.

Motion is the essence of animation. Understanding its language is essential to the task of all animators. Animation is also a particularly useful tool for understanding the mechanics and meaning of motion because it allows the discrete definition of the elements of a movement in both time and space. A first step towards communicating character traits through motion for both animators and psychologists involves the identification of the information which lead both to the recognition of individual traits and to the systematic manipulation of this information.

Because observers are so astute to the language of motion, synthetic reproduction is an arduous task. Motion can be analyzed on three levels. On one level it reflects the task involved; for instance, the act of getting from point A to point B. On another level it reflects the necessary consequences of the biomechanics of the

---

The format used in this thesis is provided by *Ecological Psychology*, the journal of the International Society for Ecological Psychology.

actor; stride is limited by leg length, balance is determined by the center of gravity. On a third level, motion is defined by the emotional state, or character traits of the actor; slow methodical movements signify melancholy; quick, abrupt movements, aggressiveness. Though observers are sensitive to these attributes, and artists are adept at their portrayal, systematic identification and quantification of aspects of the third level of motion, that which is effected by the character of the actor, has proven particularly elusive.

In order to be a useful tool for communication, computer animation must be able to produce motion which specifies information for the viewer on all three levels. The systematic study of this information and its importance to the observer forms the basis of ecological psychology:

> The act of picking up perceptual information is the act of experiencing it; the information abstracted from the objects, object complexes and events of the world are intrinsically valuable to the perceiving agent since, by definition, such information specifies the nature of its source and the active relationships the animal or human perceiver might enter into with respect to that source. (Shaw & Pittenger, 1977, p. 111)

The first step towards applying this approach to problems in computer character animation involves isolating the putative motion information from other types of information. The classic technique for accomplishing this was developed in the mid-seventies to early eighties for experiments in which the motion of a figure is made dominant over all other physical characteristics. These experiments demonstrated that observers are able to distinguish the presence of human subjects, their actions, their gender, and even their identity, based solely on the motion of point lights attached to the actor's body joints.

From the earliest experiments with actor motion, gender has been proven to be readily recognizable by observers. The visual cues which observers use to recognize gender appear to be closely tied to the motion of the hips and shoulders, and the two indices tied to that relationship which remain unchanged under widely changing conditions are the torsion index and the location of the center of moment. Both are indices linked to the structure of the actor and can be systematically and precisely varied using computer models and animation. This thesis describes a robust method for controlling synthetic actors in a 3D environment through the parametric manipulation of these indices including their exaggeration to create super-normal examples of maleness and femaleness, and their application to forms representing the human body as well as to non-human forms.

The generation of character specific motion for synthetic actors has potential application in several areas. One area is the generation of believable motion for synthetic actors in computer animated videos and films. A second area which this research impacts is the body of knowledge of ecological psychology and the tools which may be used to explore the perception of person traits. Expanding the earlier work into the 3D environment and extending the range of tests applied to it has provided opportunity to explore more systematically the invariant information for the perception of gender.

REVIEW OF LITERATURE

The Role of Motion in Communication

Although biological motion plays an integral role in the interaction between people and their environment, the majority of research into its synthetic reproduction has concerned how the motion is produced rather than how it is perceived. Since the turn of the century, the work of Eadweard Muybridge has been a standard reference for both scientists and artists interested in analyzing the way the body moves and changes under varying conditions (Muybridge, 1887/1979). Of equal importance to the mechanical analysis, especially for those interested in communicating through motion, is the analysis of the information specified by the motion. Further expansion of the uses of computer generated environments is dependent upon moving beyond a focus on the production of movement and must begin to explore the fundamental information conveyed through motion.

Actors and dancers understand the communicative power of motion. Pantomimes rely solely on the language of motion and posture for communication. The range of human conditions communicable through motion is limited only by the performer's physical vocabulary. On stage and film emotionally powerful performances are turned in time and again by a handful of talented thespians, not because they are always working with good scripts, but due to the ability to communicate through gesture and attitude.

Human actors, however, are not required for the communication of human traits. The communication of human character traits appears to be linked tightly to the type of motion rather than the form of the figure performing the motion. Geometric shapes moving in coherent ways are sufficient to cause viewers to describe the movements in terms descriptive of character (e.g., bully, heroic, and innocent) and gender (e.g., man, girl, woman, feminine) (Heider & Simmel, 1944).

The more coordinated the movements of the shapes the more meaningful those movements become to observers, and the more likely descriptions of them will become socially complex (Oatley & Yuill, 1985).

Recognition of Gender From Motion

The style of movement displayed by the geometric figures in the Heider and Simmel (1944) and Oatley and Yuill (1985) films played a large role in the attribution of gender to the shapes. Just as body shape and adornment are aspects viewed as signifiers of gender, body movements are often divided by observers according to gender. Ideas about movements that signify masculinity and femininity are an integral and pervasive part of our vocabulary. Two of the most popular performers in film, John Wayne and Marilyn Monroe, have becomes western icons of masculinity and femininity through the roles that they played and the way they physically embodied those characters. Their respective walks, the swagger and the sway, are so definitive that they have actually become caricatures of societal norms for masculine and feminine locomotion.

These caricatured aspects are the fundamentals of communicating gender for performers and animators and they are only recognizable in relation to their opposite. A masculine walk is considered masculine according to the manner in which it differs from a feminine walk and vice versa. The distinctiveness of John Wayne's swagger is much more apparent as he strides along side Katherine Hepburn than it is along side Dean Martin. This demonstrates not so much the differences between the two motions but what is common between them. It is the differences between the normal masculine movements and the normal feminine movements that becomes the basis for judging what is unique about either (Brennan, 1984). Exaggerating the differences is an essential procedure for both communicating effectively and for understanding the features which set the movements apart.

Production of such super-normal stimuli is most easily accomplished with synthetic actors.

The Synthetic Generation of Motion

The communicative power of motion has been relied upon by key-frame animators employing synthetic actors in ways that expand beyond the capacities of live actors. Perhaps the best known synthetic actors are those created by the artists at Disney Studios. Disney set a standard in the early 1930's that has remained the benchmark by which other emotionally expressive character animations are measured. Prior to this time, and long after for those who were slow to recognize the reasons behind Disney's success, the factors which distinguished one character from another in animated films were all static (e.g., Minnie Mouse wore a dress while Mickey wore short pants). Each character moved in the same manner, whether walking, jumping, or laughing. The dynamics of these motions were determined by standard rules based upon the ease with which the shapes could be drawn and redrawn consistently. Walt Disney, a very active and demanding head of the studio at that time, was unhappy with the range of appeal offered by the early styles of animation and sent his animators to drawing classes even though they were considered skilled at their profession. Under the tutelage of instructor Don Graham the animators learned to study and use nature as a reference for characterization.

> When the classes were started, most of the animators were drawing using the old cartoon formula of standardized shapes, sizes, action, and gestures, with little or no reference to nature. Out of these classes grew a way of drawing moving human figures and animals. . . The analysis of action became important to the devel-

opment of animation. (Lasseter, 1987, pp. 2)

The analysis of action pertaining to the character of the actor developed into Disney's Principles of Animation, which are still in use today and are being adapted and employed in key-framed computer animation (Thomas & Johnston, 1981; Lasseter, 1987). The animated stars of recent films such as Disney's *Beauty and the Beast* exemplify these principles in two ways. First, by reflecting through their body movements the personality of their character and second, by revealing society's expectations about those characteristics and the motions that communicate them.

Primary to the computer's role in our society is that it facilitate the efficient performance of tedious and redundant tasks; and this is precisely why it has not proven to be a facile tool for the generation of motion driven by either emotion or character traits. The ideal system for creating motion for synthetic actors would accept commands directing actor movement that are natural language based and descriptive of the meaning of the action (Calvert, 1991). However, that level of control is not possible currently and the majority of research is geared toward generating motion that is defined by either the task involved or the physical characteristics of the actor (Magnenat-Thalmann & Thalmann, 1990; Boulic & Thalmann, 1993; Webber, Badler, et al. 1993).

Point Light Displays

Synthetically producing motion which is informative of character requires determining systematically which traits are communicable through movement, apart from factors such as relative size, color, and shape. Johansson (1973) separated the static shape of the actor from the motion of the actor through the utilization of Point Light Displays (PLDs). This technique involves attaching either small lights or reflectant material to the joints of an actor. With the correct lighting and monitor adjustments the motions of the actor appear as the movement of an array of dots while all other parts of the actor or setting are invisible. In this manner the familiar cues such as relative size, hair style, and other static features are eliminated from the presentation of the motion.

Johansson found that the structure of the human body in action is recognizable by viewers of PLDs in as little as 0.1 seconds. The actions of the figure, such as running, jumping, and dancing were recognizable in as little as 0.2 seconds. Further study has found the recognition of persons in action from PLDs to take approximately 1.6 seconds (Barclay, Cutting, & Kozlowski, 1978). This technique and other similar techniques have been utilized to explore the range of information specified by human motion. Emotional states such as anger, sadness, joy and affection are readily and consistently recognizable (Sogon & Izard, 1987; Walters & Walk, 1988; de Meijer, 1989). Recognition of friends and self (Cutting & Kozlowski, 1977) and the recognition of action, intention, and deception (Runeson & Frykholm, 1983) have all been shown to be possible through the observation of movement.

The Notion of Invariance

The consistency of the recognition of gender from movement has led to the belief that there may be some aspect of the movement which is informative about gender and which remains unchanged while its surroundings undergo significant variations. Such an element is called an invariant, a perceptual term borrowed from mathematics. True to its origins, for an aspect of an event to be an invariant it must be mathematically definable (Cutting, 1986).

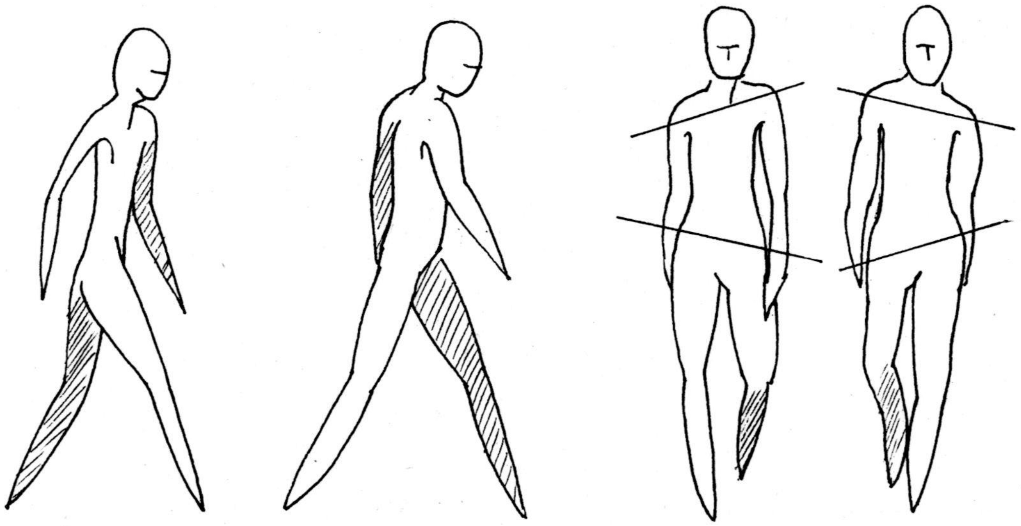
An elegant example illustrating the notion of invariance and its role in perception is provided by Shaw and Pittenger (1977). These researchers found that a single geometric transformation, the cardioidal strain, when applied to a shape such as a model of a human head, produces the effect of aging or biological growth. Thus the cardioidal strain appears to be an invariant for aging. What makes this finding even more impressive, and strengthens the theory about the presence of such an invariant, is that when the same transformation is applied to non-human models such as dogs, birds, and even Volkswagons, the "age" of the figure as identified by subjects directly reflects the degree of cardioidal strain.

In the present context, an invariant for a character trait would be one which is specific to the trait of the figure, is mathematically definable, and is directly perceptible in a wide variety of conditions. One character trait that has proven to be perceptible in a variety of conditions is gender. Kozlowski and Cutting (1977) discovered both identification performance and confidence levels to be high when viewing short sequences of walking male and female students. Viewers performed only slightly better than chance when shown static presentations of frames from the motion sequences. In similar experiments by Runeson and Frykholm (1983) correct recognition of gender from moving PLDs was typically 80%.

Invariants Which Lead to Gender Recognition

The Walk Cycle

Barclay, Cutting, and Kozlowski (1978) and Cutting, Proffitt and Kozlowski (1978) searched for the information which viewers may use to determine gender from motion, and for a biomechanical invariant which affords such recognition. Because the walk of humans is a cyclical event it is a fairly straightforward task to measure the average displacement and range of motion of body parts during the process of walking. During a normal walk cycle - the duration in which an actor moves from the position of having one foot back and the other forward, through the opposite condition, and back to the beginning position - the ipsilateral hips and shoulders move in opposite directions. As the actor stands on the right foot, the single support condition, the right hip is up and the right shoulder is down. In this same position on the other side of the body the left hip is down and the left shoulder is up (Figure 1).



Side View Front View

Figure 1. Shoulder and Hip Movement During Walk Cycle

As the left foot swings forward and the actor enters the double support condition with both feet on the ground the right hip moves back while the right shoulder moves forward. In the double support condition as with the single support condition, the elements on the left side move opposite to this (i.e., the left hip moves forward and the left shoulder moves back).

Using this information, a number of factors were identified as potential candidates for a gender invariant. Although no single element could be identified which afforded gender recognition, several derived indices did appear to show strong correlations with correct identification. These indices were the shoulder to hip ratio, torso torque, and the relationship of the center of moment to the center of gravity. The shoulder to hip ratio and the center of moment are closely related;

however, the latter is a more likely candidate because it functions during movement whereas the former does not.

The Torsion Index

In Cutting, Proffitt and Kozlowski (1978) the measure of torso torque, the torsion index, showed a relatively strong relationship to the identification of gender. The torsion index is defined as the rotation of the hips relative to the shoulders occurring as an actor walks. Torso torque, as measured by Cutting et al., is the difference between the angles created by the opposing double support conditions. When viewing the actor from the side, angle A is measured as the rotation between a line drawn from the right shoulder to the right hip, and a line drawn from the right hip to the right ankle. Angle B is measured from the opposite double support condition as the rotation between a line drawn from the right shoulder to the right hip, and from the right hip to the left ankle (Figure 2). The difference between angle A and angle B effectively measures the amount of swing occurring between the hips and shoulders when the actor is viewed from the side in 2D perspective.

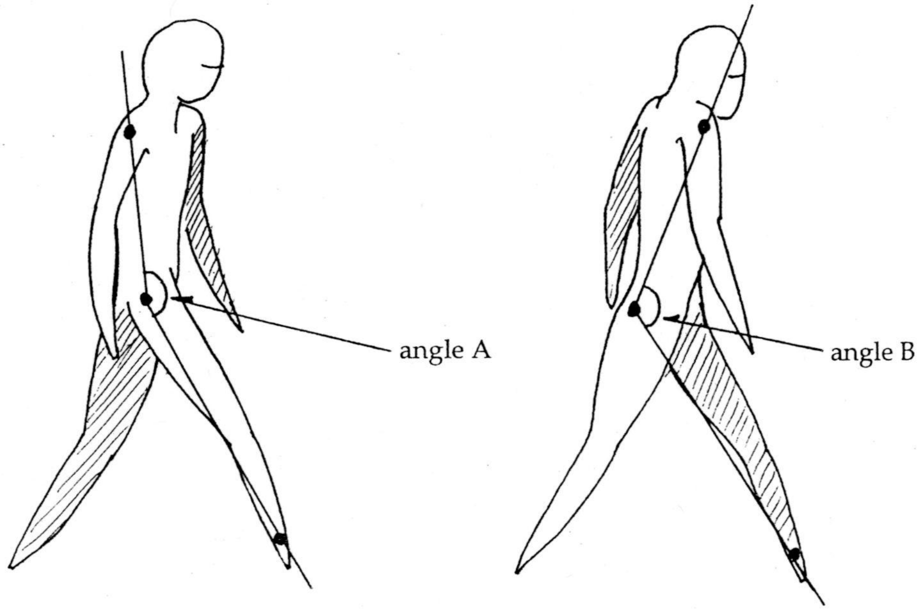


Figure 2. Cutting's Torsion Index

The torsion index in males is found to be typically higher than that of females because males tend to twist their bodies more while walking. Cutting, et al. discount and the torsion index for two reasons. First, Kozlowski and Cutting (1977) and Kozlowski and Cutting (1978) demonstrated that gender recognition is possible from viewing the motion of arms, legs, to some extent even ankles while the motion of the other joints, including hips and shoulders, is masked (i.e., the angles could not then be directly observed). Second, the torsion index is only a measure of the angle created by the motion of the shoulders relative to the hips. It does not specify if it is the shoulders which are performing the majority of the motion, or the hips. Walking males generally rotate their torsos more than females. Consequently, a range of torsion values from a population can be divided into high and low values with some degree of correspondence to male and female walkers. However, it is still possible for a single value to represent either masculine or feminine motion. A female swinging her hips a great deal would generate a high torsion index whose value could easily fall within the range of typical masculine torsion indices. Therefore the torsion index as currently defined is accurate in most cases in its correspondence to gender, but is very susceptible to erroneous interpretation regarding non-average walkers.

The Center of Moment

After careful evaluation, Cutting, Proffitt, and Kozlowski (1978) concluded that the center of moment is the most reliable index for gender recognition. The center of moment is defined as the point about which an object rotates. For a complex moving object, such as a person walking, the center of moment is the point about which the motion of the hips, shoulders, and the elements which are connected to them (e.g., knees, ankles, elbows and wrists) appear to move. In diagrammatic fashion, the center of moment is located by the intersection of two lines, one connecting the right shoulder to the left hip and the other connecting the left shoulder to the right hip. Mathematically it can be estimated by dividing shoulder width by the sum of shoulder width and hip width as in Formula (1) where *Cm* represents the center of moment, *s* the shoulder width, and *h* hip width.

$$Cm = s / (s + h) \qquad (1)$$

The value found for the *Cm* corresponds to the location of a point in 2-D space on a line bisecting the body between the shoulders and the hips. The value of the *Cm* divided by overall torso length represents the location of the *Cm* as a percentage of the overall torso length. This value can used as a comparative index between actors. Due to the typically wider shoulders than hips in males the center of moment is located at a lower position on the torso and closer to the center of gravity than for females who typically have wider hips or hips the same width as shoulders and lower centers of gravity (Figure 3).

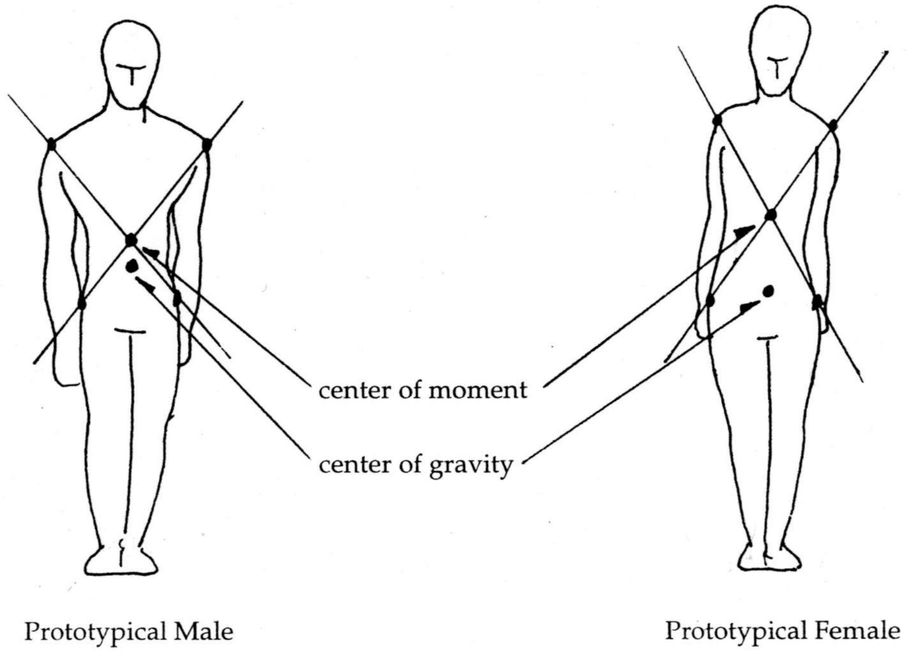


Figure 3. Centers of Moment and Gravity

The center of moment accounted for more of the positive results in these experiments than did the other indices. It is perceptible only during motion and may be perceptible from the observation of any number of elements, such as the ankle alone (Kozlowski & Cutting, 1978), because the movement of each element is mathematically linked to the center of moment. All points of the body orbit around it and thus the center of moment appears to be an invariant in relation to the activity of the actor. Because it is based on the physical measurements of the actor its location remains unchanged except for factors such as aging or disfigurement. It is not assumed that viewers are aware of the center of moment when discerning gender from motion, but that its existence is specified and located by the motion of the body, and that its location in relation to the location of the center of gravity correlate systematically with the character property, gender (Cutting, Proffitt, & Kozlowski, 1978).

Use of Invariants in the Synthetic Generation of Walkers

The analysis from Barclay et al. (1978) and Cutting et al. (1978) led to a further quantification of motion factors leading to gender recognition and their synthetic reproduction by Cutting (1978ab). Using a computer program through which the hip excursion, and shoulder excursion, and step size could be altered to produce the image of a figure walking in similar fashion to PLDs, Cutting was able to exert exact control over the motion and create a range for the movements with extremes beyond those naturally found in human walkers. Viewers identified stimuli as either male-appearing or female-appearing as they moved from left to right across the screen. Although the extremes of shoulder movement and hip movement were respectively judged to be good examples of male and female walkers, they were also judged to be the most unnatural of the examples.

As with the studies employing live actors, the synthetic representations of walking persons were from the side with the figure moving laterally left to right. The location of the center of moment in such a 2D display is geometrically defined by Formula (1) given above. Cutting also uses this formula as an index representing the amount of hip and shoulder movement, because shoulder and hip movement are a direct function of shoulder and hip widths.

Summary

In summary, the communication through motion of character properties such as gender is a process that takes place throughout interpersonal interactions and is a language to which most observers are sensitive. The attribution of social meaning and human characteristics to forms requires only that the motions appear to be coordinated in specific ways. Both traditional and computer key-frame animators have relied upon this to create characters which exude life and personality. Within this language of motion the expression of masculinity and femininity is highly defined and recognizable.

Program-driven computer animation has not generally been focused on the creation of character motion that is psychologically as well as physically informative about the actor. In order to do so, both kinds of information must be specifiable and detectable. Perceptual research has so far discovered no single cue to be sufficient for the recognition of gender; however, two putative invariants, the torsion index and the center of moment have been shown to be closely linked to gender attributions. Of these two, the center of moment is stronger conceptually because it is a mathematical construct which is tied to the actor's physical makeup, and it remains constant through changes in activity. The torsion index is based on the location of the shoulder and ankles relative to the hip during a walk cycle and is not specific to the origin of the rotation, i.e. twisting of the hips versus twisting of the shoulders.

With this limitation of the torsion index recognized, several problems remain unresolved in the earlier experiments. Both the torsion index and the center of moment, though conceptually distinct, are closely tied to one another as they are defined within the Cutting, et al. experiments. Each remains greatly effected by the walker's shoulder to hip ratio, which is itself a static index related to gender. Additionally, the evaluation of each index was based upon the correlation between the viewer's judgement of gender and the biological sex of the walker. The Cutting (1978a) experiment involving the synthetic generation of male and female walkers provided the best opportunity to separate the expression of masculinity and femininity from biological sex, but this was not the focus of the study. Finally, in that experiment as with the others from that time, all walkers, whether filmed persons or synthetically generated, were viewed from the side walking perpendicular to the viewer. In order for the existence of a biomechanical invariant which leads to recognition of gender to be demonstrated, the conditions of exploration should, as closely as possible, resemble the natural environment in which the event normally occurs, be based upon motion distinct from the effects of shape, recognize gender as a function of expressed masculinity or femininity rather than biological sex, and must, in similar fashion to the Shaw and Pittenger studies, be shown to operate across a wide variety of conditions.

SIGNIFICANCE OF THE STUDY

Purpose

Is it possible to generate believable synthetic actors? Answering this question has guided research efforts from within several disciplines. Assuming a solution is possible, its obtainment requires not simply the determination of the parts of the actor, but the determination of the parts that are important to the perceiver and the use of these parts in the development of person-models. Step one then is the analysis of motion and its quantification in physical terms. Step two is the identification of elements within the motion which are informative about character qualities. And the final step towards producing a synthetic actor is the application to the actor the elements which evoke in the observer the experience of another person.

What would reaching this goal accomplish? From the applied point of view (computer science, industrial engineering, entertainment), a synthetic actor is able to perform tasks which living models are unable to perform. These include tasks which are physically demanding beyond normal capabilities and tasks which require some a human aspect, such as bipedal locomotion or the expression of personality. From the theoretical point of view (psychology, kinesiology) synthetic actors are a tool for greater understanding of the phenomena upon which the models are based. In this regard, the synthesis of the real is a way of understanding the real. A synthetic actor could take the form of the deceased actor Humphrey Bogart and play opposite a current leading actress in a remake of the film *Casablanca*. A synthetic actor, modeled in all regards to resemble a person could jump back and forth across a distance providing exact measurements in regard to the energy required and the strain endured. The only requirements are that the models be accurate and manipulatable.

A synthetic human actor requires two things in order to be accurate and manipulatable; a form that models the features of the human body as it appears both in stasis and in motion, and a pattern of movement that models manners of locomotion and behavior. This thesis is directed toward the understanding and application of patterns of movement, specifically walking, and more specifically patterns of walking that specify gender. The methods used and their application are based upon the modeling of features which link attributes of the actor to the observer's perception of the actor traits, and the systematic manipulation of these features.

Rationale

The task of creating believable motion for synthetic actors is very complex. Factors which lead to the communication of character properties such as gender may be contained within the motion pattern of the actor. The identification and control of these elements, which are laden with information and are invariant across transformations, may lead to more efficient and powerful systems for creating virtual environments and may expand the body of knowledge concerning the perception of gender.

The Difference Between Gender and Sex

If an actor is perceived to be of a certain gender, what does that imply? For the study of movement this implies that there is something about the way the actor moves which causes the observer to perceive the actor as masculine or feminine. There are certain physical aspects pertaining to an actor which communicate gender. Among these are the primary sex characteristics, e.g. the genitals. Although these features are directly perceptible under a variety of conditions and do lead to perception of gender, they are static cues. Movement of these features is most often a result of the movement of other parts of the body. Other characteristics, such as the typically wider shoulders than hips in males are physical features pertaining to gender which play a potentially much larger role in the perception of gender. These are static features which do effect motion, but there are many women with broad shoulders and many men with low centers of gravity. To effectively discuss these features as they apply to movement the distinction must be made between gender and biological sex.

Sex is male or female. Gender is masculine or feminine. It is entirely possible, and considered quite a talent by many, for a male to move in a distinctly feminine manner and vice versa. The sex of the actor remains male while the expressed gender is female. In addition, other than the statistically small number of hermaphrodites, there is no scale between male and female. Masculinity and femininity, however, are dimensions. Consequently, there exists a range of possible values at the center of which lies androgyny, and at each extreme super-normal masculinity and super-normal femininity, respectively. John Wayne's gait is an example of motion that is a the far end of masculinity. Marilyn Monroe's walk may rest at a corresponding spot on the opposite end of the scale.

Measuring Masculinity and Femininity

Placing either walk, or any walk, on such a scale requires some method of measurement. Such a measurement must be mathematically definable, must be explicitly informative about the walk, and must be in a form that is perceptible. This is the definition of an invariant. An invariant for the recognition of gender for a person observing the motion of John Wayne compared to Marilyn Monroe would be something that the observer could perceive directly and the value of its measure would place the actors at consistently distant points on either side of androgyny.

A caveat: Androgyny is a hypothetical construct and, as such, measuring perceived masculinity or femininity against it has no applied meaning. Measures of the two are only meaningful when compared against each other or against norms for the actor's biological sex.

As the research by Kozlowski and Cutting (1977), Cutting and Kozlowski (1977), Barclay et al. (1978), Cutting, et al (1978), and Cutting (1978a) has shown the most likely source for such a measure in the motion of a walking figure is the relationship between the shoulders and hips. Simple observations, and measurements from recorded motion demonstrate that motion judged to be male is almost exactly opposite in nature to motion judged to be female in regard to the movement of the hips and shoulders. A typical male swings his shoulders and does not swing his hips in relation to his stride in almost the exact proportion that a female swings her hips and does not swing her shoulders in relation to her stride.

Three derived measures arose from this research which take advantage of these relationships. The first, the shoulder to hip size ratio is a static cue. The average shoulder size to hip size ratio for actors in the Cutting et al. studies is 1.10 for males, and 0.99 for females. This ratio is most likely a structural feature which is used to identify gender in still figures, but it probably is significant when the figure is in motion only as it relates to the other two dynamic indices, the center of moment, and the torsion index.

The Center of Moment

The center of moment (*Cm*) is located by the observation of the point about which the hips and shoulders rotate while they move. It is a point relative to the body, specifically the center of gravity of the body. Across bodies of different size the *Cm* can be found by locating the cross point of a line drawn between the right shoulder and left hip with a line drawn between the left shoulder and right hip, as in Figure 3, or mathematically via Formula (1), and measuring the height of this point as a percentage of overall body torso length. Torso length is measured as the vertical distance between hip and shoulder. Comparative values for the *Cm* are percentages, derived from the location of the *Cm* in 2-D space relative to the torso length. Average values from Cutting, Proffitt, and Kozlowski (1978, Table 1) for the location of the *Cm* as a percentage of torso length measured from the shoulders are 52% for males and 49% for females.

The Torsion Index

A second measure of gender arising from the prior studies of motion is the torsion index. As defined previously (Cutting, Proffitt, & Kozlowski, 1978), the torsion index is the measure of the difference in degrees between the angle created by the position of the right shoulder, right hip and right ankle with the right foot forward, and the angle created by the positions of the right shoulder, right hip and left ankle with the left foot forward (Figure 2). The full range of lateral movement between the hips and shoulders during a single walk cycle is thus represented. Larger measurements are considered male because males typically swing their bodies more while walking. As mentioned earlier, Cutting et al. preferred the center of movement over torsion index because the torsion index is unable to discriminate between the source of the movement, hips or shoulders, and recognition can be made consistently from displays in which the torsion index is not directly perceptible.

Reevaluating Invariants for Gender Recognition

In all research to date, presentations to viewers of figural motion whether from live action or synthetically generated, were from a ninety degree angle to the direction in which the figure was moving. In this form all movement occurs in only two dimensions over time. As a person walks, however, a point on the shoulder closest to the viewer will move in three dimensions, lateral, vertical, and in depth. The reliance on two-dimensional space forced the definition of the torsion index to be limited to the measurement of an angle measured normal to the viewer.

A more complete measure of torsion would be one which measures the 3-D movement of the hips relative to shoulders without reference to size.

Such a measurement for the shoulders considers a line drawn between the left shoulder and the right shoulder to be the diameter of a circle. The midpoint of that line then becomes the center about which the shoulders rotate. Much like a flat saucer balanced on a rod the circle is allowed six degrees freedom (Figure 4); rotation around the x, y and z axis of its own origin, as well as translation along the x, y, and z axes of the global space.

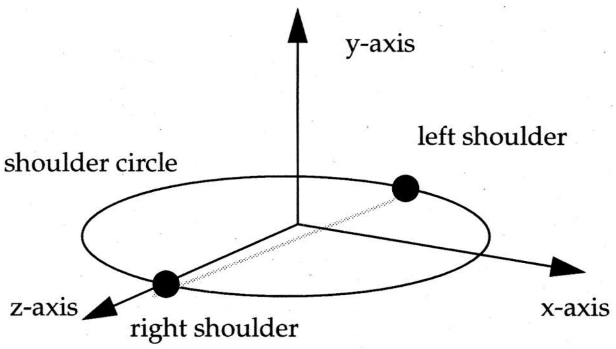


Figure 4. Three Dimensional Shoulder and Hip Rotation

The same condition may be applied to the hips. In this manner the degree of rotation for both the shoulders and the hips may be measured along three axes. These three angles are mathematically related, so that the establishment of one defines the others. This generalized torsion index thus overcomes an inability to distinguish the location of the rotation. A further extension of this is the creation of a single value for the torsion index by dividing the single value for shoulder rotation by the single value for hip rotation. In this manner an index is created, very similar to the shoulder size to hip size ratio, which is informative about the amount of rotation occurring within the shoulders and hips of a figure without being dependent upon measurement of the figure's shape.

A benefit to the redefinition of the torsion index is the potential to separate motion cues from the influence of body structure. While it is true that the majority of the population separates consistently down the lines of sex in regards to body shape there are many exceptions. For instance, a female with broader than average shoulders could easily possess a center of moment in line with the male average. Yet the motion of her walk may still be interpreted as feminine if her movements are in keeping with the norms for her sex. The reverse is true in regard to persons with structure in keeping with the average range for their sex, but whose movements are more in line with the standards for the other sex.

This situation leads to the existence of three possible invariants for gender. The first is a static form. Shoulder size to hip size ratio is an example of this condition. The second possible invariant is a structure which generates gender specific motion. The center of moment is an example of this. It is defined by the actor's anatomy but is only made apparent through the actor's motion. The third possible invariant is a measure of movement, unrelated to structure, which specifies gender. An example of this is the torsion index as defined above.

The goal is to discover and abstract an invariant that leads to gender recognition. With the torsion index the motion of a female may be judged to be masculine, and this would not weaken the relationship between the torsion index and recognition of gender because it is the motion which is masculine, independent of body shape. A strong test for such an invariant is its application to forms which are not typically described to be masculine or feminine. A similar test by Shaw and Pittenger (1977) for an aging invariant proved enlightening when the invariant was applied to items which normally are not perceived to undergo such a transformation.

Application of Invariants to Synthetic Actors

The most practical tool for applying invariants for gender to a wide assortment of actors under a range of tightly controlled conditions is the computer. Computer graphics allow the motion of 3-D models to be controlled to the exact specifications necessary for the study of this problem. A secondary benefit to the use of this tool is the ability to produce forms and motions that are seldom or never encountered in the real world. For the recognition of gender, this capability permits the establishment of a range of perceived masculinity and femininity for each model that includes points which may be considered gender-specific but not believable, neither gender-specific nor believable, or any number of combinations that are unachievable through the use of live action.

Problem Statement

The goal here is not to produce motion that exactly models human movement. The goal is to produce motion that represents the features of human motion which lead to gender recognition via a small set of rules for their synthesis and application to synthetic actors. As such, it is an understood limitation of this study that many of the factors which lead to real-world gender recognition will be overlooked. However, the work done here has as its foundation the work done by others in previous studies linking the perception of gender in walking figures to two possible invariants.

As a work intended to add to the body of knowledge concerning the perception of others and their synthesis, this thesis is focused on the determination of two questions, each in two parts: (1) Can the factors which lead to recognition of gender from the motion of walking persons be defined mathematically and systematically applied to person-models (synthetic actors) operating in a 3D environment? (2) What index, or invariant, which affords recognition of gender, appears to operate across the widest number of transformations of the figure and its environment, and is it available for systematic manipulation?

METHODS

Definitions

The following is a list of terms used in the following discussion which may be unfamiliar to the reader.

actor model -three dimensional form to which a motion model is applied.

center of moment (Cm) -the location about which the shoulders and hips rotate during the walking motion. Defined as a percentage of torso length measured from between the shoulders.

computer animation -the creation of object motion through the use of a computer.

constraining -a technique used in computer animation whereby the motion and position of the constrained object is a direct reflection of the motion and position of the constraining object.

femur -the upper leg; between the hip and knee.

frame -one individual picture in an animated sequence. Standard animation on video consists of 30 frames displayed in one second.

humerus -the upper arm between the shoulder and elbow.

hip circle -the element of the motion model representing the hips of the actor whose diameter is equal to the actor's hip width. Oriented parallel with the ground plane, it is parented to the hip torso circle and its center rests at the bottom of the hip torso circle. It has two diametrically opposed points on its periphery representing the right and left hips, respectively.

hip torso circle - an element of the motion model representing the torso of the actor. Oriented perpendicular to the ground plane, its center coincides with the center for the shoulder torso circle, the two together represent the actor's center of moment. It is the parent of the hip circle.

key-frame animation -a process of creating motion for an object based upon the required position in space for the object at discreet points in time. The in-between positions are defined by the movement of the object from one key-frame position to the next.

linear motion -the path of an object defined by key positions of the object and the direct path that the object travels from one to the other.

motion model -a collection of elements, unseen in rendered frames, to which motion is applied. Consists of parented circles and points, each representing a single anatomical aspect of an actor. Motion is applied to the circles, and their radii equal the length of the structure they represent. The elements represent the location of key joints. (circles and points are not rendered)

motion pattern -the combination of shoulder to hip size ratio and torsion index factors applied to motion model. Designated by the expression of the two ratios, e.g. 1.00-4.00.

parenting -a technique used in computer animation whereby the motion of one object influences the motion of another. The parented object maintains its freedom of movement relative to the motion it inherits from the parenting object.

patch -a curved surface, defined by a connected group of either Bezier, B-spline, or Cardinal splines. Objects composed of patches are more computationally demanding, but they offer more accurate surface determination than polygonal meshes; for a more complete definition see Foley (1990).

shoulder circle -the element of the motion model representing the shoulders of the actor whose diameter is equal to the actor's shoulder width. Oriented parallel with the ground plane, it is parented to the shoulder torso circle and its center rests at the top of the shoulder torso circle. It has two diametrically opposed points on its periphery representing the right and left shoulders, respectively.

shoulder torso circle -an element of the motion model representing the torso of the actor. Oriented perpendicular to the ground plane, its center coincides with the center for the hip torso circle, the two together represent the actor's center of moment. It is the parent of the shoulder circle.

splined motion -the curved path of an object defined by the type of curve employed, Bezier, B-spline, β-spline, or Cardinal; for a more complete definition see Foley (1990).

step size -the horizontal distance between the two feet at the double support positions of a step cycle.

tibia -the lower leg, between the knee and ankle.

torsion index (a) (as defined by Cutting et al. (1978)) the measure representing the difference between two angles created by the positions of an actor's joints (right shoulder-right hip-right ankle, and right shoulder-right hip-left ankle) in the two double support conditions.

(b) (as redefined in this thesis) the ratio of the rotation of the shoulders to the rotation of the hips in a normal walk cycle.

torso length -the vertical distance between the mid-point between the shoulders and the midpoint between the hips.

traditional animation -the creation of motion through the act of repetitively drawing each step of the object's movement on separate surfaces. The rapid consecutive display of the drawings creates the perception of movement in the object.

ulna -the lower arm, between the elbow and wrist.

walk cycle -the repetitive motion of a pedant figure. Consists of two conditions, the double support, in which one foot is in front of the body and the other is behind, and the single support, in which the entire body rests on one foot, each consisting of the two opposite positions.

weighted vertices -a modeling method which allows the model's skin to follow the movement of more than one joint. For example, a point of the patch representing an actor's upper chest could be assigned to follow the motion of the model's shoulder to a large degree and the motion of the model's hip to a lesser degree.

An Overview

The process of answering the question of the source of information for the recognition of gender in moving actors must begin with the analysis of human movement. This analysis provides the basis for all other conditions. The bulk of the analysis of walking figures used for this thesis was performed by Cutting et al. as detailed in Cutting, Proffitt and Kozlowski (1978) and Cutting (1978a), and the seminal work of Eadweard Muybridge (Muybridge, 1887/1979). Additional information was provided by the analysis and conversion of Cutting's (1978b) FORTRAN code for the generation of synthetic male and female walkers to the programming language C (see Appendix A).

The second step in the process is the application of the movement to a person-model. From this point factors can be adjusted and controlled to produce variations of the original motion due to changes both within the shape of the model and to the motion of its elements. The following is a brief description of each condition used in this study, stated in terms of the actor model and the patterns of motion applied to it. Each condition is computer generated and the pattern represents a full walk cycle which may be repeated as desired:

Actor Model 1 - Point Light Displays:

(1) Androgynous motion

(2) Masculine motion (average, exaggerated, highly exaggerated)

(3) Masculine modeling and motion (average, exaggerated, highly exaggerated)

(4) Feminine motion (average, exaggerated, highly exaggerated)

(5) Feminine modeling and motion (average, exaggerated, highly exaggerated)

Actor Model 2 - male figure:

(1) Androgynous motion

(2) Masculine motion (average, exaggerated, highly exaggerated)

(3) Feminine motion (average, exaggerated, highly exaggerated)

Actor Model 3a, 3b, & 3c - flour sack, tea pot, & broom:

(1) Androgynous motion

(2) Masculine motion (average, exaggerated, highly exaggerated)

(3) Feminine motion (average, exaggerated, highly exaggerated)

Each condition was chosen for its ability to demonstrate some aspect of the role of the torsion and center of moment indices in the recognition of gender. In the first set, the PLDs, the relative differences between the torsion index and center of moment is explored by comparing the effects of varying the center of moment only, and both the center of moment and the torsion index simultaneously, and torsion index only.

In the second condition the application of gender specific motion to a male figure explores further the degree of separation between form and motion-specific information for the recognition of gender. The male figure has a predefined shoulder to hip size ratio, and therefore a fixed center of moment which remains constant while the torsion index is varied. This investigation is followed up by the application of gender specific motion to the non-human objects, objects which have no reference to gender specifically implied in their shape. The choices of actor models springs from items which are familiar to the animation discipline. The flour sack is an object used by Disney animators to demonstrate how emotion can be conveyed through the posture of characters having little in the way of expressive features. A more recent application of this principle is demonstrated on the magic carpet character in Disney's 1992 motion picture *Alladin*. The tea pot is an object used in a similar way by the computer graphics industry. Due to its curved shape and shiny surface it is commonly used for demonstrating modeling and rendering techniques. As an actor model, it is a step closer to human form than the flour sack, with an implied head and two appendages, handle and spout. The broom, like the flour sack, is an object borrowed from The Sorcerer's Apprentice sequence in the Disney film *Fantasia*. As an actor model it is one step closer to the human form, as it has arms and legs and an implied vertical orientation but, as with the other two, no sex-specific characteristics.

All the animation produced in this study was created on high end graphical computing workstations (i.e., Silicon Graphics Indigo) using a robust 3-D animation software package (i.e., SoftImage Creative Environment Version 2.6; see Appendix B). Each condition was generated as a series of 36 frames with frame 1 and frame 36 matching so that in play-back the sequence may be cycled indefinitely using frames 1 through 35. At a play-back speed of 30 frames per second a complete walk cycle takes 1.2 seconds.The sequences were prepared on a 1280x1024 resolution monitor with 24 bit z-buffering. For completed viewing the frames were transferred to professional quality video tape (see Appendix B) and viewed on television monitors.

Building the Basic Model

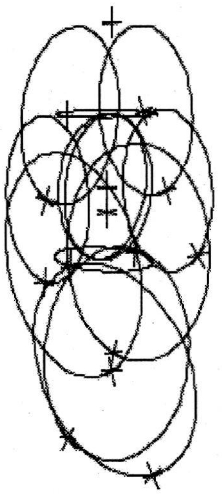
The two guiding principles in the construction of a motion pattern for this study is that the pattern represent all the spatial information necessary, and at the same time be as minimal as possible. With this in mind the motion model consists of a series of simple shapes determined by the type of motion. Once the motion is generated for these shapes the pattern can be applied to any number of actor models. The human body is a very complex mechanism but at its core it's mechanics can be specified as a series of simple and compound pendulums. As such, its basic structure can be effectively modeled through the interconnection of circles, the radii of which vary according to the body part represented. For this study, the majority of body part sizes will remain unchanged through all conditions. The only proportions that do vary according to condition are the shoulder and hip size. The basic body proportion used in this study are comprised of the measurements used for the generation of synthetic walkers in Cutting (1978ab), which in turn are based upon the human walkers used in earlier studies. The basic unit of measure for all elements is the length of the torso measured from the shoulder to the hip.

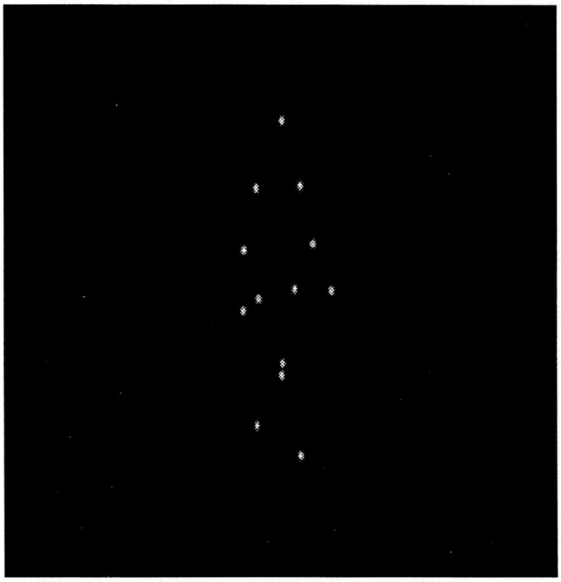
LEGS: femur length: 0.77 of torso
tibia length: 0.77 of torso
ARMS: humerus length: 0.59 of torso
ulna length: 0.56 of torso
HEAD: 0.6 of torso length above midpoint between shoulders and
0.06 of torso length forward.

The motion model is constructed first from a pair of circles whose diameters are equal to the torso length. Hips and shoulders are represented by circles placed at ninety degrees to the torso circles and whose centers are parented to the 12 o'clock position of one and 6 o'clock position of the other.

Centers of circles representing the humeri are parented to diametrically opposed points on the shoulder circle. The center of an ulna circle for each arm is then parented to a point on the circumference of each humerus circle. Femur circles are positioned in a similar manner to the hip circle, and tibia circles are positioned in a similar manner to the femurs (Figure 5a).

This model consists of all the major body parts involved in motion. Points at the center and edge of circles represent the major body joints. When this motion model is applied to the PLD actor model these points are made visible by constraining small white spheres to them (Figure 5b).





a. Motion Model *b.* PLD Actor Model

Figure 5. Motion Model and Actor Model

For a model which has shoulders and hips of equal size, the centers of the circles representing the torso occupy the same space and represent the position of the center of moment. For models with unequal shoulder and hip sizes the center of moment must be located before the torso circles can be created by establishing the shoulder and hips circles and then finding the point that lies at the intersection of two lines drawn from right shoulder to left hip and left shoulder to right hip. This intersection is the center of moment and serves as the center of two torso circles, one whose radius equals the distance from the center of moment to the center of the shoulder circle and one whose radius equals the distance from the center of moment to the center of the hip circle.

Creating the Basic Motion

Parenting and Constraint

The parenting effect is key to creating motion for a model as described above. If item A is parented to item B, the gross motion of item A will follow the motion of item B while at the same time allowing independent motion to be established for item A alone. An example of this concept and its function is provided by the wrist in relation to the elbow of one arm. The act of raising the hand and waving requires two movements, the raising of the elbow and the rotation of the wrist. The raising of the elbow effectively raises the wrist. The wrist then rotates independent of the elbow. It can be said that the wrist is parented to the elbow.

Constraint is another feature of computer animation that comes into play in the creation of motion. Constraint is similar to parenting but is much more restricting. If item A is constrained to item B, item A will occupy the exact location of item B and follow its movements in every way. Constraining is not a good tool for marrying the motion of the wrist to the elbow, for if the wrist were constrained to the elbow the distance between the two, the ulna, would not exist, and the wrist would not rotate unless the elbow rotated. Parenting is used in this study to create the motion for the model patterns. Constraining is used in this study to marry the motion of the model patterns to the actor models. For example, the skeletal element representing the right shoulder of the male figure, Actor Model 2, is constrained to the point on the shoulder circle representing the right shoulder in the motion model. In this way patterns of motion applied to a motion model can be applied to an endless variety of actor models.

Key-framed Motion

The motion generated for this study is key-framed, meaning that to produce this motion key positions are set for the elements of the motion model and the computer performs the task of generating the motion in between each position. The key-framed motion of a bouncing ball can be produced by the animator establishing the ball's position in the air at frame 1, on the ground at frame 30, and its position back in the air at frame 60. The computer automatically establishes the ball's position for each frame in between as a function of the animator's choice of a linear or curvilinear path. If set to linear the ball will move directly from its position at frame 1 to its position at frame 30 and on to its position at frame 60. If the motion is set to spline the ball will begin at its position for frame 1 and curve toward its position for frame 30 and curve again to its position at frame 60. In an animation system such as the one used here the transformations of the object, in this case the translation, can be viewed graphically allowing the user complete and precise control over position and rate of movement.

Keyframing relates directly to the methods of traditional animation. Artists in traditional animation will often first draw the key poses of an action and determine the amount of time necessary for the actor to move from one pose to the next. The in-betweening, performed by the computer in computer animation, is the laborious task in traditional animation, often assigned to apprentice animators, of creating a drawing of the character for each frame of time between one key frame and the next.

For the motion created here, four key-frames were used for each element, except the femur and tibia which required six, over the 36 frame cycle. The walk cycle is divided into four parts, each taking 9 frames to complete. Each cycle begins at frame 1 with the right foot forward double support condition. At frame 9 the body is in the right foot down single support condition, moving to the left foot forward double support condition at frame 18. By frame 27 the walk is in the left foot down single support condition and by frame 36 has returned to the right foot forward double support condition.

Throughout this movement the entire body undergoes an oscillating up and down motion. The body is at its lowest point during the double support conditions and at its highest during the single support condition when the entire body rests on a single leg which is fully extended and nearly vertical.

To create a walk cycle in this manner key-framed motion was created for a total of 11 elements: entire body, shoulder torso circle, right and left humerus circles, right and left ulna circles, hip torso circle, right and left femur circles, and right and left tibia circles. The point representing the head is parented to the shoulder torso structure and so moves as it moves.

Primary and Secondary Motion

The overall motion of actors is divided into primary and secondary motions. The primary motion consists of the motion of the hips and shoulders.

The secondary motion is the motion of the elements attached to the hips and shoulders. The motion of the hips and shoulders is given the primary position because variations in it are carried over into the motion of the arms and legs. As in the modeling of the motion model, the majority of the elements of the motion patterns are established once and will not be altered in this study. The major variations occur with the manipulation of the movement of the hips and shoulders. Throughout this discussion measures of the model's movement will assume the model to be in a cartesian space facing down the x-axis, with the y-axis running up the model's height, and the z-axis perpendicular to the model's direction of movement.

The observer's position is at a 45 degree angle to right front of the model. At a distance from which the full height and all movement of the model may be observed. The model remains centered within the observer's field of vision throughout the complete walk cycle.

Typical Motion of the Shoulders and Hips

Male and female standard approximations for the movement of the hips and shoulders were established in Cutting (1978a) and it is from this that the motion used here originates. As mentioned earlier, Cutting's work was based on the 2D motion of points representing the hips and shoulders. Viewing the profile of a figure which is positioned at the origin and facing along the x-axis, this motion is composed of x and y excursions, measured as the distance in a single direction that a point moves away from zero during motion. The amount of excursion is based upon step size. The average values for the male and female walkers used in Cutting's studies are listed in Table 1.

Table 1. Average Shoulder and Hip Excursions for Walkers

	Shoulder Excursion		Hip Excursion	
	x-axis	y-axis	x-axis	y-axis
Male	4% step size	1/5 x-axis	1% step size	1/4 x-axis
Female	1% step size	1/5 x-axis	4% step size	1/4 x-axis

For the right shoulder the x-excursion is the lateral distance, measured along the x-axis, from its location during either single support phase of a walk cycle to its position at either double support phase. The y-excursion of the right shoulder is the vertical distance, measured along the y-axis, between its position in either double support phase of the walk cycle to its position at either single support phase of the walk cycle. Due to the rolling motion of the hips and shoulders during a walk, a point moving through its x and y excursions creates a path in the form of an ellipse around which the point moves counter-clockwise (Figure 6).

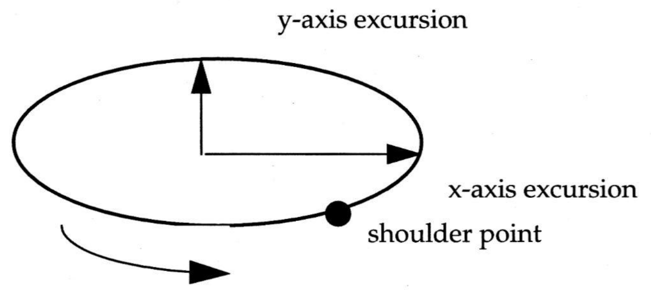


Figure 6. Measuring Shoulder Excursion

In 3-D space lateral and vertical movement is accompanied by movement in depth, along the z-axis. In order for the two-dimensional measure of a walker's shoulder and hip movement from Cutting's studies to be used in a 3-D environment these measures must be converted to a value representing the rotation of the shoulders or hips in space with depth. A mathematical method for determining the x-axis rotation from y-axis excursion in shoulder movement is diagrammed in Figure 7 and solved through Formula (2):

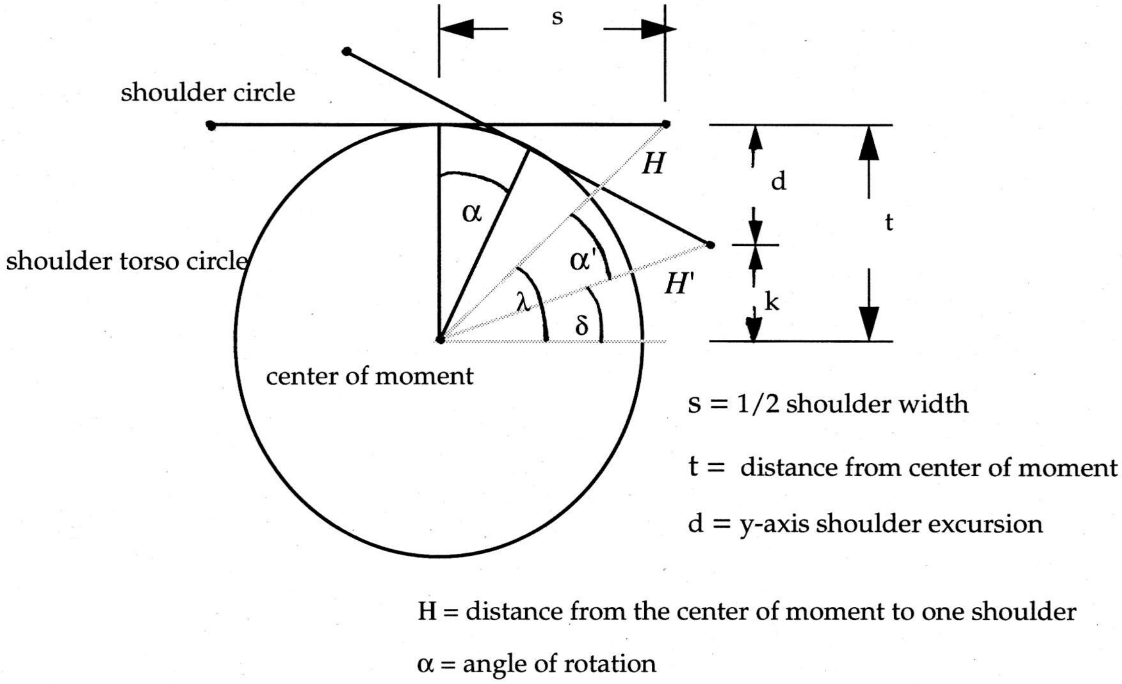


Figure 7. Excursion to Rotation Diagram

Given: t, the distance from the center of moment to the midpoint between the shoulders; s, one-half the shoulder width; and d, the y-axis shoulder excursion; α, the angle of rotation is derived as follows:

$$\alpha' = \alpha \quad \text{and} \quad H' = H$$

$$\text{where} \quad H = \sqrt{t^2 + s^2}$$

$$\text{Therefore,} \quad \alpha' = \lambda - \delta$$

$$\text{where} \quad \lambda = \arcsin\frac{t}{H} \quad \text{and} \quad \delta = \arcsin\frac{k}{H'}$$

$$\text{and} \qquad k = t - d$$

Therefore the angle of rotation is derived by:

$$\alpha = arc\sin\frac{t}{\sqrt{t^2 + s^2}} - arc\sin\frac{t-d}{\sqrt{t^2 + s^2}} \qquad (2)$$

Table 2 lists the rotation around the x, y, and z axes for the shoulder and hip structures of the average male and female walker from Cutting's studies each possessing a torso 10 units in length. These rotation transformations are applied to the shoulder torso and hip torso circles whose centers lie at the center of moment and to which the shoulder circle, and hip circle are parented. As the shoulders and hips move the majority of the rotation occurs around the x, and y axes. The z-axis rotation in the shoulders for both males and females is due to the body lean occurring maximally at each single support phase. The z-axis rotation in the hips for both sexes is due to the consistent tilt of the hips forward during walking. The y-axis rotation is reciprocal between sexes due to the same approximate average rotation occurring in a male's shoulder as occurs in a female's hips. The mathematical relationship between y-axis rotation and x-axis rotation leads to the roughly reciprocal relationship of x-axis rotation between sexes

Table 2. Average Shoulder and Hip Rotations

	Male		Female	
	shoulder	hip	shoulder	hip
x-axis	1.36	0.43	0.34	1.69
y-axis	6.44	1.69	1.69	6.44
z-axis	2.00	4.00	2.00	4.00

Typical Motion of the Arms and Legs

The motion of the arms and legs is created in a much less systematic way. Both the humerus and femur are capable of a full range of movement in relation to the shoulder and hip. The ulna and tibia, however, are not free to rotate past points in line with the elbow and knee, respectively. As the ulna and tibia are parented to the humerus and femur, rotation for these elements will be measured in respect to their parents as a number of degrees off center of a line extending from the shoulder through the elbow for the ulna, and for the tibia, extending from the hip through the knee. Rotations for the humerus and femur will be measured as degrees off true vertical (Figure 8).

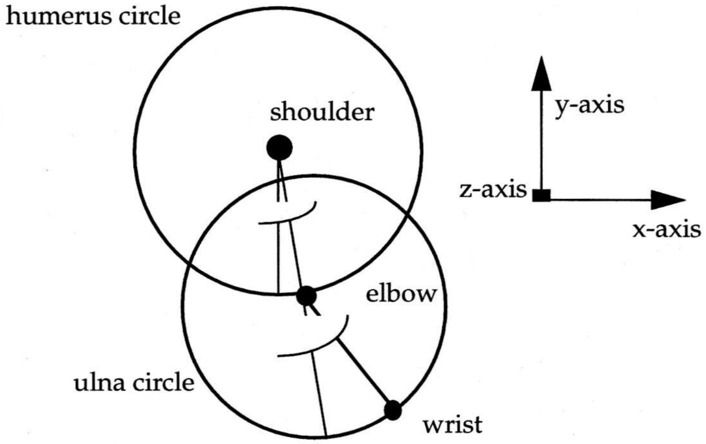


Figure 8. Parented Rotation

Creating the motion begins with the right leg forward double support condition. The extent to which the legs are stretched apart is a function of the step size. The step size used is 120% of torso length. In the double support condition the body is at the midpoint of this length and both the forward and back leg stretch equal distances from the body.

The vast majority of the rotation for the arms and legs is a pendular action occurring around the z-axis. For the legs in the double support condition, both are nearly fully extended. There is a very slight, approximately 10 degree, rotation of the tibia around the z-axis, and a more extreme cumulative rotation, 5 degrees in the femur, and 10 degrees in the tibia, around the x-axis. This x-axis rotation represents the placement of the feet beneath the center of gravity of the body rather than directly beneath the hip joints during locomotion.

As support moves to the single leg, with the right foot down, the right leg becomes nearly vertical and the left leg moves forward first with the knee and with the ankle slightly delayed and raised. This delay continues as the left leg moves forward into the extended position until the femur swings just beyond its degree of rotation at the double support left leg forward condition. The over-swing in the z-axis rotation at this point allows the tibia to catch up from its delay and meet the ground in correct position.

The movement of the arms occurs in a similar fashion but with the delay occurring in the ulna as the humerus moves back instead of forward. With the right leg forward, the right arm is back approximately 15 degrees off vertical and the elbow is not quite locked. The left arm is forward approximately 15 degrees off vertical and the left wrist is swung forward 20 degrees off line with the elbow and shoulder. As the step cycle begins to move to the single support condition the arms begin to trade places with the arm that was forward moving in a more direct line straight back than the arm which was back which makes an arc moving forward. Table 3 lists the rotations in degrees for the arms and legs during a typical walk cycle. It is important to remember that as these elements are parented to the shoulders and hips the measurements listed are relative to the parents, not absolute measures of the elements' global movements.

Table 3. Relative Rotations of Arms and Legs

Model Element	Axis of Rotation	Frame 1	9	18	27	36
Right humerus	x	-10.0	-5.0	-10.0	-2.5	-10.0
	y	0.0	0.0	0.0	0.0	0.0
	z	15.0	5.0	-15.0	0.0	15.0
Right ulna	x	10.0	2.5	7.5	-2.5	10.0
	y	0.0	0.0	0.0	0.0	0.0
	z	-12.5	-5.0	-20.0	-12.5	-12.5
Left humerus	x	10.0	2.5	10.0	5.0	10.0
	y	0.0	0.0	0.0	0.0	0.0
	z	-15.0	0.0	-2.5	5.0	-15.0
Left ulna	x	-7.5	2.5	-10.0	-2.5	-7.5
	y	0.0	0.0	0.0	0.0	0.0
	z	-20.0	-12.5	-2.5	-5.0	-20.0
Right femur	x	5.0	8.5	5.0	2.0	5.0
	y	0.0	0.0	0.0	0.0	0.0
	z	-35.0	-10.0	10.0	5.0	-35.0
Right tibia	x	10.0	10.0	10.0	10.0	10.0
	y	0.0	0.0	0.0	0.0	0.0
	z	11.5	7.5	13.5	35.0	11.5
Left femur	x	-5.0	-2.0	-5.0	-8.5	-5.0
	y	0.0	0.0	0.0	0.0	0.0
	z	10.0	-5.0	-35.0	-10.0	10.0
Left tibia	x	-10.0	-10.0	-10.0	-10.0	-10.0
	y	0.0	0.0	0.0	0.0	0.0
	z	13.5	35.0	11.5	7.5	13.5

The Variety of Conditions

Using the basic motion model a wide variety of conditions may be established. The first group involves the manipulation of the pattern itself by changing the shoulder to hip size ratio, changing the shoulder to hip rotation ratio, and the two combined. These ratios may be manipulated to any values deemed necessary. In the production of the animation for this study they were set to 50% and 100%, respectively, beyond the average motion. A second group of conditions involves the application of these various patterns to actor models. As defined previously the actor models used in this study consist of spheres representing the joints seen in a PLD, and four solid 3-D models: a human male, flour sack, tea pot, and broom. Each of these models is constructed using cardinal and b-spline patches in order to allow the greatest range of motion while maintaining a smooth non-faceted surface. A system of weighted vertices was employed to insure proper deformation of the actor's skin while in motion.

The actions of the arms and legs are not applied in any way to the model of the tea pot. Motion corresponding to the action of the knees was applied to both the flour sack and the broom in a manner which produced the effect of the model extending its lower extremities forward and back as in a walking motion. The motion of the arms and legs in the PLD and male figure actor models, and the approximations used in the flour sack and broom, were kept as consistent between conditions as possible. The rationale for doing this rests on the findings of past studies which have shown the motion of the hips and shoulders to be the primary sources of information concerning gender.

SUMMARY AND DISCUSSION

The Revised Torsion Index

The values for the male and female shoulder and hip rotation in Table 2 reflect the original analysis of shoulder and hip excursion by Cutting (1978a) which determined the values as a function of step size. Given a constant step size the ratio of shoulder to hip x-axis excursion in males is 4:1 and in females the reverse, 1:4. In the 3-dimensional transformation of excursion using Formula (2), the x-axis excursion translates most directly into y-axis rotation. As can be seen in Table 2, from the y-axis rotation values the 4:1 and 1:4 shoulder to hip rotation ratios remain virtually unchanged. This ordered relationship between the male and female average ratios creates the opportunity for efficient analysis. Variations in rotation values translate both proportionately and in real number values between sexes. For instance, increasing the masculine feature of shoulder rotation by 20% in one motion model can be easily compared against, and related to, in real number value, a 20% increase in the feminine feature of hip rotation in another motion model.

Another aspect of the Cutting analysis is that x-excursion and y-excursion values for the motion of shoulders and hips are directly related. For the shoulders the y-excursion value is 1/5 the x-excursion value. For the hips the y-excursion value is 1/4 the x-excursion value. This relationship carries over into the 3-D application with the use of rotation instead of excursion. The x-axis rotation of the shoulders is 1/5 the y-axis rotation, while the x-axis rotation of the hips is 1/4 the y-axis rotation. This relationship, plus the constancy of the z-axis rotation, allows the use of the y-axis rotation as a single measure of shoulder and hip rotation. A single value for torsion index can then be derived by dividing the y-axis rotation of the shoulders by the y-axis rotation of the hips. This is not the same shoulder size to hip size ratio which is a static cue. This is a shoulder rotation to hip rotation ratio which is information based upon movement and independent of form.

Several standard ratios were developed, based upon the typical male and female ratios, and applied to motion models possessing various shoulder and hip widths. Table 4 is a list of the standard motion patterns and their designations. The patterns are labeled in a form denoting the shoulder size to hip size ratio first and the torsion ratio second.

Table 4. Motion Pattern Designations

Pattern	Description
1.04-1.00	androgyny
1.10-4.00	typical male
0.98-0.25	typical female
1.04-4.00	masculine in movement only
1.04-0.25	feminine in movement only
1.10-1.00	masculine in form only
0.98-1.00	feminine in form only
1.10-0.25	masculine form; feminine movement
0.98-4.00	feminine form; masculine movement

These patterns of motion are then applied to the actor models, PLD, male figure, flour sack, tea pot, and broom. It will require the statistical analysis of the responses of a select study population before the extent of the correlation between this revised torsion index and the perception of gender will be known.

Only such analyses will determine if the redefinition of the torsion index will allow it to overcome the shortcomings as described by Cutting. Notable among those is the ability of subjects to recognize actor gender from the motion of elements such as the arms, or ankles without seeing the motion of the shoulders or hips. Examples for testing the torsion index under these conditions have not been developed as part of this study, although to do so simply requires the application of the range of motion patterns to revised versions of the PLD actor model. The reason for not pursuing this avenue is due to the focus of the examples on the application of the motion patterns to changing actor forms and the fact that the revision of the torsion index to represent the twisting of the shoulders relative to the hips makes it as directly perceptible in these conditions as the center of moment. The methods described here should facilitate more rigorous tests in future research.

Conclusions and Future Directions

Through the manipulation of several key features of the torso of synthetic actors, it is apparent that reasonably good representations of masculine and feminine walking styles can be accomplished across a variety of forms. See Figures 9-13 on pages 51-55. The success of this demonstration provides a strong basis from which psychological studies may be conducted to evaluate the perceptual reality of these indices. The isolation of the features of movement from features of shape through revision of the torsion index should provide opportunity to discover the existence of an invariant for gender recognition from motion alone.

The methods employed here provide a tool to support further work into person/motion perception. One important difference between this and previ-

Only such analyses will determine if the redefinition of the torsion index will allow it to overcome the shortcomings as described by Cutting. Notable among those is the ability of subjects to recognize actor gender from the motion of elements such as the arms, or ankles without seeing the motion of the shoulders or hips. Examples for testing the torsion index under these conditions have not been developed as part of this study, although to do so simply requires the application of the range of motion patterns to revised versions of the PLD actor model. The reason for not pursuing this avenue is due to the focus of the examples on the application of the motion patterns to changing actor forms and the fact that the revision of the torsion index to represent the twisting of the shoulders relative to the hips makes it as directly perceptible in these conditions as the center of moment. The methods described here should facilitate more rigorous tests in future research.

Conclusions and Future Directions

Through the manipulation of several key features of the torso of synthetic actors, it is apparent that reasonably good representations of masculine and feminine walking styles can be accomplished across a variety of forms. See Figures 9-13 on pages 51-55. The success of this demonstration provides a strong basis from which psychological studies may be conducted to evaluate the perceptual reality of these indices. The isolation of the features of movement from features of shape through revision of the torsion index should provide opportunity to discover the existence of an invariant for gender recognition from motion alone.

The methods employed here provide a tool to support further work into person/motion perception. One important difference between this and previactor's physical properties. This allows the features of form which contribute to character trait recognition to be differentiated from features of motion which contribute to character trait recognition. In this context, form is generally considered to be more informative than motion. The results here, though not quantitatively tested, appear to be consistent with that belief. Motion, however, is its own language and contains unique nuances which can either support or contrast the qualities of the model. The tea pot modeled in this study, for instance, has an implied matronly form, being wider at the bottom than at the top. The spout and handle call to mind the body position of one hand in the air while the other rests on the hip. Even with the exaggerated masculine motion applied to this form the actor itself may be perceived as feminine.

It remains to be seen what effects exaggeration beyond the 100% increase in normal masculine and feminine movements used here will have. Cutting (1978a) demonstrated that exaggeration leads to increased perception of the quality associated with a specific motion but may also lead to a decrease in believability. This relationship brings up the factor that the model shape may itself place limits on the range of motions which may be believably employed. Highly exaggerated feminine motion may be perceived as natural when applied to a form which is feminine in its shape, while the same motion may appear very unnatural when applied to a form which is more masculine.

A similar issue is defining the degrees of exaggeration required to communicate individual qualities. While the experiments created for this thesis each to some degree communicated gender within the respective forms, it is obvious that a greater degree of exaggeration of trait defining motion is required before the models begin to comprehensively be viewed as 'characters' in the sense that Mickey Mouse, John Wayne, or Marilyn Monroe are viewed as 'charsense that Mickey Mouse, John Wayne, or Marilyn Monroe are viewed as 'characters'. Again, the level of exaggeration required is greatly effected by the form of the model. The quantification of the levels of exaggeration, however, may lead to a language which is adaptable for use throughout the fields which employ synthetic actors. For example, an animator wishing to communicate femininity on the level of Marilyn Monroe in the motion of a walking tea pot could think of it in terms of 100%, 200%, or 300% increase in the average feminine walk.

Moving the language of motion to the language of numbers provides a means through which collaboration between artists and scientists may take place. There exists currently a vast gap between the work done by scientists studying and synthetically reproducing biological motion, and the accessibility of this work to artists who are communicating using biological motion. This thesis, its methods, and its findings fall somewhere within this gap by providing a quantitative, consistently reproducible method for communicating gender, while at the same time providing for wide application, ease of manipulation, and computational simplicity.

Through the joining of research from ecological psychology with computer character animation techniques it is apparent that several hurdles in the quest for efficient and believable generation of human motion may be overcome. This study took one small step in that direction with the isolation and systematic application of modeling and motion features which lead to gender recognition of synthetic actors (Figs. 9-13). Although the range of motion studied here was limited to the walk cycle it is believed that these principles, established with the center of moment and torsion indices, will be invariant over changes in the actor's activity.

plines will lead to the further study of character qualities apparent through motion, as well as to their application and use in computer animation. A further application of this knowledge is to the subject of machine-person recognition and identification. If the dynamic patterns of persons in action are tied to their anatomical make-up, and therefore undergoing only very slow transformations, the kinematic pattern of individuals may be as unique a signature as the fingerprint.

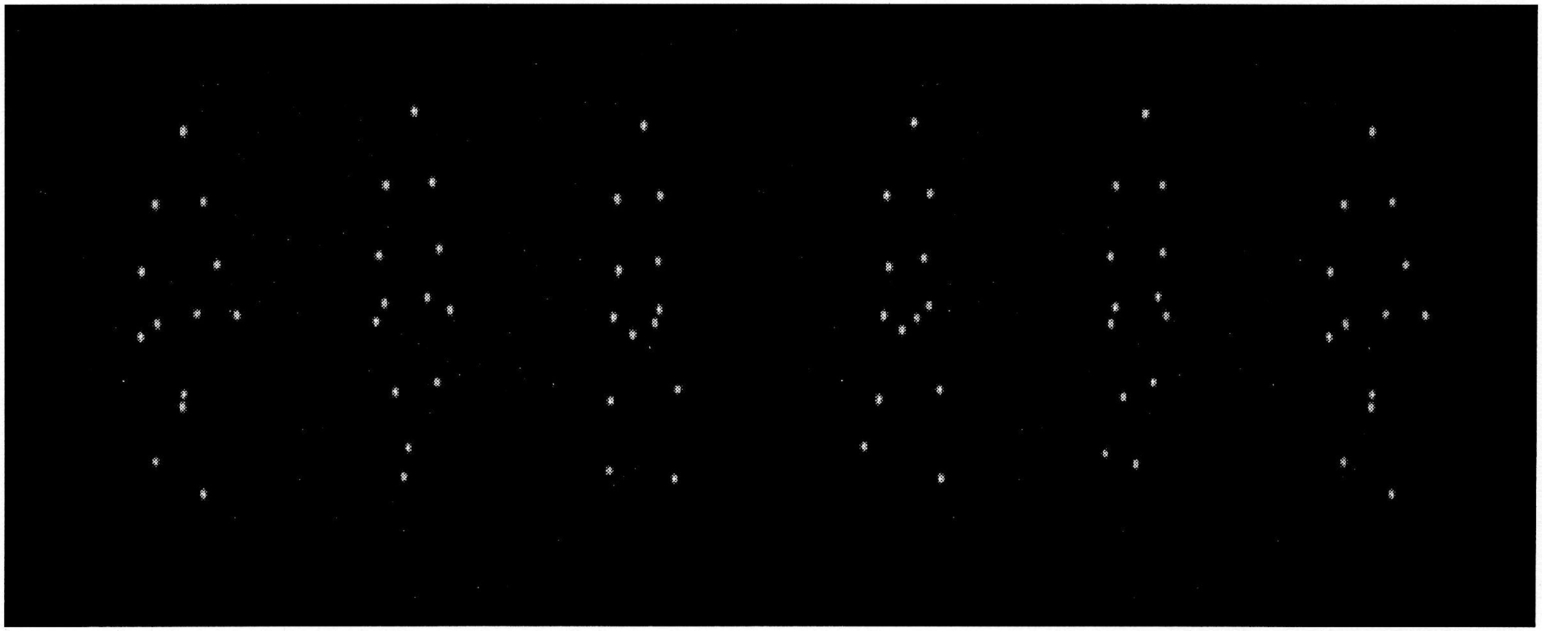
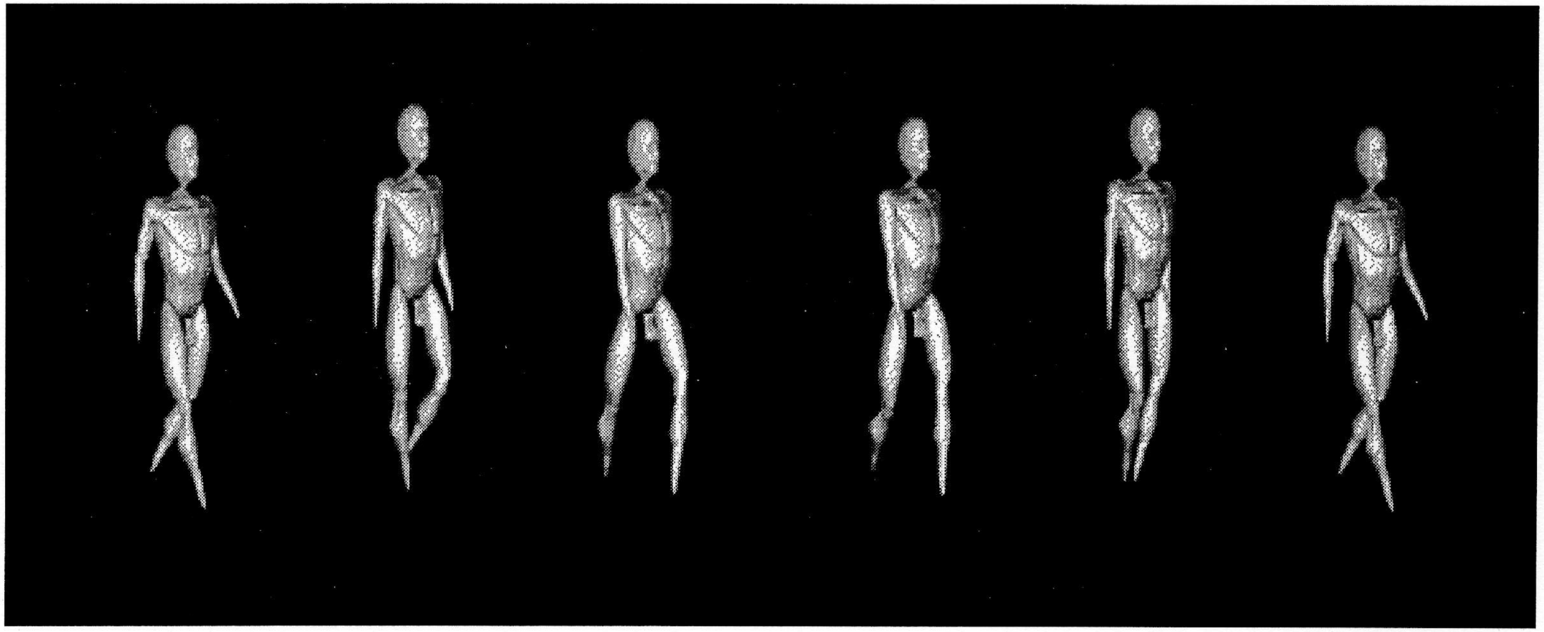
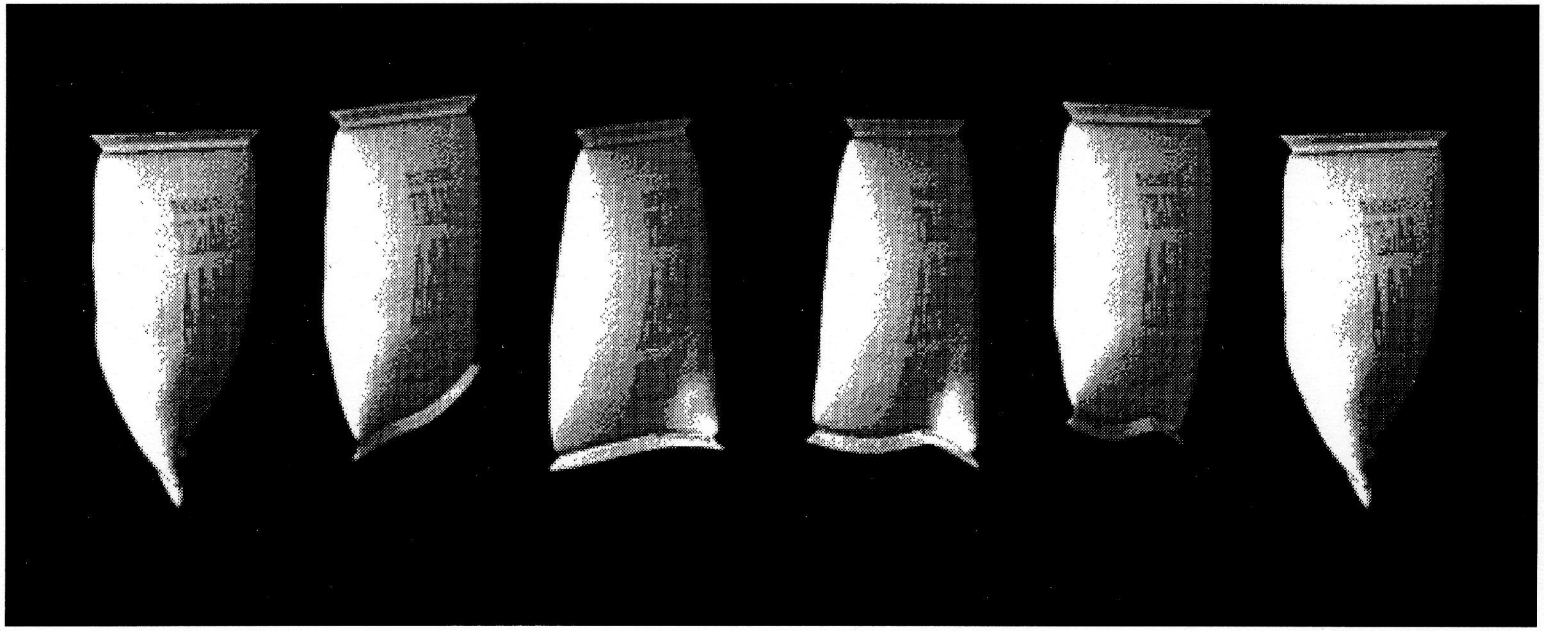


Figure 9. Pattern 1.04-1.00 on Actor Model 1



Frame 1 Frame 8 Frame 15 Frame 22 Frame 29 Frame 36

Figure 10. Motion Pattern 4.00 on Actor Model 2



Frame 1 Frame 8 Frame 15 Frame 22 Frame 29 Frame 36

Figure 11. Motion Pattern 7.62 on Actor Model 3

Figure 12. Motion Pattern 0.13 on Actor Model 4

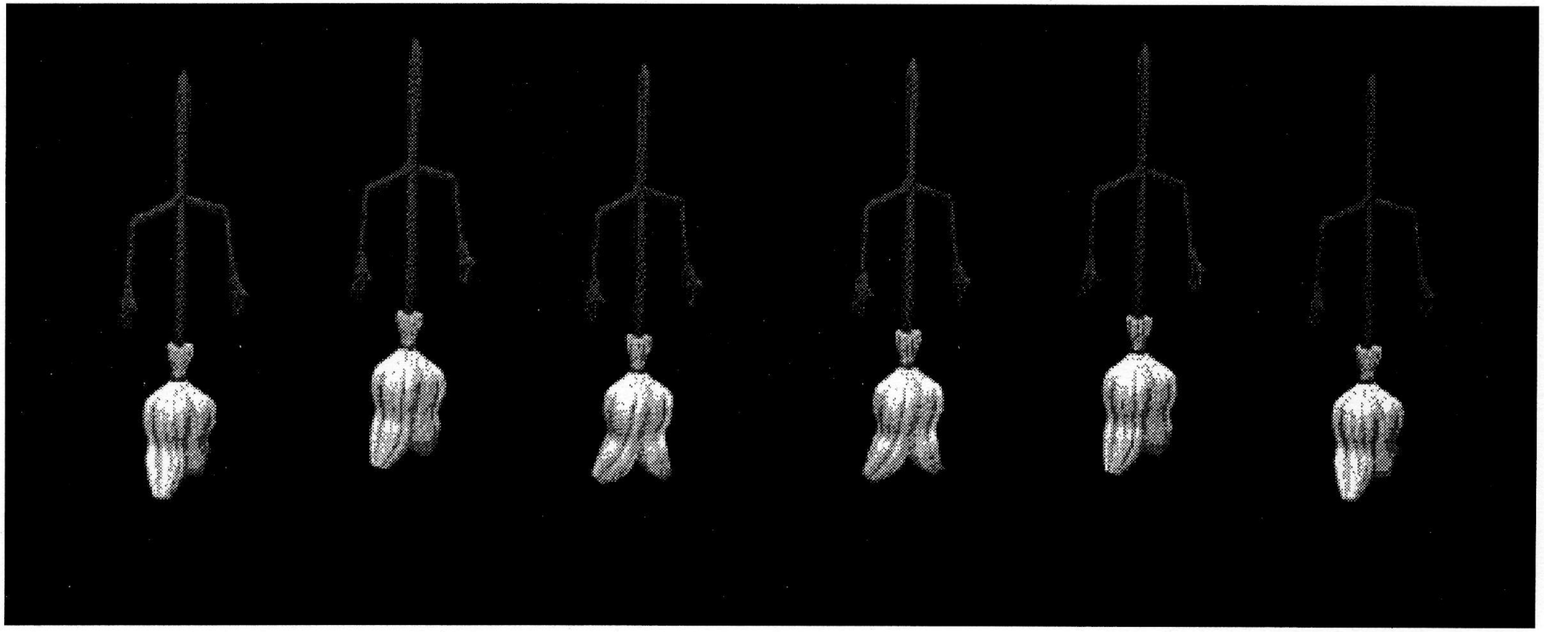


Figure 13. Motion Pattern 1.00 on Actor Model 5

REFERENCES

Barclay, C., Cutting, J. Kozlowski, L. (1978). Temporal and spatial factors in gait perception that influence gender recognition. *Perception and Psychophysics, 23*, 145-152.

Boulic, R. & Thalmann, D. (1993). Combined direct and inverse kinematic control of articulated figure motion editing. In D. Thalmann (Ed.), *SIGGRAPH Course Notes: Recent Techniques in Human Modeling, Animation, and Rendering*, (pp. 1.16-1.26). Anaheim, California: Association of Computing Machinery.

Brennan, S. (1985).The dynamic exaggeration of faces by computer. *Leonardo, 18*, 170-178.

Calvert, T. (1991). Composition of realistic animation sequences for multiple human figures. In N. Badler, B. Barsky, D. Zeltzer (Eds.), *Making Them Move: Mechanics, Control, and Animation of Articulated Figures*, (pp. 35-50). San Mateo, California: Morgan Kaufman Publishers.

Cutting, J. & Kozlowski, L. (1977). Recognizing friends by their walk: Gait perception without familiarity cues. *Bulletin of the Psychonomic Society, 9*, 353-356.

Cutting, J. (1978a). Generation of synthetic male and female walkers through manipulation of a biomechanical invariant. *Perception, 7*, 393-405.

Cutting, J. (1978b). A program to generate synthetic walkers as dynamic point-light displays. *Behavior Research Methods and Instrumentation, 10*, 91-94.

Cutting, J., Proffitt, D. & Kozlowski, L. (1978). A biomechanical invariant for gait perception. *Journal of Experimental Psychology: Human Perception and Performance, 4*, 357-372.

Foley, J., van Dam, A., Feiner, S. & Hughes, J. (1990). *Computer Graphics Principles and Practice* (2nd ed.). Reading, Massachusetts: Addison-Wesley.

Heider, F. & Simmel, M. (1944). An experimental study of apparent behavior. *American Journal of Psychology, 57,* 243-259.

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception and Psychophysics, 14,* 210-211.

Kozlowski, L. & Cutting, J. (1977). Recognizing the sex of a walker from a dynamic point-light display. *Perception and Psychophysics, 21,* 575-580.

Kozlowski, L. & Cutting, J. (1978). Recognizing the gender of walkers from point-lights mounted on ankles: Some second thoughts. *Perception and Psychophysics, 23,* 459.

Lasseter, J. (1987). Principles of traditional animation applied to 3D computer animation. In B. Kroyer & P. Bereron (Eds.), *SIGGRAPH Course Notes: 3-D Character Animation by Computer,* (pp. 1-13). Anaheim, California: Association for Computing Machinery.

Magnenat-Thalmann, N. & Thalmann, D. (1990). *Synthetic Actors in Computer Generated 3D Films.* New York: Springer-Verlag.

de Meijer, M. (1989). The contributions of the general features of body movement to the attribution of emotions. *Journal of Nonverbal Behavior, 13,* 247-268.

Muybridge, E. (1979). *Muybridge's Complete Human and Animal Locomotion.* New York: Dover Publications. (Original work published 1887).

Oatley, K. & Yuill, N. (1985). Perception of personal and interpersonal action in a cartoon film. *British Journal of Social Psychology, 24,* 115-124.

Runeson, S. & Frykholm, G. (1983). Kinematic specification of dynamics as an informational basis for person-and-action perception: Expectation, gender recognition, and deceptive intention. *Journal of Experimental Psychology: General, 112,* 585-615.

Shaw, R. & Pittenger, R. (1977) Perceiving the face of change in changing faces: Implications for a theory of object perception. In R. Shaw & J. Bransford (Eds.), *Perceiving, Acting, and Knowing: Toward an Ecological Psychology* (pp. 103-132). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Sogon, S., & Izard, C. (1987). Sex differences in emotion recognition by observing body movements: A case of American students. *Japanese Psychological Research, 29,* 89-93.

Thomas, F. & Johnston, O. (1981). *Disney Animation: The Illusion of Life.* New York: Abbeville Press.

Walters, K. & Walk, R. (1988). Perception of emotion from moving body cues in photographs. *Bulletin of the Psychonomic Society, 26,* 112-114.

Webber, B., Badler, N., Baldwin, F., Becket, W., Di Eugenio, B. Geib, C., Jung, M., Levison, L., Moore, M. & White, M. (1993). Doing what you're told: Following task instructions in changing but hospitable environments. In D. Thalmann (Ed.), *SIGGRAPH Course Notes: Recent Techniques in Human Modeling, Animation, and Rendering,* (pp. 4.3-4.31). Anaheim, California: Association of Computing Machinery.

APPENDIX A

A PROGRAM FOR THE SYNTHETIC GENERATION OF WALKERS

This program was written in C by Tim McLaughlin and Kevin Reuter as an adaptation of original FORTRAN code from Cutting (1978b). The general structure of the Synthetic Walker program is diagrammed in Figure 14. The Synthetic Walker program operates from the input of two variables, the shoulder swing excursion, and the hip swing excursion. As noted in this thesis the shoulder and hip swing provide the user with considerable flexibility in creating motion which is along a scale of masculinity and femininity in walker motion.

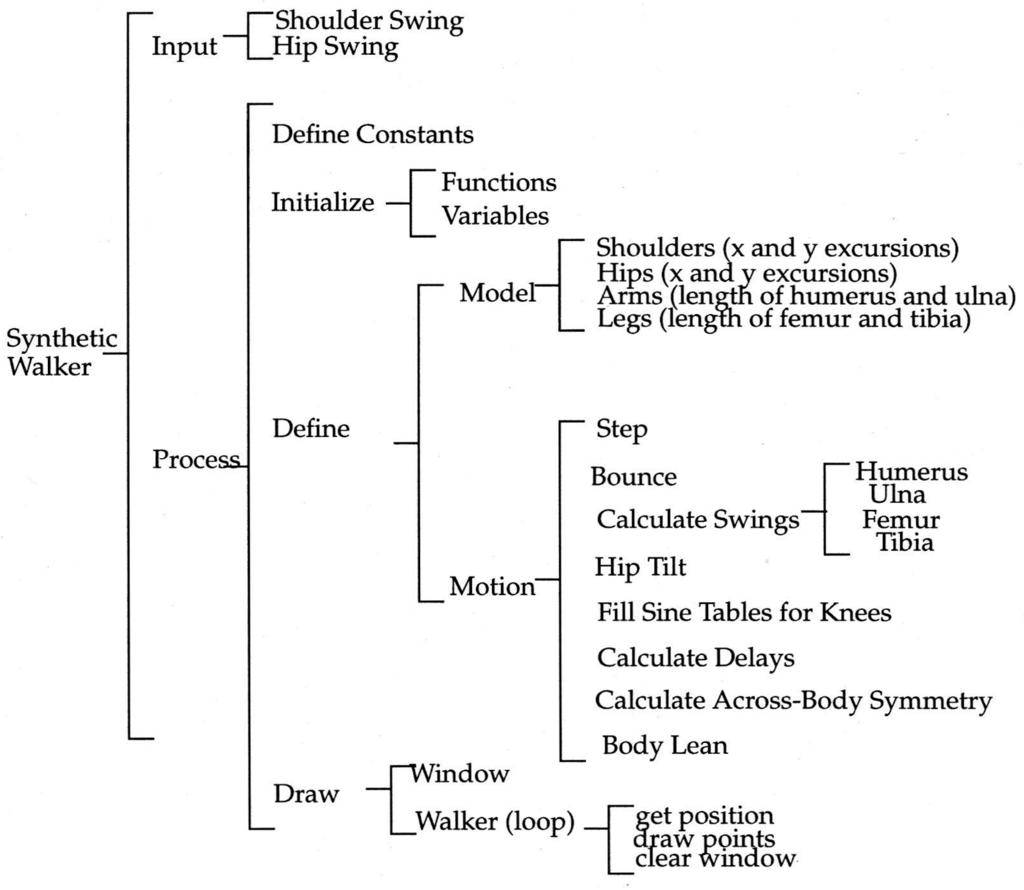


Figure 14. General Structure of Synthetic Walker Program

The Synthetic Walker program generates the image of a series of white points in coordinated movement left to right across a black field. The discrete location of each point in time is a function of that point's relation to the shoulder swing and hip swing excursion values provided by the user.

The functionality of this program remains largely unchanged from the original by Cutting (1978b). The major difference between the two lies in the step-size of the walker, which is variable under the Cutting program and is hard coded here. The other differences lie in the languages and hardware used for implementation.

```
                    /* BEGIN PROGRAM*/

/*CALL NEEDED LIBRARIES*/
#include <stdio.h>
#include <gl/gl.h>
#include <device.h>
#include <math.h>


/*DEFINE SYMBOLIC CONSTANTS*/
#define RAD 0.017453        /* degrees to radians conversion */
#define TORSO 85            /* sets the torso length */
#define YTRANS 200          /* places the points within the draw window */


main()
{


/*INITIALIZE FUNTIONS*/
 float hipsNshldrs();      /* function to input variables for walker differences */
 float armsNlegs();        /* function to determine lengths of joints */
 float hstepNbounce();     /* function to determine half-step without torso torque as
                              well as up and down body movement*/
```

```
float swings();          /* function to calculate swings of appendages */
float sin_tbl();         /* function to fill the sine table */
float ankl_tbl();        /* function to begin ankle table work */
float ankl_sym();        /* function to create symmetry about 270 degrees */
float ankl_end();        /* function to finish ankle table work */
float calc_lean();       /* function to calculate the body lean */


/*INITIALIZE VARIABLES*/
int TIME = 300;          /* time; modal is 300, minimum is 150 */
float STEP;              /* step size */

float HEX;               /* hip ellipse, x-axis*/
float HEY;               /* hip ellipse, y-axis*/
float SHER;              /* shoulder swing excursion */
float SEX;               /* shoulder ellipse, x-axis */
float SEY;               /* shoulder ellipse, y-axis */

float FEMUR;             /* length of upper leg */
float TIBIA;             /* length of lower leg */
float LEG;               /* length of leg */
float HUMOR;             /* length of upper arm */
float ULNA;              /* length of lower arm */

float HSTEP;             /* half step without torso torque */
float BOUNCE;            /* up and down movement of body due to step size and hip
                            roll*/
float SWF;               /* femur swing */
float SWH;               /* humor swing */
float SWU;               /* ulna swing */
float SWT;               /* tibia swing */

float FEMFO;             /* forward tilt of femur pendulum */
float COSFF;             /* y correction for hip */
float SI[810];           /* array containing sine values for 2.25 revolutions */
```

```
int DELAY;                /* degrees pre and post femur swing that tibia swings due to
                             foot and to compound pendulum */

float SIA[540];           /* array storing the values for the ankle table */
float XLEAN;              /* upper body lean, F(speed), 2 degree modal */
float YLEAN;              /* upper body lean, F(speed), 2 degree modal */
float XINIT;              /* initial x value in screen units */
float YINIT;              /* initial y value in screen units */
float FALFO;              /* movement falling forward within overlay period */

float SINA;               /* current knee sine table value */
float SINA1;              /* current ankle sine table value */
float SINA2;              /* current ankle table value plus 180 degrees */
float COSA;               /* current knee sine table value plus 90 degrees */
float COS2A;              /* current knee sine table value doubled plus 90 degrees */
float COSI;               /* temporary holder for current knee sine table value plus 90
                             degrees */

float XHEAD, YHEAD;       /* head location */
float HX, HY;             /* hip location */
 float X, Y;              /* mid-hip locations */
float A, Z;               /* knee locations */
int N;                    /* time-degree rotation relationship */

float XHIPR, YHIPR;       /* right hip location */
float XHIPL, YHIPL;       /* left hip location */
float XKNER, YKNER;       /* right knee location */
float XKNEL, YKNEL;       /* left knee location */
float XANKR, YANKR;       /* right ankle location */
float XANKL, YANKL;       /* left ankle location */

float XSHOR, YSHOR;       /* right shoulder location */
float XSHOL, YSHOL;       /* left shoulder location */
float XELBR, YELBR;       /* right elbow location */
float XELBL, YELBL;       /* left elbow location */
```

```
float XWRIR, YWRIR;          /* right wrist location */
float XWRIL, YWRIL;          /* left wrist location */

register int i, j, k;        /* counters */


/*FUNCTIONS CALLS*/
hipsNshldrs(&HEX, &HEY, &SHER, &SEX, &SEY, &STEP);
armsNlegs(&FEMUR, &TIBIA, &LEG, &HUMOR, &ULNA);
hstepNbounce(&HSTEP, &BOUNCE, STEP, HEX, HEY, LEG);

SWF = atan(HSTEP/(sqrt((LEG * LEG) - (HSTEP * HSTEP))));
SWH = .24 * (STEP - 4 * SEX) * RAD;
SWU = (1.65 * SWH);
SWT = 25 * RAD + SWF + 5 * HEX * RAD;

swings(&SWF, &SWH, &SWU, &SWT, HSTEP, LEG, STEP, SEX, HEX);
tiltNhip(&FEMFO, &COSFF, STEP, LEG, SWF);

sin_tbl(&SI);
DELAY = 10000/(TIME - 50);
ankl_tbl(&SIA);

N = 360 + DELAY;
ankl_sym(N, DELAY, &SIA);

N = 180 - DELAY;
ankl_end(&SIA, N);

calc_lean(TIME, &XLEAN, &YLEAN, &XINIT, &YINIT, &FALFO);


/*SETUP WINDOW*/
prefsize(720, 486);
foreground();
```

```
winopen("Synthetic Walker");
doublebuffer();
RGBmode();
gconfig();
RGBcolor(0, 0, 0);
clear();
swapbuffers();


/*BEGIN FINAL SEQUENCE*/
for (j = 1; j < 4; j++)                    /* 3 step cycles (6 steps) */
{
for (i = 0; i < 360; i += 9)               /* 360 degrees per circle, 9 degree increments */
{
   SINA = SI[i];
   COSA = SI[i + 90];
   COS2A = SI[i * 2 + 90];
   SINA1 = SIA[i];
   SINA2 = SIA[i + 180];
   if (i <= 180)                           /* advance due to inverse pendular motion */
                       COSI = COSA;
   else
                       COSI = SI[i - 90];
   if ((i >= (180 - DELAY)) && (i <= (180 + DELAY)))
                       FALFO += STEP * .02;
   if ((i >= (360 - DELAY)) || (i <= DELAY))
                       FALFO += STEP * .02;  /* extra x ankle movement dur-
                                                 ing ankle flexion */

   X = XINIT - COSI * STEP/2 + FALFO;
   Y = YINIT - BOUNCE * COS2A;

/* Locate Head */
   XHEAD = X + 1.6 * XLEAN + TORSO/15;
   YHEAD = Y + 1.6 * YLEAN;
```

```
/* Locate Hips */
    HX = HEX * COSA;
    HY = HEY * SINA - COSFF * COSA;

    XHIPR = X + HX;
    YHIPR = Y + HY;
    XHIPL = X - HX;
    YHIPL = Y - HY;

/* Locate Knees */
    A = SWF * COSA + FEMFO;
    Z = SWF * COSA - FEMFO;

    XKNER = XHIPR + FEMUR * sin((double)(A));
    YKNER = YHIPR - FEMUR * cos((double)(A));
    XKNEL = XHIPL - FEMUR * sin((double)(Z));
    YKNEL = YHIPL - FEMUR * cos((double)(Z));

/* Locate Shoulders */
    HX = SEX * COSA;
    HY = SEY * SINA;

    XSHOR = X + XLEAN - HX;
    YSHOR = Y + YLEAN - HY;
    XSHOL = X + XLEAN + HX;
    YSHOL = Y + YLEAN + HY;

/* Locate Elbows */
    HX = HUMOR * sin((double)(SWH * COSA));
    HY = HUMOR * cos((double)(SWH * COSA));

    XELBR = XSHOR - HX;
    YELBR = YSHOR - HY;
    XELBL = XSHOL + HX;
```

```
    YELBL = YSHOL - HY;

/* Locate Ankles */
    A = SWF * COSA + FEMFO - SWT * SINA1;
    Z = -SWF * COSA + FEMFO - SWT * SINA2;

    XANKR = XKNER + TIBIA * sin((double)(A));
    YANKR = YKNER - TIBIA * cos((double)(A));
    XANKL = XKNEL + TIBIA * sin((double)(Z));
    YANKL = YKNEL - TIBIA * cos((double)(Z));

/* Locate Wrists */
    HX = SWH * COSA;
    HY = SWH * (COS2A + 1)/2;

    A = SWU * (COSA - 1)/2;
    Z = SWU * (COSA + 1)/2;

    XWRIR = XELBR - ULNA * sin((double)(HX + A));
    YWRIR = YELBR - ULNA * cos((double)(HY - A));
    XWRIL = XELBL + ULNA * sin((double)(HX + Z));
    YWRIL = YELBL - ULNA * cos((double)(HY + Z));


/*DRAW PORTION*/
/* Joints Seen in Each Frame */

RGBcolor(255, 255, 255);                    /* set color to white */
pnt2(XHEAD, YHEAD + YTRANS);

pnt2(XKNER, YKNER + YTRANS);
pnt2(XANKR, YANKR + YTRANS);

pnt2(XSHOR, YSHOR + YTRANS);
pnt2(XELBR, YELBR + YTRANS);
```

```
pnt2(XWRIR, YWRIR + YTRANS);


/* Joints Seen in Many But Not All Frames */

  if ((i <= 110) || (i >= 130))
  {
    pnt2(XANKL, YANKL + YTRANS);
  }

  if (((i <= 67) || (i >= 113)) && ((i <= 247) || (i >= 293)))
  {
    pnt2(XKNEL, YKNEL + YTRANS);
  }

  if (((i <= 48) || (i >= 95)) && ((i <= 265) || (i >= 312)))
  {
    pnt2(XHIPR, YHIPR + YTRANS);
  }

  if (((i <= 88) || (i >= 140)) && ((i <= 220) || (i >= 272)))
  {
    pnt2(XWRIL, YWRIL + YTRANS);
  }

  if (((i <= 30) || (i >= 155)) && ((i <= 215) || (i >= 330)))
  {
    pnt2(XELBL, YELBL + YTRANS);
  }

  if ((i - 180) == 0)
  {
    XINIT += (int)(STEP + FALFO);
    FALFO = 0;
  }
```

```
swapbuffers();


RGBcolor(0, 0, 0);
clear();                                    /* clear screen to black */
for (k=0; k<550000; k++);
}  /*end of i loop*/

XINIT += (int)(STEP + FALFO);               /* recalculate beginning position */
FALFO = 0.0;

} /*end of j loop*/


}                        /*END OF MAIN*/


/*FUNCTIONS*/
float hipsNshldrs(float *hipsx, float *hipsy, float *shldrs, float *shldrsx, float
*shldrsy, float *stride)
{

printf ("\nInput the hip swing value.");
printf ("\nNote: for males the value is typically < 1");
printf ("\n for females the value is typically > 1");
printf ("\nHIP SWING EXCURSION:");
scanf ("%f", hipsx);

printf ("\n\nInput the shoulder swing value.");
printf ("\nNote: for males the value is typically > 3");
printf ("\n for females the value is typically < 1");
printf ("\nSHOULDER SWING EXCURSION:");
scanf ("%f", shldrs);
```

```
printf ("\n\nInput the length of stride.");
printf ("\nNote: value is typically 40 percent of figure's height");
printf ("\nSTEP SIZE -as a percentage in decimal form:");
scanf ("%f", stride);

*stride = *stride * TORSO * 3.25;

*hipsx = *hipsx * .03 * *stride;
*hipsy = *hipsx/4;

*shldrsx = *shldrs * *hipsx;
*shldrsy = *shldrsx/5;


}                               /* end of function: hipsNshldrs */


float armsNlegs(float *uleg, float *lleg, float *leg, float *uarm, float *larm)
{

*uleg = (.77 * TORSO);
*lleg = (.77 * TORSO);

*leg = *uleg + *lleg + (.3 * TORSO);

*uarm = (.59 * TORSO);
*larm = (.56 * TORSO);

}                               /* end of function: armsNlegs */


float hstepNbounce(float *hstep, float *boing, float stride, float hipsx, float hip-
sy, float leg)
{
```

```
*hstep = stride/2 - hipsx;
*boing = (leg - sqrt((double) ((leg * leg) - (*hstep * *hstep))) - hipsy)/2;


}                               /* end of function: hstepNbounce */


float swings(float *swfem, float *swhum, float *swuln, float *swtib, float hstep,
float leg, float stride, float shldrsx, float hipsx)
{

*swfem = atan(hstep/sqrt((double) ((leg * leg) - (hstep * hstep))));

*swtib = 25 * RAD + *swfem + 5 * hipsx * RAD;

*swhum = .24 * (stride - (4 * shldrsx)) * RAD;
*swuln = (1.65 * *swhum);

}                               /* end of function: swings */


float tiltNhip(float *femtilt, float *hipcorr, float stride, float leg, float swfem)
{

*femtilt = RAD * 0.4 * stride;
*hipcorr = leg * (cos((double) (swfem - *femtilt)) - cos((double) (swfem +
*femtilt)));


}                               /* end of function: tiltNhip */


float sin_tbl(float sinval[])
{
```

```
int i;

for (i = 0; i < 810; i++)
    {
    sinval[i] = sin((double)(i * RAD));
    }
}                                   /* end of function: sin_tbl */


float ankl_tbl(float sinank[])
{
int i;
for (i = 0; i < 181; i++)
    {
    sinank[i] = 0;
    sinank[i + 360] = 0;
    }
}                                   /* end of function: ankl_tbl */


float ankl_sym(int nn, int pause, float sinank[])
{
int I, j, Z;
float A;
I = 0;
for (j = 270; j < (nn + 1); j++)
    {
    Z = I;
    A = (2 * Z - 2 * pause * Z/(90 + pause)) * RAD;
    A = (cos((double)(A)) + 1)/2;
    sinank[j] = A;
    sinank[j - 2 * I] = A;
    I = I + 1;
    }
for (I = 360; I < (nn + 1); I++)
```

```
    {
    sinank[I - 360] = sinank[I];
    }
}                               /* end of function: ankl_sym */


float ankl_end(float sinank[], int nn)
{
int i;
for (i = nn; i < 181; i++)
{
    sinank[i + 360] = sinank[i];
}
}                               /* end of function: ankl_end */


float calc_lean(int time, float *xtilt, float *ytilt, int *xpos, int *ypos, float *fall)
{
float A;
A = RAD * 300/(time - 140);
*xtilt = TORSO * sin((double)(A));
*ytilt = TORSO * cos((double)(A));
*xpos = 130;
*ypos = 550;
*fall = 0;
}                               /* end of function: calc_lean */


                                /*END PROGRAM*/
```

APPENDIX B

TECHNICAL SPECIFICATIONS OF THE EQUIPMENT USED

HARDWARE:

Computer:

- Silicon Graphics Indigo
- 1 50 MHZ IP20 Processor
- CPU: MIPS R4000 Processor Chip Revision 2.2
- 64 Mbytes of Main Memory
- GR2-Elan Graphics Board

Monitor:

- Silicon Graphics 19":
- Window size 1280x1024 pixels
- 24-bit color, Z-buffered

Digital video recorder:

- Sierra Design Labs QuickFrame

SOFTWARE:

Modeling, motion genderation and rendering:

- SoftImage Creative Environment Version 2.6

Text and textures creation:

- Wavefront Visualizer Paint

VITA

Timothy David McLaughlin is a M.S. candidate in the Texas A&M University College of Architecture Visualization Sciences Program. He received his B.E.D. from Texas A&M University in 1990, and his A.A. from Kilgore College in 1987.

His academic interests include character animation, and figurative art. Outside interests include basketball, hiking and fly fishing. Upon graduation he plans to work as a computer animator in the production industry.

Tim McLaughlin can be contacted through the address:

Visualization Laboratory
Texas A&M University
216 Langford Center
College Station, Texas 77843-3137
phone: (409) 845-3465