Computer Animation: Algorithms and Techniques - a Historical Review

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Abstract

Computer animation has a history as long as computer graphics. It's old enough to have interesting divisions, blind alleys, and new trends. It's young enough for the new entrants to have the opportunity to meet most of the people who started the field.This paper reviews the historical development of computer animation noting the trends and suggesting the future.

1. Introduction

Computer animation has had a relatively long (compared to computer graphics) history. Many of the familiar names today are the people who were instrumental in getting the field off the ground as the first graduate students to work in computer animation. The history is interesting in its own right but it is also worthwhile to review in order to appreciate how fast the field has progressed and who got it to where it is today.

Computer animation appears in many contexts including virtual reality/environments, gaming, scientific simulations, and as a medium for artistic animation. For the purposes of this paper, computer animation is considered from the perspective of a type of technology for generating animation without the constraints of real-time or numerical accuracy. In order to impose some structure on the presentation, computer animation is broken down into four periods: the early days (up through the '70s), exploration ('80s), refinement ('90-'95), and character development ('95-present). These divisions are completely arbitrary and are only used so that the discussion can be somewhat modular.

The discussion of the history is composed of three aspects for each of the periods: the technological landscape, the technical advances, and the films and videos produced. The technological landscape is covered to give the reader some appreciation of the capabilities and restrictions imposed by the hardware and software available to the researcher and practitioner. The advances briefly survey the main contributions made to the field of computer animation during the period. For the most part, these advances are based on SIGGRAPH papers and, therefore, are somewhat biased toward the material in that particular venue. The major films and videos are reviewed to illustrate how the advances made their way into popular practice. In some cases, especially the early years, the films and videos come from the research labs and/or individual researchers. In the later periods, commercial films are mentioned as the techniques enter into more mainstream presentations. The reader is urged to keep in mind that this is not written as the final word on the history of computer animation but rather as something to give the reader a taste of how computer animation has developed over the years and to speculate where it's going.

Of course this historical review reflects my personal bias in many ways. My experience is founded on working with Charles Csuri at the Computer Graphics Research Group (CGRG) at Ohio State University starting late 1973. Although the lab supported several computer science graduate students like myself, it was a center in the College of the Arts and, thus, was particularly interested in computer animation as an art form.

2. The early years (- '70s)

2.1. Technological landscape

These are the years before frame buffers in which memory and compute power were expensive and not readily available. Computers were often enshrined in glass enclosed computer rooms. Minicomputers were the research tool of the day (e.g. PDP-11) and the rare supercomputer held the promise of computational things to come. Vector displays, digitally evolving from the oscilloscope, were the standard graphics output device - often accompanied by panels of buttons, dials, and a joystick. Light pens and tablets were also common input devices. Film recording was done, well, on film. Often by physi-

cally positioning a hooded camera in front of the vector display. The camera's shutter would be opened (under computer control if you were lucky) and the program would draw lines or, in the case of solid imagery, scan convert elements onto the display screen thus depositing an image on the film. If color recording was needed, then an RGB filter wheel would be placed between the display with the camera looking through one of the filters. The appropriate geometric elements of that color would be drawn/scanned out on the display. After the drawing/scanning, the shutter would close. In the case of color, the filter would be rotated to position the next color in front of the lens. The shutter would open and elements of that color would be drawn. After a frame was rendered in this fashion and the shutter closed, the film would be advanced to the next frame (thus requiring more expensive cameras capable of accurate frame registration) and the rendering for the next frame would commence. The final step would be sending the film away to be developed so that upon its return a couple of days later, the animated sequence could be critiqued. Units which were self-contained display-filters-camera were equipment for the elite labs. Film plotters provided high-resolution pixel plotting capability.

The industries which motivated development of computer graphics/animation were CAD and flight simulators. Previous to digital technology, the early flight simulators were analog using, for example, a remote controlled camera which flew over a miniature terrain model.

2.2. The advances

The early years in computer graphics were actually fairly active in computer animation. Ivan Sutherland's dissertation at MIT, usually considered the first research work in computer graphics, was an interactive constraint-based animation system. Some of the first people to embrace computer animation were computer artists. Ken Knowlton and Chuck Noll, from Bell Labs, and John Whitney Sr., an IBM artist-in-residence among other positions, employed vector displays to produce animations of abstract computer-controlled line-drawings. Chuck Csuri at Ohio State used the computer to animate more representational images of a hummingbird and a human head.

The dominant influence in this era (and, to a large extent, still today) was the University of Utah and its graduates. Dave Evans came to Utah in the late '60s to establish a computer science department and Ivan Sutherland soon followed. Utah received federal funding to conduct research in the new field of computer graphics and, of course, Evans and Sutherland established the Evans and Sutherland company. The graduate students who went through the program included Ed Catmull, Frank Crow, Fred Parke, and Jim Blinn. These students created some early animations.

Chuck Csuri, in the late '60s, started CGRG at Ohio State with the express purpose of investigating computer animation. In the mid-'70s, John Staudhammer at North Carolina State, along with students Turner Whitted, Nick England, and Mary Whitton, developed a run-length decoder and NTSC encoder for CGRG's PDP-11 computer. Animation frames could be run-length encoded in software and stored on digital disk one frame at a time for later real-time playback via the decoder/encoder board. Outside of flight simulators, this was one of the first real-time digital animation playback systems.

Late in this period, another force in computer animation arose: the New York Institute of Technology. Ed Catmull and several others from Utah migrated to NYIT. Here, digital compositing with the alpha channel, BBOP, a computer animation system which evolved into Disney's CAP system, and PAINT, one of the first paint systems, were born.

2.3. Notable films and video

The University of Utah produced some of the most impressive computer animation in the early years. Ed Catmull produced articulated hand animation and Fred Parke animated a human face using his parameterized model ('72) *Not Just Reality* by Barry Wessler ('73) incorporated lip synced facial animation of a walking human figure. At Ohio State University, Chuck Csuri and his students produced several animations of articulated figures and flexible objects in the mid to late '70s. Toward the end of the '70s the New York Institute of Technology worked on a full length movie called *The Works*. *Sunstone*, using animated textures, was produced by Ed Emshwiller at NYIT in '79.

During this period, a few companies embarked on projects involving computer animation. Mathematical Application Group, Inc., (MAGI) produced the first computer animated commercial for IBM in 1969. Information International, Inc. (III or Triple-I), a company involved in the manufacture of scanners and other peripherals was also an early computer animation company. Bob Able and Associates also entered computer animation early.

In the mid-'70s, 3D computer animation made its first forays into the entertainment industry. *FutureWorld* ('74) used sequences from Utah as futuristic images on computer displays in the movie. *Star Wars* ('77) used custom animation as a type of holographic display. *Looker* ('81) also used a wire-frame digital version of Susan Dey. Jim Blinn at the Jet Propulsion Lab used computer graphics renditions of texture-mapped objects to create animated fly-bys of planetary missions by various spacecraft ('74); he also made animations for the *Mechanical Universe* ('78)

3. Exploration (the ‘80s)

3.1. Technological landscape

The decade of the ‘80s is marked by the introduction of the IBM PC although it was not to have an impact on computer animation for some time to come. More importantly for graphics was the proliferation of the workstation by SUN, HP, and DEC, and the formation of Silicon Graphics, Inc. by Jim Clark, who a few years earlier had been a graduate student running around SIGGRAPH. As an interesting side note, Microsoft went public at $21 a share in the middle of this decade (‘86).

Frame buffers had taken a firm foothold and were readily available as external RS-232 devices from companies such as Raster Technologies. Single frame video recorders were available which allowed a frame at a time to be laid down on a 3/4” video tape. The repeated starting and stopping of the video recorder created a much wear and tear (including stretching) of the video tapes. Laser disc technology also provided single frame recording of video. At the time these were fairly expensive devices (roughly $10K-$20K) but they were significantly better than previous options.

3.2. The advances

The ‘80s offered a time in which the field was wide open. There was little published work in computer animation and ideas proliferated. With some notable exceptions, most of the groundwork for the field of computer graphics was laid during this period including ray tracing, volume graphics, fractals, solid texturing, radiosity, and environmental mapping. So, too, it was with computer animation.

The basics of interpolation were being investigated, including the use of interpolation techniques in animation. Surface patch technology was applied to interpolating curves by Bill Reeves in 1981, quaternions were introduced by Shoemake in 1985, and parametric keyframe interpolation was addressed by Steketee and Badler in 1985.

The idea of blurring the display of moving objects was addressed by several researchers: Potsmesil and Chadkravarty (‘83), Korein and Badler (‘83), and, using distributed ray tracing, by Cook, Porter, and Carpenter (‘84).

The first plant models were introduced by Alvy Ray Smith (‘84) and Prusinkeiwicz, Lindenmayer and Hanan (‘88), although issues of animation were not incorporated at this point. Nelson Max presented an animated water surface in 1981 and, later, two models for ocean waves were introduced by Fournier and Reeves (‘86) and Peachey (‘86).

Physics, constraints, and flexible models received great attention during this period with work by Barzel, Barr, Hahn, Cohen, Wilhelms, Terzopoulos, Fleischer, Haumann, and Pentland, including spacetime constraints by Witkin and Kass (‘88). The first investigations into animating the human form included facial animation by Platt and Badler (‘81) and Waters (‘87), Girard on walking (‘85), Badler’s figure positioning (‘87), layered construction by Chadwick (‘89),and skin deformations by the Thalmanns (‘89).

Other interesting work included scripts and actors by Reynolds (‘82), clouds as transparent ellipsoids by Gardner (‘83-‘85), particle systems by Reeves (‘83), Pre-multiplied alpha by Porter and Duff (‘84), cloth by Weil (‘86), FFDs by Sederberg (‘86), flocking by Reynolds (‘87), applying the principles of traditional animation to computer animation by Lasseter (‘87), and digital image warping by Wolberg (‘88).

3.3. Notable films and video

The decade of the ‘80s was marked by the proliferation of commercial animation companies. PDI was formed in 1980 and was immediately followed in 1981 by Digital Productions and Cranston-Csuri. Industrial Light and Magic was formed in 1986. Meanwhile, LucasFilm was giving birth to Pixar. Lasseter joined LucasFilm in 1984 and uses motion blur in an animation for the first time in 1984. In 1986, Pixar splits from LucasFilm.

These were the years of the first real use of computer animation in film for something other than appearing as futuristic computer displays. *TRON* (‘82) and *The Last Starfighter* (‘82) were important films demonstrating the promise of computer graphics and animation in the entertainment industry. *TRON* incorporated computer rendered scenes as an integral part of the movie. The effects were provided by the most of the companies in existence at the time: MAGI, III, Digital Productions, and Bob Able and Associates.The action of the movie takes place inside a computer, so the fact that the renderings looked like they were computer-generated was not an issue and was even desirable. *The Last Starfighter* used computer-generated 3D models of a spacecraft for the scenes in space. It was the first use of computer graphics for an object that was supposed to be a real object in the movie. *Star Trek II: The Wrath of Khan* (‘83) was the first use of a particle system in a feature film. *Young Sherlock Holmes* (‘86) used an articulated, but not completely connected, stain-glass figure which, for the first time integrated computer graphics with live action. *Howard the Duck* (‘86) was the first film to use digital wire removal.*Willow* (‘88) was the first feature film to use morphing and *Abyss* (‘88) used computer

graphics to create the alien water creature in the film. For a commercial touting the advantages of steel cans, Bob Able and Associates produced an articulated form, robotic in appearance, but demonstrating human-like movements which were digitized from live action (‘84). It was one of the first, if not the first, demonstrations of motion capture of an articulated figure.

The Lasseter films were instrumental in promoting computer animation as a viable art-form. These consisted of *The Adventures of Andre and Wally B.* (‘84), *Luxo Jr.* (‘86), *Red’s Dream* (‘87), *Tin Toy* (‘88), and *Knick-Knack* (‘89).

Research labs also produced some important animations. Nelson Max produced *Carla’s Island* (‘82), the first animated water to use a dynamic height field. *Tony de Peltrie* (‘85) animated a human form in an impressive synthetic environment and *Rendez-vous a Montreal* (‘88) showed a synthetic meeting between Marilyn Monroe and Humphrey Bogart.

4. Refinement (‘90-’95)

4.1. Technological landscape

The early ‘90s saw the advancement of the IBM PC into a computational engine capable of producing high quality computer graphics and animation in a very economical cost-performance package. PC rendering farms became viable and digital video was introduced. This was the era of desktop computing. It was also the era of special purpose game engines such as Nintendo and Playstation. And the digital representation of movies became commonplace in the entertainment industry. Of course, once a movie is in a digital form, it provides a fertile ground for computer graphics techniques.

4.2. The advances

Physics and constraints continued to receive attention during this period by research such as Metaxas, Terzopoulos, Baraff, Witkin, Cohen, Fiume, and van de Panne. Morphing of 3D objects became a topic of interest with work by Kent (‘92) and Hughes (‘92). Cognitive modeling and autonomous control also became an area of active research for several researchers including the impressive demonstration of evolving virtual machines by Sims (‘94).

Other interesting work included FEM muscles by Chen and Zeltzer (‘92), cloth and clothes by Carignan, Yang, Thalmanns (‘92), hair as linked rigid sticks by Anjyo, Usami, Kurihara (‘92), Turbulent wind fields by Stam and Fiume (‘93), Implicit surfaces by Cani (‘93), and plant developmental animation by Prusinkiewicz, Hammel, Mjolsness (‘93)

4.3. Notable films and video

This period was a watershed era for computer animation in the film industry. It became big business with the rise of companies such as Digital Domain, Dreamworks, Imageworks, Pixar, Disney, PDI, and ILM. Several important and impressive movies were produced which captured the imagination of the public as well as researchers. *Terminator 2* and *Beauty and the Beast* both hit the market in 1991 and had a huge impact on the industry. These were quickly followed by *Lawnmower Man* (‘92) and *Jurassic Par*k (‘93). These were followed by more subtle, but just as effective, use of computer graphics in films such as *True Lies* (‘94), *Forrest Gump* (‘94), *Babe* (‘94) and *Twister* (‘95).

5. Character development (‘95-present)

5.1. Technological landscape

The technology continued to develop to where we know it today: cheap memory, cheap and fast computers, and digital video on the desktop. The personal animation system became cost-effective.

5.2. The advances

The trends continued: physics, constraints, plants, 3D morphing, cognitive modeling, facial animation. The most impressive advances came in the area of modeling and animating the human form (and is where the title of this area comes from): physics-based control by Hodgins, Wooten, Brogan, and O’Brien (‘95); anatomic modeling by Scheepers and Parent (‘97) and Wilhelms and van Gelder (‘97), subdivision surfaces for modeling by DeRose, Kass, and Truong (‘98), and the impressive cloth animation of Baraff and Witkin (‘98).

Two new areas arose. The first was the modeling of fluid flow using Navier-Stokes by researchers such as Foster and Metaxas (‘97), Witting (‘99) and Stam (‘99). The second was motion capture editing by Witkin, Popovic (‘95), Bruderlin and WIlliams (‘95), Rose et al (‘96), Gleicher (‘98), Popovic and Witkin (‘98), Lee and Shin (‘99)

5.3. Notable films and video

Computer generated characters had finally been refined enough to be included in films. The creatures were often aliens (*Species*: ‘95; *Mars Attacks*: ‘95; *Men in Black*: ‘97), real or imaginary animals (*Jumanji*: ‘95; *Dragonheart*: ‘96; *Bunny*: ‘99), and a digital stunt double (*Batman Returns*:

‘95). Two worthy of special mention are *Geri’s Game* (‘99) because of the facial and cloth animation, and of course Jar-Jar in *Star Wars Episode I* (‘99) as the first humanoid main character of a feature film.

Also in this period, 3D computer generated feature length cartoons were produced. *Toy Story* (‘95) was the first full length fully computer generated 3D animated feature film. The next was *ANTZ* (‘98) which used 2D painted backgrounds. *A Bug’s Life* (‘98) followed quickly and relied strictly on 3D graphics elements.

6. Where we seem to be going

By looking at the development of the field through the years, some trends can be identified and some gaps can be seen.

Fine modeling of the human form: As the mechanism for controlling motion are honed, the more subtle issues of producing realistic motion can be addressed such as cognitive modeling; anatomic modeling; working with tools; modeling personal traits, sex, age, and race; synthetic crowd control; and the easier integration of motion capture data.

High level animation control: In order to get computer animation in the hands of users, the specification of motion has to be facilitated including encapsulated behaviors, directable models, and level of detail motion representation.

Natural Phenomena: Nature exhibits mind-boggling complexity and complete models of various natural phenomena remain a challenge: fire, plants in wind , clouds, and an integrated model of water including drops, splashing, and waves.

More complex physical simulations: As compute power becomes more available we will be able to include more complex physical simulations into the animation process including FEM, Navier-Stokes, and explosions of heterogeneous material.

7. Summary

Computer animation remains to be an active area for research and one with many challenges to be overcome. The field has come a long way since the animations from the University of Utah but in retrospect, those works are all the more amazing for the first very large strides they represent.

The initial work concentrated on the human form and concentrating on the human form is what much of the interest seems to be about today.The holy grail of a synthetic actor has been a focus since the inception of computer animation. As with illumination, only when reality is mostly conquered can researchers feel justified in addressing other issues (such as non-photorealistic rendering in the case of illumination). So a synthetic character, indistinguishable from an actor, remains the yardstick by which computer animation will be measured.

For more information on computer animation and its history, see www.computeranimation.org.

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