COMPUTER GRAPHICS
ANIMATION TECHNIQUES AND PRODUCTION PROCEDURES FOR SCIENTIFIC VISUALIZATION

Submitted

to

European Centre for Medium Range Weather Forecasts

December 1988

by

Philip C. Chen

Sci Art Technology
6959 Oakdale Ave
Canoga Park, California 91306
U. S. A.

ABSTRACT

Animation production procedures, animation techniques, scientific visualization, and meteorological data visualization will be discussed in this article.

Animation production procedures used in film and video productions will be presented. Animation techniques including hand-drawn and computer graphics animation techniques will be examined. Today's computer graphics techniques, computer-assisted key frame and physically-based animation techniques, will be explored. Scientific visualization regarding animation techniques, production procedures and available technology will be surveyed. Meteorological data visualization concerning routine and special products generation will be discussed.

TABLE OF CONTENT

1 INTRODUCTION

Hand-drawn animation techniques have evolved from numerous practical experiences of animation professionals. Basic techniques for character animation have been arrived at by classifying animation type. With the aid of these techniques, the animators achieved great success in the cartoon productions. Even today these basic animation techniques are widely used in hand-drawn animation as well as in computer graphics character/object animations.

There are several production procedures that are as important as animation techniques. There are procedures for everyday productions, and these procedures may also be important for general computer graphics productions. Very likely, they may also be indispensable to the production of scientific visualization materials.

In this article, subjects to be presented are: animation production procedures, animation techniques, scientific visualization, and meteorological data visualization. They will be presented in sections 2, 3, 4, and 5.

Section 2, animation production procedures cover procedures which have been used in film and video productions. Major pre-production, production and post-production procedures will be discussed.

Section 3, animation techniques, cover definition of animation, hand-drawn character animation techniques, and computer graphics animation techniques. Definition of animation is given in subsection 3.1. Hand-drawn character animation techniques will be presented in subsection 3.2. These techniques are included for historical reasons and completeness in the presentation. A reader may choose to omit subsection 3.2. Today's computer graphics techniques, computer-assisted key frame and physically-based animation techniques will be presented in subsection 3.3.

Section 4, scientific visualization, covers definition of scientific visualization and animation techniques, production procedures and available technology.

Section 5, meteorological data visualization covers routine product visualization and special product visualization.

2 ANIMATION PRODUCTION PROCEDURES

There are many different ways that an animation can be produced. Normally, however, the following procedures are used to complete an animation project.

2.1 Preproduction Planning

Planning tasks such as research, man-power, resource allocation and cost estimation should be done before starting an actual animation production.

2.2 Production

2.2.1 Scripting

Scripting includes story summary (synopsis) and detailed story description (scenario) of a story. Scripting should be completed before the storyboard procedure.

2.2.2 Storyboard

A storyboard is a script outline. It consists of comic strip like illustrations with appropriate captions. An illustration is usually produced by an artist who has been given instructions to draw certain key scenes. Captions are produced by a scripting staff.

An entire animation script should be divided into sequences, each sequence should be divided into scenes, and each scene should be divided into shoots. This script breakdown process is useful for scheduling filming or videotaping sequences.

2.2.3 Layout

Main characters to be animated should be designed and drawn. The relationship between the foreground and background elements should be decided. The background drawing or artwork should be prepared.

2.2.4 Audio Track

The dialogue, music and sound effects should be prepared in sound track forms for audio visual synchronization in post-production editing.

2.2.5 Key Frame Selection

Key frames should be picked and prepared. They are hand-drawn or computer generated. An animator usually prepares key frames.

2.2.6 In-betweening

In-between frames should be produced. They are hand drawings or computer generated pictures placed between two key frames. Assistant animators usually prepare in-between frames.

2.2.7 Photocopying and Inking

In a hand-drawn animation, sketches are usually drawn in pencil. They are transferred to acetate sheets, which are commonly known in the animation trade as cels, using a photocopying camera. Lines are then inked in by hand. For hand-drawn animation this procedure should be followed for producing cels.

This step can be skipped in a computer graphics animation. There is no need to produce cels.

2.2.8 Painting

In a hand-drawn animation, drawings have to be colored by hand. Painting is one of the most laborious steps.

In a computer graphics animation this step is done very differently. The objects and backgrounds are colored by computer systems software rendering tools.

Painting should be performed in order to produce a color animation.

2.2.9 Previewing

An animator often previews an animation sequence in action in order to decide whether the sequence should be accepted and released for recording.

In a hand-drawn animation, a previewing step can only be done after a preliminary filming or videotaping. This kind of previewing is sometimes called a pencil test, and it is done after the in-betweening and before the painting steps.

In a computer graphics animation, this step can be done after in-betweens have been generated or after painting has been completed. Thus, two ways of previewing are possible: wire-frame animation and raster image animation. Wire-frame animation requires fast vector drawing, while raster image animation requires a fast image display cycle.

Previewing should be performed before recording to ensure the smoothness of an animation.

2.2.10 Recording

An animation segment should be recorded on film or videotape.

2.3 Post-Production

There are several steps for finalizing an animation work. They are as follows.

2.3.1 Editing

Recorded films or video segments should be edited and spliced together according to an original storyboard. Shots should be spliced together to form a scene, scenes should be put together to form a sequence, and finally sequences should be put together to form a complete animation work. A sound track should be added and synchronized with film or video projection speed.

2.3.2 Screening

A completely edited animation work should be viewed by animators, together with a director, a producer, and the clients. Comments and suggestions from all parties present at the screening session should be summarized and any modification to the work should be performed.

2.3.3 Finalizing

All rough edges of the animation work should be smoothed and polished by re-editing and re-working.

2.3.4 Distribution

A final master should be produced. Copies for distribution should be made from the final master and distributed to clients.

2.3.5 Exhibit

Public viewing facilities should be arranged, and should be provided by clients.

3 ANIMATION TECHNIQUES

3.1 DEFINITION OF ANIMATION

Animation has many definitions. The more conventional definitions are given as follows:

- Animation is a technique in which the illusion of movement is created by recording a series of individual drawings or computer generated pictures on successive frames of film or video. The illusion is produced by projecting the film or showing the video at a certain rate.

- Animation refers to the process of dynamically generating a series of the previous frame.

Computer graphics animation, as well as hand-drawn animation, is produced by a frame-by-frame technique. A frame is either produced by a computer or by an animator's hand. The differences between hand-drawn and computer graphics animations are not entirely due to production methods. Their major differences are:

- Spatial dimensions: A hand-drawn animation is inherently two-dimensional and a computer graphics animation is three-dimensional.

- Object modelling: An object is modelled by hand-drawing in a hand-drawn animation, while an object is created by digitizing in a computer graphics animation.

- In-between frames generation: Hand-drawn animation requires artistic talents to generate frames between two key frames, while computer graphics animation requires no special talents to generate frames. A computer graphics system operated by a skillful user can automatically generate in-between frames.

3.2 HAND-DRAWN CHARACTER ANIMATION TECHNIQUES

Hand-drawn character animation has been gradually replaced by computer graphics character animation. However, some basic animation techniques which were discovered by animators around the 1920s to 30s at animation studios are still applicable to character animations in general. Examples of these basic animation techniques are:

- Weight in Movement (Squash and Stretch): Defining the rigidity and mass of an object by distorting its shape during an action. In a hand-drawn animation, real physical forces cannot be imposed on an animated character. This technique is used to imitate an object shape change under the influence of external forces.

- Timing: Spacing actions to define the weight and size of objects and the personality of characters. In a hand-drawn animation, gravity is absent. The weight is emulated by controlling object spacing in a time interval.

- Anticipation: The preparation for an action. This is an artistic animation technique to arouse audience interest.

- Staging: Presenting an idea so that it is unmistakably clear. This is an act for an animated character.

- Follow Through and Overlapping Action: The termination of an action and establishing its relationship to the next action.

- Slow In and Out: The spacing of the in-between frames to achieve subtlety of timing and movement.

- Arcs: The visual path of action for natural movement.

- Exaggeration: Accentuating the essence of an idea via the design and the action.

- Secondary Motion: The action of an object resulting from another action.

- Appeal: Creating a design or an action that the audience enjoys watching.

These techniques and others are great for animating two-dimensional characters whose environment is devoid of real physical depth and forces. Yet animators use these techniques to create the feeling of force and motion. Convincing and great animation art works were accomplished in the past using these techniques.

3.3 COMPUTER GRAPHICS ANIMATION TECHNIQUES

Hand-drawn character animation techniques, which were mentioned in the previous section, have been readily adapted by computer graphics character animators. There are, however, some improvements over the hand-drawn techniques. The improvements can be found in two different animation methods: computer-assisted key frame animation and physically-based model animation.

3.3.1 Computer-assisted Key Frame Animation

After key frames are selected, an animator proceeds to generate in-between frames by a computer graphics animation system. The system software will generate in-between frames by doing spatial and temporal interpolations. The frames are generated by linear or more realistic non-linear (spline) interpolations.

It is an animator's job to judge whether an animation sequence between two selected key frames appears natural and realistic. Many iterative and interactive adjustment steps are taken to produce an animation sequence. Since there is no provision for physical forces being animated, an animator has to be careful that no objects inadvertently collide or inter-penetrate each other.

3.3.2 Physically-based Model Animation

Recently, the technique of using a physical model to control motions of objects has become popular. Motions of objects are simulated by using a set of governing equations with prescribed external forces. Key positions of a moving object are computed for every time-step.

Numerous successful claims are made about this animation approach, especially in the realms of animating motions of solid body and flexible body. Examples of animations are:

- Solid Body: Bouncing object, colliding objects, many bodies (chain-like) motions are simulated quite realistically.

- Flexible Body: Wave motion, flapping flag, dropping cloth, snake and worm-like motion, and jello-like oscillating motion are simulated quite well.

4 SCIENTIFIC VISUALIZATION

4.1 DEFINITION

The term **scientific visualization** became known and popular in 1987. It is actually a computer graphics application for viewing and analyzing observed and/or simulated scientific data. Since scientific visualization is applied to multi-disciplinary sciences, there is no unique technique of doing it. Up to now, visualization products for different scientific fields are done with different techniques.

4.2 ANIMATION TECHNIQUES

There are many animation and modelling techniques used in computer graphics now directly applied to scientific visualization applications. Even conventional character animation techniques, which seem to be very remote from scientific applications, are being used. For example, using different **timings** to show a physical phenomenon at different display speeds in order to comprehend the different physical processes involved. Vertical scale **exaggeration** for viewing geophysical data, fast and slow speed display (**slowin and slowout**) to catch subtle details, are some identifiable inheritances from hand-drawn animation techniques.

Computer-assisted animation techniques such as in-betweening can be used for generating intermediate frames for viewing time sparse data. Physically-based animation techniques are closely related to scientific visualization techniques: governing equations and numerical methods are used for generating multi-dimensional time-dependent data.

Scientific visualization techniques may differ from conventional computer graphics techniques. The major difference may lay in the data presentation area. While in conventional computer graphics animations a character (or an object) is pre-defined and obvious, in scientific visualization an entity which may be of interest to a scientist/researcher cannot be determined a priori except for a few known spectacular events/phenomena.

There are tools being developed specifically for scientific visualization:

- Contouring: Two or three-dimensional contouring for separating different scalar field values. The contours and/or their intervals are often colored for easy viewing.

- False Coloring: Artificial colors are used to represent field values. This technique is typically used for showing two-dimensional scalar data with very fine pixel resolutions.

Several viewing techniques being used for general computer graphics applications can also be used for creating effects in viewing multi-dimensional data. These techniques are:

- Geometric Transformations: Using geometric transformation algorithms to change views and perspectives. Three major transformations are standard in computer graphics: scaling, translation and rotation. Scaling can bring out sub-scale or super-scale details, translation can move a physical entity and rotation can show features **behind the scene**. An effective viewing technique, i.e. walk-through, can be achieved by using all geometric transformations interactively.

- Hidden Surface: Backfacing polygons of an entity which should not be seen by an observer are sorted out by a hidden surface algorithm. These hidden polygons are not rendered. Thus a displayed entity using this hidden surface technique is highly visible without ambiguity.

- Lighting: This technique is used to display a relatively flat field or surface. The lighting can help to bring out three-dimensional features.

- Volume Rendering: This is another way to display a three-dimensional field. The volume transparency technique is used for showing material density in three-dimensional space. For example, this is an effective way to show fluid density distributions.

- Compositing: Two or more fields superimposed to form a composite picture; more than one field can be displayed simultaneously. For example, a vector field super-imposed on a scalar field can show motions as well as transports of a material.

4.3 PRODUCTION PROCEDURES

Production procedures stated in section 2 can be followed closely for the production of animations. However, some of them can be omitted or simplified for scientific visualization applications. For example, pre-production planning, production procedures including storyboard, layout, key frame selection, in-betweening, and painting, and post-production procedures can be scaled down. Irrelevant procedures such as photocopying and inking can be skipped entirely.

4.4 AVAILABLE TECHNOLOGY

A computer graphics system for animation applications requires high processing power, fast data transmission rate, and enormous memory and data storage capacity. In the past, animations were done with pre-rendering wire-frame (vector) objects. These objects required less memory and less processing power. A multiple-objects animation sequence could be displayed rapidly.

Due to technology advancement, several near realtime computer graphics animation systems are available today. They can display processed raster images and/or wire-frame objects, and animated results can be recorded on-line. Interactive devices such as mice, dials and digitizers are available for user applications.

4.4.1 HARDWARE

Hardware systems available today are usually specially designed. Their architecture consists of multi-processors and specialized graphics VLSIs, inter-connected with high-speed buses. Some available systems boast the peak performance of processing and rendering 100,000 polygons per second and 10 frames per second display rate. To achieve this performance, a system also has (micro-coded) firm-ware taking care of geometric transformations and rendering computations. Thus, hardware functions are gradually replacing traditional software functions in today's computer graphics systems.

4.4.2 SOFTWARE

A popular graphics software system available today is composed of layers. Typical layers are graphics primitives, graphics system, user interface tools and applications. A software developer can use any callable routine of these layers and commands/functions provided by the operating system to design and construct his/her own application software system. However, for portability and future development, it is sensible to design a software system which is not dependent on very low layer routines.

5 METEOROLOGICAL DATA VISUALIZATION

In the numerical weather prediction applications, weather data are generated by a numerical model. These data are further processed into graphics products and disseminated to weather users at different sites through network systems. Some graphics products are routinely generated and some are generated only for research or special purposes.

Observed weather data transmitted over networks are received at a weather data processing center and they can be processed into similar graphics products like the ones generated by a numerical model. The treatments of these graphics products are similar, therefore no extra discussions will be given for these observed data products.

5.1 ROUTINE PRODUCT VISUALIZATION

A numerical weather prediction model generates two-dimensional scalar fields such as pressure/height, temperature, moisture content and vorticity. These field parameters are generally contoured and maxima and minima are marked. They are usually generated at least for four pressure surfaces.

A numerical weather prediction model also generates vector quantities such as winds and streamlines. The wind vectors are usually displayed in a two-dimensional pressure/height chart and streamlines are displayed alone.

A numerical weather prediction model also generates other field products such as vorticity advection, temperature advection and cloud height. These are usually treated as supplementary charts for forecasts. They are also contoured.

There are some products that are not related to fields. Examples are station data, histograms and statistics.

To generate these routine meteorological products, a computer graphics system needs a fast vector-drawing processor with fast color fill capability, good interactive graphics subsystem and a reliable recording device.

For animating multi-dimensional field products, field continuity needs to be maintained. A field will appear jumpy if contours or vectors are not coherent in time. Time interpolations and product output interval are essential controls for smooth viewing.

5.2 SPECIAL PRODUCT VISUALIZATION

A special product is usually generated for meteorological events such as micro-burst, tornado, severe storm, hurricane and frontal passage. Since there is no unique approach to displaying data for these weather events, one can only interactively experiment to obtain a best viewing technique. However, there have been a few techniques that are used repeatedly by various meteorological data visualization investigators in the past. They are:

- Super-imposed winds and moisture content contours: A number of pressure-height layers are displayed simultaneously. Each layer consists of contours of moisture content and wind vectors. This approach is good for studying convective cloud cells and meso-scale storms. The wind vectors will show a meso-cyclone wind pattern, if such a system is present. The wind vectors are normally displayed as two-dimensional vectors. Although some investigators attempted to show three-dimensional wind vectors, the display becomes too busy and hard to view.

- Three-dimensional contouring technique: A three-dimensional contouring technique is used for displaying density related parameters such as water vapor, cloud water and rain water contents. A particular contour value will be chosen for generating an iso-surface and this surface will be rendered with a selected color. A hidden surface algorithm is also applied to remove back-facing surfaces. More than one contour value can be chosen to generate several iso-surfaces and each surface can be rendered with a different color. Volume transparency techniques can be used to display different iso-surfaces at once. This multi-colored transparent technique is good for studying a structure of evolving weather systems.

- Three-dimensional streamlines: Three-dimensional streamlines are computed from multi-layer gridded data and displayed. A three-dimensional streamlining technique is often used with the iso-surface technique. The two techniques used together will produce a product that can provide an animation showing the motions and transports.

Computational requirements for these techniques are quite stringent. For memory alone, a system should be able to accommodate a three-dimensional time-dependent database. Fast processing is required for generating three-dimensional contours (iso-surfaces) and another database is required for storing these contours. If a fancy rendering technique such as Phong shading or ray-tracing is used, then the rendering processing speed should go up many-fold.

6 CONCLUSION

This article is a survey paper for animation techniques. The chronological development of these techniques are roughly presented here and can be divided into three periods: conventional artistic hand-drawn character animation, early computer-assisted animation, and computer graphics animation. The continuity and new innovation of techniques in these three periods can be found. Humans have been gradually relieved of ordinary production chores, and more energy has been spent on creativity.

Scientific visualization is a challenging new area, where computer graphics system designers are endeavoring to make a system capable of realtime animation recording as well as realtime playback of vast scientific data.

Since available computer systems begin to show promise of realtime interactive animations more techniques are expected to be developed for meteorological data visualization applications.

7 ACKNOWLEDGEMENT

This paper was completed while the author was working as a consultant for the Graphics Project Group of European Centre for Medium Range Forecasts (ECMWF). The content of this paper was presented at the Workshop on Graphics in Meteorology at ECMWF, Shinfield Park, Reading, England, November 30 to December 2, 1988. A paper with similar content has been published in a ECMWF proceeding. The author wishes to express gratitude to Jens Daabeck, Paddy O'Sullivan, Keith Colman, and Silvia Hauri-Chen for their comments and proof reading efforts.