MOTION IN COMPUTER GRAPHICS

LE MOUVEMENT EN GRAPHIQUE

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RESUME

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Marla Schweppe received her undergraduate degree in Theater Design at the University of Kansas. Before returning to graduate school at The Ohio State University in computer graphics, she worked on numerous Broadway, Off-Broadway, television, and film productions. Ms. Schweppe worked for three years as the costume designer/director for the dance company, Jennifer Muller and the Works. Since returning to school, she has worked as a research assistant and is currently teaching computer animation at OSU.

SUMMARY

Movement in animation is created by changing any one of a number of parameters from frame to frame. In 3-D computer animation, the movement and orientation of an object in space can be controlled in a number of ways. Linear incrementation with eases is only a start. Movement along a curve goes a step further and the incorporation of Newtonian physics can generate complex motion without unduly complicating the control task. Other promising methods include algorithms for the dynamic simulation of figure motion, and robotics control techniques. In addition to these more recent developments, many of the rules that traditional animators have discovered are applicable to computer animation, since the need to model the structure and timing of figure motion is fundamental to character animation in general. However, it is important to distinguish between those principles of animation designed to express the essential qualtities of movement, from those rules necessitated by the limitations of traditional cel animation.

Un mouvement animé se crée en changeant un parmi plusieurs variables d'un cadre à l'autre. Dans l'animation d'un ordinateur 3-D, le mouvement et l'orientation d'un objet dans l'espace se sont contrôllés en plusieurs façons. Le mouvement le long d'un virage s'avance d'avantage et l'incorporation de la physique Newtonien est capable de provoquer le mouvement complexe sans trop compliquer le travail de côntrole. D'autres méthodes souhaitables comprennent les algorithms pour la simulation dynamique des mouvement des figures et des techniques de contrôle "robotics". A part ces développements récents, beaucoup de règles découvertes par des animateurs traditionels sont également applicable a l'animation des ordinateurs, en car de besoin de modeler la structure et le temps d'une figure animée est fundamental à l'animation d'un caractère en général. Il est important cepedant, de distinguer entre les principes d'animation dessinés à exprimer les qualites essentielles d'un mouvement de ces règles qui dependent de l'animation de "cel" traditionel.

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1. Introduction

As access to computer graphics becomes more common place, increasing numbers of artists will be involved in the production of 3D computer animation. As this trend develops the interface between artist and computer will become increasingly important. A methodology for organizing and using information on motion control and timing of three-dimensional, computer animated objects is necessary.

The ultimate success of an animation depends on how well it communicates to the audience. This communication depends on the proper orchestration of the factors involved in the creation of an animation. Traditionally the work has been divided into smaller tasks: inking, painting, animating, camera control, inbetweening, design of backgrounds, sound, character development. This division is crucial to the manageability of an animation. No matter what the medium, a knowledge of motion and timing is essential for the animator. Methods of motion control and timing used by traditional animators form a foundation for the 3D computer animator in developing techniques. The addition of the third dimension in animation increases the possibilities for depth and flexibility, while at the same time multiplying the number of factors which must be controlled by the animator. Disney animator, Frank Thomas said: "I look to computers ... to replace the tedious parts of traditional animation ..." (Thomas,1984). The computer can provide assistance in the management of complexity, keeping track of information, and increasing accuracy.

To animate something is to bring it to life. Motion in animation occurs between still frames. Timing is the regulation of the speed with which a motion is animated so as to produce the most effective results. Timing applies to the length of time that the motion takes and to the apparent speed of the movement (size of the increment) from frame to frame. It is the timing of a motion that gives it life and expressive quality. The animator, unlike the performer, can take nothing for granted; physical as well as expressive qualities of movement must be represented.

There is no single source to which the animator can turn for answers to questions concerning the timing and control of motion. The possibilities of motion in animation are limited only by the animator's imagination.

A library of motions, built from these resources, allows the animator to utilize and build on past efforts. This library should consist of photographs, films, algorithms, old storyboards and exposure sheets, and references on kinesiology, anatomy, mechanics, and motor patterns.

2. Principles of Motion Control and Timing in Traditional Animation

The importance of timing was established during the early years of animation largely due to work at the Disney Studios. Disney sought a caricature of realism. "Our work must have a foundation of fact in order to have sincerity."(Thomas,1981)

Realism is a basis for creating illusion and exaggeration (Whitaker,1981).

2.1. Observation, Trial and Error

Animators rely heavily on the observation of motion. Many methods are used depending on the complexity of the movement. When "actions (are) too complicated to draw or moves too subtle to capture" (Thomas,1981) it is usually an indication that the forces at work are not yet completely understood.

Two mutually independent factors are involved in timing a motion: the overall period of time required and the quality of the movement within that time. The timing of an inanimate object depends heavily on external forces and the object's physical properties. A living character, affected by the same external forces, has a broader range of possibilities for reaction and interaction with the environment.

The timing of a simple object can convey the result of an external force or it can convey expressive content. The same timing can be applied to convey that quality in the movement of a more complex character.

2.2. Physical Laws

The types of motion that an animator might want to control are infinite, but there are some basic motions that are employed repeatedly, both in isolation and as components of more complex motions. Newton's laws of motion provide a base for understanding most movement. Even movement with expressive content is based on physical laws. It is crucial to good timing and motion that the animator have an understanding of the forces in nature and how they affect movement (Salt,1976). Most sources which address the techniques of animation, provide the animator with a set of simple concepts which can be extrapolated and applied to a wider range of motion.

Experienced animators develop a series of "rules" for making a motion "look right". These rules reflect an understanding of the forces at work and an algorithmic approach to solving the problem. Animator's have generally gained this knowledge by a process of observation followed by a period of trial and error. The "principles of animation" (Thomas,1981) represent the knowledge gained by animators on the affect of various forces on the timing of movement. Even "exaggeration" is "the exaggeration of the tendency of a force" (Whitaker,1981).

2.3. Expressive Qualities and Character Development

The real challenge of animation comes in creating the personality of characters. Use of computer capabilities to aid in the control of the mechanical aspects of motion frees the animator to concentrate on expressive qualities and character development. Assistance becomes especially important in 3D computer animation where the number of factors to be controlled is greatly increased. Additionally, greater accuracy is required due to the increased flexibility of movement through a three dimensional scene and around three dimensional characters.

3. Classification of Objects for the Purpose of Motion Control

In considering the control and timing of motion for computer animated objects or characters, it is useful to divide them into categories on the basis of movement posibilities (figure 1). Rigid monolithic objects have the most limited set of motion possibilities. These same motions can be used to control all or part of a more complex object. Examples given in this section are based on properties that these objects have in actuality. Objects can be animated as if they have characteristics found in categories other than the one they fit into in actuality.

3.1. Rigid Monolithic Objects

Rigid monolithic objects have only one piece which is rigid. Many inanimate objects (rocks, ladderback chairs, mountains, pencils, bottles, and boxes) fall into the category of rigid monolithic objects, unless they aré to be animated differently. The movement possible at this level is represented in the three factors of position or path, velocity and acceleration. There are however numerous combinations of these three factors.

3.2. Plastic Monolithic Objects

Plastic monolithic objects are objects composed of a single pliable piece (e.g., a bouncing rubber ball, a hammerhead squashing as it hits a nail, a spring oscillating, a balloon being inflated, or a snake. In these cases the object remains the same but it's shape changes. At the more complex level the change is to a different object, such as a ball turning into a box or a scrawny weakling transforming into a body builder. Any shape which can be modeled from such pliable substances as clay, fabric or soft foam are included here. This implies that almost anything can be animated using objects at this level. As shall be seen, movement control of complex objects will be easier using other techniques.

3.3. Rigid Articulated Objects

Rigid articulated objects have several linked rigid monolithic parts. (wooden soldiers, skeletons, vehicles, clocks, gears, pistons and switches). The option of articulation increases not only the number of parts of the object, but also necessitates the description of joints. In terms of animating characters with human qualities, joints described by a simple revolution are the most basic and necessary. A joint which is described by rotating about a single point gives a close approximation of both the hinge joints and the ball-and-socket joints found in the human body (Zeltzer,1982). Methods for specifying the relationship between the various parts and the capability to distinguish between rotations which affect parts of the object above or below the joint. are useful. The position and orientation of the object and each of it's parts must be specified.

3.4. Plastic Articulated Objects

Plastic articulated objects consist of several linked plastic monolithic parts (e.g., a rag doll, a folding foam sofa, a paperback book, a paper airplane, an octopus). The position of a joint may change as the shape of the object changes. If the upper arm elongates the elbow would move further from the shoulder and so would the wrist and all the joints of the fingers. Specification of joints adds ease in tracking various factors in movement. The animator may want to have the shape of the parts vary according to the configuration.

3.5. Composite Objects

Composite objects are objects with both plastic and rigid parts which are linked together (e.g., animals, telephones, hardbound books, trees). Composite objects include all of the options already discussed. Realistic animation of a human being, with rigid bones and plastic muscles and flesh, would fit into this category. The animator may wish to introduce plasticity into the description of parts, like bones, which are actually rigid. Approximation of the skeletal structure and the fleshy tissue surrounding it will be sufficient for most applications, except strict simulation.

3.6. Example: Designing a Motion Sequence

The motion of the elf (figure 2) can be divided into: a parabolic trajectory which can be tested using a rigid monolithic object; an oscillation, with an exaggeration factor, which can be tested using a plastic monolithic object; and finally, the combined movements of the composite object which includes wiggling ears and blinking eyes.

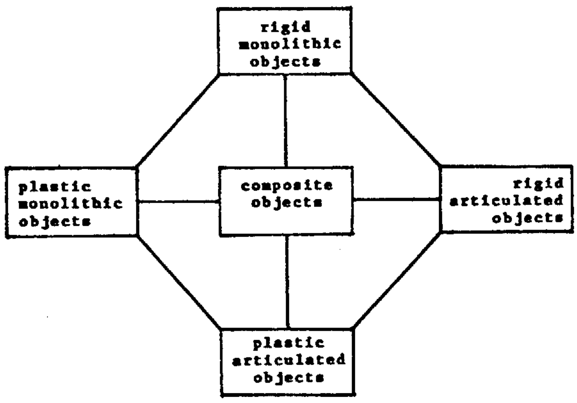

Figure 1.
Classification of Objects

Figure 2.
Frank the elf (Marsha McDevitt)

4. Types of Motion Control

The 3D computer animator must decide how to control a particular motion. The more general the solution the more applicable it will be to future work. Diverse means of control motion may be desirable within the same animation, and even for the same character. Various options for motion control should be individually accessible, with the animator specifying which kinds of control are necessary for a particular scene (Csuri,1984).

4.1. Constant Motion

Constant motion can be achieved by linear interpolation of any parameter. This is the simplest form of interpolation. It is used to represent anything which is changing at a constant rate or moving at a constant speed. Objects will appear to start or stop abruptly. Computer animation systems usually provide this kind of interpolation. As the only means of interpolation, however, it is extremely limiting.

4.2. Eases

Ease-ins and ease-outs which simulate acceleration and deceleration. are usually approximated with trigonometric or polynomial interpolations, In many cases, they provide acceptable results. Some computer animation systems include eases as an option (Gomez,1984). Animation of a particular effect can, however, be difficult with eases.

4.3. Acceleration and Deceleration

The animator will wish to simulate the actual physical forces at work, in some cases. Referring back to the example of the elf, both the parabolic function and the oscillation function control acceleration and deceleration factors. Use of these functions allows a more direct specification of the acceleration and deceleration factors in both cases, and still allows room for exaggeration.

4.4. Movement Along a Path

The animator will often want an object to move along a path which may be difficult or impossible to describe mathematically. The path can be described in full detail or with control points and a smoothing function. It is likely that the animator will want to specify the speed of travel along the path separately from the description of the path itself.

4.5. Articulated Objects

When animating an articulated object each piece of the object will have associated acceleration and deceleration factors. When dealing with a large number of factors it is useful to begin with a simple case so that the overall motion can then be worked out without concern for all the details. Exaggeration and other variances can be added later. The individual steps of developing a motion become more manageable using this strategy. For example, if an articulated object or character is to walk along a path, the character must move along the path in the proper orientation. If the character has feet or wheels, these must be reoriented to the direction of the path at each step along the way. If the character is walking across uneven ground, there will then be yet another variation in the steps.

Motion control is more easily managed if the motion for each object can be developed independently. Adjustments for interaction can be made afterwards (Fortin,1983). When controlling the parameters of several articulated characters this becomes increasingly important.

A robot arm moving freely through the air provide an example of a structure referred to as an open kinematic chain. If the animator wants both hands to grasp a stick and stir something in a pot, he must be concerned with bringing the hands in contact with the stick. Things must move in such a way that the stick stays in the pot and the hands on the stick. This structure is called a closed kinematic chain. Robotics research may provide help to the animator in this area.

The areas of robotics and artificial intelligence suggest control systems which could help in the animation of articulated objects. Researchers interested in artificial intelligence are usually interested in simulation of the real world. The same kind of systems could be used for exaggerated, expressive animation, if options are included which provide this flexibility (Zeltzer,1982). Most control systems developed for robot arms dictate the timing and the relationship of the angles between the parts. If the only concern is to move from one position to another, it is very useful. However, if the movement is to be expressive, additional flexibility must be incorporated. Pseudo inverse Jacobian control is an example of a control technique developed primarily for controlling the movement of robot arms. It has been suggested that there may be ways to introduce the necessary flexibility into this system to make it useful to animators (Maciejewski,1984).

Whereas no two characters walk exactly the same; there are more similarities than there are differences. A system which allows the animator to describe one walk, and to then vary that walk or the proportions of the character walking (Zeltzer,1984), saves time in redefining all the common characteristics of walking.

5. Observation and Research

Research from many disciplines can aid the animator in understanding motion.

5.1. Mechanics

The mechanics of human movement has been studied extensively, and can be applied to the animation of articulated objects. Characters which have an anatomy quite different from a human being can be animated using many of the same principles. If the animator wishes to depict an unrealistic situation he may be able to do it by tweeking parameters of a certain formula, (i.e. the exaggerated oscillation of the spring).

Many complex motions which an animator may wish to use have been researched and documented by physicists. Mechanics is the branch of physics that deals with motion and the phenomena of the action of forces on bodies. The motions are described in terms of mathematical equations. These equations can be implemented as algorithms for use in 3D computer animation.

The development of algorithms to control motion ultimately saves the animator time. For example, the formulae that would be used for a rolling ball can be applied to a moving train with several sets of wheels of different sizes. There are many examples of far more complex motions which could be controlled algorithmically.

5.2. Kinesiology

Kinesiology is the the study of human muscular movements. Most of the research in kinesiology is directed towards training athletes to perform more effectively. Research in this area provides many useful examples of human movement which can be applied to the movement of many articulated characters.

> Human walking is a unique activity during which the body, step by step, teeters on the edge of catastrophe (Napier,1967).

Walking, running and jumping are all controlled states of falling. When walking normally a person shifts weight forward from one foot and "falls" onto the other foot. As long as the weight is controlled properly the person remains erect. Divers, dancers and gymnasts must be expert at controlling their movement in free fall. Understanding the mechanics of these motions aids the athlete and the 3D computer animator. Many animated character will follow the same general rules as a human being. There will be differences if the character has a different skeletal structure than the human or if the character is not to move in a realistic fashion.

The center of mass of a rigid monolithic object will follow a parabolic curve during free fall. The center of mass of a complex articulated object, such as a human being, will also follow a parabolic trajectory. The center of mass of a human being however will change as he changes the internal configuration of his body parts (Walker,1982). A human being can change his orientation while traversing this parabolic path by controlling the configuration of his body. (Smith,1967). A dancer must control his angular momentum as he leaves the ground and while he is in mid-air in order to turn (Laws,1978-9). When he leaps he will be controlling his center of mass in order to affect the way he traverses a parabolic trajectory (Walker,1982). Divers and gymnasts control the same factors when they do somersaulting and twisting (Frolich,1979). When animating a character with human qualities, the animator will want to incorporate some of the same qualities. Sometimes it is difficult to understand all the factors involved in these twisting turning movements.

> Our other big surprise came in the amount of movement in the deer's spine and pelvis. The twists and tilts and turns and flexibility were more than we knew how to draw, but they helped us understand how fawns achieved the frolicking look when playing (Thomas,1981).

Two dancers partnering, have to control not only their own balance but their balance in conjunction with another person (Laws,1980). When one dancer lifts another, the weight of the lifted partner must be over the support point of the partner below. Both dancers are involved in controlling the placement of the weight. In judo, the proper placement of the body allows one person to throw another person (Walker,1980).

A gymnast performing on the uneven bars is affected by centrifugal force. Proper control of the centrifugal force leads to a good performance (Smith,1981). If, in the case of an animated character, this force is not taken into account, the motion will not be credible. In some cases, the animator may not want to exhibit realistic motion. For example, by lessening the gravitational pull on the character, or ignoring it all together, the animator could make a character perform stunts impossible for the gymnast (VanBaerle,1983).

Divers are in a state of free fall after they leave the board and all the dives they perform exhibit methods of controlled "falling". There are a limited number of factors that a diver can control while still on the diving board or in mid-air (Batterman,1968). By controlling the configuration of his body the diver can initiate twists and somersaults after he has left the board (Frolich,1979). Research in this area provides information useful not only in animating a diver, but for other situations as well (e.g. how a character who has tripped will recover; how a cat always lands on it's feet). If the character controls the factors well, he will appear to be coordinated; and if he controls them poorly, he will appear to be clumsy.

The examples above are all based on several common principles: angular momentum, changing center of mass, linear momentum, and centrifugal force. Programs designed to assist the animator in controlling these kinds of movements might begin with realistic representation. However, if representation is limited to realism, there will be no room for the incorporation of the personality of the character. Introduction of factors which allow the animated character to perform less well could add flexibility. In a general format these same basic ideas can be used to control a variety of movements that have nothing to do with diving, dancing or gymnastics.

5.3. Anatomy and Motor Control Patterns

The 3D computer animator will study anatomy from the point of view of animating it. The information of interest will be different from that of both the doctor and the artist. Traditionally, many of the characters in animation have been animals. Veterinarians provide us with anatomical drawings of many animal skeletons. Utilization of these sources provides information on skeletal structures, degrees of freedom in the movement of joints, and amount of flexibility.

Studies of motor development include descriptions of walking human beings of all ages, shapes and sizes. Accessing these descriptions gives the animator a better foundation for observing and understanding motion

(Wickstrom,1977). If, as the animator has need of certain kinds of motion control, he develops systems of controlling that motion in a general way he will have the beginnings of a motion library.

6. Conclusion

A vast amount of information is required to understand motion. A structure for thinking about and developing systems to control motion and timing in 3D computer animation is necessary. Methods of motion control and timing used by traditional animators form a foundation for the 3D computer animator in developing techniques.

Objects can be classified according to complexity and types of motion control that apply, so that various aspects of a problem can be addressed individually. Flexible algorithmic control of the mechanical aspects of motion frees the animator to concentrate on expressive qualities and character development, and provides a way of recording observations of certain motions for future use. Expressive qualities of motion cannot be described as easily algorithmically. However, through the use of films, photographs, dance notation, and records (exposure sheets, storyboards, verbal descriptions) of how a quality was achieved the animator can build a library on motions with expressive qualities as well.

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