# 1
# Historical Notes

We start our long voyage in computer graphics with a short survey of the history of this field and the names of some of its pioneers. This is followed by a detailed list of several types of available resources.

## 1.1 Historical Survey

The term "Computer Graphics" was coined in 1960 by William Fetter, to describe what he was doing at Boeing at the time, but the history of computer graphics started in the early 1950s. (In 1950, Ben Laposky, a mathematician and artist from Iowa, created the first graphic images generated by an electronic machine. These were Lissajous figures that he dubbed oscillons and displayed on an oscilloscope, which is an analog device.) This is very early, considering that the history of the modern digital electronic computer itself began in the late 1940s. However, because of high hardware prices, the field was originally the domain of a few lucky individuals, and it was only in the 1970s that it started growing fast and eventually became the vast discipline that we know today. Here is a short chronology.

A curious note. For many years, the CRT (Cathode Ray Tube) was the main graphics output device. History tells us that this device was invented in 1885 and became practical in 1897, when Ferdinand Braun in Germany developed a CRT with a fluorescent screen. The screen would emit a visible light when struck by a beam of electrons and the device became known as the cathode ray oscilloscope.

By 1951 the Whirlwind computer installed at MIT had two 16-inch graphics displays (actually, modified oscilloscopes). Surprisingly, there were no immediate users. (This computer was part of the Whirlwind project, an electronic controller for a United States Navy flight simulator to train bomber crews. The project started in 1945.)

Plotters (Section 26.13) came into use as graphics output devices in 1953.

D. Salomon, *The Computer Graphics Manual*, Texts in Computer Science,
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In 1955, the SAGE (Semi-Automatic Ground Environment) air defense system started its operations. It used vector-scanned monitors as its main output and light pens as its input devices.

Digital Equipment Corporation (DEC) was founded in 1957. It started making minicomputers that were later used in the early development of computer graphics.

Light pens (Section 26.2.3) came into wide use in 1958, the same year as the first microfilm recorder.

In 1959, a partnership of General Motors and IBM produced the first piece of drawing software, the DAC-1 (Design Augmented by Computers). Users could input the three-dimensional description of a car, view the car in perspective, and rotate it.

It was in the 1960s that the field got its first big push. In 1961, Ivan Sutherland developed Sketchpad, a drawing program, as his Ph.D. thesis at MIT. Sketchpad used a light pen as its main input device and an oscilloscope (modified to do vector scan) as its output device. The first version handled two-dimensional figures only, and was later extended to draw, transform, and project three-dimensional objects, and also to perform engineering calculations such as stress analysis. One important feature of Sketchpad was its ability to recognize constraints. The user could draw, for example, a rough square, then instruct the software to convert it to an exact square. Another feature was the ability to deal with objects, not just individual curve segments. The user could build an object out of segments, then ask the software to scale it. Because of his pioneering work, Sutherland is often acknowledged as the grandfather of interactive computer graphics and graphical user interfaces.

There are many Internet resources with information about and images of Sketchpad, see, for example, [sketchpad.wiki 10].

> I just need to figure out how things work.
> —Ivan Sutherland.

At about the same time, Steven Russell, another MIT student, developed the first video game, *Spacewar!* This program was written for the PDP-1 and was later used by DEC salespersons to demonstrate that minicomputer.

In 1963, the first computer-generated film, titled *Simulation of a two-giro gravity attitude control system*, was created by Edward E. Zajac at Bell laboratories. Others at Bell, Boeing, and Lawrence Radiation Laboratory followed soon with more films.

The first digitizer (Section 26.8), the RAND tablet, appeared in 1964.

Also in 1964, the first commercially available graphics computer, the IBM 2250 Graphics Display Unit, was announced as part of the historically-important System/360. Like many old displays, the 2250 employed vector graphics on a $1024 \times 1024$ CRT that was refreshed up to 40 times per second. Characters were constructed of short line segments and any characters and symbols could be displayed. Like any vector-scan graphics device, the refresh time became longer as more and more symbols were displayed, and the display eventually started to flicker. The 2250 used a light pen as an interactive input device.

In the mid-1960s, interest in computer graphics was picking up. More and more companies—such as TRW, Lockheed-Georgia, General Electric, and Sperry Rand—became active in the graphics field. At about the same time, David Evans and Ivan Sutherland founded their company which made, among other things, vector-scan dis-

plays. Those displays are historically important since they gave a tremendous boost to computer graphics throughout the 1960s.

In 1966, Sutherland developed the first three-dimensional head-mounted display (HMD, section 26.14.2). It displayed a stereoscopic pair of wire-frame images. This device was rediscovered in the 1980s and is commonly used today in virtual-reality applications.

In the late 1960s, both Sutherland and Evans were invited to develop a program in computer science at the University of Utah in Salt Lake City. Computer graphics quickly became the specialty of their department, and for years maintained its position as the primary world center for this field. Many important methods and techniques were developed at the UU computer graphics lab, among them illumination models, hidden-surface algorithms, and basic rendering techniques for polygonal surfaces. Names of UU students such as Phong Bui-Tuong, Henri Gouraud, James Blinn, and Ed Catmull are associated with many basic algorithms still in use today. Several accounts of computer graphics persons and projects at UU can be found on the Internet at URL
http://www.cs.utah.edu/school/history/.

Computer graphics in the 1960s was out of the reach of most computer users because the special graphics hardware was expensive. There were no personal computers or workstations. Users had to pay for mainframe time by the second or buy expensive minicomputers. Display monitors used vector scan and were black and white. The result was that few computer professionals could develop computer graphics techniques and algorithms and the software was noninteractive and non-portable.

The advent of the microprocessor, in the mid-1970s, was another factor in the rapid progress of computer graphics. Personal computers appeared on the market and suddenly anyone could afford to own a computer. This encouraged the formation of small companies that developed computer animation, mostly to be used in television commercials. Names such as Abel and Associates, Information International Inc., Digital Effects, and Systems Simulation Ltd. became well known and produced short pieces that demonstrated dazzling effects.

SIGGRAPH, the Special Interest Group on Computer Graphics (part of the ACM), was formed in 1969 and has grown in size and importance as the field of computer graphics expanded. The first of the many famous SIGGRAPH conferences was held in 1973. It attracted 1200 attendees and later conferences boasted as many as 30,000 participants and hundreds of exhibitors.

The famous Utah teapot (see Page 704 and Plate Z.6) was constructed in 1975. This is perhaps the best known three-dimensional model in computer graphics. The original teapot this model is based on is displayed at the Computer Museum in Boston.

During the 1970s, activity in basic computer graphics research started moving from UU first to NYIT, the New York Institute of Technology, then to Lucasfilm. Computer animation and computer painting were two topics seriously developed at those places.

The technique of (and hardware for) raster scan was developed in the 1970s by Richard Shoupe at Xerox Palo Alto Research Center (PARC). Workers in the field soon realized the advantages of raster scan and the word "pixel" entered the field of computer graphics.

Like any other mature discipline, computer graphics eventually got its first periodic publication. *Computer Graphics World* started carrying news and reviews in late 1977.

Fractals, developed by Benoît Mandelbrot in the 1960s and 1970s, were applied to computer graphics in the late 1970s by Loren Carpenter and others.

It was in the 1980s that personal computers, most notably, the Macintosh and Amiga, employed graphical user interfaces (GUI) to interact with the user and to graphically display results with symbols, icons, and pictures, rather than text. The term "multimedia," which originated around 1985, refers to the use of text, images, animation, and audio in computers in an integrated way, which is why computer graphics is one of the main components of multimedia.

Ray tracing, a sophisticated rendering method (Section 17.5), was developed by Turner Whitted of Bell labs and published in 1980.

Silicon Graphics Inc. (SGI) was founded in 1982 and has been building high-performance graphics computers since.

The technique of particle systems (Section 17.9) was developed in the early eighties at Lucasfilm. Morphing (Section 19.10) was developed at the same time at NYIT.

The data glove (Section 26.14.1), currently very popular for virtual-reality applications, was developed at Atari in 1983.

Radiosity came out of Cornell University in 1984. This is a sophisticated rendering method that simulates light reflection between surfaces by determining the exchange of energy between them.

GUI, graphical user interfaces, appeared in 1984 with the release of the first Macintosh computer. This personal computer immediately became, and still remains, a highly popular tool for computer graphics and is currently used by graphics amateurs and professionals, as well as by graphic-oriented businesses. The Amiga computer, made by Commodore, also had much success in the graphics field.

In 1985 came the first ISO standard, the High Sierra, for CD-ROMs. The Commodore Amiga personal computer was also introduced in the same year. It immediately became popular for what today is called multimedia applications.

PostScript, the all-important page-description language (Section 20.5), came out of Adobe Inc. at about the same time.

The 1980s saw the emergence of raster-scan display monitors as the main graphics output device. This technology has benefited from experience gained with television and has resulted in the affordable, reliable color monitors of today.

The late 1980s and early 1990s also saw the developments of graphics standards such as GKS and PHIGS.

In the late 1980s, graphics computers made by SGI (Silicon Graphics Inc.) were used to create some of the first fully computer-generated short films at Pixar.

The Microsoft Windows 3.0 operating system was first shipped in 1990 and, of course, gave a tremendous boost to the concept of GUI. More and more applications were developed to run under MS Windows.

OpenGL (Open Graphics Library) (Section 20.4), was originated by SGI in 1992.

The 1990s also saw rapid developments in three-dimensional graphics, especially in gaming, multimedia, and animation. *Quake*, one of the first fully 3D games, was released in 1996.

Released in 1997, *Toy Story* is the first full-length (79 minutes, which translates to more than 114,000 animation frames at 24 frames per second) feature film that's completely computer-animated. It represents a milestone in computer graphics and

it marks the beginning of an era when computer graphics rendering techniques have become so sophisticated that viewers may find it impossible to tell if an image is real or if it is a clever rendering of a mathematical model.

The explosion of CPU speeds and memory capacities since the late 1990s have resulted in more detailed and realistic digital images and animation, partly also due to powerful 3D-modeling software.

Reference [graphics.timeline 09] is a detailed timeline of important developments in computer graphics. Check also [hocg 06] and [masson 11].

Reference [morrison 10] is Michael Morrison's history of computer animation. A short visual history of this area is [animation-tube 10]. Search `YouTube.com` for others.

## 1.2 History of Curves and Surfaces

Section 9.4 discusses lofted surfaces but does not explain the reason for this unusual name. Historically, shipbuilders were among the first to mechanize their operation by developing mathematical models of surfaces. Ships tend to be big and the only dry place in a shipyard large enough to store full-size drawings of ship parts was the sail lofts above the shipyard's dry dock. Certain parts of a ship's surface are flat in one direction and curved in the other direction, so such surfaces became known as lofted.

In the 1960s, both car and aircraft manufacturers became interested in applying computers to automate the design of their vehicles. Traditionally, artists and designers had to make clay models of each part of the surface of a car or airplane and these models were later used by the production people to produce stamp molds. With the help of the computer it became possible to design a section of surface on the computer in an interactive process, and then have the computer drive a milling machine to actually make the part.

The box on Page 629 mentions the work of Pierre Bézier at Renault and Paul de Casteljau at Citroën, the contributions of Steven Coons to Ford Motors and William Gordon and Richard F. Riesenfeld to General Motors, and the efforts of James Ferguson in constructing airplane surfaces.

As a result of these developments in the 1960s and 1970s, the area of computer graphics that deals with curves and surfaces has become known, in 1974, as computer-aided geometric design (CAGD). Several sophisticated CAGD software systems have been developed in the 1980s for general use in manufacturing and in other fields such as chemistry (to model molecules), geoscience (for specialized maps), and architecture (for three-dimensional models of buildings).

Hardware developments in the 1980s made it possible to use CAGD techniques in the 1990s to produce computer-generated special effects for movies (an example is *Jurassic Park*), followed by full-length movies, such as *Toy story*, *Finding Nemo*, and *Shrek*, that were entirely generated by computer.

A detailed survey of the history of this field can be found in [Farin 04]. Several first-person historical accounts by pioneers in this field are collected in [Rogers 01].

## 1.3 History of Video Games

When personal computers started appearing, in the mid 1970s, many, among them computer professionals, questioned their usefulness. A common question was: Why would anyone want to have a computer at home? Typical answers were: To balance your checking account and To store your recipe collection. Few realized the correct answer which is: To entertain and communicate.

Today, those who have computers (and who hasn't) use them to communicate (by email, Internet telephone, and video chat), to be entertained (by watching movies, listening to music, and playing games), or to do both. This is why video games are so important. Because games are based on graphics, the following short history is included here.

**1958**. The experimental game *Tennis for Two* is implemented by William Higinbotham at Brookhaven Laboratory. Even though it was interactive, today this is considered more an experiment than a game.

**1966**. A short paper by Ralph Baer describes ways to use a television receiver as an output device for interactive games.

**1968**. *Spacewar!* is finally finished and is demonstrated at MIT. This early game has inspired the 1971 *Computer Space* by Nolan Bushnell.

**1971**. *Computer Space*, by Nolan Bushnell, is introduced and becomes the first coin-operated video game.

**1972**. Ralph Baer releases *Magnavox Odyssey*, the first home video game. The very successful *Pong* game, also by Nolan Bushnell, is introduced.

**1973**. Several companies, among them Chicago Coin, Midway, Ramtek, Taito, Allied Leisure, and Kee Games, enter the video game market and give this young field a big boost.

**1974**. *Tank*, by Kee Games, becomes the first game to employ ROM (Read-Only Memory) for storing game data. *TV Basketball*, by Midway, features human figures as players.

**1975**. *Gun Fight*, by Midway, is introduced and becomes the first game to be based on a microprocessor. Atari releases *Steeplechase*, the first six-player arcade video game. Kee Games announces *Indy 800*, the first eight-player game. Lots of innovations in one year.

**1976**. The first video game chip, the AY-3-8500, is built by General Instruments. The first cartridge-based home game system, the *Fairchild/Zircon Channel F* is introduced. *Night Driver*, by Atari, becomes the first game to simulate a first-person perspective. Atari also releases *Breakout*.

**1977**. After two active, successful years, the game market becomes saturated and very competitive. Several companies give up and quit the video game field as a result. The winners continue and Atari introduces its VCS home console system (later renamed the 2600). *Super Bug*, by Kee Games, becomes the first game to offer four-directional scrolling, and Nintendo, a Japanese newcomer, releases its first home video game, *Color TV Game 6*.

**1978**. The very successful and much familiar *Space Invaders* game, by Taito, appears this year. Many are familiar with how this game became the inspiration for

the many vertical shooting games that were introduced later. The technique of two-directional scrolling is introduced by *Football*, from Atari.

**1979**. *Warrior*, the first one-on-one fighting game, is made public by Vectorbeam. Two vector graphics games, *Asteroids* and *Lunar Lander* are released by Atari. Namco introduces *Galaxian*, the first game with 100% RGB colors, and *Puck-Man* (later renamed *Pac-Man*), another success story and an inspiration to many.

**1980**. *Pac-Man*, *Battlezone* (the first arcade game to feature a true 3D environment), and *Defender* are released. All are influential and a source of ideas to competitors. *Ultima* becomes the first home computer game with four-directional scrolling. *Star Fire* becomes both the first cockpit game and the first video game to feature a high-score table using players' initials.

**1981**. *Donkey Kong*, from Nintendo, and *Tempest*, by Atari, are released. The video game industry is growing fast and experts are predicting a backlash.

**1982**. *Q*bert*, by Gottlieb, appears. *Zaxxon*, by Sega, is introduced and is advertised on television (probably the first game with this distinction). The predicted economic crash starts this year (could it be a self-fulfilling prophecy?).

**1983**. After several years of continued growth, the video game industry suffers from another recession. Nevertheless, new games appear. *I, Robot*, by Atari, is the first raster video game with filled-polygon three-dimensional graphics. Atari also comes up with *Star Wars*, and the Famicon system, from Nintendo, is released in Japan.

**1984**. Even though the general economic recession that started in 1981 is now over, the video game industry is still suffering economically. *Halcyon*, by RDI, becomes the first laserdisc-based home video game system.

**1985**. A new, improved version of Famicon, renamed the Nintendo Entertainment System (NES), is released in America. It becomes so popular that it single-handedly reverses the crash and revives the video game industry. *Super Mario Bros.* is introduced by Nintendo and immediately becomes a best seller (it seems to be the best selling game ever). In the Soviet Union, Alex Pajitnov designs *Tetris*, another influential game.

**1986**. Nintendo's Famicon game system benefits from the first of the many Zelda games. Taito's *Arkanoid* and *Bubble Bobble* games appear in video game arcades. Sega releases its successful Sega Master System (SMS).

**1987**. *The Manhole*, by Cyan, becomes the first computer game released on CD-ROM. *Maniac Mansion*, by LucasArt, is the first adventure game with a point-and-click interface. *Driller*, from Incentive Software, is a personal computer game with stunning 3D graphics. *Double Dragon* is released by Taito.

**1988**. The notable game production for this year includes *Assault* by Namco, *NARC*, by Williams (the first game to run on a 32-bit processor), and *Super Mario Bros. 2*, by Nintendo.

**1989**. The list for this year includes Atari's *Hard Drivin'* and *S.T.U.N. Runner*, Gottlieb's *Exterminator* (the first game to have all digitized imagery for its backgrounds), Nintendo's **Game Boy** and Atari's **Lynx** (two handheld video game consoles), and Sega Genesis (a home console, not a game).

**1990**. This is the year *SimCity* is released, by Maxis. Designed by Will Wright, *SimCity* is the first in a long line of Sim games. Among other new games, Nintendo releases *Super Mario Bros. 3*, Sega's *Game Gear* is released in Japan, and Squaresoft's *Final Fantasy* series is sold in North America.

**1991**. New releases continue with the Super Nintendo Entertainment System (SNES), *Street Fighter, II* by Capcom, and *Sonic the Hedgehog*, by Sega.

**1992**. *Mortal Kombat* is developed by Midway (psychologists recommend replacing "C" by "K" as a means of attracting customers' attention). The best seller *The 7th Guest* is released by Virgin Games. *Virtua Racing*, a 3D racing game, is a new game by Sega. Another familiar title is *Wolfenstein 3D*, by id Software. *Dactyl Nightmare*, by Virtuality, employs a virtual reality headset and gun interface.

**1993**. Another best seller, *Myst*, from Cyan, appears this year, together with *Doom*, by id Software, and *Virtua Fighter*, by Sega. This is also the year when the world-wide-web expands rapidly.

**1994**. New, important games include *Donkey Kong Country* (Nintendo), *Saturn* (Sega), *Warcraft* (Blizzard), *Daytona USA*, (Sega), and *Warcraft II* (Blizzard). Two new game systems, the Sega Saturn and the Sony PlayStation are released in Japan and SNK's NeoGeo home console system is introduced.

**1995**. The Sega Saturn and the Sony PlayStation are now available in America. *Donkey Kong Country 2* by Nintendo and *Kong Quest*, by Diddy, are among new game releases this year.

**1996**. Virtual Boy, a portable, stereo game system with a separate screen for each eye, is released by Nintendo. At last, it is possible to obtain a degree in video game development (from Digipen Institute of Technology).

**1997**. The first GameWorks arcade opens in Seattle by DreamWorks, Sega, and Universal. The first of the MMORPG Ultima genre games appears. Designed by Richard Garriott these are multiplayer games where the action occurs in an RPG (Role-Playing Game) world. This genre has influenced many of the most successful and popular titles that followed. Other notables are *Riven*, the sequel to *Myst*, by Sega, *Top Skater*, with a skateboard interface, also by Sega, and *Mario Kart 64*, by Nintendo.

**1998**. *Dance Dance Revolution* and the first games in the Beatmania series and GuitarFreaks series, all by Konmai. *Boy Color* (Nintendo), *Half-Life* (Sierra Studios), and *Grand Theft Auto* (Rockstar Games) are among the notables this year. SNK releases the NeoGeo Pocket handheld video game system.

**1999**. The list includes *Dreamcast* (Sega), *Donkey Kong 64* (Nintendo), and *Pro Skater* (Tony Hawk). The first Independent Games Festival is held at the Game Developers Conference.

**2000**. An important announcement: Nintendo has just sold its 100 millionth Game Boy console. Sony introduces its PlayStation 2. Another milestone: The United States Post Office issues a stamp depicting video games. Have video games finally arrived?

**2001**. This is the year of the Xbox, by Microsoft, but the Nintendo GameCube is also introduced in 2001. Two surprises: Sega is leaving the home video game consoles market and Midway Games quits the arcade video game industry.

**2002**. The Sim series of games becomes a best seller and the MMORPG Sims Online game starts. Microsoft announces its Xbox Live online gaming service. Sega releases *Rez* for the PlayStation 2.

**2003**. This year marks the start of the MMORPG *Star Wars Galaxies*. *Enter the Matrix*, by atari, is released. Nokia releases the N-Gage handheld video game system.

**2004**. PlayStation Portable and PlayStation 2 (Sony) are released in Asia. The Nintendo DS (dual screen) handheld video game system is also introduced.

**2005**. The Xbox 360 (Microsoft) and the Gizmondo (Tiger Telematics) are released. The Sims series appears on postage stamps in France. We thus conclude that: Yes, video games have arrived.

**2006**. Wii (Nintendo), PlayStation 3 (Sony), and Xbox 360 (Microsoft) are released.

**2007**. *World of Warcraft*, an MMORPG game, is estimated to have more than nine million players worldwide.

**2008**. Apple entered the field of mobile gaming hardware with the release of the iPhone and iPod Touch in the summer. Software for these platforms is sold only online. Nintendo announces its Wii MotionPlus module.

**2009**. Sony releases its PSP Go. This device is a newer, slimmer version of the PSP. Microsoft and Sony present their new motion controllers: Project Natal (later renamed Kinect) and PlayStation Move, respectively. A few cloud computing services are announced, targeted at video games.

**2010**. The Nintendo 3DS, the successor to the Nintendo DS, has been released in early 2011. The new Xbox 360 console (referred to as the Xbox 360 S or Slim) is revealed by Microsoft.

See also [Wolf 08].

> Life is a video game. No matter how good you get, you are always zapped in the end.
>
> —Anonymous.

## 1.4 Pioneers of Computer Graphics

The following is an alphabetical list of many pioneers, researchers, and notable figures of this important field.

(A writer's apology. Any such list is necessarily incomplete. I apologize in advance for any omissions. They are unintentional, and when brought to my attention would be included in the errata list of the book.)

- Bill Atkinson, developed graphics algorithms, implemented the revolutionary MacPaint software for the Macintosh, as well as Hypercard, QuickDraw, and the Macintosh menu bar.
- Michael Barnsley, worked on fractals.
- Brian A. Barsky, developed beta splines (with tension).
- Richard H. Bartels, codeveloper of the Kochanek-Bartels splines.
- Pierre Étienne Bézier, created efficient algorithms for curves and surfaces.
- Jim F. Blinn, artist-mathematician-programmer, the originator of many graphics algorithms, implementations, and video productions.
- Jack Elton Bresenham, came up with extremely efficient methods for scan converting straight lines and circles.
- Tom Brigham worked on morphing in 1982.

- Nolan Kay Bushnell, created early video games.
- Loren Carpenter, programmer and researcher, implemented fractal methods to draw realistic terrain and mountains.
- Paul de Faget de Casteljau, developed Bézier curves and surfaces using an approach radically different from that of Bézier.
- Ed Catmull, founded Pixar, a maker of digital films and videos.
- George Merrill Chaikin, developed subdivision methods for surfaces.
- Jim Clark, entrepreneur and scientist. Founder, in 1982, of Silicon Graphics.
- Steven Anson Coons, an early researcher in the field of surface design and implementation.
- Charles Csuri, an early pioneer in computer animation and digital fine art.
- Carl Wilhelm Reinhold de Boor, a pioneer in the application of splines to curves.
- Tom A. DeFanti is a distinguished computer graphics researcher and pioneer.
- Tony DeRose is a distinguished computer graphics researcher.
- Donald Doo, developed Doo–Sabin subdivision surfaces.
- Gerald Farin is a distinguished computer graphics researcher.
- Charles Geschke developed PostScript and cofounded Adobe.
- Henri Gouraud, originated the shading algorithm named after him.
- Donald Peter Greenberg, a leading educator and innovator in computer graphics and the chief developer of radiosity.
- Charles Hermite, a 19th century mathematician who originated the interpolation method named after him.
- Alan Kay Originated the notion of a graphical user interface (GUI). He said "the best way to predict the future is to invent it."
- Doris H. U. Kochanek, codeveloper of the Kochanek-Bartels splines.
- Kenneth C. Knowlton, is a computer graphics pioneer, artist, mosaicist, and portraitist.
- Joseph-Louis Lagrange is the father of the Lagrange polynomial.
- Charles T. Loop developed Loop subdivision surfaces.
- Benoît B. Mandelbrot, a major figure in the field of fractals.
- Martin Newell, developed the Newell algorithm for hidden surface removal and created the Utah teapot which was made famous by Frank Crow.
- A. Michael Noll is a pioneer of computer art.
- Phong Bui Tuong, originated the shading algorithm named after him.

- Richard F. Riesenfeld, developer of B-splines.
- Ton Roosendaal is the original creator of *Blender*.
- Steve Russell is a programmer and scientist known for creating *Spacewar!*, one of the earliest videogames, in 1961.
- Malcolm A. Sabin, codeveloper of the Doo–Sabin subdivision surfaces.
- Daniel J. Sandin is a video and computer graphics artist and researcher. He was part of the team that developed the first data glove.
- Alvy Ray Smith, entrepreneur and researcher. Founder, or active in, several computer graphics enterprises.
- Ivan Edward Sutherland, designed and implemented *Sketchpad*, an early 2D and 3D graphics system. Cofounded Evans and Sutherland. Other achievements too numerous to list here.
- Dick A. Termes, an internationally acclaimed artist painting in $n$-point perspective on spheres.
- John Warnock developed PostScript and cofounded Adobe.
- Turner Whitted, a pioneer of ray tracing.
- Edward E. Zajac created the first computer-generated film.

## 1.5 Resources For Computer Graphics

The following types of resources are listed here: (1) organizations and societies, (2) research institutions, (3) universities, (4) journals, (5) books, (6) other graphics-related websites, and (7) software. There are hundreds of academic websites and the ones listed here were selected (somewhat arbitrarily) from hundreds of easily-located similar URLs. Similarly, there are hundreds of textbooks on computer graphics and the few listed here have been selected because they offer complete coverage and are also familiar to me. The reader should bear in mind that the field and its resources develop and change constantly, so readers should search the Internet for new, useful, and exciting sources of information. Search items may be selected from "history of computer graphics," "computer graphics," "computer animation," "image processing," "computer vision," "computer-aided design (CAD)," and many other phrases. A few resources are also listed on Pages 196 and 431.

**1. Societies**.

- SIGGRAPH, the ACM special interest group on graphics, is perhaps the single most important source of information about computer graphics. It is located at `http://www.siggraph.org/` and offers a wealth on information on art and design, computer graphics events, a computer graphics bibliography database, jobs and careers in the field, industry directory, and many related links worldwide. SIGGRAPH is also

known for its publications (*Computer Graphics Quarterly*, *SIGGRAPH Video Review*, and *ACM Transactions on Graphics*) and annual conferences.

- Eurographics is the European Association for Computer Graphics. Find it at http://www.eg.org/.

- CGsociety, at http://forums.cgsociety.org/, is the society of digital artists. Its mission is to cater for 3D Animation and Visual Effects developers.

- http://www.vrs.org.uk/ is The Virtual Reality Society (VRS). This is an international society dedicated to the discussion and advancement of virtual reality and synthetic environments.

**2. Research Organizations**.

- http://www.wavelet.org/. This site offers several services intended to foster the exchange of knowledge and viewpoints related to theory and applications of wavelets. It is relevant to computer graphics because of the applications of wavelets to image compression.

- http://www.igd.fhg.de/ is the address of the Fraunhofer Institute for Computer Graphics Research (IGD) which concentrates on the development of product prototypes (hardware and software) and the realization of concepts, models, and solutions for computer graphics.

- Look at http://www.ccg.pt/ for information on the Computer Graphics Center, devoted to research and development in virtual reality, multimedia systems, electronic commerce, and other, graphics-related, topics.

**3. Academic Websites**.

- Free lecture notes, image gallery, and students' assignments, projects, and examinations are available at MIT
http://ocw.mit.edu/courses/electrical-engineering-and-computer-science/.

- http://www.cs.brown.edu/exploratories/freeSoftware/home.html is located at Brown University. It offers a collection of Java applets for learning about computer graphics, including color theory, imaging (convolution and filters), viewing techniques, coordinate systems, splines), and texture mapping.

- Site http://www.eecs.berkeley.edu/Research/Projects/Areas/GR.html lists graphics projects at the University of California, Berkeley.

- Graphics-related research at the California Institute of Technology (Caltech) can be found at http://www.gg.caltech.edu/. It focuses primarily on the mathematical foundations of computer graphics.

- Cornell university, at http://www.graphics.cornell.edu/, has an advanced program in computer graphics.

- http://www.cg.inf.ethz.ch/ will tell you all about the Computer Graphics Laboratory at the Eidgenössische Technishce Hochschule (ETH), in Zürich.

- The Georgia Tech (GaTech), at http://gvu.cc.gatech.edu/, has a strong graphics program.

- Check out http://groups.csail.mit.edu/graphics/ for the graphics program at MIT.

- Computer Graphics, Visualization and Animation at the University of Utah is located at http://www.cs.utah.edu/research/areas/graphics/.

- http://mambo.ucsc.edu/psl/cg.html is a jumping point to many sites that deal with computer graphics.

- A similar site is http://www.cs.rit.edu/~ncs/graphics.html that also has many links to computer graphics sites.

- A very extensive site of computer-graphics-related pointers is http://ls7-www.informatik.uni-dortmund.de/html/englisch/servers.html.

- See http://graphics.idav.ucdavis.edu/education/GraphicsNotes/ for computer graphics course notes at the Computer Science Department, University of California, Davis.

- Site http://ls7-www.cs.uni-dortmund.de/cgotn/ lists many links to computer graphics resources.

**4. Journals, Magazines, and Conference Proceedings**.

- See http://www.siggraph.org/publications/newsletter for *The ACM SIGGRAPH Computer Graphics Quarterly*. This is the official publication of the ACM SIGGRAPH organization. It is published in February, May, August, and November of each year.

- See http://www.siggraph.org/publications/video-review for the *SIGGRAPH Video Review*, an important video-based publication. It illustrates the latest concepts in computer graphics and interactive techniques.

- *ACM Transactions on Graphics* is the premiere peer-reviewed journal of graphics research. See more information at http://www.siggraph.org/publications/tog.

- The proceedings (including visual material, such as the Computer Animation Festival) of the annual ACM SIGGRAPH Conferences are published extensively. See http://www.siggraph.org/publications/acm-siggraph-conference-documentation.
A satire on the 1992 conference, by Steve Connelly and Tim Hall, can be found at http://steve.hollasch.net/cgindex/misc/sgsatire.html.

- *Computer Graphics World* is the premiere authority on innovative graphics, technology, and applications. It is located at http://www.cgw.com/.

- http://crossings.tcd.ie/ is a multidisciplinary online journal that explores the areas where technology and art intersect.

- http://computer.org/cga is the home of the *IEEE Computer Graphics and Applications*, a bimonthly magazine that covers a variety of topics catering to both computer

graphics practitioners and researchers. This popular publication bridges the theory and practice of computer graphics, from specific algorithms to full system implementations.

- See http://jgt.akpeters.com for the *journal of graphics, gpu, and game tools*, a quarterly journal whose primary mission is to provide the computer-graphics research, development, and production communities with practical ideas and techniques that solve real problems.

- Ray Tracing News Guide is a website maintained by Eric Haines who also compiles its content. It is located at http://tog.acm.org/resources/RTNews/html/. This is not a formal journal. It periodically features news of ray tracing.

- *Animation Magazine* is a monthly publication covering the entire animation field, computer and otherwise. Check it at http://www.bcdonline.com/animag/.

- *Digital Imaging* is a bimonthly reporting on the digital imaging industry.

**5. Books**.

- James D. Foley, Andries van Dam, Steven K. Feiner, and John F. Hughes, *Computer Graphics: Principles and Practice in C*, Addison-Wesley Professional, 2nd ed., 1995. This textbook is a classic. It covers all the important topics and areas of the field. It is not easy reading, though, and some may claim that it is showing its age.

- Peter Shirley and Steve Marschner, *Fundamentals of Computer Graphics*, A K Peters; 3rd revised ed., 2009). Covers the basic topics (except computer animation).

- Francis S. Hill Jr. and Stephen M. Kelley, *Computer Graphics Using OpenGL*, Prentice Hall, 3rd. ed., 2006. Very clear and easy to read. The treatment of ray tracing is especially comprehensive. There are many practice exercises.

- Donald D. Hearn and M. Pauline Baker, *Computer Graphics with OpenGL*, Prentice Hall, 3rd ed., 2003. In addition to its full coverage of the CG field, this book offers a nice OpenGL user's manual.

- *Graphics Gems* is a series of books, started in 1990 by Andrew S. Glassner and written by him and others. See http://www.graphicsgems.org/.

- There are hundreds of other books on this subject, mostly concentrating on specific topics, such as ray tracing, curves and surfaces, programming in OpenGL, and computer animation.

> The colonists did not have a library at their disposal, but the engineer was a book that was always ready, always open to the page needed, a book which answered all their questions and which they often leafed through.
>
> —Jules Verne, *The Mysterious Island*, 1874.

**6. Other Websites**.

- The following UseNet groups are dedicated to various aspects of computer graphics: `comp.graphics.animation`, `comp.graphics.digest`, `comp.graphics.opengl`, `comp.graphics.raytracing`, and `comp.graphics.visualization`.

- 3D ARK (http://www.3dark.com/) is a free online archive of 3D related content and resources for 3D enthusiasts.
- http://www.colormatters.com/ is a resource for all things color.
- http://www.computergraphica.com/ is all about human-pixel interaction.
- The Graphics File Formats page is at http://www.martinreddy.net/gfx/.
- http://www.opengl.org/ is the chief site for OpenGL, the open-ended graphics language.
- Site http://steve.hollasch.net/cgindex/index.html is Steve's Computer Graphics Index. This is a collection of topics related to computer graphics. It is maintained by Steve Hollasch.
- Nan's Computer Graphics Page (http://www.cs.rit.edu/~ncs/graphics.html) is a list of links to places that offer help and information related to computer graphics. The site is owned by Nan Schaller.
- http://www.refdesk.com/compgrah.html is an encyclopedia of facts and topics of computer graphics.
- The Persistence of Vision Raytracer is a high-quality, totally free tool for creating stunning three-dimensional graphics. It is available in official versions for several popular platforms. See http://www.povray.org/.
- GRAFICA Obscura, at http://www.graficaobscura.com/?/, is an evolving computer graphics notebook. This is a compilation of technical notes, pictures, and essays that Paul Haeberli has accumulated over the years. It seems that this site is no longer being maintained.
- Website http://i33www.ira.uka.de/applets/mocca/html/noplugin/ has applets for computer-aided geometric design (CAGD).
- http://www.faqs.org/faqs/graphics/faq by John Grieggs contains answers to frequently asked questions on graphics.

**7. Graphics Software**.

Most graphics applications can be classified as two-dimensional or three-dimensional (abbreviated here as 2D and 3D, respectively). In the former class we find painting, drawing, illustration, drafting, and CAD programs. The latter class consists of modelers and renderers.

A painting program includes tools such as brush, spray paint, pencil, and eraser. A picture can be painted by moving these tools with the mouse, pad, or other pointing device. Editing a painting is very difficult, because the individual graphics elements are not saved by the program. Once a stroke has been painted, it may be impossible to erase. The (now obsolete) MacPaint program of 1984–1988 was perhaps the first successful painting program.

A drawing program offers tools such as a rectangle, ellipse, line, arc, and curve. Each element drawn is saved by the program as a set of data (or control) points. Thus, it is possible to select any element, edit it, move it, or delete it. An illustration program

includes colors, patterns, and textures. A drafting program allows the accurate drawing of graphics elements with precise dimensions. A CAD program may output the drawing in a special format to another program that drives a cutting tool to actually manufacture an item.

A 3D modeler allows the user to construct any three-dimensional object in the computer and save it in a special 3D format, whereas a renderer may render such an object accurately, often by tracing every ray of light and computing its reflections from several surfaces.

For many years, graphics software remained primitive because computers that were fast enough to process images and compute accurate renderings tended to be expensive. It was only in the late 1980s that several 2D programs were introduced and were slowly developed over the years. The rapid development of fast personal computers and large color display monitors in the 1990s paved the way for sophisticated 2D and 3D graphics software, and today, in 2011, we witness an explosion of such programs. The following survey is necessarily incomplete, but it lists the most important graphics applications available today. I apologize in advance for any omissions; they are unintentional.

- *Mathematica* is general-purpose mathematical software that can perform numeric calculations and symbolic manipulations and display its results graphically. Both 2D and 3D graphics are supported, with many options allowing the user to precisely specify what will be displayed and how. This software was conceived by Stephen Wolfram and was first introduced in 1988. It is currently in version 8. Even though *Mathematica* is not a graphics application, it is listed here because of its powerful graphics capabilities. See http://en.wikipedia.org/wiki/Mathematica.

- **Matlab**, by The Mathworks (http://www.mathworks.com/) is a software tool designed mostly for numerical computations. Its capabilities can be extended by individual packages that allow detailed computations and study of topics such as wavelets, symbolic manipulations, and neural networks. Matlab can plot the curves and surfaces it computes, which makes it an important graphics program.

  The name Matlab is short for Matrix Lab, because all variables in Matlab, even scalars, are matrices (there is also an upazila, a subdistrict, called Matlab in Bangladesh).

### 2D Applications

- **Adobe Photoshop** is a graphics editing program developed by Adobe Systems. The software can edit and process bitmap images (i.e., images where only the pixels are given, without any geometric information). The main features of the program include layers with masks, color spaces, ICC profiles, transparency, text, alpha channels and spot colors, clipping paths, and duotone settings. See http://www.adobe.com.

- **Adobe Illustrator** is a vector-based image editor, now at version 15, designed for illustrations. First released in 1988, the software immediately became popular due to its chief innovation, a simple, natural way to draw curves, based on cubic Bézier curves (Section 13.2). Over the years, many features have been added, including some 3D capabilities to extrude and revolve shapes.

  Among the most recent sophisticated features and tools of Illustrator are Live Trace, Live Paint, a control palette and custom workspaces, aligning individual points, multiple

crop areas, the Color Guide panel, the Live Color feature, the ability to create multiple artboards, a blob brush, a gradient tool, a perspective grid tool, and a bristle brush.

In spite of the vast literature (books, videos, and other training materials) that exists for this program, it takes years to master all its capabilities and power. For more information see http://en.wikipedia.org/wiki/Adobe_Illustrator.

- **GIMP** is a free image manipulation program for tasks such as photo retouching, image composition, and image authoring. It is available from [GIMP 05] for many operating systems, in many languages.

- **Inkscape** is an editor for images in vector format. It runs on several computer platforms, it is free and is distributed under the GNU license. Its developer intends Inkscape to become a powerful graphics tool while being fully compliant with the XML, SVG, and CSS standards.

  At the time of writing, Inkscape is under active development, with new features being added regularly. See http://www.inkscape.org/.

- **CorelDRAW** is a vector-based graphics suite, offering more than just a vector graphics editor. It has been developed by http://www.corel.com/. It supports many powerful, useful features such as layout, tracing, photo editing, Web graphics, and animation. Having powerful competitors, CorelDRAW tries to improve on them in several ways, the most important of which is its being a suite of programs. It consists of the following applications:

  * CorelDRAW: Vector graphics editing software
  * Corel PHOTO-PAINT: Raster image creation and editing software
  * Corel CONNECT: Content organizer
  * Corel CAPTURE: Enables several methods of image-capture
  * Corel PowerTRACE: Converts raster images to vector graphics (available inside the CorelDRAW suite)

- **Graphing Calculator** is a tool for quickly visualizing mathematical objects and results. The user types an equation and the software computes and displays it without complicated dialogs or commands. See http://www.nucalc.com/.

- **K3DSurf** is software for plotting surfaces or higher-dimensional manifolds. See http://k3dsurf.sourceforge.net/. It can plot equations of three variables, parametric expressions for higher-dimension surfaces, and can also morph two images based on a variable.

- **3D-XplorMath**, at http://3d-xplormath.org/, is software for visualization of geometric objects and processes. Surfaces, both 2D and 3D curves, complex-valued functions, and differential equations can all be plotted and animated. This software is particularly useful for those working in differential geometry, differential equations, or minimal surfaces.

- **Virtual Math Labs**. A group at the technical university of Berlin has developed a number of programs for exploring curves and surfaces. See http://www.math.tu-berlin.de/geometrie/lab/curvesnsurfaces.shtml.

- **Gnuplot**, at http://www.gnuplot.info, is a portable command-line driven graphing utility for linux, OS/2, MS Windows, OSX, VMS, and many other platforms. It was originally created to allow scientists and students to visualize mathematical functions and data interactively, but has grown to support many non-interactive uses such as web scripting.

**Windows Programs for Plotting Curves and Surfaces**

MathGV: http://www.mathgv.com/.
3D Grapher: http://www.romanlab.com/.
Graphmatica: http://www8.pair.com/ksoft/.
Graphis: http://www.kylebank.com/.
DPGraph: http://www.dpgraph.com/.
Advanced Grapher: http://www.serpik.com/.
MathGrapher: http://www.mathgrapher.com/.

**3D Graphics Applications**

- **POV-Ray**, at http://www.povray.org/ is mostly a 3D ray-tracing renderer, but it has many commands and options that make it possible to build quite complex models. The acronym POV stands for persistence of vision. Several modelers, such as Bishop3D and LionSnake, output POV-Ray code that can be rendered directly. The program SU2POV converts the output of SketchUp to POV-Ray code.

- **SketchUp**, at http://sketchup.google.com/ is a 3D modeler designed for architects, civil engineers, filmmakers, game developers, and related professions. It has been acquired in 2006 by Google, so it also includes features to facilitate the placement of models in Google Earth. It was originally developed in 1999–2000 and it immediately became clear that its developers had hit on the right way to manipulate 3D objects on the 2D monitor screen. The basic SketchUp is free, while the pro version is commercial.

  The chief innovation of SketchUp is its Push/Pull technology, described in its patent application as follows: "System and method for three-dimensional modeling: A three-dimensional design and modeling environment allows users to draw the outlines, or perimeters, of objects in a two-dimensional manner, similar to pencil and paper, already familiar to them. The two-dimensional, planar faces created by a user can then be pushed and pulled by editing tools within the environment to easily and intuitively model three-dimensional volumes and geometries."

  There are quite a few books on this useful software. Many training videos are available at http://sketchup.google.com/training/videos.html.

  A feature of SketchUp is the 3D Warehouse that lets SketchUp users search for models made by others and contribute models.

- **Maya**, by Autodesk, is a high-level application for 3D animation, 3D modeling, simulation, visual effects, rendering, matchmoving, and compositing. Maya is used for animation in film and television, in commercials, video games, and architectural visualization and design. See http://en.wikipedia.org/wiki/Maya_(software).

  The name Maya has nothing to do with the Maya civilization or with Maya Angelou. It is simply the Sanskrit term for "illusion."

- **Modo** is a powerful polygon and subdivision surface modeling and rendering tool. It also supports morphing, sculpting, 3D painting, and animation. Modo is developed by Luxology (http://www.luxology.com/modo/) and is currently at version 501. Modo is heavily used both by commercial entities (television, film, and video games) and by private individuals. The program incorporates features such as n-gons, 3D painting, and edge weighting, and runs on Mac OS X and Microsoft Windows platforms.

  Because of its large user base, huge libraries of textures, scenes, studio lighting, and special effects (such as hair, splashes, and water/fog) are available for Modo. There is also much training material. See http://en.wikipedia.org/wiki/Modo_(software).

- **Carrara**, from http://www.daz3d.com, is a 3D modeler and renderer. Judging from the examples displayed in its gallery, its users tend to develop models of humans, animals, and aliens.

- **Bryce**, also from http://www.daz3d.com, is a 3D modeling and animation package that purports to be the first name in 3D landscapes. It combines powerful features with a smart and simple user interface to create realistic digital landscapes.

- **Blender**, from http://www.blender.org, is free software with all the features of commercial programs. It has many active users and its price makes it the default choice for many people. However, its user interface is non-standard so it creates a feeling of user-unfriendliness. Some users complain about incomplete documentation.

- **Zbrush**, from http://www.pixologic.com, is a 3D painting and sculpting tool. An object is created by selecting a brush and using it to paint, chisel, and mold.

- **3d Studio Max**, from http://www.autodesk.com/3dsmax, is considered by many the equivalent of Maya because of its similar set of features.

- **Softimage**, from http://www.softimage.com, is one of the most advanced 3D animation and character creation software for video games and movies. It uses several non-proprietary languages for its scripting, but its current user base seems small, perhaps because of its price.

Many other modelers and renderers are currently available. A detailed list can be found at http://en.wikipedia.org/wiki/3D_computer_graphics_software. The following is an alphabetical list with just the names of the most important ones: 3ds Max (Autodesk), AC3D (Inivis), Aladdin4D (DiscreetFX), Cinema 4D (MAXON), CityEngine (Procedural Inc.), Cobalt, Electric Image Animation System (EI Technology Group), form'Z (AutoDesSys, Inc.), Houdini (Side Effects Software), Inventor (Autodesk), LightWave 3D (NewTek), MASSIVE, NX (Siemens PLM Software), Silo (Nevercenter), solidThinking (solidThinking), Solid Edge (Siemens PLM Software), SolidWorks (SolidWorks Corporation), Swift 3D (Electric Rain), trueSpace (Caligari Corporation), and Vue (E-on Software).

Yesterday is history. Tomorrow is a mystery. And today?
Today is a gift. That's why we call it the present.
—Babatunde Olatunji