Chapter One
Introduction to Computer Graphics

1.1 Introduction to Computer Graphics

Computer Graphics is a branch of Computer Science that deals with the theory and technology for Computer Image synthesis and it refers to the creation, storage and manipulation of pictures and drawings using a digital computer.

Computer Graphics (CG) is the field of visual computing, where one utilizes computers both to generate visual images synthetically and to integrate or alter visual and spatial information sampled from the real world." It is the pictorial representation and manipulation of data by a computer.

Computer Graphics can also be refers to any sketch, drawing, special artwork or other material generated with the help of computer to pictorially depict an object or a process or otherwise convey information, as a supplement to or instead of written descriptions".

Computer graphics can be broadly divided into the following classes:

- ✓ **Business Graphics** or the broader category of Presentation Graphics, which refers graphics, such as bar-charts (also called histograms), pie-charts, pictograms (i.e., scaled symbols), x-y charts, etc. used to present quantitative information to inform and convince the audience.
- ✓ **Scientific Graphics,** such as x-y plots, curve-fitting, contour plots, system or program flowcharts etc.
- ✓ **Scaled Drawings**, such as architectural representations, drawings of buildings, bridges, and machines.
- ✓ **Cartoons and artwork**, including advertisements.
- ✓ **Graphics User Interfaces** (GUIs) which are the images that appear on almost all computer screens these days, designed to help the user utilise the software without having to refer to manuals or read a lot of text on the monitor.

The most familiar and useful class of computer graphics involves movies and video games. Movies generally need graphics that are indistinguishable from physical reality, whereas video games need graphics that can be generated quickly enough to be perceived as smooth motion. These two needs are incompatible, but they define two-ways of communications between users and computations. In video games, the subject matter of computations is generally characters chasing and shooting at each other. A more familiar use of computer graphics exists for interacting with scientific computations apart from movies and games. This familiarization of the use of computer graphics has influenced our life, through simulations, virtual reality, animation, education, entertainment, analysis, etc.

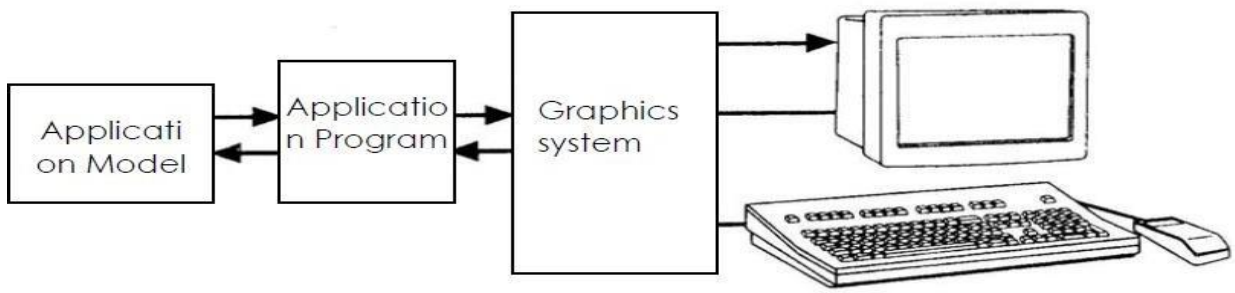
1.2 Types of Computer Graphics

Computer graphics can be categorized in two ways:

- ✓ **Interactive Computer Graphics** which is interactively used by users e.g., games.
- ✓ **Passive Computer Graphic** which has no option for users to interact or use computer graphics e.g., movies.

1.2.1 Interactive Computer Graphics

In Interactive Computer graphics, user have some control over the picture (i.e. user can make any change in the produced image). One example of it is the ping pong game. The conceptual model of any interactive graphics system is given in the picture shown in Figure below. At the Hardware level (*not shown in picture*), a computer receives input from interaction devices, and outputs images to a display device. The software has three components. The first is the application program that creates, stores into, and retrieves from the second component, the application model, which represents the graphic primitive to be shown on the screen. The Application program also handles user input. It produces views by sending to the third component, the graphics system, a series of graphics output commands that contain both a detailed geometric description of what is to be viewed and the attributes describing how the objects should appear. After the user input is processed, it sent to the graphics system is for actually producing the picture. Thus, the graphics system is a layer in between the application program and the display hardware that effects an output transformation from objects in the application model to a view of the model.



The objective of the application model is to captures all the data, objects, and relationships among them that are relevant to the display and interaction part of the application program and to any non-graphical post-processing modules.

1.2.2 Passive Computer Graphics

A Passive Graphics is a computer graphics operation that transfers automatically and without operator intervention. Non-interactive computer graphics involves one way communication between the computer and the user. Picture is produced on the monitor and the user does not have any control over the produced picture.

1.3 Application of Computer Graphics

Computer graphics is used today in many different areas of industry, business, government, education, entertainment, and most recently, the home. The list of applications is enormous and is growing rapidly as computers with graphics capabilities become commodity products. Some of them are:-

(a) **Presentation Graphics:-** To produce illustrations which summarize various kinds of data. Except 2D, 3D graphics are good tools for reporting more complex data.

(b) **Computer-Aided Design for Engineering and Architectural systems:** Objects may be displayed in a wireframe outline form. Multi-window environment is also favored for producing various zooming scales and views. Animations are useful for testing performance.

(c) **Computer Art:**- Painting packages are available. With cordless, pressure-sensitive stylus, artists can produce electronic paintings which simulate different brush strokes, brush widths, and colors. Photorealistic techniques, morphing and animations are very useful in commercial art. For films, 24 frames per second are required. For video monitor, 30 frames per second are required.

(d) **User Interfaces**: As soon mentioned, most applications that run on personal computers and workstations, and even those that run on terminals attached to time shared computers and network computer servers, have user interfaces that rely on desktop window systems to manage multiple simultaneous activities, and on point and click facilities to allow users to select menu items, icons, and objects on the screen; typing is necessary only to input text to be stored and manipulated. Word processing, spreadsheet, and desktop-publishing programs are typical applications that take advantage of such user-interface techniques.

(e) **Entertainment:-** Motion pictures, Music videos, and TV shows, Computer games.

(f) **Education and Training:**- Training with computer-generated models of specialized systems such as the training of ship captains and aircraft pilots.

(g) **Image Processing:**- Image processing is to apply techniques to modify or interpret existing pictures. It is widely used in medical applications.

(h) **Cartography:** Computer graphics is used to produce both accurate and schematic representations of geographical and other natural phenomena from measurement data. Examples include geographic maps, relief maps, exploration maps for drilling and mining, oceanographic charts, weather maps, contour maps, and population density maps.

(i) **(Interactive) plotting in business, science and technology**: The next most common use of graphics today is probably to create 2D and 3D graphs of mathematical, physical, and economic functions; histograms, bar and pie charts; task-scheduling charts; inventory and production charts, and the like . All these are used to present meaningfully and concisely the trends and patterns gleaned from data, so as to clarify complex phenomena and to facilitate informed decision making.

(j) **Office automation and electronic publishing**: The use of graphics for the creation and dissemination of information has increased enormously since the advent of desktop publishing on personal computers. Many organizations whose publications used to be printed by outside specialists can now produce printed materials in-house. Office automation and electronic publishing can produce both traditional printed (hardcopy) documents and electronic (softcopy) documents that allow browsing of networks of interlinked multimedia documents are proliferating.

(k) **Computer-aided drafting and design:** In computer-aided design (CAD), interactive graphics is used to design components and systems of mechanical, electrical, electromechanical, and electronic devices, including structure such as buildings, automobile bodies, airplane and ship hulls, very large scale-integrated (VLSI) chips, optical systems, and telephone and computer networks. Sometimes, the use merely wants to produce the precise drawings of components and assemblies, as for online drafting or architectural blueprints Color Plate.

(l) **Simulation and animation for scientific visualization and entertainment:** Computer produced animated movies and displays or the time-varying behavior of real and simulated objects are becoming increasingly popular for scientific and engineering visualization. We can use them to study abstract mathematical entries as well as mathematical models of such phenomena as fluid flow, relativity, nuclear and chemical reactions, physiological system and organ function, and deformation of mechanical structures under various kinds of loads. Another advanced-technology area is interactive cartooning. The simpler kinds of systems for producing 'Flat" cartons are becoming cost-effective in creating routine 'in-between" frames that interpolate between two explicitly specified 'key frames". Cartoon characters will increasingly be modeled in the computer as 3D shape descriptions whose movements are controlled by computer commands, rather than by the figures being drawn manually by cartoonists. Television commercials featuring flying logos and more exotic visual trickery have become common, as have elegant special effects in movies. Sophisticated mechanisms are available to model the objects and to represent light and shadows.

(m) Art and commerce: Overlapping the previous categories the use of computer graphics in art and advertising here, computer graphics is used to produce pictures that express a message and attract attention. Personal computers and Teletext and Videotexts terminals in public places such as in private homes, offer much simpler but still informative pictures that let users orient themselves, make choices, or even "teleshop" and conduct other business transactions. Finally, slide production for commercial, scientific, or educational presentations is another cost-effective use of graphics, given the steeply rising labor costs of the traditional means of creating such material.

(n) Process control: Whereas flight simulators or arcade games let users interact with a simulation of a real or artificial world, many other applications enable people or interact with some aspect of the real world itself. Status displays in refineries, power plants, and computer networks show data values from sensors attached to critical system components, so that operators can respond to problematic conditions. For example, military commanders view field data – number and position of vehicles, weapons launched, troop movements, causalities – on command and control displays to revise their tactics as needed; flight controller airports see computer-generated identification and status information for the aircraft blips on their radar scopes, and can thus control traffic more quickly and accurately than they could with the uninitiated radar data alone; spacecraft controllers monitor telemetry data and take corrective action as needed.

1.4 History of Computer Graphics

In the 1950's, output are via teletypes, line printer, and Cathode Ray Tube (CRT). Using dark and light characters, a picture can be reproduced. In the 1960's, beginnings of modern interactive graphics, output are vector graphics and interactive graphics. One of the worst problems was the cost and inaccessibility of machines. In the early 1970's, output start using raster displays while graphics capability was still fairly chunky. In the 1980's output are built-in raster graphics, bitmap image and pixel. Personal computers costs decrease drastically; trackball and mouse become the standard interactive devices. In the 1990's, since the introduction of VGA and SVGA, personal computer could easily display photo-realistic images and movies. 3D image renderings became the main advances and it stimulated cinematic graphics applications.

The Table be1ow gives a general history of computer graphics.

1950	Ben Laposky created the first graphic images, an Oscilloscope, generated by an electronic (analog) machine. The image was produced by manipulating electronic beams and recording them onto high-speed film.
1951	(a) UNIVAC-I: the first general purpose commercial computer, crude hardcopy devices, and line printer pictures. (b) MIT – Whirlwind computer, the first to display real time video, and capable of displaying real time text and graphic on a large oscilloscope screen.
1960	William Fetter coins the computer graphics to describe new design methods.
1961	Steve Russel developed Spacewars, the first video/computer game

1953	(a) Douglas Englebart developed first mouse. (b) Ivan Sutherland developed Sketchpad, an interactive Computer Graphics (CG) system, a man-machine graphical communication system with pop-up menus, constraint-based drawing, hierarchical modeling, and utilized light pen for interaction. He formulated the ideas of using primitives, lines polygons, arcs, etc. and constraints on them; He developed the dragging, rubber banding and transforming algorithms; He introduced data structures for storing. He is considered the founder of the computer graphics.
1964	William Fetter developed first computer model of a human figure
1965	Jack Bresenham designed line-drawing algorithm
1968	(a) Tektronix – a special CRT, the direct-view storage tube, with keyboard and mouse, a simple computer interface for $15, 000, which made graphics affordable (b) Ivan Sutherland developed first head-mounted display
1969	(a) John Warnock – area subdivision algorithm, hidden-surface algorithms (b) Bell Labs – first frame buffer containing 3 bits per pixel
1972	Nolan Kay Bushnell – Pong, video arcade game
1973	John Whitney. Jr. and Gary Demos – “Westworld”, first film with computer graphics
1974	(a) Edwin Catmuff –texture mapping and Z-buffer hidden-surface algorithm (b) James Blinn – curved surfaces, refinement of texture mapping (c) Phone Bui-Toung – specular highlighting
1975	(a) Martin Newell – famous Computer Graphics (CG) teapot, using Bezier patches (b) Benoit Mandelbrot – fractal/fractional dimension
1976	James Blinn – environment mapping and bump mapping
1977	Steve Wozniak -- Apple II, color graphics personal computer
1979	Roy Trubshaw and Richard Bartle – MUD, a multi-user dungeon/Zork
1982	(a) Steven Lisberger – “Tron”, first Disney movie which makes extensive use of 3-D graphics (b) Tom Brighman – “Morphing”, first film sequence plays a female character

	which deforms and transforms herself into the shape of a lynx. (c) John Walkner and Dan Drake – AutoCAD
1983	Jaron Lanier – “DataGlove”, a virtual reality film.
1984	Wavefron tech. – Polhemus, first 3D graphics software
1985	(a) Pixar Animation Studios – “Luxo Jr.”, 1989, “ Tin toy” (b) NES – Nintendo home game system
1987	IBM – VGA, Video Graphics Array introduced
1989	Video Electronics Standards Association (VESA) – SVGA, Super VGA formed
1990	Hanrahan and Lawson – Renderman
1991	Disney and Pixar – “Beauty and the Beast”, CGI was widely used, Renderman systems provides fast, accurate and high quality digital computer effects.
1992	Silicon Graphics – OpenGL specification
1993	(a) University of Illinois -- Mosaic, first graphic Web browser (b) Steven Spielberg – “Jurassic Park” a successful CG fiction film.
1995	(a) Buena Vista Pictures – “Toy Story”, first full-length, computer-generated, feature film (b) NVIDIA Corporation – GeForce 256, GeForce3(2001)
2003	ID Software – Doom3 graphics engine

1.5 Basic Terminologies

1.5.1 Pixel

A *Pixel* may be defined as the smallest size object or colour spot that can be displayed and addressed on a monitor. Any image that is displayed on the monitor is made up of thousands of such small pixels (also known as picture elements). The closely-spaced pixels divide the image area into a compact and uniform two-dimensional grid of pixel lines and columns. Each pixel has a particular colour and brightness value. Though the size of a pixel depends mostly on the size of the electron beam within the CRT, they are too fine and close to each other to be perceptible by the human eye. The finer the pixels, the more the numbers of pixels displayable on a monitor screen. However, it should be remembered that the number of pixels in an image is fixed by the program that creates the image and not by the hardware that displays it.

1.5.2 Resolution

Resolution is the maximum number of points displayed on the CRT screen or the number of points/centimeter that can be plotted horizontally and vertically. There are two distinctly different terms, which are often confused. One is *Image Resolution* and the other is *Screen Resolution*. **Image resolution** refers to the pixel spacing (i.e., the distance from one pixel to the next pixel). A typical PC monitor displays screen images with a resolution somewhere between 25 pixels per inch and 80 pixels per inch (ppi).

In other words, **Resolution of an image** refers to the total number of pixels along the entire height and width of the image. For example, a full-screen image with resolution 800 × 600 means that there are 800 columns of pixels, each column comprising 600 pixels,(i.e. a total of 800 × 600 = 4,80,000 pixels in the image area). The internal surface of the monitor screen is coated with red, green and blue phosphor material that glows when struck by a stream of electrons. This coated material is arranged into an array of millions of tiny cells–red, green and blue, usually called *dots*. The ***Dot pitch*** is the distance between adjacent sets (triads) of red, green and blue dots. This is also same as the shortest distance between any two dots of the same colour (i.e., from red- to-red, or, green-to-green like that). Usually monitors are available with a dot pitch specification 0.25 mm to 0.40 mm. Each dot glow with a single pure colour (red, green or blue) and each glowing triad appears to our eye as a small spot of colour (a mixture of red, green and blue). Depending on the intensity of the red, green and blue colours, different colours results in different triads. *The Dot pitch of the monitor thus indicates how fine the coloured spots that make up the picture can be, though electron beam dia is an important factor in determining the spot size.*

Pixel therefore, is the smallest element of a displayed image, and dots (red, green and blue) are the smallest elements of a display surface (monitor screen). The dot pitch is the measure of screen resolution. The smaller the dot pitch, the higher the resolution, sharpness and detail of the image displayed. In order to use different resolutions on a monitor, the monitor must support automatic changing of resolution modes. Originally, monitors were fixed at a particular resolution, but for most monitors today, display resolution can be changed using software control. This lets you use higher or lower resolution depending on the need of your application. A higher resolution display allows you to see more information on your screen at a time and is particularly useful for operating systems such as Windows. However, the resolution of an image you see is a function of what the video card outputs and what the monitor is capable of displaying. To see a high resolution image such as 1280 × 1024, you require both a video card capable of producing an image and a monitor capable of displaying it.

1.5.3 Image Resolution versus Dot Pitch

If the image resolution is more as compared to the inherent resolution of the display device, then the displayed image quality gets reduced. As the image has to fit in the limited resolution of the monitor, the screen pixels (comprising a red, a green and a blue dot) show the average colour and brightness of several adjacent image pixels. Only when the two resolutions match, will the image be displayed perfectly and only then is the monitor used to its maximum capacity.

1.5.4 Aspect Ratio

Aspect ratio is the ratio of vertical points to horizontal points necessary to produce equal length line in both directions on the screen. The *Aspect ratio* of the image is the ratio of the number of X pixels to the number of Y pixels. The standard aspect ratio for PCs is 4:3, and some resolutions even use a ratio of 5:4. Monitors are calibrated to this standard so that when you draw a circle it appears to be a circle and not an ellipse. Displaying an image that uses an aspect ratio of 5:4 will cause the image to appear somewhat distorted. The only mainstream resolution that uses 5:4 is the high-resolution 1280 × 1024.

Resolution	Number of Pixels	Aspect Ratio
320×200	64,000	8:5
640×480	307,200	4:3
800×600	480,000	4:3
1024×768	786,432	4:3
1280×1024	1,310,720	5:4
1600×1200	1,920,000	4:3

Table 1.1: *Common Resolutions, Respective Number of Pixels and Standard Aspect Ratios*

1.5.5 Fluorescence is the term used to refer to the light given off by a phosphor while it is being exposed to an electronic beam. Fluorescence persists for a short lifetime of the transition between the two energy levels.

1.5.6 Phosphorescence is the term used to describe the light given off by a phosphor after it has been exposed to an electron beam. Phosphorescence persists for much longer time (more than 10 -8s).

1.5.7 Persistence:- The duration of phosphorescence exhibited by a phosphor. Persistence is defined as the time it takes the emitted light from the screen to decay to one tenth of its original intensity.

1.6 Graphical User Interface (GUI)

A Graphical User Interface (GUI) is a type of user interface, which allows people to interact with a computer and computer-controlled devices that employ graphical icons, visual indicators or special graphical elements called "widgets", along with text, labels or text navigation to represent the information and actions available to a user. The actions are usually performed through direct manipulation of the graphical elements. The precursor to graphical user interfaces was invented by researchers at the Stanford Research Institute, led by Douglas Engelbart. They developed the use of text-based hyperlinks manipulated with a mouse for the On-Line System. The concept of hyperlinks was further refined and extended to graphics by researchers at Xerox PARC, who went beyond text-based hyperlinks and used a GUI as the primary interface for the Xerox Alto computer. Most modern general-purpose GUIs are derived from this system. As a result, some people call this class of interface a PARC User Interface (PUI). Following PARC, the first commercially successful GUI-centric computer operating models were those of the Apple Lisa but more successfully is that of Macintosh System graphical environment. The graphical user interfaces familiar to most people today are Microsoft Windows, Mac OS X, and the X Window System interfaces. IBM and Microsoft used many of Apple's ideas to develop the Common User Access specifications that formed the basis of the user interface found in Microsoft Windows, IBM OS/2 Presentation Manager, and the Unix Motif toolkit and window manager. The most current graphical user interfaces have largely common idioms.

Graphical user interface design is an important adjunct to application programming. Its goal is to enhance the usability of the underlying logical design of a stored program. The visible graphical interface features of an application are sometimes referred to as "chrome". They include graphical elements (widgets) that may be used to interact with the program. Common widgets are windows, buttons, menus, and scroll bars. *A widget is an element of a graphical user interface (GUI) that displays information or provides a specific way for a user to interact with an application. Widgets include icons, pull-down menus, buttons, selection boxes, progress indicators, on-off checkmarks, scroll bars, windows, window edges (that let you resize the window), toggle buttons, form, and many other devices for displaying information and for inviting, accepting, and responding to user actions.* Larger widgets, such as windows, usually provide a frame or container for the main presentation content such as a web page, email message or drawing. Smaller ones usually act as a user-input tool. The widgets of a well-designed system are functionally independent from and indirectly linked to program functionality, so the graphical user interface can be easily customized, allowing the user to select or design a different *skin* at will. Some graphical user interfaces are designed for the rigorous requirements of vertical markets. These are known as "application specific graphical user interfaces." Examples of application specific graphical user interfaces:

- ✓ Touch screen point of sale software used by wait staff in busy restaurants.
- ✓ Self-service checkouts used in some retail stores.
- ✓ ATMs
- ✓ Airline self-ticketing and check-in
- ✓ Information kiosks in public spaces like train stations and museums
- ✓ Monitor/control screens in embedded industrial applications, which employ a real time operating system (RTOS).

The latest cell phones and handheld game systems also employ application specific touch screen graphical user interfaces. Cars have graphical user interfaces in them. For example, GPS navigation, touch screen multimedia centers, and even on dashboards of the newer cars.

1.7 Graphics Software Standards

A general graphics-programming package provides an extensive set of graphics functions that can be used in a high-level programming language, such as C or FORTRAN. An example of a general graphics-programming package is the GL (Graphics Library) system on Silicon Graphics equipment. Basic functions in a general package include those for generating picture components (straight lines, polygons, circles, and other figures), setting colour and intensity values, selecting views, and applying transformations.

Application graphics packages, on the other hand, are designed for nonprogrammers, so that users can generate displays without worrying about how graphics operations work. The interface to the graphics routines in such packages allows users to communicate with the programs in their own terms. Examples of such applications packages are the artist's painting programs and various business, medical, and CAD systems.

The primary goal of standardized graphics software is portability. When packages are designed with standard graphics functions, software can be moved easily from one hardware system to another and used in different implementations and applications. Without standards, programs designed for one hardware system often cannot be transferred to another system without extensive rewriting of the programs.

A list of graphics standards are:-

- ✓ CGI (the computer graphics interface) which is the low-level interface between GKS and the hardware.
- ✓ CGM (Computer Graphics Metafile) which is defined as the means of communicating between different software packages.
- ✓ 3D-GKS (three-dimensional extension of GKS)
- ✓ PHIGS (Programmers Hierarchical Interactive Graphics System – another three-dimensional standard (based on the old SIGGRAPH core).

1.7.1 Graphical Kernel System (GKS)

The Graphical Kernel System (GKS) is accepted as an international standard for two-dimensional graphics (although largely ignored in the USA). The two-dimensional Computer Graphics is closely related to the six output functions of GKS. These are:-

(a) **Polyline:-** It draws one or more straight lines through the coordinates supplied.

(b) **Polymarker:** - It draws a symbol at each of the coordinates supplied. The software allows the choice of one of the five symmetric symbols, namely: x + * 0 and **'.'.**

(c) **Text:-** This allows a text string to be output in a number of ways, starting at the coordinate given.

(d) **Fill-area:-** This allows a polygon to be drawn and filled, using the coordinates given. Possible types of fill include hollow, solid and a variety of hatching and patterns.

(e) **Cell-array:-** This allows a pattern to be defined and output in the rectangle defined by the coordinates given.

(f) **Generalised Drawing Primitive (GDP):-** This allows the provision of a variety of other facilities. Most systems include software for arcs of circles or ellipses and the drawing of a smooth curve through a set of points.

Following the acceptance of GKS as an international standard, work commenced on two related standards, namely Computer Graphics Metafile (CGI) and Computer Graphics Metafile (CGM). The **Computer Graphics Interface (CGI)** provides a low-level standard between the actual hardware and GKS and specifies how device-drivers should be written. The **Computer Graphics Metafile (CGM)** is used to transfer graphics segments from one computer system to another.

1.7.2 Programmer's Hierarchical Interactive Graphics System (PHIGS)

The Programmer's Hierarchical Interactive Graphics System (PHIGS) is a 3D graphics standard which was developed within ISO in parallel to GKS-3D. The PHIGS standard defines a set of functions and data structures to be used by a programmer to manipulate and display 3-D graphical objects. It was accepted as a full International Standard in 1988. A great deal of PHIGS is identical to GKS-3D, including the primitives, the attributes, the workstation concept, and the viewing and input models. However, PHIGS has a single Central Structure Store (CSS), unlike the separate Workstation Dependent and Workstation Independent Segment Storage (WDSS and WISS) of GKS. The CSS contains Structures which can be configured into a hierarchical directed-graph database, and within the structures themselves are stored the graphics primitives, attributes, and so forth. PHIGS is aimed particularly at highly interactive applications with complicated hierarchical data structures, for example: Mechanical CAD, Molecular Modelling, Simulation and Process Control.

1.7.3 OpenGL

OpenGL provides a powerful but primitive set of rendering commands, and all higher-level drawing must be done in terms of these commands. It is a standard interface developed by Silicon Graphics and subsequently endorsed by Microsoft. OpenGL is a widely accepted standard Application Programming Interface (API) for high-end graphics applications. For example, Code written in OpenGL would typically include subroutine calls to do things like "draw a triangle." The details of exactly how the triangle is drawn are inside OpenGL and are hidden from the applications programmer. This leaves open the possibility of having different implementations of OpenGL, all of which work with the application because they all have the same subprogram calls. Different implementations of OpenGL are written for different graphics accelerators.

The OpenGL Utility Library (GLU) contains several routines that use lower-level OpenGL commands to perform such tasks as setting up matrices for specific viewing orientations and projections, performing polygon tessellation, and rendering surfaces. This library is provided as part of every OpenGL implementation. For every window system, there is a library that extends the functionality of that window system to support OpenGL rendering. For machines that use the X Window System, the OpenGL Extension to the X Window System (GLX) is provided as an adjunct to OpenGL. GLX routines use the prefix **glX**. For Microsoft Windows, the WGL routines provide the Windows to OpenGL interface. The OpenGL Utility Toolkit (GLUT) is a window system-independent toolkit, written by Mark Kilgard, to hide the complexities of differing window system APIs.