A HISTORY OF COMPUTER GRAPHICS AND SPECIAL EFFECTS

When we watch a movie like *Avatar*, we are seeing the results of nearly 200 years of dreamers. It started in the nineteenth century, with Charles Babbage. He grew up among wonderful new inventions, including machines to transport people and goods faster than ever before, and ones that achieved precision in manufacturing previously impossible. He imagined a machine that could be made to do complicated mathematics (Figure 1.1). His analytical engine was unfortunately never funded and many of his modern ideas wouldn't be matched for almost 100 years.

The earliest computers were mechanical adding machines. Later, electronic computers were used in World War II in the USA to help crack communication codes, create artillery tables, and help with the mathematics needed to develop the atomic bomb. They weren't practical for anyone other than government or large research institutions. First of all, they were huge, taking up the entire floor of an office building. They were expensive and broke down a lot. This was because they used vacuum tubes instead of our modern transistors. Shaped like a long light bulb, these were large, fragile, and hot.

These computers had no screens or interactivity. Every equation had to be programmed in which was achieved by changing the circuitry of the computer at switchboards. Variables were input using a punch card reader, and the answer was received in the same way, with a punch card (Figure 1.2).

Before any graphics could be done on computers, there had to be a display. The first was another military invention, the Whirlwhind, which used an oscilloscope to show an airplane's location and a light pen to get more information about them.

In 1963 at MIT Ivan Sutherland created *SKETCHPAD* as part of his doctoral thesis. He is known as the father of computer graphics for good reasons. A person could draw shapes, both
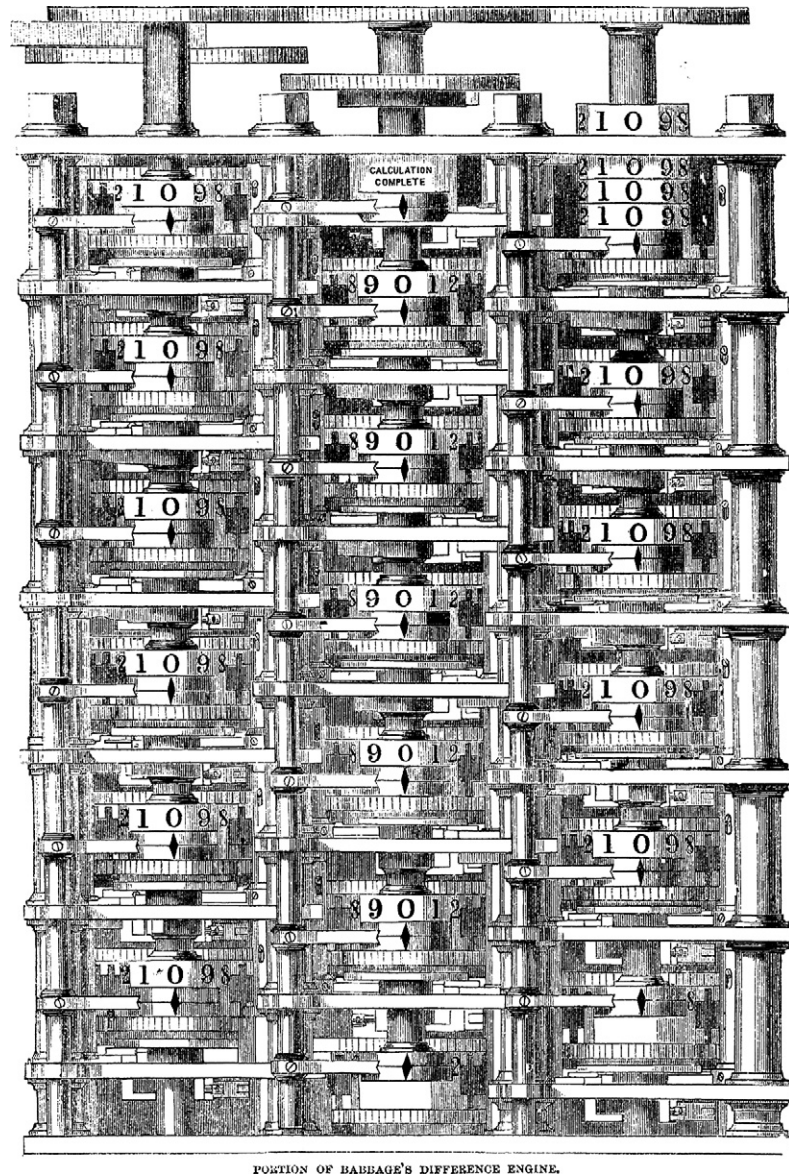
PORTION OF BABBAGE'S DIFFERENCE ENGINE.

Figure 1.1 A drawing of part of Babbage's analytical machine.

two- and three-dimensional (2D and 3D), with *SKETCHPAD*, using the light pen on the screen. This was the first time a user could truly interact with the computer program other than by running a bunch of punch card instructions through. The TX-2 system that Sutherland used to run his program was based on the
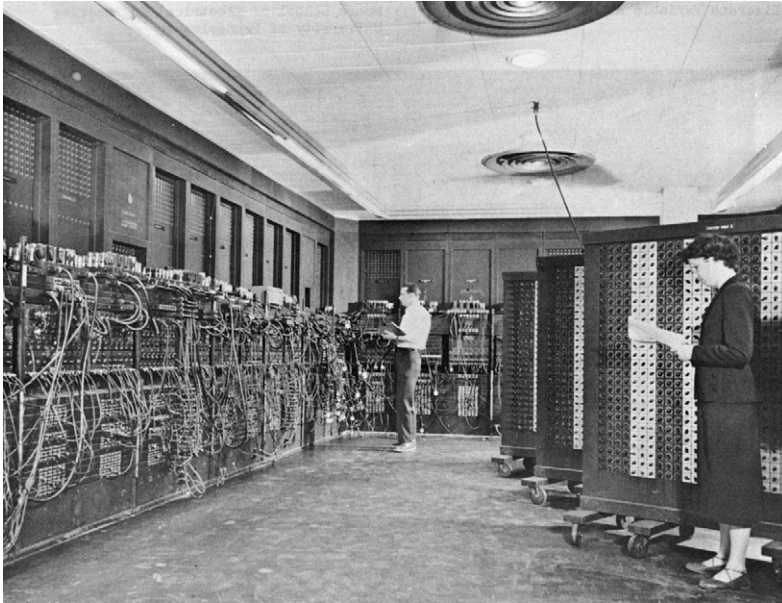
Figure 1.2 The ENIAC.

Whirlwind, but used transistors instead of vacuum tubes. This shrunk computers to a decent-sized room and made them far less likely to break down. Sutherland had to rig the TX-2 especially for his program, and then restore it to the way it was when he finished. *SKETCHPAD* couldn't run on any other machine (Figure 1.3).

This was one of the difficulties that had to be overcome before computer graphics (a term coined by another pioneer, William

Figure 1.3 Ivan Sutherland running *SKETCHPAD* on a TX-2.

Fetter, when he used a computer to create ergonomic designs) could become a common reality. Early computers had no operating system or programming language as we understand them today, let alone "reusable programs" that one could purchase. If you bought a computer in the early 1960s, you would have to program it with switches before you could do anything on it. To make them commercially viable, strong and successful efforts developed computers to a point where they were useful upon turning them on, and easily programmed using a programming language that could be input with a keyboard. Still, they were so expensive that many organizations rented computer time rather than owned computers, and computer access was precious indeed at the universities. It was not uncommon to be scheduled in the middle of the night to work on the computer.

Still, this didn't stop people from creating and playing computer games, which was pretty much an act of clandestine love during the 1960s. No one got paid. Copies were passed around in a programmer's underground of sorts, often in the form of booklets printed with the code. If someone wanted to play a game, they would have to type in all the code.

Which game was the first computer game is up for grabs, but one of the earliest interactive ones was called *Spacewar!* (Figure 1.4). Created by Steve "Slug" Russell, Martin "Shag" Graetz, and Wayne Witaenem in 1962, it took about 200 man-hours to code. People spread copies around so that nearly every
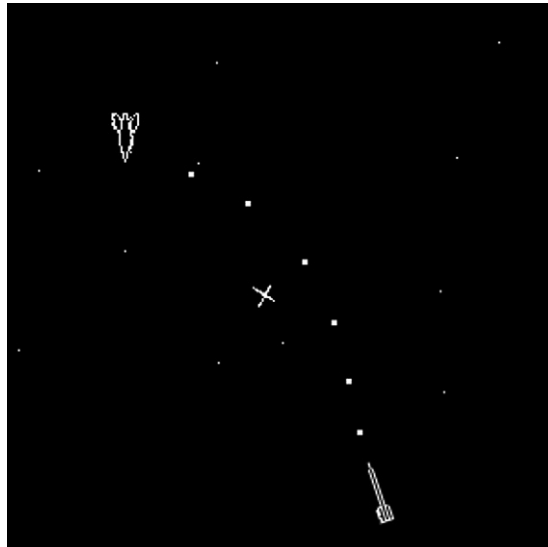

Figure 1.4 A screenshot of *Spacewar!*

owner of a DEC PDP-1 (a commercial version of MIT's TX-2) had one. People had to rig their own controls for the game to play it. Of course, before long a copy fell into the hands of Digital Equipment Corporation, who ended up using it to test PDP computers in the factory and shipping a copy with each system sold. Computer programmers who loved *Spacewar!* ported it to other computer systems and several arcade versions were released in the 1970s.

The graphics of both *SKETCHPAD* and *Spacewar!* were simple white-line drawings on cathode ray tube (CRT) screens. 3D objects, made up of polygons, could only be viewed as wireframes. You could see through them, to the back as easily as their front. This, and many other difficulties still had to be resolved to be able to make realistic pictures using computers. Several institutions chipped away at the problems, but the University of Utah had a sledgehammer of a program in 1973 with a $5 million a year grant from the Advanced Research Projects Agency of the US Department of Defense (ARPA).

ARPA's interest in computer graphics lay in the ability to create simulations. This would be an inexpensive and safe way to train soldiers and airplane pilots. Simulation technologies are now a major aspect of training pilots, allowing them to practice dealing with potentially fatal situations. This has led directly to a reduction in airplane crashes. Other graphics of the time were devoted to computer-assisted design (CAD), scientific visualizations, and medical imaging.

Miniaturization and other advances at this level of financing led to packing more and more computing power into single supercomputers. These monoliths of circuitry were still so costly to build and maintain that only well-funded institutions had them. The University of Utah was able to afford these assets because of the ARPA grant.

Sutherland, who had been working at ARPA, was recruited to Utah's program by its head, long-time friend Dale Evans. There, researchers in the program created an algorithm that would hide surfaces, improving on the wireframe and giving it a solid appearance. At Utah and in other places, shaders had been invented to shade the colors of surfaces based on how the light hit them. These were big improvements, but objects still did not look like they had natural lighting. Bui Tuong Phong noted that direct lighting on objects created highlights, and developed the Phong shader algorithm to simulate these. As he worked on this problem, which was to be his doctoral thesis, he learned that he had leukemia. Though a terminal diagnosis, he kept on and received his PhD in 1975 before passing away. Phong shading

produced great results, but was quite slow to render. Another Utah graduate student, Jim Blinn, used Phong's work to figure out a faster way. Both Phong and Blinn shaders are in common use today in most 3D applications.

Other important advances to come out of the University of Utah included texture mapping, shadows, antialiasing, facial animation, and many more. The famous Utah teapot (Figure 1.5) was first modeled by Martin Newell. Its primitive is still found today in 3D applications, because the simple round shape with the elements of the spout and handle make it ideal for testing lighting and maps.

Among the other big Utah names was graduate student Ed Catmull. Catmull had long wanted to go into animation, but found out he couldn't really draw well. But he did know mathematics, so he studied physics and computer science at the University of Utah and after a short stint in the military, returned for graduate school. After he gained his PhD in 1974, he was recruited to the Computer Graphics Laboratory (CGL) in New York. The efforts of his team there led to further advancements in animation and texturing, and attracted the attention of George Lucas, the visionary behind *Star Wars*.

Lucas had become interested in using computer graphics, and set about creating a computer graphics division within his special effects production house, Industrial Light and Magic (ILM). He recruited Catmull and others from CGL to form this department, where they created the first fully computer-generated animation that would appear in a feature film: the Genesis Effect simulation sequence from *Star Trek II: The Wrath of Kahn* was released in 1982. Some of the advances seen in the animation were particle effects and motion blur.

Figure 1.5 The Utah teapot with Phong shading.

That same year, Disney's *Tron* came out. Disney had used the services of three computer graphics companies to create *Tron*. But the innovative animation and compositing of live footage with it could not prop up the storyline. *Tron* tanked at the box offices.

Seeing this, and noting how expensive computer graphics were (the power alone for the supercomputers needed at the time could be in the hundreds of dollars per day), Lucas decided to drop the computer graphics division. Still passionate about being able to create animations with computers, Catmull kept the department together and began to look for someone who could finance them. Steve Jobs, founder of Apple Computers, took on sponsorship, and that led to the birth of Pixar Animation Studios.

Though animated computer graphics were thriving in areas such as advertising and opening credits for television shows, *Tron*'s failure frightened most producers away from using computer graphics in movies. One exception was *The Last Starfighter*, produced through the turmoil of those years and released in 1985. Unlike any other movie that was set in space before then, no physical models were used for the spaceships. They were 3D rendered models. In this production, using computers saved time and ended up saving money compared to the traditional techniques. Critics gave *The Last Starfighter* above-average reviews, and it succeeded at the box office, leading to a revival of interest of filmmakers in using computer graphics for movies. One of the first milestones from this era was *The Abyss*, which in 1989 had the first convincing 3D graphics creature in the form of a pseudopod with a face on it. Terminator II pushed it further with a whole human model that moved naturally. By the time of *Jurassic Park* (1993) and *Walking with Dinosaurs* (1999), the state of the art had progressed to having fully realized computer-generated dinosaurs interacting with their environment.

That same year, *Babylon 5* brought 3D graphics technology to television serials, coping with the lower budget and rapid production cycles. This had become possible because of advances in both computers and software, and some sleight of hand. In the first couple of seasons, they were unable to render the spacecraft the entire way around, because of the memory load. *Babylon 5* computer graphics would be produced using networks of personal computers (PCs) to render. With this jump in technology, computer graphics had become less expensive than many traditional special effects. This continued to spread through all aspects of the feature film industry. Computer-generated 3D graphics were brought to cartoons as well. *Reboot* was the first of these 3D cartoons to air, in 1994. Production on it started in 1988

and it was purposely set as a world within a computer mainframe because at the time, they could only create blocky looking models.

In 1995, Pixar came to maturity as a film production company with the release of *Toy Story*. Equipment and experience allowed them to make much smoother models, but they still animated mostly inorganic surfaces with the toys. Creating realistic organic surfaces still had many challenges to overcome including complex surfaces, the changing shape of those surfaces when a character or creature moves, hair, and the translucency of skin. *Jurassic Park* had overcome some of these problems simply by the sparseness of the actual computer graphics: only a total of six minutes was computer generated and in none of that were the dinosaurs ever seen really close up.

In 2001, *Final Fantasy: The Spirits Within* attempted to create such a fully realized human CGI character that they would use her as a star in later films. Though most of the capabilities were there, both movement and problems with realistic skin contributed to the uncanny valley, a place where characters are almost human but not quite, making the audience uncomfortable. Much of this continues to be a problem of animation: getting the character to move right. One of the developments to help with this has been motion capture technology.

Several movies use motion capture to bring realistic movement into their characters. The best examples are usually not fully human, such as Gollum in *Lord of the Rings: The Two Towers* (2002) and Davy Jones in *Pirates of the Caribbean: Dead Man's Chest* (2006), but technology is improving. Of special concern has been the subtle facial expressions that give us our humanity because of our ability to decode emotion on the human face from even tiny movements. A big improvement in this ability was seen in *The Curious Case of Benjamin Button* (2008).

One of the biggest movies of 2009 was *Avatar*, in which the main characters were entirely computer generated either some or all of the time and which used sophisticated motion capture techniques. Once again, these characters were not completely human but were entirely convincing.

Not only did *Avatar* feature incredible characters; most of its environment was computer generated as well, allowing incredible effects such as glowing plants and floating mountains to increase the power of the natural setting. Using computer graphics to create set extensions or even entire sets is becoming a more common practice. Another example is the completely artificial environment of *Tron: Legacy*, in 2010. With hardware and software advances, including digital cameras and editing

software, much of the technology has become more efficient and less expensive to use than traditional methods of on-location shooting. It is becoming more common to film in front of green screens even for those films that are not special effects focused.

Much of the programming that created the first computer-generated effects seen in movies was completed in-house. Even with the off-the-shelf software for creating 3D animations that is available today, studios, artists, and researchers often need to add capabilities through other programs they develop. Many of the advances in software are due to software companies working with studios to give them what they need or acquiring plugins that studios have created. These leading-edge technologies are finding their way more and more quickly into the personal computers of 3D art enthusiasts and students, who can now create their own computed-generated artwork from home.

From Institutions to Homes

Two developments had to occur before users could create 3D computer graphics at home. One was the development of hardware, and the second was the development of software.

The first computers to make it into the home were actually console games. More sophisticated than their house-sized predecessors, these were made small and portable by using hard-wired programming in the form of cartridges. The first console, the Magnavox Odyssey, had 28 games. As far as graphics are concerned, it could only produce white lines and dots. Game backgrounds took the form of plastic overlays that were placed on the television screen. The first commercial release of Odyssey was in 1972, about the same time as Evans, Sutherland, and their graduate students at Utah were pioneering 3D graphics.

Through several industry stumbles, game consoles continued to evolve and thrive in the home market. At the same time, business computers were also improving, with a push to bring these minicomputers into the home. These home/game computers of the early 1980s were aimed at making both parents and kids happy: you could play games or run educational software or even program in the BASIC language on them. They connected to televisions, but now the graphics were more exciting, with up to 256 colors from Atari 400 and 800 models (early 1980s), although the images were still very pixelated because of the low resolutions used.

Gaming capabilities would continue to push personal and home computing technology forward, but art was also a part of

this development. Even the early computers such as the Atari 400/800, Apple II, and Commodore 64 had drawing programs, as did the IBM PCs. For better graphics, not only was color necessary, but so were higher resolutions and the ability to perform complicated graphics calculations quickly.

In 1986, Eric Graham created a 3D animation on his Amiga computer, writing a ray-tracing renderer in the process. *The Juggler* featured a man made up of spheres, juggling three reflective spheres. It was 24 frames long and looped so it could play continuously. It even included a little sound when a sphere was caught. Up until this time, people believed that a mainframe computer was required to do any kind of ray tracing. He showed it to Commodore, who believed he had written it on a mainframe until he sent the source code so they could run it themselves on an Amiga. They immediately purchased rights to use it in their promotional material and ran an article about it in their magazine. It generated so much interest that they asked Graham to turn his home-made program into something more complete that could be sold commercially. Thus was born Sculpt3D in 1987, the first 3D graphics software that could be run on a home computer. It had many features common in today's applications, including primitive 3D shapes, more than one view of the object, a camera (called the Observer), and lights (Figure 1.6). 3D models were made of triangles, of which only a few hundred could be handled by the computer. For long rendering tasks, a cardboard stop sign was provided with the software that read, "Caution: Raytrace in progress".

Amiga computers cost around $3000, meaning that only those with a special interest in computers were likely to invest. It was
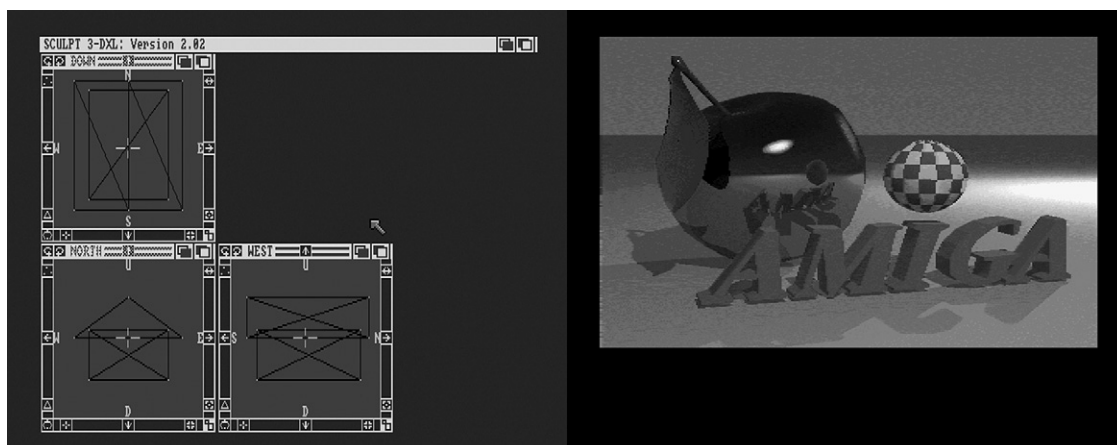

Figure 1.6 Screenshot from David Watts' website, http://www.classicamiga.com (used with permission).

the 1990s before the average person could afford a machine powerful enough to create their own 3D graphics at home. At that point, most commercial programs they were likely to encounter were still in the thousands of dollars, generally used by those who did freelance work. However, computer programmers have a tendency to code for the pure joy of it and share their work. All of the algorithms needed to create 3D programs were public knowledge, and several people programmed freeware to pass around. POV-Ray is a prominent example of these early open-source 3D applications, and is still in existence today.

This trend for free programs continued to go strong. Blender started as an in-house application, was briefly released for free online and sold for commercial use, and then became completely free and open source in 2002 through the Blender Foundation. It is currently the most powerful of all the free 3D toolsets available.

For a few years, only very expensive programs or free programs were available, both of them with interfaces that tended to have steep learning curves. But starting in the early 2000s, with computers common in middle-class households, a new class of 3D software began to be released, with simple interfaces and prices comparable to the purchase of a couple of games. Communities grew up around this new gratifying pastime, supporting other artists.

With this upswing of use, a new kind of commodity came into being: 3D models and other assets, including entire scenes. Modeling is a skill that not all artists enjoy. Many hobbyists just wanted to arrange and pose models in scenes. They could go to websites such as Turbosquid, Daz Productions, Renderosity, and Cornuciopia3D, which provided a market for the communities and activities such as contests. Because of their ability to make money through the sale of content, much of the software that used to cost a few hundred dollars is now free. Part of this content has been tutorials, many of which are free themselves. Many professional artists of today have been mentored in the online communities through these tutorials and personal feedback by professionals.

Modelers are also starting to have another outlet. The advent of 3D printers has allowed the distribution of their creations in physical form.

Because of the increase in computer and console games, and the need for effects and visualization in advertisement as well as television and film, demand for 3D artists and the tools they use has risen. This has led to a lowering of prices for professional-level software, so that now it is within the range of the serious hobbyist. Hardware is also continuing to grow in power as well as

shrink in size and price. For those with a computer and internet access, it is an art form now more easily available than paints and canvas or clay.

3D art on computers has come a long way from being available only to those who could hard code machines. These days, children as young as five are playing with it and older people who could barely draw stick figures can bring to life the beauty that has been in their imagination. Solo artists have already been able to create short animations on their own. Perhaps in the near future, individuals may be able to make entire movies all by themselves.