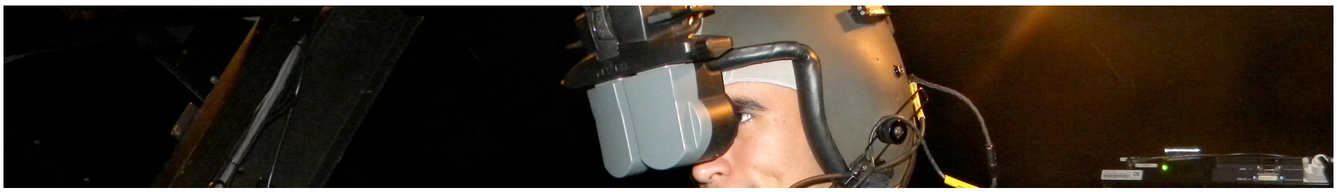
17.1 Virtual Reality

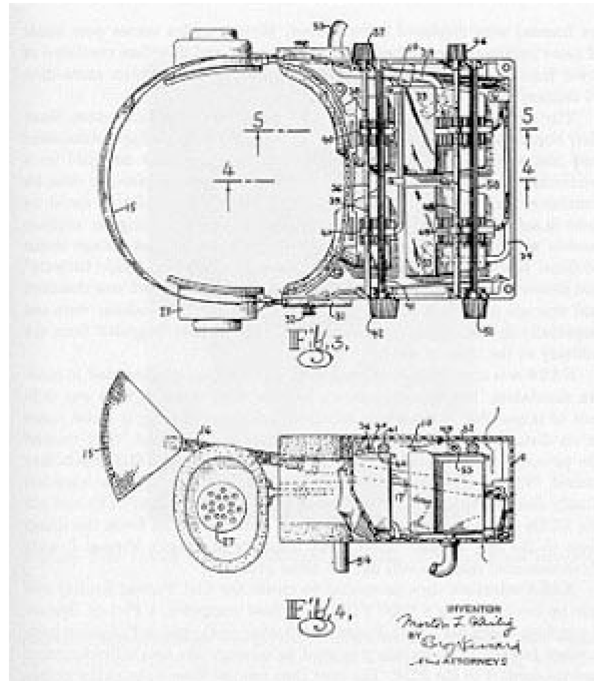


During the late 1980s and 1990s, virtual reality was touted as a new and emerging application that promised to revolutionize interactivity and man-computer interfaces. In fact, VR is much older than the 1980s, older or nearly as old as the entire computer graphics field itself.

The Sensorama Machine was invented in 1957

In 1956, Morton Heilig began designing the first multi-sensory virtual experiences. Resembling one of today's arcade machines, the Sensorama combined projected film, audio, vibration, wind, and odors, all designed to make the user feel as if he were actually in the film rather than simply watching it. Patented in 1961, the Sensorama placed the viewer in a one person theater and, for a quarter, the viewer could experience one of five two-minute 3D full color films with ancillary sensations of motion, sound, wind in the face and smells. The five "experiences" included a motorcycle ride through New York, a bicycle ride, a ride on a dune buggy, a helicopter ride over Century city in 1960 and a dance by a belly dancer. Since real-time computer graphics were many years away, the entire experience was prerecorded, and played back for the user.

Heilig also patented an idea for a device that some consider the first Head-Mounted Display (HMD). He first proposed the idea in 1960 and applied for a patent in 1962. It used wide field of view optics to view 3D photographic slides, and had stereo sound and an "odor generator". He later proposed an idea for an immersive theater that would permit the projection of three dimensional images without requiring the viewer to wear special glasses or other devices. The audience would be seated in tiers and the seats would be connected with the film track to provide not only stereographic sound, but also the sensation of motion. Smells would be created by injecting various odors into the air conditioning system. Unfortunately, Heilig's "full experience" theater was never built.



Helig's HMD

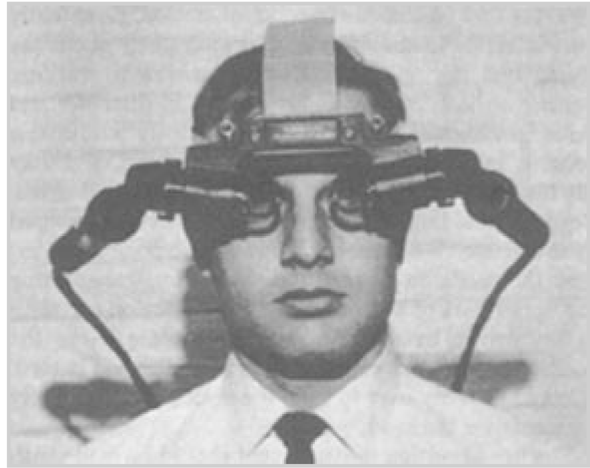
Comeau and Bryan, employees of Philco Corporation, constructed the first actual fabricated head-mounted display in 1961. Their system, called Headsight featured a single CRT element attached to the helmet and a magnetic tracking system to determine the direction of the head. The HMD was designed to be used with a remote controlled closed circuit video system for remotely viewing dangerous situations. While these devices contributed intellectual ideas for display and virtual experiences, the computer and image generation were yet to be integrated.

The field we now know as **virtual reality** (VR), a highly multidisciplinary field of computing, emerged from research on three-dimensional interactive graphics and vehicle simulation in the 1960s and 1970s. Not surprisingly, the development of the discipline can be traced to early work at MIT and Utah and none other than Ivan Sutherland.

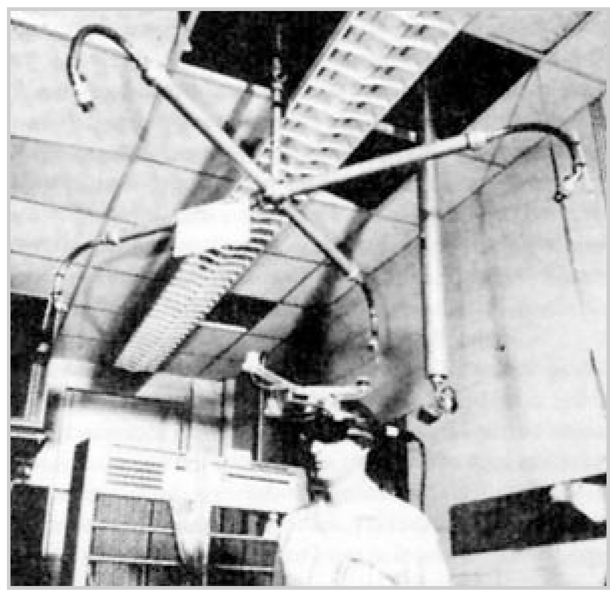
Two of the necessary foundations of VR were being addressed at MIT by Larry Roberts and Sutherland, among others. The first necessary practical contributions included the research and development that allowed the CRT to serve as an affordable and effective device on which to create a computer generated image, and the interactive interfaces that showed that a user could interact with the CRT image to accomplish some desired task.

As we mentioned in Chapter 4, Roberts wrote the first algorithm to eliminate hidden or obscured surfaces from a perspective picture in 1963. His solutions to this and other related problems prompted attempts over the next decade to find faster algorithms for generating hidden surfaces. Among the important activities of Sutherland and his colleagues and students at the University of Utah were efforts to develop fast algorithms for removing **hidden surfaces** from 3D graphics images, a problem identified as a key computational bottleneck.

Students of the Utah program made two important contributions in this field, including an area search method by Warnock (1969) and a scan-line algorithm that was developed by Watkins (1970) and developed into a hardware system. One of the most important breakthroughs was Henri Gouraud's development of a simple scheme for continuous shading (1971). Unlike polygonal shading, in which an entire polygon (a standard surface representation) was a single level of gray, Gouraud's scheme involved interpolation between points on a surface to describe **continuous shading** across a single polygon, thus achieving a closer approximation of reality. The effect made a surface composed of discrete polygons appear to be continuous. This ability is essential in the process of generating the quality of visual images necessary to present a believable VR environment.



HMD images from Sutherland's AFIPS and FJCC papers



The mechanical head position sensor

The ultrasonic head position sensor

Each of these efforts provided part of the foundation for early attempts at addressing the concept of a virtual environment. The other part was the earlier work that resulted in the commercial development of the important head mounted display. The Ultimate Display was created by Sutherland in 1965. What made it so important was the fact that it had a **stereoscopic display** (one CRT element for each eye). The HMD had a mechanical tracking system, and later Sutherland experimented with an ultrasonic tracker. As was discussed in the National Academy of Sciences report *Funding a Revolution: Government Support for Computing Research*, the HMD was the central research component of the emerging field. The following text, from this report, outlines the important work in this area:

> Work on **head-mounted displays** (HMDs) illustrates the synergy between the applications-focused environments of industry and government-funded (both military and civilian) projects and the fundamental research focus of university work that spills across disciplinary boundaries. Work on head-mounted displays benefited from extensive interaction and cross-fertilization of ideas among federally funded, mission-oriented military projects and contracts as well as private-sector initiatives. The players included NASA Ames, Armstrong Aerospace Medical Research Laboratory of the Air Force, Wright-Patterson Air Force Base, and, more recently, DOD programs on modeling and simulation, such as the Synthetic Theater of War program. Each of these projects generated a stream of published papers, technical reports, software (some of which became commercially available), computer-animated films, and even hardware that was accessible to other graphics researchers. Other important ideas for the head-mounted display came from Knowlton and Schroeder’s work at Bell Laboratories, the approach to real-time hidden-line solutions by the MAGI group, and the GE simulator project (Sutherland, 1968).
>
> Early work on head-mounted displays took place at Bell Helicopter Company. Designed to be worn by pilots, the Bell display received input from a servo-controlled infrared camera, which was mounted on the bottom of a helicopter. The camera moved as the pilot’s head moved, and the pilot’s field of view was the same as the camera’s. This system was intended to give military helicopter pilots the capability to land at night in rough terrain. The helicopter experiments demonstrated that a human could become totally immersed in a remote environment through the eyes of a camera.
>
> The power of this immersive technology was demonstrated in an example cited by Sutherland (1968). A camera was mounted on the roof of a building, with its field of view focused on two persons playing catch. The head-mounted display was worn by a viewer inside the building, who followed the motion of the ball, moving the camera by using head movements. Suddenly, the ball was thrown at the camera (on the roof), and the viewer (inside the building) ducked. When the camera panned the horizon, the viewer reported seeing a

panoramic skyline. When the camera looked down to reveal that it was "standing" on a plank extended off the roof of the building, the viewer panicked!

In 1966, Ivan Sutherland moved from ARPA to Harvard University as an associate professor in applied mathematics. At ARPA, Sutherland had helped implement J.C.R. Licklider's vision of human-computer interaction, and he returned to academe to pursue his own efforts to extend human capabilities. Sutherland and a student, Robert Sproull, turned the "remote reality" vision systems of the Bell Helicopter project into VR by replacing the camera with computer-generated images.(Other head-mounted display projects using a television camera system were undertaken by Philco in the early 1960s, as discussed by Ellis in 1996.) The first such computer environment was no more than a wire-frame room with the cardinal directions–north, south, east, and west–initialed on the walls. The viewer could "enter" the room by way of the "west" door and turn to look out windows in the other three directions. What was then called the head-mounted display later became known as VR.

Sutherland's experiments built on the network of personal and professional contacts he had developed at MIT and ARPA. Funding for Sutherland's project came from a variety of military, academic, and industry sources. The Central Intelligence Agency provided $80,000, and additional funding was provided by ARPA, the Office of Naval Research, and Bell Laboratories. Equipment was provided by Bell Helicopter. A PDP-1 computer was provided by the Air Force and an ultrasonic head-position acoustic sensor was provided by MIT Lincoln Laboratory, also under an ARPA contract.

Sutherland outlined a number of forms of interactive graphics that later became popular, including **augmented reality**, in which synthetic, computer-generated images are superimposed on a realistic image of a scene. He used this form of VR in attempting a practical medical application of the head-mounted display. The first published research project deploying the 3D display addressed problems of representing hemodynamic flow in models of prosthetic heart valves. The idea was to generate the results of calculations involving physical laws of fluid mechanics and a variety of numerical analysis techniques to generate a synthetic object that one could walk toward and move into or around (Greenfield, Harvey, Donald Vickers, Ivan Sutherland, Willem Kolff, et al. 1971. "Moving Computer Graphic Images Seen from Inside the Vascular System," Transactions of the American Society of Artificial Internal Organs, 17:381-385.)

As Sutherland later recalled, there was clearly no chance of immediately realizing his initial vision for the head-mounted display. Still, he viewed the project as an important "attention focuser" that "defined a set of problems that motivated people for a number of years." Even though VR was impossible at the time, it provided "a reason to go forward and push the technology as hard as you could. Spin-offs from that kind of pursuit are its greatest value." ?(Ivan Sutherland in Virtual Reality Before It Had That Name, a videotaped lecture before the Bay Area Computer History Association.)

http://www.nap.edu/readingroom/books/far/contents.html

VR is one of those fields that Ivan Sutherland would christen "holy grails" – fields involving the synthesis of many separate, expensive, and risky lines of innovation in a future too far distant and with returns too unpredictable to justify the long-term investment.

Sutherland (1965) The Ultimate Display
The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked.

The actual term "Virtual Reality" is attributed to Jaron Lanier of VPL in 1986 in a conversation regarding the work of Scott Fisher. Fisher, of NASA Ames, had been referring to the field as "Virtual Environments".

Myron Krueger labeled the activity "Artificial Reality" in 1983, the title of his book, and a year later, William Gibson coined the term "Cyberspace" in his book Neuromancer.
https://www.theguardian.com/books/2011/sep/22/william-gibson-beyond-cyberspace

> Virtual Reality — a three dimensional, computer generated simulation in which one can navigate around, interact with, and be immersed in another environment
> (John Briggs – The Futurist)

> Virtual Reality — the use of computer technology to create the effect of an interactive three-dimensional world in which the objects have a sense of spatial presence.
> (Steve Bryson – NASA Ames)

Heilig's head mounted display from his patent application
http://www.mortonheilig.com/TelesphereMask.pdf

"The Ultimate Display," Sutherland, I.E., Proceedings of IFIPS Congress 1965, New York, May 1965, Vol. 2, pp. 506-508. ?(reprinted in Wired's "Beyond the Beyond")

Sutherland, Ivan E. 1968. "A Head-Mounted Three Dimensional Display," pp. 757-764 in Proceedings of the Fall Joint Computer Conference. AFIPS Press, Montvale, N.J.

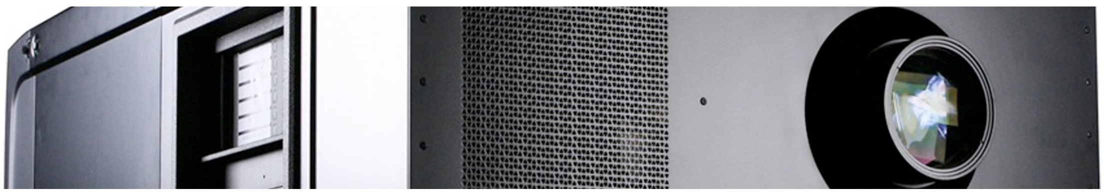
Ellis, S. What are Virtual Environments? IEEE Computer Graphics & Applications.

Ellis, S. (1996). Virtual Environments and Environmental Instruments, In Simulated and Virtual Realities, Taylor & Francis: 1996.

Furness, T. 1986. The super cockpit and its human factors challenges. Proceedings of the Human Factors Society. 30, 48-52.

An interview with Tom Furness: 50 years of VR with Tom Furness: The Super Cockpit, Virtual Retinal Display, HIT Lab, & Virtual World Society

17.2 Virtual Projection



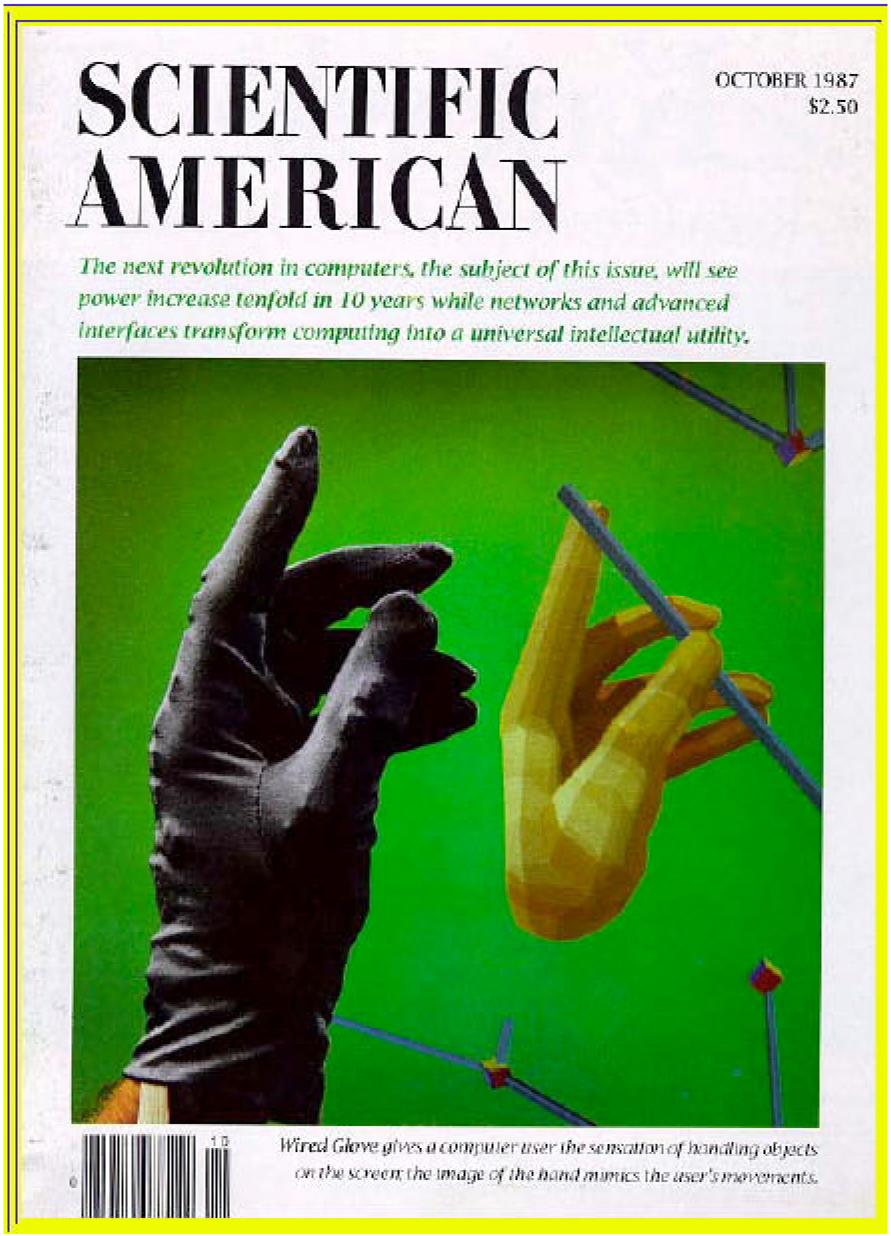
Around the same time, Thomas A. Furness, a scientist at Wright-Patterson Air Force Base in Ohio, began to work on better cockpit technology for pilots. “I was trying to solve problems of how humans interact with very complex machines,” said Furness. “In this case, I was concerned with fighter-airplane cockpits.” Aircraft were becoming so complicated that the amount of information a fighter pilot had to assimilate from the cockpit’s instruments and command communications had become overwhelming. The solution was a cockpit that fed 3-D sensory information directly to the pilot, who could then fly by nodding and pointing his way through a simulated landscape below. Today, such technology is critical for air wars that are waged mainly at night, since virtual reality replaces what a pilot can’t see with his eyes.

“To design a virtual cockpit, we created a very wide field of vision,” said Furness, who now directs the *University of Washington’s Human Interface Technology (HIT) Lab*. “About 120 degrees of view on the horizontal as opposed to 60 degrees.” In September of 1981, Furness and his team turned on the virtual-cockpit projector for the first time. “I felt like Alexander Graham Bell, demonstrating the telephone,” recalled Furness. “We had no idea of the full effect of a wide-angle view display. Until then, we had been on the outside, looking at a picture. Suddenly, it was as if someone reached out and pulled us inside.”

The Human Interface Technology Laboratory is a research and development lab in virtual interface technology. HITL was established in 1989 by the Washington Technology Center (WTC) to transform virtual environment concepts and early research into practical, market-driven products and processes. HITL research strengths include interface hardware, virtual environments software, and human factors.

While multi-million dollar military systems have used head-mounted displays in the years since Sutherland’s work, the notion of a personal virtual environment system as a general purpose user-computer interface was generally neglected for almost twenty years. Beginning in 1984, Michael McGreevy created the first of NASA’s virtual environment workstations (also known as personal simulators and Virtual Reality systems) for use in human-computer interface research. With contractors Jim Humphries, Saim Eriskin and Joe Deardon, he designed and built the Virtual Visual Environment Display system (VIVED, pronounced “vivid”), the first low-cost, wide field-of-view, stereo, head-tracked, head-mounted display. Clones of this design, and extensions of it, are still predominant in the VR market.

Next, McGreevy configured the workstation hardware: a Digital Equipment Corporation PDP-11/40 computer, an Evans and Sutherland Picture System 2 with two 19″ monitors, a Polhemus head and hand tracker, video cameras, custom video circuitry, and the VIVED system. With Amy Wu, McGreevy wrote the software for NASA's first virtual environment workstation. The first demonstrations of this Virtual Reality system at NASA were conducted by McGreevy in early 1985 for local researchers and managers, as well as visitors from universities, industry, and the military. Since that time, over two dozen technical contributors at NASA Ames have worked to develop Virtual Reality for applications including planetary terrain exploration, computational fluid dynamics, and space station telerobotics. In October 1987 Scientific American featured VIVED – a minimal system, but one which demonstrated that a cheap immersive system was possible.



Scientific American issue on VR

17.3 Hypermedia and Art

In 1978 Andy Lippman and group of researchers from MIT (including Michael Naimark and Scott Fisher) developed what is probably the first true hypermedia system. The Aspen Movie Map was what they termed “a surrogate travel application” that allowed the user to enjoy a simulated ride through the city of Aspen, Colorado.

Scene from Aspen Movie Map

The system used a set of videodisks containing photographs of all the streets of Aspen. Recording was done by means of four cameras, each pointing in a different direction, and mounted on a truck. Photo’s were taken every 3 meters. The user could always continue straight ahead, back up, move left or right.

Each photo was linked to the other relevant photos for supporting these movements. In theory the system could display 30 images per second, simulating a speed of 200 mph (330 km/h). The system was artificially slowed down to at most 10 images per second, or 68 mph (110 km/h).

Movie 17.1 Aspen Map example

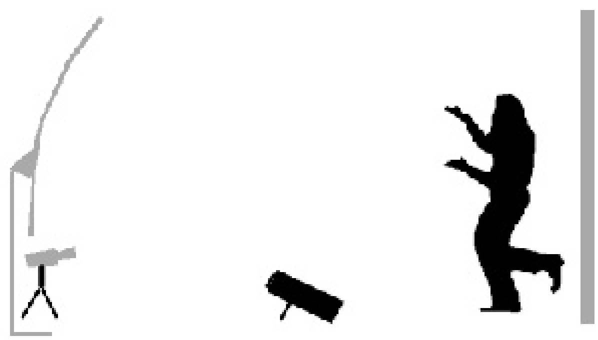
https://osu.pb.unizin.org/graphicshistory/wp-content/uploads/sites/45/2017/04/aspen-map-1.m4v

To make the demo more lively, the user could stop in front of some of the major buildings of Aspen and walk inside. Many buildings had also been filmed inside for the videodisk. The system used two screens, a vertical one for the video and a horizontal one that showed the street map of Aspen. The user could point to a spot on the map and jump directly to it instead of finding her way through the city.

Working on human-computer interaction at the University of Wisconsin in the late 1960s and early 1970s, **Myron Krueger** experimented and developed several computer art projects.

Scene from VIDEOPLACE

After several other experiments, VIDEOPLACE was created. The computer had control over the relationship between the participant's image and the objects in the graphic scene, and it could coordinate the movement of a graphic object with the actions of the participant. While gravity affected the physical body, it didn't control or confine the image which could float, if needed. A series of simulations could be programmed based on any action. VIDEOPLACE offered over 50 compositions and interactions (including Critter, Individual Medley, Fractal, Finger Painting, Digital Drawing, Body Surfacing, Replay, and others).

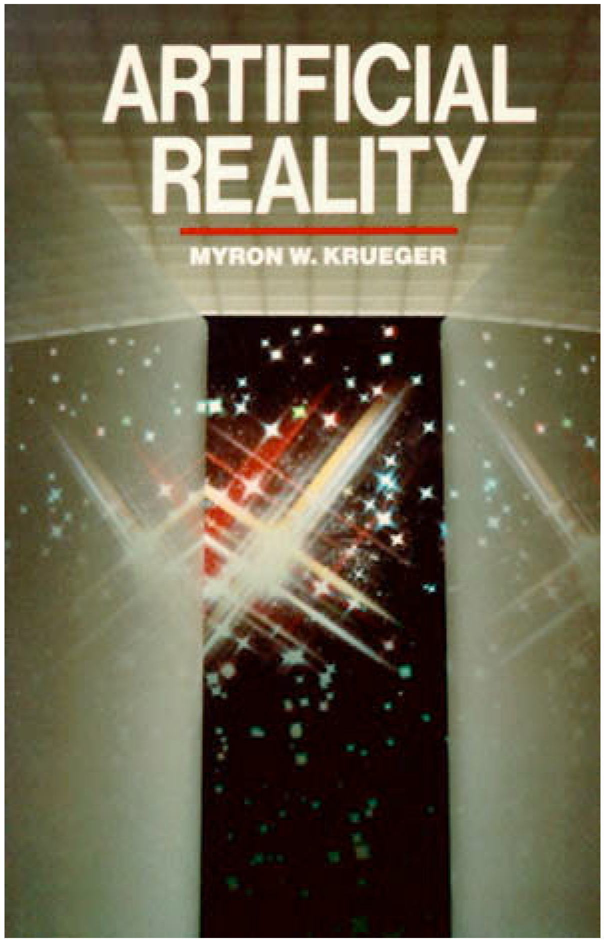


VIDEOPLACE configuration

In the installation, the participant faced a video-projection screen while the screen behind him was backlit to produce high contrast images for the camera (in front of the projection screen), allowing the computer to distinguish the participant from the background.

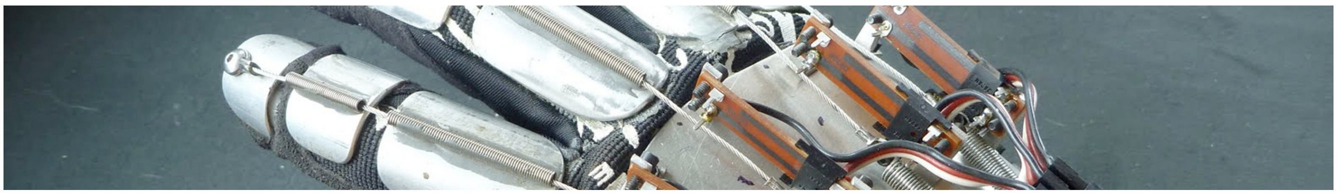
The participant's image was then digitized to create silhouettes which were analyzed by specialized processors. The processors could analyze the image's posture, rate of movement, and its relationship to other graphic objects in the system. They could then react to the movement of the participant and create a series of responses, either visual or auditory reactions. Two or more environments could also be linked.

In 1983 Krueger published his now-famous book Artificial Reality, which was updated in 1990.

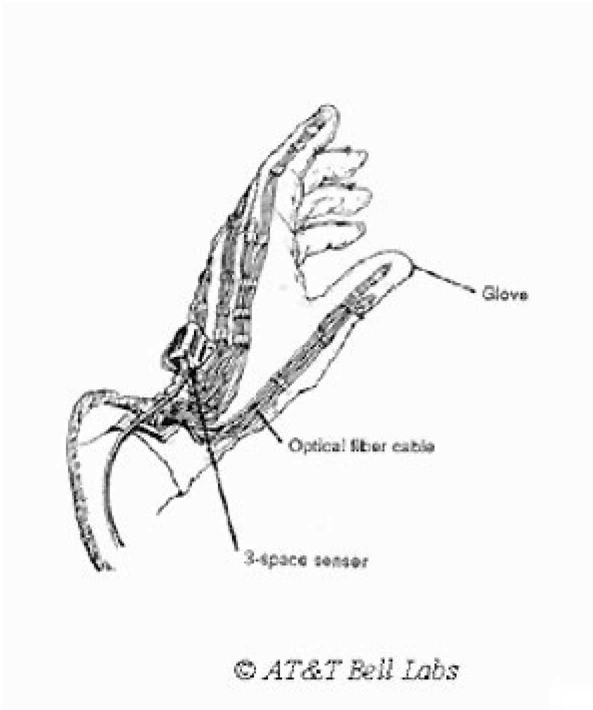


Krueger, M.W., "Artificial Reality" ?Reading, Mass., Addison Wesley, 1983

17.4 Interaction



One of the first instrumented gloves described in the literature was the Sayre Glove, developed by Tom Defanti and Daniel Sandin in a 1977 project for the National Endowment for the Arts. (In 1962 Uttal from IBM patented a glove for teaching touch typing, but it was not general purpose enough to be used in VR applications.) The Sayre glove used light based sensors with flexible tubes with a light source at one end and a photocell at the other. As the fingers were bent, the amount of light that hit the photocells varied, thus providing a measure of finger flexion. The glove, based on an idea by colleague Rich Sayre, was an inexpensive, lightweight glove that could monitor hand movements by measuring the metacarpophalangeal joints of the hand. It provided an effective method for multidimensional control, such as mimicking a set of sliders.



Grimes Glove

The first widely recognized device for measuring hand positions was developed by Dr. Gary Grimes at Bell Labs. Patented in 1983, Grimes' Digital Data Entry Glove had finger flex sensors, tactile sensors at the fingertips, orientation sensing and wrist-positioning sensors. The positions of the sensors themselves were changeable. It was intended for creating "alpha-numeric" characters by examining hand positions. It was primarily designed as an alternative to keyboards, but it also proved to be effective as a tool for allowing non-vocal users to "finger-spell" words using such a system.

This was soon followed by an optical glove, which was later to become the VPL DataGlove. This glove was built by Thomas Zimmerman, who also patented the optical flex sensors used by the gloves. Like the Sayre glove, these sensors had fibre optic cables with a light at one end, and a photodiode at the other. Zimmerman had also built a simplified version, called the Z-glove, which he had attached to his Commodore 64. This device measured the angles of each of the first two knuckles of the fingers using the fibre optic devices, and was usually combined with a Polhemus tracking device. Some also had abduction measurements. This was really the first commercially available glove, however at about $9000 was prohibitively expensive.

The Dataglove (originally developed by VPL Research) was a neoprene fabric glove with two fiber optic loops on each finger. Each loop was dedicated to one knuckle, which occasionally caused a problem. If a user had extra large or small hands, the loops would not correspond very well to the actual knuckle position and the user was not able to produce very accurate gestures. At one end of each loop was an LED and at the other end a photosensor. The fiber optic cable had small cuts along its length. When the user bent a finger, light escaped from the fiber optic cable through these cuts. The amount of light reaching the photosensor was measured and converted into a measure of how much the finger was bent. The Dataglove required recalibration for each user, and often for the same user over a session's duration. Coupled with a problem of fatigue (because of the stiffness) it failed to reach the market penetration that was anticipated.

VPL DataGlove

Source: NASA

Again from the National Academy of Sciences report:

> The basic technologies developed through VR research have been applied in a variety of ways over the last several decades. One line of work led to applications of VR in biochemistry and medicine. This work began in the 1960s at the University of North Carolina (UNC) at Chapel Hill. The effort was launched by **Frederick Brooks**, who was inspired by Sutherland's vision of the ultimate display as enabling a user to see, hear, and feel in the virtual world. Flight simulators had incorporated sound and haptic feedback for some time. Brooks selected molecular graphics as the principal driving problem of his program. The goal of Project GROPE, started by Brooks in 1967, was to develop a haptic interface for molecular forces. The idea was that, if the force constraints on particular molecular combinations could be "felt," then the designer of molecules could more quickly identify combinations of structures that could dock with one another.

The GROPE force feedback system

> GROPE-I was a 2D system for continuous force fields. GROPE II was expanded to a full six-dimensional (6D) system with three forces and three torques. The computer available for GROPE II in 1976 could produce forces in real time only for very simple world models — a table top; seven child's blocks; and the tongs of the Argonne Remote Manipulator (ARM), a large mechanical device. For real-time evaluation of molecular forces, Brooks and his team estimated that 100 times more computing power would be necessary. After building and testing the GROPE II system, the ARM was mothballed and the project was put on hold for about a decade until 1986, when VAX computers became available. GROPE III, completed in 1988, was a full 6D system. Brooks and his students then went on to build a full-molecular-force-field evaluator and, with 12 experienced biochemists, tested it in GROPE IIIB experiments in 1990. In these experiments, the users changed the structure of a drug molecule to get the best fit to an active site by manipulating up to 12 twistable bonds.

The test results on haptic visualization were extremely promising. The subjects saw the haptic display as a fast way to test many hypotheses in a short time and set up and guide batch computations. The greatest promise of the technique, however, was not in saving time but in improving situational awareness. Chemists using the method reported better comprehension of the force fields in the active site and of exactly why each particular candidate drug docked well or poorly. Based on this improved grasp of the problem, users could form new hypotheses and ideas for new candidate drugs.

The Docker haptic feedback system

The docking station is only one of the projects pursued by Brooks's group at the UNC Graphics Laboratory. The virtual world envisioned by Sutherland would enable scientists or engineers to become immersed in the world rather than simply view a mathematical abstraction through a window from outside. The UNC group has pursued this idea through the development of what Brooks calls "intelligence-amplifying systems." Virtual worlds are a subclass of intelligence-amplifying systems, which are expert systems that tie the mind in with the computer, rather than simply substitute a computer for a human.

In 1970, Brooks's laboratory was designated as an NIH Research Resource in Molecular Graphics, with the goal of developing virtual worlds of technology to help biochemists and molecular biologists visualize and understand their data and models. During the 1990s, UNC has collaborated with industry sponsors such as HP to develop new architectures incorporating 3D graphics and volume-rendering capabilities into desktop computers (HP later decided not to commercialize the technology).

Since 1985, NSF funding has enabled UNC to pursue the Pixel-Planes project, with the goal of constructing an image-generation system capable of rendering 1.8 million polygons per second and a head-mounted display system with a lagtime under 50 milliseconds. This project is connected with GROPE and a large software project for mathematical modeling of molecules, human anatomy, and architecture. It is also linked to VISTANET, in which UNC and several collaborators are testing high-speed network technology for joining a radiologist who is planning cancer therapy with a virtual world system in his clinic, a Cray supercomputer at the North Carolina Supercomputer Center, and the Pixel-Planes graphics engine in Brooks's laboratory.

With Pixel-Planes and the new generation of head-mounted displays, the UNC group has constructed a prototype system that enables the notions explored in GROPE to be transformed into a wearable virtual-world workstation. For example, instead of viewing a drug molecule through a window on a large screen, the chemist wearing a head-mounted display sits at a computer workstation with the molecule suspended in front of him in space. The chemist can pick it up, examine it from all sides, even zoom into remote interior dimensions of the molecule. Instead of an ARM gripper, the chemist wears a force-feedback exoskeleton that enables the right hand to "feel" the spring forces of the molecule being warped and shaped by the left hand.

In a similar use of this technology, a surgeon can work on a simulation of a delicate procedure to be performed remotely. A variation on and modification of the approach taken in the GROPE project is being pursued by UNC medical researcher James Chung, who is designing virtual-world interfaces for radiology. One approach is data fusion, in which a physician wearing a head-mounted display in an examination room could, for example, view a fetus by ultrasound imaging superimposed and projected in 3D by a workstation. The physician would see these data fused with the body of the patient. In related experiments with MRI and CT scan data fusion, a surgeon has been able to plan localized radiation treatment of a tumor.

Movie 17.2 UNC Fetal Surgery VR

https://osu.pb.unizin.org/graphicshistory/wp-content/uploads/sites/45/2017/04/fetal-surgery-1.m4v

The term **Haptic** refers to our sense of touch, and consists of input via mechano-receptors in the skin, neurons which convey information about texture, and the sense of proprioception, which interprets information about the size, weight and shape of objects objects via feedback from muscles and tendons in the hands and other limbs. Haptic Feedback refers to the way we attempt to simulate this haptic sense in our virtual environment, by assigning physical properties to the virtual objects we encounter and designing devices to relay these properties back to the user. Haptic feedback devices use vibrators, air bladders, heat/cold materials, and Titanium-Nickel alloy transducers which provide a minimal sense of touch.

UNC uses a ceiling mounted ARM (Argonne remote manipulator) to test receptor sites for a drug molecule. The researcher, in virtual reality, grasps the drug molecule, and holds it up to potential receptor sites. Good receptor sites attract the drug, while poor ones repel it. Using a force feedback system, scientists can easily feel where the drug can and should go.
http://www.cs.unc.edu/Research/

In 1979, F.H. Raab and others described the technology behind what has been one of the most widely utilized tracking systems in the VR world — the Polhemus. This six degrees of freedom electromagnetic position tracking was based on the application of orthogonal electromagnetic fields. Two varieties of electromagnetic position trackers were implemented — one used alternating current (AC) to generate the magnetic field, and the other used direct current (DC).

In the Polhemus AC system, mutually perpendicular emitter coils sequentially generated AC magnetic fields that induced currents in the receiving sensor, which consisted of three passive mutually perpendicular coils. Sensor location and orientation therefore were computed from the nine induced currents by calculating the small changes in the sensed coordinates and then updating the previous measurements.

Polhemus 3space

In 1964 Bill Polhemus started Polhemus Associates, a 12-person engineering studies company working on projects related to navigation for the U.S. Department of Transportation and similar European and Canadian departments, in Ann Arbor, Michigan. His research was focused on determining an object's position and orientation in a three-dimensional space.

??He relocated the company to Malletts Bay in 1969 and the company went beyond studies and began focusing on hardware. In late 1970, after an influx of what Polhemus called "a very clever team from a division of Northrop Corp. (now Northrop Grumman Corp.) that had a lot of experience in development of miniaturized inertial and magnetic devices," the firm changed its name to Polhemus Navigation Sciences, later shortened to Polhemus, and incorporated in Vermont.

Polhemus tracking equipment

"The Polhemus system is used to track the orientation of the pilot's helmet," Polhemus said of the electromagnetic technology he pioneered. "The ultimate objective is to optically project an image on the visor of the pilot's helmet so he can look anywhere and have the display that he needs. … It's critical to know, in a situation like that, where the pilot's helmet is pointed, so you know what kind of a display to put up on the visor," he added before comparing the system to a "**heads-up display**" or "gun sight," which projects similar data onto an aircraft's windshield.

Polhemus was supported for a few years in the early 1970s by Air Force contracts. But by late 1973, "in the absence of any equity capital to speak of, we just ran dry," in his words. "By that time, however, the device looked attractive to a number of companies, and there were several bids for it. We finally wound up selling to the Austin Company," a large conglomerate with headquarters in Cleveland, Ohio.

The next few years saw the company change hands to McDonnell Douglas Corp. of St. Louis, Mo., and then to Kaiser Aerospace and Electronics Corp. of Foster City, Calif., in 1988.

Ernie Blood was an engineer and Jack Scully a salesman at Polhemus. Blood and Scully created the digitizer used for George Lucas' groundbreaking Star Wars series, which won an Academy Award for Polhemus (Blood's name was on the patent.) They had been discussing possible expanded commercial uses for the Polhemus motion tracking technology, possibly in the entertainment field, in training situations, or in the medical field. However, Polhemus was focused on military applications, and was not interested in any other markets. When they took the idea of a spinoff company to their superiors at McDonnell-Douglas, the parent company of Polhemus, they were fired in 1986.

Still convinced that there were commercial possibilities, Blood and Scully started a new company in 1986, which they called Ascension. The first few years were lean years, but Blood improved upon the head-tracking technology for fighter pilots and Scully eventually negotiated a licensing agreement with GEC (General Electric Co. of Great Britain). The contract was put on hold for two years when Polhemus, which had been purchased by Kaiser Aerospace, a direct competitor of GEC, sued Ascension for patent infringement. Polhemus dropped the case shortly before it went to trial, and Ascension, with the financial backing of GEC, was able to stay afloat. The licensing agreement was finalized with GEC, and Ascension sales of equipment based on the technology took off, particularly in the medical field.

When the virtual reality revolution erupted in the early 1990s, Ascension played a part in it, developing motion trackers that could be used in high-priced games. "We decided from the beginning that we were not going to go after a single-segment application," Blood said. "From day one, we've always made sure we were involved in a lot of different markets." As the VR market declined, this philosophy helped Ascension's sales stay constant.

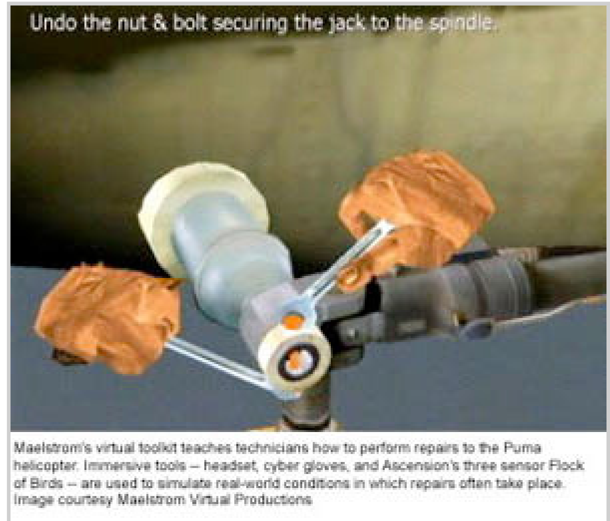
A constant for Ascension was its work in the field of animation. Scully says "Ascension deserves some of the credit for inventing real-time animation, in which sensors capture the motions of performers for the instant animation of computerized characters." Ascension's Flock of Birds product has been used to capture this motion and define the animated characters. It has been used in the animation of characters in hundreds of television shows (MTV's CyberCindy, Donkey Kong), commercials (the Pillsbury Doughboy, the Keebler elves), video games (Legend, College Hoops Basketball, SONY's The Getaway) and movies (Starship Warriors, and pre-animation for Star Wars).

Ascension Technology served six markets: animation, medical imaging, biomechanics, virtual reality, simulation/training and military targeting systems from its facility. Using DC magnetic, AC magnetic, infrared-optical, inertial and laser technologies, Ascension provides turnkey motion capture systems for animated entertainment as well as custom tracking solutions for original equipment manufacturers to integrate into their products.

Sturman, D.J. and Zeltzer, D., *A survey of glove-based input*, Computer Graphics and Applications, IEEE, V14 #1, Jan. 1994,30 -39

F. Raab, E. Blood, T. Steiner, and H. Jones, Magnetic position and orientation tracking system, IEEE Transactions on Aerospace and Electronic Systems, Vol. 15, No. 5, 1979, pp. 709-718.

3D Bird mounted on the back of a Sony LDI-100 HMD in Audi TT coupe



Maelstrom's virtual toolkit teaches technicians how to perform repairs on the Puma helicopter, using Ascension Flock of Birds

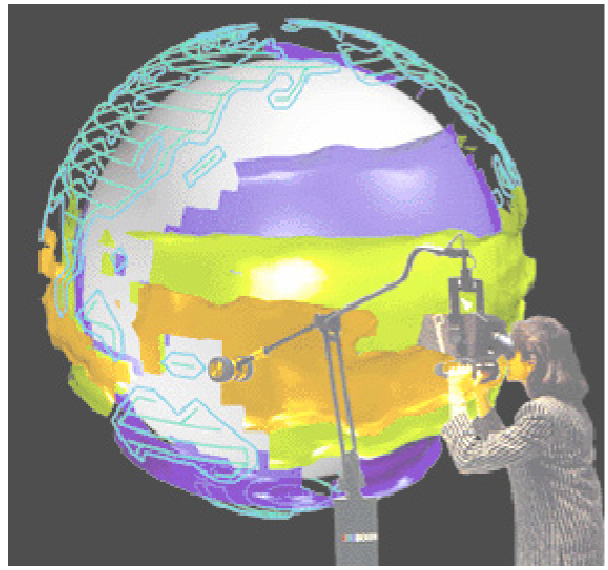
17.5 Virtual Spaces

LEEP Optical System started to develop wide angle lenses for 3-D still photography applications in 1975. The Large Expanse, Extra Perspective (LEEP) optical system was designed by Eric Howlett in 1979 and provided the basis for most of the virtual reality helmets that were developed. The combined system gave a very wide field of view stereoscopic image. The users of the system were impressed by the sensation of depth in the scene and the corresponding realism.

Vived

The original LEEP system was redesigned for the NASA Ames Research Center in 1985 for their first virtual reality installation, the VIEW (Virtual Interactive Environment Workstation) by Scott Fisher. The system was built according to lessons learned using the LEEP display earlier, and proved to be quite impressive. It already featured many techniques that were often used: a Polhemus tracker, 3D audio output, gesture recognition using VPLs DataGlove, a remote camera, and a BOOM-mounted CRT display.

In 1988 Fakespace began building a telepresence camera system for the Virtual Environment Workstation (View) project at NASA Ames Research Center. The complete system combined a teleoperated camera platform and 3D viewing system.To increase image quality, Fakespace invented the BOOM (Binocular Omni-Orientation Monitor). Very small monitors were mounted on a mechanical arm, and users looked into the monitors like they would look into a pair of binoculars. Tracking occured when the user moved the arm, which changed the perspective. When a user released the BOOM, another person could look at the same thing from the same perspective, which was an advantage over HMDs. Since real monitors were used, the resolution was quite good.



BOOM system

The concept of a room with graphics projected from behind the walls was invented at the Electronic Visualization Lab at the University of Illinois Chicago Circle in 1992. The images on the walls were in stereo to give a depth cue. The main advantage over ordinary graphics systems was that the users were surrounded by the projected images, which means that the images were in the users' main field of vision.

This environment was called a "CAVE", (CAVE Automatic Virtual Environment). The first CAVE (as well as the concept) was created by Carolina Cruz-Neira, Dan Sandin, and Tom DeFanti, along with other students and staff of EVL. This back-projection method of virtual reality gained a strong following.

The CAVE was a surround-screen, surround-sound, projection-based virtual reality (VR) system. The illusion of immersion was created by projecting 3D computer graphics into a 10'x10'x10′ cube composed of display screens that completely surrounded the viewer. It was coupled with head and hand tracking systems to produce the correct stereo perspective and to isolate the position and orientation of a 3D input device. A sound system provided audio feedback. The viewer explored the virtual world by moving around inside the cube and grabbing objects with a three-button, wand-like device.

Unlike users of the video-arcade type of VR system, CAVE dwellers did not wear helmets to experience VR. Instead, they put on lightweight stereo glasses and walked around inside the CAVE as they interacted with virtual objects. Multiple viewers often shared virtual experiences and easily carried on discussions inside the CAVE, enabling researchers to exchange discoveries and ideas. One user was the active viewer, controlling the stereo projection reference point, while the rest of the users were passive viewers.

The CAVE was designed from the beginning to be a useful tool for scientific visualization; EVL's goal was to help scientists achieve discoveries faster, while matching the resolution, color and flicker-free qualities of high-end workstations. Most importantly, the CAVE could be coupled to remote data sources, supercomputers and scientific instruments via high-speed networks. It had obvious benefits: it was easy for several people to be in the room simultaneously and therefore see images together; and it was easy to mix real and virtual objects in the same environment. Also, because users saw, for example, their own hands and feet as part of the virtual world, they got a heightened sense of being inside that world.

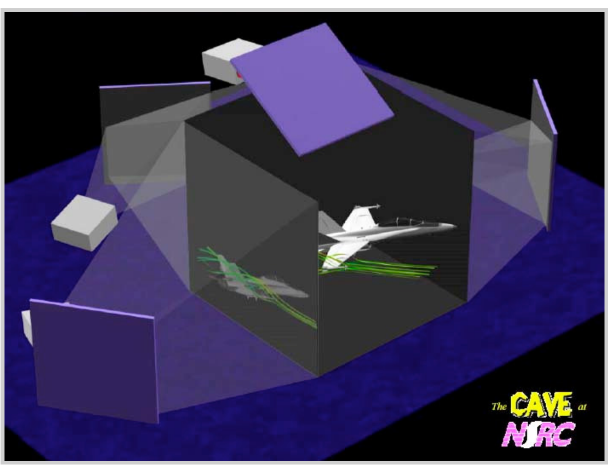
Various CAVE-like environments existed all over the world. Most of these had up to four projection surfaces; images were then usually projected on three walls and the floor. Adding projection on the ceiling gave a fuller sense of being enclosed in the virtual world. Projection on all six surfaces of a room allowed users to turn around and look in all directions. Thus, their perception and experience were never limited, which was necessary for full immersion. The PDC Cube at the Center for Parallel Computers at the Royal Institute of Technology in Stockholm in Sweden was the first fully immersive CAVE.

For a discussion of VR devices, see

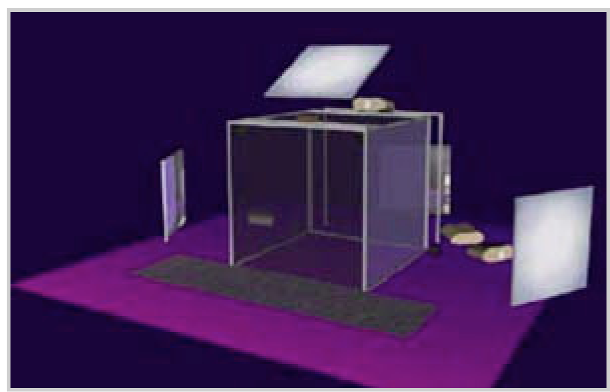
Review of Virtual Environment Interface Technology, IDA Paper P-3186, by Christine Youngblut, Rob E. Johnson, Sarah H. Nash, Ruth A. Wienclaw, and Craig A. Will

Virtual Reality in Training and Education: Resource Guide to Citations and Online Information

Gallery 17.1 CAVE Environments



A diagram of the CAVE at the National Supercomputing Research Center (NSRC). The CAVE (CAVE Automatic Virtual Environment) was developed by DeFanti, et al at the University of Illinois. This CAVE installation is an enclosed 10 feet cube room-sized advanced visualization tool that combines high-resolution, stereoscopic projection and 3D computer graphics to create the illusion of complete immersion in a virtual environment.



CAVE environment

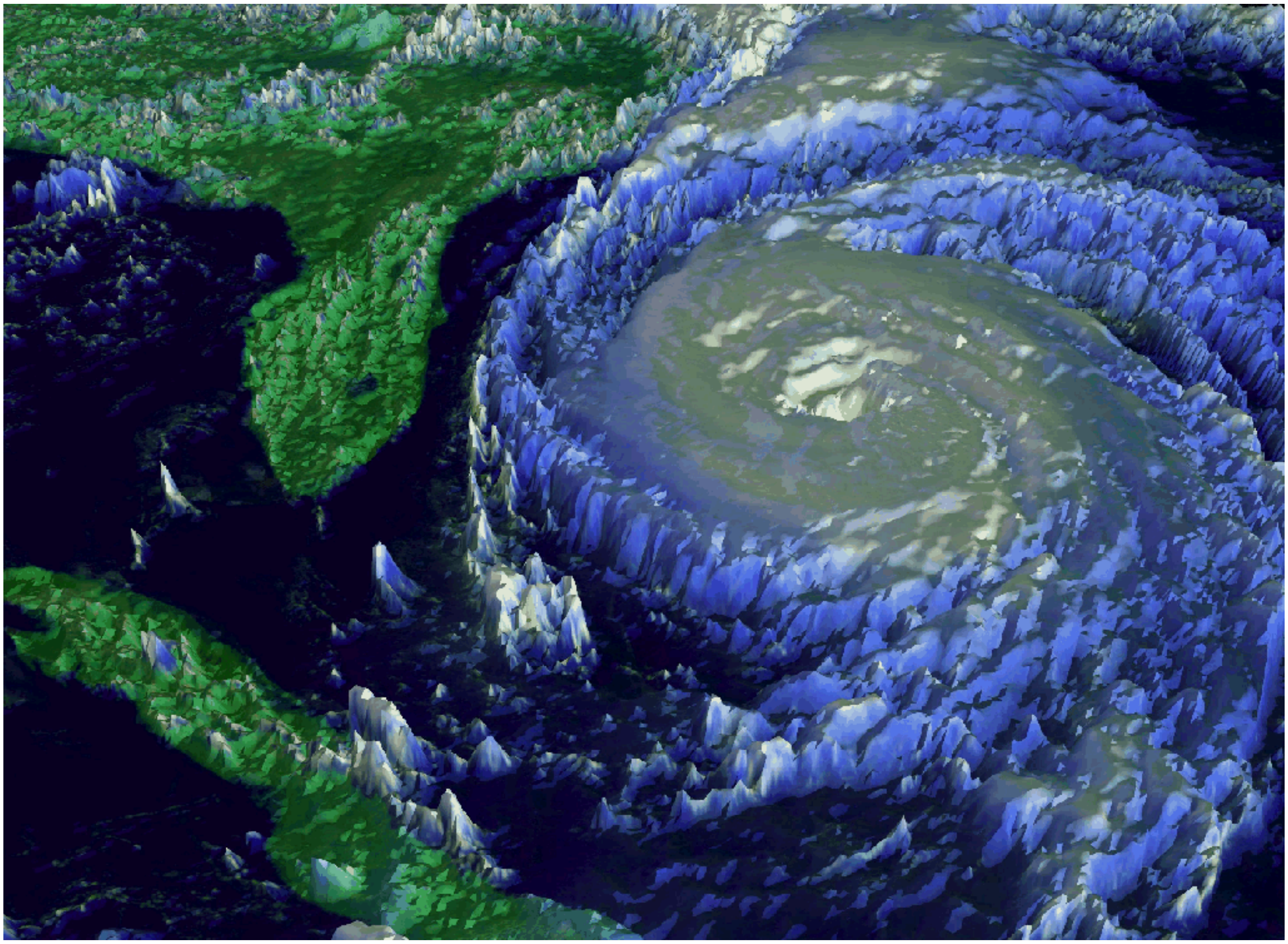
CAVE installed at IU

Crayoland

Chapter 18: Scientific Visualization

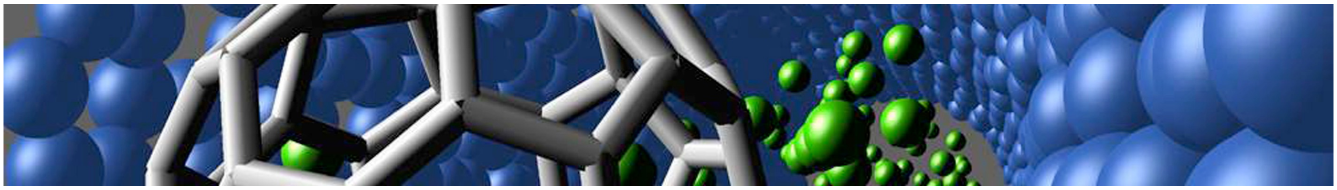
Scientific Visualization

3D graphics techniques provided a means of creating a visual representation of complex and extensive data collections. In particular, scientific data sets were quite large, and the growth area around this visual image creation was called *scientific visualization.*

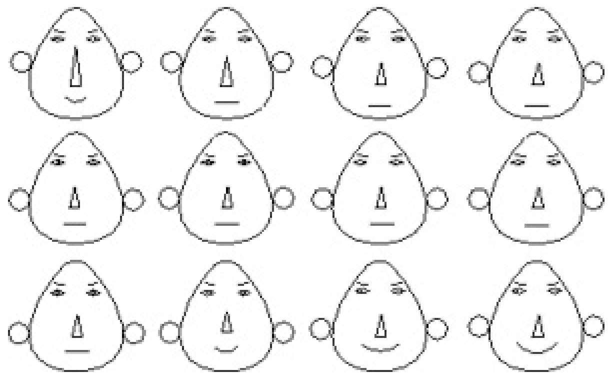


Hurricane Fran – NASA (1996)

18.1 Introduction



Visualization in its broadest terms represents any technique for creating images to represent abstract data. Thus much of what we do in computer graphics and animation can fall into this category. One specific area of visualization, though, has evolved into a discipline of its own. We call this area Scientific Visualization, or Visualization in Scientific Computing, although the field encompasses other areas, for example business (information visualization) or computing (process visualization).

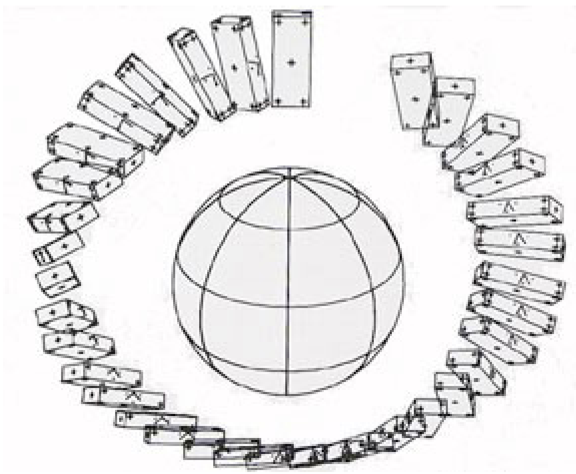


Chernoff faces

In 1973, Herman Chernoff introduced a visualization technique to illustrate trends in multidimensional data. His Chernoff Faces were especially effective because they related the data to facial features, something which we are used to differentiating between. Different data dimensions were mapped to different facial features, for example the face width, the level of the ears, the radius of the ears, the length or curvature of the mouth, the length of the nose, etc. An example of Chernoff faces is shown to the left; they use facial features to represent trends in the values of the data, not the specific values themselves. While this is clearly a limitation, knowledge of the trends in the data could help to determine which sections of the data were of particular interest.

In general the term "**scientific visualization**" is used to refer to any technique involving the transformation of data into visual information, using a well understood, reproducible process. It characterizes the technology of using computer graphics techniques to explore results from numerical analysis and extract meaning from complex, mostly multi-dimensional data sets. Traditionally, the visualization process consists of filtering raw data to select a desired resolution and region of interest, mapping that result into a graphical form, and producing an image, animation, or other visual product. The result is evaluated, the visualization parameters modified, and the process run again. The techniques which can be applied and the ability to represent a physical system and the properties of this system are part of the realm of scientific visualization.

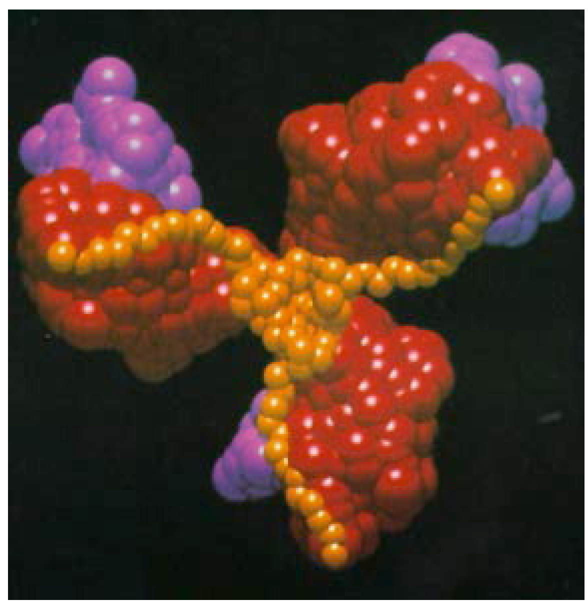
Visualization is an important tool often used by researchers to understand the features and trends represented in the large datasets produced by simulations on high performance computers.



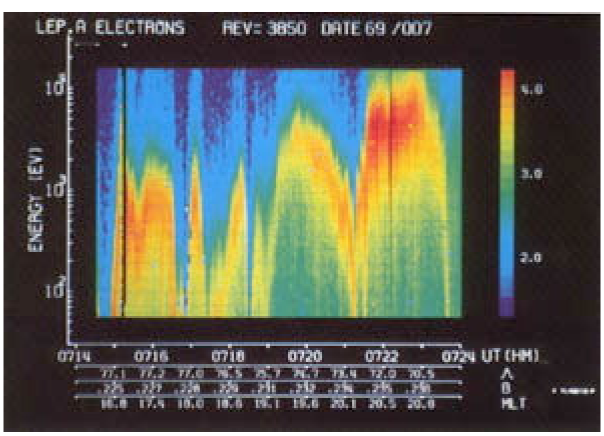
Zajac film composite

From the early days of computer graphics, users saw the potential of this image to present technology as a way to investigate and explain physical phenomena and processes, many from space physics or astrophysics. Ed Zajac from Bell Labs produced probably one of the first visualizations with his animation titled *A two gyro gravity gradient altitude control system*. Nelson Max at Lawrence Livermore used the technology for molecular visualization, making a series of films of molecular structures. Bar graphs and other statistical representations of data were commonly generated as graphical images. Ohio State researchers created a milestone visualization film on the interaction of neighboring galaxies in 1977.

One of the earliest color visualizations was produced in 1969 by Dr. Louis Frank from the University of Iowa. He plotted the energy spectra of spacecraft plasma by plotting the energy against time, with color representing the number of particles per second measured at a specific point in time.



Nelson Max molecular visualization



Louis Frank visualization

One of the most well-known examples of an early process visualization is the film "Sorting out Sorting", created by Ronald Baecker at the University of Toronto in 1980, and presented at SIGGRAPH 81. It explained concepts involved in sorting an array of numbers, illustrating comparisons and swaps in various algorithms. The film ends with a race among nine algorithms, all sorting the same large random array of numbers.The film was very successful, and is still used to teach the concepts behind sorting. Its main contribution was to show that algorithm animation, by using computer generated images, can have great explanatory power.

Three-dimensional imaging of medical datasets was introduced shortly after clinical CT (Computed axial tomography) scanning became a reality in the 1970s. The CT scan process images the internals of an object by obtaining a series of two-dimensional x-ray axial images. The individual x-ray axial slice images are taken using a x-ray tube that rotates around the object, taking many scans as the object is gradually passed through a gantry. The multiple scans from each 360 degree sweep are then processed to produce a single cross-section.

The goal in the visualization process is to generate visually understandable images from abstract data. Several steps must be done during the generation process. These steps are arranged in the so called Visualization Pipeline.

Data is obtained either by sampling or measuring, or by executing a computational model. Filtering is a step which pre-processes the raw data and extracts information which is to be used in the mapping step. Filtering includes operations like interpolating missing data, or reducing the amount of data. It can also involve smoothing the data and removing errors from the data set. Mapping is the main core of the visualization process. It uses the pre-processed filtered data to transform it into 2D or 3D geometric primitives with appropriate attributes like color or opacity. The mapping process is very important for the later visual representation of the data. Rendering generates the image by using the geometric primitives from the mapping process to generate the output image. There are number of different filtering, mapping and rendering methods used in the visualization process.

Gabor Herman was a professor of computer science at SUNY Buffalo in the early 1970s, and produced some of the earliest medical visualizations, creating 3D representations from the 2D CT scans, and also from electron microscopy. Early images were polygons and lines (e.g., wireframe) representing three-dimensional volumetric objects. James Greenleaf of the Mayo Clinic and his colleagues were the first to introduce methods to extract information from volume data, a process called **volume visualization**, in 1970 in a paper that demonstrated pulmonary blood flow.

Mike Vannier and his associates at the Mallinckrodt Institute of Radiology, also used 3D imaging as a way of abstracting information from a series of transaxial CT scan slices. Not surprisingly, many early applications involved the visualization of bone, especially in areas like the skull and craniofacial regions (regions of high CT attenuation and anatomic zones less affected by patient motion or breathing). According to Elliot Fishman from Johns Hopkins, although most radiologists at the time were not enthusiastic about 3D reconstructions, referring physicians found them extremely helpful in patient management decisions, especially in complex orthopedic cases.In 1983, Vannier adapted his craniofacial imaging techniques to uncover hidden details of some of the world's most important fossils.

There are other early examples that used graphics to represent **isolines** and **isosurfaces**, cartographic information, and even some early **computational fluid dynamics**. But the area that we now call scientific visualization really didn't come into its own until the late 1980s.

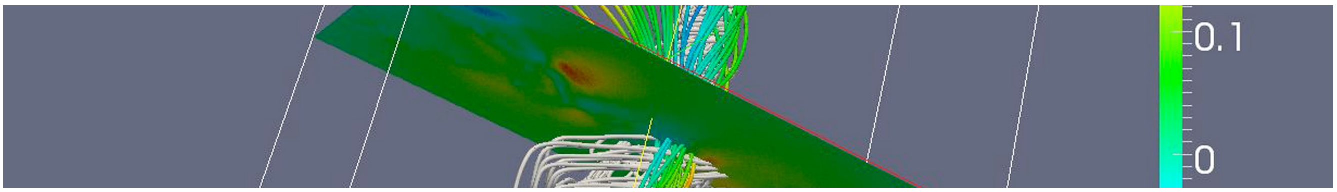
Herman Chernoff, The use of faces to represent points in k-dimensional space graphically, Journal of the American Statistical Association, V68, 1973.

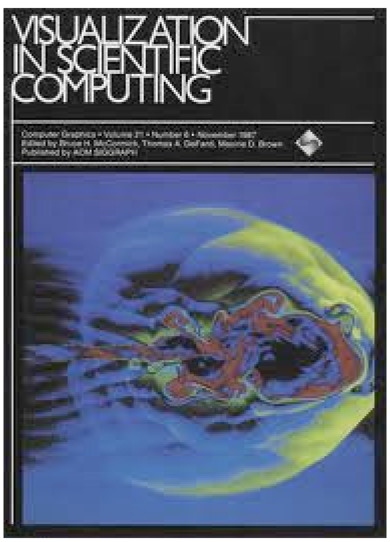
To see a Java based demonstration of sorting algorithms, similar to the visualization done by Baecker, go to
http://www.cs.ubc.ca/spider/harrison/Java/sorting-demo.html

Herman, G.T., Liu, H.K.: Three-dimensional display of human organs from computed tomograms, Computer Graphics and Image Processing 9:1-21, 1979

Michael W. Vannier , Jeffrey L. Marsh , James O. Warren, Three dimensional computer graphics for craniofacial surgical planning and evaluation, Proceedings of SIGGRAPH 83, Detroit, Michigan

18.2 Visualization Systems



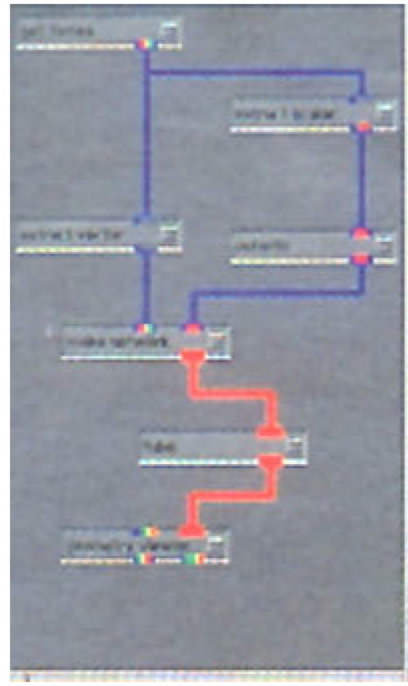


Special Issue on Visualization in Scientific Computing, Computer Graphics, Publication of ACM/SIGGRAPH, Vol 21, No. 6, November 1987.Bruce McCormick, Maxine Brown, and Tom DeFanti

In 1987 an ACM-SIGGRAPH panel released a report done for the National Science Foundation, *Visualization in Scientific Computing*, that was a milestone in the development of the emerging field of Scientific Visualization. As a result, the field was now on the radar screen of funding agencies, and conferences, workshops and publication vehicles soon followed.

Publication of this NSF report prompted researchers to investigate new approaches to the visualization process and also spawned the development of integrated software environments for visualization. Besides several systems that only addressed specific application needs, such as computational fluid dynamics or chemical engineering, a few more general systems evolved. Among these were IBM's Data Explorer, Ohio State University's apE, Wavefront's Advanced Visualizer, SGI's IRIS Explorer, Stardent's AVS and Wavefront's Data Visualizer.Two lesser known but important systems were Khoros (from the University of New Mexico) and PV-WAVE (Precision Visuals' Workstation Analysis and Visualization Environment), originally from Precision Visuals, Inc., but later owned by Visual Numerics, Inc. (VNI).

These visualization systems were designed to take the burden of making the visualization image off of the shoulders of the scientist, who often didn't know anything of the graphics process. The most usable systems therefore utilized a visual programming style interface, and were built on the *dataflow* paradigm: software modules were developed independently, with standardized inputs and outputs, and were visually linked together in a pipeline. They were sometimes referred to as **modular visualization environments** (MVEs). MVEs allowed the user to create visualizations by selecting program modules from a library and specifying the flow of data between modules using an interactive graphical networking or mapping environment. In a MVE **dataflow** diagram, the boxes represent process modules, which are linked by lines representing the flow of data between the modules. Maps or networks could be saved for later recall.



Dataflow diagram

General classes of modules included:

- data readers – input the data from the data source
- data filters – convert the data from a simulation or other source into another form which is more informative or less voluminous.
- data mappers – convert it into another completely different domain, such as 2D or 3D geometry or sound.
- viewers or renderers- rendering the 2D and 3D data as images.
- control structures – examples include initialization of the display device, control of recording devices, open graphics windows, etc.
- data writers – output the original or filtered data

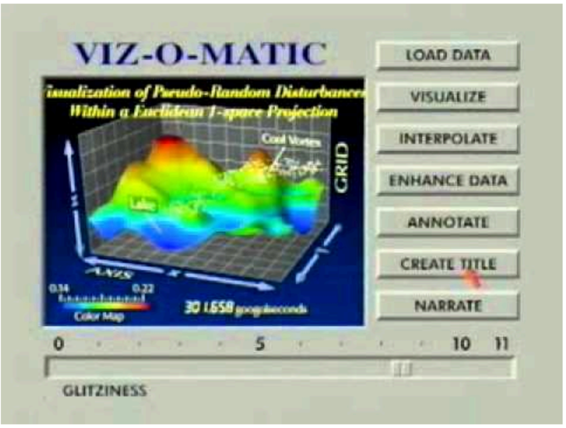
Advantages of MVEs included:

- Required no graphics expertise
- Allowed for rapid prototyping and interactive modifications
- Promoted code reuse
- Extensible- allowed new modules to be created
- Reasonably powerful and complete for a broad range of problems
- Often allowed computations to be distributed across machines, networks and platforms

The problem with such packages included poor performance on large data sets, they were more restrictive than general programming environments, they were often not built on accepted graphics standards, and their ease of use sometimes promoted poor visualizations (this often involved a "high glitz factor").

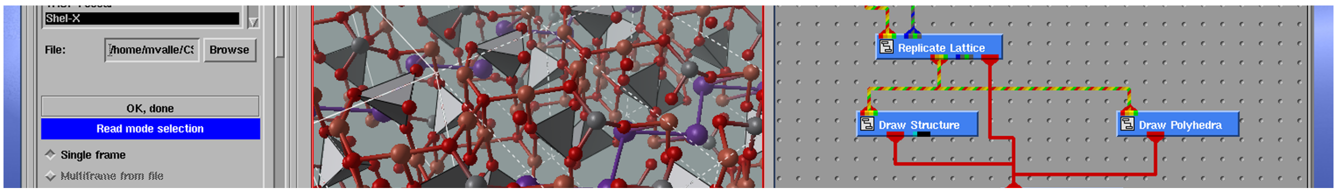
Wayne Lytle, who worked with the Cornell Theory Center, produced this parody of scientific visualizations for SIGGRAPH 93, called *The Dangers of Glitziness and Other Visualization Faux Pas*, using fictitious software named "Viz-o-Matic." The video documents the enhancement and subsequent "glitz buffer overload of a sparsely data-driven visualization trying to masquerade as a data-driven, thoughtfully rendered presentation," according to Lytle.

Movie 18.1 Viz-O-Matic

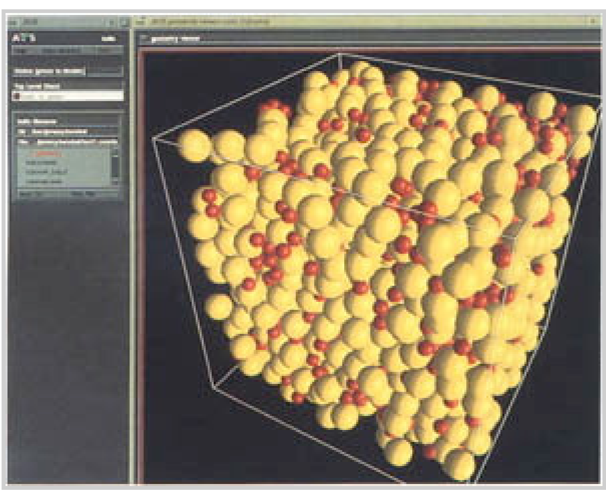


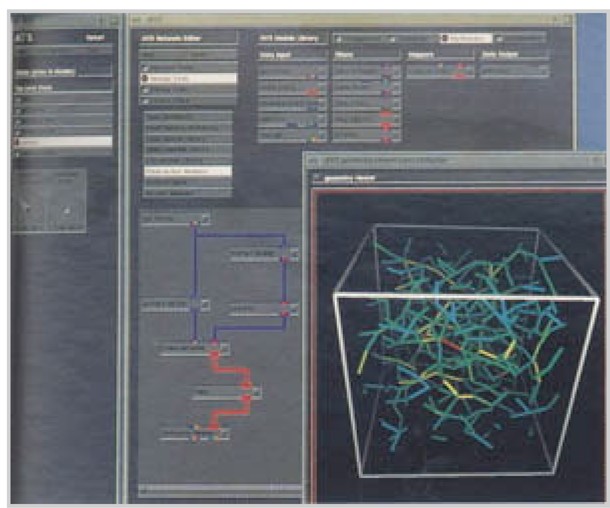
https://www.youtube.com/watch?v=fP-7rhb-qMg
Viz-o-Matic – The Dangers of Glitziness and Other Visualization Faux Pas, or What's Wrong With This Visualization?
by Wayne Lytle – Cornell University Theory Center, 1993.

18.3 Hardware and Software



In the mid 80's, Stellar Computer was marketing a graphic supercomputer. To demonstrate the capabilities of their hardware, they developed a software package called Application Visualization System (AVS) that they gave away with the hardware. AVS was one of the first integrated visualization systems, and was developed by Digital Productions veteran Craig Upson and others. Over time, Stellar merged with Ardent Computer to become Stardent Computer. When business conditions changed, some of the engineering staff and management of Stardent formed a new company called Advanced Visual Systems, Inc. to continue the development of the AVS product line.

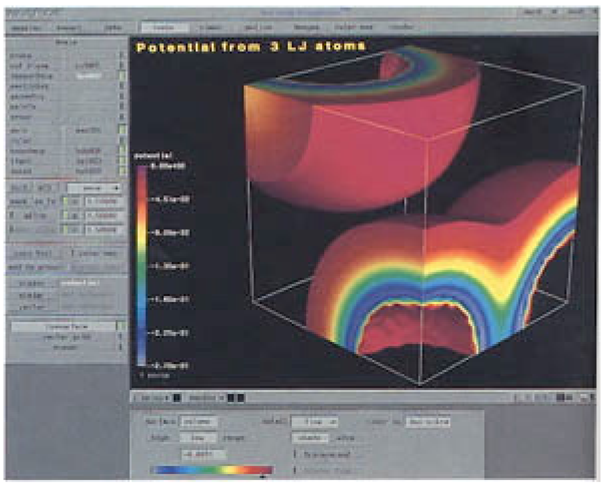




Screenshots from AVS

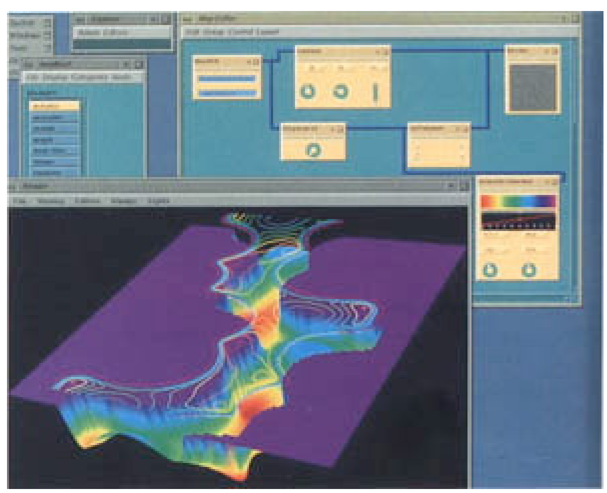
The computational model of AVS was based on a collection of parametric modules, that is, autonomous building blocks which could be connected to form larger data processing networks. Each module had definite I/0 dataflow properties, specified in terms of a small collection of data structures such as field, **colormap**, or geometry. The Network Editor, operating as a part of the AVS kernel, offered interactive visual tools for selecting modules, specifying connectivity and designing convenient GUIs to control module parameters. A set of base modules for mapping, filtering, and rendering was built into the AVS kernel. The user extensibility model was defined at the C/Fortran level, allowing for new modules to be constructed and appended to the system in the form of independent UNIX processes, supported by appropriate dataflow interfaces.

> Dana Computer Inc. was founded by Allen Michels in Sunnyvale, California in the early 1980s. The company was renamed Ardent Computer in December 1987 because another company named Dana Computer already existed. Ardent was financed by venture capital and Kubota Ltd., (Kubota paid $50,000,000 for 44% of Ardent). In 1989 Ardent merged with Newton, Mass. based Stellar Computer to become Stardent Computer. The Sunnyvale facility was closed in 1990, followed soon after by the Massachusetts facility. Kubota Pacific Computer then gained the intellectual property from Stardent. Kubota Pacific Computer became Kubota Graphics Corporation and lasted until February 1, 1995. Several industry notables worked for Ardent including Gordon Bell, the founder of DEC, who was VP of Engineering.



Screenshot from Advanced Visualizer

Other visualization systems came out of the commercial animation software industry. The Wavefront Advanced Visualizer was a modeling, animation and rendering package which provided an environment for interactive construction of models, camera motion, rendering and animation without any programming. The user could use many supplied modeling primitives and model deformations, create surface properties, adjust lighting, create and preview model and camera motions, do high quality rendering, and save the resulting images for writing to video tape. It was more of a general graphics animation system, but was used for many scientific visualization projects.



Screenshot from Iris Explorer

Iris Explorer was a data-flow, object-oriented system for data visualization developed by G. J. Edwards and his colleagues at SGI. The product was later marketed by NAG (Numerical Applications Group). Like other dataflow systems, it allowed the user to connect pre-built modules together using a "drag and drop" approach. The modules were X Windows programs developed in C or FORTRAN, and was built around the OpenGL standard.

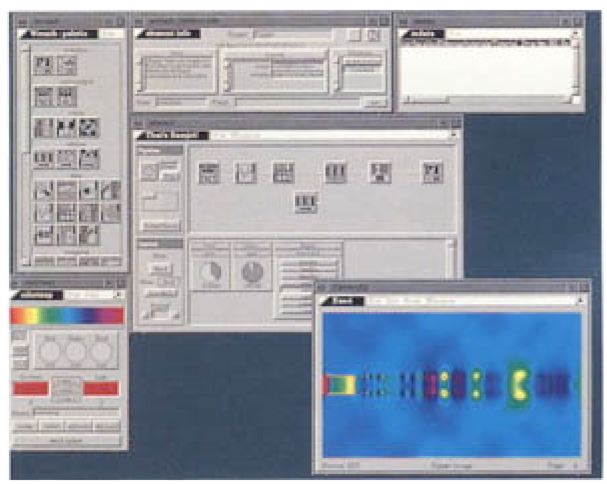
Iris Explorer had three main components:

- The Librarian module contained the list of modules and previously created maps
- The Map Editor was the work area for creating and modifying maps.
- DataScribe was a data conversion tool for moving data between Explorer and other data formats

A map was a dataflow network of modules connected or "wired" together. The user wired together the modules by connecting the appropriate ports, e.g. the output port of one module to the input port of the next module. Each module accepted data, processed it, and then output it to the next module. A map could be created and then stored for future use. It could also be made part of another map.

Explorer Data Types

- Parameter (scalar)
- Lattice (array, including images)
- Pyramid (irregular grid)
- Geometry (Inventor-based)
- Pick (user interaction with geometry)
- In addition, users could define their own types with a typing language

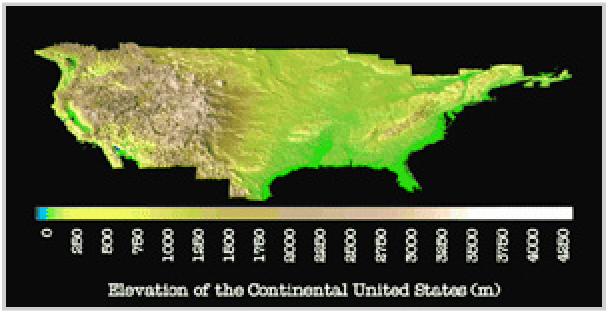


Screenshot from apE

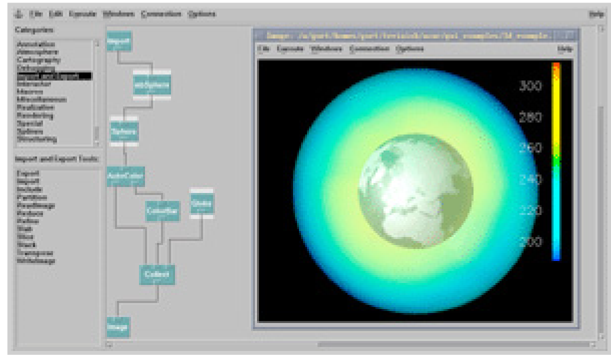
In 1984, Ohio State University competed for an NSF supercomputer center, but was unsuccessful. So the University took the proposal to the state legislature, who established the Ohio Supercomputer as a state center in 1987. One of the reasons for the success of the proposal was the connection with Ohio State's very highly regarded Computer Graphics Research Group, which became the Advanced Computing Center for the Arts and Design at about the same time. The connection was made formal when the Ohio Supercomputer Graphics Project of ACCAD was made part of the OSC structure. Researchers from OSGP set out to develop a visualization package based on the dataflow paradigm, and in 1988 the apE (animation production Environment) software was released. It was originally distributed free of charge to any users who wanted to use it, and it allowed for these users to write their own modules to extend the capabilities.

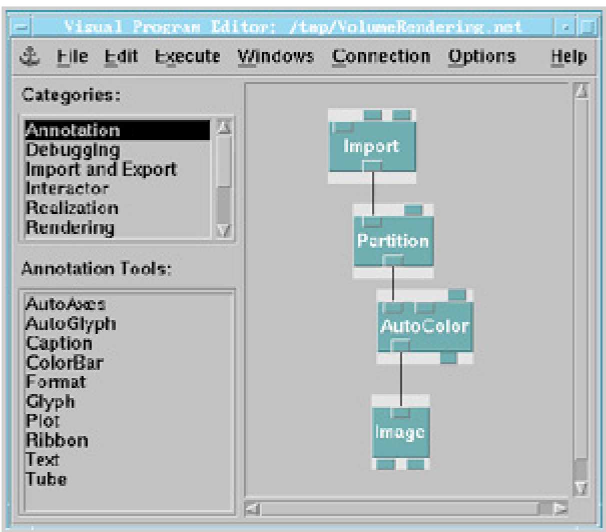
In 1991 OSC decided to commercialize this popular free software, and contracted with Taravisuals, Inc. to maintain and distribute it. Unfortunately, at about the same time, Iris Explorer was released and was freely bundled with the SGI workstation, one of the more popular apE platforms, and the apE effort was discontinued.

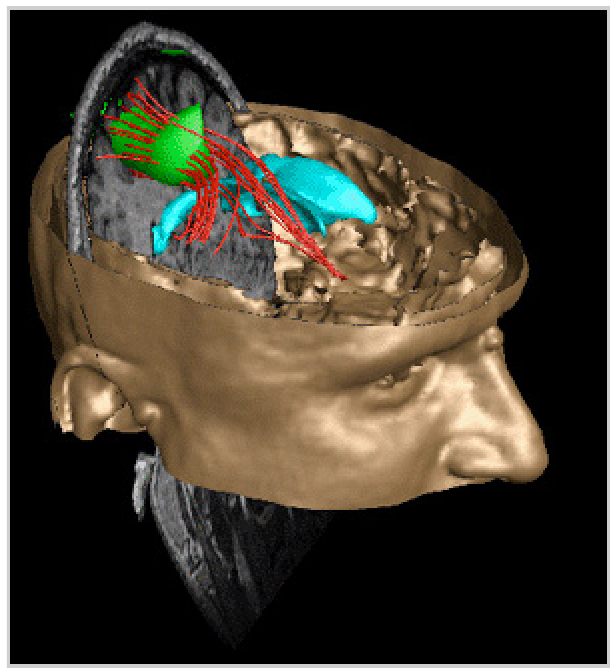
Like most of the other systems of the time, Data Explorer (DX) was a general-purpose visualization application in which the user created visualizations by combining existing modules into a network. It was discipline independent and easily adaptable to new applications and data. The program provided a full set of tools for manipulating, transforming, processing, realizing, rendering and animating data.



Screenshots from Data Explorer







Registered 3D MRI and Magnetoencephalographic ?Scans – NYU Medical Center

DX used visual programming and a data flow approach to visualization and analysis. The data flow modules were connected together to direct the data flow. This was analogous to creating a flow chart, and the resulting diagrams were called networks.

Users could work solely with the modules that came with Data Explorer or they could create macros. A macro was a network that was named and used in place of a module. There grew a large public collection of these macros that users could download.

DX provided visualization and analysis methods based on points, lines, areas, volumes, images or geometric primitives in any combination. It worked with 1-, 2-, and 3-dimensional data and with data which was rectangularly gridded, irregularly gridded, gridded on a non-rectangular grid, or scattered.

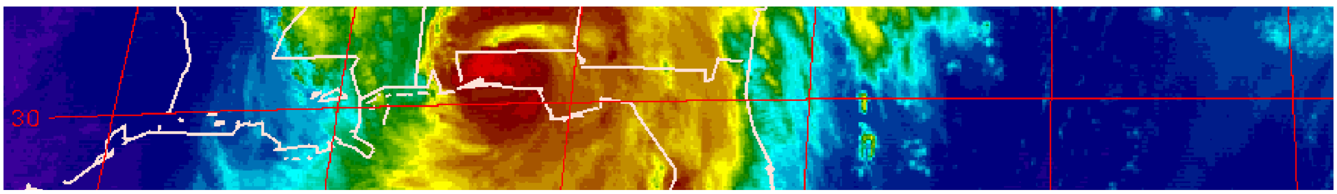
B. Lucas et al. *An architecture for a scientific visualization system*. In Proceedings of Visualization ’92, pages 107–114. IEEE Computer Society Press, 1992

Craig Upson, et al, *The Application Visualization System: A Computational Environment for Scientific Visualization*, IEEE CG&A, July 1989, pp 30-42

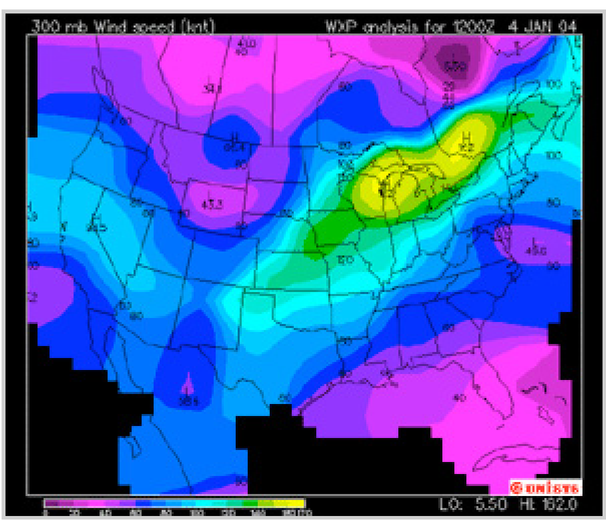
G.J. Edwards. The design of a second generation visualization environment. In J.J. Connor, S. Hernandez, T.K.S. Murthy, and H. Power, editors, Visualization and Intelligent Design in Engineering and Architecture, pages 3-16.

D. Scott Dyer. *A dataflow toolkit for visualization*. IEEE Computer Graphics and Applications, 10(4):60–69, July 1990

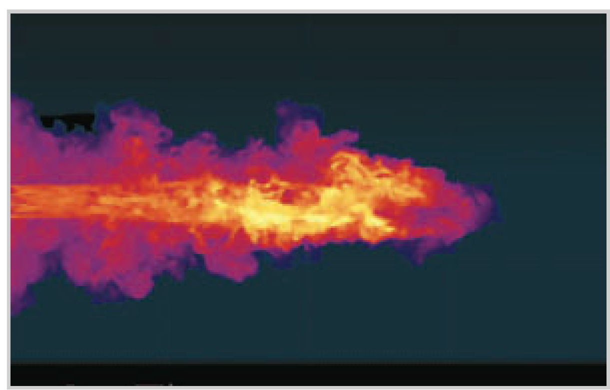
18.4 Algorithms



Most of the early visualization techniques dealt with 2D scalar or vector data that could be expressed as images, wireframe plots, scatter plots, bar graphs or contour plots. Contour plots are basically images of **multivariate data** that represent the thresholds of data values, that is for example fi(x,y)<=ci. The contours ci are drawn as curves in 2D space, and the shading represents values that are less than the contour value, and greater than the lower one. Often, the contour plots are redrawn over time, to get an animated sequence of a phenomenon. For example, Mike Norman of NCSA created an animation of a gas jet using sequential shaded **contour plots**.

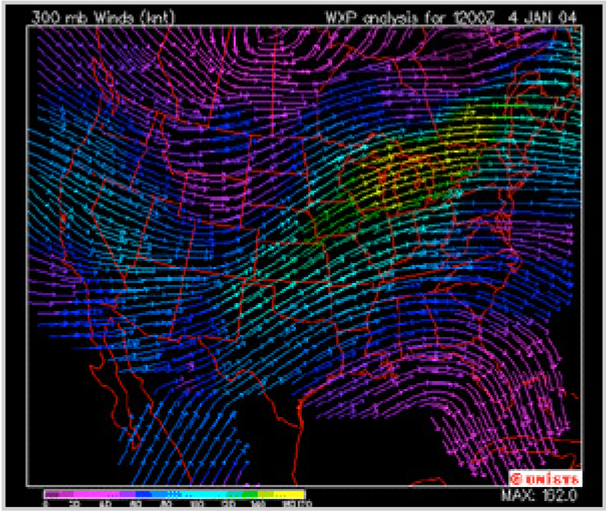


Contour Plot

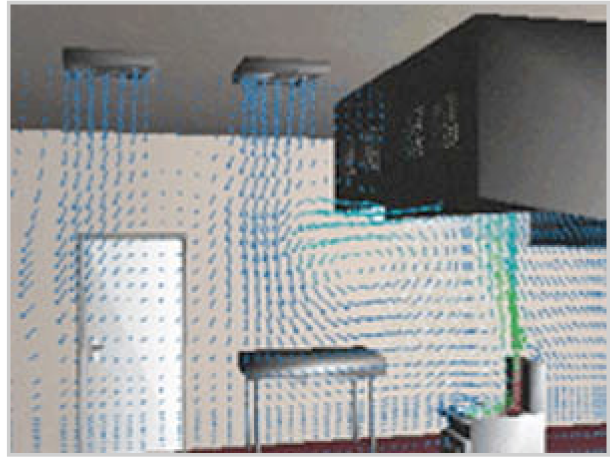


Contour Plot – Norman

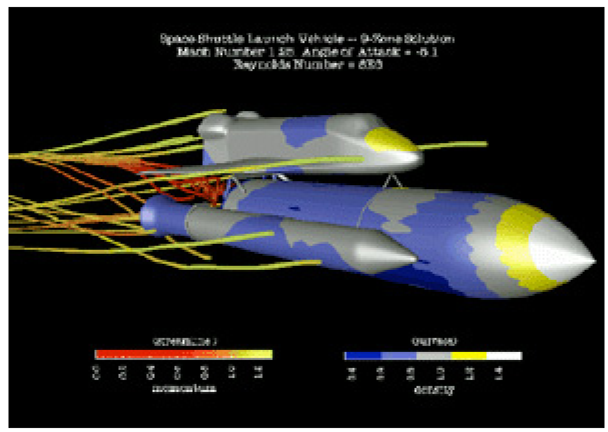
Vector or flow fields provide an effective means of visualizing certain phenomena, such as wind, gases, smoke, etc. By giving a direction to data within a certain interval, one could easily determine patterns within the data. For example, a stream plot was an example of a vector field which can be used to depict wind over the United States, as in the image to the above right. The image below the stream plot shows cool air entering a kitchen through ceiling vents, and the vectors show how the direction and temperature of the air changes as it is influenced by a gas-fired appliance, like a stove.



Vector Field – Wind flow over the U.S.



Vector Field – Air flow in commercial kitchen.



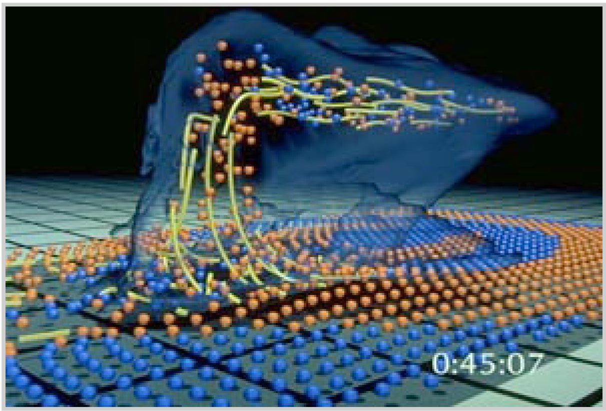
Momentum is shown as streamlines colored by magnitude and the density on the shuttle surface is shown as shaded contours – NASA Ames

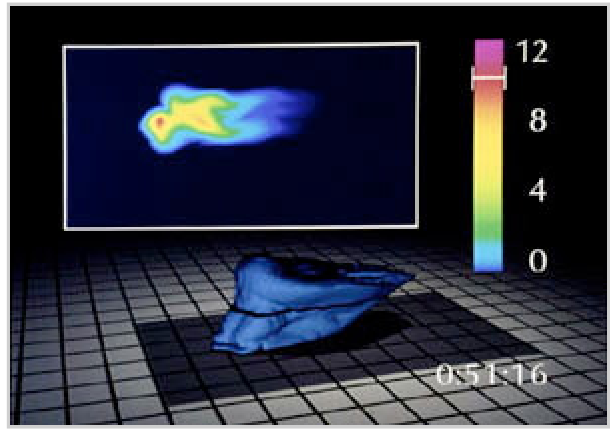
Any of these techniques can be combined, as is shown in the visualization of the energy over the space shuttle In this case, stream lines represent one data domain, while shaded contours represent another domain.

3D visualization presented a more difficult problem. Data that is obtained in 3D usually needs to be converted to an alternative geometric form in order to send it to the rendering part of the pipeline. Early researchers, like Herman (mentioned in Section 1) and Harris in the late 1970s used primitive techniques to map the “values” of CT scans into 3D volumes, but the computational overhead was tremendous. One approach, which utilized the “**lofting**” algorithm developed by Henry Fuchs, et al, involved tracing the important boundaries from the planar scans, and then joining the adjacent traces with triangles to create a 3D surface.

Probably the most important 3D geometry conversion algorithm was presented by Bill Lorensen an Harvey Cline of General Electric in 1987. The Marching Cubes algorithm defined cubes between two adjacent planar data scans. Then it used a particular density value, or contour value, and “marched” from cube to cube, finding the portions of the cube that had the same contour value, subdividing the cube as necessary in the process. When all surfaces of all cubes having the same value were presented, a “level” surface or isosurface was created, which could then be rendered.

One of the most famous examples of isosurfaces in visualization was done by Wilhelmson and others at NCSA at the University of Illinois in 1990. It was an animated visualization of a severe storm, and besides the surfaces, it used other techniques, like contour shading, flowlines, stream lines and ribbons, etc. to tell the scientific story of the storm. The isosurfaces were supplemented with flow lines and stream lines to depict the details of the storm.



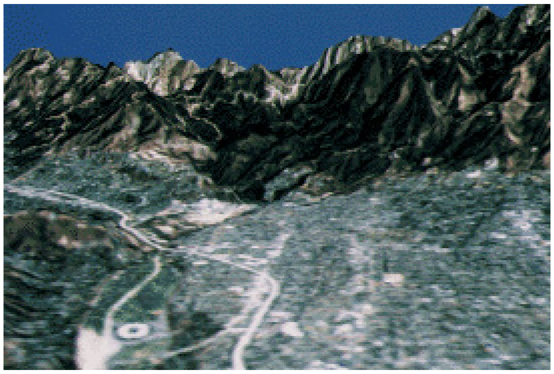


Scenes from NCSA Severe Storm Visualization

As mentioned above, data acquisition can be accomplished in various ways (CT scan, MRI scans, ultrasound, confocal microscopy, computational fluid dynamics, etc.). Another acquisition approach is remote sensing. Remote sensing involves gathering data and information about the physical "world" by detecting and measuring phenomena such as radiation, particles, and fields associated with objects located beyond the immediate vicinity of a sensing device(s).

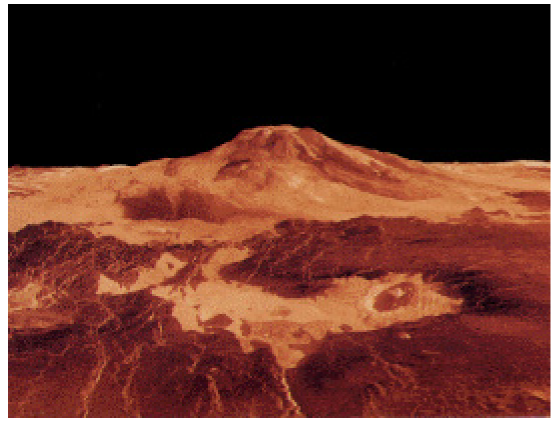
It is most often used to acquire and interpret geospatial data for features, objects, and classes on the Earth's land surface, oceans, and atmosphere, but can also be used to map the exteriors of other bodies in the solar system, and other celestial bodies such as stars and galaxies.

Data is obtained via aerial photography, spectroscopy, radar, radiometry and other sensor technologies. The filtering and mapping steps of the visualization pipeline vary, depending on the type of data acquisition method. One of the most famous **remote sensing** related visualizations is seen in the animation *L.A. the Movie*, produced by the Visualization and Earth Sciences Application group at JPL. The VESA group has performed data visualization at JPL since the mid 1980's.



Scene from L.A. the Movie. The Rose Bowl is in the foreground and JPL is in the foothills of the San Gabriel Mountains.

L.A. The Movie is a 3D perspective rendering of a flight around the Los Angeles area starting off the coast behind Catalina Island and includes a brief flight up the San Andreas Fault-line.



Scene from Mars the Movie

Since then the group produced other animations including flights around Mars, Venus, Miranda (a moon of Jupiter) and more. *L.A. the Movie* was created in 1987 utilizing multispectral image data acquired by the Landsat earth orbiting spacecraft. The remotely sensed imagery was rendered into perspective projections using digital elevation data sets available for the area within a Landsat image.

For more information about remote sensing, go to https://landsat.gsfc.nasa.gov/education/formal-education/

To read more about the L.A. the Movie process see *Animation and Visualization of Space Mission Data* in the August 1997 issue of Animation World Magazine

Harris, Lowell D., R. A. Robb, T. S. Yuen, AND E. L. Ritman, “Non-invasive numerical dissection and display of anatomic structure using computerized x-ray tomography,” Proceedings SPIE 152 pp. 10-18 (1978).

H. Fuchs , Z. M. Kedem , S. P. Uselton, *Optimal surface reconstruction from planar contours*, Communications of the ACM, v.20 n.10, p.693-702, Oct. 1977

William E. Lorensen , Harvey E. Cline, *Marching cubes: A high resolution 3D surface construction algorithm*, ACM SIGGRAPH Computer Graphics, v.21 n.4, p.163-169, July 1987

The Visualization Toolkit — An Object-Oriented Approach to 3D Graphics, by Will Schroeder, Ken Martin and Bill Lorensen, Prentice Hall, 1996

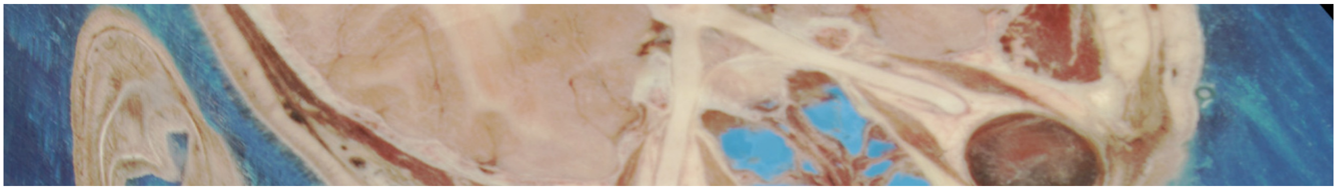
David M. Reed, Lawson Wade, Peter G. Carswell, and Wayne E. Carlson. “Particle Tracing in Curvilinear Grids,” Proceedings of the IS&T/SPIE Symposium on Electronic Imaging: Science and Technology, Visual Data Exploration and Analysis II, The International Society for Optical Engineering, IS&T/SPIE Proc. 2410, February, 1995, pp 120-128.

Movie 18.2 *L.A. The Movie (1987) – 3D terrain animation created at JPL, circa 1987.*
http://www.youtube.com/watch?v=6RsXCbpJG54

Movie 18.3 *Mars The Movie (1989) – 3D terrain animation created at JPL, circa 1989 – a follow-up to their prior film LA: The Movie*
http://www.youtube.com/watch?v=vMjlD6h2qko

Movie 18.4 *NCSA Severe Storm Visualization (Visualization Of An F3 Tornado Within A Supercell Thunderstorm Simulation) – Scientists used pre-storm conditions from an observed F4 tornado in South Dakota in 2003 to initialize a simulation that produces a severe supercell storm that produces a powerful tornado and terabytes of data, which is used to drive the visualization.*
http://www.youtube.com/watch?v=EgumU0Ns1YI

18.5 Volumes

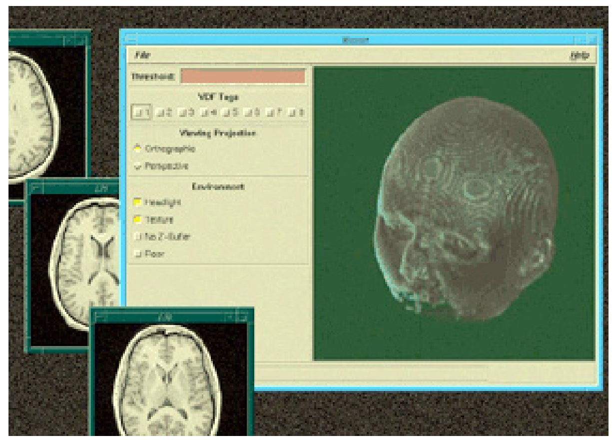


Another major approach to 3D visualization was **Volume Rendering**. Volume rendering allows for the display of information throughout a 3D data set, not just on the surface. There are several famous methods of volume rendering that should be discussed. The first was developed at Pixar for the Pixar Image Computer in 1988 by Robert Drebin and others. The algorithm used independent 3D cells within the volume, called "**voxels**". The basic assumption was that the volume was composed of voxels that each had the same property, such as density. A surface would occur between groups of voxels with two different values. The algorithm used color and intensity values from the original scans and gradients obtained from the density values to compute the 3D solid.

3D Voxel based volume rendering (Drebin)

3D ray-traced volume rendering (Levoy)

The second approach used ray-tracing. The basic idea was to cast rays from screen pixel positions through the data, obtain the desired information along the ray, and then display this information. The data could be an average of the data in a cell, called a "voxel", or of all cells intersected by the ray, or some other such measure. This was used in areas such as medical imaging and displaying seismic data. The first major contribution was by Marc Levoy of the University of North Carolina in 1988. There have subsequently been many variations on the ray-tracing volume rendering approach.



Splatting approach to volume rendering

A third approach was developed by Lee Westover of UNC. *Splatting* is a volume rendering algorithm that combines efficient volume projection with a sparse data representation. In **splatting**, the final image is generated by computing for each voxel in the volume dataset its contribution to the final image. Only voxels that have values inside a determined iso-range need to be considered, and these voxels can be projected via efficient rasterization schemes. In splatting, each projected voxel is represented as a radially symmetric interpolation kernel, equivalent to a fuzzy ball. Projecting such a basis function leaves a fuzzy impression, called a footprint or splat, on the screen. The algorithm works by virtually "throwing" the voxels onto the image plane. The computation is processed by virtually "peeling" the object space in slices, and by accumulating the result in the image plane. Splatting traditionally classified and shaded the voxels prior to projection, and thus each voxel footprint was weighted by the assigned voxel color and opacity.

As previously discussed, the representation of the data draws from many disciplines such as computer graphics, image processing, art, graphic design, human-computer interface, cognition, and perception. Donna Cox, from the School of Art and Design and the National Center for Supercomputing Applications at the University of Illinois, Urbana-Champaign, understood the potential of bringing scientists and visual design artists together to address the big picture of data visualization. In 1987 Cox developed the concept of "Renaissance Teams," a team of domain experts and visualization experts whose goal was to determine visual representations which both appropriately and instructively presented domain specific scientific data. As Vibeke Sorenson said in a 1989 essay,

"the accumulated knowledge of the fine arts can be extremely useful to Scientific Visualization, a field which will rely more and more on visual skills and ideas. A study of art history can help to gain insights into visual form-giving and unique ways of solving problems which could enhance the scientific research environment in new and unexpected ways."

A similar approach was the basis for the ACCAD and OSGP groups at Ohio State, at Cornell, and at many other visualization centers.

Cox, D. "Renaissance Teams and Scientific Visualization: A Convergence of Art and Science", Collaboration in Computer Graphics Education, SIGGRAPH 88 Educator's Workshop Proceedings, August 1-5, 1988, p. 81 – 104.
http://www.ncsa.uiuc.edu/People/cox/

Sorensen, Vibeke, The Contribution of the Artist to Scientific Visualization, 1989
http://visualmusic.org/Biography/Index.html

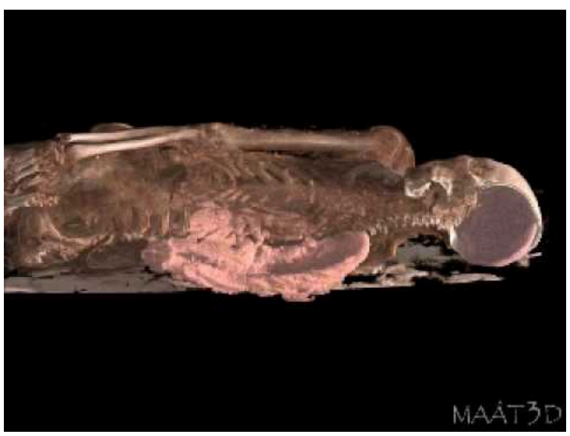
Drebin, R. A., Carpenter, L., and Hanrahan, P. *Volume Rendering*. Computer Graphics 22, 4 (Aug. 1988), 65–74.

Marc Levoy, *Display of Surfaces from Volume Data*, IEEE Computer Graphics and Applications, v.8 n.3, p.29-37, May 1988

Westover, L., Splatting: A Parallel, Feed-Forward Volume Rendering Algorithm. PhD Dissertation, July 1991

David Y. Yun, Hong-Mei C. Garcia, Seong K. Mun, James E. Rogers, Walid G. Tohme, Wayne E. Carlson, Stephen May, and Roni Yagel. "Three Dimensional Volume Visualization in Remote Radiation Treatment Planning", Proceedings of the IS&T/SPIE Symposium on Electronic Imaging: Science and Technology, Visual Data Exploration and Analysis III, The International Society for Optical Engineering, IS&T/SPIE Proc. 2656, February, 1996.

Movie 18.5 Egyptology: 3D Mummy



https://www.youtube.com/watch?v=Il8gZbD9bkM
Medical Visualization: Egyptology in 3D – A revealing high-resolution look at a 2300-year-old mummy – Renderings of the Champollion mummy in VGStudio Max 2.0 reveal the mummy's physiology through transparentized wrapping layers (Toulouse France, 2006)

Chapter 19: Quest for Visual Realism

Quest for Visual Realism

As the CG discipline matured, researchers moved from trying to discover fundamental drawing and rendering techniques, and looked to increasing the *complexity*, and in some respects, the *realism* of synthetic images. This chapter highlights some of these researchers and their contributions.

19.1 Particle Systems and Artificial Life

As the CG discipline has matured, researchers have moved from trying to discover fundamental drawing and rendering techniques, and have looked to increasing the complexity, and in some respects, the realism of synthetic images. Hardware has helped in this quest, but the algorithms that are embedded in hardware were first (usually) written and tested in software, later migrating to hardware.

One of the keys to complex realistic images is to represent the laws of nature and the physical environment in such a way that they are reasonably accurate and consistent, yet approximated in such a way as to allow reasonable computation speeds. CG researchers have often resorted to “tricks” that fool the observer into believing that the physical laws are represented … the proof, as some maintain, is in the believability of the image, not necessarily in the accuracy of the representation.

Some of the more important attempts at realistic image synthesis are covered in the next sections. Many of the researchers are leaders in the field, and many have won awards for their contributions to the discipline.

One of the problems with generating highly complex imagery of an organic and realistic nature is the ability to control motion, change of form, dynamics, and surface characteristics of the models in the scene. An early contribution to the solution of this problem was provided by Bill Reeves, in his seminal paper *Particle Systems – A Technique for Modeling a Class of Fuzzy Objects*, presented at SIGGRAPH 82 and published in the April, 1983 ACM Transactions on Graphics.

Bill Reeves

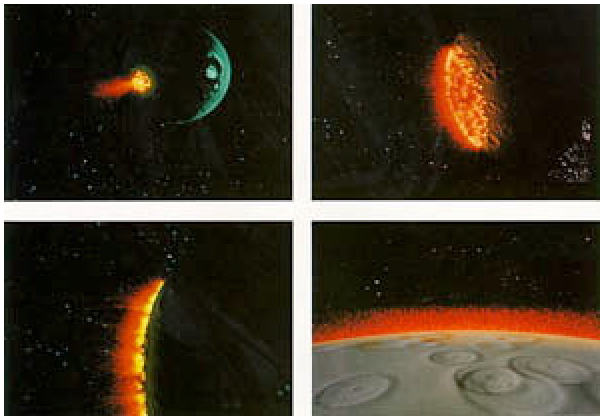
Bill Reeves began his graphics career at the University of Waterloo and at the University of Toronto, where he received his B.S. in math and M.A. and Ph.D. in computer science. In 1980, Reeves joined the computer division of Lucasfilm as project leader of the *systems* group and a member of the computer graphics group. Several years into a career that focused Reeves on the field of animation, he invented the particle systems image synthesis technique that enabled the generation of very complex and detailed images.

From 1982 to 1986, he worked as project leader of the *modeling and animation* group at Lucasfilms. In 1986, Reeves joined Pixar as head of Animation Research and Development. His film credits while at Lucasfilm, Ltd. and Pixar include: *Star Trek II: The Wrath of Khan*, *Return of the Jedi*, *Young Sherlock Holmes*, *Luxo Jr.* (1986 Academy Award nominee), *Red's Dream*, *Tin Toy and Knickknac* and others. In 1988, Reeves received an Academy Award for Best Animated Short Film for his work as technical director on *Tin Toy*.

A particle system is used to describe techniques for modeling, rendering, and animation of dynamic objects. The system involves a collection of particles, each of which has attributes that directly or indirectly impact the behavior of the particle and/or its neighboring particles. The individual particles can be graphical primitives such as points or lines, but they can also be any geometric entity (birds, stones, snowflakes, water drops, etc.) The other characteristic of a particle system is a random element that controls the actions and characteristics of each particle (eg, position, velocity, color, transparency, etc.) The random element is stochastically controlled, meaning that the randomness has bounds, controlled variance, or some mode of distribution.

For the *Star Trek II – The Wrath of Khan Genesis Effect* scene, Reeves and his colleagues were trying to create a wall of fire spreading out from the point of impact of a projectile on a planetary surface. Every particle in Reeve's system was a single point in space and the wall of fire was represented by thousands of these individual points. Each particle had the following attributes:

- Position in 3D space
- Velocity (speed and direction)
- Color
- Lifetime (how long it is active)
- Age
- Shape
- Size
- Transparency



Frames from the Genesis Effect

Each particle in the system is born (or generated), undergoes some dynamic changes, and dies. Particles in the system are generated semi-randomly within the bounds of some initial object. This space is termed the generation shape of the fuzzy object. Each of the particle's attributes is given an initial value that may be fixed or may be determined by a stochastic process.

The particle undergoes dynamics, meaning the attributes of each of the particles may vary over time. That is, each of the particle attributes can be specified by a parametric equation with time as the parameter and they can be functions of both time and other particle attributes. Each particle has its age and lifetime. Age is the time that the particle has been active (measured in frames from its generation). Lifetime is the maximum amount of time that the particle can live. When the particle age matches it's lifetime it is destroyed. There may also be other criteria for terminating a particle before its lifetime bounds. For example

- If a particle moves out of the viewing area and will not reenter it, it can be killed.
- Particles that impact a "ground plane" burn out and can be killed.
- Some other related attribute reaches a bounding threshold. For example, if the particle color is so close to black or the background color that it will not contribute any color to the final image, it can be killed.

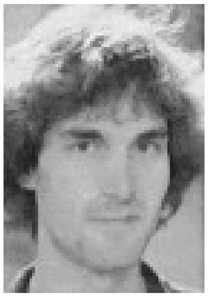
Reeves also used the particle system approach to model bushes in the image *Road to Point Reyes* and trees in the movie *The Adventures of Andre and Wally B.* Each tree was created by using a particle system, and the position of a tree within the forest was also controlled by a particle system. The system can use a "trace" of the trajectory of each particle, and when it dies (eg, at the end of a branch) a leaf can be created.

Gallery 19.1 ILM Particle Systems Images

Road to Point Reyes

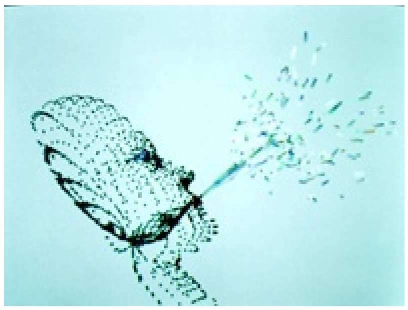
Plants from Road to Point Reyes – Alvy Ray Smith

Trees and vegetation from André and Wally B.



Karl Sims

Karl Sims received a B.S. in Life Sciences from MIT in 1984. After working at Thinking Machines Corporation for a year he returned to MIT to study graphics and animation at the Media Laboratory and received his masters in 1987. He then joined the production research team at Whitney/Demos Production in California, and later became co-founder and director of research for Hollywood based Optomystic. He worked at Thinking Machines Corporation as an artist-in-residence and was sometimes employed elsewhere as a part time consultant. He started GenArts, Inc. in Cambridge, Massachusetts, which created special effects software plugins for various packages used for the motion picture industry.



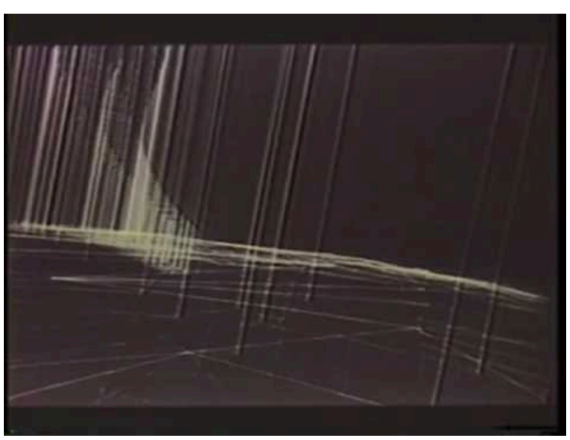
Scene from Particle Dreams

Sims became known for his particle system studies in his short films *Excerpts from Leonardo's Deluge* and *Particle Dreams* (1988). He won the Prix Ars Electronica Golden Nica award two years in a row, in 1991 for *Panspermia*, and in 1992 for *Liquid Selves* and *Primordial Dance*. He has also contributed greatly to the graphics world in the area of artificial evolution and virtual creatures. In 1996, Sims and Gary Oberbrunner created GenArts' Sapphire technology, for use in the creation of visual effects. In 1998 he was awarded a prestigious MacArthur Foundation fellowship.

Sims' company GenArts develops visual effects software for the film, television and video industries. Sims launched GenArts in 1996 out of his barn and just a year later saw his visual effects software used in the making of *Titanic*, the first Oscar winner for the company. The following excerpt is from the company website:

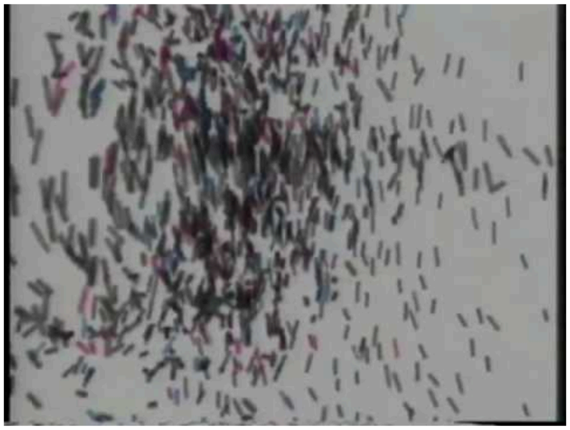
> *"Since the company's founding, GenArts software has been utilized in hundreds of films and in more than 20 Oscar nominated pieces, including Titanic, I Robot, Armageddon, Star Wars Episode I, II and III, The Matrix trilogy, The Lord of the Rings trilogy, Pearl Harbor, Spider Man, Pirates of the Caribbean, Harry Potter and the Prisoner of the Azkaban, Transformers, The Chronicles of Narnia: The Lion, the Witch and the Wardrobe, Iron Man, Benjamin Button, and many more."* http://www.genarts.com/karl/

Movie 19.1 Genesis Sequence



https://www.youtube.com/watch?v=Qe9qSLYK5q4
The making of the Genesis effect from Star Trek II: The Wrath of Khan. Created in 1982 by the Lucasfilm computer graphics division (later to become Pixar).

Movie 19.2 Particle Dreams



https://www.youtube.com/watch?v=tFD4jMMXRbg
Karl Sims movie, Particle Dreams

Movie 19.3 Panspermia (1990)

https://www.youtube.com/watch?v=F4asE2JdSOY
Karl Sims movie, Panspermia

Movie 19.4 Locomotion Studies (1987)
http://www.youtube.com/watch?v=aUdCS1lLiYs

Movie 19.5 Evolved Virtual Creatures – 1994
http://www.youtube.com/watch?v=bBt0imn77Zg

The Adventures of Andre and Wally B.
http://www.youtube.com/watch?v=2doT5t51HGs

"*Particle Systems – A Technique for Modeling a Class of Fuzzy Objects*" B. Reeves, presented at SIGGRAPH 82 and published in the April, 1983 ACM Transactions on Graphics.

"*Artificial Evolution for Computer Graphics*" K.Sims, Computer Graphics (SIGGRAPH 91 proceedings), July 1991, pp.319-328.

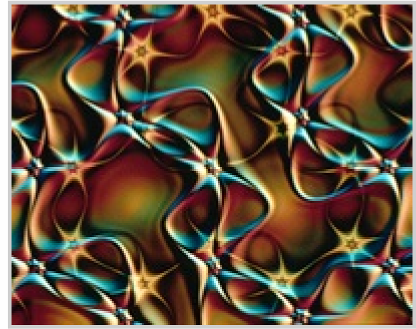
"*Particle Animation and Rendering Using Data Parallel Computation*" K.Sims, Computer Graphics (SIGGRAPH 90 proceedings), Aug. 1990, pp.405-413.

Gallery 19.2 Images from Karl Sims

Scene from Panspermia

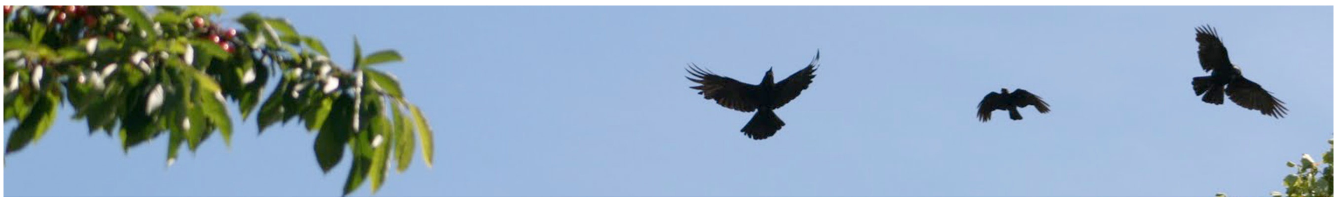
Scene from Panspermia

Scene from Panspermia



Scene from Primordial Dance

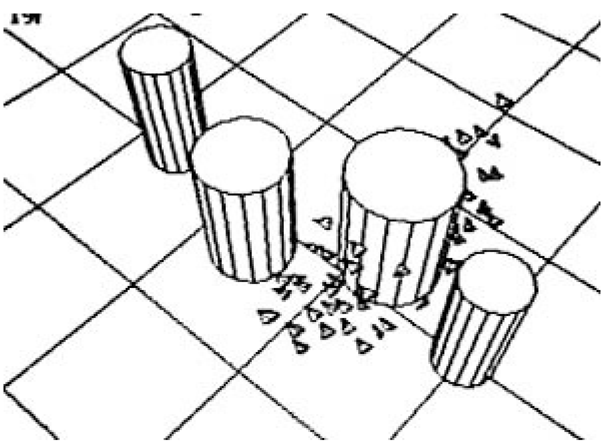
19.2 Flocking Systems



Craig Reynolds

A variation of the particle system was used by **Craig Reynolds** to model the flocking and schooling behavior of birds and fish. In this particle system the particles are used to represent what Reynolds called "boids". In this case, each particle is an entire polygonal object rather than a graphical primitive, each particle has a local coordinate system, and there are a fixed number of particles that are not created or destroyed. The attributes which control the boids behavior is dependent on external as well as internal conditions, allowing a boid particle to react to what other particles are doing around it. Some characteristics of this system include:

- Collision avoidance – a boid is constrained from colliding with other boids or obstacles;
- Velocity matching – each boid attempts to go the same speed and direction as neighboring boids;
- Flock centering – each boid attempts to stay close to nearby flockmates.



Test Scene from Boids

According to Reynolds:

> Typical computer animation models only the shape and physical properties of the characters, whereas behavioral or character-based animation seeks to model the behavior of the character. The goal is for such simulated characters to handle many of the details of their actions, and hence their motions. These behaviors include a whole range of activities from simple path planning to complex "emotional" interactions between characters. The construction of behavioral animation characters has attracted many researchers, but it is still a young field in which more work is needed.

Reynolds' 1986 computer model of coordinated animal motion was based on three dimensional computational geometry. The flocking model placed an individual "boid" in a flock, and determined the motion path using the steering behaviors that were based on the positions and velocities nearby flockmates:

- Separation: steer to avoid crowding local flockmates
- Alignment: steer towards the average heading of local flockmates
- Cohesion: steer to move toward the average position of local flockmates

Scene from Stanley and Stella: Breaking the Ice

Each boid has direct access to the whole scene's geometric description, but it needs to react only to flockmates within a certain small neighborhood around itself. The neighborhood is characterized by a distance (measured from the center of the boid) and an angle, measured from the boid's direction of flight. Flockmates outside the local neighborhood are ignored.

Reynolds produce a short film for the SIGGRAPH 87 electronic theatre called *Stanley and Stella in: Breaking the Ice*. to demonstrate the basic flocking and schooling algorithms in his system, which he called BOIDS. The film was made in conjunction with Symbolics and Whitney/Demos Productions.

Scene from Eurhythmy

Reynolds flocking algorithm was not the first such algorithm. For the famous film *Eurhythmy* produced at Ohio State, Susan Amkraut implemented what she referred to as a "force-field" flocking algorithm. She describes her approach in an interview with later collaborator Paul Kaiser:

> Yes, I'd started working on the problem of flocking. Whereas Michael's [Girard] project [at Ohio State] was to look at the human body in motion, mine was to take a mathematical algorithm and to see where it could lead. I'd begun by animating particles using force-fields in 3D. These force-fields would attract, or repel, or shape the movement of the

> particles. So, for example, I could have a sink that drew all the particles in, or a source they'd funnel out of, or even a spiral they'd fly around. I soon saw how this could lead to an elegant solution for flocking.
>
> The problem posed by flocking is this: you have multiple creatures who don't want to run into each other, but also want to stay very close together — and they have to avoid hitting any external obstacles as well. Algorithms had been developed in which a lead bird guided the flock. But real flocks behave in a more interesting fashion: they have no leader. So, neither did my algorithm, which worked like this. I put a little force-field around every bird, so that if any other bird got near, it was told to go away. And of course each bird had a corresponding attraction field, so that if the other bird got too far away, it was told to come closer. So every bird at every frame of the animation considers every force-field around it, and moves accordingly.
>
> It's a difficult algorithm to work with because you can't tell where you are at any given point in time unless you know where you started and have computed all the way back up from there. My interest in this went beyond wanting to simulate actual flocks. I wanted to create a flock of birds all flying realistically as individuals, but flying collectively in patterns that could never happen in the real world.

As Reynolds points out on his web site, since 1987 there have been many other applications of the boids model in the realm of behavioral animation. The 1992 Tim Burton film *Batman Returns* was the first. It contained computer simulated bat swarms and penguin flocks which were created with modified versions of the original boids software developed at Symbolics. Andy Kopra (then at VIFX, which later merged with Rhythm & Hues) produced realistic imagery of bat swarms. Andrea Losch (then at Boss Films) and Paul Ashdown created animation of an "army" of penguins marching through the streets of Gotham City.

A similar approach was used to produce the famous Wildebeest stampede in the Disney movie *The Lion King*. According to the film notes at *http://www.lionking.org/text/FilmNotes.html*

Wildebeest stampede

> For the pivotal scene in the film where Scar enacts his plan to do away with his royal relatives, Mufasa and Simba, directors Allers and Minkoff wanted to create something with the same visual impact as the dramatic events that were unfolding. The script called for thousands of stampeding wildebeests to pour over the hilltop into the gorge below. Feature Animation's CGI (Computer Generated Imagery) department was called upon to help pull off this amazing feat and to enhance the emotional impact of the scene. Five specially trained animators and technicians in this department spent over two years creating the impressive 2-1/2 minute sequence, which represents a new level of sophistication for the art form and a dramatic highlight for the film.

Starting with a 2-dimensional model sheet and some conventional hand-drawn rough animation, created by supervising animator Ruben Aquino, Johnston and his CGI team were able to generate 3-dimensional representations of a wildebeest inside the computer. Once this digitized computer version existed, the camera could be placed anywhere to allow different angles during the course of a scene.

"Since the scene called for a stampede, we had to come up with a way that our animators could control the behavior of herds of wildebeests without having them bump into each other," says Johnston. "We developed a simulation program that would allow us to designate leaders and followers within each group. We were also able to individualize and vary the movement of each animal within a group to give them a certain random quality.

Effectively they could all be doing different things with the library of behavior including slow and fast gallops, various head tosses and even a few different kinds of leaps."

In the end, the hand-drawn animation of Simba and Mufasa was composited with the CGI wildebeest stampede and the film's other hand-drawn elements (backgrounds and effects). "The object is to make the wildebeests look like the other characters in the film," says Johnston. "We don't want them to stand out. We just want a dramatic effect."

Scene from Titanic

The flocking algorithms developed by Reynolds and others have advanced significantly, and variations on the same approach have been used (coupled with new technologies such as motion capture) to generate crowds and large numbers of animated characters for motion pictures. In the movie *Sharkslayers*, large schools of fish are animated. There are armies in *Star Wars*, *The Mummy, and Lord of the Rings*, colonies of ants in *Antz*, insects in *A Bug's Life*, and passengers on the *Titanic*. Production companies such as PDI and ILM have developed their own approach to crowd control, and software packages like Houdini and Character Studio have included crowd animation components.

Several articles by Barbara Robertson of Computer Graphics World have dealt with crowd animation, including *Crowd Control* in the February, 1998 issue, *Faces and Crowds* in the July 1998 issue, *A Bug's Eye View* in the November 1998 issue, and more recently *The Two Towers* (February 2003).

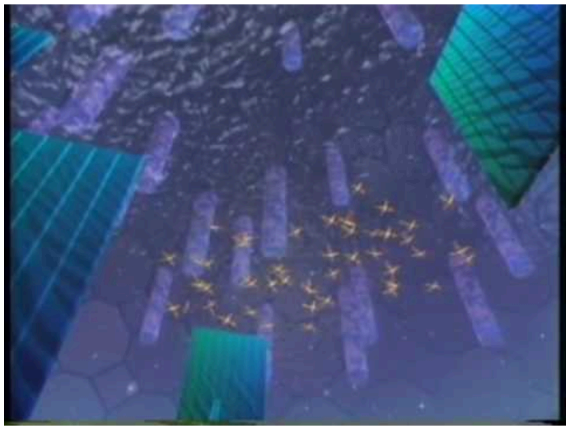
Scene from Two Towers

Movie 19.6 Eurhythmy Motion Studies (1985)

https://www.youtube.com/watch?v=qVcyttQbKP0

Produced at Ohio State by Michael Girard and Susan Amkraut, it uses Amkraut's flocking behavior for the birds animation

Movie 19.7 Stanley and Stella in Breaking the Ice



https://www.youtube.com/watch?v=3bTqWsVqyzE
Animated by Phillipe Bergeron using Craig Reynolds behavioral animation techniques (1987)

Flocks, Herds, and Schools: A Distributed Behavioral Model, Craig Reynolds, Computer Graphics, 21(4), July 1987, pp. 25-34
http://www.cs.toronto.edu/~dt/siggraph97-course/cwr87/

Comprehensive review of flocking literature and contributions:
http://www.red3d.com/cwr/boids/

19.3 Physical-based Modeling

These approaches to defining environments and actions in the “physical world” defined by a computer graphics-based synthetic approach can be considered part of a collective family of algorithmic approaches called physically-based modeling. According to **Demetri Terzopolous**, one of the pioneers of this approach, in a SIGGRAPH 89 panel discussion:

Physically-based techniques facilitate the creation of models capable of automatically synthesizing complex shapes and realistic motions that were, until recently, attainable only by skilled animators, if at all. Physically-based modeling adds new levels of representation to graphics objects. In addition to geometry — forces, torques, velocities, accelerations, kinetic and potential energies, heat, and other physical quantities are used to control the creation and evolution of models. Simulated physical laws govern model behavior, and animators can guide their models using physically-based control systems. Physically-based models are responsive to one another and to the simulated physical worlds that they inhabit.

Centers of activity in the physically-based modeling and animation area included Ohio State (Dave Haumann, James Hahn, Michael Girard and John Chadwick), CalTech (Al Barr, Kurt Fleischer, Ronen Barzel, John Platt) Carnegie Mellon (Andrew Witkin and David Baraff) and Apple Computer (Gavin Miller, Michael Kass, Lance Williams, Ned Greene and others) and later at Pixar (Baraff, Witkin, Fleischer, Barzel and Kass).

Ohio State University

Rigid Body Dynamics – James Hahn

Two early physically based modeling research experiments were done at Ohio State by Dave Haumann and James Hahn. Hahn's 1988 work created an animation system that gave the animator control over the simulation of dynamic interaction between rigid objects, taking into account physical characteristics of friction, mass, motion, elasticity and moments of inertia. His system effectively combined kinematics and dynamics in a computationally efficient method. Hahn went on to continue his research as the Director of The Institute for Computer Graphics at The George Washington University.

Flexible Bodies – Dave Haumann

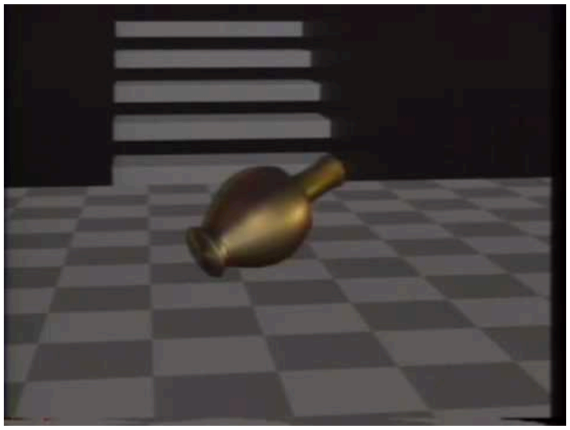
Haumann's work with physically-based simulations used simple mass-spring models, through which he could model bridge cables and tanzan vines. He added vector fields to simulate flags and curtains as well. These effects were shown in a 1988 movie that accompanied a paper in SIGGRAPH. His research was used by Chris Wedge in a 1989 movie produced at Ohio State called *Balloon Guy*. Haumann went to IBM, and experimented with effects for demonstrating the shattering of a physical object. He then experimented with time-varying vector fields, including vortices, sources, sinks and uniform fields for a movie that simulated leaves blowing in these fields. He then expanded his model of leaves, picked a leaf shape that floated nicely, and showed a movie illustrating his work. After IBM he went to Pixar, where he worked on the Pixar short *Geri's Game*.

Hahn, James. "*Realistic Animation of Rigid Bodies*", Computer Graphics, Proceedings SIGGRAPH 88, Association for Computing Machinery (ACM), Vol. 22, No. 4 (August 1988), pp. 299-308

Haumann, D., "Modeling the Physical Behavior of Flexible Objects", in Topics in Physically-Based Modeling, SIGGRAPH Tutorial 17 Notes, 1987.

Jakub Wejchert , David Haumann, Animation aerodynamics, ACM SIGGRAPH Computer Graphics, v.25 n.4, p.19-22, July 1991

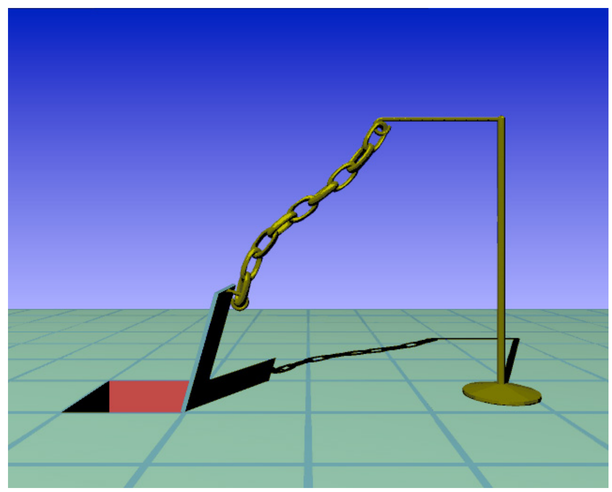
Movie 19.8 Rigid Body Dynamics



https://www.youtube.com/watch?v=AmFYMbJ0Eew
Produced at Ohio State by James Hahn (1987)

Cal Tech

Al Barr advised several important researchers at the Graphics Group at Cal Tech. His students included Ronen Barzel (Pixar), John Platt (Microsoft), David Kirk (NVIDIA), Kurt Fleischer (Pixar) and others. Together with **Andrew Witkin**, Barr coordinated several sessions related to physically-based modeling for the SIGGRAPH courses program (1987-1991), as well as panels and papers on the topic. The list of papers below shows the influence of the CalTech researchers on this area of graphics. A complete list of their publications can be found on their web site at
http://www.gg.caltech.edu/publications.html#papers



Pandora's Chain – Al Barr – CalTech

Dynamic Constraints: A New Paradigm for Computer Graphics Modeling, State of the Art in Image Synthesis, ACM SIGGRAPH 1986

Elastically Deformable Models, with D. Terzopoulos, J. Platt and K. Fleischer, Computer Graphics(21), ACM SIGGRAPH, 1987.

Energy Constraints on Parameterized Models, with A. Witkin and K. Fleischer, Computer Graphics(21), ACM SIGGRAPH, 1987.

Introduction to Physically Based Modeling, Course Notes, with A. Witkin, ACM SIGGRAPH, 1990 and 1991

Topics in Physically-based Modeling, Course Notes, ACM SIGGRAPH, 1987, 1988 and 1989

Physically-Based Modeling: Past, Present, and Future, "Panel Proceedings, D. Terzopoulis chair, ACM SIGGRAPH, 1989

Constraint Methods for Flexible Models, Barr and Platt, Computer Graphics(22), 1988.

Teleological Modeling," Computer Graphics and the Sciences, ACM SIGGRAPH, 1988.

A Modeling System Based on Dynamic Constraints, with R. Barzel, Computer Graphics(22), ACM SIGGRAPH 1988.

Elastically Deformable Models, with D. Terzopoulos, J. Platt and K. Fleischer, Computer Graphics(21), ACM SIGGRAPH, 1987.

Energy Constraints on Parameterized Models, with A. Witkin and K. Fleischer, Computer Graphics(21), ACM SIGGRAPH, 1987.

Ronen Barzel, A Structured Approach to Physically-Based Modeling, Ph.D. Thesis, California Institute of Technology, 1992

Ronen Barzel, Controlling Rigid Bodies with Dynamic Constraints, Master's Thesis, Caltech-CS-TR-88-19, California Tech, 1988


Terzopoulos facial expressions

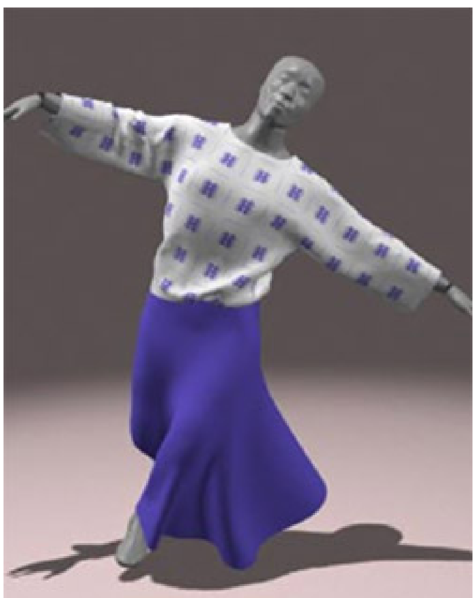
Demetri Terzopoulos received his university education at McGill University (B.Eng. 1978, M.Eng. 1980) and MIT (PhD 1984). He does pioneering work in artificial life, an emerging field that cuts across computer science and biological science. He devises computer models of animal locomotion, perception, behavior, learning and intelligence. Terzopoulos and his students have created artificial fishes, virtual inhabitants of an underwater world simulated in a powerful computer. These autonomous, lifelike creatures swim, forage, eat and mate on their own. Terzopoulos has also done important work on human facial modeling. He has produced what is widely recognized as the most realistic biomechanical model of the human face to date. Expressive synthetic faces are useful in entertainment and human-computer interaction, but they can also play a role in planning reconstructive facial surgery, as well as in automated face recognition and teleconferencing systems. Terzopoulos is widely known as the inventor of deformable models, a family of shape modeling algorithms that have bridged the fields of computer vision and computer graphics and have opened up new avenues of research in medical imaging and computer-aided design.

ACM SIGGRAPH recognized **Andrew Witkin** for his pioneering work in bringing a physics-based approach to computer graphics with the 2001 Computer Graphics Achievement Award. Witkin's papers on active contours (snakes) and deformable models, variational modeling, scale-space filtering, space time constraints, and dynamic simulation are considered landmarks that have been inspirational to others and have shaped the field in such different areas as image analysis, surface modeling, and animation.

He received his Ph.D. at the Massachusetts Institute of Technology in the psychology department. In the early

1980s, the vision and graphics research communities were largely disjoint. Witkin was one of the first to bridge the divide in a series of papers that included his 1987 prize winning paper *Constraints on Deformable Models: Recovering 3D Shape and Non-rigid Motion* and *Snakes: Active Contour Models*, both co-authored with Michael Kass and Demetri Terzopoulos. These papers popularized the idea that computer vision techniques could provide interactive "power assists" to a human operator creating computer graphics models.

While still at Schlumberger, and subsequently as a professor at Carnegie Mellon University, Witkin did notable work on the use of physically-based modeling techniques not only for animating rigid or deformable objects, but also as an interaction technique for a range of problems including constrained geometric modeling and camera control (with Michael Gleicher) and visualization of implicit surfaces (with Paul Heckbert). In 1992, with Michael Kass, Witkin won a Golden Nica from Ars Electronica for his use of physically based modeling of reaction-diffusion equations to synthesize organic looking textures. In 1988 Witkin, with Michael Kass, introduced the idea of using control theory in computer graphics with their *Spacetime Constraints* paper and showed that optimization could be used to direct physically-based character animation.

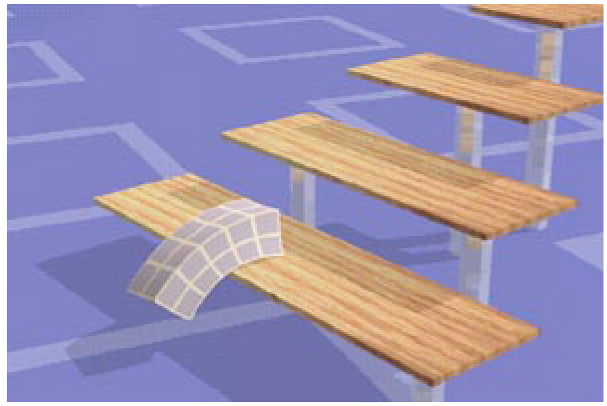


Flowing cloth was difficult to ?describe algorithmically

Witkin then became interested in the very difficult problem of clothing simulation. With David Baraff at Carnegie Mellon University, Witkin developed the clothing simulator which formed the basis of Maya Cloth, and which was used in the production of *Stuart Little*, among other films. With David Baraff and Michael Kass at Pixar Animation Studios, Witkin developed the clothing and hair simulator used in the Pixar/Disney film *Monsters, Inc.*

Monsters Inc. marked Pixar's first extensive use of physical simulation in a feature film. Pixar animators directly controlled the movements of the characters' bodies and faces, but much of their hair and clothing movement was computed using simulations of Newtonian physics. Physical simulation allowed a degree of realism of motion that would not have been possible with traditional methods. Nonetheless, adding this type of simulation into the Pixar production pipeline sometimes caused surprising and amusing results. One of the key developments that allowed clothing simulation to go smoothly during the production was a set of algorithms for untangling simulated clothing when the animation process distorted it significantly. The algorithms allowed the simulator to handle a range of non-physical situations like character interpenetrations without producing unpleasant visual artifacts.

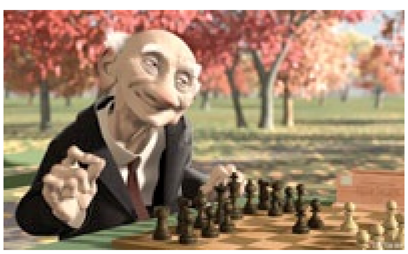
David Baraff joined Pixar Animation Studios in 1998 as a Senior Animation Scientist in Pixar's research and development group. Prior to his arrival at Pixar, he was an Associate Professor of Robotics, and Computer Science at Carnegie Mellon University. Baraff received his Ph.D. in computer science from Cornell University in 1992, and his Bs.E. in computer science from the University of Pennsylvania in 1987. Before and during his graduate studies, he also worked at Bell Laboratories' Computer Technology Research Laboratory doing computer graphics research, including real-time 3D interactive animation and games. In 1992, he joined the faculty of Carnegie Mellon University. In 1995, he was named an ONR Young Investigator.



Dynamic simulation of non-penetrating objects – David Baraff

Apple Advanced Technology Group

Several important contributors to the computer graphics discipline spent time with the research lab at Apple Computer. The Apple Advanced Technology Group (ATG) started in 1986 and worked on many fundamental issues, including human computer interaction, video compression, handwriting analysis, speech synthesis and advanced computer graphics. The group included such CG notables as Eric Chen, Gavin Miller, Michael Kass, Ned Greene, Lance Williams, Frank Crow, David Em, Larry Yaeger, Eric Hoffert, Pete Litwinowicz, Ken Turkowski, Michael Gleicher, and others. They contributed several papers and animations to the physically based modeling community, including computational fluid flow, mass-spring solutions, and dynamics.



Scene from Geri's Game

Michael Kass held a research position at Schlumberger Palo Alto Research before joining the ATG. He then left to become a Senior Scientist at Pixar Animation Studios in 1995. He received his B.A. from Princeton in 1982, his M.S. from M.I.T. in 1984, and his PhD from Stanford in 1988. Kass received numerous awards for his research on physically-based methods in computer graphics and computer vision including several conference best paper awards, the Prix Ars Electronica for the image *Reaction Diffusion Texture Buttons*, and the Imagina Grand Prix for the animation *Splash Dance*, a film he produced with Gavin Miller. Kass published widely, and two of his notable papers dealt with constraint-based dataflow and rapid, stable fluid dynamics. He also contributed to cloth and hair simulation, particularly for *Geri's Game* and *Monsters Inc*.

Gavin Miller and Ned Greene modeled and rendered with fluid flow simulation

Gavin Miller contributed to the animated shorts *Splash Dance* (with Kass), *The Audition* (with Eric Chen), *Flow* (with Ned Greene),and *Her Majesty's Secret Serpent* (with Kass and Lance Williams). He worked on issues of motion dynamics (of snakes and worms), viscous fluid animation, terrain mapping, flexible body motion, and other areas of natural phenomena representation. He received his PhD at Cambridge University and was at Alias before joining ATG. He left to join Adobe, where he worked on Acrobat 3D. The image above shows his fluid flow and his accessibility shading research, with the left model of him and the right of his co-contributor Ned Greene.

Ned Greene graduated from UC-Santa Cruz after working from 1980 to 1989 at NYIT and later at ATG from 1989 to 1996. He worked with Kass and Miller modeling scenes for several animations (*Flow* – 1993, *Splash Dance* – 1990, *The Audition* – 1990), and also on visibility algorithms for rendering complex scenes. Greene left ATG to go to HP and NVIDIA.

Movie 19.9 Flow

https://osu.pb.unizin.org/graphicshistory/wp-content/uploads/sites/45/2017/04/FLOW320-2.m4v

Gavin Miller & Ned Greene – Apple Advanced Technology Group

Movie 19.10 Her Majesty's Secret Service
Apple Technology Group – Gavin Miller and Michael Kass (1989
https://www.youtube.com/watch?v=qtJmulx3c8E

Movie 19.11 Natural Phenomena
Alias and SGI – Gavin Miller (1988)
https://www.youtube.com/watch?v=gL7YiApRvFY

David Baraff and Andrew Witkin. Dynamic simulation of non-penetrating flexible bodies. Computer Graphics, 26:303-308, 1992. Proc. Siggraph ’92.

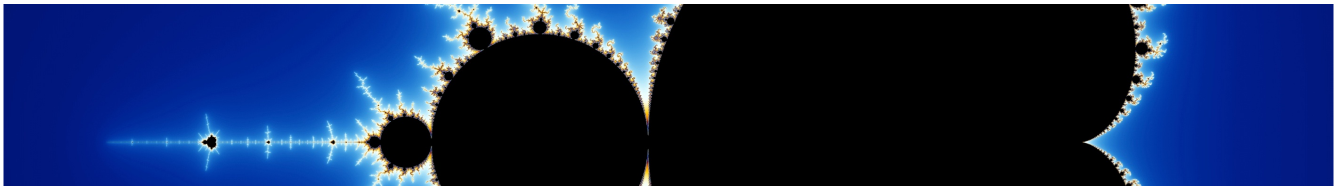
Andrew Witkin and Michael Kass. Reaction-diffusion textures. Computer Graphics, 25(3), July 1991. Proc. Siggraph 91.

Miller, Gavin S. P., “Efficient Algorithms for Local and Global Accessibility Shading”, Proceedings of SIGGRAPH ’94.

Greene, Ned, Michael Kass, Gavin Miller, “Hierarchical Z-Buffer Visibility”, Proceedings of SIGGRAPH ’93.

David Baraff, A. Witkin and M. Kass, “Untangling cloth,” ACM Trans. Graph. 22(3): 862-870 (2003).

19.4 Noise functions and Fractals



Ken Perlin received a B.A. in theoretical mathematics from Harvard University in 1979 and his Ph.D. in Computer Science from New York University in 1986. Perlin started his graphics career as the System Architect for computer generated animation at MAGI (Mathematical Applications Group, Inc.) in Elmsford, NY. While at MAGI he worked on the movie TRON and began thinking about what would be his **noise functions** and how they could be used to efficiently create textures for use in complex images. Between 1984 and 1987 Perlin was Head of Software Development at R/Greenberg Associates in New York. He then became a professor in the Media Research Laboratory in the Department of Computer Science at New York University and served as the co-Director of the NYU Center for Advanced Technology. According to his bio on the NYU site, he has served on the Board of Directors of the New York chapter of ACM/SIGGRAPH, and on the Board of Directors of the New York Software Industry Association. His research interests include graphics, animation, and multimedia. In 2002 he received the NYC Mayor's award for excellence in Science and Technology and the Sokol award for outstanding Science faculty at NYU. In 1991 he received a Presidential Young Investigator Award from the National Science Foundation.

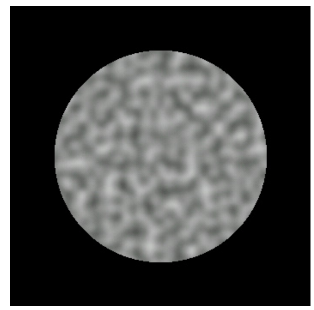
Perlin Noise Function Vase

Perlin Noise Functions

In 1997 Perlin won an Academy Award for Technical Achievement from the Academy of Motion Picture Arts and Sciences for his *noise and turbulence procedural texturing techniques*, which are widely used in feature films and television.

As Perlin said in a lecture at the Game Developers Conference HardCore seminars titled *Making Noise* [1] in 1999,

> "The first thing I did in 1983 was to create a primitive space-filling signal that would give an impression of randomness. It needed to have variation that looked random, and yet it needed to be controllable, so it could be used to design various looks. I set about designing a primitive that would be "random" but with all its visual features roughly the same size (no high or low spatial frequencies).
>
> I ended up developing a simple pseudo-random "noise" function that fills all of three dimensional space (a slice of the 3D is shown here). In order to make it controllable, the important thing is that all the apparently random variations be the same size and roughly isotropic. Ideally, you want to be able to do arbitrary translations and rotations without changing its appearance too much."



Perlin Noise Functions

Perlin modified his noise functions so that he could make naturally looking textures using controllable mathematical expressions, which he integrated into shaders. He later expanded the noise to generate 3D models, a process he dubbed *Hypertexture* in a 1989 paper. A tutorial about Perlin noise, with code, can be found on the scratchapixel.com tutorial site.

Perlin Noise Functions

1. This site is currently offline, but can be found in web archive at https://web.archive.org/web/20160303232627/ http://www.noisemachine.com/talk1/

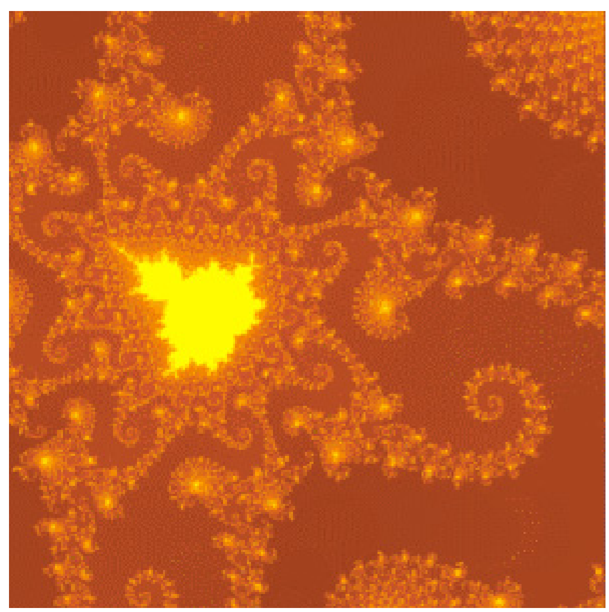
Perlin Noise Functions

Benoit Mandelbrot

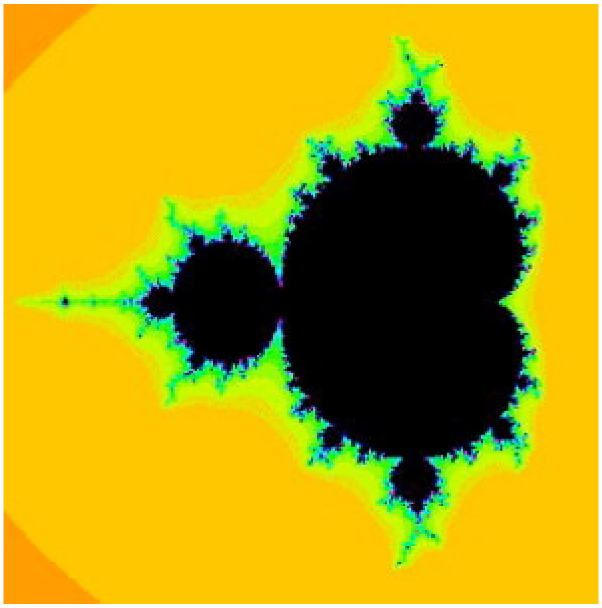
Benoit Mandelbrot is largely responsible for the present interest in **fractal** geometry, which has found its way into the fibre of computer graphics. He showed how fractals can occur in many different places in both mathematics and elsewhere in nature. In 1958, after a stint at the Institute for Advanced Study, he came to the United States permanently and began his long standing collaboration with IBM as an IBM Fellow at their Thomas J. Watson Research Laboratory in Yorktown Heights.

The IBM Watson laboratory provided Mandelbrot the opportunity to research many different concepts and approaches to looking at nature, in his words "an opportunity which no university post could have given me." After retiring from IBM, became a professor at Yale University, where he received tenure and served as the Sterling Professor of Mathematical Sciences.

He had been introduced at an early age to the mathematical concepts of the mathematicians Gaston Julia and his rival Pierre Fatou, whose contributions to the mathematics discipline were important but pretty much forgotten because of their rivalry until Mandelbrot revived a discussion of them. Mandelbrot had been working in other areas of scientific concepts, not in math, until he started rethinking about some areas of geometry and how they could provide a lens for visualizing science. This interest in geometric concepts brought him back to some of the ideas of Julia, in particular the one unifying aspect of certain geometries that was the concept of self-similarity. In the mid-1970s he coined the word "fractal" as a label for the underlying objects, since he observed that they had fractional dimensions.



Fractals



Fractals

A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. Fractals are generally self-similar and independent of scale, that is they have similar properties at all levels of magnification or across all times. Just as the sphere is a concept that unites physical objects that can be described in terms of that shape, so fractals are a concept that unites plants, clouds, mountains, turbulence, and coastlines, that do not correspond to simple geometric shapes.

According to Mandelbrot,

> "I coined fractal from the Latin adjective fractus. The corresponding Latin verb frangere means "to break" or to create irregular fragments. It is therefore sensible – and how appropriate for our needs – that, in addition to "fragmented" (as in fraction or refraction), fractus should also mean "irregular," both meanings being preserved in fragment."
> (The *Fractal Geometry of Nature,* page 4.)

He gives a mathematical definition of a fractal as a set for which the **Hausdorff-Besicovich dimension** strictly exceeds the topological dimension.

With the aid of computer graphics, Mandelbrot was able to show how Julia's work is a source of some of the most beautiful fractals known today. To do this he had to develop not only new mathematical ideas, but also he had to develop some of the first computer programs to print graphics. An example fractal is the Mandelbrot set (others include the Lyapunov fractal, Julia set, Cantor set, Sierpinski carpet and triangle, Peano curve and the Koch snowflake).

To graph the Mandelbrot set a test determines if a given number in the complex number domain is inside the set or outside the set. The test is based on the equation $Z = Z^2 + C$ where C represents a constant number, meaning that it does not change during the testing process. Z starts out as zero, but it changes as the equation is repeatedly iterated. With each iteration a new Z is created that is equal to the old Z squared plus the constant C.

The actual value of Z as it changes is not of interest per se, only its magnitude. As the equation is iterated, the magnitude of Z changes and will either stay equal to or below 2 forever (and will be part of the Mandelbrot set), or it will eventually surpass 2 (and will be excluded from the set). To create the visual representation a color is assigned to a number if it is not part of the Mandelbrot set. The actual color value is determined by how many iterations it took for the number to surpass 2.

Mandelbrot's work was first described in his book *Les Objets Fractals, Forn, Hasard et Dimension* (1975) and later in *The Fractal Geometry of Nature* (1982).

http://en.wikipedia.org/wiki/Fractal

Loren Carpenter was employed at Boeing in Seattle when he decided he wanted to pursue a career in the evolving graphics film production industry. As an engineer at Boeing, Carpenter worked on problems related to the creation of high-quality *renderings of free-form surfaces*. He was also responsible for the development of algorithms for the use of fractal geometry as a tool for creating complex scenes for graphic display.

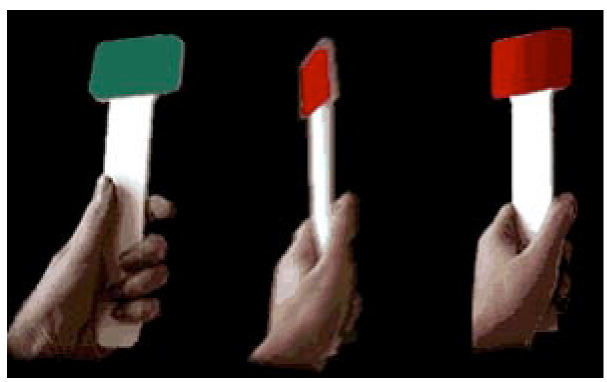
Scene from Vol Libre

In 1980 Carpenter used the fractal concept to create mountains for his film *Vol Libre*, which generated widespread interest in the possibilities that this approach promised. His technical contributions, along with the seminal work with fractals, resulted in a position with Lucasfilm's Computer Division in 1981 (see the sidebar at the end of this section). He recreated the fractal mountains used in *Vol Libre* as part of the *Genesis Demo* for *Star Trek II: The Wrath of Khan*. Another of his contributions, the A-buffer hidden surface algorithm, was central to the systems used by many production companies to create images for television and motion pictures.

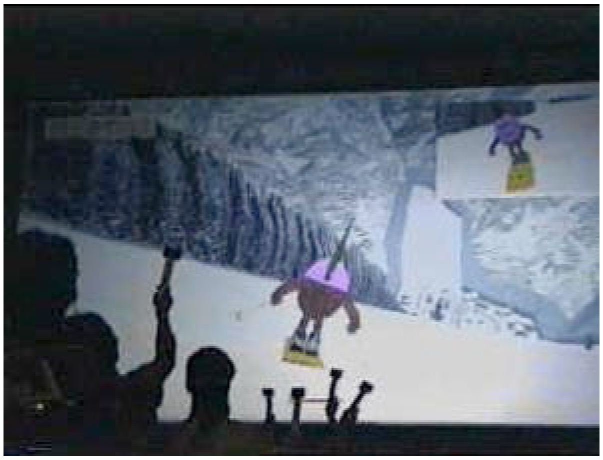
He is the author of numerous fundamental papers in computer image synthesis and display algorithms. His research contributions include **motion blur**, fractal rendering, **scan-line patch rendering**, the **A-buffer**, distributed ray tracing and many other algorithmic approaches to image making. He holds several patents both personally and through Pixar, and his technical awards include the third SIGGRAPH Technical Achievement Award in 1985.

In 1986, when Lucasfilm's Computer Division spun off to form Pixar, Loren became Chief Scientist for the company. In 1993, Loren received a Scientific and Technical Academy Award for his fundamental contributions to the motion picture industry through the invention and development of the RenderMan image synthesis software system. RenderMan has been used by many computer-generated films, including use by Lucasfilm's Industrial Light and Magic to render the dinosaurs in Jurassic Park.

Carpenter also patented an interactive entertainment system which, through the use of simple retroreflectors, allows large audiences to play a variety of games together either as competing teams or unified toward a common goal, such as flying a plane. Enthusiastic audiences have shown that many types of people find this new method of communicating fun and exciting. Concurrently with his leadership of Pixar, Loren and his wife Rachel founded Cinematrix to explore the intersection of computers and art. Cinematrix's Interactive Entertainment Systems division is focusing on the development of an interactive audience participation technology that enables thousands of people to simultaneously communicate with a computer, making possible an entire new class of human-computer interaction.



Cinematrix Wand



Reflectors used by audience to control motion

http://www.cinematrix.com/

Other people involved in using fractals as a basis for their work in image-making include Richard Voss, Ken Musgrave, Michael Barnsley, Melvin Prueitt (and high school and college students all over the world!)

Loren Carpenter, Rob Cook and Ed Catmull – And the Oscar Goes to… (IEEE Spectrum, April 2001)

Movie 19.12 Vol Libre

https://vimeo.com/5810737

1980 film by Loren Carpenter, created while he was at Boeing, and shown to attendees of the 1980 SIGGRAPH conference

The following account is from the book *Droidmaker- George Lucas and the Digital Revolution*, by Michael Rubin.

> Fournier gave his talk on fractal math, and Loren gave his talk on all the different algorithms there were for generating fractals, and how some were better than others for making lightning bolts or boundaries. "All pretty technical stuff," recalled Carpenter. "Then I showed the film."
>
> He stood before the thousand engineers crammed into the conference hall, all of whom had seen the image on the cover of the conference proceedings, many of whom had a hunch something cool was going to happen. He introduced his little film that would demonstrate that these algorithms were real. The hall darkened. And the Beatles began.
>
> Vol Libre soared over rocky mountains with snowy peaks, banking and diving like a glider. It was utterly realistic, certainly more so than anything ever before created by a computer. After a minute there was a small interlude demonstrating some surrealistic floating objects, spheres with lightning bolts electrifying their insides. And then it ended with a climatic zooming flight through the landscape, finally coming to rest on a tiny teapot, Martin Newell's infamous creation, sitting on the mountainside.
>
> The audience erupted. The entire hall was on their feet and hollering. They wanted to see it again. "There had never been anything like it," recalled Ed Catmull. Loren was beaming.
>
> "There was strategy in this," said Loren, "because I knew that Ed and Alvy were going to be in the front row of the room when I was giving this talk." Everyone at SIGGRAPH knew about Ed and Alvy and the aggregation at Lucasfilm. They were already rock stars. Ed and Alvy walked up to Loren Carpenter after the film and asked if he could start in October.
> *(Available as an eBook from the iTunes store)*

Ken Perlin, *An image synthesizer*, SIGGRAPH 1985, pp. 287 – 296.

Ken Perlin and Eric Hoffert, *Hypertexture*, SIGGRAPH 1989, pp. 253 – 262.

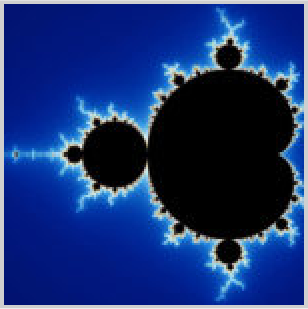
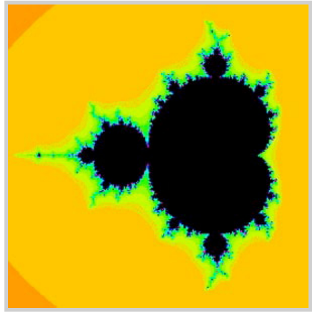
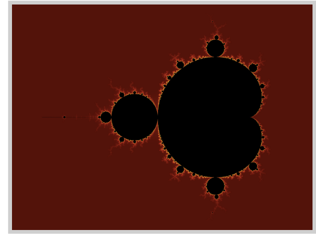
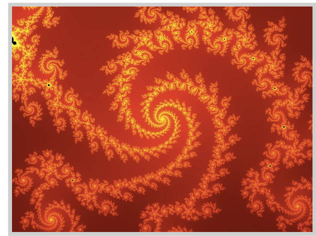
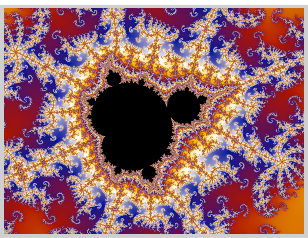
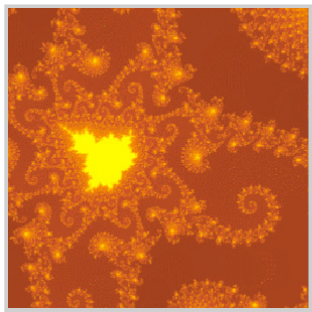
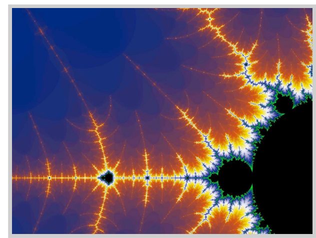
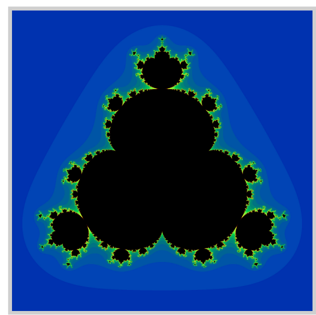
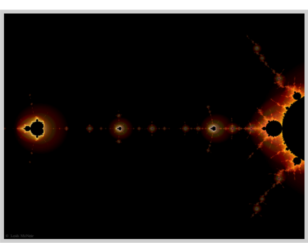
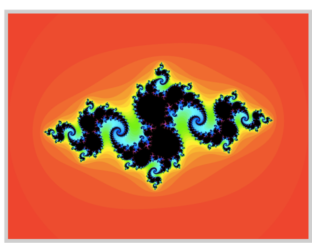
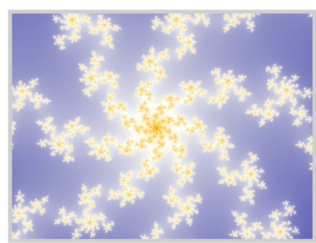
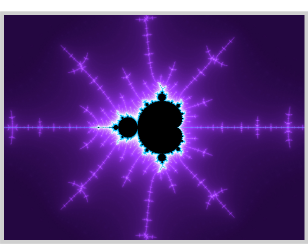
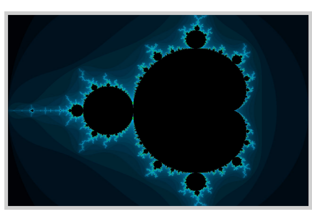
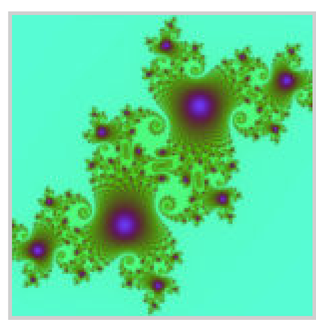
Mandelbrot, B. *Fractals: Form, Chance and Dimension*, W. H. Freeman and Company, 1977, xviii + 265 pp.

Mandelbrot, B. *The Fractal Geometry of Nature*, W. H. Freeman and Company, 1982, xii + 461 + xvi pp. (twenty-two reprints by 2005)

Mandelbrot, B. *Fractals and Chaos: The Mandelbrot Set and Beyond*, New York NY: Springer, 2004, xii + 308 pp.

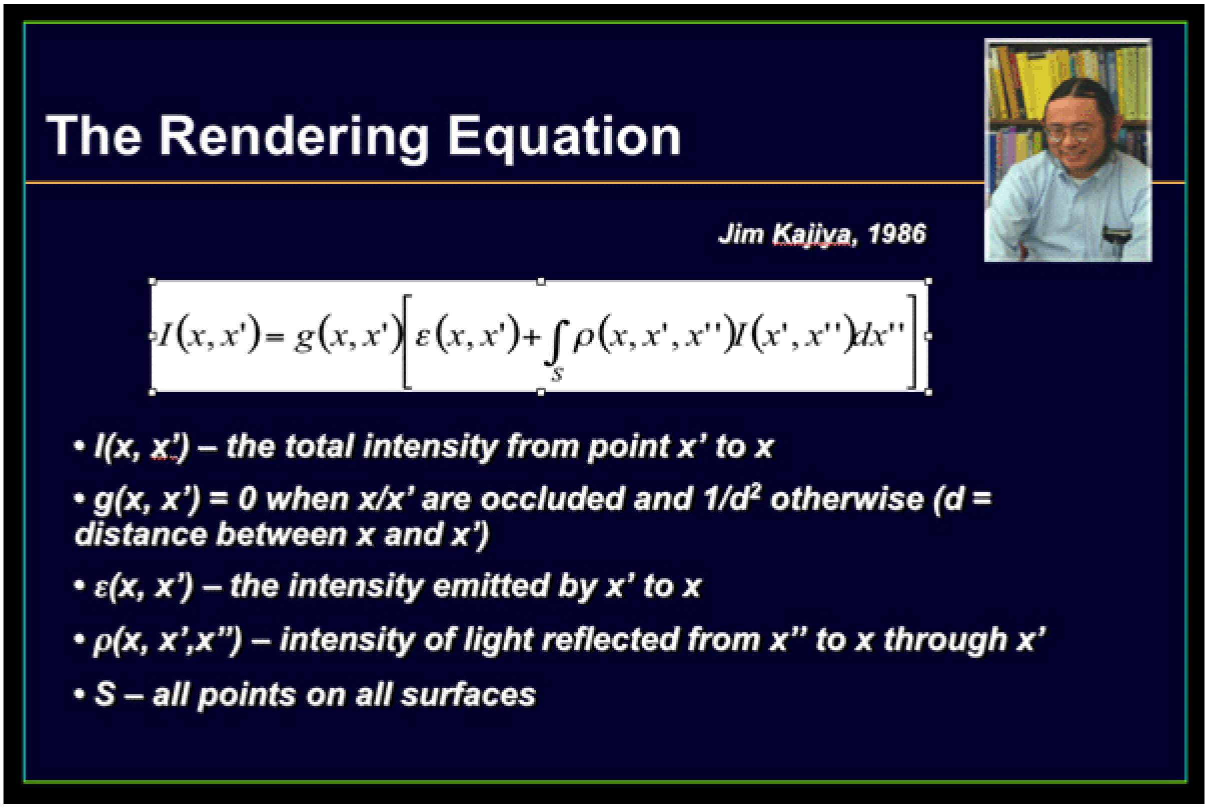
Lane, J., L. Carpenter, T. Whitted, and J. Blinn, "*Scan Line Methods for Displaying Parametrically Defined Surfaces*," CACM, 23(1), January 1980.

Gallery 19.3 Fractal Images

19.5 Global Illumination

Another important component of complex and realistic images is accurate lighting. Lighting is one of the most complicated of all computer graphics algorithms, and it is also one of the most critical for believable images. The lighting is what gives the surface detail that is keyed to the object's physical properties. The basis of most lighting approximation techniques is in estimating the amount of light energy being transmitted, reflected or absorbed at a given point on a surface. Almost every reasonable algorithm is derived from the **rendering equation**, a very important contribution to the field of computer graphics by **James T. Kajiya** of CalTech in 1986. Kajiya based his idea on the theory of radiative heat transfer.



The intensity of light that travels from point x' to point x assumes there are no surfaces between to deflect or scatter the light.
I(x, x') is that energy of radiation per unit time per unit area of source dx' per unit area dx of the target. In many cases, computer graphics researchers do not deal with joules of energy when talking about intensity of light. Instead, more descriptive terms are used. White, for example, is considered a hot (or high intensity) color while deep blues, purples and very dark shades of grey are cool (or low intensity) colors. Once all calculations are done, the numerical value of I(x, x') is usually normalized to the range [0.0, 1.0].

The quantity g(x, x') represents the occlusion between point x' and point x. The value of g(x, x') is exactly zero if there is no straight line-of-sight from x' to x and vice versa. From a geometric standpoint this makes perfect sense. If the geometry of the scene is such that no light can travel between two points, then whatever illumination that x' provides cannot be absorbed and/or reflected at x. If there is, however, some mutual visibility between the two points, g(x, x') is equal to the inverse of r squared where r is the distance from x' to x (a common physics law).

The amount of energy emitted by a surface at point x' reaching a point x is measured in per unit time per unit area of source per unit area of target. This sounds very similar for the units of transport intensity I. The difference however, is that emittance is also a function of the distance between x' and x.

Surfaces are often illuminated indirectly. That is, some point x receives scattered light from point x' that originated from x". The scattering term is a dimensionless quantity.

As one can conclude from the equation itself, evaluating the integrated intensity I for each point on a surface is a very expensive task. Kajiya, in the paper that introduced the rendering equation, also introduced a **Monte**

Carlo method for approximating the equation. Other good approximations have since been introduced and are widely used, but the theory introduced by Kajiya has influenced the derivation of most alternative approaches. Also, much simplified equations for I(x, x') are typically substituted in the case of indoor lighting models.

Global illumination refers to a class of algorithms used in 3D computer graphics which, when determining the light falling on a surface, takes into account not only the light which has taken a path directly from a light source (local illumination), but also light which has undergone reflection from other surfaces in the world. This is the situation for most physical scenes that a graphics artist would be interested in simulating.

Images rendered using global illumination algorithms are often considered to be more photorealistic than images rendered using local illumination algorithms. However, they are also much slower and more computationally expensive to create as well. A common approach is to compute the global illumination of a scene and store that information along with the geometry. That stored data can then be used to generate images from different viewpoints within the scene (assuming no lights have been added or deleted). Radiosity, ray tracing, cone tracing and photon mapping are examples of global illumination algorithms.

Radiosity was introduced in 1984 by researchers at Cornell University (Goral, etal) in their paper *Modeling the interaction of light between diffuse surfaces*. Like Kajiya's rendering equation, the radiosity method has its basis in the theory of thermal radiation, since radiosity relies on computing the amount of light energy transferred between two surfaces. In order to simplify the algorithm, the radiosity algorithm assumes that this amount is constant across the surfaces (perfect or ideal **Lambertian** surfaces); this means that to compute an accurate image, geometry in the scene description must be broken down into smaller areas, or patches, which can then be recombined for the final image.

Form factors used by radiosity algorithm

The amount of light energy transfer can be computed by using the known reflectivity of the reflecting patch and the emission quantity of an "illuminating" patch, combined with what is called the **form factor** of the two patches. This dimensionless quantity is computed from the geometric orientation of the two patches, and can be thought of as the fraction of the total possible emitting area of the first patch which is covered by the second patch.

The form factor can be calculated in a number of ways. Early methods used a hemicube (an imaginary cube centered upon the first surface to which the second surface was projected, devised by Cohen and Greenberg in 1985) to approximate the form factor, which also solved the intervening patch problem. This is quite computationally expensive, because ideally form factors must be derived for every possible pair of patches, leading to a quadratic increase in computation with added geometry.

Ray tracing is one of the most popular methods used in 3D computer graphics to render an image. It works by tracing the path taken by a ray of light through the scene, and calculating reflection, refraction, or absorption of the ray whenever it intersects an object (or the background) in the scene.

For example, starting at a light source, trace a ray of light to a surface, which is transparent but refracts the light beam in a different direction while absorbing some of the spectrum (and altering the color). From this point, the beam is traced until it strikes another surface, which is not transparent. In this case the light undergoes both absorption (further changing the color) and reflection (changing the direction). Finally, from this second surface it is traced directly into the virtual camera, where its resulting color contributes to the final rendered image.

Ray tracing's popularity stems from its realism over other rendering methods; effects such as reflections and shadows, which are difficult to simulate in other algorithms, follow naturally from the ray tracing algorithm. The main drawback of ray tracing is that it can be an extremely slow process, due mainly to the large numbers of light rays which need to be traced, and the larger number of potentially complicated intersection calculations between light rays and geometry (the result of which may lead to the creation of new rays). Since very few of the potential rays of light emitted from light sources might end up reaching the camera, a common optimization is to trace hypothetical rays of light in the opposite direction. That is, a ray of light is traced starting from the camera into the scene, and back through interactions with geometry, to see if it ends up back at a light source. This is usually referred to as backwards ray tracing.

Nonetheless, since its first use as a graphics technique by Turner Whitted in 1980, much research has been done on acceleration schemes for ray tracing; many of these focus on speeding up the determination of whether a light ray has intersected an arbitrary piece of geometry in the scene, often by storing the geometric database in a spatially organized data structure. Ray tracing has also shown itself to be very versatile, and in the last decade ray tracing has been extended to global illumination rendering methods such as photon mapping and Metropolis light transport.

Photon mapping is a ray tracing technique used to realistically simulate the interaction of light with different objects. It was pioneered by Henrik Wann Jensen. Specifically, it is capable of simulating the refraction of light through a transparent substance, such as glass or water, diffuse inter-reflections between illuminated objects, and some of the effects caused by particulate matter such as smoke or water vapor.

In the context of the refraction of light through a transparent medium, the desired effects are called caustics. A caustic is a pattern of light that is focused on a surface after having had the original path of light rays bent by an intermediate surface.

With photon mapping (most often used in conjunction with ray tracing) light packets (photons) are sent out into the scene from the light source (reverse ray tracing) and whenever they intersect with a surface, the 3D coordinate of the intersection is stored in a cache (also called the photon map) along with the incoming direction and the energy of the photon. As each photon is bounced or refracted by intermediate surfaces, the energy gets absorbed until no more is left. We can then stop tracing the path of the photon. Often we stop tracing the path after a pre-defined number of bounces, in order to save time.

Also to save time, the direction of the outgoing rays is often constrained. Instead of simply sending out photons in random directions (a waste of time), we send them in the direction of a known object that we wish to use as a photon-manipulator to either focus or diffuse the light.

This is generally a pre-process and is carried out before the main rendering of the image. Often the photon map is stored for later use. Once the actual rendering is started, every intersection of an object by a ray is tested to see if it is within a certain range of one or more stored photons and if so, the energy of the photons is added to the energy calculated using a more common equation.

There are many refinements that can be made to the algorithm, like deciding where to send the photons, how many to send and in what pattern. This method can result in extremely realistic images if implemented correctly.

Paul Debevec

Paul Debevec earned degrees in Math and Computer Engineering at the University of Michigan in 1992 and a Ph.D. in Computer Science at UC Berkeley in 1996 [1]. He began working in image-based rendering in 1991 by deriving a textured 3D model of a Chevette from photographs for an animation project. At Interval Research Corporation he contributed to Michael Naimark's Immersion '94 virtual exploration of the Banff National forest and collaborated with Golan Levin on Rouen Revisited, an interactive visualization of the Rouen Cathedral and Monet's related series of paintings. Debevec's Ph.D. thesis presented an interactive method for modeling architectural scenes from photographs and rendering these scenes using **projective texture-mapping**. With this he led the creation of a photorealistic model of the Berkeley campus for his 1997 film *The Campanile Movie* whose techniques were later used to create the virtual backgrounds for the "bullet time" shots in the 1999 Keanu Reeves film *The Matrix*.

Scene from Fiat Lux

Since his Ph.D. Debevec has worked on techniques for capturing real-world illumination and illuminating synthetic objects with real light, facilitating the realistic integration of real and computer generated imagery. His 1999 film *Fiat Lux* placed towering monoliths and gleaming spheres into a photorealistic reconstruction of St. Peter's Basilica, all illuminated by the light that was actually there. For real objects, Debevec led the development of the Light Stage, a device that allows objects and actors to be synthetically illuminated with any form of lighting. In May 2000 Debevec became the Executive Producer of Graphics Research at USC's Institute for Creative Technologies, where he directs research in virtual actors, virtual environments, and applying computer graphics to creative projects.

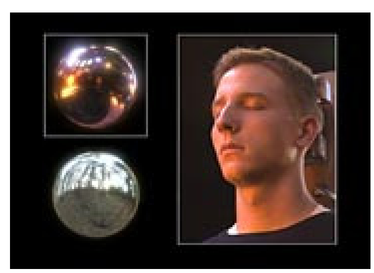


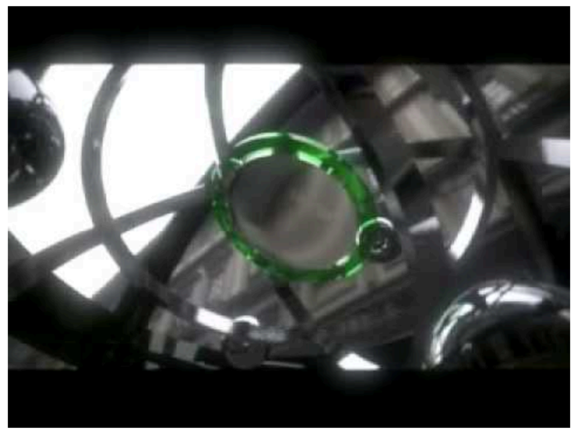
Image-based lighting

1. from Paul Debevec's bio at http://www.debevec.org/

Rendering with Natural Light

In 2001 Paul Debevec received ACM SIGGRAPH's first Significant New Researcher Award for his Creative and Innovative Work in the Field of Image-Based Modeling and Rendering, and in 2002 was named one of the world's top 100 young innovators by MIT's Technology Review Magazine.

Movie 19.13 Fiat Lux – The Movie



http://www.pauldebevec.com/FiatLux/movie/
Produced in 1999 by Paul Debevec showing elaborate lighting techniques

Kajiya, Jim, The Rendering Equation, Computer Graphics, 20(4):143-150, Aug. 1986.

Cindy Goral, Ken Torrance, Don Greenberg and B. Battaile, *Modeling the interaction of light between diffuse surfaces*. Computer Graphics, V18, #3, July 1984.

Paul Debevec is the consummate researcher and is very prolific in publishing and filmmaking. An extended list of his research, projects and films is at

http://www.pauldebevec.com
His publication list can be found at
http://ict.debevec.org/~debevec/Publications/

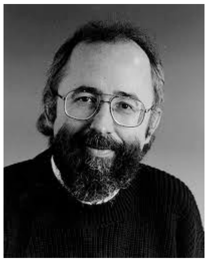
Movie 19.14 Campanile
http://www.youtube.com/watch?v=RPhGEiM_6lM

Movie 19.15 Rendering with Natural Light (Radeon implementation)
http://www.youtube.com/watch?v=fW_GPCR9_GU

Movie 19.16 Simulation of the Parthenon Lighting
http://www.youtube.com/watch?v=QeWLpTLzZVc

Movie 19.17 Presentation by Paul Debevec
Achieving Photo-Real Digital Actors
Palo Alto Film Festival
http://www.youtube.com/watch?v=VKx_DZp_0EI

19.6 Plants



Przemyslaw Prusinkiewicz

Dr. Przemyslaw Prusinkiewicz's interest in computer graphics began in the late 1970s. By 1986 he originated a method for visualizing the structure and growth of plants based on **L-systems**, a mathematical theory of development of multicellular organisms introduced by the late Professor Aristid Lindenmayer. Prusinkiewicz, his students, and collaborators transformed L-systems into a powerful programming language for expressing plant models, and extended the range of phenomena that can be simulated. Specifically, parametric L-systems facilitate the construction of models by assigning attributes to their components. Differential L-systems make it possible to simulate plant growth in continuous time, which is essential to the animation of developmental processes. Environmentally-sensitive and open L-systems provide a framework for simulating the interactions between plants and their environment. The power of these concepts is demonstrated by the wide range of biological structures already modeled, from algae to wild flowers to gardens and stands of trees competing for light.

In addition to the important extensions of L-systems, Prusinkiewicz's research also includes studies of fundamental problems of morphogenesis – emergence of patterns and three dimensional forms in nature. This includes the modeling of spiral phyllotactic patterns in plants, and developmental patterns and forms of seashells.

As a result of the research on the extension of L-systems, plants can be modeled with unprecedented visual and behavioral fidelity to nature. Prusinkiewicz authored the book, *The Algorithmic Beauty of Plants*, demonstrating that plant models can be combined artistically into stunning and inspiring images. His website, Visual Models of Morphogenesis: A Guided Tour is a spectacular explanation of the techniques used to model organic shapes such as plants.

The website for Prusinkiewicz' research lab at the University of Calgary can be found at

http://www.cpsc.ucalgary.ca/Research/bmv/vmm-deluxe/TableOfContents.html

John Hutchinson demonstrated in 1981 a branch of mathematics now known as *Iterated Function Theory*. Later in the decade Michael Barnsley, a leading researcher from Georgia Tech, wrote the popular book *Fractals Everywhere*. The book presented the mathematics of **Iterated Functions Systems** (IFS), and proved a result known as the Collage Theorem.

An IFS fractal, according to Barnsley, is defined by a set of elementary geometric transformations which are called "linear" or "**affine**" by mathematicians. In the everyday language, they are a combination of

- translations
- rotations
- linear compressions along the vertical or horizontal axis, or both. The compression ratios along the two axes can be different.
- vertical or horizontal shears, such that a rectangle is transformed into a parallelogram through the sliding of a side along itself.

The only requirement is that the transformations must be contractive, i.e. the distance between two points must decrease (at least, not increase) in the transformation.The transformations to be implemented in the IFS set depend upon the figure to be redrawn. As Barnsley stated, "There is a magical precept that must be satisfied: if the target figure is transformed through the various transformations in the set, one must get exact parts of this figure, and superimposing all these parts must reconstruct the whole figure."

Barnsley introduced the theory of Iterated function systems (IFS): with a small set of affine transformations it is possible to generate every type of self-similar fractals. Based on IFS, Barnsley has a patent for an algorithm that compresses every picture to FIF: fractal image format.

The Collage Theorem presented a possibility that intrigued researchers, particularly Barnsley and some of his students. If, in the forward direction, fractal mathematics is good for generating natural looking images, then, in the reverse direction, could it not serve to compress images? Going from a given image to an Iterated Function System that can generate the original (or at least closely resemble it), is known as the inverse problem.

Barnsley and his research team applied the Collage Theorem to try and solve the inverse problem, and published the technique in articles for Computer Graphics World and a famous article in the January 1988 Byte Magazine issue. He and Alan Sloan applied for and were granted a software patent, and left Georgia Tech to found Iterated Systems Inc. This Byte article didn't really address the inverse problem directly, but it did exhibit several images purportedly compressed in excess of 10,000:1.

The images were given suggestive names such as "Black Forest" and "Monterey Coast" and "Bolivian Girl" and they were all manually constructed.

M.F. Barnsley and S. Demko, *Iterated function systems and the global construction of fractals*, Proc. Roy. Soc. London A399, 243-275 (1985).

J. Hutchinson, *Fractals and self-similarity*, Indiana Univ. J. Math. 30, 713-747 (1981).

M.F. Barnsley, V. Ervin, D. Hardin and J. Lancaster, *Solution of an inverse problem for fractals and other sets*, Proc. Nat. Acad. Sci. USA 83, 1975-1977 (1985).

Barnsley, M.F., *Fractals Everywhere*, Academic press, 1988

Barnsley, M.F., and Sloan, A.D., *A Better Way to Compress Images*, Byte Magazine, January 1988, Pages 215-222

Barnsley and Sloan, *Chaotic Compression*, Computer Graphics World, November 1987. Pennwell Publishing

Midori Kitagawa, an associate professor in the Department of Art and the Advanced Computing Center for the Arts and Design at Ohio State, developed the Branching Object Generation and Animation System (BOGAS) [1] to create realistic models of trees, plants, blood vessels, nervous systems, underwater animals and even imaginary

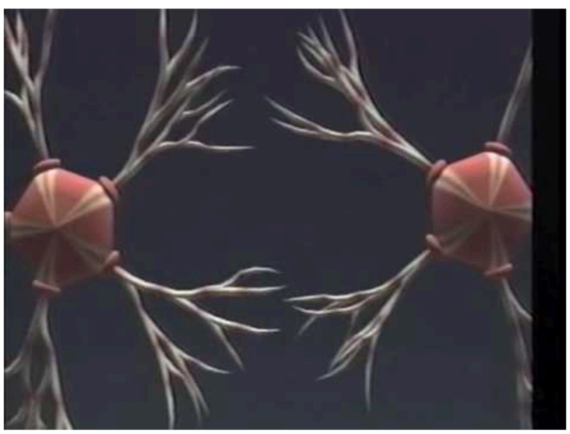
1. Kitagawa developed the Branching Object Generation and Animation System (BOGAS) which generated and animated branching structures, such as trees and plants. It was used in visualization research and art making.

creatures. The system was designed to help scientists, botanists and artists visualize realistic branching objects, permitting them to generate the objects interactively and then to see how factors like gravity and sunlight affect growth.

Scene from I Have Never Seen, But I Know…

Scene from I Have Never Seen, But I Know…

Movie 19.18 I Have Never Seen, But I Know…



https://www.youtube.com/watch?v=Xb50LQ8lhAU

Film by Midori Kitagawa (1990) using the BOGAS system for plant generation. Music by Daniel Remler (Ohio State University ACCAD)

Kitagawa De Leon, M. *Branching Object Generation and Animation System with Cubic Hermite Interpolation*, Journal of Visualization and Computer Animation. 2, 2, 60-67, 1994.

Images in the gallery below, in order are:

Developmental sequence of Mycelis muralis.
Copyright © 1987 P. Prusinkiewicz and J. Hanan.

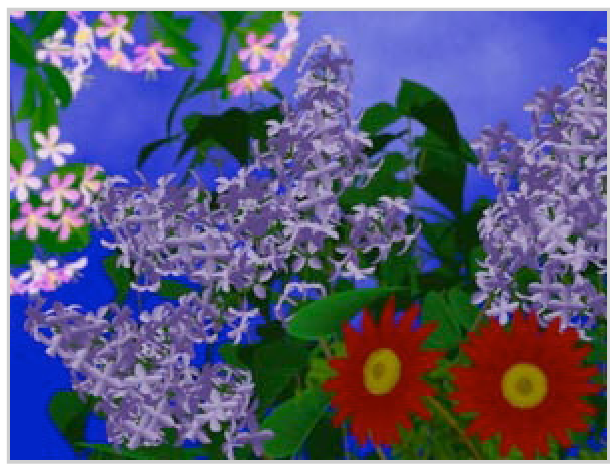
The Garden of L.
Copyright © 1988 P. Prusinkiewicz, F.D. Fracchia, J. Hanan, and D. Fowler.

Green coneflower.
Copyright © 1992 D. Fowler, P. Prusinkiewicz, and J. Battjes.

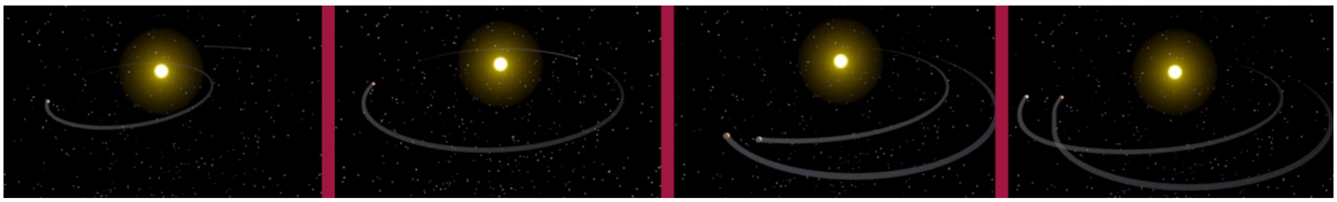
Table of cacti, including realistic models of the elongated Mammillaria spinosissima.
Copyright © 1992 D. Fowler, P. Prusinkiewicz, and J. Battjes.

Topiary dinosaur.
R. Mech, P. Prusinkiewicz, and B. Wyvill.
Copyright © 1994 P. Prusinkiewicz.

Gallery 19.4 Images from Prusinkiewicz

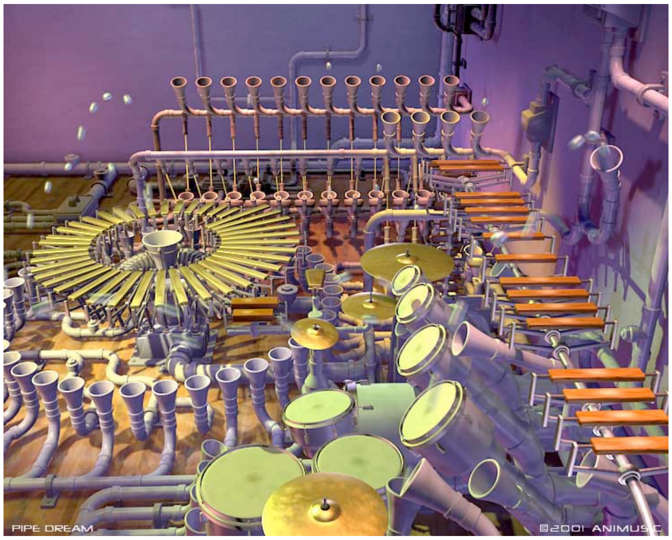


19.7 Data-driven Imagery



Wayne Lytle began his graphics career as a visualization staff member at the Cornell Theory Center. He received a Master's degree from Cornell in 1989 with his thesis titled "*A modular testbed for realistic image synthesis*". His first full multi-instrument music animation *More Bells and Whistles* premiered in the Electronic Theater at SIGGRAPH 1990. It has since won awards and been shown in various contexts world-wide. In 1991 Lytle received an award from IBM for his early work in music animation. Lytle also contributed to the debate about standards for visual representation, which persists along with questions about numerical simulations. This was illustrated by an animation from the Cornell Theory Center by Lytle called *The Dangers of Glitziness and Other Visualization Faux Pas*, using fictitious software named *Viz-o-Matic*. The video, shown in the Electronic Theater at SIGGRAPH 93, documented the enhancement and subsequent "glitz buffer overload" of a sparsely data-driven visualization trying to masquerade as a **data-driven**, thoughtfully rendered presentation.

Scene from More Bells and Whistles



Scene from Pipe Dreams

In 1995, Lytle formed Animusic, a content creation company. Two of the more famous animations are *Stick Figures* and *Pipe Dreams*, shown at SIGGRAPH 2000 and 2001, respectively. The principle focus of Animusic is the production of 3D computer graphics music animation. Animusic uses proprietary motion generation software called MIDImotion™. Without this software, animating instruments using traditional "keyframing" techniques would be prohibitively time-consuming, and inaccurate. By combining motion generated by approximately 12 algorithms (each with 10 to 50 parameters), the instrument animation is automatically generated with sub-frame accuracy. If the music is changed, the animation is regenerated effortlessly.

The technique differs significantly from reactive sound visualization technology, as made popular by music player plug-ins. Rather than reacting to sound with undulating shapes, the animation is correlated to the music at a note-for-note granularity, based on a non-real-time analysis pre-process. Animusic instruments generally appear to generate the music heard, rather than respond to it.

Scene from Scene from Stick Figures

At any given instant, not only do they take into account the notes currently being played, but also notes recently played and those coming up soon. These factors are combined to derive "intelligent", natural-moving, self-playing instruments. And although the original instruments created for the"video album" are reminiscent of real instruments, the motion algorithms can be applied to arbitrary graphics models, including non-instrumental objects and abstract shapes.

Movie 19.19 More Bells and Whistles

http://www.youtube.com/watch?v=qSdR4gFumps

Movie 19.20 Stick Figures

https://www.youtube.com/watch?v=LM6kB6ce_5M

Movie 19.21 Pipe Dreams

https://www.youtube.com/watch?v=Xu-A0jqMPd8

The Dangers of Glitziness and Other Visualization Faux Pas

Steve May, **Kirk Bowers**, and **Mark Fontana** produced in 1997 an animation titled *Butterflies in the Rain*, which tells the story of a butterfly exploring a piano that is mysteriously being played by water droplets falling from above. The piece is accompanied by and algorithmically synchronized to MIDI music data transcribed from the reproducing piano roll *Butterflies in the Rain*, a piece from the 1930's composed by Sherman Myers and played by Frank Milne.

Scenes from "Butterflies in the Rain"

The animation makes extensive use of procedural techniques. All modeling and animation was done using AL, an animation system developed by Steve May. PhotoRealistic RenderMan ® (Pixar) was used for rendering. Houdini (Side Effects) was used for compositing. All work was performed on Silicon Graphics workstations.

Movie 19.22 Butterflies in the Rain

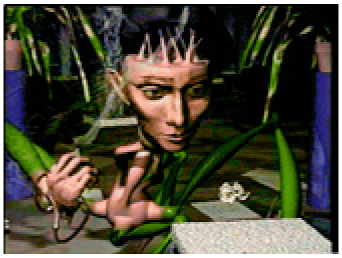
https://www.youtube.com/watch?v=lVXmtckavDQ

Based on a concept by Brad Winemiller, this film was produced by Kirk Bowers, Mark Fontana and Steve May at The Ohio State University's Advanced Computing Center for the Arts and Design (ACCAD). Additional modeling support (piano harp and strings) was provided by Phil Massimi. Software used was emacs (text editor) for modeling, Steve May's Scheme-based Animation Language ("AL") for animation, GIMP for texture maps, Pixar's RenderMan for rendering, and Side Effects' Houdini for compositing.

19.8 Character motion

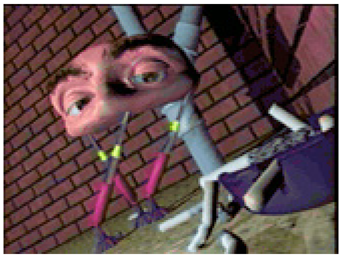
Chris Landreth

After graduating from the University of Illinois with a specialty in mechanical engineering, **Chris Landreth** joined the North Carolina Supercomputing Center as a scientific visualization animator. He later became a Senior Animator at NCSC, where he produced his famous animation *Data Driven: The Story of Franz K.* (1993) in which various artistic elements were mixed with scientific visualization procedures to create a compelling animation.



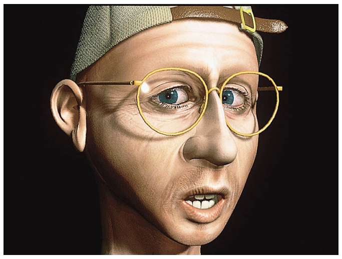
Scene from Date Driven: The Story of Franz K.

In 1994, he went to Alias/Wavefront as a Senior Animator, where he produced *the end* (which won a number of awards in addition to an Academy Award nomination.) He has become known for his advanced character animations and scientific visualizations which explore unique ways of representing humanity and nature.



Scene from The Listener

Other Landreth works include *The Listener* (1991), *Caustic Sky: A Portrait of Regional Acid Deposition* (1992), and *Bingo* (1998). *Bingo* is based on the short play *Disregard This Play* by Chicago's Neo-Futurist Theatre Company. The story deals with the age-old question: "What if a lie is told long enough and loud enough?" *Bingo* is the first animated short fully produced with Alias/Wavefront's animation software, Maya.



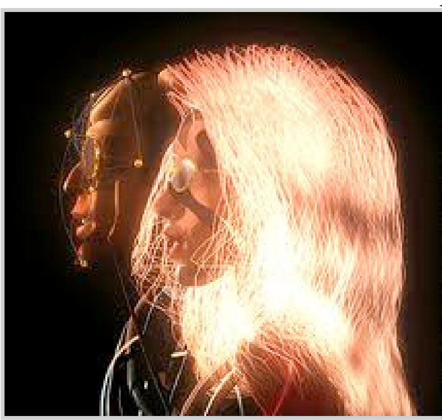
Scene from Bingo

Scene from Bingo

Bingo was originally conceived as an extensive in-house quality assurance project aimed at rigorously testing and demonstrating the technical capabilities of Maya. In Landreth's words, "This was in many ways a very unusual production. We were an ad-hoc production studio within a software development company. During this production, people who were programmers, testers and expert users became some of the most brilliant modelers, animators, technical directors and rendering artists I've ever seen in a production environment."

Ryan

The following text is by Amy Johns from the October, 1998 Wired Magazine:

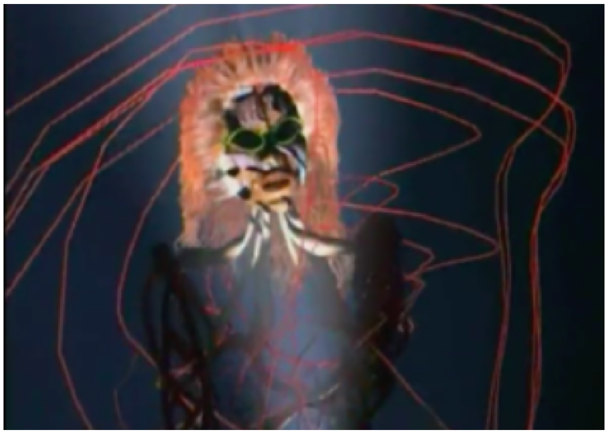


Beta testers don't usually get much attention on Oscar night. But Chris Landreth – who was nominated for an Academy Award for his 1996 all-digital short *The End* – is not your usual guy. A senior animator at Alias|Wavefront, Landreth says his job is "to be a tyrant." Long before his company's Maya program hit top f/x houses, Landreth put it to the test, searching for bugs and demanding new features.

For this untrained artist and onetime mechanical engineer, working at Alias is a "Faustian deal." He pushes, prods, and tests products, and in exchange he gets company time to create his own animations. His latest tour de force, Bingo, is a disturbing short based on a play by Chicago's Neo-Futurists. The eerily lifelike effects – from the swing of a pigtail to the twitch of an eyebrow – exploit features Landreth wrested from coders during a year and a half of testing.

In the increasingly specialized CG industry, Landreth relishes his dual role: "I am able to be technical – to help design the software – and at the same time be an artist who tells a story with those tools."

Movie 19.23 *the end* – Chris Landreth



https://vimeo.com/23454509.

"the end" was a short film produced by animator Chris Landreth to demonstrate the capabilities of the Alias/Wavefront suite of software modules. It was nominated for an Academy Award in 1996

Movie 19.24 *Bingo* – Chris Landreth

https://vimeo.com/23191218

Created in 1998, this film was produced by animator Chris Landreth as part of the development of the Maya animation system.

Scientific Visualization article by Landreth and Rheingold
http://www.cs.umbc.edu/~rheingan/pubs/perception.html

"*Hair-Raising Effects*"
Barbara Robertson, CGW October 1995 (hair simulation)

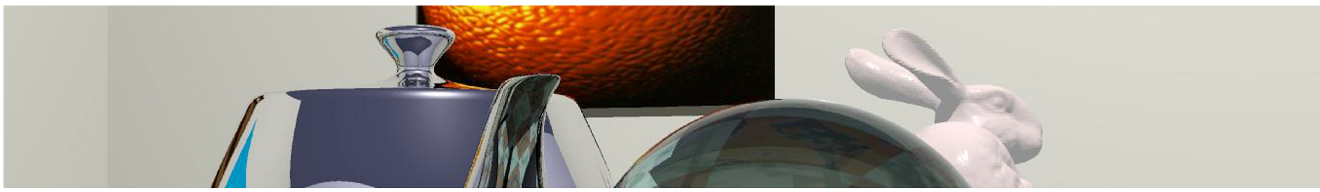
"*Read My Lips*"
Barbara Robertson, CGW August 1997 (lip-synch)

Chapter 20: CG Icons

CG Icons

Computer Graphics researchers and animators commonly used 3D objects for algorithm and system testing. The more they were used, the more iconic they became.

20.1 CG Icons



The Teapot

The Utah teapot is a 3D model which has become a standard reference object in the computer graphics community. It is a simple, round, partially concave mathematical model of an ordinary teapot.

The teapot data was created in 1975 by early computer graphics researcher Martin Newell, a member of the pioneering graphics program at the University of Utah. Newell needed a moderately simple mathematical model of a familiar object for his work, and his wife's teapot (a Melitta) provided a convenient solution. The shape contains a number of elements that make it ideal for the graphics experiments of the time – it's round, contains saddle-points, has a concave element (the hole in the handle), and looks reasonable when displayed without a complex surface texture.

Utah Teapot c. 1974

Newell made the mathematical data which describes the teapot's geometry (largely a set of three-dimensional coordinates) publicly available, and soon other researchers began to use the same data for their computer graphics experiments. These researchers needed something with roughly the same characteristics that Newell had, and using the teapot data meant they didn't have to laboriously enter geometric data for some other object. Although technical progress meant that the simple act of rendering the teapot was no longer the challenge it was in 1975, the teapot continued to be used as a reference object for increasingly advanced graphics techniques. The common (rather squat) appearance of the teapot differs from the

Melita original, reportedly because Newell's colleague Jim Blinn transformed it to compensate for the non-square pixels on his early frame buffer.

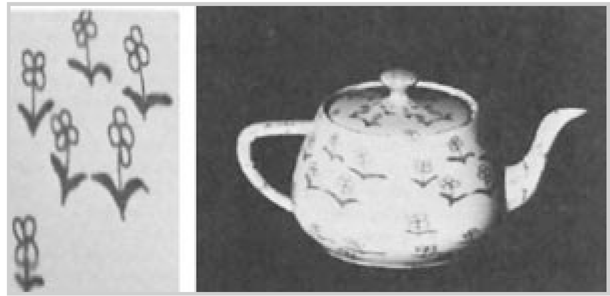
As the most common of the graphics icons, it was featured at the SIGGRAPH 89 conference in a "Call for Teapots" as part of the "Call for Participation".

> Originally purchased by graduate student Martin Newell in a Salt Lake City, Utah, department store, this ordinary teapot became a famous model used by many pioneers of the computer graphics community. Researchers developing rendering algorithms for texture and shading tested them on the data that described the teapot's shape. The actual teapot is about 30% taller than many of its computer-generated images because the data was originally recorded for the rectangular pixels of early displays.

Scene from cover of Conference Proceedings

Image from a video by Frank Crow to demonstrate capabilities of III software

Texture maps and reflection maps from Ed Catmull's dissertation

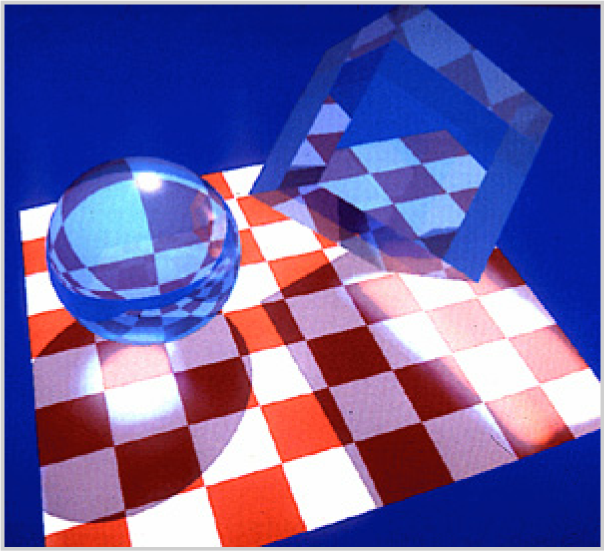


Ray-traced image by Arvo and Kirk – The Six Platonic Solids

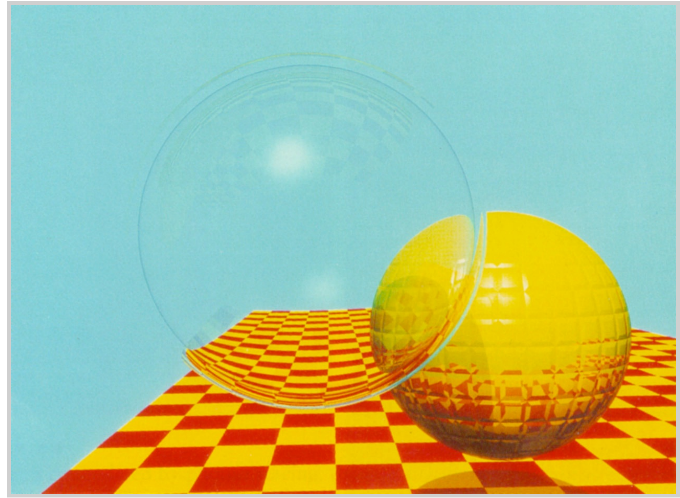
Pixar's Shutterbug series

Checkerboard floors and architectural columns

Two common elements of early computer generated images were the checkerboard floor plane and the column. The checkerboard was a good indicator of the perspective **foreshortening** effect, and also provided interesting visual effects in transparent and refractive surfaces. The column was an easy data set to create, usually being a regular surface of revolution. It provided a sense of depth and scale to the early images.

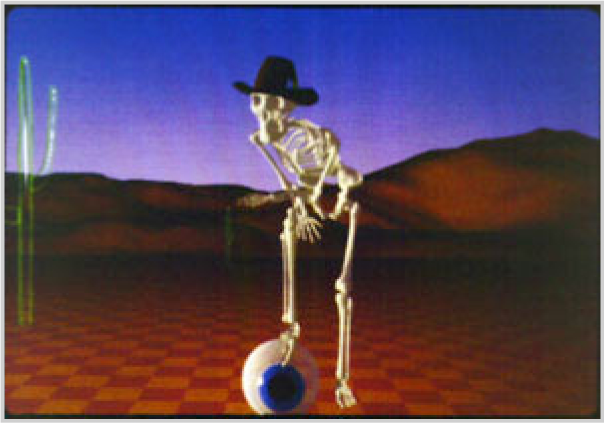


Turner Whitted – Bell Labs

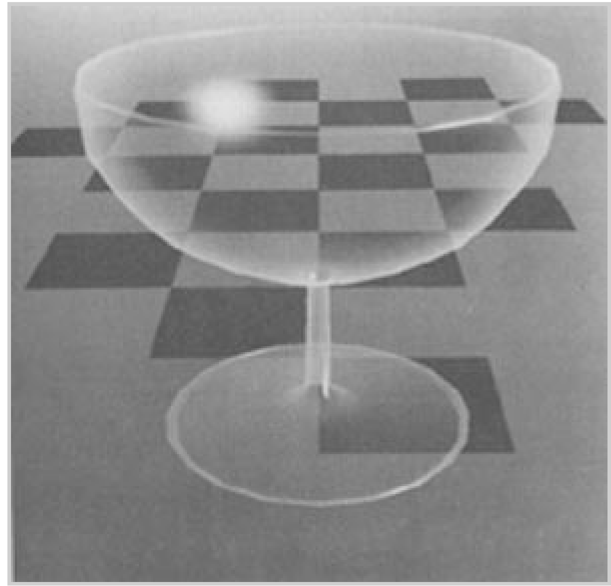


Turner Whitted – Bell Labs

“George in the Desert”



"George in the Desert" – data created by Don Stredney on DG2



Phong shading with transparency

Frank Crow

Wayne Carlson and Rick Balabuck -?Ohio State University

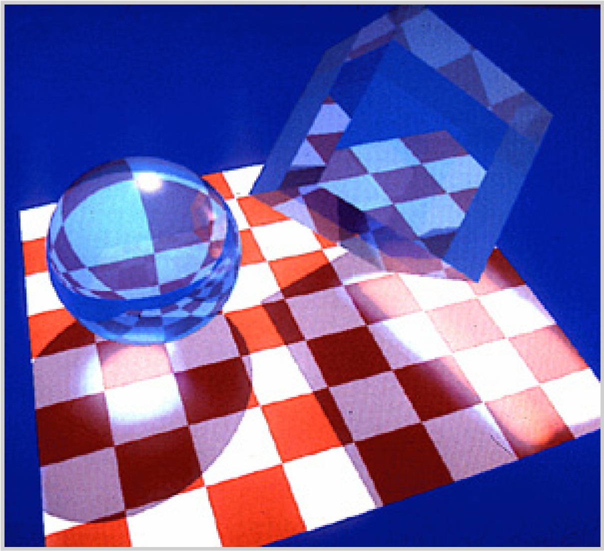
Ray-traced image by Arvo and Kirk – The Six Platonic Solids

Arnold Gallardo, author of 3D Lighting: History, Concepts, and Techniques

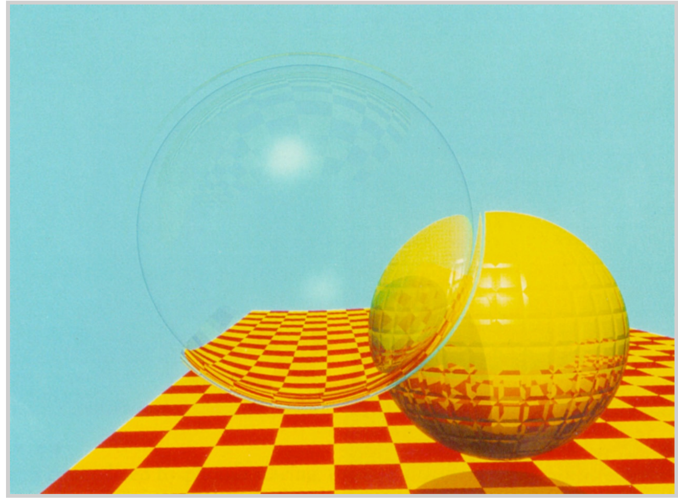
Eurhythmy

The ray-traced sphere

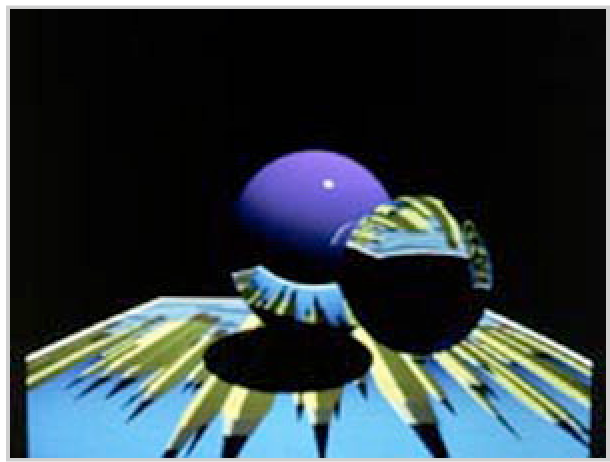
From the time that Turner Whitted demonstrated his now famous ray traced image, the sphere (solid, opaque, transparent, colored, etc.) has played a major role in the ray traced image. It is easy to create, it demonstrates nice effects with **refraction** and reflection, but most importantly the intersection computation between the cast rays and the spherical surface are relatively easy to compute in this otherwise compute intensive process.



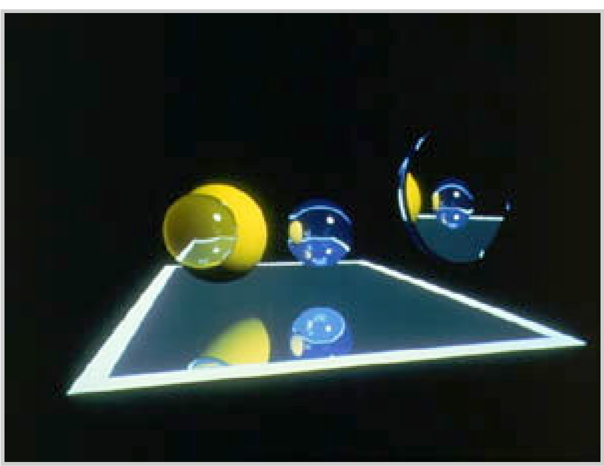
Turner Whitted – Bell Labs



Turner Whitted – Bell Labs



Hsuen Chung Ho – C/CP



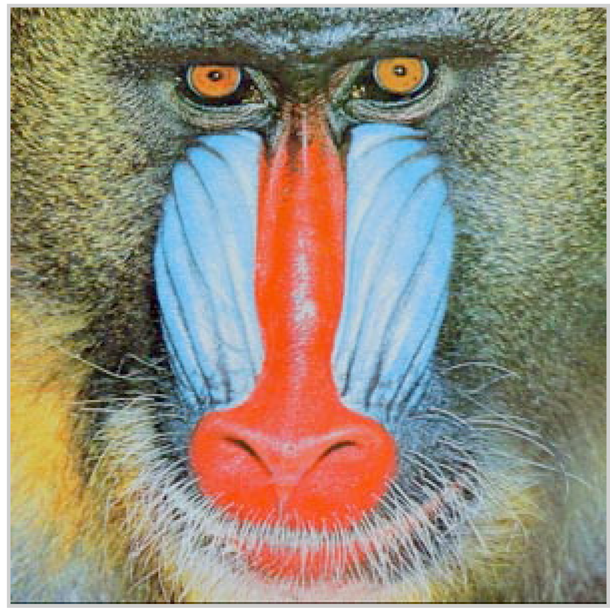
Bob Conley – C/CP

Political Agenda
1999
Unix environment and AL
Cibachrome
122 x 165 cm (48 x 65 in.)

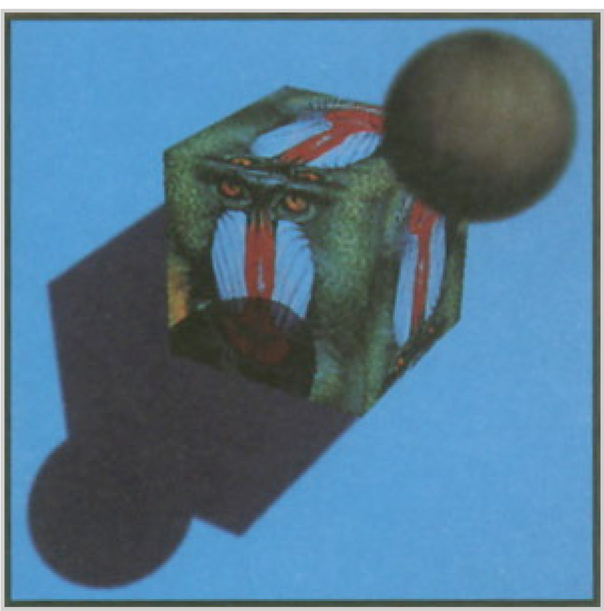
Collection of the Ohio
Supercomputer Center

The Mandrill

Image processing and computer graphics have been linked for many years by many similar issues, theories and algorithms. They are also linked by the common usage of the image of the Mandrill, an ape with a distinctive colorful face. The image is very good for image compression, enhancement, an processing tests, and has been used very frequently as a texture map or background image for CGI purposes.



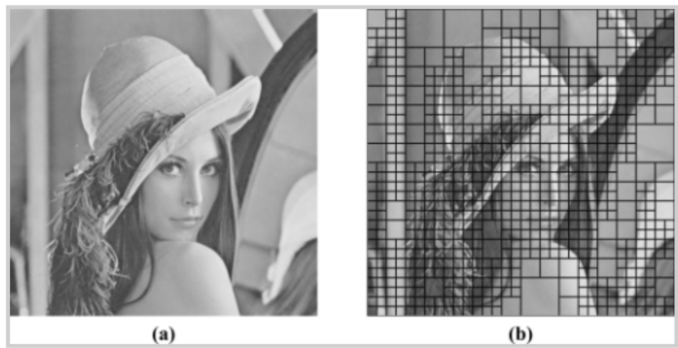
Indrinil Chakravarty and Michael Potmesil



Lena

The Lena image has been used for many years in graphics and for image processing tests. The original Lena image was a photograph of a Swedish woman named Lena Sjooblom, who originally was the *centerfold* in the November 1972 issue of Playboy Magazine. (In English, Lena is sometimes spelled Lenna, to encourage proper pronunciation.) The image was later digitized at the University of Southern California as one of many possible images for use by the imaging research community. The Lena image became a standard in the industry because the image contains a good mixture of detail, flat regions, shading, and texture that are important for testing various image processing algorithms.

Image transformation



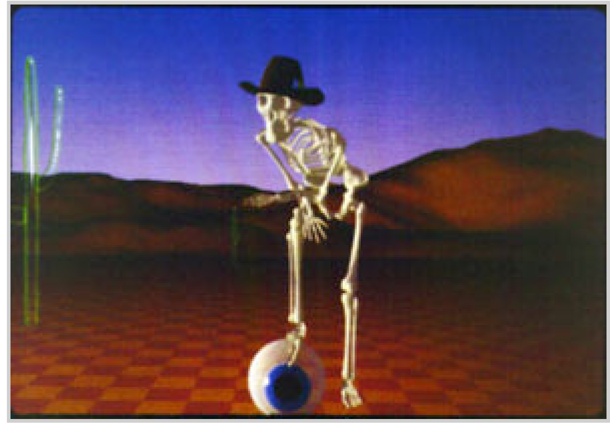
Quadtree decomposition

Edge detection

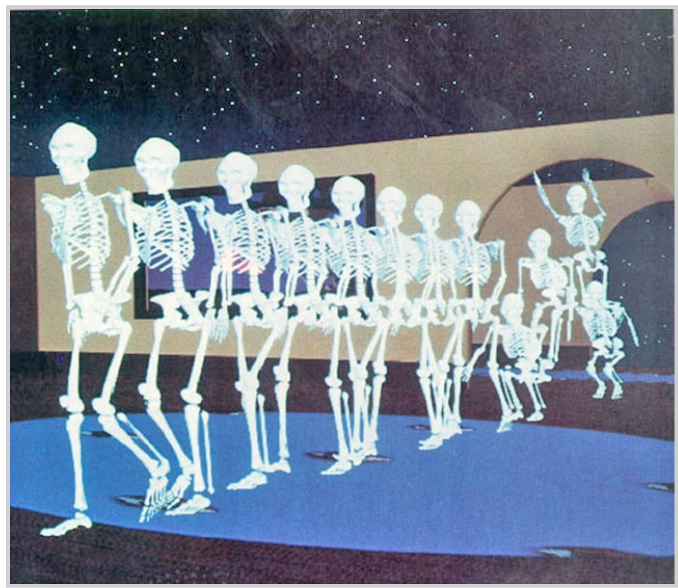
The skeleton

Because of the complexity of the structure of the human skeleton, it became a common model to demonstrate the capabilities of evolving 3D modeling systems. Animators, once they had the model, liked creating sequences in which the skeleton performed activities such as a real human form would participate in, such as dancing, singing, running, etc. This model, nicknamed "George" was created with Wayne Carlson's DG2 system at Ohio State by medical illustrator Don Stredney. It was placed in an ftp site, and was downloaded hundreds of times.

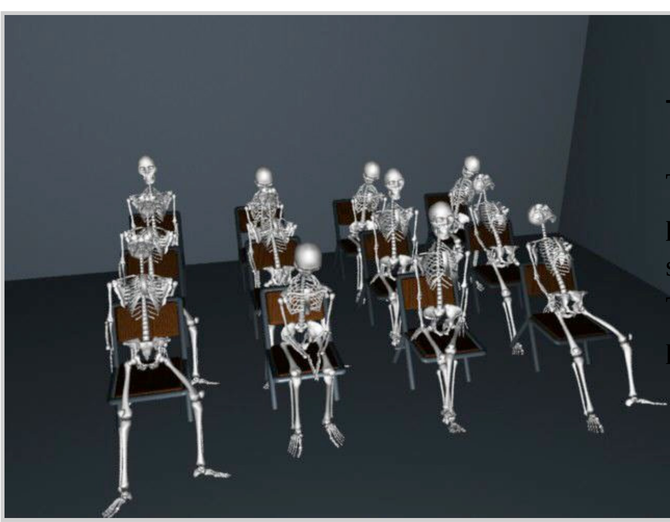
"George in the Desert"



"George in the Desert" – data created by Don Stredney on DG2



Scene composite from Zeltzer SAS system

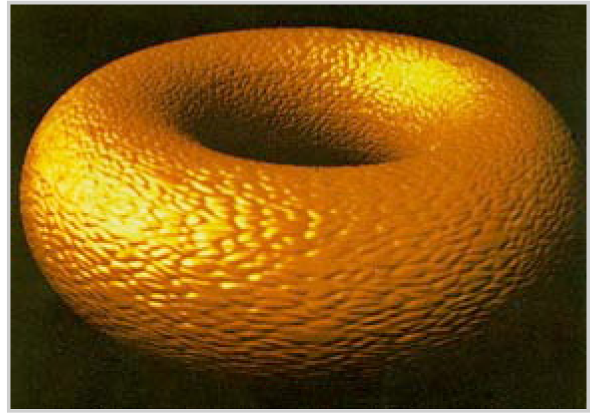


Class time

The "donut"

The kind of geometry that the donut represents, the torus, provided challenges to early renderers and algorithms for such things as texture mapping because of the hole in it. Techniques were thus tested on the donut as a complex proof of concept.

Rob Rosenblum's Hairy Donots – Ohio State University



Jim Blinn's Bump Mapping

Perlin Noise Functions

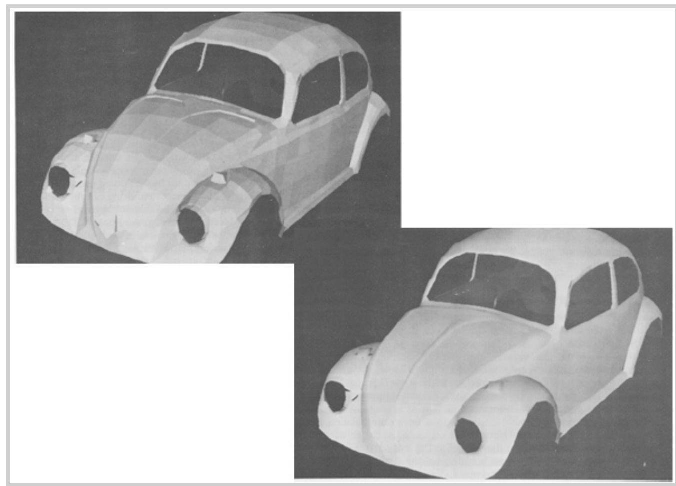
Pixar's Shutterbug series

The VW bug

In order to get interesting data bases to use in the imaging experiments taking place at the University of Utah in the late 70s, Ivan Sutherland volunteered his Volkswagen bug to be digitized. Faculty and students taped off a grid of polygons and took measurements, resulting in a polygonal shell of a VW.

Digitizing Sutherland's Bug

University of Utah



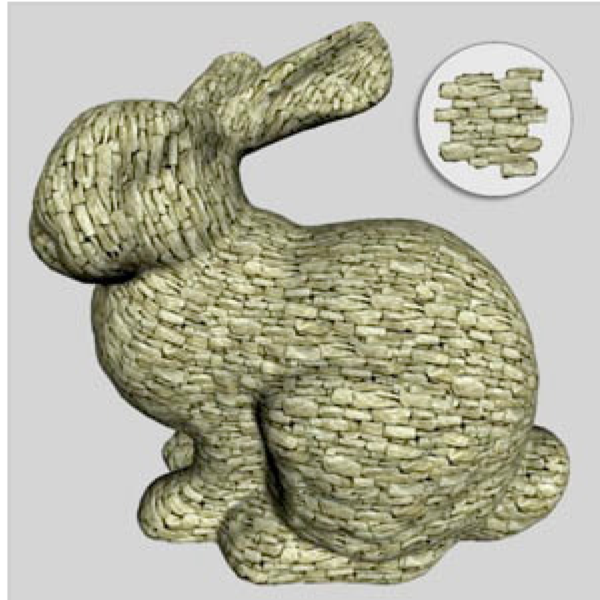
Shading – University of Utah

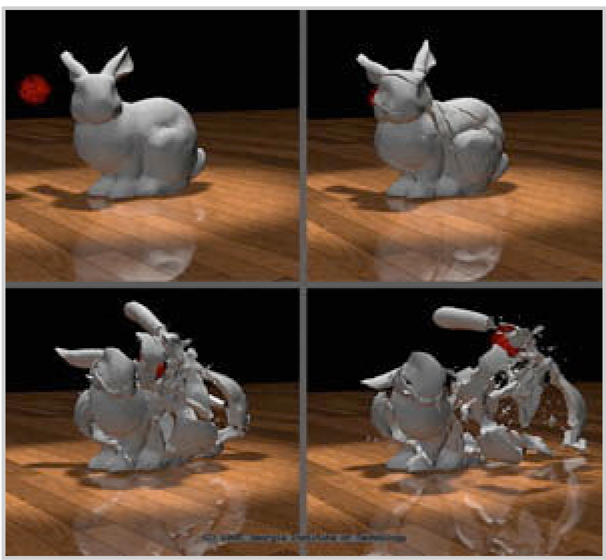
The Stanford bunny

The Stanford Bunny model was originally constructed in 1994 by Greg Turk and Marc Levoy using a technique they developed to create polygonal models from range scans (Zippered Polygon Meshes from Range Images, Greg Turk and Marc Levoy, SIGGRAPH 94, pp. 311-318). The Bunny model consisted of 69,451 triangles. The model was created using a technique to create polygonal models from several range scans.

A range scan is a grid of distance values that tell how far the points on a physical object is from the device that creates the scans (usually known as a range scanner). One way to think of a range scan is as a 2D image of pixels, but in which each pixel contains a distance value instead of a color. In fact, one common way to examine a **range image** is to draw it as a black-and-white image, with shorter distances shown as bright pixels and farther distances being darker. It is usually necessary to piece together several range scans in order to capture the full geometry of an object. Because of the interesting geometry, researchers have used the bunny for everything from texture mapping tests, to
growing hair on it, to algorithmically breaking it into pieces.

The Bunny has it's own website at http://www.cc.gatech.edu/~turk/bunny/bunny.html.



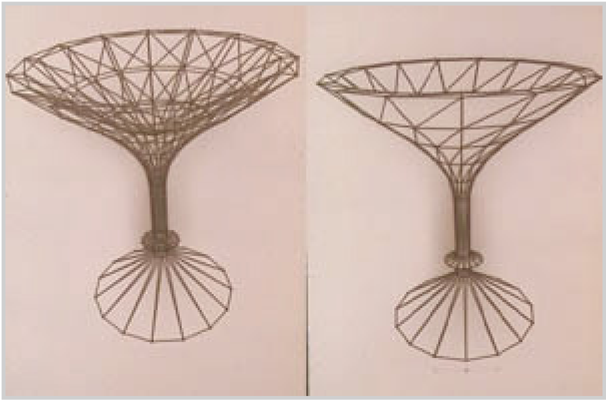


James O'Brien and Jessica Hodgins, Animating Fracture, CACM 7/ 2000

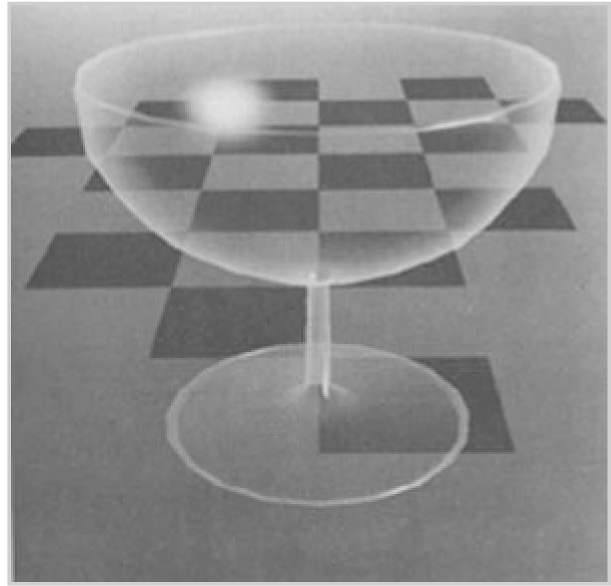
Range-scanned Bunny

The wineglass and vase

The wineglass and the vase were popular test models, because they were easy to generate the geometry (eg, a simple regular **surface of revolution**) and they had attributes that could demonstrate visible/hidden surfaces and rendering techniques, such as transparency, refractivity, **caustics**, etc.



Images from Jim Blinn, University of Utah



Phong shading with transparency

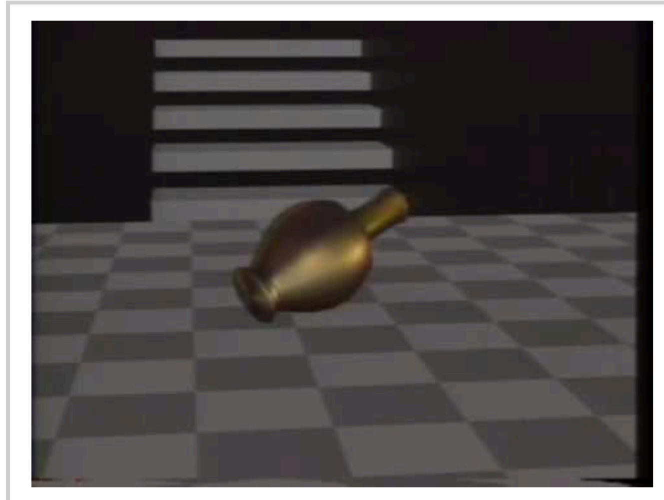
Jim Blinn, University of Utah

Alias Maya ?tutorial

Blender ?tutorial

CG image of a samovar vase created at Cornell PCG.

Perlin Noise Functions



James Hahn

Hsuen Chung Ho

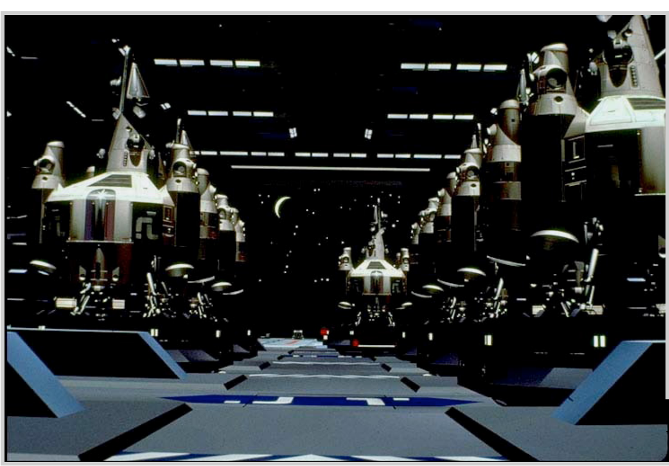
The X-Wing fighter, Starfighters, and other space ships

Because of their use in motion pictures such as *The Last Starfighter* and *Star Wars*, many early film tests that utilized CGI used space fighters such as the x-wing fighter and the gunstar as models.

?X-wing fighter from The Last Starfighter

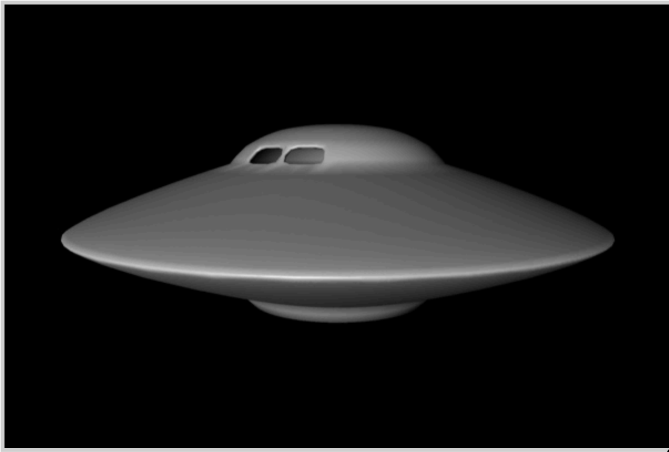
Cover of the August, 1979 IEEE Computer Magazine. Gary Demos produced this X-wing fighter image to convince George Lucas that CG could be used to make images for Star Wars.

X-Wing Fighter



?Scene from The Last Starfighter

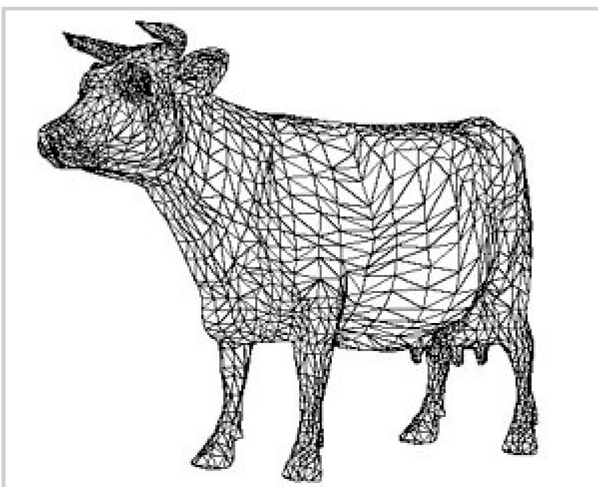
Flight of the Navigator

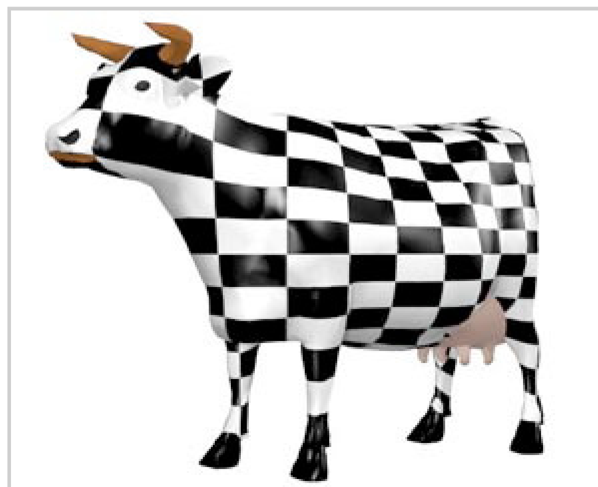


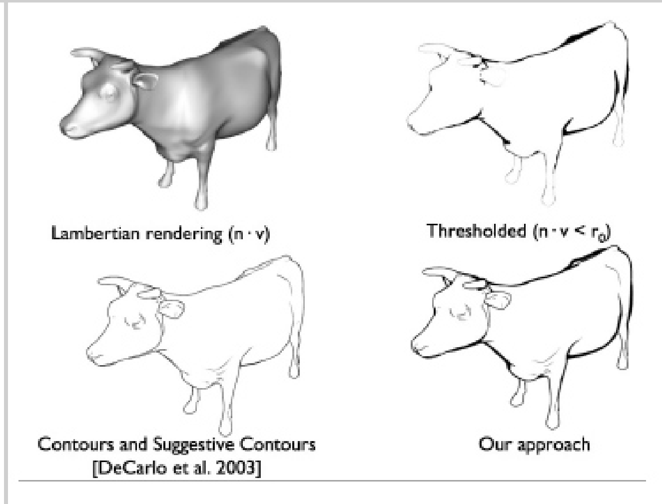
Autodesk

The Cow

One of the many classic data sets from the Viewpoint Data Labs portfolio, the cow has achieved status as a CG icon, appearing in many demonstrations and exemplary images. It is a complex surface that has a recognizable quality, and has most often appeared out of context in environments that are not usual cow playgrounds.

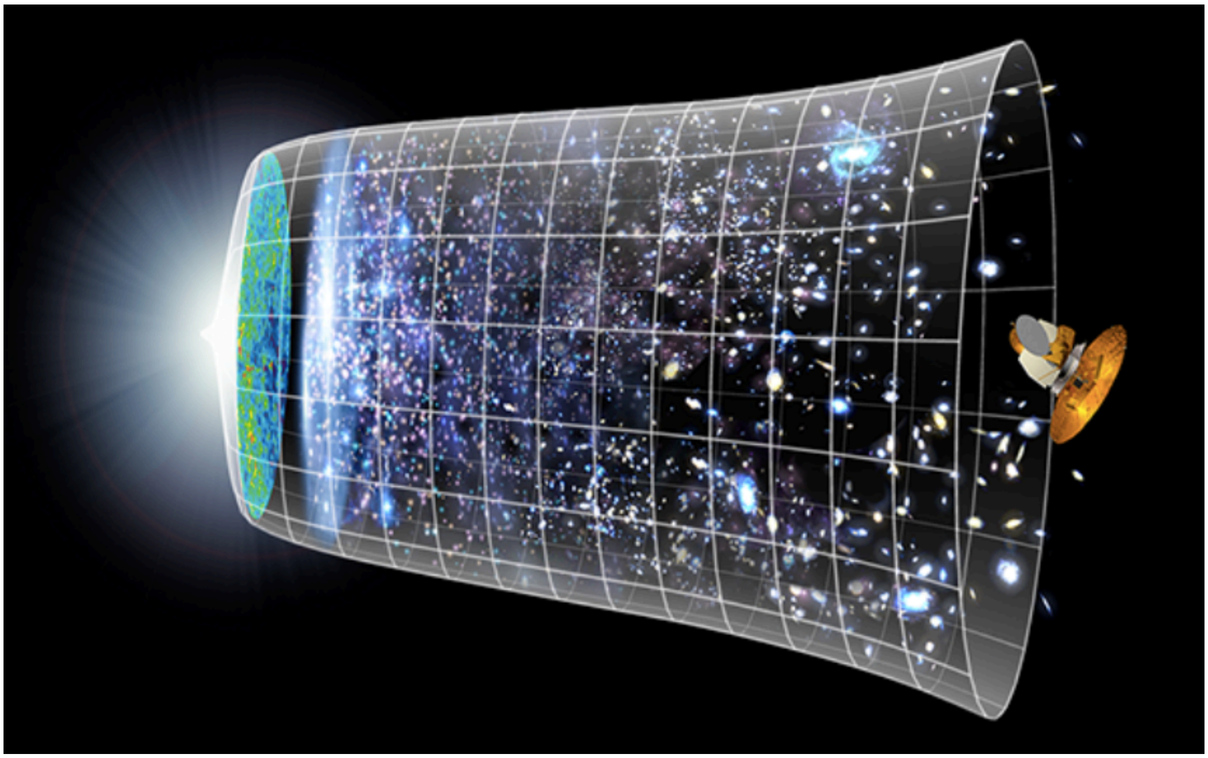





Lambertian rendering (n · v)
Thresholded (n · v < r0)
Contours and Suggestive Contours
[DeCarlo et al. 2003]
Our approach

CG Historical Timeline

This timeline depicts key events in the evolution of the CGI discipline.



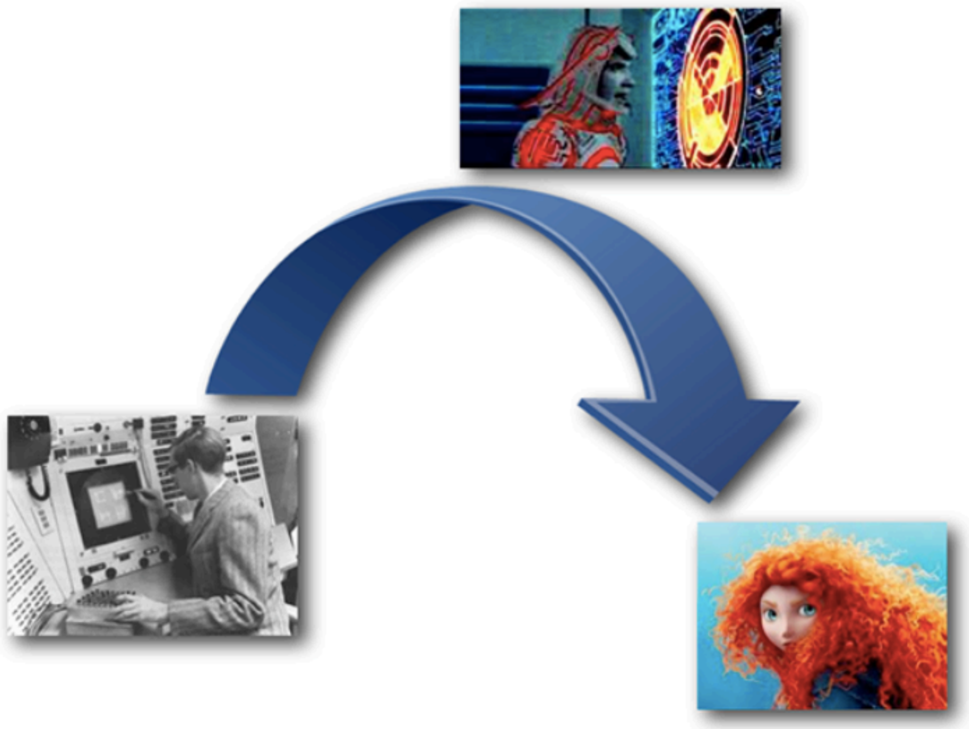
Timeline of the Universe (NASA)

Click below to jump to the decade:

Pre-1950s
1950s
1960s
1970s
1980s

1990s
2000s

The following timeline depicts key events in the evolution of the CGI discipline. It is not exhaustive, and some of the dates are controversial, as some references give one date and others give a different date. Some dates refer to when a contribution began, and others when a contribution was made public. We have tried to determine which is the appropriate date, but for some events the records are minimal.



Pre-1950s

1200

- Chinese Abacus

1617

- Napier's bones

Napier's Bones

1450

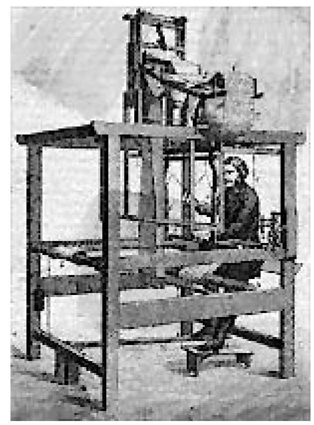
- Gutenberg press

1687

- Principia Mathematica – Isaac Newton

1801

- Jacquard loom



Jacquard Loom

1811

- Luddites riot

1826

- Photography (Niepce)

1830

- Babbage Analytical Engine designed

1842

- FAX (Alexander Bain)

1843

- Morse's telegraph installed between Philadelphia and Washington

1864

- Maxwell electromagnetic wave theory becomes basis for radio wave propagation

1877

- Edison invents phonograph

Phonograph

1884

- Nipkow (Germany) devises scanner for scanning and transmitting images

1885

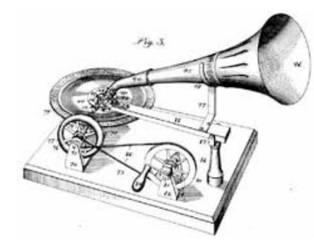
- CRT (Cathode Ray Tube)

1887

- Edison patents motion picture camera

1888

- Edison and Dickson design Kinetoscope – (motion pictures from successive photos on a cylinder)
- Berliner invents gramophone
- Oberlin Smith publishes basics of magnetic recording



Gramaphone

1890

- Hollerith introduces an automated punch-card driven tabulation device for the Census Bureau

1891

- Dickson uses Edison's kinetograph to record motion pictures

1898

- Poulsen invents the Telegraphone, the first magnetic recording device

1905

- *Fleming electron tube*
- *Einstein's Theory of Relativity*

Fleming Tube

1906

- de Forest develops Audion vacuum tube amplifier

1923

- Zworykin develops Iconoscope at Westinghouse

1926

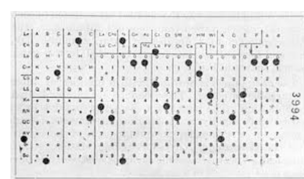
- First television (J.L. Baird)?• 1st teleconference – between Washington and New York

1927

- Philo Farnsworth invents fully electronic TV (First all-electronic TV is made by RCA in 1932)?• Motion picture film standardized at 24 fps

1928

- Hollerith introduces the 80-column "punch card"



Punch Card

1929

- BBC begins broadcasting

1930

- Philo Farnsworth receives patents for transmitting images by electronic means

1931

- 1st stereo recordings

1936

- The Magnetophone is 1st true magnetic tape recorder

Magnetophone

1938

- Valensi proposes color TV

1939

- Bill Hewlett and Dave Packard design the Audio Oscillator

1941

- First U.S. regular TV broadcast?• 1st TV commercial (for Bulova watches)

1945

- Whirlwind computer project starts at MIT

1946

- ENIAC computer built at University of Pennsylvania

1947

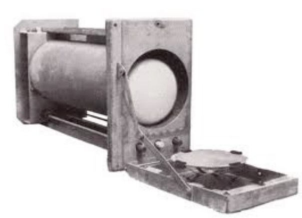
- Shockley, Bardeen and Brattain of Bell Labs invent transistors (“transfer resistance”)

1948

- Cable TV is installed

1949

- John Whitney enters first International Experimental Film Competition in Belgium
- Williams tube (CRT storage tube);
- Whirlwind computer built;
- Core memory developed by Wang of Harvard



Williams Tube

1950s

1950

- Cybernetics and Society – Norbert Weiner (MIT)
- Ben Laposky uses oscilloscope to display waveforms which were photographed as artwork

1951

- Graphics display on vectorscope on Whirlwind computer in first public demonstration

1952

- Mr. Potato Head invented; later starred in Toy Story
- *Air Force Project Blue Book* organized to categorize UFO sightings

1953

- NTSC broadcast code

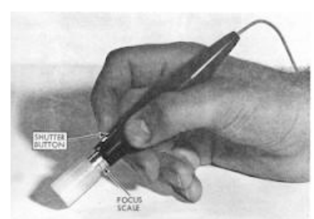
NTSC Spectrum

1954

- FCC authorizes color TV broadcast
- FORTRAN – John Backus

1955

- Disneyland opens
- SAGE system at Lincoln Lab uses first light pen (Bert Sutherland)



Light Pen

1956

- Lawrence Livermore National Labs connects graphics display to IBM 704; use film recorder for color images
- Ray Dolby, Charles Ginsberg and Charles Anderson of Ampex develop the first videotape recorder
- Alex Poniatoff (Ampex) introduces the VR1000 videotape recorder (2″tape) – the first practical broadcast quality VTR

1957

- 1st image-processed photo at National Bureau of Standards

- Max Mathews demonstrates first computer (IBM 704) synthesis of music (Music I) at Bell Labs
- Digital Equipment Corporation founded

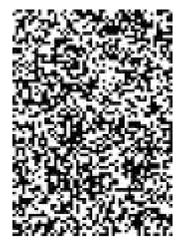
DEC Logo

1958

- Numerical controlled digital drafting machines, APT II (Automated Programming Tools)- MIT
- CalComp 565 drum plotter
- Saul Bass creates titles for Hitchcock's Vertigo
- Integrated circuit (IC, or Chip) invented by Jack St. Clair Kilby of Texas Instruments and Robert Noyce of Fairchild Electronics
- John Whitney Sr. uses analog computer to make art

1959

- First film recorder – General Dynamics Stromberg Carlson 4020 (uses Charactron tube)
- TX-2 computer at MIT uses graphics console
- Béla Julesz creates random-dot stereogram
- GM begins DAC program



Random Dot Stereogram

1960s

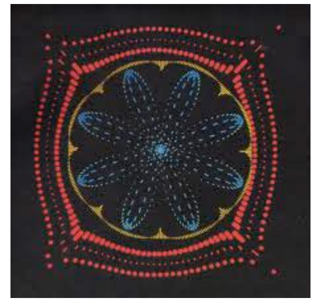
1960

- William Fetter of Boeing coins the term "computer graphics" for his human factors cockpit drawings
- John Whitney Sr. founds Motion Graphics, Inc.
- LISP developed by John McCarthy
- DEC PDP-1 introduced

1961

- *Spacewars*, 1st video game, developed by Steve Russell at MIT for the PDP-1

- Catalogue (John Whitney)



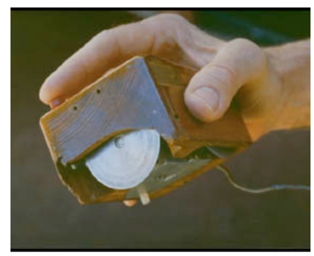
Whitney

1962

- Information International Inc. (Triple I) founded
- Itek begins Electronic Drafting Machine project
- *Mr. Computer Image ABC* produced on Scanimate by Lee Harrison

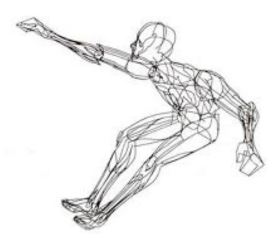
1963

- 1st computer art competition, sponsored by Computers and Automation
- Sketchpad developed beginning in 1961 by Ivan Sutherland at MIT is unveiled (Ref: Sutherland, Ivan E. Sketchpad: *A Man-Machine Graphical Communication System*. Proceedings of the AFIPS Spring Joint Computer Conference Washington, D.C.: 1963, p. 329-346.)
- Mouse invented by Doug Englebart of SRI



Mouse

- Coons' patches
- Early computer generated film by Edward Zajac (Bell Labs)
- BEFLIX developed at Bell Labs by Ken Knowlton
- Charles Csuri makes his first computer generated artwork
- DAC-1, first commercial CAD system, developed in 1959 by IBM for General Motors is shown at JCC
- Lockheed Georgia starts graphics activity (Chase Chasen)
- Michael Noll (Bell Labs) starts his Gaussian Quadratic series of artwork
- Roberts hidden line algorithm (MIT)
- The Society for Information Display established
- Fetter of Boeing creates the "First Man" digital human for cockpit studies



First Man

1964

- Project MAC (MIT)
- IBM 2250 console ($125,000) introduced with IBM 360 computer
- *Poem Field* by Stan Vanderbeek and Ken Knowlton
- Itek Digigraphic Program (later Control Data graphics system)
- The BASIC programming language developed by Kurtz and Kemeny
- Ruth Weiss introduces drawing software that performs hidden line elimination (Ref: Weiss, Ruth E. *BE VISION, a Package of IBM 7090 FORTRAN Programs to Drive Views of Combinations of Plane and Quadric Surfaces*. Journal of the ACM 13(4) April 1966, p. 194-204.)

- RAND tablet input device (commercially known as Grafacon)
- Compact cassette tape (Phillips)
- New York World's Fair
- Electronic character generator

Cassette Tape Deck

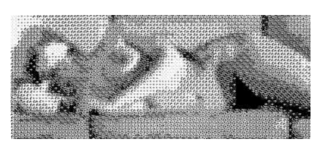
1965

- 1st computer art exhibition, at Technische Hochschule in Stuttgart
- 1st U.S. computer art exhibition, at Howard Wise Gallery in New York
- Dolby Laboratories founded by Ray Dolby, inventor of the first videotape recorder (1956)
- Adage founded
- Roberts introduces homogeneous coordinates (Ref: Roberts, Lawrence G. 1965. *Homogenous Matrix Representation and Manipulation of N-Dimensional Constructs*, MS-1505. MIT Lincoln Laboratory, Lexington, Mass.)
- Utah computer science department founded
- Bresenham Algorithm for plotting lines (Ref: *Bresenham, J. E. Algorithm for Computer Control of a Digital Plotter*. IBM Systems Journal 4(1) 1965, p. 25-30.)
- Tektronix Direct View Storage Tube (DVST)
- CADAM developed at Lockheed; CADD developed at McDonnell Douglas
- Project DEMAND consortium (IBM, Lockheed, McDonnell Douglas, Rockwell, TRW, Rolls Royce)
- BBN Teleputer uses Tektronix CRT

Tektronix DVST

1966

- *Odyssey*, home video game developed by Ralph Baer of Sanders Assoc., is 1st consumer CG product
- Group 1 FAX machines (using CCITT compression)
- Lincoln Wand developed
- Plasma Panel introduced (first developed at Illinois in 1964 as part of the PLATO project)
- *Studies in Perception I* by Ken Knowlton and Leon Harmon (Bell Labs)
- MAGI founded by Phil Mittleman
- Joint Defense Department / Industry symposium on CAD/NC held in Oklahoma City
- Experiments in Art and Technology (E.A.T.) started in New York by artist Robert Rauschenberg and Bell Labs engineer Billy Klüver



Studies in Perception

- IBM awards Artist-in-Residence to John Whitney, Sr.
- Loutrel hidden line algorithm

1967

- Appel hidden line algorithm (Ref: Appel, Arthur. *The Notion of Quantitative Invisibility and the Machine Rendering of Solids*. Proceedings of the
- ACM National Conference 1967, p. 387-393.)
- Steven Coons publishes his surface patch “little red book” (Ref: Coons, Steven A. 1967. *Surfaces for Computer-aided Design of Space Forms* , Project MAC Report MAC-TR-41. Massachusetts Institute of Technology, Cambridge, Mass.)
- *Sine Curve Man* and *Hummingbird* created by Chuck Csuri
- Adage real time 3D line drawing system
- Lee Harrison’s ANIMAC graphic device
- GE introduces first full color real time interactive flight simulator for NASA – Rod Rougelet
- MIT’s Center for Advanced Visual Studies founded by Gyorgy Kepes
- Instant replay and Slo-Mo introduced using Ampex HS-100 disc recorder
- Cornell’s program started in Architecture by Don Greenberg
- 1/2 inch open reel video tape recorder

Sine Curve Man

1968

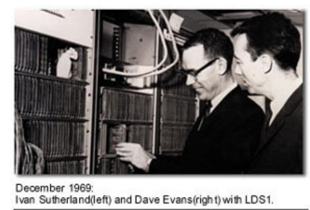
- DEC 338 intelligent graphics terminal
- Tektronix 4010
- Intel founded
- University of Utah asks Dave Evans to form a CG department in computer science
- Warnock algorithm
- Watkins algorithm
- Edsger Dijkstra writes article Go To Statement Considered Harmful which signals beginning of structured programming
- Cybernetic Serendipity: *The Computer and the Arts* exhibition at London Institute of Contemporary Arts

Tektronix Display

- Csuri's *Hummingbird* purchased by Museum of Modern Art for permanent collection

Hummingbird

- *Permutations* – John Whitney, Sr.
- Sutherland Head Mounted Display (Sword of Damocles), developed in 1966, shown (AFIPS Conference) (Ref: Sutherland, Ivan E. *A Head-Mounted Three-Dimensional Display*. Proceedings of the AFIPS Fall Joint Computer Conference Washington, D.C.: Thompson Books, 1968, p. 757-764.)
- Evans & Sutherland Calma, Computek, Houston Instrument, Imlac founded
- ARDS terminal, Computek 400 terminal
- LDS-1 ($250,000) from E&S introduces line clipping



LDS-1

1969

- Computer Image Corporation founded
- UNIX developed by Thompson and Ritchie at Bell Labs (in PDP-7 assembly code)
- SCANIMATE commercialized – Lee Harrison
- Genesys animation system – Ron Baecker
- GRAIL (Graphics Input Language) developed at Rand
- Computer Space arcade game built by Nolan Bushnell
- Xerox PARC founded
- Lee Harrison's CAESAR animation system
- Bell Labs builds first framebuffer (3 bits)
- Sony U-Matic 3/4″ video cassette
- Intel introduces the 1 KB RAM chip
- 1st use of CGI for commercials – MAGI for IBM
- Graphical User Interface (GUI) developed by Xerox (Alan Kay)
- SIGGRAPH formed (began as special interest committee in 1967 by Sam Matsa and Andy vanDam)
- ComputerVision, Applicon, Vector General founded
- ARPANET is born

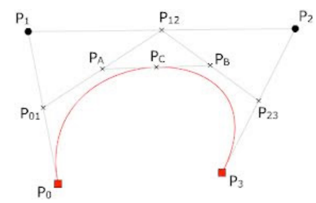
U-matic Tape

1970s

1970

- Sonic Pen 3-D input device
- ISSCO (Integrated Software Systems Corporation) founded (marketed DISSPLA software) by Peter Preuss
- Watkins algorithm for visible surfaces
- Lillian Schwartz produces *Pixellation* at Bell Labs
- Pascal programming language developed by Wirth
- Imlac PDS-1 programmable graphics computer marketed
- John Staudhammer starts NCSU Graphics Lab at NC State
- Pierre Bezier from Renault develops Bezier freeform curve representation

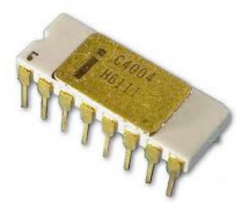
Sonic Pen



Bezier Curve

1971

- Gouraud shading (Ref: Gouraud, Henri. *Continuous Shading of Curved Surfaces*. IEEE Transactions on Computers C-20(6), June 1971, p. 623-29.)
- Ramtek founded
- GINO (graphics input output specification) – Cambridge University
- Intel 4004 4-bit processor
- *Interactive Graphics for Computer-Aided Design* (Prince) published
- MCS (Manufacturing and Consulting Services) founded by Patrick Hanratty, considered the "father" of mechanical CAD/CAM – introduces ADAM
- CAD software, which is the heart of many modern software systems
- Robert Abel and Associates founded
- Floppy disk (8″) – IBM



Intel 4004

Floppy Disk

1972

- MAGI Synthevision started
- CGRG founded at Ohio State
- NASA IPAD (Integrated Program for Aerospace Vehicle Design) initiative started
- Graphics Standards Planning Committee organized by ACM-SIGGRAPH
- The @ symbol selected for email addresses by BBN
- C language developed by Ritchie

- Emmy awarded to Lee Harrison for SCANIMATE
- Alto computer introduced by Xerox PARC (Alan Kay)
- Intel 8008 8-bit processor
- Megatek, Summagraphics, Computervision, Applicon founded
- Utah hand (Catmull) and face (Parke) animations produced (Ref: Catmull, Edwin. *A System for Computer Generated Movies*. Proceedings of the ACM National Conference August 1972, p. 422-431. and Parke, Frederic I. *Computer Generated Animation of Faces*. Proceedings of the ACM National Conference 1972, p. 451-457.)

Intel 8008

- Computer Graphics and Image Processing journal begins publication
- 8-bit frame buffer developed by Dick Shoup at Xerox PARC
- Sandin Image Processor – Dan Sandin, Univ. Illinois-Chicago Circle
- Atari formed (Nolan Bushnell)
- Newell, Newell and Sancha visible surface algorithm (Ref: Newell, M. E., R. G. Newell and T. L. Sancha. *A Solution to the Hidden Surface Problem*. Proceedings of the ACM National Conference 1972, p. 443-450)
- Video game Pong developed for Atari
- Graphics Symbiosis System (GRASS) developed at Ohio State by Tom DeFanti

Pong

1973

- E&S begins marketing first commercial frame buffer
- Ethernet – Bob Metcalf (Harvard)
- Quantel founded
- *Westworld* – uses 2D graphics
- Circle Graphics Habitat founded at Univ. Illinois Chicago (Tom DeFanti & Dan Sandin)
- Moore’s Law (the number of transistors on a microchip will double every year and a half) by Intel’s chairman, Mr. Gordon Moore
- Nolan Bushnell’s video game Computer Space appears in movie *Soylent Green*

- First SIGGRAPH conference (Boulder)
- 3/4 inch Portapack replaces 16mm film for news gathering
- Richard Shoup develops PARC raster display
- Rich Riesenfeld (Syracuse) introduces b-splines for geometric design (Ref: R.F. Riesenfeld. *Applications of B-Spline Approximation to Geometric Problems of Computer Aided Design*. PhD Dissertation, Syracuse University , 1973.)
- *Principles of Interactive Computer Graphics* (Newman and Sproull) first comprehensive graphics textbook is published

Portapak

1974

- Motion Pictures Product Group formed at III by John Whitney, Jr. and Gary Demos
- Alex Schure opens CGL at NYIT, with Ed Catmull as Director
- Barnhill and Riesenfeld introduce the name "Computer-Aided Geometric Design" (CAGD)
- SuperPaint developed by Dick Shoup and Alvy Ray Smith
- TCP protocol (Vint Cerf, Bob Kahn)
- DEC VT52 incorporated the first addressable cursor in a graphics display terminal
- Intel (Zilog) 8080
- Z-buffer developed by Ed Catmull (University of Utah) (Ref: E. Catmull. *A Subdivision Algorithm for Computer Display of Curved Surfaces*, Ph.D. Thesis, Report UTEC-CSc-74-133, Computer Science Department, University of Utah, Salt Lake City, UT, 1974)

VT 52

- *Futureworld* (sequel to *Westworld*) uses 3D CGI (III)
- *Hunger/La Faim* produced by Peter Foldes at National Research Council of Canada; wins Cannes Film Festival Prix de Jury award for animation

1975

- Phong shading – Bui-Toung Phong (University of Utah) (Ref: Bui-Tuong, Phong. *Illumination for Computer Generated Pictures*. Communications of the ACM 18(6) June 1975, p. 311-317.)
- Sony Betamax recorder

- USAF ICAM (Integrated Computer Aided Manufacturing) initiative started
- Cray 1 introduced
- Altair 8800 computer
- fractals – Benoit Mandelbrot (IBM)
- Winged edge polyhedra representation (Bruce Baumgart)

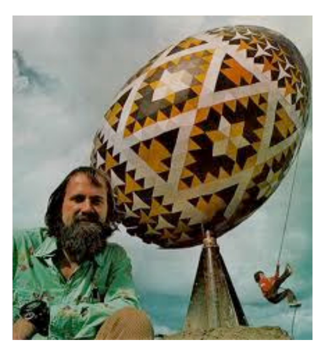
Betamax

- Catmull curved surface rendering algorithm (Ref: Catmull, Edwin. *Computer Display of Curved Surfaces*. Proceedings of the IEEE Conference on Computer Graphics, Pattern Recognition and Data Structures (IEEE Cat. No. 75CH0981-1C) 1975, p. 11-17.)
- Bill Gates starts Microsoft
- Quantel (QUANtized TELevision) introduces the DFS3000 Digital Framestore
- Martin Newell (Utah) develops CGI teapot (physical teapot now in the Computer Museum in Boston)
- JPL Graphics Lab developed (Bob Holzman)
- *Arabesque* completed (John Whitney)
- *Anima* animation system developed at CGRG at Ohio State (Csuri)

Teapot

1976

- MITs Visible Language Workshop founded by Muriel Cooper
- Ed Catmull develops "tweening" software (NYIT)
- Jim Clark's Hierarchical model for visible surface detection [Ref: J. H. Clark. *Hierarchical geometric models for visible surface algorithms*. Communications of the ACM, 19(10):547– 554, 1976.)
- N. Burtnyk , M. Wein, *Interactive skeleton techniques for enhancing motion dynamics in key frame animation*, CACM, V19, #10, Oct 1976, 564-569
  Dolby sound
- Jim Blinn develops reflectance and environment mapping (University of Utah)
- Nelson Max's sphere inversion film
- Ukrainian Pysanka Egg erected in Vegraville, Canada by Ron Resch (University of Utah) to commemorate the RCMP
- Sony Beta home video
- Floppy disk (5 1/4″)
- Apple 1 (Wozniak)
- IFIP (The International Federation of Information Processing) conference at Seillac in France on "The Methodology of Computer Graphics" begins standardization process



Pysanka

- Computer Graphics Newsletter started by Joel Orr; becomes Computer

Graphics World in 1978

- Peter Fonda's head digitized and rendered by III for *Futureworld*
- Ampex VPR-1 Type C 1″ video recorder
- Wang word processing
- *Artist and Computer*, by Ruth Leavitt
- *Mathematical Elements for Computer Graphics* (David Rogers) published
- Steve Jobs and Steve Wozniak start Apple computer.

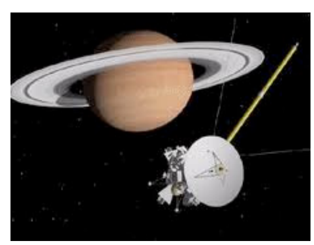
VPR-1

1977

- Apple Computer incorporated
- VHS (Video Home System) format – Matsushita
- JVC VHS home video
- Apple II released
- TRS-80 introduced
- Frank Crow introduces antialiasing (Ref: Franklin C. Crow, *The aliasing problem in computer-generated shaded images*, Communications of the ACM, v.20 n.11, p.799-805, Nov. 1977)
- Jim Blinn introduces a new illumination model that considers surface "facets" (Ref: *Models of light reflection for computer synthesized pictures*, James F. Blinn , Proceedings of the 4th annual conference on Computer graphics and interactive techniques July 1977, V11, #2, pp192-198)

TRS-80

- Computer Graphics World begins publication (started by Joel and N'omi Orr as Computer Graphics Newsletter)
- Academy of Motion Pictures Arts and Sciences introduces Visual Effects category for Oscars
- Nelson Max joins LLL
- Jim Blinn joins JPL
- R/Greenberg founded (Richard and Robert Greenberg)
- SIGGRAPH CORE Graphics standard
- Ampex ESSTM (Electronic Still Store) system introduced for network sports slo-mo;adapted for use as animation sequential storage device



Blinn animation

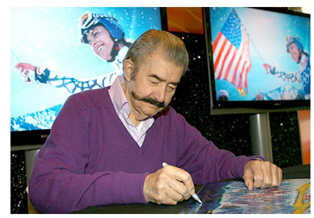
- GKS (Graphical Kernal System) graphics standard introduced
- Fuchs multiprocessor visible surface algorithm (Ref: Fuchs, Henry. *Distributing A Visible Surface Algorithm Over Multiple Processors*. Proceedings of the ACM National Conference 1977, p. 449-451.)

- Larry Cuba produces Death Star simulation for *Star Wars* using Grass at UICC developed by Tom DeFanti at Ohio State

Cuba graphics

1978

- Tom DeFanti's GRASS system rewritten for Bally home computer (Zgrass)
- E&S goes public
- AT&T and Canadian Telidon introduce videotex graphics standard (NAPLPS)
- Digital Effects founded (Judson Rosebush, Jeff Kleiser, et al)
- Lance Williams curved shadows paper (Ref: Lance Williams, *Casting curved shadows on curved surfaces*, Proceedings of the 5th annual conference on Computer graphics and interactive techniques, p.270-274, August 23-25, 1978)
- Ikonas frame buffer – England/Whitton
- Leroy Neiman uses Ampex AVA-1TM video art system to draw (on air) football players in Super Bowl XII



Leroy Nieman

- 1st CGI film title – Superman (R. Greenberg)
- Computer Graphics World begins publication
- James Blinn produces the first of a series of animations titled *The Mechanical Universe*
- DEC VAX 11/780 introduced
- Video laser disc
- Bump mapping introduced (Blinn) (Ref: *Simulation of wrinkled surfaces*, James F. Blinn, Proceedings of the 5th annual conference on Computer graphics and interactive techniques August 1978, V12, #3, pp 286-292.)

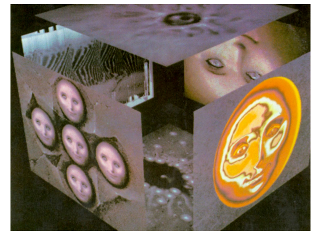
VAX 11-780

1979

- National Computer Graphics Association (NCGA) organized by Peter Preuss of ISSCO and Joel Orr
- IGES graphics file format specified
- IBM 3279 color terminal
- E&S PS-300
- Motorola 68000 32-bit processor
- Atari 8-bit computers introduced
- Disney produces *The Black Hole* using CGI for the opening

IBM 3279

- *Sunstone* – Ed Emshwiller (NYIT)
- George Lucas hires Ed Catmull, Ralph Guggenheim and Alvy Ray Smith to form Lucasfilm



Frame from Sunstone

1980s

1980

- *Vol Libre* – Loren Carpenter of Boeing
- Apollo Computer founded – introduces the 68000 based DN100 workstation
- Turner Whitted of Bell Labs publishes ray tracing paper (Ref: Turner Whitted, *An improved illumination model for shaded display*, Communications of the ACM, v.23 n.6, p.343-349, June 1980)
- First NCGA conference – Arlington, Virginia – Steven Levine, President

Apollo Computer

- *Donkey Kong* introduced by Nintendo (Mario named in US release)
- IBM licenses DOS from Microsoft
- Apple Computer IPO – 4.6M shares @ $22
- Aurora Systems founded by Richard Shoup
- SIGGRAPH Core standard reorganized as ANSC X3H3.1 (PHIGS)

Donkey Kong

- EUROGRAPHICS (The European Association for Computer Graphics) formed; first conference at Geneva
- Disney contracts Abel, III, MAGI and DE for computer graphics for the movie *Tron*
- MIT Media Lab founded by Nicholas Negroponte
- Pacific Data Images founded by Carl Rosendahl
- Computer hard disk drive – Seagate
- Hanna-Barbera, largest producer of animation in the U.S., begins implementation of computer automation of animation process

- Sony Walkman
- Quantel introduces Paintbox

Walkman

1981

- Sony Betacam
- Tom DeFanti expands GRASS to Bally Z-50 machine (ZGRASS) – University Illinois – Chicago Circle
- IBM introduces the first IBM PC (16 bit 8088 chip)
- DEC introduces VT100
- IEEE *Computer Graphics and Applications* published by IEEE Computer Society and NCGA
- Ampex ADO® system introduced; garners an Emmy award in 1983
- Digital Productions formed by Whitney and Demos
- Cranston/Csuri Productions founded by Chuck Csuri, Robert Kanuth and Jim Kristoff.
- R/Greenberg opens CGI division (Chris Woods)
- MITI Fifth Generation Computer Project announced by Japanese Ministry of International Trade and Industry
- REYES renderer written at LucasFilm
- Penguin Software (now Polarware) introduces the Complete Graphics System
- *Looker* includes the virtual human character Cindy (Susan Dey) – 1st film with shaded graphics(III)
- *Adam Powers, the Juggler* produced by III
- *Carla's Island* – Nelson Max

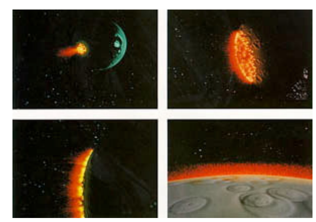
Adam Powers

1982

- *The Last Starfighter* (Digital Productions) begins production
- *Tron* released
- The Geometry Engine (Clark) (Ref: Clark, James H. *The Geometry Engine: A VLSI Geometry System for Graphics*. Computer Graphics (SIGGRAPH 82 Proceedings) 16(3) July 1982, p. 127-133.)
- Jim Clark founds Silicon Graphics Inc.
- Sun Microsystems founded (sun := Stanford University Network)
- Alain Fournier , Don Fussell , Loren Carpenter, *Computer Rendering of Stochastic Models*. Communications of the ACM, v.25 n.6, p.371-384, June 1982 (Fractal Rendering paper)
- *Skeleton Animation System* (SAS) developed at CGRG at Ohio State (Dave Zeltzer)

- Sony still frame video camera (Mavica)
- ACM begins publication of TOG (*Transactions on Graphics*)
- Tom Brighham develops morphing (NYIT)
- Adobe founded by John Warnock
- Toyo Links established in Tokyo
- Quantel Mirage
- Symbolics Graphics Division founded
- EPCOT Center opens
- Atari develops the data glove.
- *Where the Wild Things Are* test (MAGI) – digital compositing used to combine CG backgrounds and traditional animation
- AutoDesk founded; AutoCAD released
- ILM computer graphics division develops “Genesis effect” for *Star Trek II – The Wrath of Khan*

Mavica



Frames from the Genesis Effect

1983

- Particle systems (Reeves – Lucasfilm) (Ref: Reeves, William T. *Particle Systems: A Technique for Modeling a Class of Fuzzy Objects*. Computer Graphics (SIGGRAPH 83 Proceedings) 17(3) July 1983, p. 359-376.)
- SGI IRIS 1000 graphics workstation
- Non-Uniform Rational B-Splines (NURBS) introduced by Tiller (Note: this date is somewhat misleading, since the concept built on the work of Vesprille (1975), Riesenfeld (1973), Knapp (1979), Coons (1968) and Forrest (1972))
- *Road to Point Reyes* created – Lucasfilm
- *The Last Starfighter* released
- Jim Blinn receives the first (1983) ACM SIGGRAPH CG Achievement Award
- Ivan Sutherland receives the first (1983) ACM SIGGRAPH Steven A. Coons Award
- Steve Dompier’s “Micro Illustrator”
- UNIX System V
- Utah Raster Toolkit introduced (Spencer Thomas)
- Autodesk introduces first PC-based CAD software
- Alias founded in Toronto by Stephen Bingham, Nigel McGrath, Susan McKenna and David Springer mip-mapping introduced for efficient texture mapping (Williams – NYIT) (Ref: Williams, Lance. *Pyramidal Parametrics*. Computer Graphics (SIGGRAPH 83 Proceedings) 17(3) July 1983, p. 1-11.

- Sony and Philips introduce 1st CD player
- Wacom Co., Ltd started in Japan

Sony CD Player

1984

- Robert Abel & Associates produces the 1st computer generated 30 second commercial used for Super Bowl (*Brilliance*)
- Wavefront Technologies is the first commercially available 3D software package (founded by Mark Sylvester, Larry Barels and Bill Kovacs)
- Thomson Digital Image (TDI) founded
- Jim Clark receives the 1984 ACM SIGGRAPH CG Achievement Award
- International Resource Development report predicts the extinction of the keyboard in the next decade

Scene from Brilliance

- A-buffer (or alpha-buffer) introduced by Carpenter of Lucasfilm
- Distributed ray tracing introduced by Lucasfilm (Ref: Cook, Robert L., Thomas Porter and Loren Carpenter. *Distributed Raytracing*. Computer Graphics (SIGGRAPH 84 Proceedings) 18(3) July 1984, p. 137-145.)
- Cook shading model (Lucasfilm) (Ref: Cook, Robert L. *Shade Trees*. Computer Graphics (SIGGRAPH 84 Proceedings) 18(3) July 1984, p. 223-231.)
- 14.5 minute computer generated IMAX film (The Magic Egg) shown at SIGGRAPH 84 – 18 teams; 20 segments
- Universal Studios opens CG department
- First Macintosh computer is sold; introduced with Clio award winning commercial 1984 during Super Bowl
- McDonnel Douglas introduces the Polhemus 3Space digitizer and body Tracker
- The Cornell Box invented by Cohen
- Radiosity born – Cornell University (Ref: Goral, Cindy M., Kenneth E. Torrence, Donald P. Greenberg and Bennett Battaile.*Modeling the Interaction of Light Between Diffuse Surfaces*. Computer Graphics (SIGGRAPH 84 Proceedings) 18(3) July 1984, p. 213-222.)
- John Lasseter joins Lucasfilm
- Motorola 68020
- Digital Productions (Whitney and Demos) get Academy Technical Achievement Award for CGI simulation of motion picture photography

Cornell Box

- Lucasfilms introduces motion blur effects
- Porter and Duff compositing algorithm (Lucasfilm) (Ref: Porter, Thomas and Tom Duff. *Compositing Digital Images*. Computer Graphics (SIGGRAPH 84 Proceedings) 18(3) July 1984, p. 253-259.)
- The Adventures of Andre and Wally B. (Lucasfilm)

Motorola 68020

1985

- Commodore launches the new Amiga

Amiga

- Loren Carpenter receives the 1985 ACM SIGGRAPH CG Achievement Award
- Pierre Bezier receives the 1985 ACM SIGGRAPH Steven A. Coons Award
- Sogitec founded (Xavier Nicolas)
- *Max Headroom* – computer-mediated live action figure
- Judson Rosebush Co. started
- Abel Image Research takes Robert Abel & Associates to shaded graphics business
- *Tony de Peltrie* airs

Tony De Peltrie

- stereo TV
- *Biosensor* (Toyo Links)
- Cray 2
- GKS standard
- Quantel Harry is first non-linear editor
- UNIX X10R1
- CGW predicts 90s graphics workstation
- Targa 16 board (AT&T) goes to market

Targa

- Pixar Image Computer goes to market
- NeXT Incorporated founded by Steve Jobs and five former Apple senior managers
- Perlin's noise functions introduced (Ref: Perlin, Ken. *An Image Synthesizer*. Computer Graphics (SIGGRAPH 85 Proceedings) 19(3) July 1985, p. 287-296.)
- CD-ROMs High Sierra (ISO9660) standard introduced
- PostScript (Adobe – John Warnock)

- PODA creature animation system developed by Girard and Maciejewski at Ohio State (Ref: Girard, Michael and A. A. Maciejewski. *Computational Modeling for the Computer Animation of Legged Figures*. Computer Graphics (SIGGRAPH 85 Proceedings) 19(3) July 1985, p. 263-270.)
- Boss Films founded by Richard Edlund
- MIT Media Lab moves to new home
- *Young Sherlock Holmes* stained glass knight (Lucasfilm), *2010* (Boss Films)and *Looker* (DP)

Media Lab

1986

- *The Great Mouse Detective* was the first animated film to be aided by CG.
- Pixar purchased from Lucasfilm by Steve Jobs
- X-Window System (MIT Project Athena)
- Trancept Systems founded by Nick England and Mary Whitton – graphics board for Sun
- CGI group starts at Industrial Light and Magic (Doug Kay and George Joblove)
- Softimage founded by Daniel Langlois in Montreal
- Sun Microsystems goes public
- mental images founded in Berlin
- Computer Associates acquires ISSCO
- Microsoft goes public (IPO raises $61M; share prices go from $21 to $28)
- Apple IIgs introduced
- Silicon Graphics Incorporated IPO
- SGI IRIS 3000 (MIPS processor)
- Turner Whitted receives the 1986 ACM SIGGRAPH CG Achievement Award
- Jim Henson Waldo project introduces motion capture (Digital Productions)
- Kajiya's Rendering Equation (Ref: Kajiya, James T. *The Rendering Equation*. Computer Graphics (SIGGRAPH 86 Proceedings) 20(4) August 1986, p. 143-150.)
- Omnibus assumes Robert Able & Associates and Digital Productions in hostile takeovers by John Pennie and investors

Jim Henson – Waldo

- Whitney/Demos Productions founded
- Intel introduces 82786 graphics coprocessor chip ; Texas Instruments introduces TMS34010 Graphics System Processor
- NSFNet

- *Luxo Jr.* nominated for Oscar (first CGI film to be nominated – Pixar)
- TIFF (Aldus)
- Scitex founded for prepress

Luxo Jr.

1987

- GIF format (CompuServe), JPEG format (Joint Photographic Experts Group)
- *Willow* (Lucasfilm) popularizes morphing
- *Max Headroom* debuts
- LucasArts formed
- Adobe Illustrator
- CGM (Computer Graphics Metafile) standard
- Side Effects Software established
- VGA (Video Graphivs Array) invented by IBM
- Windows 2.0, MS/OS 2, Excel
- Sun 4 SPARC workstation
- Reynolds' flocking behavior algorithm (Symbolics) (Ref: Reynolds, Craig W. *Flocks, Herds and Schools: A Distributed Behavior Model*. Computer Graphics (SIGGRAPH 87 Proceedings) 21(4) July 1987, p. 25-34.)
- *Stanley and Stella in: Breaking the Ice*
- Rob Cook receives the 1987 ACM SIGGRAPH CG Achievement Award
- Don Greenberg receives the 1987 ACM SIGGRAPH Steven A. Coons Award
- Advanced Computing Center for the Arts and Design (ACCAD) founded at Ohio State (formerly CGRG)
- Omnibus closes, eliminating DP and Abel
- Cranston/Csuri Productions closes
- Marching Cubes algorithm (Lorensen and Cline – GE) (Ref: Lorensen, William and Harvey E. Cline. *Marching Cubes: A High Resolution 3D Surface Construction Algorithm*. Computer Graphics (SIGGRAPH 87 Proceedings) 21(4) July 1987, p. 163-170.)
- Metrolight Studios, RezN8 Productions, Kleiser/Walczak Construction Co., DeGraf/Wahrman founded

Sparc Station 4

1988

- PICT format (Apple)
- Apple sues Microsoft for copyright infringement for GUI
- GKS, PHIGS standards
- Prime Computer acquires Computervision

- Solid Texturing introduced (Perlin Noise Functions) (Ref: K. Perlin. *An image synthesizer*. Computer Graphics, 19(3):287–296, 1985)
- Al Barr receives the 1988 ACM SIGGRAPH CG Achievement Award
- Internet Worm infects servers all over the world
- Gary Demos founds DemoGraFX
- Open Software Foundation (OSF)
- NeXT Cube – For $6500, it features: 25-MHz 68030 processor and 68882 math coprocessor, 8 MB RAM, 17-inch monochrome monitor, 256 MB read/write magneto-optical drive, and object-oriented NexTSTEP operating system.

NeXT Cube

- JCGL purchased by NAMCO
- US Patent awarded to Pixar for RenderMan
- Who Framed Roger Rabbit mixes live action and animation
- Willow (Lucasfilm) uses morphing in a feature film
- D-2 composite video format introduced by Ampex
- Disney and Pixar develop CAPS (Computer Animation Paint System) (academy technical award in 1992)
- PIXAR wins Academy award for Tin Toy

1989

- John Warnock receives the 1989 ACM SIGGRAPH CG Achievement Award
- David Evans receives the 1989 ACM SIGGRAPH Steven A. Coons Award
- 8MM videotape introduced by Sony
- Adobe Photoshop
- PHIGS+
- OSF Motif V1.0 released
- Intel 80486
- mental ray renderer released (integrated with Wavefront (1992), Softimage (1993), Maya (2002)) – awarded AMPAS Technical Achievement Award in 2002
- HP buys Apollo
- Computervision acquires Calma

8mm Tape

- ILM creates the Abyss
- PIXAR starts marketing RenderMan

Abyss

1990s

1990

- Microsoft ships Windows 3.0
- NewTek Video Toaster
- First edition of Graphics Gems published by Academic Press (Andrew Glassner, editor)
- US Patent awarded to Pixar for point sampling
- Richard Shoup and Alvy Ray Smith receive the 1990 ACM SIGGRAPH CG Achievement Award
- 3D Studio (AutoDesk)
- Windows 3.0
- IBM RS6000 workstation
- John Wiley & Sons begins publishing The Journal of Visualization and Computer Animation

RS 6000

1991

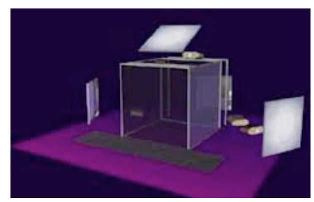
- World Wide Web (CERN)
- Jim Kajiya receives the 1991 ACM SIGGRAPH CG Achievement Award
- Andy van Dam receives the 1991 ACM SIGGRAPH Steven A. Coons Award
- Disney and PIXAR agree to create 3 films, including the first computer animated full-length film Toy Story
- ILM produces Terminator 2
- The Academy of Motion Pictures Arts and Sciences Special Achievement Award for Visual Effects for Total Recall (Metrolight Studios)
- Beauty and the Beast (Disney)
- Symbolics Graphics Division sold to Nichimen Graphics
- Motorola 68040
- Kodak PhotoCD
- JPEG/MPEG
- SunSoft – software subsidiary of Sun Microsystems

- SGI Indigo workstation
- Disney (Randy Cartwright, David Coons, Lem Davis, Tom Hahn, Jim Houston, Mark Kimball, Dylan Kohler, Peter Nye, Mike Shaantzis, David Wolf) get Academy Scientific and Engineering Award for CAPS production system.
- Ray Feeney, Richard Keeney and Richard Lundell get Academy Scientific and Engineering Award for the Solitair Film Recorder .

SGI Indigo

1992

- QuickTime introduced (Apple)
- Henry Fuchs receives the 1992 ACM SIGGRAPH CG Achievement Award
- Softimage goes public
- SGI acquires MIPS
- OpenGL (SGI) released
- University of Illinois debuts CAVE virtual reality technology at SIGGRAPH 92
- Lawnmower Man (Effects by Angel Studios and Xaos)
- US Patent awarded to Pixar for Non-Affine Image Warping
- VIFX uses flock animation with Prism software to create large groups of animals



CAVE

- Jim Hourihan of Santa Barbara Studios develops willy into Dynamation, which will become a part of the Wavefront software system.
- Tom Brigham and Doug Smythe and ILM get Academy Technical Achievement Award for morphing technique (MORF)
- Loren Carpenter, Rob Cook, Ed Catmull, Tom Porter, Pat Hanrahan, Tony Apodaca and Darwyn Peachey get the Academy Scientific and Engineering Award for Renderman
- Novell buys UNIX from AT&T – $150M (transfers UNIX trademark to X/Open standards organization in 1993)

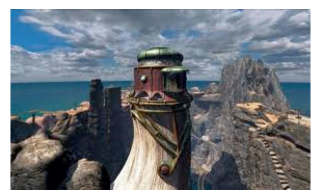
1993

- February (premiere) issue of DV magazine advises “[to be able to do digital video, get] the most souped up system you can get your hands on. A fast processor (68040 on Amiga or Mac, 80486 on PC) and lots of RAM (8-64 MB) are in order. So is a large hard drive (200 MB – 1 GB) if you want to take on serious production.”
- Disk array and compression codecs allow for nonlinear editing and full motion video
- Academy Scientific and Engineering Award is given to Les Dittart, Mark Leather, Doug Smythe and

George Joblove for the development of the Digital Motion Picture Retouching System (rig removal and dirt cleanup)

- GPS system
- Adobe Acrobat
- Pat Hanrahan receives the 1993 ACM SIGGRAPH CG Achievement Award
- Ed Catmull receives the 1993 ACM SIGGRAPH Steven A. Coons Award
- Jurassic Park – ILM and Steven Spielberg
- Wavefront buys TDI
- Wired Magazine launched
- Windows NT
-
- Babylon 5 uses Amiga and Macintosh generated CGI
- Mosaic browser (NCSA)
- Xaos Tools Pandemonium image processor for the SGI
- Doom released
- Myst released (Cyan) – in 1998, it became the top selling game of all time
- Digital Domain founded by James Cameron, Stan Winston, and Scott Ross
- 1994
- SGI and Nintendo team up for Nintendo 64 product
- ILM earns Oscar for special effects for Jurassic Park

Adobe Acrobat



Myst

- Microsoft acquires Softimage – announces Windows 95
- Iomaga Zip drive
- Linux 1.0 released
- Reboot (CG cartoon) uses 3D characters (Mainframe Entertainment)
- Direct Broadcast Satellite service
- SGI founder Jim Clark resigns, forms Mosaic Communications
- Netscape browser
- VRML introduced (Mark Pesce)
- HDTV standard for transmission adopted in US
- The AMPAS Academy Award of Merit goes to Peter and Paul Vlahos for Ultimatte electronic blue screen compositing.
- Academy Scientific and Engineering Awards go to Gary Demos and Dan Cameron of III, David

Iomega Zip Drive

Difrancesco and Gary Starkweather of Pixar, and Scott Squires of ILM for pioneering work in film scanning; Lincoln Hu and Mike Mackenzie of ILM and Glenn Kennel and Mike Davis of Kodak for development work on a linear array CCD film input scanning system; and Ray Feeney, Will McCown and Bill Bishop of RFX and Les Dittert of PDI for their development work on an area array CCD film input scanning system

- Academy Technical Achievement Awards go to Mike Boudry of the Computer Film Company for pioneering work in film input scanning; and David and Lloyd Addleman for their inventions in digital image compositing.
- US Patent awarded to Pixar for creating, manipulating and displaying images
- Facetracker used by SimmGraphics to animate facial expressions for Super Mario
- Ken Torrance receives the 1994 ACM SIGGRAPH CG Achievement Award

Super Mario

1995

- Toy Story (Pixar)
- DreamWorks SKG founded (Steven Spielberg, Jeffrey Katzenberg and David Geffen)
- DreamWorks SKG and Microsoft form DreamWorks Interactive
- Internet Explorer 2.0
- amazon.com established
- Academy Scientific and Engineering Award goes to Alvy Ray Smith, Ed Catmull, Tom Porter and Tom Duff (Pixar) for pioneering inventions in digital compositing.
- Academy Technical Achievement Awards go to Gary Demos, David Ruhoff, Dan Cameron and Michelle Feraud for creation of the Digital Productions digital film compositing system; the Computer Film Company for the CFC Digital Film Compositor; and Doug Smythe, Lincoln Hu,, Doug Kay and ILM for the ILM digital film compositing system.
- US Patent awarded to Pixar for image volume data
- John Lasseter of Pixar gets Academy Award for development and application of techniques used in Toy Story
- Kurt Akeley (SGI) receives the 1995 ACM SIGGRAPH CG Achievement Award
- Jose Encarnacao receives the 1995 ACM SIGGRAPH Steven A. Coons Award
- Wavefront and Alias merge
- Pixar goes public with 6.9M share offering
- Netscape IPO ($58.25/share)

- Sony Playstation introduced
- Sun introduces Java
- Internet 2 unveiled
- MP3 standard format developed
- MSNBC debuts

Playstation

1996

- John Whitney passes away (1922-1996)
- Quake hits game market
- Macromedia buys FutureSplash Animator from FutureWave Technologies… it will become Flash.
- Marc Levoy receives the 1996 ACM SIGGRAPH CG Achievement Award
- Academy Scientific and Engineering Awards go to Jim Hourihan for particle systems in Dynamation; Brian Knep, Zoran Kacic-Alesic and Tom
- Williams of ILM for the Viewpaint 3D Paint system; and Bill Reeves for the original development and concept of particle systems.

Quake

- Academy Technical Achievement Awards go to Jim Kajiya of Cal Tech and Tim Kay for pioneering work in the creation of CGI hair and fur; Nestor Burtnyk and Marceli Wein of the National Research Center of Canada for computer assisted key framing for animation; Garth Dickie for shape-driven warping and morphing in the Elastic Reality Special Effects System; Jeff Yost, Christian Rouet, David Benson and Florian Kainz for the development of a system to create and control hair and fur in CGI; Brian Knep, Craig Hayes, Rick Sayre and Tom Williams of ILM for the creation and development of the direct input device; and Ken Perlin for the development of the Perlin Noise technique.
- Colossal Pictures files Chapter 11 bankruptcy
- Yahoo! IPO ($43/share)
- eBay launched
- SGI buys Cray Research – $764M
- SGI introduces O2 workstation
- Disney purchases DreamQuest Images; Dreamworks buys interest in PDI
- PalmPilot introduced
- Windows 95 ships

SGI O2

1997

- VIFX joins with Blue Sky
- Flash 1.0 released

- Bryce 3D
- Riven
- DVD technology unveiled
- SGI Octane
- IBM Deep Blue wins at chess
- Przemyslaw Prusinkiewicz receives the 1997 ACM SIGGRAPH CG Achievement Award
- James Foley receives the 1997 ACM SIGGRAPH Steven A. Coons Award

SGI Octane

- Academy Scientific and Engineering Awards go to Bill Kovacs and Roy Hall for the engineering efforts that result in the Wavefront Advanced Visualizer software; Richard Shoup, Alvy Ray Smith and Tom Porter for the development of digital paint systems; John Gibson, Rob Kreiger, Milan Novacek, Glen Ozymok, and Dave Springer for the development of geometric modeling in Alias PowerAnimator; Craig Reynolds for pioneering contributions to 3D computer animation; Eben Ostby, Bill Reeves, Sam Leffler and Tom Duff for the Pixar Marionette animation system; and Dominique Boisvert, Rejean Gagne, Daniel Langlois, and Richard Lapierriere for the Actor component of the Softimage animation system.
- Academy Technical Achievement Awards go to Jim Keating, Michael Wahrman and Richard Hollander for the Wavefront Advanced Visualizer software development; Greg Hermanovic, Kim Davidson, Mark Elendt and Paul Breslin for the development of PRISMS software; and Richard Chuang, Glenn Entis and Carl Rosendahl for the PDI animation system.
- Pixar interactive division dissolved
- Microsoft sued by Justice Department
- Apple Computer acquires NeXT

1998

Titanic

- Titanic becomes the largest grossing motion picture in US history
- Alias Maya released
- Quicktime 3.0 released
- Google launched
- Boss Films closes
- Riven released
- Sun gets back into graphics with the Darwin Ultra series of workstations
- MPEG-4 standard announced
- XML standard
- CGI cartoon Voltron produced in US

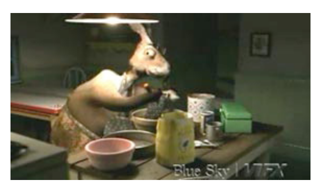
- SGI and Microsoft form partnership to develop APIs; SGI will develop NT-based PCs
- Geri's Game (Pixar) – awarded the Academy Award for Animated Short
- Colossal Pictures emerges from Chapter 11 bankruptcy
- Avid purchases SoftImage from Microsoft
- The SIGGRAPH Conference celebrates its 25th Anniversary in Orlando. The Siggraph 98 History Project was established to review the history to that point.

Scene from Geri's Game

- Carl Machover envisions a book that would be a compilation of significant papers in the history of CG. Edited by Rosalee Wolfe and titled *Seminal Graphics: Pioneering Efforts that Shaped the Field*, it started with a jury (Jim Blinn, Michael Cohen, Jim Foley, Don Greenberg, Machover, Stephen Spencer, and Turner Whitted) to select the "seminal" papers that would be included. The book was published in December.
- Jim Blinn delivers the SIGGRAPH 98 Keynote address
- Michael Cohen (Microsoft) receives the 1998 ACM SIGGRAPH CG Achievement Award
- Maxine Brown receives the first SIGGRAPH Outstanding Service Award
- Academy Technical Achievement Awards go to Doug Roble (Digital Domain) and Thad Beier (Hammerhead) for Tracking Technology; Nick Foster (PDI) for water simulation systems; David Difrancesco, Bala Manian and Tom Noggle for laser film recording and Cary Philips for the ILM Caricature animation system
- Academy Scientific and Engineering Awards go to Gary Tregaski for the primary design and Dominique Boisvert, Philipe Panzini and Andre Leblanc for the development of the Flame and Inferno software; Roy Ference, Steve Schmidt, Richard Federico, Rockwell Yarid and Mike McCrackan for the design and development of the Kodak Lightning laser recorder.

1999

- The graphics world loses David Evans at age 74
- Bunny (Chris Wedge – Blue Sky) – awarded the Academy Award for Animated Short
- Star Wars Episode One – The Phantom Menace uses 66 digital characters composited with live action



Scene from Bunny

- VIFX and Rhythm & Hues merge
- The graphics world loses Pierre Bezier
- Silicon Graphics Incorporated changes its name to SGI
- Fred Brooks receives the Turing Award
- NewTek ports Toaster to NT
- melissa computer virus

- SIGGRAPH celebrates its 30th Anniversary as an organization at SIGGRAPH 99 in Los Angeles
- Tony DeRose (Pixar) receives the 1999 ACM SIGGRAPH CG Achievement Award
- Jim Blinn receives the 1999 ACM SIGGRAPH Steven A. Coons Award
- SGI cuts Cray, NT production and High end graphic design
- Side Effects Houdini ported to Linux
- Napster created
- Toy Story 2 produced by Pixar
- Stuart Little produced by Sony Pictures Imageworks
- Fantasia 2000 produced by Disney
- Disney's DreamQuest and Feature Animation join to form The Secret Lab (TSL)

Stuart Little

2000s

2000

- Playstation 2
- SGI sells Cray to Tera Computer
- Human genome mapped by Celera
- Microsoft X-Box prototype shown at SIGGRAPH 2000
- Dinosaur produced by Disney
- The graphics world loses Phil Mittleman (MAGI)
- Walking with Dinosaurs – Framestore (UK)
- Mission to Mars effects produced by ILM and The Secret Lab
- Academy of Motion Pictures Arts and Sciences Award of Merit awarded to Rob Cook, Loren Carpenter and Ed Catmull for the significant advancements to the field of motion picture rendering as exemplified in Pixar's Renderman

Dinosaur

- Academy Technical Achievement Awards go to Venkat Krishnamurthy for the Paraform software for digital form development; and George Burshukov, Kim Libreri and Dan Piponi for image based rendering
- SIGGRAPH 2000 held in New Orleans
- Tom DeFanti and Copper Giloth receive the 2000 SIGGRAPH Outstanding Service Award
- David Salesin receives the 2000 ACM SIGGRAPH CG Achievement Award

- Hollow Man produced by Sony Pictures Imageworks
- How the Grinch Stole Christmas (Centropolis)
- Maya ported to Macintosh
- Mac OS-X introduced

Hollowman

2001

- SIGGRAPH 2001 held in Los Angeles
- Lance Williams receives the 2001 ACM SIGGRAPH Steven A. Coons Award
- Andrew Witkin receives the 2001 ACM SIGGRAPH CG Achievement Award
- Paul Debevec receives the 2001 ACM SIGGRAPH Significant New Researcher Award
- The graphics world loses Bob Abel (Sept 23)
- Disney's Secret Lab closes
- Apple iPod
- Side Effects Houdini ported to Sun
- AOL/TimeWarner merger
- Autodesk acquires Media100 software product line
- Advanced Audio Coding (AAC) format introduced by Dolby Labs and Fraunhofer Institute
- Windows XP

iPod

- Academy Technical Achievement Awards go to Garland Stern for the Cel Paint software system; Uwe Sassenberg and Rolf Schneider for the 3D Equalizer matchmove system; Lance Williams for pioneering influence in animation and effects; Bill Spitzak, Paul Van Camp, Jonathan Egstad and Price Pethal for the NUKE-2D compositing software; Steve Sullivan and Eric Shafer for the ILM Motion and Structure Recovery System (MARS); and John Anderson, Jim Hourihan, Cary Philips and Sebastion Marino for the ILM Creature Dynamics System
- The Academy of Motion Pictures Arts and Sciences approve a new category for the Oscars titled Best Animated Feature Film Award. Nine films were declared eligible: Final Fantasy: The Spirits Within, Jimmy Neutron: Boy Genius, Marco Polo: Return to Xanadu, Monsters, Inc., Osmosis Jones, The Prince of Light, Shrek, The Trumpet of the Swan, and Waking Life.
- Significant FX movies – Final Fantasy (Square), Monsters Inc.(Pixar), Harry Potter, A.I., Lord of the Rings, Shrek (PDI), The Mummy Returns (ILM), Tomb Raider (Cinesite), Jurassic Park III, Pearl Harbor (ILM), Planet of the Apes (Asylum)

- Microsoft xBox and Nintendo Gamecube released

xBox

2002

- SIGGRAPH 2002 held in San Antonio, Texas
- Bert Hertzog (Fraunhofer Center for Research in Computer Graphics) receives the 2002 Outstanding Service Award for extraordinary service to ACM SIGGRAPH by a volunteer
- David Kirk (NVIDIA) receives the 2002 ACM SIGGRAPH CG Achievement Award
- HP / Compaq merger
- William Fetter (Boeing) passes away.
- Steven Gortler (Harvard Univ) receives the 2002 ACM SIGGRAPH Significant New Researcher Award
- Alias|Wavefront, an SGI company, was awarded an Academy Award of Merit Oscar at the Scientific and Technical Awards ceremony of the Academy of Motion Picture Arts and Sciences for its development of Maya software.
- Mark Elendt, Paul Breslin, Greg Hermanovic and Kim Davidson receive a Scientific and Engineering Award for their continued development of the procedural modeling and animation components of their Prisms program, as exemplified in the Houdini software package.
- Academy Technical Achievement Awards ?To Dick Walsh for the development of the PDI/ Dreamworks Facial Animation System. ?To Thomas Driemeyer and to the mathematicians, physicists and software engineers of Mental Images for their contributions to the Mental Ray rendering software for motion pictures. ?To Eric Daniels ,George Katanics ,Tasso Lappas and Chris Springfield for the development of the Deep Canvas rendering software.

2003

- Atari Games Corporation (Midway Games West) out of business.
- Oscar nominees for Best animated short film: The Cathedral, Platige Image, Tomek Baginski; The Chubb Chubbs!, Sony Pictures Imageworks,Eric Armstrong; Das Rad, Filmakademie Baden-Württemberg GmbH, Chris Stenner and Heidi Wittlinger; Mike’s New Car, Pixar Animation Studios,Pete Docter and Roger Gould; Mt. Head, Yamamura Animation Production, Koji Yamamura; for Achievement in visual effects: The Lord of the Rings: The Two Towers, Jim Rygiel, Joe Letteri, Randall William Cook and Alex Funke; Spider-Man, John Dykstra, Scott Stokdyk, Anthony LaMolinara and John Frazier, Star Wars Episode II: Attack of the Clones, Rob Coleman, Pablo Helman, John Knoll and Ben Snow;Ice Age nominated for Best Animated Feature Film
- Dolby Labs acquires DemoGraFX, Gary Demos’ company
- SIGGRAPH 2003 held in San Diego
- David Brown (founder – Blue Sky and ex of MAGI) passes away

- Pat Hanrahan (Stanford) receives the 2003 ACM SIGGRAPH Steven A. Coons Award
- Peter Schrøder (Cal Tech) receives the 2003 ACM SIGGRAPH CG Achievement Award
- Mathieu Desbrun (USC) receives the 2003 ACM SIGGRAPH Significant New Researcher Award
- The Cathedral selected as Best Short Film in SIGGRAPH Electronic Theatre
- Apple introduces the Power Mac G5
- Alias/Wavefront becomes Alias

PowerMac G5

2004

- Jim Clark elected to Fellow in Academy of Arts and Sciences
- Oscar nominees for Best animated short film: Harvie Krumpet – Adam Elliot; Boundin' – Bud Luckey; Destino – Dominique Monfery, Roy Edward Disney; Gone Nutty – Carlos Saldanha, John C. Donkin; Nibbles – Christopher Hinton; for Best animated feature : Finding Nemo – Andrew Stanton; Brother Bear – Aaron Blaise, Robert Walker; Triplettes de Belleville, Les – Sylvain Chomet; for Achievement in Visual Effects: Lord of the Rings: The Return of the King – Jim Rygiel, Joe Letteri, Randall William Cook, Alex Funke; Master and Commander: The Far Side of the World – Daniel Sudick, Stefen Fangmeier, Nathan McGuinness, Robert Stromberg; Pirates of the Caribbean: The Curse of the Black Pearl – John Knoll, Hal T. Hickel, Charles Gibson, Terry D. Frazee
- Academy Scientific and Engineering Awards go to Stephen Regelous for the design and development of Massive, the autonomous agent animation system used for the battle sequences in "The Lord of the Rings" trilogy. Academy Technical Achievement Awards go to Christophe Hery, Ken McGaugh, and Joe Letteri for their groundbreaking implementations of practical methods for rendering skin and other translucent materials using subsurface scattering techniques; Henrik Wann Jensen, Stephen R. Marschner, and Pat Hanrahan for their pioneering research in simulating subsurface scattering of light in translucent materials as presented in their paper "A Practical Model for Subsurface Light Transport."
- SIGGRAPH 2004 held in Los Angeles
- Steve Cunningham and Judith Brown receive the 2004 Outstanding Service Award for extraordinary service to ACM SIGGRAPH by a volunteer
  Hugues Hoppe (Microsoft) receives the 2004 ACM SIGGRAPH CG Achievement Award
- Zoran Popovic (Univ. Washington) receives the 2004 ACM SIGGRAPH Significant New Researcher Award
- Chris Landreth's Ryan selected for Jury Award in SIGGRAPH Electronic Theatre; Sejong Park's Birthday Boy selected Best Animated Short
- Ub Iwerks Award given to Ed Catmull for creative work at Pixar
- Alias acquired from SGI by Accel-KKR and the Ontario Teachers' Pension Plan.

Ryan

2005

- Oscar nominees for Best animated short film: Sejong Park & Andrew Gegory – Birthday Boy; Jeff Fowler & Tim Miller – Gopher Broke; Bill Plympton – Guard Dog; Mike Gabriel & Baker Bloodworth – Lorenzo; Chris Landreth – Ryan; for Best animated feature : Brad Bird – The Incredibles; Bill Damasschka – Shark Tale; Andrew Adamson – Shrek 2; for Achievement in Visual Effects: Roger Guyett, Tim Burke, John Richardson and Bill George – Harry Potter and the Prisoner of Azkaban; John Nelson, Andrew R. Jones, Erik Nash and Joe Letteri – I, Robot; John Dykstra, Scott Stokdyk, Anthony LaMolinara and John Frazier – Spider-Man 2
- Academy Scientific and Technical Awards go to Dr. Julian Morris, Michael Birch, Dr. Paul Smyth and Paul Tate for the development of the Vicon motion capture technology; Dr. John O. B. Greaves, Ned Phipps, Antonie J. van den Bogert and William Hayes for the development of the Motion Analysis motion capture technology; Dr. Nels Madsen, Vaughn Cato, Matthew Madden and Bill Lorton for the development of the Giant Studios motion capture technology; Alan Kapler for the design and development of Storm , a software toolkit for artistic control of volumetric effects.
- SIGGRAPH 2005 held in Los Angeles
    - Steve Cunningham and Judith Brown receive the 2004 Outstanding Service Award for extraordinary service to ACM SIGGRAPH by a volunteer
      Tomoyuki Nishita (Tokyo University) receives the 2005 ACM SIGGRAPH Steven Anson Coons Award
    - Jos Stam (Alias) receives the 2005 ACM SIGGRAPH CG Achievement Award
    - Ron Fedkiw (Stanford) receives the 2005 ACM SIGGRAPH Significant New Researcher Award
    - Shane Acker's 9 selected for Best of Show in SIGGRAPH Electronic Theatre; Fallen Art and La Migration Bigoudenn selected for Jury Honors
- Adobe purchases Macromedia for US$3.4B.

2006

- Oscar nominees for Best animated short film: "Badgered" – A National Film and Television School Production, Sharon Colman; "The Moon and the Son: An Imagined Conversation" – A John Canemaker Production, John Canemaker and Peggy Stern; "The Mysterious Geographic Explorations of Jasper Morello" (Monster Distributes) – A 3D Films Production, Anthony Lucas; "9" – A Shane Acker Production, Shane Acker; "One Man Band" – A Pixar Animation Studios Production, Andrew Jimenez and Mark Andrews. for Best animated feature : "Howl's Moving Castle" (Buena Vista) – Hayao Miyazaki; "Tim Burton's Corpse Bride" (Warner Bros.) – Mike Johnson and Tim Burton; "Wallace & Gromit in the Curse of the Were-Rabbit" (DreamWorks Animation SKG) – Nick Park and Steve Box. for Achievement in Visual Effects: "The Chronicles of Narnia: The Lion, the Witch and the Wardrobe" (Buena Vista) – Dean Wright, Bill Westenhofer, Jim Berney and Scott Farrar; "King Kong" (Universal) – Joe Letteri, Brian Van't Hul, Christian Rivers and Richard Taylor; "War of the Worlds" (Paramount and DreamWorks) – Dennis Muren, Pablo Helman, Randal M. Dutra and Daniel Sudick

- Academy Scientific and Technical Awards go to David Baraff, Michael Kass and Andrew Witkin for their pioneering work in physically-based computer-generated techniques used to simulate realistic cloth in motion pictures.; to John Platt and Demetri Terzopoulos for their pioneering work in physically-based computer-generated techniques used to simulate realistic cloth in motion pictures; to Ed Catmull, for the original concept, and Tony DeRose and Jos Stam for their scientific and practical implementation of subdivision surfaces as a modeling technique in motion picture production. Gary Demos was honored with the 19th Gordon E. Sawyer Award, presented to an individual in the motion picture industry whose technological contributions have brought credit to the industry.
- Disney acquires Pixar for $7.4B; Ed Catmull named President; Steve Jobs joins Disney Board
- Apple Computer adopts the Intel chip, introduces Bootcamp to run Windows.
- SGI files Chapter 11 protection
- Richard “Doc” Bailey, the “Jimi Hendrix of CG” passes away
- Michael Bay and Wyndcrest Holdings buy Digital Domain, replace Scott Ross
- SIGGRAPH 2006 held in Boston. SIGGRAPH awards are as follows:
    - Computer Graphics Achievement Award Thomas W. Sederberg, Brigham Young University
    - Significant New Researcher Award Takeo Igarashi, The University of Tokyo
    - ACM SIGGRAPH Outstanding Service Award John M. Fujii, Hewlett Packard Company
    - One Rat Short – Best of Show, Computer Animation Festival Alex Weil, Charlex Inc.
- CGI pioneer Bill Kovacs passes away.
- AMD purchases ATI Technologies for $5.4B
- Autodesk acquires Alias for US$197M.

2007

- SIGGRAPH 2007 held in San Diego. SIGGRAPH awards are as follows:
    - Computer Graphics Achievement Award – Greg Ward (Radiance)
    - Significant New Researcher Award – Ravi Ramamoorthi
    - Steven Coons Award – Nelson Max
    - Ark – Best of Show, Computer Animation Festival; Dreammaker – Jury Honors; En Tus Brazos – Award of Excellence
- Academy Award nominations for Animated feature: Ratatouille (Disney/Pixar) – Brad Bird, Persepolis (Sony Pictures Classics) – Marjane Satrapi and Vincent Paronnaud, Surf’s Up (Columbia/Sony Pictures Animation) – Ash Brannon and Chris Buck. For Animated Short: Peter & the Wolf – Se-ma-for, BreakThru Films – Suzie Templeton, Even Pigeons Go To Heaven – BUF – Samuel Tourneux and Simon Vanesse, I Met the Walrus – Josh Raskin, Madame Tutli-Putli – National Film Board of Canada – Chris Lavis and Maciek Szczerbowski, My Love – Aleksandr Petrov. For Visual Effects: The Golden Compass – Michael

Fink, Bill Westenhofer, Ben Morris, and Trevor Wood, Pirates of the Caribbean: At World's End – John Knoll, Hal Hickel, Charles Gibson, and John Frazier, Transformers – Scott Farrar, Scott Benza, Russell Earl, and John Frazier.

2008

- SIGGRAPH 2008 held in Los Angeles. SIGGRAPH awards are as follows:
    - Computer Graphics Achievement Award – Ken Perlin
    - Significant New Researcher Award – Maneesh Agrawala
    - ACM SIGGRAPH Outstanding Service Award – Stephen Spencer, University of Washington
    - Oktapodi – Best of Show; 893 – Best Student Piece; Mauvais Role – Jury Award; Our Wonderful Nature – Best Told Fable; Oktapodi – Audience Prize Computer Animation Festival
- Academy Award nominations for Animated feature: WALL-E (Disney/Pixar) – Andrew Stanton, Bolt (Disney) – Chris Williams and Byron Howard, Kung Fu Panda (DreamWorks/Pacific Data Images) – John Wayne Stevenson and Mark Osborne. For Animated Short: La Maison en petits cubes – Robot & Oh! Production – Kunio Katō, Lavatory – Lovestory – Melnitsa Animation Studio – Konstantin Bronzit, Oktapodi – Gobelins L'Ecole de L'Image – Emud Mokhberi and Thierry Marchand, Presto – Pixar – Doug Sweetland, This Way Up – Nexus Productions – Alan Smith and Adam Foulkes. For Visual Effects: The Curious Case of Benjamin Button – Eric Barba, Steve Preeg, Burt Dalton, and Craig Barron, The Dark Knight – Nick Davis, Chris Corbould, Tim Webber, and Paul Franklin, Iron Man – John Nelson, Ben Snow, Dan Sudick, and Shane Mahan

2009

- SIGGRAPH 2009 held in New Orleans. SIGGRAPH awards are as follows:
    - Computer Graphics Achievement Award – Michael Kass
    - Significant New Researcher Award – Wojciech Matusik
    - Stephen A. Coons Award – Robert Cook
    - Distinguished Artist Award for Lifetime Achievement in Digital Art – Lynne Hershman Leeson, Roman Verostko
    - French Roast – Best of Show; Project: Alpha – Best Student Piece; Dix – Jury Award; Unbelievable Four – Best Told Fable, Computer Animation Festival
- Academy Award nominations for Animated feature: Up (Disney/Pixar) – Pete Docter, Coraline (Focus Features/LAIKA) – Henry Selick, Fantastic Mr. Fox (20th Century Fox/Regency) – Wes Anderson, The Princess and the Frog (Disney) – John Musker and Ron Clements, The Secret of Kells (Cartoon Saloon) – Tomm Moore and Nora Twomey. For Animated Short: Logorama – H5, Autour de Minuit Productions – Nicolas Schmerkin, Granny O'Grimm's Sleeping Beauty – Brown Bag Films – Nicky Phelan and Darragh O'Connell, French Roast – Fabrice Joubert, The Lady and the Reaper – Kandor Graphics – Javier Recio

Gracia, A Matter of Loaf and Death – Aardman Animations – Nick Park. For Visual Effects: Avatar – Joe Letteri, Stephen Rosenbaum, Richard Baneham, and Andrew R. Jones, District 9 – Dan Kaufman, Peter Muyzers, Robert Habros, and Matt Aitken, Star Trek – Roger Guyett, Russell Earl, Paul Kavanagh, and Burt Dalton

- Significant animated movies: 9 (USA), A Christmas Carol (USA), Afro Samurai: Resurrection (USA and Japan), Alvin and the Chipmunks: The Squeakquel (USA), Astro Boy (USA and Japan), Cloudy with a Chance of Meatballs (USA), Coraline (USA), Fantastic Mr. Fox (USA), Garfield's Pet Force (USA and South Korea), Ice Age 3: Dawn of the Dinosaurs (USA), Monsters vs. Aliens (USA), Up (USA)

2010

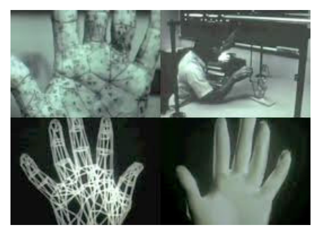
- SIGGRAPH 2010 held in Los Angeles. SIGGRAPH awards are as follows:
    - Computer Graphics Achievement Award Jessica Hodgins
    - Significant New Researcher Award – Alexei Efros
    - ACM SIGGRAPH Outstanding Service Award Kellogg S. Booth
    - Distinguished Artist Award for Lifetime Achievement in Digital Art – Yoichiro Kawaguchi
    - Loom – Best of Show; Best Student Piece – The Wonder Hospital; Jury Award – Poppy, Computer Animation Festival
- Academy Award nominations for Animated feature: Toy Story 3 (Disney/Pixar) – Lee Unkrich, How to Train Your Dragon (DreamWorks/Pacific Data Images) – Chris Sanders and Dean DeBlois, The Illusionist (Pathé Pictures/Sony Pictures Classics) – Sylvain Chomet. For Animated Short: The Lost Thing – Shaun Tan and Andrew Ruhemann, Day & Night – Pixar – Teddy Newton, The Gruffalo – Magic Light Pictures, Studio Soi – Jakob Schuh and Max Lang, Let's Pollute – Geefwee Boedoe, Madagascar, a Journey Diary – Bastien Dubois.
- For Visual Effects: Inception – Paul Franklin, Chris Corbould, Andrew Lockley and Peter Bebb, Alice in Wonderland – Ken Ralston, David Schaub, Carey Villegas and Sean Phillips, Harry Potter and the Deathly Hallows: Part 1 – Tim Burke, John Richardson, Christian Manz and Nicolas Aithadi, Hereafter – Michael Owens, Bryan Grill, Stephan Trojanski and Joe Farrell, Iron Man 2 – Janek Sirrs, Ben Snow, Ged Wright and Daniel Sudick
- Significant animated movies: Alpha and Omega (USA), Despicable Me (USA), MegaMind (USA), Shrek Forever After (USA), Tangled (USA), Tinker Bell And The Great Fairy Rescue (USA), Toy Story 3 (USA).

2011

- SIGGRAPH 2011 held in Vancouver. SIGGRAPH awards are as follows:
    - Computer Graphics Achievement Award – Richard Szeliski
    - Significant New Researcher Award – Olga Sorkine
    - Stephen A. Coons Award – Jim Kajiya

    - Distinguished Artist Award for Lifetime Achievement in Digital Art – Charles Csuri
    - The Fantastic Flying Books of Mr. Morris Lessmore – Best of Show; Flamingo Pride – Best Student Piece; Paths of Hate – Jury Award, Computer Animation Festival

- Academy Award nominations for Animated feature: Rango (Paramount Pictures/Nickelodeon Movies/Blind Wink/GK Films) – Gore Verbinski, A Cat in Paris (Folimage with Digit Anima, France 3 Cinéma, Lumière, Lunanime, Radio Télévision Belge Francophone) – Alain Gagnol and Jean-Loup Felicioli, Chico & Rita (Isle of Man Film/Magic Light Pictures/Disney/CinemaNX) – Fernando Trueba and Javier Mariscal, Kung Fu Panda 2 (DreamWorks Animation/Paramount Pictures) – Jennifer Yuh Nelson, Puss in Boots (DreamWorks Animation/Paramount Pictures) – Chris Miller.
- For Animated Short: The Fantastic Flying Books of Mr. Morris Lessmore – Moonbot Studios – William Joyce and Brandon Oldenburg, Dimanche – National Film Board of Canada – Patrick Doyon, La Luna – Pixar – Enrico Casarosa, A Morning Stroll – Studio AKA – Grant Orchard and Sue Goffe, Wild Life – National Film Board of Canada – Wendy Tilby and Amanda Forbis.
- For Visual Effects: Hugo – Rob Legato, Joss Williams, Ben Grossmann and Alex Henning, Harry Potter and the Deathly Hallows: Part 2 – Tim Burke, David Vickery, Greg Butler, and John Richardson, Real Steel – Erik Nash, John Rosengrant, Danny Gordon Taylor, and Swen Gillberg, Rise of the Planet of the Apes – Joe Letteri, Dan Lemmon, R. Christopher White, and Daniel Barrett, Transformers: Dark of the Moon – Scott Farrar, Scott Benza, Matthew E. Butler, and John Frazier
- Significant animated movies: Arthur Christmas (USA), Cars 2 (USA), Gnomeo and Juliet (USA/UK), Happy Feet 2 (USA/Australia), Hop (USA), Kung Fu Panda 2 (USA), Puss in Boots (USA), Rango (USA, Rio (Brazil and USA), The Adventures of Tintin: Secret of the Unicorn (USA, The Smurfs (USA).
- Ed Catmull's CG Hand added to National Film Registry



Catmull's Hand

2012

- Carl Machover, computer graphics pioneer and graphics "evangelist", dies at 84.
- Buzz Potamkin, legendary animation producer ("I Want My MTV") and head of Buzzco Productions dies at 66.
- Digital Domain files for Chapter 11 and closes all Florida studios; emerges from bankruptcy after selling to Galloping Horse America, a division of a Beijing media company, and Reliance MediaWorks, part of the Indian conglomerate Reliance Group in late September for $30.2M
- SIGGRAPH 2012 held in Los Angeles. SIGGRAPH awards are as follows:

    - Computer Graphics Achievement Award – Greg Turk
    - Significant New Researcher Award – Karen Liu
    - Outstanding Service Award – David Kasik
    - Distinguished Artist Award for Lifetime Achievement in Digital Art – Jean-Pierre Hébert
    - Réflexion – Best in Show; Estefan – Best Student Piece; How To Eat Your Apple – Jury Award,,

Rosette – Well Told Fable Award – Computer Animation Festival

2013

- Rhythm and Hues files for bankruptcy (February) – Purchased by Prana Studios (April)
- SIGGRAPH 2013 held in Anaheim. SIGGRAPH awards are as follows:
    - Computer Graphics Achievement Award – Holly Rushmeier
    - Steven Anson Coons Award – Turner Whitted
    - Significant New Researcher Award – Niloy Mitra
    - Distinguished Artist Award for Lifetime Achievement in Digital Art – Manfred Mohr
    - Outstanding Service Award – Mary Whitton
    - À la Française – Best in Show; Rollin' Safari – Best Student Piece; Lost Senses – Jury Award, – Computer Animation Festival

Other Related Historical Links

Other related historical links

- Computer Graphics World 25th Anniversary Retrospectives
  - *Part 1 – Digital Art*
  - *Part 2 – CAD/CAM/CAE*
  - *Part 3 – Gaming*
  - *Part 4 – Broadcast*
  - *Part 5 – Science*
  - *Part 6 – Architecture*
  - *Part 7 – Movies*
- *http://eriq.lecture.ub.ac.id/files/2010/04/CG-Timelines-artof3d.pdf* (Timelines and Milestones of Computer Animation and Visual Effects, from The Art of Computer Animation and Imaging (Kerlow)
- *http://www.oscars.org/oscars/awards-databases-0* (AMPAS Visual Effects Awards Database)
- *https://www.timetoast.com/timelines/media-timeline-most-important-inventions-in-media-history*/ (History of media)
- *https://arstechnica.com/gadgets/2013/06/the-future-of-tv-a-star-is-born/* (History of Television Broadcast)
- *http://aleph0.clarku.edu/~djoyce/mathhist/* (History of mathematics)
- *http://www.xnumber.com/xnumber/Microcomputer_invention.htm*(History of microcomputers)
- *http://ei.cs.vt.edu/~history/* (History of computing)
- *http://www.computerhistory.org*/ (Computer History Museum)
- *http://www.virtualaltair.com/virtualaltair.com/vac_history.asp* (History of the Microcomputer Revolution)
- *http://www.apple-history.com*/ (History of Apple Computer)
- *http://apple2history.org*/ (History of the Apple II)
- *http://www.xnumber.com/xnumber/Microcomputer_invention.htm* (History of the development of the Macintosh)

- *http://www.timetoast.com/timelines/77845* (ITGS history page)
- *http://joelorr.squarespace.com/community-caddcam-history-proj/* (Joel Orr's Community History of CADD and PLM)
- *http://pctimeline.info/workstation/*(History of the Workstation)
- *http://www.nobelprize.org/educational/physics/integrated_circuit/history/http://www.nobelprize.org/educational/physics/integrated_circuit/history/* (Integrated Circuit History)
- *http://www.lifesmith.com/history.html* (History of Fractals)
- *http://www.inwap.com/mf/reboot/alliance/1980s.txt* (Taken from "On Becoming an Animator" (Miller))
- *http://www.awn.com/mag/issue2.5/2.5pages/2.5collinssiggraph.html* (Joan Collins article from 8/97 AWN)
- *http://thinkquest.org/pls/html/think.library* (ThinkQuest History page)
- *http://www.amazon.com/Computer-Animation-Second-Algorithms-Techniques/dp/0125320000/ref=dp_ob_title_bk?ie=UTF8&qid=998169184&sr=1-39*(Rick Parent's book on Computer Animation)
- *http://www.internetvalley.com/intval1.html* (History of the Internet) *http://www.vtoldboys.com/editingmuseum/index.htm* (Museum of Video Editing)
- *http://dam.org/home*(Digital Art Museum history site)
- *AMPAS Scientific and Technical Awards in Digital Effects* (from the AMPAS Awards database)

Corporate historical links

- *http://www.lucasfilm.com/inside/history/* (Timeline of Lucasfilm history)
- *http://www.motorolasolutions.com/US-EN/About/Company+Overview/History/Timeline* (Motorola timeline)
- *http://www.bbn.com/timeline/* (BBN and internet timeline)
- *http://www.synthespianstudios.com/about/* (Kleiser/Walczak history)
- *http://www.rga.com/about/*(R. Greenberg History)
- *http://timelineindex.com/content/view/1087* (Microsoft timeline)
- *http://www.hp.com/hpinfo/abouthp/histnfacts/museum/* (HP Virtual Museum)
- *http://www.ampex.com/ampex-history/* (Ampex Corporation history)
- *http://www.visualeffectssociety.com*/ Visual Effects Society

Other Visual Effects Resources

- *http://www.vfxhq.com*/ (Visual Effects Headquarters)
- *https://wmavity.wordpress.com/2017/01/21/a-history-of-visual-effects-oscar-shortlists-and-bake-offs/*(History of Special Effects [at the Oscars] (Intl Cinematographers Guild))
- *http://www.cinefex.com/* (Cinefex magazine)

Video Games

- *http://www.landley.net/history/mirror/atari/museum/Atari-Timeline.html* (History of Atari)
- *http://www.movingimage.us/files/exhibitions/minisites/computerspace98/index2.html*(American Museum of the Moving Image Computer Space 98 video game exhibition)
- *http://www.lysator.liu.se/adventure/* (a site dedicated to a listing of adventure games (interactive fiction))

List of Movies and Videos and Image Galleries

Movies and Videos (External and Embedded)

Number	Title	URL
Intro	History of CG	HistoryCG-1.m4v
1.1	Simulation of a Vacuum Tube	monkeysVIDEO_T1-1.m4v
2.1	On Guard! – 1956	http://www.youtube.com/watch?v=Kpahs3MAEDc
2.2	John Whitney Animation Flipbook	http://www.youtube.com/watch?v=_cmrTxtlgLA
2.3	Computers: Challenging Man's Supremacy – John Whitney Interview (1976)	https://www.youtube.com/watch?v=5eMSPtm6u5Y
2.4	Screening Room Interview with John Whitney	JohnWhitneyInterview_med.m4v
2.5	Interview with John Whitney	https://www.youtube.com/watch?v=pGH5aCYtjeE
2.6	Whitney Catalog (1961)	https://www.youtube.com/watch?v=TbV7loKp69s
2.7	Arabesque (John Whitney)	Arabesque_1963_med.m4v
2.8	Lapis – James Whitney (1966)	http://www.youtube.com/watch?v=kzniaKxMr2g
2.9	Permutations (1966)	http://www.youtube.com/watch?v=BzB31mD4NmA
2.10	Matrix III (1972)	http://www.youtube.com/watch?v=ZrKgyY5aDvA
3.1	Alan Kay – Video of Sketchpad	alankay-on-sketchpad-1987.m4v
3.2	Original Sketchpad Demo – Excerpt	https://www.youtube.com/watch?v=57wj8diYpgY
3.3	General Motors DAC-1 Demo	DAC-1demo-1.m4v
4.1	Generalized Coons' Surface	https://www.youtube.com/watch?v=5Jc007b0CaU
4.2	Scenes from The Artist and The Computer	
4.3	Two Gyro Gravity Gradient Altitude Control System	https://www.youtube.com/watch?v=m8Rbl7JG4Ng
4.4	Incredible Machine	http://techchannel.att.com/play-video.cfm/2012/6/14/ AT&T-Archives-Incredible-Machine-Bonus-Edition
4.5	A Computer Technique for the Animation of Movies	http://techchannel.att.com/play-video.cfm/2012/9/10/ AT&T-Archives-Computer-Technique-Production-Animated-Movies
4.6	PoemField No. 2 (1966)	http://techchannel.att.com/play-video.cfm/2012/8/13/AT&T-Archives-
4.7	Force, Mass and Motion	http://techchannel.att.com/play-video.cfm/2012/8/20/AT&T-Archives-
4.8	Hypercube/4D Hypermovie	http://techchannel.att.com/play-video.cfm/2012/8/17/AT&T-Archives-
4.9	Carla's Island – 1981	https://www.youtube.com/watch?v=kO-JB1WHmRc
4.10	DNA with Ethidium (1978)	http://www.youtube.com/watch?v=TD0-2lkvfgU
4.11	Intercalation of Doxorubicin with DNA (1980)	http://www.youtube.com/watch?v=pCVsJ-maSa8
4.12	Halftone Animation (1972)	HandFace_1972.m4v
4.13	Pong Man (Van Hook)	pongman_77.m4v
4.14	Dawn of an Epoch (OSU)	epochd-1.m4v
4.15	Form•Z 2007 User Reel	https://www.youtube.com/watch?v=3PewiPQdA5g

Number	Title	URL
4.16	Hummingbird (1966)	http://www.youtube.com/watch?v=awvQp1TdBqc
4.17	Rigid Body Dynamics	http://www.youtube.com/watch?v=AmFYMbJ0Eew
4.18	PM Magazine	http://www.youtube.com/watch?v=-4b2DsTEXag
4.19	Interacting Galaxies	http://excelsior.biosci.ohio-state.edu/~carlson/history/moovees/galaxie
4.20	Anima II	http://www.youtube.com/watch?v=Sknwhx0aUbo
4.21	The Circus	http://www.youtube.com/watch?v=u1z9Q4tU2a8
4.22	Procedural Terrain Models	http://www.youtube.com/watch?v=Qy-kyqU7J9I
4.23	Snoot and Muttly	http://www.youtube.com/watch?v=3RlrtAf7Qsg
4.24	Broken Heart	http://www.youtube.com/watch?v=iPLFB6_xpAI
4.25	Tuber's Two Step	http://www.youtube.com/watch?v=k-GZ0PogVLw
4.26	Zeltzer SAS V1	http://excelsior.biosci.ohio-state.edu/~carlson/history/moovees/SAS.m
4.27	Euhrthmy Motion Studies	http://www.youtube.com/watch?v=qVcyttQbKP0
4.28	Euhrythmy	http://www.youtube.com/watch?v=HLiD2yCBY8o
4.29	Coredump	http://www.youtube.com/watch?v=4CcJx0_b3mo
4.30	Tectonic Evolution	http://www.youtube.com/watch?v=92ZTkMQe0q4
4.31	Mechanical Universe Excerpts	Em
4.32	LA – The Movie (1987)	http://www.youtube.com/watch?v=6RsXCbpJG54
4.33	Mars – The Movie (1989)	http://www.youtube.com/watch?v=vMjlD6h2qko
4.34	Voyager 2 Flyby of Saturn (1981)	https://www.youtube.com/watch?v=SQk7AFe13CY
4.35	Evolution (1980) – from Cosmos	https://www.youtube.com/watch?v=YEdm1GoUo-o
4.36	Pioneer 11 Encounters Saturn (1980)	https://www.youtube.com/watch?v=myYIKJF589g
4.37	Voyager 2 Encounters Jupiter (1978)	https://www.youtube.com/watch?v=o4xIJlEV8Kw
4.38	Project Mathematics! (1988)	https://www.youtube.com/watch?v=PslowEd4-68
4.39	Voyager 2 Flyby of Uranus (1986)	https://www.youtube.com/watch?v=DrKQaDupdWQ
4.40	Computer Visions feature on Jim Blinn (1991)	https://www.youtube.com/watch?v=ePZ301Sg4HI&t=6s
4.41	Excerpt from Hunger/LaFaim	hunger-excerpt.m4v
5.1	Cornell In Perspective	Em
5.2	Sunstone (1979)	https://www.youtube.com/watch?v=tMW15OajuKc
5.3	Excerpt from The Works (NYIT)	works.m4v
5.4	The Works – 1984	http://www.youtube.com/watch?v=18OSLeWJVJQ
5.5	Kraftwerk Musique	http://www.dailymotion.com/video/x175jh_kraftwerk-music-non-stop_
5.6	JCGL Demo Reel 1983	https://www.youtube.com/watch?v=_WlAnrdtGmg
5.7	Pixel Planes (NCSU)	https://www.youtube.com/watch?v=7mzpZ861wEw
5.8	Sorting Out Sorting	https://www.youtube.com/watch?v=gv0JUEqaAXo
5.9	NC State Graphics (c1973)	https://www.youtube.com/watch?v=4MHzU4xJ4pk

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	EVL – Electronic Visualization Event	https://www.youtube.com/watch?v=pNJ-f-hqAWI
6.1	Digital Effects 1985 Demo	https://www.youtube.com/watch?v=Mv78UsrZ07g
6.2	Where the Wild Things Are Test	Em
6.3	MAGI Demo – 1980	magi_80-1.m4v
6.4	MAGI Demo – 1982	https://www.youtube.com/watch?v=WxetroPVCl0
6.5	MAGI Demo – 1984	https://www.youtube.com/watch?v=Ivk_LPQP6Ag
6.6	First Flight	https://www.youtube.com/watch?v=EQZO1-4D0lg
6.7	Triple-I Demo – excerpt	tripli-i-excerpt.m4v
6.8	The Little Death (Elson)	https://www.youtube.com/watch?v=rLGRSOfnnUM
6.9	Virtually Yours (Symbolics)	https://www.youtube.com/watch?v=BdTGJChDKrM
6.10	Digital Productions Demo – 1984	https://www.youtube.com/watch?v=N6u7yF2HtCw
6.11	Humantech	http://www.youtube.com/watch?v=c0mu8hnWSLg
6.12	Last Starfighter	http://www.youtube.com/watch?v=fEeGERPVxQU
6.13	Mick Jagger's Hard Woman	https://www.youtube.com/watch?v=LKcTGDBJUt8
6.14	Abel – Panasonic Glider	https://www.youtube.com/watch?v=3KFV0HbYULk
6.15	Abel Image Research High Fidelity – Excerpt (1982)	hi-fi.m4v
6.16	AT&T Ad	http://www.youtube.com/watch?v=IrnUdM_uF7s
6.17	Abel 1981 Demo	abel1981-excerpt.m4v
6.18	Abel 1982 Demo	http://www.youtube.com/watch?v=cT3_3d2JcR0
6.19	Abel 1985 Demo	http://www.youtube.com/watch?v=-1Yozk0g1YM
6.20	7-Up ad (1974)	https://www.youtube.com/watch?v=K2U-lP-SOSQ
6.21	Hawaiian Punch	http://www.youtube.com/watch?v=SIfh0XMrg6w
6.22	Benson and Hedges	http://www.youtube.com/watch?v=fdBoKOpctp4
6.23	Brilliance	http://www.youtube.com/watch?v=sCXYxNt02RI
6.24	Making of Brilliance	http://www.youtube.com/watch?v=eedXpclrKCc
6.25	C/CP NCGA Gears	CCP_NCGAGears-1.m4v
6.26	Cranston/Csuri Productions Demo – 1982	https://www.youtube.com/watch?v=ghNjMCHyu5w
6.27	Cranston/Csuri Productions Demo – 1983	http://www.youtube.com/watch?v=6EOFjHbiVMY
6.28	C/CP Demo – 1985	https://www.youtube.com/watch?v=Q8TYobTi234
6.29	C/CP TRW	http://www.youtube.com/watch?v=GvICw-8WaGk
6.30	C/CP Ads	http://www.youtube.com/watch?v=8CVkBZJ_zpI
6.31	PDI Morph Reel	https://www.youtube.com/watch?v=0b1_4NI3XIM
6.32	Pacific Data Images Demo – 1983	https://www.youtube.com/watch?v=b0cHnFxxLC4
6.33	Locomotion	https://www.youtube.com/watch?v=0b1_4NI3XIM
6.34	Chromosaurus	http://www.youtube.com/watch?v=HOUYSLStGak

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6.35	Waldo Demo w/ Jim Henson	https://www.youtube.com/watch?v=dP6TUB7KQc4
6.36	Richard Chuang Interview	http://www.youtube.com/watch?v=cQkEA62KWQQ
6.37	Omnibus Demo – 1985	https://www.youtube.com/watch?v=K18ZcE2t1Kw
6.38	Bo Gehring Demo – 1982	https://www.youtube.com/watch?v=Es8VdR-E8Wg
6.39	Harry Marks Demo	http://www.youtube.com/watch?v=6c3nWhR41D0
8.1	Alias/Wavefront Demo – 1986	https://www.youtube.com/watch?v=dolXi-3BcuA
8.2	Alias/Wavefront Demo – 1988	https://www.youtube.com/watch?v=2WU2Mckj15k
8.3	Wavefront Engineering Samples Reel	https://www.youtube.com/watch?v=0NY4dXRA3BM
8.4	Wavefront Users Group Demo	http://www.youtube.com/watch?v=3PBH0tvZCaE
8.5	Alias/Wavefront Maya Demo	https://www.youtube.com/watch?v=pHFLapfliN8
	Bill Buxton Movies	http://billbuxton.com/buxtonAliasVideos.html
8.6	Alias/Wavefront Maya Demo	https://www.youtube.com/watch?v=pHFLapfliN8
8.7	Side Effects 20th Anniversary Reel (2007)	https://www.youtube.com/watch?v=ScrDrCN5b5s
8.8	SoftImage Demo (1995)	https://www.youtube.com/watch?v=LrNQQvAKO2o
	Part 2	http://www.youtube.com/watch?v=xHeKXv4BY0M
8.9	Eurhythmy	eurythmy-1.m4v
8.10	Dancing Baby Cha	baby1-1.m4v
9.1	Larry Cuba – Calculated Movements	https://www.youtube.com/watch?v=HcvN1dt0yJo
	Interview with Larry Cuba	https://www.well.com/~cuba/VideoArt.html
	Star Wars: Episode IV – A New Hope. Making the graphics for Star Wars (Larry Cuba)	https://www.youtube.com/watch?v=yMeSw00n3Ac
	Lillian Schwartz – Artist and the Computer	http://www.lillian.com
	Lillian Schwartz – 3 Films and Interview	https://vimeo.com/31521570
9.2	Interview with Yoichiro Kawaguchi (1990) (Part 2)	https://www.youtube.com/watch?v=6qKjd0QXQO4
	Interview with Yoichiro Kawaguchi (1990) (Part 1)	http://www.youtube.com/watch?v=nJH0fLTR7YU
11.1	From Star Wars to Star Wars – The Story of ILM (1999)	https://www.youtube.com/watch?v=AFNTe7speqk
11.2	Jurassic Park excerpt – from ILM: Creating the Impossible	http://www.youtube.com/watch?v=NxfxsjCR_-o
11.3	André and Wally B.	https://www.youtube.com/watch?v=rQsCw1v-cEU
	The Making of Genesis	http://www.youtube.com/watch?v=Qe9qSLYK5q4
	Young Sherlock Holmes Knight	http://www.youtube.com/watch?v=uOsxXi-tu_U
	Pixar Image Computer	http://www.youtube.com/watch?v=ckE5U9FsgsE
11.4	Pixar Listerine Ad (1994)	https://www.youtube.com/watch?v=48tIwbuctYQ
11.5	Pixar – Luxo Jr.	https://www.youtube.com/watch?v=6G3O60o5U7w
	Pixar Shorts	http://www.youtube.com/watch?v=ckE5U9FsgsE

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	Pixar Executives Interview	http://www.youtube.com/watch?v=YjSExqtiIyg
11.6	Metrolight Demo	metrolight91-1.m4v
	Steam	https://www.youtube.com/watch?v=Qt87bLX7m_o
	Stanley and Stella – Breaking the Ice	http://www.youtube.com/watch?v=3bTqWsVqyzE
11.7	Technological Threat	https://www.youtube.com/watch?v=PLAGn3isH4o
11.8	Rhythm and Hues Demo – 1988	RHads-2.m4v
11.9	Making of Coca-Cola Bears	makeBears-1.m4v
11.10	Scenes from Lawnmower Man	lawnmower-1.m4v
11.11	Superman Movie Open	Superman-1.m4v
11.12	Bunny	https://www.youtube.com/watch?v=Gzv6WAlpENA
11.13	Maya	http://www.youtube.com/watch?v=a3KnzIdm7Aw
11.14	Sextone for President	http://www.youtube.com/watch?v=H9aYZ9KCWPk
11.15	Don’t Touch Me – Dozo (1988)	https://www.youtube.com/watch?v=8ovn8qRezPA
11.16	500 Nations	https://www.youtube.com/watch?v=24IA_viq1ZY
11.17	Sogitec Demo – 1985	https://www.youtube.com/watch?v=S8gMdY9L7Wk
11.18	Stand By Me (Ex Machina)	http://www.youtube.com/watch?v=0MjoqsXkErA
11.19	Incredible Crash Dummies	https://www.youtube.com/watch?v=g-WgF5jGVdA
12.1	Scanimate	scanimate-1.m4v
12.2	A Conversation with Roy Weinstock	http://www.youtube.com/watch?v=n9CQddf-Bdw
12.3	Image West Demo – 1981	https://www.youtube.com/watch?v=ispW6-7b2sA
12.4	Ron Hays Music Image Demo	http://www.youtube.com/watch?v=kACpN3vhFtY
12.5	Quantel – PIP	olympic-pip-flame-1.m4v
12.6	Max Headroom	headroom-1.m4v
13.1	Flight Simulation	flightsim-1.m4v
13.2	Singer-Link Demo	https://www.youtube.com/watch?v=uy8sJ9AxvYI
13.3	Evans and Sutherland History	e-s-history-1.m4v
13.4	NASA Simulation (2004)	https://www.youtube.com/watch?v=QA1is2UtQnw
13.5	Beethoven’s 6th in CIG	beethoven-2.m4v
13.6	Microsoft Flight Simulation	https://www.youtube.com/watch?v=ICb9ZXiD3q4
14.1	Animated Characters in Movies`	https://vimeo.com/14437767
14.2	Disney Silly Symphony: Farmyard Symphony (1938)	https://www.youtube.com/watch?v=5OVKAobiyIg
14.3	Queen: Bohemian Rhapsody	https://www.youtube.com/watch?v=irp8CNj9qBI
14.4	Cars: You Might Think	https://www.youtube.com/watch?v=3dOx510kyOs

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14.5	Rebecca Allen: Adventures in Success	https://www.youtube.com/watch?v=j5BLHeOdvYI
14.6	Rebecca Allen: Smile	https://www.youtube.com/watch?v=g43lzoRamWE
14.7	Money for Nothing Excerpt	https://www.youtube.com/watch?v=lAD6Obi7Cag
14.8	Peter Gabriel: Steam Excerpt	https://www.youtube.com/watch?v=Qt87bLX7m_o
14.9	Rebecca Allen – Musique	http://www.dailymotion.com/video/x175jh_kraftwerk-music-non-stop_
14.10	Michael Jackson: Black or White	https://www.youtube.com/watch?v=R4kLKv5gtxc
14.11	Godley & Creme: Cry Excerpt	https://www.youtube.com/watch?v=KxtPRF6NG7I
14.12	Todd Rundgren: Change Myself	https://vimeo.com/24768198
	Interview with Todd Rundgren	https://www.youtube.com/watch?v=Jhs24mL8Lx0
14.13	Def Leppard: Let's Get Rocked	https://www.youtube.com/watch?v=BO1Nae_EBvQ
14.14	Rammstein: Making of Links 2-3-4	https://www.youtube.com/watch?v=ax0G7MKe0hE
14.15	Creed: Bullets Excerpt	https://www.youtube.com/watch?v=oPzhUp8mWgs
14.16	Robbie Williams: Making of Rock D.J.	https://www.youtube.com/watch?v=Z4yO5yTW73I
14.17	TRON Trailer (1982)	https://www.youtube.com/watch?v=3efV2wqEjEY
15.1	SGI Iris 2400 Demo (1985)	https://www.youtube.com/watch?v=9EEY87HAHzk
15.2	NVIDIA Dawn (2002)	https://www.youtube.com/watch?v=4D2meIv08rQ
15.3	Spacewar! (1961)	https://www.youtube.com/watch?v=Rmvb4Hktv7U
15.4	Interview with Nolan Bushnell	https://www.youtube.com/watch?v=WW_rCV254yg
15.5	Interview with Ralph Baer	https://vimeo.com/37870722
16.1	Xerox Star Demo	https://www.youtube.com/watch?v=Cn4vC80Pv6Q
16.2	Macintosh 1984 Ad (with Jobs comments)	https://www.youtube.com/watch?v=lSiQA6KKyJo
	Macintosh 1984 Remake	http://www.youtube.com/watch?v=9pTHlG8USUg
16.3	Elton John: Nikita Excerpt	https://www.youtube.com/watch?v=Tg-Q-Acv4qs
16.4	Steve Jobs Introduces Macintosh (1984)	https://www.youtube.com/watch?v=2B-XwPjn9YY
16.5	Bill Gates and Steve Jobs (2007)	https://www.youtube.com/watch?v=1Bk-qTzN7vE
16.6	Gates/Jobs Rivalry	https://www.youtube.com/watch?v=P_5xhcpoeoM
16.7	Only Amiga!	https://www.youtube.com/watch?v=iNR5vxAR22A
16.8	Amiga and Newtek Toaster	https://www.youtube.com/watch?v=seznQmDp2pU
17.1	Aspen Map example	aspen-map-1.m4v
17.3	UNC Fetal Surgery Virtual Reality	fetal-surgery-1.m4v
18.1	Viz-O-Matic	https://www.youtube.com/watch?v=fP-7rhb-qMg
18.2	L.A.: The Movie (1987)	https://www.youtube.com/watch?v=6RsXCbpJG54

Number	Title	URL
18.3	Mars: The Movie (1989)	https://www.youtube.com/watch?v=vPXQq1XNi0c
18.4	NCSA Severe Storm Visualization	https://www.youtube.com/watch?v=EgumU0Ns1YI
18.5	Egyptology: 3D Mummy	https://www.youtube.com/watch?v=Il8gZbD9bkM
19.1	Particle Dreams – Sims	https://www.youtube.com/watch?v=tFD4jMMXRbg
19.2	Genesis Sequence – ILM	https://www.youtube.com/watch?v=Qe9qSLYK5q4
19.3	Panspermia – Sims	https://www.youtube.com/watch?v=F4asE2JdSOY
19.4	Locomotion	https://www.youtube.com/watch?v=Qe9qSLYK5q4
19.5	Evolved Creatures	http://www.youtube.com/watch?v=bBt0imn77Zg
19.6	Eurhythmy – Girard/Amkraut	https://www.youtube.com/watch?v=HLiD2yCBY8o
19.7	Stanley and Stella in Breaking the Ice	https://www.youtube.com/watch?v=3bTqWsVqyzE
19.8	Rigid Body Dynamics – 1987	https://www.youtube.com/watch?v=AmFYMbJ0Eew
19.9	Flow – Apple ATG	FLOW320-2.m4v
19.10	Her Majesty's Secret Service	https://www.youtube.com/watch?v=qtJmulx3c8E
19.11	Natural Phenomena	https://www.youtube.com/watch?v=gL7YiApRvFY
19.12	Vol Libre	https://vimeo.com/5810737
19.13	Fiat Lux	https://www.youtube.com/watch?v=IOuNA7mMgYY
19.14	Campanile	http://www.youtube.com/watch?v=RPhGEiM_6lM
19.15	Rendering with Natural Light	http://www.youtube.com/watch?v=fW_GPCR9_GU
19.16	Simulation of Parthenon Lighting	http://www.youtube.com/watch?v=bBt0imn77Zg
19.17	Interview with Paul Debevec	http://www.youtube.com/watch?v=VKx_DZp_0EI
19.18	I Have Never Seen, But I Know	https://www.youtube.com/watch?v=Xb50LQ8lhAU
19.19	More Bells and Whistles	http://www.youtube.com/watch?v=qSdR4gFumps
19.20	Stick Figures	https://www.youtube.com/watch?v=LM6kB6ce_5M
19.21	Pipe Dreams	https://www.youtube.com/watch?v=Xu-A0jqMPd8
19.22	Butterflies in the Rain	https://www.youtube.com/watch?v=lVXmtckavDQ
19.23	the end – Landreth	https://vimeo.com/23454509
19.24	Bingo – Landreth	https://vimeo.com/23191218

Photo Image Galleries

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5.1	Cornell PCG Image Collection	5.1 – Cornell and NYIT
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5.4	Circle Graphics Habitat Images	5.4 – Illinois-Chicago and Penn
5.5	Hiroshima University Images	5.5 Other Labs and NSF Tech Cen
6.1	Triple-I Image Collection	6.3 Information International Inc.
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6.3	Robert Abel & Associates Image Collection	6.5 Robert Abel & Associates
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Glossary

A

A-buffer or Alpha-buffer

An extra Color channel to hold transparency information; pixels become quad values (RGBA). In a 32-bit frame buffer there are 24 bits of color, 8 each for red, green, and blue, along with an 8-bit alpha channel. Alpha is used for determining and displaying transparency, shadows, and anti-aliasing.

Related Glossary Terms: Antialiasing, Frame buffer

Term Source: Chapter 19 – Noise functions and Fractals

Abel, Robert

Robert Abel was a pioneer in visual effects, computer animation and interactive media, best known for the work of his company, Robert Abel and Associates. He received degrees in Design and Film from UCLA. He began his work in computer graphics in the 1950s, as an apprentice to John Whitney. In the 1960s and early 1970s, Abel wrote or directed several films, including The Making of the President, 1968, Elvis on Tour and Let the Good Times Roll.

In 1971, Abel and Con Pederson founded Robert Abel and Associates (RA&A), creating slit- scan effects and using motion-controlled cameras for television commercials and films. RA&A began using Evans & Sutherland computers to pre-visualize their effects; this led to the creation of the trailer for The Black Hole, and the development of their own software for digitally animating films (including Tron).In 1984, Robert Abel and Associates produced a commercial named Brilliance for the Canned Food Information Council for airing during the Super Bowl. It featured a sexy robot with reflective environment mapping and human-like motion.

Abel & Associates closed in 1987 following an ill-fated merger with now defunct Omnibus Computer Graphics, Inc., a company which had been based in Toronto.In the 1990s, Abel founded Synapse Technologies, an early interactive media company, which produced pioneering educational projects for IBM, including “Columbus: Discovery, Encounter and Beyond” and “Evolution/Revolution: The World from 1890-1930”.He received numerous honors, including a Golden Globe Award (for Elvis on Tour), 2 Emmy Awards, and 33 Clios.

Abel died from complications following a myocardial infarction at the age of 64.

Related Glossary Terms: DOA

Term Source: Chapter 6 – Robert Abel and Associates

Abstract expressionism

A painting movement in which artists typically applied paint rapidly, and with force to their huge canvases in an effort to show feelings and emotions, painting gesturally, non- geometrically, sometimes applying paint with large brushes, sometimes dripping or even throwing it onto canvas. Their work is characterized by a strong dependence on what appears to be accident and chance, but which is actually highly planned. Some Abstract Expressionist artists were concerned with adopting a peaceful and mystical approach to a purely abstract image. Usually there was no effort to represent subject matter. Not all work was abstract, nor was all work expressive, but it was generally believed that the spontaneity of the artists' approach to their work would draw from and release the creativity of their unconscious minds. The expressive method of painting was often considered as important as the painting itself.

Related Glossary Terms:

Term Source: Chapter 9 – Ed Emshwiller

Affine transformation

In geometry, an affine transformation or affine map or an affinity (from the Latin, affinis, "connected with") is a transformation which preserves straight lines (i.e., all points lying on a line initially still lie on a line after transformation) and ratios of distances between points lying on a straight line (e.g., the midpoint of a line segment remains the midpoint after transformation). It does not necessarily preserve angles or lengths.

Related Glossary Terms:

Term Source: Chapter 19 – Plants

Alpha channel

the concept of an alpha channel was introduced by Alvy Ray Smith in the late 1970s, and fully developed in a 1984 paper by Thomas Porter and Tom Duff. In a 2D image element, which stores a color for each pixel, additional data is stored in the alpha channel with a value between 0 and 1. A value of 0 means that the pixel does not have any coverage information and is transparent; i.e. there was no color contribution from any geometry because the geometry did not overlap this pixel. A value of 1 means that the pixel is opaque because the geometry completely overlapped the pixel.

Related Glossary Terms: Frame buffer

Term Source: Chapter 5 – Cornell and NYIT, Chapter 15 – Early hardware

Analog

Relating to, or being a device in which data are represented by continuously variable, measurable, physical quantities, such as length, width, voltage, or pressure; a device having an output that is proportional to the input.

Related Glossary Terms: Digital

Term Source: Chapter 1 – Early analog computational devices

Anisotropic reflection

Anisotropic Reflections are just like regular reflections, except stretched or blurred based on the orientation of small grooves (bumps, fibers or scratches) that exist on a reflective surface. The kinds of objects include anything that has a fine grain that goes all in predominantly one direction. Good everyday examples would be hair, brushed metals, pots and pans, or reflections in water that's being perturbed (for example, by falling rain).

Related Glossary Terms:

Term Source: Chapter 5 – Cal Tech and North Carolina State

Antialiasing

antialiasing is a software technique for diminishing jaggies – stair-step-like lines that should be smooth. Jaggies occur because the output device, the monitor or printer, doesn't have a high enough resolution to represent a smooth line. Antialiasing reduces the prominence of jaggies by surrounding the stair-steps with intermediate shades of gray (for gray-scaling devices) or color (for color devices). Although this reduces the jagged appearance of the lines, it also makes them fuzzier.

Related Glossary Terms: A-buffer or Alpha-buffer, Jaggies

Term Source: Chapter 15 – Early hardware

API

API, an abbreviation of application program interface, is a set of routines, protocols, and tools for building software applications. A good API makes it easier to develop a program by providing all the building blocks. A programmer then puts the blocks together.

Most operating environments, such as the Apple Quartz API, provide an API so that programmers can write applications consistent with the operating environment. Although APIs are designed for programmers, they are ultimately good for users because they guarantee that all programs using a common API will have similar interfaces. This makes it easier for users to learn new programs.

Related Glossary Terms:

Term Source: Chapter 15 – Graphics Accelerators

Atkinson, Bill

Bill Atkinson is a computer engineer and photographer. Atkinson worked at Apple Computer from 1978 to 1990. He received his undergraduate degree from the University of California, San Diego, where Apple Macintosh developer Jef Raskin was one of his professors. Atkinson continued his studies as a graduate student at the University of Washington. Atkinson was part of the Apple Macintosh development team and was the creator of the ground-breaking MacPaint application, among others. He also designed and implemented QuickDraw, the fundamental toolbox that the Macintosh used for graphics. QuickDraw's performance was essential for the success of the Macintosh's graphical user interface. Atkinson also designed and implemented HyperCard, the first popular hypermedia system.

Related Glossary Terms:

Term Source: Chapter 16 – Apple Computer

Augmented reality

Augmented reality (AR) is a live, direct or indirect, view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data. It is related to a more general concept called mediated reality, in which a view of reality is modified (possibly even diminished rather than augmented) by a computer. As a result, the technology functions by enhancing one's current perception of reality. By contrast, virtual reality replaces the real world with a simulated one.

Related Glossary Terms: Virtual reality

Term Source: Chapter 17 – Virtual Reality

B

B-rep

In solid modeling and computer-aided design, boundary representation—often abbreviated as B-rep or BREP—is a method for representing shapes using the limits. A solid is represented as a collection of connected surface elements, the boundary between solid and non-solid.

Boundary representation models are composed of two parts: topology and geometry (surfaces, curves and points). The main topological items are: faces, edges and vertices. A face is a bounded portion of a surface; an edge is a bounded piece of a curve and a vertex lies at a point. Other elements are the shell (a set of connected faces), the loop (a circuit of edges bounding a face) and loop-edge links (also known as winged edge links or half- edges) which are used to create the edge circuits. The edges are like the edges of a table, bounding a surface portion.

Related Glossary Terms: Solids modeling

Term Source: Chapter 10 – SDRC / Unigraphics

Badler, Norman

Norman I. Badler is professor of computer and information science at the University of Pennsylvania and has been on that faculty since 1974. He has been active in computer graphics since 1968, with research interests centered on computational connections between language and human action. Badler received the B.A. degree in creative studies mathematics from the University of California at Santa Barbara in 1970. He received the M.Sc. in mathematics in 1971 and the Ph.D. in computer science in 1975, both from the University of Toronto. He directs the SIG Center for Computer Graphics and the Center for Human Modeling and Simulation at Penn.

Related Glossary Terms:

Term Source: Chapter 5 – Illinois-Chicago and University of Pennsylvania

Baecker, Ron

Dr. Baecker is an expert in human-computer interaction (“HCI”) and user interface (“UI”) design. His research interests include work on electronic memory aids and other cognitive prostheses; computer applications in education; computer-supported cooperative learning, multimedia and new media; software visualization; groupware and computer-supported cooperative work; computer animation and interactive computer graphics; computer literacy and how computers can help us work better and safer; and entrepreneurship and the management of small business as well as the stimulation of innovation. Baecker is also interested in the social implications of computing, especially the issue of responsibility when humans and computers interact.

Related Glossary Terms:

Term Source: Chapter 5 – UNC and Toronto

Baraff, David

David Baraff is a Senior Animation Scientist at Pixar Animation Studios. He received a BsE in Computer Science from the University of Pennsylvania, and a Ph.D. in Computer Science from Cornell. From 1992 to 1998 Baraff was a Professor of Robotics at Carnegie Mellon University in Pennsylvania. Simulation software from Physical Effects, Inc., a software company he co-founded, has been used in numerous movies at studios outside of Pixar. In 2006 he received a Scientific and Technical Academy Award for his work on cloth simulation.

Related Glossary Terms:

Term Source: Chapter 19 – Physical-based Modeling

Barr, Al

Al Barr, PhD RPI, now on the faculty at Caltech, works "to enhance the mathematical and scientific foundations of computer graphics, extending it beyond mere picture-making to the point that reconfigurable models have great predictive power.

Related Glossary Terms:

Term Source: Chapter 5 – Cal Tech and North Carolina State

Bass, Saul

Saul Bass was a graphic designer and filmmaker, perhaps best known for his design of film posters and motion picture title sequences. During his 40-year career Bass worked for some of Hollywood's greatest filmmakers, including Alfred Hitchcock, Otto Preminger, Billy Wilder, Stanley Kubrick and Martin Scorsese. Amongst his most famous title sequences are the animated paper cut-out of a heroin addict's arm for Preminger's The Man with the Golden Arm, the credits racing up and down what eventually becomes a high-angle shot of the C.I.T. Financial Building in Hitchcock's North by Northwest, and the disjointed text that races together and apart in Psycho.

Bass designed some of the most iconic corporate logos in North America, including the AT&T "bell" logo in 1969, as well as AT&T's "globe" logo in 1983 after the breakup of the Bell System. He also designed Continental Airlines' 1968 "jetstream" logo and United Airlines' 1974 "tulip" logo which became some of the most recognized airline industry logos of the era.

Related Glossary Terms:

Term Source: Chapter 6 – Robert Abel and Associates

Bergeron, Philippe

Philippe Bergeron holds a B.Sc. and M.Sc. in Computer Science from University of Montreal. He wrote over a dozen articles on computer graphics. He co-directed the short "Tony de Peltrie," the world's first 3-D CGI human with emotions. It closed SIGGRAPH'85. He was technical research director at Digital Productions, and head of Production Research at Whitney/Demos Productions where he character animated "Stanley and Stella in Breaking The Ice." Bergeron is also an actor and landscape designer.

Related Glossary Terms:

Term Source: Chapter 8 – Introduction

Bezier curves

A Bézier curve is a parametric curve frequently used in computer graphics and related fields. Generalizations of Bézier curves to higher dimensions are called Bézier surfaces, of which the Bézier triangle is a special case.

In vector graphics, Bézier curves are used to model smooth curves that can be scaled indefinitely. "Paths," as they are commonly referred to in image manipulation programs, are combinations of linked Bézier curves. Paths are not bound by the limits of rasterized images and are intuitive to modify. Bézier curves are also used in animation as a tool to control motion

Related Glossary Terms:

Term Source: Chapter 14 – CGI and Effects in Films and Music Videos

Bézier, Pierre

Pierre Étienne Bézier was a French engineer and one of the founders of the fields of solid, geometric and physical modeling as well as in the field of representing curves, especially in CAD/CAM systems. As an engineer at Renault, he became a leader in the transformation of design and manufacturing, through mathematics and computing tools, into computer-aided design and three-dimensional modeling. Bézier patented and popularized, but did not invent the Bézier curves and Bézier surfaces that are now used in most computer-aided design and computer graphics systems.

Related Glossary Terms:

Term Source: Chapter 4 – Other research efforts

Bit BLT

Bit BLT (which stands for bit-block [image] transfer but is pronounced bit blit) is a computer graphics operation in which several bitmaps are combined into one using a raster operator.

The operation involves at least two bitmaps, a source and destination, possibly a third that is often called the "mask" and sometimes a fourth used to create a stencil. The pixels of each are combined bitwise according to the specified raster operation (ROP) and the result is then written to the destination.

This operation was created by Dan Ingalls, Larry Tesler, Bob Sproull, and Diana Merry at Xerox PARC in November 1975 for the Smalltalk-72 system.

Related Glossary Terms:

Term Source: Chapter 15 – Early hardware, Chapter 16 – Xerox PARC

Blinn, James

James F. Blinn is a computer scientist who first became widely known for his work as a computer graphics expert at NASA's Jet Propulsion Laboratory (JPL), particularly his work on the pre-encounter animations for the Voyager project, his work on the Carl Sagan Cosmos documentary series and the research of the Blinn–Phong shading model.

Blinn devised new methods to represent how objects and light interact in a three dimensional virtual world, like environment mapping and bump mapping. He is well known for creating animation for three television series: Carl Sagan's Cosmos: A Personal Voyage; Project MATHEMATICS!; and the pioneering instructional graphics in The Mechanical Universe. His simulations of the Voyager spacecraft visiting Jupiter and Saturn have been seen widely. He is now a graphics fellow at Microsoft Research. Blinn also worked at the New York Institute of Technology in the summer of 1976

Related Glossary Terms:

Term Source: Chapter 4 – JPL and National Research Council of Canada

Blue Screen

Chroma key compositing, or chroma keying, is a special effects / post-production technique for compositing (layering) two images or video streams together, used heavily in many fields to remove a background from the subject of a photo or video – particularly the newscasting, motion picture and videogame industries. A color range in the top layer is made transparent, revealing another image behind. The chroma keying technique is commonly used in video production and post-production. This technique is also referred to as color keying, color-separation overlay (CSO), or by various terms for specific color- related variants such as green screen, and blue screen – chroma keying can be done with backgrounds of any color that are uniform and distinct, but green and blue backgrounds are more commonly used because they differ most distinctly in hue from most human skin colors and no part of the subject being filmed or photographed may duplicate a color used in the background

Related Glossary Terms: Chroma key compositing

Term Source: Chapter 14 – CGI and Effects in Films and Music Videos

Brooks, Frederick

Frederick Phillips Brooks, Jr. is a software engineer and computer scientist, best known for managing the development of IBM's System/360 family of computers and the OS/360 software support package, then later writing candidly about the process in his seminal book The Mythical Man-Month. Brooks has received many awards, including the National Medal of Technology in 1985 and the Turing Award in 1999. It was in The Mythical Man- Month that Brooks made the now-famous statement: "Adding manpower to a late software project makes it later." This has since come to be known as the Brooks's law.

Related Glossary Terms:

Term Source: Chapter 17 – Interaction

Bump mapping

Bump mapping is a technique in computer graphics for simulating bumps and wrinkles on the surface of an object. This is achieved by perturbing the surface normals of the object and using the perturbed normal during lighting calculations. The result is an apparently bumpy surface rather than a smooth surface although the surface of the underlying object is not actually changed. Bump mapping was introduced by Blinn in 1978

Related Glossary Terms: Blinn, University of Utah

Term Source:

Burtnyk, Nestor

NRC scientists Nestor Burtnyk and Marceli Wein, were recently honored at the Festival of Computer Animation in Toronto. They were recognized as Fathers of Computer Animation Technology in Canada. Burtnyk, who began his career with NRC in 1950, started Canada's first substantive computer graphics research project in the 1960s. Wein, who joined this same project in 1966, had been exposed to the potential of computer imaging while studying at McGill. He teamed up with Burtnyk to pursue this promising field.

One of their main contributions was the Academy Award nominated film "Hunger/La Faim" (produced by the National Film Board of Canada) using their famous key-frame animation approach and system.

Related Glossary Terms: Wein, Marceli

Term Source: Chapter 4 – JPL and National Research Council of Canada

Buxton, Bill

William Arthur Stewart "Bill" Buxton (born March 10, 1949) is a Canadian computer scientist and designer. He is currently a Principal researcher at Microsoft Research. He is known for being one of the pioneers in the human–computer interaction field.

Related Glossary Terms:

Term Source: Chapter 5 – UNC and Toronto

C

CAD

CAD – computer-aided design

The use of computer programs and systems to design detailed two- or three-dimensional models of physical objects, such as mechanical parts, buildings, and molecules.

Related Glossary Terms: CADD, CAE, CAID, CAM

Term Source: Chapter 3 – General Motors DAC, Chapter 10 – Introduction, Chapter 10 – Introduction

CADD

CADD – Computer Aided Drafting and Design, Computer-Aided Design & Drafting, or Computer-Aided Design Development

The use of the computer to help with the drafting of product plans.

Related Glossary Terms:CAD, CAE, CAID, CAM

Term Source: Chapter 3 – General Motors DAC Chapter 10 – Introduction

CAE

CAE – computer-aided engineering

Use of computers to help with all phases of engineering design work. Like computer aided design, but also involving the conceptual and analytical design steps.

Related Glossary Terms: CADD, CAD, CAID, CAM

Term Source: Chapter 10 – Introduction Chapter 10 – SDRC / Unigraphics

CAID

Computer-aided industrial design (CAID) is CAD adapted and specialized for aesthetic design. From a designer's point of view, CAD is for the pocket-protector brigade, while CAID is for the creative.

Related Glossary Terms: CADD, CAE, CAD, CAM

Term Source: Chapter 8 – Alias Research

CAM

CAM – computer-aided manufacturing

The process of using specialized computers to control, monitor, and adjust tools and machinery in manufacturing.

Related Glossary Terms: CADD, CAE, CAID, CAD

Drag related terms here

Term Source: Chapter 10 – Introduction, Chapter 10 – MCS / CalComp / McAuto

Carpenter, Loren

Loren Carpenter is a computer graphics researcher and developer. He is co-founder and chief scientist of Pixar Animation Studios and the co-inventor of the Reyes rendering algorithm. He is one of the authors of the PhotoRealistic RenderMan software which implements Reyes and is used to create the imagery for Pixar's movies. Following Disney's acquisition of Pixar, Carpenter became a Senior Research Scientist at Disney Research.[1]

Carpenter began work at Boeing Computer Services in Seattle, Washington. In 1980 he gave a presentation at the SIGGRAPH conference, in which he showed "Vol Libre", a 2 minute computer generated movie. This showcased his software for generating and rendering fractally generated landscapes. At Pixar Carpenter worked on the "genesis effect" scene of Star Trek II: The Wrath of Khan, which featured an entire fractally- landscaped planet.

Related Glossary Terms:

Term Source: Chapter 19 – Noise functions and Fractals

Cathode Ray Tube

A vacuum tube generating a focused beam of electrons that can be deflected by electric fields, magnetic fields, or both. The terminus of the beam is visible as a spot or line of luminescence caused by its impinging on a sensitized screen at one end of the tube. Cathode-ray tubes are used to study the shapes of electric waves, to reproduce images in television receivers, to display alphanumeric and graphical information on computer monitors, as an indicator in radar sets, etc. Abbreviation: CRT

Related Glossary Terms: Vacuum tube

Term Source: Chapter 1 – Electronic devices

Caustics

In optics, a caustic or caustic network is the envelope of light rays reflected or refracted by a curved surface or object, or the projection of that envelope of rays on another surface. The caustic is a curve or surface to which each of the light rays is tangent, defining a boundary of an envelope of rays as a curve of concentrated light. Therefore in an image the caustics can be the patches of light or their bright edges. These shapes often have cusp singularities.

In computer graphics, most modern rendering systems support caustics. Some of them even support volumetric caustics. This is accomplished by raytracing the possible paths of the light beam through the glass, accounting for the refraction and reflection. Photon mapping is one implementation of this.

Related Glossary Terms: Photon mapping, Ray-trace

Term Source: Chapter 20 – CG Icons

Charactron

a cathode-ray tube used in information display units to reproduce letters, numbers, map symbols, and other characters. Invented in the USA in 1941, the Charactron is an instantaneous-operation numerical indicator tube.

In the Charactron, the characters reproduced on the tube's screen are formed by means of a matrix, which is an opaque plate containing a set of 64 to 200 microscopic openings in the shape of the characters to be displayed. The matrix is located in the path of the electron beam between two deflection systems. The first deflection system guides the beam to the desired character on the matrix; the second system guides the shaped beam to the desired location on the screen. When the beam passes through the matrix, the cross section of the beam takes on the shape of the character through which it has passed. Hence, an image of the desired character—rather than a point, as in ordinary cathode-ray tubes—is illuminated at the place where the beam strikes the screen.

Related Glossary Terms:

Term Source: Chapter 3 – Other output devices

Chroma key compositing

Chroma key compositing, or chroma keying, is a special effects / post-production technique for compositing (layering) two images or video streams together, used heavily in many fields to remove a background from the subject of a photo or video – particularly the newscasting, motion picture and video game industries. A color range in the top layer is made transparent, revealing another image behind. The chroma keying technique is commonly used in video production and post-production. This technique is also referred to as color keying, color-separation overlay (CSO), or by various terms for specific color- related variants such as green screen, and blue screen – chroma keying can be done with backgrounds of any color that are uniform and distinct, but green and blue backgrounds are more commonly used because they differ most distinctly in hue from most human skin colors and no part of the subject being filmed or photographed may duplicate a color used in the background

Related Glossary Terms: Blue Screen

Term Source:

Clipping

Any procedure which identifies that portion of a picture which is either inside or outside a region to be displayed on a CRT or screen is referred to as a clipping algorithm or clipping.

The region against which an object is to be clipped is called clipping window.

Related Glossary Terms:

Term Source: Chapter 3 – General Motors DAC, Chapter 4 – MIT and Harvard

Colormap

Color mapping is a function that maps (transforms) the colors of one (source) image to the colors of another (target) image. A color mapping may be referred to as the algorithm that results in the mapping function or the algorithm that transforms the image colors. Color mapping is also sometimes called color transfer or, when grayscale images are involved, brightness transfer function (BTF).

Related Glossary Terms:

Term Source: Chapter 18 – Hardware and Software

Combinatorial geometry

Computational (sometimes referred to as combinatorial) geometry is a branch of computer science devoted to the study of algorithms which can be stated in terms of geometry. Some purely geometrical problems arise out of the study of computational geometric algorithms, and such problems are also considered to be part of computational geometry.

The main impetus for the development of computational geometry as a discipline was progress in computer graphics and computer-aided design and manufacturing (CAD/CAM), but many problems in computational geometry are classical in nature, and may come from mathematical visualization.

Related Glossary Terms:

Term Source: Chapter 6 – MAGI

Computational fluid dynamics

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions.

Related Glossary Terms:

Term Source: Chapter 18 – Introduction

Computer graphics

1. pictorial computer output produced on a display screen, plotter, or printer.
2. the study of the techniques used to produce such output.
3. the use of a computer to produce and manipulate pictorial images on a video screen, as in animation techniques or the production of audiovisual aids

Related Glossary Terms:

Term Source: Preface – Preface

Computer-generated art

Digital art is a general term for a range of artistic works and practices that use digital technology as an essential part of the creative and/or presentation process. Since the 1970s, various names have been used to describe the process including computer art, computer-generated art, and multimedia art, and digital art is itself placed under the larger umbrella term new media art.

Related Glossary Terms:

Term Source: Chapter 9 – Lillian Schwartz

Constructivist

Constructivism, Russian *Konstruktivizm*, Russian artistic and architectural movement that was first influenced by Cubism and Futurism and is generally considered to have been initiated in 1913 with the “painting reliefs”—abstract geometric constructions—of Vladimir Tatlin.

Related Glossary Terms:

Term Source: Chapter 9 – Manfred Mohr

Continuous shading

Continuous shading is the smooth shading of polygons with bilinear interpolation. In other words, the brightness of the shading varies within individual polygons, without altering the color being applied. It is often referred to as Gouraud shading.

Related Glossary Terms: Gouraud shading

Term Source: Chapter 17 – Virtual Reality

Contour plots

A contour plot is a graphical technique for representing a 3-dimensional surface by plotting constant z slices, called contours, on a 2-dimensional format. That is, given a value for z, lines are drawn for connecting the (x,y) coordinates where that z value occurs.

The contour plot is an alternative to a 3-D surface plot.

Related Glossary Terms: Isolines, Isosurfaces

Term Source: Chapter 18 – Algorithms

Coons, Steven

Steven Anson Coons (March 7, 1912 – August 1979) was an early pioneer in the field of computer graphical methods. He was a professor at the Massachusetts Institute of Technology in the Mechanical Engineering Department. Steven Coons had a vision of interactive computer graphics as a design tool to aid the engineer.

The Association for Computing Machinery SIGGRAPH has an award named for Coons. The Steven Anson Coons Award for Outstanding Creative Contributions to Computer Graphics is given in odd-numbered years to an individual to honor that person’s lifetime contribution to computer graphics and interactive techniques. It is considered the field’s most prestigious award.

Related Glossary Terms:

Term Source: Chapter 4 – MIT and Harvard

Core memory

Magnetic-core memory was the predominant form of random-access computer memory for 20 years (circa 1955–75). It uses tiny magnetic toroids (rings), the cores, through which wires are threaded to write and read information. Each core represents one bit of information. The cores can be magnetized in two different ways (clockwise or counterclockwise) and the bit stored in a core is zero or one depending on that core’s magnetization direction. The wires are arranged to allow an individual core to be set to either a “one” or a “zero”, and for its magnetization to be changed, by sending appropriate electric current pulses through selected wires. The process of reading the core causes the core to be reset to a “zero”, thus erasing it. This is called destructive readout.

Such memory is often just called core memory, or, informally, core. Although core memory had been superseded by semiconductor memory by the end of the 1970s, memory is still occasionally called “core”

Each core was a donut shaped metal, often ferrite, that had two electrical wires strung through it. Neither wire was strong enough in power to change the state of the magnetism of the core, but together they were. Thus it was a randomly addressable storage and access medium.

Related Glossary Terms:

Term Source: Chapter 2 – Whirlwind and SAGE

Cray

Cray Inc.is an American supercomputer manufacturer based in Seattle, Washington. The company’s predecessor, Cray Research, Inc. (CRI), was founded in 1972 by computer designer Seymour Cray. Seymour Cray went on to form the spin-off Cray Computer Corporation (CCC), in 1989, which went bankrupt in 1995, while Cray Research was bought by SGI the next year. Cray Inc. was formed in 2000 when Tera Computer Company purchased the Cray Research Inc. business from SGI and adopted the name of its acquisition. Their computers included the Cray-1, Cray-2, and Cray X-MP

Related Glossary Terms:

Term Source: Chapter 6 – Digital Productions (DP)

CSG

Constructive solid geometry (CSG) is a technique used in solid modeling. Constructive solid geometry allows a modeler to create a complex surface or object by using Boolean operators to combine objects. Often CSG presents a model or surface that appears visually complex, but is actually little more than cleverly combined or decombined objects.

In 3D computer graphics and CAD CSG is often used in procedural modeling. CSG can also be performed on polygonal meshes, and may or may not be procedural and/or parametric.

Related Glossary Terms: Solids modeling

Term Source: Chapter 10 – Introduction

Csuri, Charles

Charles Csuri is best known for pioneering the field of computer graphics, computer animation and digital fine art, creating the first computer art in 1964. Csuri has been recognized as the father of digital art and computer animation by Smithsonian, and as a leading pioneer of computer animation by the Museum of Modern Art (MoMA) and The Association for Computing Machinery Special Interest Group Graphics (ACM SIGGRAPH). Between 1971 and 1987, while a senior professor at the Ohio State University, Charles Csuri founded the Computer Graphics Research Group, the Ohio Super Computer Graphics Project, and the Advanced Computing Center for Art and Design, dedicated to the development of digital art and computer animation. Csuri was co-founder of Cranston/ Csuri Productions (C/CP), one of the world's first computer animation production companies.

Related Glossary Terms: The Ohio State University

Term Source: Chapter 4 – University of Utah, Chapter 4 – The Ohio State University

Cuba, Larry

Larry Cuba is a computer-animation artist who became active in the late 1970s and early 80s. He received A.B. from Washington University in St. Louis in 1972 and his Master's Degree from California Institute of the Arts In 1975, John Whitney, Sr. invited Cuba to be the programmer on one of his films. The result of this collaboration was "Arabesque". Subsequently, Cuba produced three more computer-animated films: 3/78 (Objects and Transformations), Two Space, and Calculated Movements. Cuba also produced computer graphics for Star Wars Episode IV: A New Hope in 1977 on Tom DeFanti's Grass system at EVL. His animation of the Death Star is shown to pilots in the Rebel Alliance. Cuba received grants for his work from the American Film Institute and The National Endowment for the Arts

Related Glossary Terms: EVL

Term Source: Chapter 9 – Larry Cuba

D

DAC-1

DAC-1, for Design Augmented by Computer, was one of the earliest graphical computer aided design systems. Developed by General Motors, IBM was brought in as a partner in 1960 and the two developed the system and released it to production in 1963. It was publicly unveiled at the fall Joint Computer Conference in Detroit 1964. GM used the DAC system, continually modified, into the 1970s when it was succeeded by CADANCE.

Related Glossary Terms:

Term Source: Chapter 3 – General Motors DAC

Data-driven

Computer graphics visualization has evolved by focusing algorithmic approaches to the synthesis of imagery. Recently, various methods have been introduced to exploit pre- recorded data to improve the performance and/or realism of things like dynamic deformations. This data can guide the algorithms, or in some cases determine which algorithms are used in the synthesis process. It has seen successful usage in visualizations of music, dynamic deformation of faces, soft volumetric tissue, and cloth, as examples.

Related Glossary Terms:

Term Source: Chapter 19 – Data-driven Imagery

Dataflow

Dataflow is a software architecture based on the idea that changing the value of a variable should automatically force recalculation of the values of variables which depend on its value.

There have been a few programming languages created specifically to support dataflow. In particular, many (if not most) visual programming languages have been based on the idea of dataflow.

Related Glossary Terms: Modular visualization environments

Term Source: Chapter 18 – Visualization Systems

Debevec, Paul

Paul Debevec is a researcher in computer graphics at the University of Southern California's Institute for Creative Technologies. He is best known for his pioneering work in high dynamic range imaging and image-based modeling and rendering. Debevec received a Ph.D. in computer science from UC Berkeley in 1996; his thesis research was in photogrammetry, or the recovery of the 3D shape of an object from a collection of still photographs taken from various angles.In 1997 he and a team of students produced The Campanile Movie, a virtual flyby of UC Berkeley's famous Campanile tower. Debevec's more recent research has included methods for recording real-world illumination for use in computer graphics; a number of novel inventions for recording ambient and incident light have resulted from the work of Debevec and his team, including the light stage, of which five or more versions have been constructed, each an evolutionary improvement over the previous. Techniques based on Debevec's work have been used in several major motion pictures, including The Matrix (1999), Spider-Man 2 (2004), King Kong (2005), Superman Returns (2006), Spider-Man 3 (2007), and Avatar (2009). In addition Debevec and his team have produced several short films that have premiered at SIGGRAPH's annual Electronic Theater, including Fiat Lux (1999) and The Parthenon (2004).

Debevec, along with Tim Hawkins, John Monos and Mark Sagar, was awarded a 2009 Scientific and Engineering Award from the Academy of Motion Picture Arts and Sciences for the design and engineering of the Light Stage capture devices and the image-based facial rendering system developed for character relighting in motion pictures.

Related Glossary Terms:

Term Source: Chapter 19 – Global Illumination

DeFanti, Tom

Tom DeFanti is a computer graphics researcher and pioneer. His work has ranged from early computer animation, to scientific visualization, virtual reality, and grid computing. He is a distinguished professor of Computer Science at the University of Illinois at Chicago, and a research scientist at the California Institute for Telecommunications and Information Technology. DeFanti did his PhD work in the early 1970s at Ohio State University, under Charles Csuri in the Computer Graphics Research Group. For his dissertation, he created the GRASS programming language, a three-dimensional, real-time animation system usable by computer novices.

In 1973, he joined the faculty of the University of Illinois at Chicago. With Dan Sandin, he founded the Circle Graphics Habitat, now known as the Electronic Visualization Laboratory (EVL). At UIC, DeFanti further developed the GRASS language, and later created an improved version, ZGRASS. The GRASS and ZGRASS languages have been used by a number of computer artists, including Larry Cuba, in his film 3/78 and the animated Death Star sequence for Star Wars. Later significant work done at EVL includes development of the graphics system for the Bally home computer, invention of the first data glove, co- editing the 1987 NSF-sponsored report Visualization in Scientific Computing that outlined the emerging discipline of scientific visualization, invention of PHSColograms, and invention of the CAVE Automatic Virtual Environment.

DeFanti contributed greatly to the growth of the SIGGRAPH organization and conference. He served as Chair of the group from 1981 to 1985, co-organized early film and video presentations (which became the Electronic Theatre), and in 1979 started the SIGGRAPH Video Review, a video archive of computer graphics research.

DeFanti is a Fellow of the Association for Computing Machinery. He has received the 1988 ACM Outstanding Contribution Award, the 2000 SIGGRAPH Outstanding Service Award, and the UIC Inventor of the Year Award.

Related Glossary Terms:EVL, Sandin, Dan

Term Source: Chapter 5 – Illinois-Chicago and University of Pennsylvania

DeGraf, Brad

DeGraf has been an innovator in computer animation in the entertainment industry since 1982, particularly in the areas of realtime characters, ride films, and the Web. He founded and/or managed several ground-breaking animation studios including Protozoa (aka Dotcomix), Colossal Pictures Digital Media, deGraf/Wahrman, and Digital Productions. In 2000, Wired called Brad "an icon in the world of 3D animation". Brad is currently CEO and co-founder (with Michael Tolson formerly of XAOS and Envoii) of Sociative Inc.

His film credits include: Duke2000.com, a campaign with Garry Trudeau to get his Ambassador Duke character elected president; Moxy, emcee for the Cartoon Network, the first virtual character for television; Floops, the first Web episodic cartoon; Peter Gabriel's Grammy award- winning video, Steam; "The Funtastic World of Hanna-Barbera", the first computer-generated ride film; Feature films "The Last Starfighter", "2010″, "Jetsons: the Movie", "Robocop 2″,

Related Glossary Terms:

Term Source: Chapter 6 – Digital Productions (DP)

Demos, Gary

Gary Demos was one of the principals of the Motion Picture Project at Information International Inc. (1974–1981), Digital Productions (1981–1986), and Whitney/Demos Productions (1986–1988). In 1988 Demos formed DemoGraFX, which became involved in technology research for advanced television systems and digital cinema, as well as consulting and contracting for computer companies and visual effects companies. DemoGraFX was sold to Dolby Labs in 2003. Demos attended Cal Tech and worked with Ivan Sutherland at E&S and later at the Picture/Design Group before co-founding the graphics group at Triple-I.

Related Glossary Terms: DOA

Term Source: Chapter 6 – Digital Productions (DP)

Diffuse reflection

Diffuse reflection is the reflection of light from a surface such that an incident ray is reflected at many angles rather than at just one angle as in the case of specular reflection. An illuminated ideal diffuse reflecting surface will have equal luminance from all directions in the hemisphere surrounding the surface (Lambertian reflectance).

Related Glossary Terms: Lambertian, Specular reflection

Term Source:

Digital

A description of data which is stored or transmitted as a sequence of discrete symbols from a finite set, most commonly this means binary data represented using electronic or electromagnetic signals.

Related Glossary Terms: Analog

Term Source: Chapter 1 – Early digital computational devices

Digital compositing

Compositing is the combining of visual elements from separate sources into single images, often to create the illusion that all those elements are parts of the same scene. Live-action shooting for compositing is variously called “chroma key”, “blue screen”, “green screen” and other names. Today, most, though not all, compositing is achieved through digital image manipulation. Pre-digital compositing techniques, however, go back as far as the trick films of Georges Méliès in the late 19th century; and some are still in use.

Related Glossary Terms:

Term Source:

Digital painting

Digital painting differs from other forms of digital art, particularly computer-generated art, in that it does not involve the computer rendering from a model. The artist uses painting techniques to create the digital painting directly on the computer. All digital painting programs try to mimic the use of physical media through various brushes and paint effects. Included in many programs are brushes that are digitally styled to represent the traditional style like oils, acrylics, pastels, charcoal, pen and even media such as airbrushing. There are also certain effects unique to each type of digital paint which portraying the realistic effects of say watercolor on a digital ‘watercolor’ painting

Related Glossary Terms:

Term Source: Chapter 11 – Pixar

Digital Scene Simulation

Digital Scene Simulation was Digital Productions’ philosophy for creating visual excellence in computer-generated imagery and simulation. The approach it advocated required the use of powerful hardware, sophisticated software, and top creative talent. With a CRAY supercomputer at the heart of its computer network and its own proprietary image rendering and simulation software, Digital Productions was revolutionizing state-of-the-art computer graphics. At the forefront of computer graphics technology, Digital Productions was redefining traditional methods of visual communications and creating new forms of self-expression, instruction, and entertainment.

(From the Abstract of the invited paper “Digital scene simulations: The synergy of computer technology and human creativity”, by Demos, G.; Brown, M.D.; and Weinberg, R.A. Proceedings of the IEEE, Volume: 72 , Issue: 1, Jan. 1984, Page(s): 22 – 31)

Related Glossary Terms:

Term Source: Chapter 6 – Information International Inc. (Triple-I), Chapter 6 – Information International Inc. (Triple-I)

Digitize

1. to convert (data) to digital form for use in a computer.
2. to convert (analogous physical measurements) to digital form.

Related Glossary Terms: Digital

Term Source: Chapter 4 – MIT and Harvard

DOA

DOA == Digital/Omnibus/Abel

In about 1985, the Digital Productions board went along with a hostile takeover bid by Omnibus and their leader, John Pennie, breaking the agreement with partners John Whitney Jr. and Gary Demos. Later that same year, Omnibus also purchased Robert Abel and Associates. The huge amount of debt, much of it provided by the Royal Bank of Canada, proved to be a burden for the company, and they declared bankruptcy) only 9 months later on April 13th of 1987. The closure had significant rippling effects on the CG industry, and impacted the lives of many top-flight CG professionals.

Related Glossary Terms: Abel, Robert, Demos, Gary, Pennie, John

Term Source: Chapter 8 – Wavefront Technologies

Drum plotter

A graphics output device that draws lines with a continuously moving pen on a sheet of paper rolled around a rotating drum that moves the paper in a direction perpendicular to the motion of the pen.

Related Glossary Terms:

Term Source: Chapter 10 – MCS / CalComp / McAuto

Dynamics

In the field of physics, the study of the causes of motion and changes in motion is dynamics. In other words the study of forces and why objects are in motion. Dynamics includes the study of the effect of torques on motion. These are in contrast to kinematics, the branch of classical mechanics that describes the motion of objects without consideration of the causes leading to the motion.

Related Glossary Terms: Kinematics

Term Source: Chapter 8 – Introduction

E

Elin, Larry

Larry Elin started his career as an animator at Mathematical Applications Group, Inc., in Elmsford, NY, in 1973, one of the first 3-D computer animation companies. By 1980, Elin had become head of production, and hired Chris Wedge, who later founded Blue Sky Studios, among others. Elin and Wedge were the key animators on MAGI's work on the feature film Tron, which included the Lightcycle, Recognizer, and Tank sequences. Elin later became executive producer at Kroyer Films, which produced the animation for FernGully: The Last Rainforest.

Related Glossary Terms:

Term Source: Chapter 6 – MAGI

Ellipsoids

a geometric surface, symmetrical about the three coordinate axes, whose plane sections are ellipses or circles. Standard equation: x2/a2 + y2/b2 + z2/c2 = 1, where ±a, ±b, ±c are the intercepts on the x-, y-, and z- axes

Related Glossary Terms:

Term Source: Chapter 13 – Other Approaches

Em, David

David Em is one of the first artists to make art with pixels. He was born in Los Angeles and grew up in South America. He studied painting at the Pennsylvania Academy of the Fine Arts and film directing at the American Film Institute. Em created digital paintings at the Xerox Palo Alto Research Center (Xerox PARC) in 1975 with SuperPaint, “the first complete digital paint system”. In 1976, he made an articulated 3D digital insect at Information International, Inc. (III) that could walk, jump, and fly, the first 3D character created by a fine artist.

Related Glossary Terms:

Term Source: Chapter 9 – David Em

Emshwiller, Ed

Emshwiller was one of the earliest video artists. With Scape-Mates (1972), he began his experiments in video, combining computer animation with live-action. In 1979, he produced Sunstone, a groundbreaking three-minute 3-D computer-generated video made at the New York Institute of Technology with Alvy Ray Smith. Now in the Museum of Modern Art’s video collection, Sunstone was exhibited at SIGGRAPH 79, the 1981 Mill Valley Film Festival and other festivals. In 1979, it was shown on WNET’s Video/Film Review, and a single Sunstone frame was used on the front cover of Fundamentals of Interactive Computer Graphics, published in 1982 by Addison-Wesley

Related Glossary Terms:

Term Source: Chapter 9 – Ed Emshwiller

Engelbart, Douglas C.

Douglas Carl Engelbart (born January 30, 1925) is an American inventor, and an early computer and internet pioneer. He is best known for his work on the challenges of human– computer interaction, particularly while at his Augmentation Research Center Lab in SRI International, resulting in the invention of the computer mouse,[3] and the development of hypertext, networked computers, and precursors to graphical user interfaces.

Related Glossary Terms:

Term Source: Chapter 3 – Input devices

ENIAC

ENIAC stands for Electronic Numerical Integrator and Computer. It was a secret World War II military project carried out by John Mauchly, a 32-year-old professor at Penn’s Moore School of Electrical Engineering and John Presper Eckert Jr., a 24-year-old genius inventor and lab assistant. The challenge was to speed up the tedious mathematical calculations needed to produce artillery firing tables for the Army. ENIAC was not completed until after the war but it performed until 1955 at Aberdeen, Md. ENIAC was enormous. It contained 17,500 vacuum tubes, linked by 500,000 soldered connections. It filled a 50-foot long basement room and weighed 30 tons. Today, a single microchip, no bigger than a fingernail, can do more than those 30 tons of hardware.

Related Glossary Terms:

Term Source: Chapter 2 – Programming and Artistry

Environment mapping

Environment mapping is a technique that simulates the results of ray-tracing. Because environment mapping is performed using texture mapping hardware, it can obtain global reflection and lighting results in real-time.

Environment mapping is essentially the process of pre-computing a texture map and then sampling texels from this texture during the rendering of a model. The texture map is a projection of 3D space to 2D space.

Related Glossary Terms: Reflection mapping

Term Source:

Euler operators

In mathematics, Euler operators are a small set of operators to create polygon meshes. They are closed and sufficient on the set of meshes, and they are invertible.

A “polygon mesh” can be thought of as a graph, with vertices, and with edges that connect these vertices. In addition to a graph, a mesh has also faces: Let the graph be drawn (“embedded”) in a two-dimensional plane, in such a way that the edges do not cross (which is possible only if the graph is a planar graph). Then the contiguous 2D regions on either side of each edge are the faces of the mesh.

Related Glossary Terms:

Term Source: Chapter 5 – Other labs and NSF

Evans, David

David Cannon Evans (February 24, 1924 – October 3, 1998) was the founder of the computer science department at the University of Utah and co-founder (with Ivan Sutherland) of Evans & Sutherland, a computer firm which is known as a pioneer in the domain of computer-generated imagery

Related Glossary Terms:

Term Source: Chapter 4 – University of Utah

F

Facial animation

Computer facial animation is primarily an area of computer graphics that encapsulates models and techniques for generating and animating images of the human head and face. Due to its subject and output type, it is also related to many other scientific and artistic fields from psychology to traditional animation. The importance of human faces in verbal and non-verbal communication and advances in computer graphics hardware and software have caused considerable scientific, technological, and artistic interests in computer facial animation.

Related Glossary Terms: Kinematics, Motion capture

Term Source: Chapter 8 – Alias/Wavefront

Farnsworth, Philo

Philo Taylor Farnsworth was an American inventor and television pioneer. Although he made many contributions that were crucial to the early development of all-electronic television, he is perhaps best known for inventing the first fully functional all-electronic image pickup device (video camera tube), the "image dissector", the first fully functional and complete all-electronic television system, and for being the first person to demonstrate such a system to the public. Farnsworth developed a television system complete with receiver and camera, which he produced commercially in the firm of the Farnsworth Television and Radio Corporation, from 1938 to 1951.

Related Glossary Terms:

Term Source: Chapter 1 – Electronic devices

Fetter, William

William Fetter was a graphic designer for Boeing Aircraft Co. and in 1960, was credited with coining the phrase "Computer Graphics" to describe what he was doing at Boeing at the time.

Related Glossary Terms:

Term Source: Chapter 2 – Programming and Artistry

Film recorder

A Film Recorder is a graphical output device for transferring digital images to photographic film.

All film recorders typically work in the same manner. The image is fed from a host computer as a raster stream over a digital interface. A film recorder exposes film through various mechanisms; flying spot (early recorders; photographing a high resolution video monitor; electron beam recorder (Sony); a CRT scanning dot (Celco); focused beam of light from an LVT (Light Valve Technology) recorder; a scanning laser beam (ARRILASER); or recently, full-frame LCD array chips;

Related Glossary Terms: Optical printers

Term Source: Chapter 6 – Digital Effects

Finite Element Analysis

The finite element method (FEM) (its practical application often known as finite element analysis (FEA)) is a numerical technique for finding approximate solutions of partial differential equations (PDE) as well as integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge- Kutta, etc.

Related Glossary Terms:

Term Source: Chapter 10 – SDRC / Unigraphics

Flicker

a visual sensation, often seen in a television or CRT image, produced by periodic fluctuations, often due to the rate of refreshing the image on the screen, in the brightness of light at a frequency below that covered by the persistence of vision

Related Glossary Terms: Cathode Ray Tube

Term Source: Chapter 3 – Other output devices

Floating point

A real number (that is, a number that can contain a fractional part). The following are floating-point numbers: 3.0, -111.5, 1⁄2, 3E-5 The last example is a computer shorthand for scientific notation. It means 3*10-5 (or 10 to the negative 5th power multiplied by 3).

The term floating point is derived from the fact that there is no fixed number of digits before and after the decimal point; that is, the decimal point can float. There are also representations in which the number of digits before and after the decimal point is set, called fixed-point representations. In general, floating-point representations are slower and less accurate than fixed-point representations, but they can handle a larger range of numbers.

Related Glossary Terms:

Term Source: Chapter 15 – Graphics Accelerators

Foonly F1

Foonly was the computer company formed by Dave Poole, who was one of the principal Super Foonly designers. The Foonly was to be a successor to the DEC PDP-10, and was to have been built (along with a new operating system) by the Super Foonly project at the Stanford Artificial Intelligence Laboratory (SAIL). The intention was to leapfrog from the old DEC timesharing system SAIL was then running to a new generation, bypassing TENEX which at that time was the ARPANET standard. ARPA funding for both the Super Foonly and the new operating system was cut in 1974. The design for Foonly contributed greatly to the design of the PDP-10 model KL10. One of the prototype models was built for Information International Incorporated (Triple-I) and was used to compute CG for TRON.

Related Glossary Terms:

Term Source: Chapter 6 – Information International Inc. (Triple-I)

Forced perspective

Forced perspective is a technique that employs optical illusion to make an object appear farther away, closer, larger or smaller than it actually is. It is used primarily in photography, filmmaking and architecture. It manipulates human visual perception through the use of scaled objects and the correlation between them and the vantage point of the spectator or camera.

Related Glossary Terms:

Term Source: Chapter 14 – CGI and Effects in Films and Music Videos

Foreshortening

Foreshortening occurs when an object appears compressed when seen from a particular viewpoint, and the effect of perspective causes distortion. Foreshortening is a particularly effective artistic device, used to give the impression of three-dimensional volume and create drama in a picture.

Foreshortening is most successful when accurately rendered on the picture plane to create the illusion of a figure in space.

Related Glossary Terms:

Term Source: Chapter 20 – CG Icons

Form factor

In radiative heat transfer, a form factor is the proportion of all that radiation which leaves surface A and strikes surface B.

In radiosity calculations, the “form factor” describes the fraction of energy which leaves one surface and arrives at a second surface. It takes into account the distance between the surfaces, computed as the distance between the center of each of the surfaces, and their orientation in space relative to each other, computed as the angle between each surface’s normal vector and a vector drawn from the center of one surface to the center of the other surface. It is a dimensionless quantity.

Related Glossary Terms: Radiosity

Term Source: Chapter 19 – Global Illumination

Fractal

A geometrical or physical structure having an irregular or fragmented shape at all scales of measurement between a greatest and smallest scale such that certain mathematical or physical properties of the structure, as the perimeter of a curve or the flow rate in a porous medium, behave as if the dimensions of the structure (fractal dimensions) are greater than the spatial dimensions.

A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. Fractals are generally self-similar and independent of scale, that is they have similar properties at all levels of magnification or across all times.

Related Glossary Terms:

Term Source: Chapter 19 – Noise functions and Fractals

Frame buffer

A frame buffer (or framebuffer) is a video output device that drives a video display from a memory buffer containing a complete frame of data.The information in the memory buffer typically consists of color values for every pixel (point that can be displayed) on the screen. Color values are commonly stored in 1-bit binary (monochrome), 4-bit palettized, 8-bit palettized, 16-bit high color and 24-bit true color formats. An additional alpha channel is sometimes used to retain information about pixel transparency. The total amount of the memory required to drive the frame buffer depends on the resolution of the output signal, and on the color depth and palette size.

Frame buffers differ significantly from the vector displays that were common prior to the advent of the frame buffer. With a vector display, only the vertices of the graphics primitives are stored. The electron beam of the output display is then commanded to move from vertex to vertex, tracing an analog line across the area between these points. With a frame buffer, the electron beam (if the display technology uses one) is commanded to trace a left- to-right, top-to-bottom path across the entire screen, the way a television renders a broadcast signal. At the same time, the color information for each point on the screen is pulled from the frame buffer, creating a set of discrete picture elements (pixels).

Related Glossary Terms: A-buffer or Alpha-buffer

Term Source: Chapter 6 – Information International Inc. (Triple-I)

Frame-grabbing

A frame grabber is an electronic device that captures individual, digital still frames from an analog video signal or a digital video stream. It is usually employed as a component of a computer vision system, in which video frames are captured in digital form and then displayed, stored or transmitted in raw or compressed digital form. Historically, frame grabbers were the predominant way to interface cameras to PC's

Related Glossary Terms:

Term Source: Chapter 16 – Amiga

Free-form surface

Free-form surface, or freeform surfacing, is used in CAD and other computer graphics software to describe the skin of a 3D geometric element. Freeform surfaces do not have rigid radial dimensions, unlike regular surfaces such as planes, cylinders and conic surfaces. They are used to describe forms such as turbine blades, car bodies and boat hulls. Initially developed for the automotive and aerospace industries, freeform surfacing is now widely used in all engineering design disciplines from consumer goods products to ships. Most systems today use nonuniform rational B-spline (NURBS) mathematics to describe the surface forms; however, there are other methods such as Gorden surfaces or Coons surfaces .

Related Glossary Terms: B-rep, Solids modeling

Term Source: Chapter 10 – Intergraph / Bentley / Dassault

Fuchs, Henry

Prof. Henry Fuchs is a fellow of the American Academy of Arts and Sciences (AAAS) and the Association for Computing Machinery (ACM) and the Federico Gill Professor of Computer Science at the University of North Carolina at Chapel Hill (UNC). He is also an adjunct professor in biomedical engineering. His research interests are in computer graphics, particularly rendering algorithms, hardware, virtual environments, telepresence systems, and applications in medicine. In 1992, he received both the ACM SIGGRAPH Achievement Award and the Academic Award of the National Computer Graphics Association (NCGA)

Related Glossary Terms:

Term Source: Chapter 5 – UNC and Toronto

G

Gates, Bill

William Henry “Bill” Gates III is the former chief executive and current chairman of Microsoft, the world’s largest personal-computer software company, which he co-founded with Paul Allen. He is consistently ranked among the world’s wealthiest people. During his career at Microsoft, Gates held the positions of CEO and chief software architect, and remains the largest individual shareholder.

Related Glossary Terms:

Term Source: Chapter 16 – The IBM PC and Unix

Gehring, Bo

Bo Gehring was hired by Phil Mittleman of MAGI in 1972 to develop the division of the company focused on computer image making (MAGI Synthavision). He was the principle of Gehring Aviation and Bo Gehring Associates in Venice, California, and originally came to the west coast to do computer animation tests for Steven Spielberg’s CLOSE ENCOUNTERS OF THE THIRD KIND.

Related Glossary Terms:

Term Source: Chapter 6 – Bo Gehring and Associates

Genlocking

Genlock (generator locking) is a common technique where the video output of one source, or a specific reference signal from a signal generator, is used to synchronize other television picture sources together. The aim in video applications is to ensure the coincidence of signals in time at a combining or switching point. When video instruments are synchronized in this way, they are said to be generator locked, or genlocked.

Related Glossary Terms:

Term Source: Chapter 16 – Amiga

Global illumination

Global illumination is a general name for a group of algorithms used in 3D computer graphics that are meant to add more realistic lighting to 3D scenes. Such algorithms take into account not only the light which comes directly from a light source (direct illumination), but also subsequent cases in which light rays from the same source are reflected by other surfaces in the scene, whether reflective or not (indirect illumination).

Related Glossary Terms:

Term Source: Chapter 19 – Global Illumination

Glyphs

A glyph (pronounced GLIHF ; from a Greek word meaning carving) is a graphic symbol that provides the appearance or form for a character . A glyph can be an alphabetic or numeric font or some other symbol that pictures an encoded character.

It is a particular graphical representation, in a particular typeface, of a grapheme, or sometimes several graphemes in combination (a composed glyph), or a part of a grapheme. It can also be a grapheme or grapheme-like unit of text, as found in natural language writing systems (scripts). It may be a letter, a numeral, a punctuation mark, or a pictographic or decorative symbol such as dingbats. A character or grapheme is an abstract unit of text, whereas a glyph is a graphical unit.

For example, the sequence ffi contains three characters, but can be represented by one glyph, the three characters being combined into a single unit known as a ligature. Conversely, some typewriters require the use of multiple glyphs to depict a single character (for example, two hyphens in place of an em-dash, or an overstruck apostrophe and period in place of an exclamation mark).

Related Glossary Terms:

Term Source: Chapter 16 – Xerox PARC

Gouraud shading

Gouraud shading, named after Henri Gouraud, is an interpolation method used in computer graphics to produce continuous shading of surfaces represented by polygon meshes. In practice, Gouraud shading is most often used to achieve continuous lighting on triangle surfaces by computing the lighting at the corners of each triangle and linearly interpolating the resulting colors for each pixel covered by the triangle. Gouraud first published the technique in 1971.

Related Glossary Terms: Continuous shading, Phong shading

Term Source: Chapter 14 – CGI and Effects in Films and Music Videos

Graphics acceleration

Graphics accelerators are a type of graphics hardware that contains its own processor to boost performance levels. These processors are specialized for computing graphical transformations, so they achieve better results than the general-purpose CPU used by the computer. In addition, they free up the computer's CPU to execute other commands while the graphics accelerator is handling graphics computations.

The popularity of graphical applications, and especially multimedia applications, has made graphics accelerators not only a common enhancement, but a necessity. Most computer manufacturers now bundle a graphics accelerator with their mid-range and high-end systems.

Related Glossary Terms:

Term Source: Chapter 13 – Evans and Sutherland, Chapter 15 – Graphics Accelerators

Graphics processing unit

A graphics processing unit or GPU (also occasionally called visual processing unit or VPU) is a specialized electronic circuit designed to rapidly manipulate and alter memory in such a way so as to accelerate the building of images in a frame buffer intended for output to a display.

Related Glossary Terms: Graphics acceleration

Term Source: Chapter 15 – Graphics Accelerators

Graphics tablet

A graphics tablet (or digitizing tablet , graphics pad , drawing tablet) is a computer input device that allows one to hand-draw images and graphics, similar to the way one draws images with a pencil and paper. These tablets may also be used to capture data of handwritten signatures.

A graphics tablet (also called pen pad) consists of a flat surface upon which the user may “draw” an image using an attached stylus, a pen-like drawing apparatus. The image generally does not appear on the tablet itself but, rather, is displayed on the computer monitor. Some tablets however, come as a functioning secondary computer screen that you can interact with directly using the stylus.

Related Glossary Terms:

Term Source: Chapter 3 – Input devices

Graphics workstation

A workstation is a high-end microcomputer designed for technical or scientific applications. Intended primarily to be used by one person at a time. It is commonly connected to a local area network and run multi-user operating systems.

Historically, workstations had offered higher performance than desktop computers, especially with respect to CPU and graphics, memory capacity, and multitasking capability. Graphics workstations are optimized for the visualization and manipulation of different types of complex data such as 3D mechanical design, engineering simulation (e.g. computational fluid dynamics), animation and rendering of images, and mathematical plots. Consoles consist of a high resolution display, a keyboard and a mouse at a minimum, but also offer multiple displays, graphics tablets, 3D mice (devices for manipulating 3D objects and navigating scenes), etc.

Related Glossary Terms:

Term Source: Chapter 15 – Apollo / Sun / SGI

Greenberg, Donald P.

Donald Peter Greenberg is the Jacob Gould Schurman Professor of Computer Graphics at Cornell University. He joined the Cornell faculty in 1968 with a joint appointment in the College of Engineering and College of Architecture. He currently serves as Director of the Program of Computer Graphics.

In 1971, Greenberg produced an early sophisticated computer graphics movie, Cornell in Perspective, using the General Electric Visual Simulation Laboratory. Greenberg also co- authored a series of papers on the Cornell Box.

An internationally recognized pioneer in computer graphics, Greenberg has authored hundreds of articles and served as a teacher and mentor to many prominent computer graphic artists and animators. Greenberg was the founding director of the National Science Foundation Science and Technology Center for Computer Graphics and Scientific Visualization when it was created in 1991.

Greenberg received the Steven Anson Coons Award in 1987, the most prestigious award in the field of computer graphics.

Related Glossary Terms:

Term Source: Chapter 5 – Cornell and NYIT

GUI (Graphical User Interface)

An interface for issuing commands to a computer utilizing a pointing device, such as a mouse, that manipulates and activates graphical images on a monitor.

Related Glossary Terms:

Term Source: Chapter 3 – Work continues at MIT, Chapter 16 – Xerox PARC

H

Haptic

Haptic technology, or haptics, is a tactile feedback technology which takes advantage of the sense of touch by applying forces, vibrations, or motions to the user. This mechanical stimulation can be used to assist in the creation of virtual objects in a computer simulation, to control such virtual objects, and to enhance the remote control of machines and devices (telerobotics). It has been described as "doing for the sense of touch what computer graphics does for vision". Haptic devices may incorporate tactile sensors that measure forces exerted by the user on the interface.

Related Glossary Terms:

Term Source: Chapter 17 – Interaction

Hausdorff-Besicovich dimension

the Hausdorff dimension (also known as the Hausdorff–Besicovitch dimension) is an extended non-negative real number associated with a metric space. The Hausdorff dimension generalizes the notion of the dimension of a real vector space in that the Hausdorff dimension of an n-dimensional inner product space equals n. This means, for example, the Hausdorff dimension of a point is zero, the Hausdorff dimension of a line is one, and the Hausdorff dimension of the plane is two. There are, however, many irregular sets that have noninteger Hausdorff dimension. The concept was introduced in 1918 by the mathematician Felix Hausdorff. Many of the technical developments used to compute the Hausdorff dimension for highly irregular sets were obtained by Abram Samoilovitch Besicovitch.

Related Glossary Terms:

Term Source: Chapter 19 – Noise functions and Fractals

Head-mounted displays

A head-mounted display or helmet mounted display, both abbreviated HMD, is a display device, worn on the head or as part of a helmet, that has a small display optic in front of one (monocular HMD) or each eye (binocular HMD).

A typical HMD has either one or two small displays with lenses and semi-transparent mirrors embedded in a helmet, eye-glasses (also known as data glasses) or visor. The display units are miniaturized and may include CRT, LCDs, Liquid crystal on silicon (LCos), or OLED.

Related Glossary Terms: Stereoscopic display

Term Source: Chapter 17 – Virtual Reality

Heads-up display

A head-up display or heads-up display—also known as a HUD—is any transparent display that presents data without requiring users to look away from their usual viewpoints. The origin of the name stems from a pilot being able to view information with the head positioned "up" and looking forward, instead of angled down looking at lower instruments.

Although they were initially developed for military aviation, HUDs are now used in commercial aircraft, automobiles, and other applications.

Related Glossary Terms:

Term Source: Chapter 17 – Interaction

Height maps

In computer graphics, a height map or height field is a raster image used to store values, such as surface elevation data, for display in 3D computer graphics. A height map can be used in bump mapping to calculate where this 3D data would create shadow in a material, in displacement mapping to displace the actual geometric position of points over the textured surface, or for terrain where the height map is converted into a 3D mesh.

Related Glossary Terms:

Term Source: Chapter 13 – Other Approaches

Hidden line elimination

Hidden line elimination is an extension of wireframe model rendering where lines (or segments of lines) covered by surfaces of a model are not drawn, resulting in a more accurate representation of a 3D object.

Related Glossary Terms: Hidden surfaces

Term Source:

Hidden surfaces

In 3D computer graphics, hidden surface determination (also known as hidden surface removal (HSR), occlusion culling (OC) or visible surface determination (VSD)) is the process used to determine which surfaces and parts of surfaces are not visible from a certain viewpoint. A hidden surface determination algorithm is a solution to the visibility problem, which was one of the first major problems in the field of 3D computer graphics.

Related Glossary Terms: Hidden line elimination

Term Source: Chapter 17 – Virtual Reality

Hopper, Grace

Rear Admiral Grace Murray Hopper was an American computer scientist and United States Navy officer. A pioneer in the field, she was one of the first programmers of the Harvard Mark I computer, and developed the first compiler for a computer programming language. She conceptualized the idea of machine-independent programming languages, which led to the development of COBOL, one of the first modern programming languages. She is credited with popularizing the term “debugging” for fixing computer glitches (motivated by an actual moth removed from the computer).

Related Glossary Terms:

Term Source: Chapter 2 – Programming and Artistry

I

I&D architectures

I&D (instructions and data) – refers to the ability to address instructions and data in the same computer “word”

Related Glossary Terms:

Term Source: Chapter 3 – TX-2 and DEC

Image processing

In imaging science, image processing is any form of signal processing for which the input is an image, such as a photograph or video frame; the output of image processing may be either an image or a set of characteristics or parameters related to the image. Most image- processing techniques involve treating the image as a two-dimensional signal and applying standard signal-processing techniques to it.

Related Glossary Terms:

Term Source: Chapter 13 – NASA

Imax

IMAX is a motion picture film format and a set of proprietary cinema projection standards created by the Canadian company IMAX Corporation. IMAX has the capacity to record and display images of far greater size and resolution than conventional film systems.

Related Glossary Terms:

Term Source:

Chapter 11 – Sogitec Audiovisuel

Ink and paint

Digital ink-and-paint is the computerized version of finalizing animation art using scanning, instead of inking, for each pencil drawing, and digitally coloring instead of hand-painting each cel. With all the ink-and-paint programs now available it is possible to drop fill (single- click paint an entire enclosed area) or use a digital paintbrush to fill colors into characters.

Related Glossary Terms:

Term Source: Chapter 11 – Metrolight / Rezn8

Integrated circuit

A circuit of transistors, resistors, and capacitors constructed on a single semiconductor wafer or chip, in which the components are interconnected to perform a given function. Abbreviation: IC

Related Glossary Terms:

Term Source: Chapter 1 – Electronic devices

Interpolation

Linear interpolation, in computer graphics often called “LERP” (Linear interpolation), is a very (if not the simplest) method of interpolation.

For a set of discrete values linear interpolation can approximate other values in between, assuming a linear development between these discrete values. An interpolated value, calculated with linear interpolation, is calculated only in respect to the two surrounding values, which makes it a quite inappropriate choice if the desired curve should be smooth. If a curvier interpolation is needed, cubic interpolation or splines might be an option.

Linear interpolation is the simplest method of getting values at positions in between the data points. The points are simply joined by straight line segments.

Cubic interpolation is the simplest method that offers true continuity between segments. As such it requires more than just the two endpoints of the segment but also the two points on either side of them. So the function requires 4 points in all.

Related Glossary Terms:

Term Source: Chapter 8 – Introduction

Isolines

An isoline (also contour line, isopleth, or isarithm) of a function of two variables is a curve along which the function has a constant value. For example, in cartography, a contour line (often just called a "contour") joins points of equal elevation (height) above a given level, such as mean sea level.[A contour map is a map illustrated with contour lines, for example a topographic map, which thus shows valleys and hills, and the steepness of slopes. The contour interval of a contour map is the difference in elevation between successive contour lines.

Related Glossary Terms: Isosurfaces

Term Source: Chapter 18 – Introduction

Isosurfaces

An isosurface is a three-dimensional analog of an isoline. It is a surface that represents points of a constant value (e.g. pressure, temperature, velocity, density) within a volume of space; in other words, it is a level set of a continuous function whose domain is 3D-space.

Related Glossary Terms: Contour plots, Isolines

Term Source: Chapter 18 – Introduction

Iterated function systems

In mathematics, iterated function systems or IFSs are a method of constructing fractals; the resulting constructions are always self-similar.

IFS is the term originally devised by Michael Barnsley and Steven Demko for a collection of contraction mappings over a complete metric space, typically compact subsets of Rn . The landmark papers of John Hutchinson and, independently, Barnsley and Demko showed how such systems of mappings with associated probabilities could be used to construct fractal sets and measures: the former from a geometric measure theory setting and the latter from a probabilistic setting.

http://links.uwaterloo.ca/ResearchIFSFractalCoding.html

Related Glossary Terms:

Term Source: Chapter 19 – Plants

J

Jaggies

Jaggies" is the informal name for artifacts in raster images, most frequently from aliasing,[1] which in turn is often caused by non-linear mixing effects producing high-frequency components and/or missing or poor anti-aliasing filtering prior to sampling.

Jaggies are stair like lines that appear where there should be smooth straight lines or curves. For example, when a nominally straight, un-aliased line steps across one pixel, a dogleg occurs halfway through the line, where it crosses the threshold from one pixel to the other.

Related Glossary Terms: Antialiasing

Term Source: Chapter 15 – Graphics Accelerators

Jobs, Steve

Steven Paul "Steve" Jobs was an American entrepreneur who is best known as the co- founder, chairman, and chief executive officer of Apple Inc. Through Apple, he was widely recognized as a charismatic pioneer of the personal computer revolution and for his influential career in the computer and consumer electronics fields. Jobs also co-founded and served as chief executive of Pixar Animation Studios; he became a member of the board of directors of The Walt Disney Company in 2006, when Disney acquired Pixar.

Related Glossary Terms:

Term Source: Chapter 16 – Apple Computer

K

Kajiya, Jim

Jim Kajiya is a pioneer in the field of computer graphics. He is perhaps best known for the development of the rendering equation.Kajiya received his PhD from the University of Utah in 1979, was a professor at Caltech from 1979 through 1994, and is currently a researcher at Microsoft Research.

Related Glossary Terms:

Term Source: Chapter 5 – Cal Tech and North Carolina State, Chapter 19 – Global Illumination

Kawaguchi, Yoichiro

Yoichiro Kawaguchi is a Japanese computer graphics artist, professor at the University of Tokyo. Kawaguchi rose to international prominence in 1982 when he presented "Growth Model" in the international conference SIGGRAPH.

Related Glossary Terms:

Term Source: Chapter 9 – Yoichiro Kawaguchi

Keyframe

A key frame in animation and filmmaking is a drawing that defines the starting and ending points of any smooth transition. They are called "frames" because their position in time is measured in frames on a strip of film. A sequence of keyframes defines which movement the viewer will see, whereas the position of the keyframes on the film, video or animation defines the timing of the movement. Because only two or three keyframes over the span of a second do not create the illusion of movement, the remaining frames are filled with in- betweens.

Related Glossary Terms:

Term Source: Chapter 4 – University of Utah, Chapter 4 – The Ohio State University, Chapter 4 – JPL and National Research Council of Canada

Kinematics

Forward kinematic animation is a method in 3D computer graphics for animating models.

The essential concept of forward kinematic animation is that the positions of particular parts of the model at a specified time are calculated from the position and orientation of the object, together with any information on the joints of an articulated model. So for example if the object to be animated is an arm with the shoulder remaining at a fixed location, the location of the tip of the thumb would be calculated from the angles of the shoulder, elbow, wrist, thumb and knuckle joints. Three of these joints (the shoulder, wrist and the base of the thumb) have more than one degree of freedom, all of which must be taken into account. If the model were an entire human figure, then the location of the shoulder would also have to be calculated from other properties of the model.

Forward kinematic animation can be distinguished from inverse kinematic animation by this means of calculation – in inverse kinematics the orientation of articulated parts is calculated from the desired position of certain points on the model. It is also distinguished from other animation systems by the fact that the motion of the model is defined directly by the animator – no account is taken of any physical laws that might be in effect on the model, such as gravity or collision with other models.

Related Glossary Terms: Dynamics

Term Source: Chapter 8 – Introduction

Kinetic Art

Kinetic art is art that contains moving parts or depends on motion for its effect. The moving parts are generally powered by wind, a motor or the observer. Kinetic art encompasses a wide variety of overlapping techniques and styles.

Related Glossary Terms:

Term Source: Chapter 9 – Vera Molnar

Kleiser, Jeff

Jeff Kleiser is widely recognized as a leader in animation and visual effects. He has produced and directed visual effects for numerous award-winning television commercials, and has created unique location-based entertainment projects such as the 3D stereoscopic films Corkscrew Hill (for Bush Gardens), Santa Lights up New York (for Radio City Music Hall), and The Amazing Adventures of Spider-Man (for Universal Studios). Kleiser's film credits range from Walt Disney's Tron, the ground-breaking CGI movie released to critical acclaim in 1982, to recent Hollywood releases such as X-Men (including X-Men 2 and X- Men: The Last Stand), Fantastic Four, Scary Movie (3 and 4), Slither, Son of the Mask, Exorcist: The Beginning, and many more. In 1987 Kleiser and partner Diana Walczak founded the visual effects studio Kleiser-Walczak and together coined the term "synthespian" to describe digital actors (synthetic thespians). In 2005 Kleiser and Walczak founded Synthespian Studios (synthespians.net) to create original projects for animated characters.

Related Glossary Terms:

Term Source: Chapter 6 – Digital Effects

Kodalith

A high contrast black and white film made by Kodak, used also as a special effect film in the darkroom (allowed for the recording ultra high contrast images)

Related Glossary Terms:

Term Source: Chapter 2 – Programming and Artistry

Kovacs, Bill

Bill Kovacs received a Bachelor of Architecture degree from Carnegie Mellon University in 1971. He worked for Skidmore, Owings and Merrill (New York office) while getting a Masters of Environmental Design from Yale University (1972). He was then transferred to the Chicago Office, where he worked on a computer-aided design system.

In 1978, Kovacs left SOM to become VP of R&D for the early computer animation company Robert Abel and Associates (1978-1984). At Abel, Kovacs (along with Roy Hall and others) developed the company's animation software. Kovacs used this software, with others in the film Tron. He later co-founded Wavefront Technologies as CTO (1984-1994), leading the development of products such as The Advanced Visualizer as well as animated productions. Along with Richard Childers and Chris Baker, he was a key organizer of the Infinite Illusions at the Smithsonian Institution exhibit in 1991.

Following retirement from Wavefront, Kovacs co-founded Instant Effects, worked as a consultant to Electronic Arts and RezN8, serving as RezN8's CTO from 2000 until his death. In 1998, Kovacs received a 1997 (Scientific and Engineering) Academy Award from the Academy of Motion Picture Arts and Sciences. In 1980, he received two Clio Awards for his work on animated TV commercials.

Related Glossary Terms:

Term Source: Chapter 6 – Robert Abel and Associates

Kristoff, Jim

President of Cranston/Csuri Productions, and founder of Metrolight Productions in Los Angeles.

Related Glossary Terms:

Term Source: Chapter 6 – Cranston/Csuri Productions

Krueger, Myron

Myron Krueger is an American computer artist who developed early interactive works. He is also considered to be one of the first generation virtual reality and augmented reality researchers. He earned a Ph.D. in Computer Science at the University of Wisconsin– Madison and in 1969, he collaborated with Dan Sandin, Jerry Erdman and Richard Venezky on a computer controlled environment called "glowflow," a computer-controlled light sound environment that responded to the people within it. Krueger went on to develop Metaplay, an integration of visuals, sounds, and responsive techniques into a single framework. A later project, “Videoplace,” was funded by the National Endowment for the arts and a two- way exhibit was shown at the Milwaukee Art Museum in 1975. From 1974 to 1978 Krueger performed computer graphics research at the Space Science and Engineering Center of the University of Wisconsin–Madison in exchange for institutional support for his “Videoplace” work. In 1978, joined the computer science faculty at the University of Connecticut, where he taught courses in hardware, software, computer graphics and artificial intelligence.

Related Glossary Terms:

Term Source: Chapter 17 – Hypermedia and Art

L

L-systems

An L-system or Lindenmayer system, is a parallel rewriting system, namely a variant of a formal grammar, most famously used to model the growth processes of plant development, but also able to model the morphology of a variety of organisms. An L-system consists of an alphabet of symbols that can be used to make strings, a collection of production rules which expand each symbol into some larger string of symbols, an initial “axiom” string from which to begin construction, and a mechanism for translating the generated strings into geometric structures. L-systems can also be used to generate self-similar fractals such as iterated function systems.

Related Glossary Terms:

Term Source: Chapter 19 – Plants

Lambertian

If a surface exhibits Lambertian reflectance, light falling on it is scattered such that the apparent brightness of the surface to an observer is the same regardless of the observer’s angle of view. More technically, the surface luminance is isotropic. For example, unfinished wood exhibits roughly Lambertian reflectance, but wood finished with a glossy coat of polyurethane does not, since specular highlights may appear at different locations on the surface. Not all rough surfaces are perfect Lambertian reflectors, but this is often a good approximation when the characteristics of the surface are unknown. Lambertian reflectance is named after Johann Heinrich Lambert.

In computer graphics, Lambertian reflection is often used as a model for diffuse reflection. This technique causes all closed polygons (such as a triangle within a 3D mesh) to reflect light equally in all directions when rendered.

Related Glossary Terms: Diffuse reflection, Specular reflection

Term Source: Chapter 19 – Global Illumination

Langlois, Daniel

Daniel Langlois is the president and founder of the Daniel Langlois Foundation, Ex-Centris, and Media Principia Inc. He also founded Softimage Inc., serving as its president and chief technology officer from November 1986 to July 1998. The company is recognized in the fields of cinema and media creation for its digital technologies and especially its 3-D computer animation techniques. Softimage software was used to create most of the 3-D effects in the movies Star Wars Episode I: The Phantom Menace, The Matrix, Titanic, Men in Black, Twister, Jurassic Park, The Mask and The City of Lost Children.

Related Glossary Terms:

Term Source: Chapter 8 – SoftImage

Laposky, Ben

Ben Laposky was a mathematician and artist from Iowa. In 1950, he created the first graphic images generated by an electronic (in his case, an analog) machine.

Related Glossary Terms:

Term Source: Chapter 2 – Programming and Artistry

Lasseter, John

John Alan Lasseter is an American animator, film director and the chief creative officer at Pixar and Walt Disney Animation Studios. He is also currently the Principal Creative Advisor for Walt Disney Imagineering. Lasseter's first job was with The Walt Disney Company, where he became an animator. Next, he joined Lucasfilm, where he worked on the then- groundbreaking use of CGI animation. After the Graphics Group of the Computer Division of Lucasfilm was sold to Steve Jobs and became Pixar in 1986, Lasseter oversaw all of Pixar's films and associated projects as executive producer and he directed Toy Story, A Bug's Life, Toy Story 2, Cars, and Cars 2.

He has won two Academy Awards, for Animated Short Film (for Tin Toy), as well as a Special Achievement Award (for Toy Story).

Related Glossary Terms:

Term Source: Chapter 6 – MAGI

Light pen

a rodlike device which, when focused on the screen of a cathode-ray tube, can detect the time of passage of the illuminated spot across that point thus enabling a computer to determine the position on the screen being pointed at

Related Glossary Terms: Cathode Ray Tube

Term Source: Chapter 3 – General Motors DAC, Chapter 3 – Input devices

Lofting

The creation of a 3D surface model by joining adjacent cross-sectional data with surface elements, such as triangles.

Related Glossary Terms:

Term Source: Chapter 18 – Algorithms

Lytle, Wayne

Wayne Lytle is the founder of Animusic, an American musical computer animation company. In 1988, he joined the Cornell Theory Center, where he could experiment with his idea as a scientific visualization producer. He created the piece More Bells & Whistles at Cornell in 1990 and composed Beyond The Walls in 1996. Lytle founded Animusic (originally under the name Visual Music) in 1995 with his associate David Crognale.

Related Glossary Terms:

Term Source: Chapter 19 – Data-driven Imagery

M

Machover, Carl

Carl Machover,a computer graphics pioneer and graphics “evangelist” is president of Machover Associates Corp (MAC), a computer graphics consultancy he founded in 1976,which provides a broad range of management, engineering, marketing, and financial services worldwide to computer graphics users, suppliers, and investors. Machover is also an Adjunct Professor at RPI, president of ASCI, past-president of NCGA, SID, and Computer Graphics Pioneers, on the editorial boards of many industry publications, writes and lectures world-wide on all aspects of computer graphics, and was guest editor of special computer graphics art issues of Computer and Graphics and the IEEE Computer Graphics and Applications, Machover received the North Carolina State University, Orthogonal Award , the NCGA Vanguard Award, .and was was inducted into the FAMLI Computer Graphics Hall of Fame. Machover passed away in 2012.

Related Glossary Terms:

Term Source: Chapter 6 – MAGI

Mandelbrot, Benoit

Benoît B. Mandelbrot was a French American mathematician. Born in Poland, he moved to France with his family when he was a child. Mandelbrot spent much of his life living and working at IBM in the United States, where he worked on a wide range of mathematical problems, including mathematical physics and quantitative finance. He is best known as the father of fractal geometry. He coined the term fractal and described the Mandelbrot set.

Related Glossary Terms:

Term Source: Chapter 19 – Noise functions and Fractals

Marks, Harry

Harry Marks is considered by many to be the founding father of modern broadcast design. He began his career as a typographer and publications designer at Oxford University Press. In the mid-1960s, he moved to Los Angeles and landed a job at ABC-TV, where his assignment was to improve the on-air graphic appearance of the network. He is also known for his work as an independent graphics consultant, including six years of on-air graphics for NBC-TV, brand packaging for international TV networks, and an Emmy-winning main title for Entertainment Tonight. Harry is well known for his innovative use of emerging technologies, such as computer graphics and slit scan. He has earned nearly every award in broadcast design and promotion, including an Emmy and the first Lifetime Achievement Award from the Broadcast Design Association. In 1984, Harry had the notion of facilitating a gathering of people from the converging worlds of technology, entertainment, and design, so he partnered with Richard Saul Wurman and created the TED Conference.

Related Glossary Terms:

Term Source: Chapter 6 – Pacific Data Images, Chapter 6 – Robert Abel and Associates

Max, Nelson

Max's research interests are in the areas of scientific visualization, computer animation, and realistic computer graphics rendering. In visualization he works on molecular graphics, and volume and flow visualization, particularly on irregular finite element meshes. He has rendered realistic lighting effects in clouds, trees, and water waves, and has produced numerous computer animations, shown at the annual SIGGRAPH conferences, and in Omnimax at the Fujitu Pavilions at Expo '85 in Tsukuba Japan, and Expo '90 in Osaka Japan. His early work was done at Lawrence Livermore and he is currently affiliated with UC-Davis.

Related Glossary Terms:

Term Source: Chapter 4 – Bell Labs and Lawrence Livermore

Metaballs

Metaballs are, in computer graphics, organic-looking n-dimensional objects. The technique for rendering metaballs was invented by Jim Blinn in the early 1980s. Each metaball is defined as a function in n-dimensions.

Related Glossary Terms:

Term Source: Chapter 8 – Side Effects, Chapter 9 – Yoichiro Kawaguchi

MIP mapping

In 3D computer graphics texture filtering, mipmaps (also MIP maps) are pre-calculated, optimized collections of images that accompany a main texture, intended to increase rendering speed and reduce aliasing artifacts. They are widely used in 3D computer games, flight simulators and other 3D imaging systems. Mipmapping was invented by Lance Williams in 1983 and is described in his paper Pyramidal parametrics.

Related Glossary Terms:

Term Source:

Modular visualization environments

several systems have been developed around the concepts of applying visual languages to visualization application building; decomposing a visualization application into separable process (such as data analysis, geometric representation, and rendering); and finally creating a real-time development environment where applications are created interactively. These systems have given rise to disposable applications by utilizing reusable visualization and graphics algorithms. These techniques can be connected in a visual manner to create problem-targeted applications with a short lifetime, which dramatically reduces the time devoted to problem solving.

Because of their focus, these systems blur the distinction between program visualization (the process of dynamically viewing the execution ordering of a program), visualization programming (creating visualization applications using graphics libraries), and visualization prototyping (building visualization applications interactively).

Related Glossary Terms: Dataflow

Term Source: Chapter 18 – Visualization Systems

Monte Carlo method

Monte Carlo methods (or Monte Carlo experiments) are a class of computational algorithms that rely on repeated random sampling to compute their results. Monte Carlo methods are often used in computer simulations of physical and mathematical systems. These methods are most suited to calculation by a computer and tend to be used when it is infeasible to compute an exact result with a deterministic algorithm. This method is also used to complement theoretical derivations.

Monte Carlo methods are especially useful for simulating systems with many coupled degrees of freedom, such as fluids, disordered materials, strongly coupled solids, and cellular structures (see cellular Potts model). They are used to model phenomena with significant uncertainty in inputs, such as the calculation of risk in business. They are widely used in mathematics, for example to evaluate multidimensional definite integrals with complicated boundary conditions. When Monte Carlo simulations have been applied in space exploration and oil exploration, their predictions of failures, cost overruns and schedule overruns are routinely better than human intuition or alternative "soft" methods.

The Monte Carlo method was coined in the 1940s by John von Neumann, Stanislaw Ulam and Nicholas Metropolis, while they were working on nuclear weapon projects (Manhattan Project) in the Los Alamos National Laboratory.

Related Glossary Terms:

Term Source: Chapter 19 – Global Illumination

MOOG synthesizer

Moog synthesizer refers to any number of analog synthesizers designed by Dr. Robert Moog or manufactured by Moog Music, and is commonly used as a generic term for older- generation analog music synthesizers.

Related Glossary Terms: Sandin, Dan

Term Source: Chapter 5 – Illinois-Chicago and University of Pennsylvania

Morphing

Morphing is a special effect in motion pictures and animations that changes (or morphs) one image into another through a seamless transition. Most often it is used to depict one person turning into another through technological means or as part of a fantasy or surreal sequence. Traditionally such a depiction would be achieved through cross-fading techniques on film. Since the early 1990s, this has been replaced by computer software to create more realistic transitions.

Related Glossary Terms:

Term Source: Chapter 4 – University of Utah, Chapter 4 – The Ohio State University

Motion blur

Motion blur is the apparent streaking of rapidly moving objects in a still image or a sequence of images such as a movie or animation. It results when the image being recorded changes during the recording of a single frame, either due to rapid movement or long exposure.

In computer animation (2D or 3D) it is computer simulation in time and/or on each frame that the 3D rendering/animation is being made with real video camera during its fast motion or fast motion of "cinematized" objects or to make it look more natural or smoother.

Related Glossary Terms:

Term Source: Chapter 19 – Noise functions and Fractals

Motion blur

Motion blur is the apparent streaking of rapidly moving objects in a still image or a sequence of images such as a movie or animation. It results when the image being recorded changes during the recording of a single exposure, either due to rapid movement or long exposure.

Related Glossary Terms:

Term Source: Chapter 11 – ILM

Motion capture

Motion capture, or mocap, is a technique of digitally recording movements for entertainment, sports and medical applications. It started as an analysis tool in biomechanics research, but has grown increasingly important as a source of motion data for computer animation as well as education, training and sports and recently for both cinema and video games. A performer wears a set of one type of marker at each joint: acoustic, inertial, LED, magnetic or reflective markers, or combinations, to identify the motion of the joints of the body. Sensors track the position or angles of the markers, optimally at least two times the rate of the desired motion. The motion capture computer program records the positions, angles, velocities, accelerations and impulses, providing an accurate digital representation of the motion.

Related Glossary Terms: Performance animation

Term Source: Chapter 4 – University of Utah

Mouse

Computers . a palm-sized, button-operated pointing device that can be used to move, select, activate, and change items on a computer screen.

Related Glossary Terms:

Term Source: Chapter 3 – Input devices

Multi-texturing

Texture mapping is a method for adding detail, surface texture (a bitmap or raster image), or color to a computer-generated graphic or 3D model. Its application to 3D graphics was pioneered by Dr Edwin Catmull in his Ph.D. thesis of 1974. Multitexturing is the use of more than one texture at a time on a polygon. For instance, a light map texture may be used to light a surface as an alternative to recalculating that lighting every time the surface is rendered. Another multitexture technique is bump mapping, which allows a texture to directly control the facing direction of a surface for the purposes of its lighting calculations; it can give a very good appearance of a complex surface, such as tree bark or rough concrete.

Related Glossary Terms: Texture Mapping

Term Source:

Multitasking

In computing, multitasking is a method where multiple tasks, also known as processes, are performed during the same period of time.

Related Glossary Terms:

Term Source: Chapter 16 – Apple Computer

Multivariate data

Data collected on several variables for each sampling unit. For example, if we collect information on weight (w), height (h), and shoe size (s) from each of a random sample of individuals, then we would refer to the triples (w1, h1, s1), (w2, h2, s2),…as a set of multivariate data.

Related Glossary Terms:

Term Source: Chapter 18 – Algorithms

N

Noise functions

Perlin noise is a procedural texture primitive, a type of gradient noise used by visual effects artists to increase the appearance of realism in computer graphics. The function has a pseudo-random appearance, yet all of its visual details are the same size (see image). This property allows it to be readily controllable; multiple scaled copies of Perlin noise can be inserted into mathematical expressions to create a great variety of procedural textures. Synthetic textures using Perlin noise are often used in CGI to make computer-generated visual elements – such as fire, smoke, or clouds – appear more natural, by imitating the controlled random appearance of textures of nature.

Noise functions are also frequently used to generate textures when memory is extremely limited, such as in demos, and is increasingly finding use in Graphics Processing Units for real-time graphics in computer games.

Related Glossary Terms: Fractal, Procedural rendering

Term Source: Chapter 6 – MAGI, Chapter 19 – Noise functions and Fractals

Numerical-control

A control system in which numerical values corresponding to desired tool or control positions are generated by a computer. Abbreviated CNC. Also known as computational numerical control; soft-wired numerical control; stored-program numerical control

Related Glossary Terms:

Term Source: Chapter 10 – MCS / CalComp / McAuto

NURBS

Non-uniform rational basis spline (NURBS) is a mathematical model commonly used in computer graphics for generating and representing curves and surfaces which offers great flexibility and precision for handling both analytic (surfaces defined by common mathematical formulae) and modeled shapes.

Related Glossary Terms:

Term Source: Chapter 8 – Alias Research

O

Object-oriented programming

Object-oriented programming (OOP) is a programming paradigm using "objects" – data structures consisting of data fields and methods together with their interactions – to design applications and computer programs. Programming techniques may include features such as data abstraction, encapsulation, messaging, modularity, polymorphism, and inheritance.

Related Glossary Terms:

Term Source: Chapter 16 – Apple Computer

Olsen, Ken

Kenneth Harry Olsen was an American engineer who co-founded Digital Equipment Corporation (DEC) in 1957 with colleague Harlan Anderson.

Related Glossary Terms:

Term Source: Chapter 3 – TX-2 and DEC

Omnimax

A variation of the IMAX film format that is projected on an angled dome

Related Glossary Terms:

Term Source: Chapter 5 – Cal Tech and North Carolina State

Op-art

Op art, also known as optical art, is a style of visual art that makes use of optical illusions.

Related Glossary Terms:

Term Source: Chapter 9 – Vera Molnar

Operating system

the collection of software that directs a computer's operations, controlling and scheduling the execution of other programs, and managing storage, input/output, and communication resources. Abbreviation: OS

Related Glossary Terms:

Term Source: Chapter 3 – TX-2 and DEC

Optical printers

An optical printer is a device consisting of one or more film projectors mechanically linked to a movie camera. It allows filmmakers to re-photograph one or more strips of film. The optical printer is used for making special effects for motion pictures, or for copying and restoring old film material.

Common optical effects include fade outs and fade ins, dissolves, slow motion, fast motion, and matte work. More complicated work can involve dozens of elements, all combined into a single scene.

Related Glossary Terms: Film recorder

Term Source: Chapter 6 – Robert Abel and Associates

Orthographic

Orthographic projection (or orthogonal projection) is a means of representing a three- dimensional object in two dimensions. It is a form of parallel projection, where all the projection lines are orthogonal to the projection plane, resulting in every plane of the scene appearing in affine transformation on the viewing surface. It is further divided into multi- view orthographic projections and axonometric projections. A lens providing an orthographic projection is known as an (object-space) tele-centric lens.

Related Glossary Terms:

Term Source: Chapter 4 – Bell Labs and Lawrence Livermore

Oxberry animation camera

An animation camera, a type of rostrum camera, is a movie camera specially adapted for frame-by-frame shooting animation or stop motion. It consists of a camera body with lens and film magazines, a stand that allows the camera to be raised and lowered, and a table, often with both top and underneath lighting. The artwork to be photographed is placed on this table. The Oxberry was made by Oxberry LLC in New Jersey.

Related Glossary Terms:

Term Source: Chapter 11 – Sogitec Audiovisuel

P

Paged architecture

In paging, the memory address space is divided into equal, small pieces, called pages. Using a virtual memory mechanism, each page can be made to reside in any location of the physical memory, or be flagged as being protected. Virtual memory makes it possible to have a linear virtual memory address space and to use it to access blocks fragmented over physical memory address space.

Related Glossary Terms:

Term Source Chapter 3 – TX-2 and DEC

Parametric modeling

Parametric modeling uses parameters to define a model (dimensions, for example). Examples of parameters are: dimensions used to create model features, material density, formulas to describe swept features, imported data (that describe a reference surface, for example). The parameter may be modified later, and the model will update to reflect the modification.

Related Glossary Terms:

Term Source: Chapter 10 – SDRC / Unigraphics

Particle system

The term particle system refers to a computer graphics technique to simulate certain fuzzy phenomena, which are otherwise very hard to reproduce with conventional rendering techniques. Examples of such phenomena which are commonly replicated using particle systems include fire, explosions, smoke, moving water, sparks, falling leaves, clouds, fog, snow, dust, meteor tails, hair, fur, grass, or abstract visual effects like glowing trails, magic spells, etc.

Related Glossary Terms:

Term Source: Chapter 4 – University of Utah, Chapter 4 – The Ohio State University

Patch panel

A panel of electronic ports contained together that connects incoming and outgoing lines of a LAN or other communication, sound, electronic or electrical system. Connections are made with patch cords. The patch panel allows circuits to be arranged and rearranged by plugging and unplugging the patch cords.

Related Glossary Terms:

Term Source: Chapter 12 – ANIMAC / SCANIMATE

Pennie, John

President of Omnibus

Related Glossary Terms: DOA

Term Source: Chapter 6 – Omnibus Computer Graphics

Performance animation

Performance animation could be described as ‘improvisation meets CG (computer graphics). This involves providing real-time rendered 3D animated characters that are doing the same movements as actors, at the same time. The 3D character(s) can exist within a computer generated ‘virtual set’ or can interact with human characters in a real environment (often seen in dance performances) or human characters in a virtual environment.

Related Glossary Terms: Motion capture

Term Source: Chapter 6 – Pacific Data Images (PDI)

Perlin, Ken

Ken Perlin is a professor at New York University, founding director of the Media Research Lab at NYU, and the Director of the Games for Learning Institute. He developed or was involved with the development of techniques such as Perlin noise, hypertexture, real-time interactive character animation, and computer-user interfaces such as zooming user interfaces, stylus-based input, and most recently, cheap, accurate multi-touch input devices. He is also the Chief Technology Advisor of ActorMachine, LLC. His invention of Perlin noise in 1985 has become a standard that is used in both computer graphics and movement.

Perlin was founding director of the NYU Media Research Laboratory and also directed the NYU Center for Advanced Technology from 1994 to 2004. He was the System Architect for computer generated animation at Mathematical Applications Group, Inc. 1979-1984, where he worked on Tron.

Related Glossary Terms:

Term Source: Chapter 19 – Noise functions and Fractals

Perspective (or Perspective Projection)

Perspective projection is a type of drawing that graphically approximates on a planar (two-dimensional) surface (e.g. computer display) the images of three-dimensional objects so as to approximate actual visual perception. It is sometimes also called perspective view or perspective drawing or simply perspective.

Related Glossary Terms:

Term Source:

Phong shading

Phong shading refers to an interpolation technique for surface shading in 3D computer graphics. It is also called Phong interpolation or normal-vector interpolation shading. Specifically, it interpolates surface normals across rasterized polygons and computes pixel colors based on the interpolated normals and a reflection model. Phong shading may also refer to the specific combination of Phong interpolation and the Phong reflection model.

Phong shading and the Phong reflection model were developed by Bui Tuong Phong at the University of Utah, who published them in his 1973 Ph.D. dissertation. Phong's methods were considered radical at the time of their introduction, but have evolved into a baseline shading method for many rendering applications.

Related Glossary Terms: Gouraud shading

Term Source: Chapter 14 – CGI and Effects in Films and Music Videos

Photon mapping

In computer graphics, photon mapping is a two-pass global illumination algorithm developed by Henrik Wann Jensen that approximately solves the rendering equation. Rays from the light source and rays from the camera are traced independently until some termination criterion is met, then they are connected in a second step to produce a radiance value. It is used to realistically simulate the interaction of light with different objects. Specifically, it is capable of simulating the refraction of light through a transparent substance such as glass or water, diffuse interreflection between illuminated objects, the subsurface scattering of light in translucent materials, and some of the effects caused by particulate matter such as smoke or water vapor. It can also be extended to more accurate simulations of light such as spectral rendering.

Related Glossary Terms:

Term Source: Chapter 19 – Global Illumination

Pixel

In digital imaging, a pixel, or pel, (picture element) is a physical point in a raster image, or the smallest, addressable element in a display device; so it is the smallest, controllable element of a picture represented on the screen. The address of a pixel corresponds to its physical coordinates. LCD pixels are manufactured in a two-dimensional grid, and are often represented using dots or squares, but CRT pixels correspond to their timing mechanisms and sweep rates.

Related Glossary Terms: Voxels

Term Source: Chapter 4 – MIT and Harvard

Plasma panel

A plasma display panel (PDP) is a type of flat panel display now commonly used for large TV displays (typically above 37-inch or 940 mm). Many tiny cells located between two panels of glass hold an inert mixture of noble gases. The gas in the cells is electrically turned into a plasma which then excites phosphors to emit light. Plasma displays are commonly confused with LCDs, another lightweight flatscreen display but with very different technology.

Related Glossary Terms: Cathode Ray Tube

Term Source: Chapter 3 – Other output devices

Post production

Post-production is part of filmmaking and the video production process. It occurs in the making of motion pictures, television programs, radio programs, advertising, audio recordings, photography, and digital art. It is a term for all stages of production occurring after the actual end of shooting and/or recording the completed work.

Post-production is, in fact, many different processes grouped under one name. These typically include:

- Video editing the picture of a television program using an edit decision list (EDL)
- Writing, (re)recording, and editing the soundtrack.
- Adding visual special effects – mainly computer-generated imagery (CGI) and digital copy from which release prints will be made (although this may be made obsolete by digital- cinema technologies).
- Sound design, Sound effects, ADR, Foley and Music, culminating in a process known as sound re-recording or mixing with professional audio equipment.
- Transfer of Color motion picture film to Video or DPX with a telecine and color grading (correction) in a color suite.

Related Glossary Terms:

Term Source: Chapter 6 – Cranston/Csuri Productions

Pre-visualizing

Pre-visualization (also known as pre-rendering, preview or wireframe windows) is a function to visualize complex scenes in movie before filming. It is also a concept in still photography. Pre-visualization is applied to techniques such as storyboarding, either in the form of charcoal drawn sketches or in digital technology in the planning and conceptual of movie scenery make up. The advantage of pre-visualization is that it allows directors to experiment with different staging and art direction options – such as lighting, camera placement and movement, stage direction and editing – without having to incur the costs of actual production.

Related Glossary Terms:

Term Source: Chapter 8 – Wavefront Technologies

Procedural modeling

Procedural modeling is an umbrella term for a number of techniques in computer graphics to create 3D models and textures from sets of rules. L-Systems, fractals, and generative modeling are procedural modeling techniques since they apply algorithms for producing scenes. The set of rules may either be embedded into the algorithm, configurable by parameters, or the set of rules is separate from the evaluation engine. The output is called procedural content, which can be used in computer games, films, be uploaded to the internet, or the user may edit the content manually. Procedural models often exhibit database amplification, meaning that large scenes can be generated from a much smaller amount of rules. If the employed algorithm produces the same output every time, the output need not be stored. Often, it suffices to start the algorithm with the same random seed to achieve this.

Although all modeling techniques on a computer require algorithms to manage and store data at some point, procedural modeling focuses on creating a model from a rule set, rather than editing the model via user input. Procedural modeling is often applied when it would be too cumbersome to create a 3D model using generic 3D modelers, or when more specialized tools are required. This is often the case for plants, architecture or landscapes.

Related Glossary Terms:

Term Source: Chapter 8 – Side Effects

Procedural rendering

Procedural generation (procedural modeling, procedural rendering) is a widely used term in the production of media; it refers to content generated algorithmically (procedurally) rather than manually. Often, this means creating content on the fly rather than prior to distribution. This is often related to computer graphics applications and video game level design.

Related Glossary Terms:

Term Source: Chapter 6 – MAGI

Projective texture-mapping

Projective texture mapping is a method of texture mapping that allows a textured image to be projected onto a scene as if by a slide projector. Projective texture mapping is useful in a variety of lighting techniques and it is the starting point for shadow mapping.

Related Glossary Terms: Texture Mapping

Term Source: Chapter 19 – Global Illumination

Prusinkiewicz, Przemyslaw

Przemyslaw (Przemek) Prusinkiewicz advanced the idea that Fibonacci numbers in nature can be in part understood as the expression of certain algebraic constraints on free groups, specifically as certain Lindenmayer grammars. Prusinkiewicz's main work is on the modeling of plant growth through such grammars.

Prusinkiewicz is currently a professor of Computer Science at the University of Calgary. Prusinkiewicz received the 1997 SIGGRAPH Computer Graphics Achievement Award for his work.

Related Glossary Terms:

Term Source: Chapter 19 – Plants

Q

Quantitative invisibility

In CAD/CAM, quantitative invisibility (QI) is the number of solid bodies that obscure a point in space as projected onto a plane. Often, CAD engineers project a model into a plane (a 2D drawing) in order to denote edges that are visible with a solid line, and those that are hidden with dashed or dimmed lines.

Related Glossary Terms: Hidden line elimination, Hidden surfaces

Term Source: Chapter 4 – Other research efforts

R

Radiosity

Radiosity (computer graphics), a rendering algorithm which gives a realistic rendering of shadows and diffuse light.

Radiosity is a global illumination algorithm used in 3D computer graphics rendering. Unlike direct illumination algorithms (such as Ray tracing), which tend to simulate light reflecting only once off each surface, global illumination algorithms such as Radiosity simulate the many reflections of light around a scene, generally resulting in softer, more natural shadows and reflections.

Related Glossary Terms: Form factor

Term Source: Chapter 5 – Cornell and NYIT, Chapter 19 – Global Illumination

Random Access Memory

a type of computer memory that can be accessed randomly; that is, any byte of memory can be accessed without touching the preceding bytes. RAM is the most common type of memory found in computers and other devices, such as printers.

Related Glossary Terms:

Term Source: Chapter 15 – Early hardware

Range image

Range imaging is the name for a collection of techniques which are used to produce a 2D image showing the distance to points in a scene from a specific point, normally associated with some type of sensor device.

The resulting image, the range image, has pixel values which correspond to the distance, e.g., brighter values mean shorter distance, or vice versa. If the sensor which is used to produce the range image is properly calibrated, the pixel values can be given directly in physical units such as meters.

Related Glossary Terms:

Term Source: Chapter 20 – CG Icons

Raster-scanned

A raster scan, or raster scanning, is the rectangular pattern of image capture and reconstruction in television. By analogy, the term is used for raster graphics, the pattern of image storage and transmission used in most computer bitmap image systems. The word raster comes from the Latin word rastrum (a rake), which is derived from radere (to scrape)

Related Glossary Terms: Cathode Ray Tube, Vector

Term Source: Chapter 1 – Electronic devices

Ray casting

Ray casting is the use of ray-surface intersection tests to solve a variety of problems in computer graphics. The term was first used in computer graphics in a 1982 paper by Scott Roth to describe a method for rendering CSG models. The first ray casting (versus ray tracing) algorithm used for rendering was presented by Arthur Appel in 1968. The idea behind ray casting is to shoot rays from the eye, one per pixel, and find the closest object blocking the path of that ray – think of an image as a screen-door, with each square in the screen being a pixel. This is then the object the eye normally sees through that pixel. Using the material properties and the effect of the lights in the scene, this algorithm can determine the shading of this object. The simplifying assumption is made that if a surface faces a light, the light will reach that surface and not be blocked or in shadow. The shading of the surface is computed using traditional 3D computer graphics shading models. One important advantage ray casting offered over older scan-line algorithms is its ability to easily deal with non-planar surfaces and solids, such as cones and spheres. If a mathematical surface can be intersected by a ray, it can be rendered using ray casting. Elaborate objects can be created by using solid modeling techniques and easily rendered.

Ray casting for producing computer graphics was first used by scientists at Mathematical Applications Group, Inc., (MAGI) of Elmsford, New York.

Roth, Scott D. (February 1982), "Ray Casting for Modeling Solids", Computer Graphics and Image Processing 18 (2): 109–144

Goldstein, R. A., and R. Nagel. 3-D visual simulation. Simulation 16(1), pp. 25–31, 1971.

Related Glossary Terms: Ray-trace, Scanline rendering

Term Source: Chapter 11 – R/Greenberg Associates / Blue Sky Studios

Ray-trace

Optical ray tracing describes a method for producing visual images constructed in 3D computer graphics environments, with more photorealism than either ray casting or scanline rendering techniques. It works by tracing a path from an imaginary eye through each pixel in a virtual screen, and calculating the color of the object visible through it.

Ray tracing is capable of simulating a wide variety of optical effects, such as reflection and refraction, scattering, and dispersion phenomena (such as chromatic aberration).

Related Glossary Terms: Radiosity, Reflection mapping, Rendering, Scanline rendering

Term Source: Chapter 5 – Cal Tech and North Carolina State

Reeves, Bill

William "Bill" Reeves is the technical director who worked with John Lasseter on the animation breakthrough shorts Luxo Jr and The Adventures of André and Wally B. at ILM and Pixar. After obtaining a Ph.D. at the University of Toronto, Reeves was hired by George Lucas as a member of Industrial Light and Magic. He was one of the founding employees of Pixar when it was sold in 1986 to Steve Jobs. Reeves is the inventor of the first Motion Blur algorithm and methods to simulate particle motion in CGI. Reeves received the Academy Award for Best Animated Short Film (Oscar) in 1988 for his work (with John Lasseter) on the film Tin Toy. Their collaboration continued with Reeves acting as the Supervising Technical Director of the first feature length, computer-animated film Toy Story.

Related Glossary Terms:

Term Source: Chapter 19 – Particle Systems and Artificial Life

Reflection mapping

In computer graphics, environment mapping, or reflection mapping, is an efficient image- based lighting technique for approximating the appearance of a reflective surface by means of a precomputed texture image. The texture is used to store the image of the distant environment surrounding the rendered object.

Several ways of storing the surrounding environment are employed. The first technique was sphere mapping, in which a single texture contains the image of the surroundings as reflected on a mirror ball. It has been almost entirely surpassed by cube mapping, in which the environment is projected onto the six faces of a cube and stored as six square textures or unfolded into six square regions of a single texture.

Related Glossary Terms: Environment mapping, Radiosity

Term Source: Chapter 5 – Cornell and NYIT

Refraction

Refraction is the phenomenon when a wave changes direction due to a change in speed of the wave, most notably in response to the wave traveling from one medium to another. This is most commonly discussed in reference to the change in the path of a light beam, but affects other waves such as sound as well.

The rule which describes this change in direction is known as Snell’s Law, which says that the proportion of the sines of the angles are equal to the inverse proportion of the indices of refraction and also to the proportion of the velocities.

Related Glossary Terms:

Term Source: Chapter 20 – CG Icons

Remote sensing

Remote sensing is the acquisition of information about an object or phenomenon, without making physical contact with the object. In modern usage, the term generally refers to the use of aerial sensor technologies to detect and classify objects on Earth (both on the surface, and in the atmosphere and oceans) by means of propagated signals (e.g. electromagnetic radiation emitted from aircraft or satellites)

Related Glossary Terms:

Term Source: Chapter 18 – Algorithms

Render farm

A render farm is high performance computer system, e.g. a computer cluster, built to render computer-generated imagery (CGI), typically for film and television visual effects.

The rendering of images is a highly parallelizable activity, as each frame usually can be calculated independently of the others, with the main communication between processors being the upload of the initial source material, such as models and textures, and the download of the finished images.

Related Glossary Terms:

Term Source:

Chapter 11 – Rhythm and Hues / Xaos

Rendering

Rendering is the process of generating an image from a model (or models in what collectively could be called a scene file), by means of computer programs.

Related Glossary Terms:

Term Source: Chapter 4 – University of Utah, Chapter 4 – The Ohio State University

Rendering equation

The rendering equation is an integral equation in which the equilibrium radiance leaving a point is given as the sum of emitted plus reflected radiance under a geometric optics approximation. It was simultaneously introduced into computer graphics by David Immel et al. and James Kajiya in 1986. The various realistic rendering techniques in computer graphics attempt to solve this equation.

The physical basis for the rendering equation is the law of conservation of energy. Assuming that L denotes radiance, we have that at each particular position and direction, the outgoing light (Lo) is the sum of the emitted light (Le) and the reflected light. The reflected light itself is the sum of the incoming light (Li) from all directions, multiplied by the surface reflection and cosine of the incident angle.

Related Glossary Terms:

Term Source: Chapter 19 – Global Illumination

Reynolds, Craig

Craig W. Reynolds (born March 15, 1953), is an artificial life and computer graphics expert, who created the Boids artificial life simulation in 1986. Reynolds worked on the film Tron (1982) as a scene programmer, and on Batman Returns (1992) as part of the video image crew. Reynolds won the 1998 Academy Scientific and Technical Award in recognition of “his pioneering contributions to the development of three-dimensional computer animation for motion picture production.” He is the author of the OpenSteer library.

Related Glossary Terms:

Term Source: Chapter 6 – Information International Inc. (Triple-I)

Rig removal (wire removal)

A post production technique that is used to remove elements of an image or sequence that were needed during the principle photography, but must be taken out for the finished shot.

For example, a production technique called a “wire gag” is used where the talent is fitted with wires to either assist him to jump, fall or otherwise move in a non-normal way, or as a safety feature to save him from injury or death.

Wires are often also used for explosions. An explosion that would blow the extras into the air is not possible, so wire harnesses are added to the on-screen talent and they are yanked away from the explosion as or before it takes place.

Another example similar to wire removal is rig removal. A rig is any kind of device used on the set to hold up an item up for filming, or items in a scene that can’t be eliminated before the shot. After shooting, it must then be removed from the scene.

The post process requires replacing the scene including the rig or wire with a clean view. It can be a clean background frame for the area covered by the offending item (clean plate) and may also require a matte painting if a clean plate can’t be provided.

Related Glossary Terms:

Term Source: Chapter 6 – Pacific Data Images (PDI)

RISC

Reduced instruction set computing, or RISC, is a CPU design strategy based on the insight that simplified (as opposed to complex) instructions can provide higher performance if this simplicity enables much faster execution of each instruction. A computer based on this strategy is a reduced instruction set computer also called RISC.

Related Glossary Terms:

Term Source: Chapter 15 – Apollo / Sun / SGI

Roberts, Lawrence

Lawrence G. Roberts designed and managed the first packet network, the ARPANET (the precursor to the Internet). At that time, in 1967, Dr. Roberts became the Chief Scientist of ARPA taking on the task of designing, funding, and managing the radically new communications network concept of packet switching. Since then Dr. Roberts has founded five startups; Telenet, NetExpress, ATM Systems, Caspian Networks, and Anagran.

Roberts wrote the first algorithm to eliminate hidden or obscured surfaces from a perspective picture. In 1965, Roberts implemented a homogeneous coordinate scheme for transformations and perspective. His solutions to these problems prompted attempts to find faster algorithms for generating hidden surfaces.

Related Glossary Terms:

Term Source: Chapter 4 – MIT and Harvard

Rosebush, Judson

Judson Rosebush is a director and producer of multimedia products and computer animation, an author, artist and media theorist. He is the founder of Digital Effects Inc. and the Judson Rosebush Company. He is the former editor of Pixel Vision magazine, the serialized Pixel Handbook, and a columnist for CD-ROM Professional magazine. He has worked in radio and TV, film and video, sound, print, and hypermedia, including CD-ROM and the Internet. He has been an ACM National Lecturer since the late 1980s and is a recipient of its Distinguished Speaker Award.

Related Glossary Terms:

Term Source: Chapter 6 – Digital Effects

Rosendahl, Carl

Carl graduated with a BSEE from Stanford University in 1979 and founded Pacific Data Images in 1980. PDI became, and continues to be, one of the pioneering and most highly innovative creators of computer animation for film and television. During his 20 years of leading the organization, PDI produced over 700 commercials, worked on visual effects for over 70 feature films and, in partnership with DreamWorks SKG, produced the hit animated film “Antz” and the Academy Award winning “Shrek.” Carl received multiple Emmy Awards and in 1998 was recognized with a Technical Achievement Academy Award for PDI’s contributions to modern filmmaking. In early 2000 he sold PDI to DreamWorks SKG, where the company continues to develop and produce animated feature films, including the “Shrek” series and “Madagascar.”

Carl is currently a faculty member of Carnegie Mellon’s Entertainment Technology Center. Prior to joining Carnegie Mellon, Carl was the CEO and founder of Uth TV, a television and web outlet tapping into the exploding power of youth voice and digital storytelling.

From 2000 through 2002, Carl was a Managing Director at Mobius Venture Capital (formerly Softbank Venture Capital) where he focused on investments in the technology and media space.

Carl is also active with a number of non-profit organizations and was a founding board member of the Visual Effects Society (VES) in 1995 and served as the Chair of the Society’s Board of Directors from 2004 through 2006.

Related Glossary Terms:

Term Source: Chapter 6 – Pacific Data Images (PDI)

Rotoscoping

to rotoscope is to create an animated matte indicating the shape of an object or actor at each frame of a sequence, as would be used to composite a CGI element into the background of a live-action shot. 2. Historically, a rotoscope was a kind of projector used to create frame-by-frame alignment between filmed live-action footage and hand-drawn animation. Mounted at the top of an animation stand, a rotoscope projected filmed images down through the actual lens of the animation camera and onto the page where animators draw and compose images.

Related Glossary Terms: Motion capture

Term Source: Chapter 6 – Bo Gehring and Associates

Run length encoding

Run-length encoding (RLE) is a very simple form of data compression in which runs of data (that is, sequences in which the same data value occurs in many consecutive data elements) are stored as a single data value and count, rather than as the original run. This is most useful on data that contains many such runs: for example, simple graphic images such as icons, line drawings, and animations. It is not useful with files that don’t have many runs as it could greatly increase the file size.

RLE may also be used to refer to an early graphics file format supported by CompuServe for compressing black and white images, but was widely supplanted by their later Graphics Interchange Format

Related Glossary Terms: Raster-scanned

Term Source: Chapter 4 – University of Utah, Chapter 4 – The Ohio State University

S

SAGE

The Semi-Automatic Ground Environment (SAGE) was the Cold War operator environment created for the automated air defense (AD) of North American and by extension, the name of the associated network of radars, computer systems, and aircraft command and control equipment (“SAGE Defense System”)

Related Glossary Terms:

Term Source:

Chapter 2 – Whirlwind and SAGE

Sandin, Dan

Daniel J. Sandin (born 1942) is a video and computer graphics artist/researcher. He is a Professor Emeritus of the School of Art & Design, University of Illinois at Chicago, and Co- director of the Electronic Visualization Laboratory at the University of Illinois at Chicago. He is an internationally recognized pioneer in computer graphics, electronic art and visualization.

Related Glossary Terms: MOOG synthesizer

Term Source: Chapter 5 – Illinois-Chicago and University of Pennsylvania

Scanline rendering

Scanline rendering is an algorithm for visible surface determination, in 3D computer graphics, that works on a row-by-row basis rather than a polygon-by-polygon or pixel-by- pixel basis. All of the polygons to be rendered are first sorted by the top y coordinate at which they first appear, then each row or scan line of the image is computed using the intersection of a scan line with the polygons on the front of the sorted list, while the sorted list is updated to discard no-longer-visible polygons as the active scan line is advanced down the picture.

Related Glossary Terms:

Term Source:

Schure, Alexander

Alexander Schure founded the New York Institute of Technology (NYIT) in 1955. He also served as the Chancellor of Nova Southeastern University (NSU) from 1970 until 1985.

Schure was an early and decisive champion of computer animation. For almost five years, NYIT gave research funding and a home to the brain trust that would evolve into Pixar Animation Studios. In November, 1974, Schure hired recent University of Utah doctoral graduate Edwin Catmull to direct NYIT's fledgling computer graphics lab. The core technical team included computer animation pioneers Catmull, Alvy Ray Smith, David DiFrancesco, Ralph Guggenheim, Jim Blinn, and Jim Clark.

Related Glossary Terms:

Term Source: Chapter 5 – Cornell and NYIT

Schwartz, Lillian

Lillian F. Schwartz is an American artist who is known for being a creator of 20th century computer-developed art. One notable work she created is Mona Leo, where she morphed the image of a Leonardo da Vinci self-portrait with the Mona Lisa. She made one of the first digitally created films to be shown as a work of art, Pixillation, which shows diagonal red squares and other shapes such as cones and pyramids on black on white backgrounds. She worked in the early stages of her career with Bell Laboratories, developing mixtures of sound, video, and art. Afterwards, during the 1980s, Schwartz experimented with manipulating artwork images using computer technology and creating artwork of her own.

Related Glossary Terms:

Term Source: Chapter 9 – Lillian Schwartz

Scientific visualization

Scientific visualization (also spelled scientific visualisation) is an interdisciplinary branch of science according to Friendly "primarily concerned with the visualization of three- dimensional phenomena (architectural, meteorological, medical, biological, etc.), where the emphasis is on realistic renderings of volumes, surfaces, illumination sources, and so forth, perhaps with a dynamic (time) component". It is also considered a branch of computer science that is a subset of computer graphics. The purpose of scientific visualization is to graphically illustrate scientific data to enable scientists to understand, illustrate, and glean insight from their data.

Michael Friendly (2008). "Milestones in the history of thematic cartography, statistical graphics, and data visualization"

Related Glossary Terms: Modular visualization environments, Visualization, Volume visualization

Term Source: Chapter 18 – Introduction

Sims, Karl

Karl Sims is a computer graphics artist and researcher, who is best known for using particle systems and artificial life in computer animation. Sims received a B.S. from MIT in 1984, and a M.S. from the MIT Media Lab in 1987. He worked for Thinking Machines as an artist- in-residence, for Whitney-Demos Production as a researcher, and co-founded Optomystic. He currently heads GenArts, a Cambridge, Massachusetts company that develops special effects plugins used by motion picture studios.

Related Glossary Terms:

Term Source: Chapter 19 – Particle Systems and Artificial Life

Sketchpad

Sketchpad was a revolutionary computer program written by Ivan Sutherland in 1963 in the course of his PhD thesis, for which he received the Turing Award in 1988. It helped change the way people interact with computers. Sketchpad is considered to be the ancestor of modern computer-aided drafting (CAD) programs as well as a major breakthrough in the development of computer graphics in general. For example, the Graphic User Interface was derived from the Sketchpad as well as modern object oriented programming.

Related Glossary Terms:

Term Source: Chapter 3 – Work continues at MIT

Slit-scan

Originally used in static photography to achieve blurriness or deformity, the slit-scan technique was perfected for the creation of spectacular animations. It enables the cinematographer to create a psychedelic flow of colors. It was adapted for film by Douglas Trumbull during the production of Stanley Kubrick's 2001: A Space Odyssey and used extensively in the "stargate" sequence.

This type of effect was revived in other productions, for films and television alike. For instance, slit-scan was used by Bernard Lodge to create the Doctor Who title sequences for Jon Pertwee and Tom Baker used between December 1973 and January 1980. Slit-scan was also used in Star Trek: The Next Generation to create the "stretching" of the starship Enterprise-D when it engaged warp drive. Due to the expense and difficulty of this technique, the same three warp-entry shots, all created by Industrial Light and Magic for the series pilot, were reused throughout the series virtually every time the ship went into warp.

Related Glossary Terms:

Term Source: Chapter 6 – Robert Abel and Associates

Solids modeling

Solid modeling (or modeling) is a consistent set of principles for mathematical and computer modeling of three-dimensional solids. Solid modeling is distinguished from related areas of geometric modeling and computer graphics by its emphasis on physical fidelity. Together, the principles of geometric and solid modeling form the foundation of computer-aided design and in general support the creation, exchange, visualization, animation, interrogation, and annotation of digital models of physical objects.

Related Glossary Terms: B-rep, CSG

Term Source: Chapter 6 – MAGI

Spacewar

Spacewar! is one of the earliest known digital computer games. It is a two-player game, with each player taking control of a spaceship and attempting to destroy the other. A star in the centre of the screen pulls on both ships and requires maneuvering to avoid falling into it. In an emergency, a player can enter hyperspace to return at a random location on the screen, but only at the risk of exploding if it is used too often.

Steve “Slug” Russell, Martin “Shag” Graetz, and Wayne Wiitanen of the fictitious “Hingham Institute” conceived of the game in 1961, with the intent of implementing it on a DEC PDP-1 at the Massachusetts Institute of Technology.

Related Glossary Terms:

Term Source: Chapter 3 – TX-2 and DEC

Specular reflection

Specular reflection is the mirror-like reflection of light (or of other kinds of wave) from a surface, in which light from a single incoming direction (a ray) is reflected into a single outgoing direction. Such behavior is described by the law of reflection, which states that the direction of incoming light (the incident ray), and the direction of outgoing light reflected (the reflected ray) make the same angle with respect to the surface normal, thus the angle of incidence equals the angle of reflection.

Related Glossary Terms: Diffuse reflection, Lambertian

Term Source:

Splatting

In direct volume rendering, Splatting is a technique which trades quality for speed. Here, every volume element is splatted, as Lee Westover said, like a snow ball, on to the viewing surface in back to front order. These splats are rendered as disks whose properties (color and transparency) vary diametrically in normal (Gaussian) manner. Flat disks and those with other kinds of property distribution are also used depending on the application.

Related Glossary Terms: Volume Rendering

Term Source: Chapter 18 – Volumes

Sprite

In computer graphics, a sprite is a two-dimensional image or animation that is integrated into a larger scene. Initially used to describe graphical objects handled separately from the memory bitmap of a video display, the term has since been applied more loosely to refer to various elements of graphical overlays.

Originally, sprites were a method of integrating unrelated bitmaps so that they appeared to be part of the normal bitmap on a screen, such as creating an animated character that can be moved on a screen without altering the data defining the overall screen. Such sprites can be created by either electronic circuitry or software. In circuitry, a hardware sprite is a hardware construct that employs custom DMA channels to integrate visual elements with the main screen in that it super-imposes two discrete video sources. Software can simulate this through specialized rendering methods.

As three-dimensional graphics became more prevalent, the term was used to describe a technique whereby flat images are seamlessly integrated into complicated three- dimensional scenes, often as textures on 2D or 3D objects whose normal always faced the camera.

Related Glossary Terms:

Term Source: Chapter 15 – Influence of Games

Stereoscopic display

Stereoscopy (also called stereoscopics or 3-D imaging) refers to a technique for creating or enhancing the illusion of depth in an image by presenting two offset images separately to the left and right eye of the viewer. These two-dimensional images are then combined in the brain to give the perception of 3-D depth. Besides the technique of free viewing, which must be learned by the viewer, three strategies have been used to mechanically present different images to each eye: have the viewer wear eyeglasses to combine separate images from two offset sources, have the viewer wear eyeglasses to filter offset images from a single source separated to each eye, or have the light source split the images directionally into the viewer’s eyes (no glasses required; known as Autostereoscopy)

Related Glossary Terms: Head-mounted displays

Term Source: Chapter 17 – Virtual Reality

Stop-Motion

Stop motion (also known as stop frame) is an animation technique to make a physically manipulated object appear to move on its own. The object is moved in small increments between individually photographed frames, creating the illusion of movement when the series of frames is played as a continuous sequence. Dolls with movable joints or clay figures are often used in stop motion for their ease of repositioning. Stop motion animation using clay is called clay animation or "clay mation"

Related Glossary Terms:

Term Source: Chapter 14 – CGI and Effects in Films and Music Videos

Storage tube

An electron tube in which information is stored as charges for a predetermined time

Related Glossary Terms: Cathode Ray Tube, Vacuum tube

Term Source: Chapter 1 – Electronic devices

Storage tube vector graphics

a storage tube is a special monochromatic CRT whose screen has a kind of 'memory' (hence the name): when a portion of the screen is illuminated by the CRT's electron gun, it stays lit until a screen erase command is given. Thus, screen update commands need only be sent once and this allows the use of a slower data connection, typically serial—a feature very well adapted to computer terminal use in 1960s and 1970s computing. The two main advantages were:

▪ Very low bandwidth needs compared to vector graphics displays, thus allowing much longer cable distances between computer and terminal

▪ No need for display-local RAM (as in modern terminals), which was prohibitively expensive at the time.

Related Glossary Terms:

Term Source: Chapter 3 – Other output devices

Supercomputing

A powerful computer that can process large quantities of data of a similar type very quickly

Related Glossary Terms:

Term Source: Chapter 4 – Bell Labs and Lawrence Livermore

Surface of revolution

A surface of revolution is a surface in Euclidean space created by rotating a curve (the generatrix) around a straight line in its plane (the axis).

Related Glossary Terms:

Term Source: Chapter 20 – CG Icons

Sutherland, Ivan

Ivan Edward Sutherland (born May 16, 1938)[1] is an American computer scientist and Internet pioneer. He received the Turing Award from the Association for Computing Machinery in 1988 for the invention of Sketchpad, an early predecessor to the sort of graphical user interface that has become ubiquitous in personal computers. He was a professor at Utah when he co-founded computer graphics company Evans and Sutherland (E&S) in 1968.

Related Glossary Terms:

Term Source: Chapter 3 – Work continues at MIT

Synthespians

A virtual human or digital clone is the creation or re-creation of a human being in image and voice using computer-generated imagery and sound. The process of creating such a virtual human on film, substituting for an existing actor, is known, after a 1992 book, as Schwarzeneggerization, and in general virtual humans employed in movies are known as synthespians, virtual actors, vactors, cyberstars, or “silicentric” actors.

Related Glossary Terms:

Term Source: Chapter 11 – Kleiser Walczak Construction Company

T

Taylor, Richard

Richard Taylor is a director, production designer and special effects supervisor. He was the Visual Effects Supervisor for the movie, TRON and was responsible for organizing the effects and designing the film's graphics and costumes, as well as blending the live-action footage with the CGI animation.

He began his career as an artist and holds a BFA in painting & drawing from the University of Utah. After graduation he co-founded Rainbow Jam, a multi-media light show and graphics company which gave concert performances in tandem with top musical groups such as The Grateful Dead, Santana, Led Zeppelin and Jethro Tull. In 1971 he received the Cole Porter Fellowship from USC where he earned an MFA in Print Making and Photography. In 1973, Richard joined Robert Abel and Associates. He directed many award-winning television commercials and received four Clio awards for his work on the 7UP Bubbles "See the Light", 7UP "Uncola" and the Levi's "Trademark" commercials. During his tenure at the Abel Studio he created many of the on air graphics for ABC television and designed new theatrical logos for CBS Theatrical Films and Columbia Pictures.

He supervised the design and construction of the miniatures and designed and directed special effects sequences for Paramount's' STAR TREK, THE MOTION PICTURE. In 1978, he became the creative director at Information International Inc. (III). While at III Richard directed many of the first computer generated commercials and designed and directed the special effects for the feature film "LOOKER" which was written and directed by Michael Crichton.

In 1981 Richard became the Special Effects Director of Walt Disney's TRON, the innovative film that introduced America to the world of computer simulation. Following TRON, Richard opened the West Coast office of Magi Synthavision, the computer animation studio that along with III generated the computer simulation scenes for Tron. One of the first commercials Richard directed at Magi, "Worm War One" won the first Clio for Computer Animation.

He was also at Apogee Production Inc. Lee Lacy & Associates, Image Point Productions, Dryer/Taylor Productions, and Rhythm & Hues Studios.

Related Glossary Terms:

Term Source: Chapter 6 – MAGI

Terzopoulos, Demetri

Demetri Terzopoulos is a professor at the University of California, Los Angeles, where he directs the UCLA Computer Graphics and Vision Laboratory. After graduation from MIT, he was a research scientist at the MIT Artificial Intelligence Lab, then joined the University of Toronto His published work is in computer vision, computer graphics, medical image analysis, computer-aided design, and artificial intelligence/life. Professor Terzopoulos is the recipient of a 2005 Academy Award for Technical Achievement from the Academy of Motion Picture Arts and Sciences for his pioneering work on realistic cloth simulation for motion pictures. In 2007, he was the inaugural recipient of the Computer Vision Significant Researcher Award from the IEEE "For his pioneering and sustained research on Deformable Models and their applications".

Related Glossary Terms:

Term Source: Chapter 19 – Physical-based Modeling

Tesler, Larry

Larry Tesler is a computer scientist working in the field of human-computer interaction. Tesler studied computer science at Stanford and worked for a time at the Stanford Artificial Intelligence Laboratory. From 1973 to 1980, he was at Xerox PARC, where, among other things, he worked on the Gypsy word processor and Smalltalk. Copy and paste was first implemented in 1973-1976 by Tesler while working on the programming of Smalltalk-76 at Xerox Palo Alto Research Center.

In 1980, Tesler moved to Apple Computer, where he held various positions, including Vice President of AppleNet, Vice President of the Advanced Technology Group, and Chief Scientist. He worked on the Lisa team, and was enthusiastic about the development of the Macintosh as the successor to the Lisa. In 1985, Tesler worked with Niklaus Wirth to add object-oriented language extensions to the Pascal programming language, calling the new language Object Pascal. He also was instrumental in developing MacApp, one of the first class libraries for application development. Eventually, these two technologies became shipping Apple products. Starting in 1990, Tesler led the efforts to develop the Apple Newton, initially as Vice President of the Advanced Development Group, and then as Vice President of the Personal Interactive Electronics division.

Related Glossary Terms:

Term Source: Chapter 16 – Xerox PARC

Texture Mapping

Texture mapping is a method for adding detail, surface texture (a bitmap or raster image), or color to a computer-generated graphic or 3D model. Its application to 3D graphics was pioneered by Dr Edwin Catmull in his Ph.D. thesis of 1974

Related Glossary Terms: Multi-texturing

Term Source:

Transistor

A semiconductor device that amplifies, oscillates, or switches the flow of current between two terminals by varying the current or voltage between one of the terminals and a third: although much smaller in size than a vacuum tube, it performs similar functions without requiring current to heat a cathode.

Related Glossary Terms: Vacuum tube

Term Source: Chapter 1 – Electronic devices

Troubetskoy, Eugene

Dr. Eugene Troubetzkoy had a PhD in Theoretical Physics from Columbia and worked as a nuclear physicist to create computer simulations of nuclear particle behavior. He is credited with helping develop the amazing technique for capturing 3D scenes with remarkable realism called Raytrace rendering. He was one of the founders of Blue Sky.

Related Glossary Terms:

Term Source: Chapter 6 – MAGI

Turnkey

a computer system purchased from hardware and software vendors, customized and put in working order by a firm that then sells the completed system to the client that ordered it.

Related Glossary Terms:

Term Source:

Chapter 10 – Auto-trol / Applicon / ComputerVision

Tweening

Short for in-betweening, the process of generating intermediate frames between two images to give the appearance that the first image evolves smoothly into the second image. Tweening is a key process in all types of animation, including computer animation. Sophisticated animation software enables you to identify specific objects in an image and define how they should move and change during the tweening process.

Related Glossary Terms: Keyframe

Term Source: Chapter 8 – Introduction

U/V

Vacuum tube

1. Also called, especially British , vacuum valve . an electron tube from which almost all air or gas has been evacuated: formerly used extensively in radio and electronics.
2. A sealed glass tube with electrodes and a partial vacuum or a highly rarefied gas, used to observe the effects of a discharge of electricity passed through it.

The vacuum tube was invented by Lee de Forest in 1906. It was an improvement on the Fleming tube, or Fleming valve, introduced by John Ambrose Fleming two years earlier. The vacuum tube contains three components: the anode, the cathode and a control grid. It could therefore control the flow of electrons between the anode and cathode using the grid, and could therefore act as a switch or an amplifier.

Related Glossary Terms: Cathode Ray Tube, Transistor

Term Source: Chapter 1 – Electronic devices

Van Dam, Andy

Andries “Andy” van Dam (born 8 December 1938, Groningen) is a Dutch-born American professor of computer science and former Vice-President for Research at Brown University in Providence, Rhode Island. Together with Ted Nelson he contributed to the first hypertext system, HES in the late 1960s. He co-authored Computer Graphics: Principles and Practice along with J.D. Foley, S.K. Feiner, and John Hughes. He also co-founded the precursor of today’s ACM SIGGRAPH conference.

Related Glossary Terms:

Term Source: Chapter 5 – Other labs and NSF

Vector Graphics

Vector graphics is the use of geometrical primitives such as points, lines, curves, and shapes or polygon(s), which are all based on mathematical expressions, to represent images in computer graphics. “Vector”, in this context, implies more than a straight line.

Vector graphics is based on images made up of vectors (also called paths, or strokes) which lead through locations called control points. Each of these points has a definite position on the x and y axes of the work plan. Each point, as well, is a variety of database, including the location of the point in the work space and the direction of the vector (which is what defines the direction of the track). Each track can be assigned a color, a shape, a thickness and also a fill. This does not affect the size of the files in a substantial way because all information resides in the structure; it describes how to draw the vector.

Related Glossary Terms: Cathode Ray Tube, Raster-scanned

Term Source: Chapter 1 – Electronic devices

Videosynthesizer

A Video Synthesizer is a device that electronically creates a video signal. A video synthesizer is able to generate a variety of visual material without camera input through the use of internal video pattern generators, as seen in the still frames of motion sequences shown above. It can also accept and “clean up and enhance” or “distort” live television camera imagery. The synthesizer creates a wide range of imagery through purely electronic manipulations. This imagery is visible within the output video signal when this signal is displayed. The output video signal can be viewed on a wide range of conventional video equipment, such as TV monitors, theater video projectors, computer displays, etc.

Related Glossary Terms:

Term Source: Chapter 12 – Image West / Dolphin Productions / Ron Hays

Virtual memory

In computing, virtual memory is a memory management technique developed for multitasking kernels. This technique virtualizes a computer architecture’s various forms of computer data storage (such as random-access memory and disk storage), allowing a program to be designed as though there is only one kind of memory, “virtual” memory, which behaves like directly addressable read/write memory (RAM).

Related Glossary Terms:

Term Source: Chapter 3 – TX-2 and DEC

Virtual reality

Virtual reality (VR), is a term that applies to computer-simulated environments that can simulate physical presence in places in the real world, as well as in imaginary worlds. Most current virtual reality environments are primarily visual experiences, displayed either on a computer screen or through special stereoscopic displays, but some simulations include additional sensory information, such as sound through speakers or headphones. Some advanced, haptic systems now include tactile information, generally known as force feedback, in medical and gaming applications. Furthermore, virtual reality covers remote communication environments which provide virtual presence of users with the concepts of telepresence and telexistence or a virtual artifact (VA) either through the use of standard input devices such as a keyboard and mouse, or through multimodal devices such as a wired glove, devices such as the Polhemus, and omnidirectional treadmills.

Related Glossary Terms: Augmented reality

Term Source: Chapter 17 – Virtual Reality

Vistavision

VistaVision is a higher resolution, widescreen variant of the 35mm motion picture film format which was created by engineers at Paramount Pictures in 1954.

Paramount did not use anamorphic processes such as CinemaScope but refined the quality of their flat widescreen system by orienting the 35mm negative horizontally in the camera gate and shooting onto a larger area, which yielded a finer-grained projection print.

Related Glossary Terms:

Term Source: Chapter 11 – Kleiser Walczak Construction Company

Visualization

Visualization is any technique for creating images, diagrams, or animations to communicate a message. Visualization through visual imagery has been an effective way to communicate both abstract and concrete ideas since the dawn of man. Examples from history include cave paintings, Egyptian hieroglyphs, Greek geometry, and Leonardo da Vinci's revolutionary methods of technical drawing for engineering and scientific purposes.

Visualization today has ever-expanding applications in science, education, engineering (e.g., product visualization), interactive multimedia, medicine, etc. Typical of a visualization application is the field of computer graphics. The invention of computer graphics may be the most important development in visualization since the invention of central perspective in the Renaissance period. The development of animation also helped advance visualization.

Related Glossary Terms: Scientific visualization

Term Source: Chapter 18 – Introduction

VLSI

Very-large-scale integration (VLSI) is the process of creating integrated circuits by combining thousands of transistors into a single chip. VLSI began in the 1970s when complex semiconductor and communication technologies were being developed. The microprocessor is a VLSI device.

Related Glossary Terms:

Term Source: Chapter 15 – Apollo / Sun / SGI

Volume Rendering

In scientific visualization and computer graphics, volume rendering is a set of techniques used to display a 2D projection of a 3D discretely sampled data set.

A typical 3D data set is a group of 2D slice images acquired by a CT, MRI, or MicroCT scanner. Usually these are acquired in a regular pattern (e.g., one slice every millimeter) and usually have a regular number of image pixels in a regular pattern. This is an example of a regular volumetric grid, with each volume element, or voxel represented by a single value that is obtained by sampling the immediate area surrounding the voxel.

Related Glossary Terms: Volume visualization

Term Source: Chapter 18 – Volumes

Volume visualization

Volume visualization (Kaufman, 1992) – a direct technique for visualizing volume primitives without any intermediate conversion of the volumetric data set to surface representation.

Related Glossary Terms: Volume Rendering

Term Source: Chapter 18 – Introduction

Voxels

A voxel (volumetric pixel or Volumetric Picture Element) is a volume element, representing a value on a regular grid in three dimensional space. This is analogous to a pixel, which represents 2D image data in a bitmap (which is sometimes referred to as a pixmap). As with pixels in a bitmap, voxels themselves do not typically have their position (their coordinates) explicitly encoded along with their values. Instead, the position of a voxel is inferred based upon its position relative to other voxels (i.e., its position in the data structure that makes up a single volumetric image). In contrast to pixels and voxels, points and polygons are often explicitly represented by the coordinates of their vertices. A direct consequence of this difference is that polygons are able to efficiently represent simple 3D structures with lots of empty or homogeneously filled space, while voxels are good at representing regularly sampled spaces that are non-homogeneously filled.

Related Glossary Terms: Pixel

Term Source: Chapter 18 – Volumes

W

Walker, John

John Walker is a computer programmer and a co-founder of the computer-aided design software company Autodesk, and a co-author of early versions of AutoCAD, a product Autodesk originally acquired from programmer Michael Riddle.

Related Glossary Terms:

Term Source: Chapter 8 – Autodesk/Kinetix/Discreet

Warnock, John

John Warnock is best known as the co-founder with Charles Geschke of Adobe Systems Inc., the graphics and publishing software company. Warnock has pioneered the development of graphics, publishing, Web and electronic document technologies that have revolutionized the field of publishing and visual communications. He was part of the pioneering work at the University of Utah while a graduate student there.

In 1976, while Warnock worked at Evans & Sutherland, the computer graphics company, the concepts of the PostScript language were seeded. Prior to co-founding Adobe, Warnock worked at Xerox's Palo Alto Research Center (Xerox PARC). Unable to convince Xerox management of the approach to commercialize the InterPress graphics language for controlling printing, he left Xerox to start Adobe in 1982. At their new company, they developed an equivalent technology, PostScript, from scratch, and brought it to market for Apple's LaserWriter in 1984.

In his 1969 doctoral thesis, Warnock invented the Warnock algorithm for hidden surface determination in computer graphics. It works by recursive subdivision of a scene until areas are obtained that are trivial to compute. It solves the problem of rendering a complicated image by avoiding the problem. If the scene is simple enough to compute then it is rendered; otherwise it is divided into smaller parts and the process is repeated.

In the Spring of 1991, Warnock outlined a system called "Camelot" that evolved into the Portable Document Format (PDF) file-format. The goal of Camelot was to "effectively capture documents from any application, send electronic versions of these documents anywhere, and view and print these documents on any machines".

One of Adobe's popular typefaces, Warnock, is named after him.

Related Glossary Terms:

Term Source: Chapter 16 – Xerox PARC

Wedge, Chris

Chris Wedge received his BFA in Film from State University of New York at Purchase in Purchase, New York in

1981, and subsequently earned his MA in computer graphics and art education at the Ohio State University. He has taught animation at the School of Visual Arts in New York City where he met his future film directing partner, Carlos Saldanha. Wedge is co-founder and Vice President of Creative Development at Blue Sky Studios and is the owner of WedgeWorks, a film production company founded by Wedge.

In 1982, Wedge worked for MAGI/SynthaVision, where he was a principal animator on the Disney film Tron, credited as a scene programmer. Some of his other works include Where the Wild Things Are (1983), Dinosaur Bob, George Shrinks, and Santa Calls. In 1998, he won an Academy Award for the short animated film, Bunny. He is also the voice of Scrat in the Ice Age film series, performing the character's "squeaks and squeals".[2]

Related Glossary Terms:

Term Source: Chapter 6 – MAGI

Wein, Marceli

NRC scientists Nestor Burtnyk and Marceli Wein, were recently honored at the Festival of Computer Animation in Toronto. They were recognized as Fathers of Computer Animation Technology in Canada. Burtnyk, who began his career with NRC in 1950, started Canada's first substantive computer graphics research project in the 1960s. Wein, who joined this same project in 1966, had been exposed to the potential of computer imaging while studying at McGill. He teamed up with Burtnyk to pursue this promising field.

One of their main contributions was the Academy Award nominated film "Hunger/La Faim" (produced by the National Film Board of Canada) using their famous key-frame animation approach and system.

Related Glossary Terms: Burtnyk, Nestor

Term Source: Chapter 4 – JPL and National Research Council of Canada

Whirlwind

The Whirlwind computer was developed at the Massachusetts Institute of Technology. It is the first computer that operated in real time, used video displays for output, and the first that was not simply an electronic replacement of older mechanical systems. Its development led directly to the United States Air Force's Semi-Automatic Ground Environment (SAGE) system, and indirectly to almost all business computers and minicomputers in the 1960s.

Related Glossary Terms:

Term Source: Chapter 2 – Whirlwind and SAGE

Whitney, John Sr.

John Whitney, Sr. (April 8, 1917 – September 22, 1995) was an American animator, composer and inventor, widely considered to be one of the fathers of computer animation.

Related Glossary Terms:

Term Source: Chapter 2 – Programming and Artistry

Whitted, Turner

Turner Whitted is senior researcher and area manager at Microsoft Research. Whitted is an Association for Computing Machinery fellow and a member of the National Academy of Engineering. Whitted has served as a distinguished lecturer in the Rice University Department of Electrical and Computer Engineering. He is on the editorial boards of IEEE Computer Graphics and Applications and Association for Computing Machinery Transactions on Graphics. Whitted is credited with being the “father” of ray tracing, as exemplified with his famous short movie The Compleat Angler.

Related Glossary Terms:

Term Source: Chapter 5 – Cal Tech and North Carolina State

WIMP

In human–computer interaction, WIMP stands for “windows, icons, menus, pointer”, denoting a style of interaction using these elements of the user interface. It was coined by Merzouga Wilberts in 1980. Other expansions are sometimes used, substituting “mouse” and “mice” or “pull-down menu” and “pointing”, for menu and pointing, respectively

Related Glossary Terms: GUI (Graphical User Interface)

Term Source: Chapter 16 – Apple Computer

Wireframe

A wire frame model is a visual presentation of a three dimensional or physical object used in 3D computer graphics. It is created by specifying each edge of the physical object where two mathematically continuous smooth surfaces meet, or by connecting an object’s constituent vertices using straight lines or curves. The object is projected onto the computer screen by drawing lines at the location of each edge.The term wireframe comes from designers using metal wire to represent the 3 dimensional shape of solid objects.3D wireframe allows to construct and manipulate solids and solid surfaces.3D solid modeling technique efficiently draws high quality representation of solids than the conventional line drawing.

Related Glossary Terms:

Term Source: Chapter 15 – Graphics Accelerators

Witkin, Andrew

Andrew P. Witkin was an American computer scientist who made major contributions in computer vision and computer graphics. Witkin worked briefly at SRI International on computer vision, then moved to Schlumberger's Fairchild Laboratory for Artificial Intelligence Research, later Schlumberger Palo Alto Research, where he led research in computer vision and graphics; here he invented scale-space filtering, scale-space segmentation and Active Contour Models. From 1988 to 1998 he was a professor of computer science, robotics, and art at Carnegie-Mellon University, after which he joined Pixar in Emeryville, California. At CMU and Pixar, with his colleagues he developed the methods and simulators used to model and render natural-looking cloth, hair, water, and other complex aspects of modern computer animation. Witkin received the ACM SIGGRAPH Computer Graphics Achievement Award in 2001 "for his pioneering work in bringing a physics based approach to computer graphics." As senior scientist at Pixar Animation Studios, Witkin received a technical academy award in 2006 for "pioneering work in physically-based computer-generated techniques used to simulate realistic cloth in motion pictures.

Related Glossary Terms:

Term Source: Chapter 19 – Physical-based Modeling

Wozniak, Steve

Steve Wozniak (the Woz) is an American computer engineer and programmer who founded Apple Computer (now Apple Inc.) with Steve Jobs and Ronald Wayne. Wozniak is the inventor of the Apple I computer and its successor, the Apple II computer, which contributed significantly to the microcomputer revolution.

Related Glossary Terms:

Term Source: Chapter 16 – Apple Computer

WYSIWYG

an acronym for What You See Is What You Get. The term is used in computing to describe a system in which content (text and graphics) displayed onscreen during editing appears in a form closely corresponding to its appearance when printed or displayed as a finished product, which might be a printed document, web page, or slide presentation.

Related Glossary Terms:

Term Source: Chapter 16 – Xerox PARC

X/Y/Z

Zajac, Edward

Zajac is recognized internationally as the first person in history to create computer animation, at first as a visual means to share with his colleagues the positions of satellites as they orbit Earth. Appearing antiquated and simple in today's world, his early computer- animated films produced at Bell Labs won much acclaim at the time, and awards in the U.S. and oversees, and are considered classics today.

Related Glossary Terms:

Term Source: Chapter 4 – Bell Labs and Lawrence Livermore

Afterword

The *Road to Point Reyes* was developed by Lucasfilm Computer Graphics Project personnel (Alvy Ray Smith, Rob Cook, Loren Carpenter, Bill Reeves, Tom Porter and Davis Salesin) in 1983, and was featured as the title page image for the SIGGRAPH 83 conference proceedings. It was exhibited at the Computer Museum in Boston in 1984-1985. The goal at Lucasfilm was to create an image of the complexity and resolution to show that CG technology could be used effectively in the movie-making process. The image (4096×4096 at 24 bits per pixel) has been called “a movie in a frame”, and showed the application of significant advances in the CG technology that were being perfected at Lucasfilm, including advanced 3D modeling, fractals, particle systems, “graftals”, compositing, texture mapping, advanced lighting and atmospheric effects, water and water effects, and graphics hardware and systems.

The image is a tribute to the researchers at Lucasfilm that subscribed to the philosophy that permeated the computer graphics discipline, that **advances in technology should be shared with peers in the interest of achieving the long term goals of creating better synthetic imagery**.