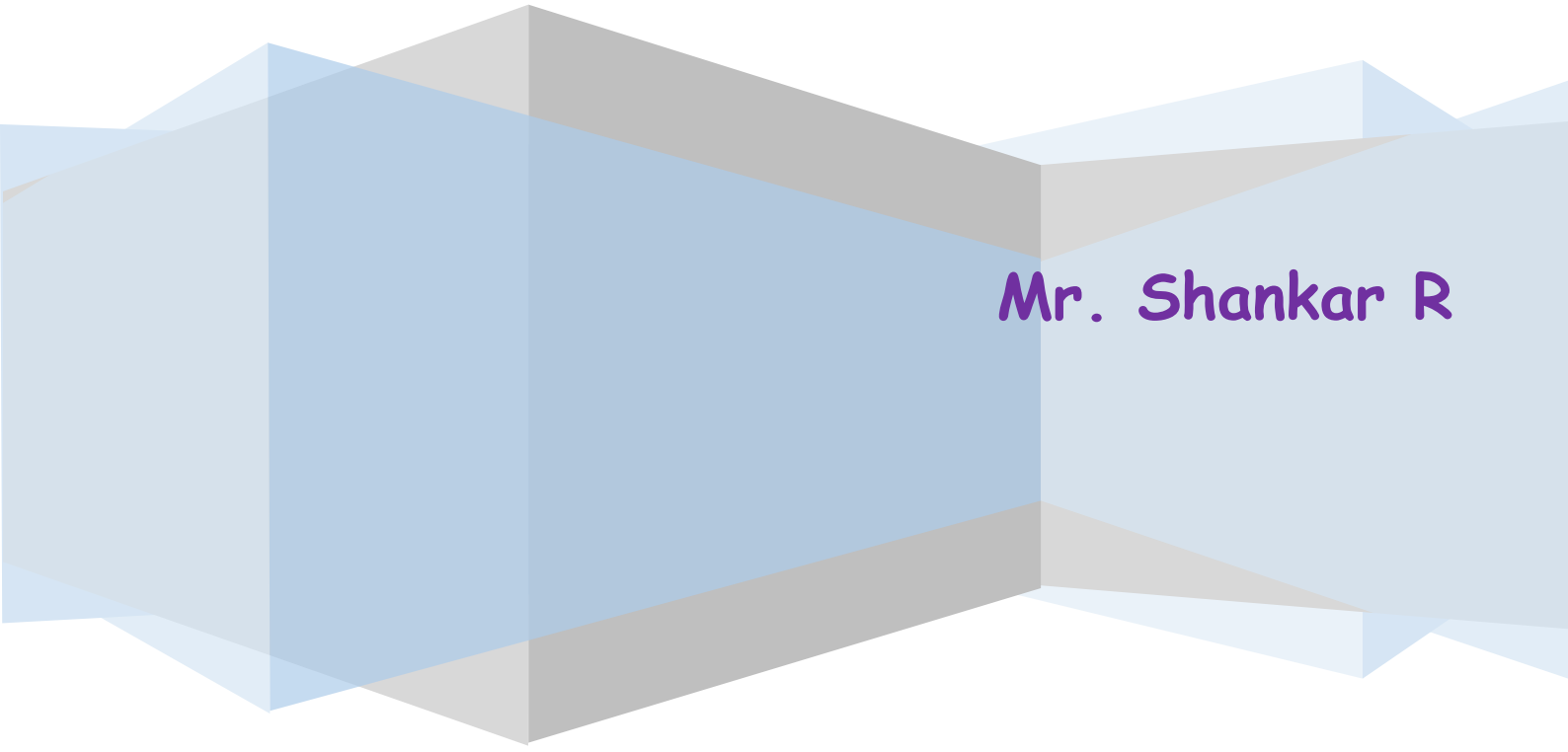
BMSIT & M, Bengaluru -560064

15CSL68 – Computer Graphics Lab Manual

A comprehensive package



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SYLLABUS

PART A

Design, develop, and implement the following programs using OpenGL API

1. Implement Bresenham's line drawing algorithm for all types of slope.
2. Create and rotate a triangle about the origin and a fixed point.
3. Draw a colour cube and spin it using OpenGL transformation matrices.
4. Draw a color cube and allow the user to move the camera suitably to experiment with perspective viewing.
5. Clip a line using Cohen-Sutherland algorithm
6. To draw a simple shaded scene consisting of a tea pot on a table. Define suitably the position and properties of the light source along with the properties of the surfaces of the solid object used in the scene.
7. Design, develop and implement recursively subdivide a tetrahedron to form 3D sierpinski gasket. The number of recursive steps is to be specified by the user.
8. Develop a menu driven program to animate a flag using Bezier Curve algorithm.
9. Develop a menu driven program to fill the polygon using scan line algorithm

PART –B (MINI-PROJECT)

Student should develop mini project on the topics mentioned below or similar applications using Open GL API. Consider all types of attributes like color, thickness, styles, font, background, speed etc., while doing mini project.

(During the practical exam: the students should demonstrate and answer Viva-Voce)

Sample Topics: Simulation of concepts of OS, Data structures, algorithms etc.

Conduction of Practical Examination:

1. All laboratory experiments from part A are to be included for practical examination.
2. Mini project has to be evaluated for 30 Marks as per 6(b).
3. Report should be prepared in a standard format prescribed for project work.
4. Students are allowed to pick one experiment from the lot.
5. Strictly follow the instructions as printed on the cover page of answer script.
6. Marks distribution: a) Part A: Procedure + Conduction + Viva:10 + 35 +5 =50 Marks b) Part B: Demonstration + Report + Viva voce = 15+10+05 = 30 Marks
7. Change of experiment is allowed only once and marks allotted to the procedure part to be made zero.

INTRODUCTION

Computer graphics are graphics created using computers and, more generally, the representation and manipulation of image data by a computer hardware and software. The development of computer graphics, or simply referred to as CG, has made computers easier to interact with, and better for understanding and interpreting many types of data. Developments in computer graphics have had a profound impact on many types of media and have revolutionized the animation and video game industry. 2D computer graphics are digital images—mostly from two-dimensional models, such as 2D geometric models, text (vector array), and 2D data. 3D computer graphics in contrast to 2D computer graphics are graphics that use a three-dimensional representation of geometric data that is stored in the computer for the purposes of performing calculations and rendering images.

OPEN GL

OpenGL is the most extensively documented 3D graphics API(Application Program Interface) to date. Information regarding OpenGL is all over the Web and in print. It is impossible to exhaustively list all sources of OpenGL information. OpenGL programs are typically written in C and C++. One can also program OpenGL from Delphi (a Pascal-like language), Basic, Fortran, Ada, and other langauges. To compile and link OpenGL programs, one will need OpenGL header files. To run OpenGL programs one may need shared or dynamically loaded OpenGL libraries, or a vendor-specific OpenGL Installable Client Driver (ICD).

GLUT

The OpenGL Utility Toolkit (GLUT) is a library of utilities for OpenGL programs, which primarily perform system-level I/O with the host operating system. Functions performed include window definition, window control, and monitoring of keyboard and mouse input. Routines for drawing a number of geometric primitives (both in solid and wireframe mode) are also provided, including cubes, spheres, and cylinders. GLUT even has some limited support for creating pop-up menus. The two aims of GLUT are to allow the creation of rather portable code between operating systems (GLUT is cross-platform) and to make learning OpenGL easier. All GLUT functions start with the glut prefix (for example, glutPostRedisplay marks the current window as needing to be redrawn).

KEY STAGES IN THE OPENGL RENDERING PIPELINE:

- **Display Lists**

All data, whether it describes geometry or pixels, can be saved in a *display list* for current or later use. (The alternative to retaining data in a display list is processing the data immediately - also known as *immediate mode*.) When a display list is executed, the retained data is sent from the display list just as if it were sent by the application in immediate mode

- **Evaluators**

All geometric primitives are eventually described by vertices. Parametric curves and surfaces may be initially described by control points and polynomial functions called basis functions. Evaluators provide a method to derive the vertices used to represent the surface from the control points. The method is a polynomial mapping, which can produce surface normal, texture coordinates, colors, and spatial coordinate values from the control points.

- **Per-Vertex Operations**

For vertex data, next is the "per-vertex operations" stage, which converts the vertices into primitives. Some vertex data (for example, spatial coordinates) are transformed by 4 x 4 floating-point matrices. Spatial coordinates are projected from a position in the 3D world to a position on your screen. If advanced features are enabled, this stage is even busier. If texturing is used, texture coordinates may be generated and transformed here. If lighting is enabled, the lighting calculations are performed using the transformed vertex, surface normal, light source position, material properties, and other lighting information to produce a color value.

- **Primitive Assembly**

Clipping, a major part of primitive assembly, is the elimination of portions of geometry which fall outside a half-space, defined by a plane. Point clipping simply passes or rejects vertices; line or polygon clipping can add additional vertices depending upon how the line or polygon is clipped. In some cases, this is followed by perspective division, which makes distant geometric objects appear smaller than closer objects. Then viewport and depth (z coordinate) operations are applied. If culling is enabled and the primitive is a polygon, it then may be rejected by a culling test. Depending upon the polygon mode, a polygon may be drawn as points or lines.

The results of this stage are complete geometric primitives, which are the transformed and clipped vertices with related color, depth, and sometimes texture-coordinate values and guidelines for the rasterization step.

- **Pixel Operations**

While geometric data takes one path through the OpenGL rendering pipeline, pixel data takes a different route. Pixels from an array in system memory are first unpacked from one of a variety of formats into the proper number of components. Next the data is scaled, biased, and processed by a pixel map. The results are clamped and then either written into texture memory or sent to the rasterization step If pixel data is read from the frame buffer, pixel-transfer operations (scale, bias, mapping, and clamping) are performed. Then these results are packed into an appropriate format and returned to an array in system memory.

There are special pixel copy operations to copy data in the framebuffer to other parts of the framebuffer or to the texture memory. A single pass is made through the pixel transfer operations before the data is written to the texture memory or back to the framebuffer.

- **Texture Assembly**

An OpenGL application may wish to apply texture images onto geometric objects to make them look more realistic. If several texture images are used, it's wise to put them into texture objects so that you can easily switch among them.

Some OpenGL implementations may have special resources to accelerate texture performance. There may be specialized, high-performance texture memory. If this memory is available, the texture objects may be prioritized to control the use of this limited and valuable resource.

- **Rasterization**

Rasterization is the conversion of both geometric and pixel data into *fragments*. Each fragment square corresponds to a pixel in the framebuffer. Line and polygon stipples, line width, point size, shading model, and coverage calculations to support antialiasing are taken into consideration as vertices are connected into lines or the interior pixels are calculated for a filled polygon. Color and depth values are assigned for each fragment square.

- **Fragment Operations**

Before values are actually stored into the framebuffer, a series of operations are performed that may alter or even throw out fragments. All these operations can be enabled or disabled.

The first operation which may be encountered is texturing, where a texel (texture element) is generated from texture memory for each fragment and applied to the fragment. Then fog calculations may be applied, followed by the scissor test, the alpha test, the stencil test, and the depth-buffer test (the depth buffer is for hidden-surface removal). Failing an enabled test may end the continued processing of a fragment's square. Then, blending, dithering, logical operation, and masking by a bitmask may be performed.Finally, the thoroughly processedfragment is drawn into the appropriate buffer, where it has finally advanced to be a pixel and achieved its final resting place.

- **OpenGL-Related Libraries**

OpenGL provides a powerful but primitive set of rendering commands, and all higher-level drawing must be done in terms of these commands. Also, OpenGL programs have to use the underlying mechanisms of the windowing system. A number of libraries exist to allow you to simplify your programming tasks, including the following:

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. Portions of the GLU are described in the *OpenGL*

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. All WGL routines use the prefix wgl. For IBM OS/2, the PGL is the Presentation Manager to OpenGL interface, and its routines use the prefix pgl.

The OpenGL Utility Toolkit (GLUT) is a window system-independent toolkit, written by Mark Kilgard, to hide the complexities of differing window system APIs. Open Inventor is an object-oriented toolkit based on OpenGL which provides objects and methods for creating interactive three-dimensional graphics applications. Open Inventor, which is written in C++, provides prebuilt objects and a built-in event model for user interaction, high-level application components for creating and editing three-dimensional scenes, and the ability to print objects and exchange data in other graphics formats. Open Inventor is separate from OpenGL.

- **GLUT, the OpenGL Utility Toolkit**

As you know, OpenGL contains rendering commands but is designed to be independent of any window system or operating system. Consequently, it contains no commands for opening windows or reading events from the keyboard or mouse. Unfortunately, it's impossible to write a complete graphics program without at least opening a window, and most interesting programs require a bit of user input or other services from the operating system or window system. In many cases, complete programs make the most interesting examples, so this book uses GLUT to simplify opening windows, detecting input, and so on. If you have an implementation of OpenGL and GLUT on your system, the examples in this book should run without change when linked with them.

In addition, since OpenGL drawing commands are limited to those that generate simple geometric primitives (points, lines, and polygons), GLUT includes several routines that create more complicated three-dimensional objects such as a sphere, a torus, and a teapot. This way, snapshots of program output can be interesting to look at. (Note that the OpenGL Utility Library, GLU, also has quadrics routines that create some of the same three-dimensional objects as GLUT, such as a sphere, cylinder, or cone.)

GLUT may not be satisfactory for full-featured OpenGL applications, but you may find it a useful starting point for learning OpenGL. The rest of this section briefly describes a small subset of GLUT routines so that you can follow the programming examples in the rest of this book.

OBJECTIVE AND APPLICATION OF THE LAB

The objective of this lab is to give students hands on learning exposure to understand and apply computer graphics with real world problems. The lab gives the direct experience to Visual Basic Integrated Development Environment (IDE) and GLUT toolkit. The students get a real world exposure to Windows programming API. Applications of this lab are profoundly felt in gaming industry, animation industry and Medical Image Processing Industry. The materials learned here will useful in Programming at the Software Industry.

Setting up GLUT - main()

GLUT provides high-level utilities to simplify OpenGL programming, especially in interacting with the Operating System (such as creating a window, handling key and mouse inputs). The following GLUT functions were used in the above program:

- **glutInit:** initializes GLUT, must be called before other GL/GLUT functions. It takes the same arguments as the main().

  void **glutInit**(int *argc, char **argv)

- **glutCreateWindow:** creates a window with the given title.

  int **glutCreateWindow**(char *title)

- **glutInitWindowSize:** specifies the initial window width and height, in pixels.

  void **glutInitWindowSize**(int width, int height)

- **glutInitWindowPosition:** positions the top-left corner of the initial window at (x, y). The coordinates (x, y), in term of pixels, is measured in window coordinates, i.e., origin (0, 0) is at the top-left corner of the screen; x-axis pointing right and y-axis pointing down.

  void **glutInitWindowPosition**(int x, int y)

- **glutDisplayFunc:** registers the callback function (or event handler) for handling window-paint event. The OpenGL graphic system calls back this handler when it receives a window re-paint request. In the example, we register the function display() as the handler.

  void **glutDisplayFunc**(void (*func)(void))

- **glutMainLoop:** enters the infinite event-processing loop, i.e, put the OpenGL graphics system to wait for events (such as re-paint), and trigger respective event handlers (such as display()).

  void **glutMainLoop**()

- **glutInitDisplayMode:** requests a display with the specified mode, such as color mode (GLUT_RGB, GLUT_RGBA, GLUT_INDEX), single/double buffering (GLUT_SINGLE, GLUT_DOUBLE), enable depth (GLUT_DEPTH), joined with a bit OR '|'.

  void **glutInitDisplayMode**(unsigned int displayMode)

- **void glMatrixMode (GLenum mode);**

  The **glMatrixMode** function specifies which matrix is the current matrix.

- **void glOrtho(GLdoubleleft,GLdoubleright,GLdoublebottom,GLdoubletop,GLdoublezNear,GLdoublezFar);**

  The **glOrtho** function multiplies the current matrix by an orthographic matrix.

- **void glPointSize (GLfloat size);**

  The **glPointSize** function specifies the diameter of rasterized points.

- **voidglutPostRedisplay(void);**

  glutPostRedisplay marks the current window as needing to be redisplayed.

- **void glPushMatrix (void);**

  void glPopMatrix (void);

  The **glPushMatrix** and **glPopMatrix** functions push and pop the current matrix stack.

- **GLintglRenderMode (GLenum mode);**

  The **glRenderMode** function sets the rasterization mode.

- **void glRotatef (GLfloat angle, GLfloat x, GLfloat y, GLfloat);**

  The glRotatef functions multiply the current matrix by a rotation matrix.

- **void glScalef (GLfloat x, GLfloat y, GLfloat z);**

  The **glScalef** functions multiply the current matrix by a general scaling matrix.

- **void glTranslatef (GLfloat x, GLfloat y, GLfloat z);**

  The glTranslatef functions multiply the current matrix by a translation matrix.

- **void glViewport (GLint x, GLint y, GLsizei width, GLsizei height);**

  The **glViewport** function sets the viewport.

- **void glEnable, glDisable();**

  The **glEnable** and **glDisable** functions enable or disable OpenGL capabilities.

- **glutBitmapCharacter();**

  The **glutBitmapCharacter** function used for font style.

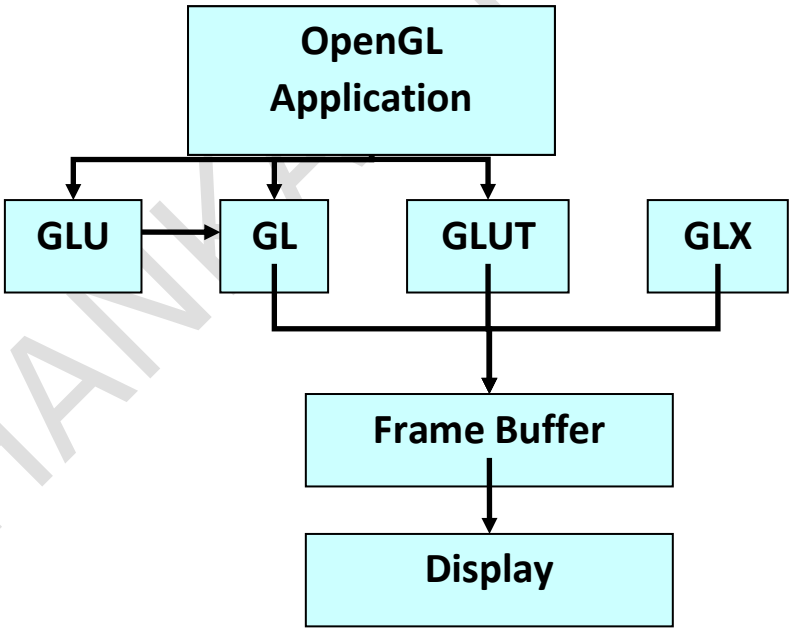
OpenGL Primitives

Value	Meaning
GL_POINTS	individual points
GL_LINES	pairs of vertices interpreted as individual line segments
GL_POLYGON	boundary of a simple, convex polygon
GL_TRIANGLES	triples of vertices interpreted as triangles
GL_QUADS	quadruples of vertices interpreted as four-sided polygons
GL_LINE_STRIP	series of connected line segments
GL_LINE_LOOP	same as above, with a segment added between last and first vertices
GL_TRIANGLE_STRIP	linked strip of triangles
GL_TRIANGLE_FAN	linked fan of triangles
GL_QUAD_STRIP	linked strip of quadrilaterals

INTRODUCTION TO openGL

OpenGL is an API.OpenGL is nothing more than a set of functions you call from your program (think of as collection of .h files.

OpenGL Libraries:



OpenGL Hierarchy:

- Several levels of abstraction are provided
- GL
  - Lowest level: vertex, matrix manipulation
  - glVertex3f(point.x, point.y, point.z)
- GLU

- Helper functions for shapes, transformations
- gluPerspective(fovy, aspect, near, far)
- gluLookAt(0, 0, 10, 0, 0, 0, 0, 1, 0);

- GLUT
  - Highest level: Window and interface management
  - glutSwapBuffers()
  - glutInitWindowSize (500, 500);

OpenGL Implementations :

- OpenGL IS an API (think of as collection of .h files):
  - #include <GL/gl.h>
  - #include <GL/glu.h>
  - #include <GL/glut.h>
- Windows, Linux, UNIX, etc. all provide a platform specific implementation.
- Windows: opengl32.lib glu32.lib glut32.lib
- Linux: -l GL -l GLU –l GLUT

Event Loop:

- OpenGL programs often run in an event loop:
  - Start the program
  - Run some initialization code
  - Run an infinite loop and wait for events such as
    - Key press
    - Mouse move, click
    - Reshape window
    - Expose event

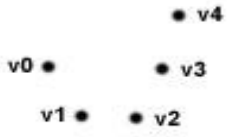
OpenGL Command Syntax (1) :

- OpenGL commands start with “gl”
- OpenGL constants start with “GL_”
- Some commands end in a number and one, two or three letters at the end (indicating number and type of arguments)
- A Number indicates number of arguments
- Characters indicate type of argument

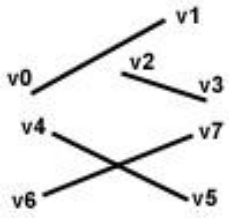
OpenGL Command Syntax (2)

- `f' float
- `d' double float
- `s' signed short integer
- `i' signed integer
- `b' character
- `ub' unsigned character
- `us' unsigned short integer
- `ui' unsigned integer

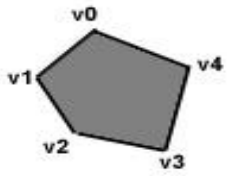
Ten gl Primitives:



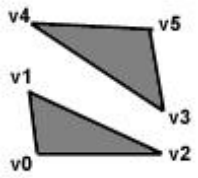
GL_POINTS



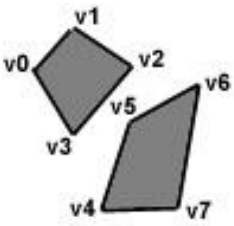
GL_LINES



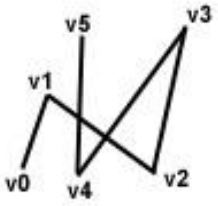
GL_POLYGON



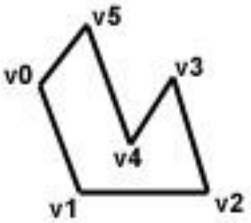
GL_TRIANGLES



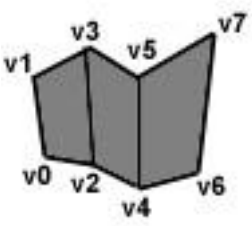
GL_QUADS



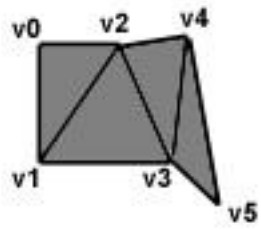
GL_LINE_STRIP



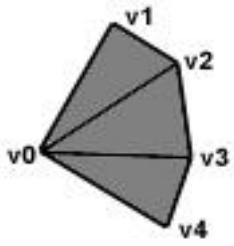
GL_LINE_LOOP



GL_QUAD_STRIP



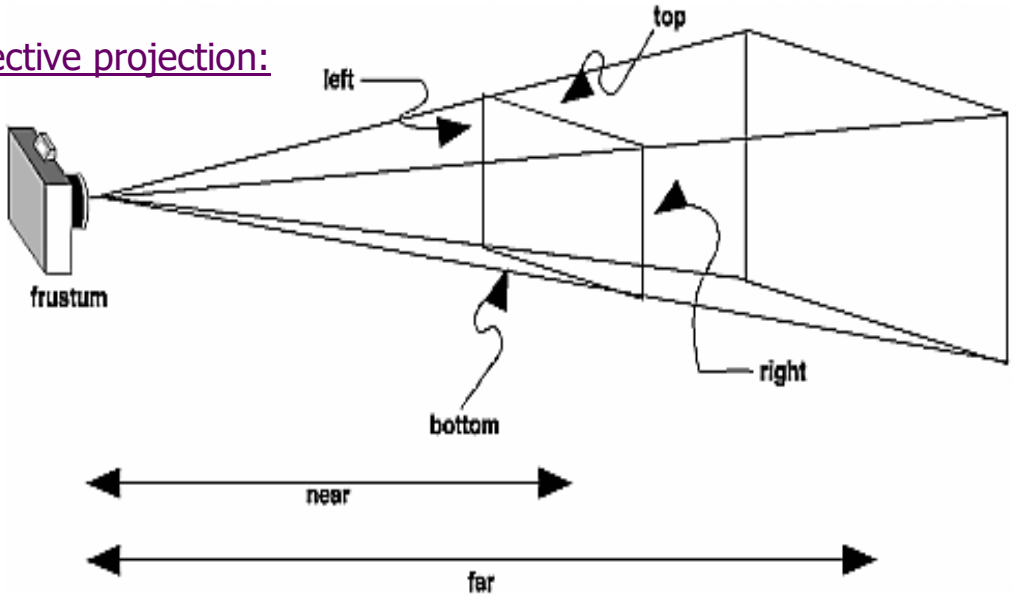
GL_TRIANGLE_STRIP



GL_TRIANGLE_FAN

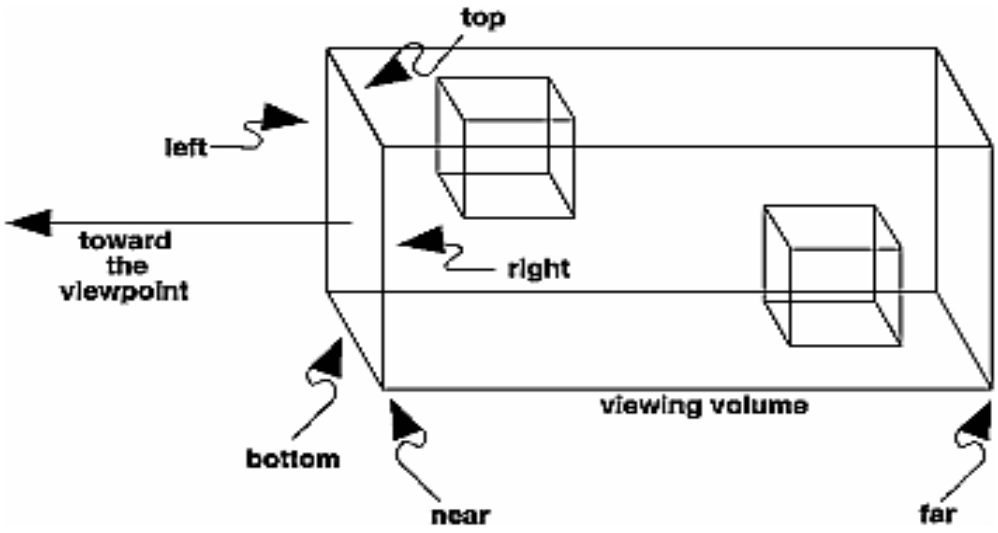
Projections in OpenGL

Perspective projection:



*void **glFrustum**(GLdouble left, GLdouble right, GLdouble bottom,GLdouble top, GLdouble near, GLdouble far);*

Orthographic projection:



*void **glOrtho**(GLdouble left, GLdouble right, GLdouble bottom,*

GLdouble top, GLdouble near, GLdouble far)

Viva questions and answers

1. What is Computer Graphics? Answer: Computer graphics are graphics created using computers and, more generally, the representation and manipulation of image data by a computer.
2. What is OpenGL? Answer: OpenGL is the most extensively documented 3D graphics API (Application Program Interface) to date. It is used to create Graphics.
3. What is GLUT? Answer: The OpenGL Utility Toolkit (GLUT) is a library of utilities for OpenGL programs, which primarily perform system-level I/O with the host operating system.
4. What are the applications of Computer Graphics? Answer: Gaming Industry, Animation Industry and Medical Image Processing Industries. The sum total of these industries is a Multi Billion Dollar Market. Jobs will continue to increase in this arena in the future.
5. Explain in breif 3D Sierpinski gasket? Answer: The Sierpinski triangle (also with the original orthography Sierpinski), also called the Sierpinski gasket or the Sierpinski Sieve, is a fractal named after the Polish mathemati-cian Waclaw Sierpinski who described it in 1915. Originally constructed as a curve, this is one of the basic examples of self-similar sets, i.e. it is a mathematically generated pattern that can be reproducible at any magnifcation or reduction.
6. What is Liang-Barsky line clipping algorithm? Answer: In computer graphics, the Liang-Barsky algorithm is a line clipping algorithm. The Liang-Barsky algorithm uses the parametric equation of a line and inequalities describing the range of the clipping box to determine the intersections between the line and the clipping box. With these intersections it knows which portion of the line should be drawn.
7. Explain in brief Cohen-Sutherland line-clipping algorithm? Answer: The Cohen-Sutherland line clipping algorithm quickly detects and dispenses with two common and trivial cases. To clip a line, we need to consider only its endpoints. If both endpoints of a line lie inside the window, the entire line lies inside the window. It is trivially accepted and needs no clipping. On the other hand, if both endpoints of a line lie entirely to one side of the window, the line must lie entirely outside of the window. It is trivially rejected and needs to be neither clipped nor displayed.
8. Explain in brief scan-line area flling algorithm? Answer: The scanline fll algorithm is an ingenious way of flling in irregular polygons. The algorithm begins with a set of points. Each point is connected to the next, and the line between them is considered to be an edge of the polygon. The points of each edge are adjusted to ensure that the point with the smaller y value appears frst. Next, a data structure is created that contains a list of edges that begin on each scanline of the image. The program progresses from the frst scanline upward. For each line, any pixels that contain an intersection between this scanline and an edge of the polygon are flled in. Then, the algorithm progresses along the scanline, turning on when it reaches a polygon pixel and turning of when it reaches another one, all the way across the scanline.

9. Explain Midpoint Line algorithm Answer: The Midpoint line algorithm is an algorithm which determines which points in an n-dimensional raster should be plotted in order to form a close approximation to a straight line between two given points. It is commonly used to draw lines on a computer screen, as it uses only integer addition, subtraction and bit shifting, all of which are very cheap operations in standard computer architectures.

10. What is a Pixel? Answer: In digital imaging, a pixel (or picture element) is a single point in a raster image. The Pixel is the smallest addressable screen element; it is the smallest unit of picture which can be controlled. Each Pixel has its address. The address of Pixels corresponds to its coordinate. Pixels are normally arranged in a 2-dimensional grid, and are often represented using dots or squares.

11. What is Graphical User Interface? Answer: A graphical user interface (GUI) is a type of user interface item that allows people to interact with programs in more ways than typing such as computers; hand-held devices such as MP3 Players, Portable Media Players or Gaming devices; household appliances and ofce equipment with images rather than text commands.

12. What is the general form of an OpenGL program? Answer: There are no hard and fast rules. The following pseudocode is generally recognized as good OpenGL form. program entrypoint { // Determine which depth or pixel format should be used. // Create a window with the desired format. // Create a rendering context and make it current with the window. // Set up initial OpenGL state. // Set up callback routines for window resize and window refresh. } handle resize { glViewport(...); glMatrixMode(GL PROJECTION); glLoadIdentity(); // Set projection transform with glOrtho, glFrustum, gluOrtho2D, gluPerspective, etc. } handle refresh { glClear(...); glMatrixMode(GL MODELVIEW); glLoadIdentity(); // Set view transform with gluLookAt or equivalent // For each object (i) in the scene that needs to be rendered: // Push relevant stacks, e.g., glPushMatrix, glPushAttrib. // Set OpenGL state specifc to object (i). // Set model transform for object (i) using glTranslatef, glScalef, glRotatef, and/or equivalent. // Issue rendering commands for object (i). // Pop relevant stacks, (e.g., glPopMatrix, glPopAttrib.) // End for loop. // Swap bufers. }

13. What support for OpenGL does Open,Net,FreeBSD or Linux provide? Answer: The X Windows implementation, XFree86 4.0, includes support for OpenGL using Mesa or the OpenGL Sample Implementation. XFree86 is released under the XFree86 license. http://www.xfree86.org/

14. What is the AUX library? Answer: The AUX library was developed by SGI early in OpenGL's life to ease creation of small OpenGL demonstration programs. It's currently neither supported nor maintained. Developing OpenGL programs using AUX is strongly discouraged. Use the GLUT instead. It's more fexible and powerful and is available on a wide range of platforms. Very important: Don't use AUX. Use GLUT instead.

15. How does the camera work in OpenGL? Answer: As far as OpenGL is concerned, there is no camera. More specifcally, the camera is always located at the eye space coordinate (0., 0., 0.). To give the appearance of moving the camera, your OpenGL application must move the scene with the inverse of the camera transformation.

16. How do I implement a zoom operation? Answer: A simple method for zooming is to use a uniform scale on the ModelView matrix. However, this often results in clipping by the zNear and zFar clipping planes if the model is scaled too large. A better method is to restrict the width and height of the view volume in the Projection matrix.

17. What are OpenGL coordinate units? Answer: Depending on the contents of your geometry database, it may be convenient for your application to treat one OpenGL coordinate unit as being equal to one millimeter or one parsec or anything in between (or larger or smaller). OpenGL also lets you specify your geometry with coordinates of difering values. For example, you may fnd it convenient to model an airplane's controls in centimeters, its fuselage in meters, and a world to fy around in kilometers. OpenGL's ModelView matrix can then scale these diferent coordinate systems into the same eye coordinate space. It's the application's responsibility to ensure that the Projection and ModelView matrices are constructed to provide an image that keeps the viewer at an appropriate distance, with an appropriate feld of view, and keeps the zNear and zFar clipping planes at an appropriate range. An application that displays molecules in micron scale, for example, would probably not want to place the viewer at a distance of 10 feet with a 60 degree feld of view.

18. What is Microsoft Visual Studio? Answer: Microsoft Visual Studio is an integrated development environment (IDE) for developing windows applications. It is the most popular IDE for developing windows applications or windows based software.

19. What does the .gl or .GL fle format have to do with OpenGL? Answer: .gl fles have nothing to do with OpenGL, but are sometimes confused with it. .gl is a fle format for images, which has no relationship to OpenGL.

20. Who needs to license OpenGL? Who doesn't? Is OpenGL free software? Answer: Companies which will be creating or selling binaries of the OpenGL library will need to license OpenGL. Typical examples of licensees include hardware vendors, such as Digital Equipment, and IBM who would distribute OpenGL with the system software on their workstations or PCs. Also, some software vendors, such as Portable Graphics and Template Graphics, have a business in creating and distributing versions of OpenGL, and they need to license OpenGL. Applications developers do NOT need to license OpenGL. If a developer wants to use OpenGL that developer needs to obtain copies of a linkable OpenGL library for a particular machine. Those OpenGL libraries may be bundled in with the development and/or run-time options or may be purchased from a third-party software vendor, without licensing the source code or use of the OpenGLtrademark.

21. How do we make shadows in OpenGL? Answer: There are no individual routines to control neither shadows nor an OpenGL state for shadows. However, code can be written to render shadows.

22. What is the use of Glutinit? Answer: void glutInit(int *argcp, char **argv); glutInit will initialize the GLUT library and negotiate a session with the window system. During this process, glutInit may cause the termination of the GLUT program with an error message to the user if GLUT cannot be properly initialized.

23. Describe the usage of glutInitWindowSize and glutInitWindowPosition? Answer: void glutInitWindowSize(int width, int height); void glutInitWindowPosition(int x, int y); Windows created by glutCreateWindow will be requested to be created with the current initial window position and size. The intent of the initial window position and size values is

to provide a suggestion to the window system for a window's initial size and position. The window system is not obligated to use this information. Therefore, GLUT programs should not assume the window was created at the specifed size or position. A GLUT program should use the window's reshape callback to determine the true size of the window.

24. Describe the usage of glutMainLoop? Answer: void glutMainLoop(void); glutMainLoop enters the GLUT event processing loop. This routine should be called at most once in a GLUT program. Once called, this routine will never return. It will call as necessary any callbacks that have been registered.