Introduction to OpenGL

OpenGL is a low-level graphics library specification. It makes available to the programmer a small set of geometric primitives - points, lines, polygons, images, and bitmaps. OpenGL provides a set of commands that allow the specification of geometric objects in two or three dimensions, using the provided primitives, together with commands that control how these objects are rendered (drawn).

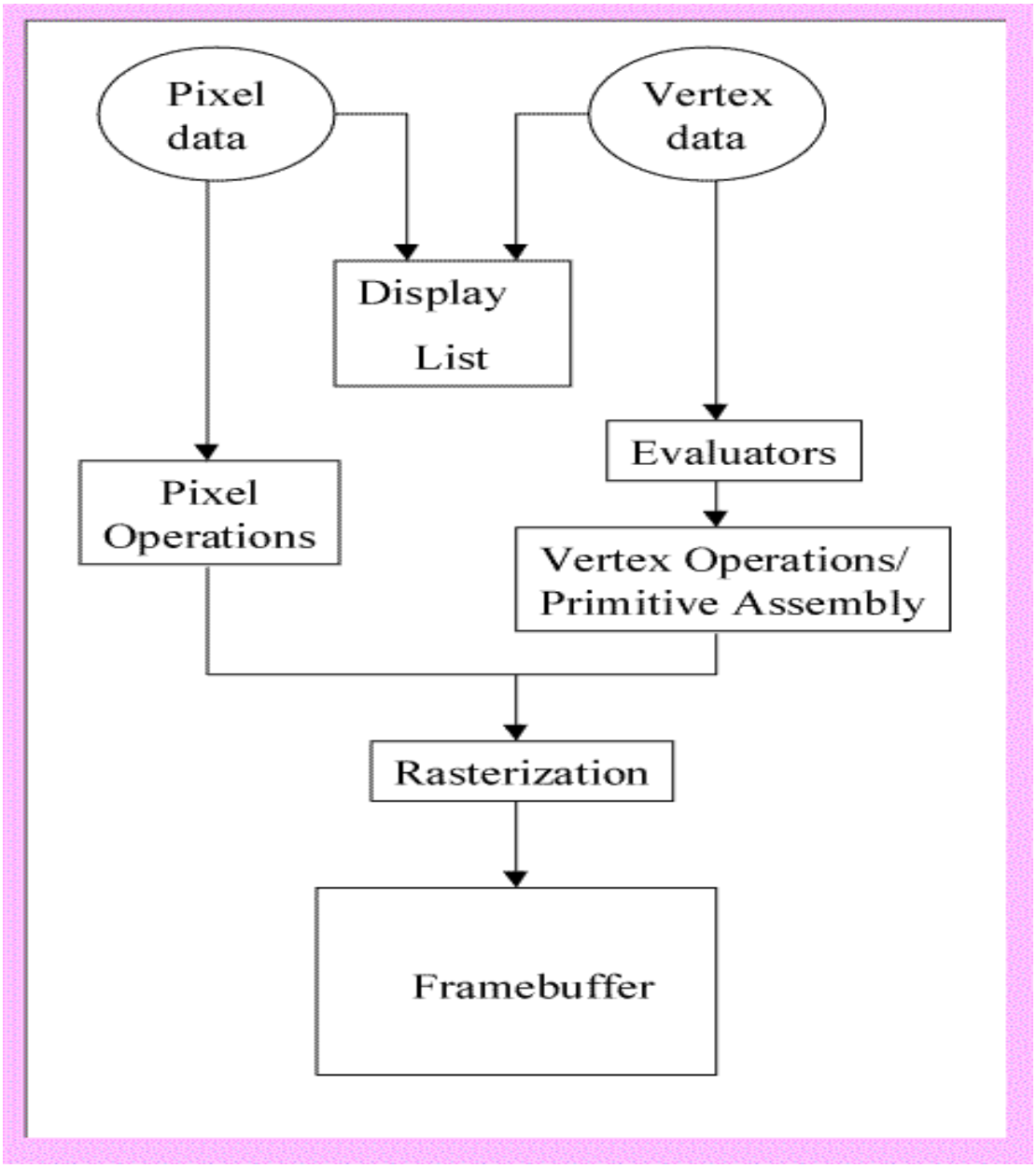
Since OpenGL drawing commands are limited to those that generate simple geometric primitives (points, lines, and polygons), the OpenGL Utility Toolkit (GLUT) has been created to aid in the development of more complicated three-dimensional objects such as a sphere, a torus, and even a teapot. GLUT may not be satisfactory for full-featured OpenGL applications, but it is a useful starting point for learning OpenGL.

GLUT is designed to fill the need for a window system independent programming interface for OpenGL programs. The interface is designed to be simple yet still meet the needs of useful OpenGL programs. Removing window system operations from OpenGL is a sound decision because it allows the OpenGL graphics system to be retargeted to various systems including powerful but expensive graphics workstations as well as mass-production graphics systems like video games, set-top boxes for interactive television, and PCs.

GLUT simplifies the implementation of programs using OpenGL rendering. The GLUT application programming interface (API) requires very few routines to display a graphics scene rendered using OpenGL. The GLUT routines also take relatively few parameters.

1.1 Rendering Pipeline

Most implementations of OpenGL have a similar order of operations, a series of processing stages called the OpenGL rendering pipeline. Although this is not a strict rule of how OpenGL is implemented, it provides a reliable guide for predicting what OpenGL will do. Geometric data (vertices, line, and polygons) follow a path through the row of boxes that includes evaluators and per-vertex operations, while pixel data (pixels, images and bitmaps) are treated differently for part of the process. Both types of data undergo the same final step (rasterization) before the final pixel data is written to the frame buffer.



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-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. Evaluators provide a method for deriving the vertices used to represent the surface from the control points. The method is a polynomial mapping, which can produce surface normal, colors, and spatial coordinate values from the control points.

Per-Vertex and Primitive Assembly: For vertex data, the next step converts the vertices into primitives. Some types of vertex data are transformed by 4x4 floating-point matrices. Spatial coordinates are projected from a position in the 3D world to a position on your screen. In some cases, this is followed by perspective division, which makes distant geometric objects appear smaller than closer objects. Then view port and depth operations are applied. The results at this point are geometric primitives, which are transformed with related color and depth 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 form one of a variety of formats into the proper number of components. Next the data is scaled, biased, processed by a pixel map, and sent to the rasterization step.

Rasterization: Rasterization is the conversion of both geometric and pixel data into fragments. Each fragment square corresponds to a pixel in the frame buffer. Line width, point size, shading model, and coverage calculations to support antialiasing are taken it to 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. The processed fragment is then drawn into the appropriate buffer, where it has finally advanced to be a pixel and achieved its final resting place.

1.2 Libraries

OpenGL provides a powerful but primitive set of rendering command, and all higher-level drawing must be done in terms of these commands. There are several libraries that allow you to simplify your programming tasks, including the following:

- 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 and rendering surfaces.
- OpenGL Utility Toolkit (GLUT) is a window-system-independent toolkit, written by Mark Kilgard, to hide the complexities of differing window APIs.

1.3 Include Files

For all OpenGL applications, you want to include the gl.h header file in every file. Almost all OpenGL applications use GLU, the aforementioned OpenGL Utility Library, which also requires inclusion of the glu.h header file. So almost every OpenGL source file begins with:

#include<GL/gl.h>
#include <GL/glu.h>

If you are using the OpenGL Utility Toolkit (GLUT) for managing your window manager tasks, you should include:

#include <GL/glut.h>

Note that glut.h guarantees that gl.h and glu.h are properly included for you so including these three files is redundant. To make your GLUT programs portable, include glut.h and do not include gl.h or glu.h explicitly.

1.4 Setting up Compilers

- **Windows Using MS Visual C++**

  Installing GLUT

  Most of the following files (ie. OpenGL and GLU) will already be present if you have installed MS Visual C++ v5.0 or later. The following GLUT files will need to be copied into the specified directories.

  1. To install:
     - right-click each link
     - choose **Save Link As...**
     - accept the default name (just click **Save**)
     - libraries (place in the **lib**\ subdirectory of Visual C++)
       - opengl32.lib
       - glu32.lib
       - glut32.lib
     - include files (place in the **include\GL**\ subdirectory of Visual C++)
       - gl.h
       - glu.h
       - glut.h
     - dynamically-linked libraries (place in the **Windows\System** subdirectory
       - opengl32.dll
       - glu32.dll
       - glut32.dll

Compiling OpenGL/GLUT Programs

1. Create a new project:
    - choose **File | New** from the File Menu
    - select the **Projects** tab
    - choose **Win32 Console Application**
    - fill in your Project name
2. Designate library files for the linker to use:
    - choose **Project | Settings** from the File Menu
    - under **Oject/library modules:** enter "opengl32.lib glu32.lib glut32.lib"
3. Add/Create files to the project:
    - choose **Project | Add to Project | Files** from the File menu
    - add the required program files
4. Build and Execute

1.5 Initialization

The first thing we need to do is call the glutInit() procedure. It should be called before any other GLUT routine because it initializes the GLUT library. The parameters to glutInit() should be the same as those to main(), specifically main(int argc, char** argv) and glutInit(&argc, argv), where argcp is a pointer to the program's unmodified argc variable from main. Upon return, the value pointed to by argcp will be updated, and argv is the program's unmodified argv variable from main. Like argcp, the data for argv will be updated.

The next thing we need to do is call the glutInitDisplayMode() procedure to specify the display mode for a window. You must first decide whether you want to use an RGBA (GLUT_RGBA) or color-index (GLUT_INDEX) color model. The RGBA mode stores its color buffers as red, green, blue, and alpha color components. The forth color component, alpha, corresponds to the notion of opacity. An alpha value of 1.0 implies complete opacity, and an alpha value of 0.0 complete transparancy. Color-index mode, in contrast, stores color buffers in indices. Your decision on color mode should be based on hardware availability and what you application requires. More colors can usually be simultaneously represented with RGBA mode than with color-index mode. And for special effects, such as shading, lighting, and fog, RGBA mode provides more flexibility. In general, use RGBA mode whenever possible. RGBA mode is the default.

Another decision you need to make when setting up the display mode is whether you want to use single buffering (GLUT_SINGLE) or double buffering (GLUT_DOUBLE). Applications that use both front and back color buffers are double-buffered. Smooth animation is accomplished by rendering into only the back buffer (which isn't displayed), then causing the front and back buffers to be swapped. If you aren't using animation, stick with single buffering, which is the default.

Finally, you must decide if you want to use a depth buffer (GLUT_DEPTH), a stencil buffer (GLUT_STENCIL) and/or an accumulation buffer (GLUT_ACCUM). The depth buffer stores a depth value for each pixel. By using a "depth test", the depth buffer can be used to display objects with a smaller depth value in front of objects with a larger depth value. The second buffer, the stencil buffer is used to restrict drawing to certain portions of the screen, just as a cardboard stencil can be used with a can of spray paint to make a printed image. Finally, the accumulation buffer is used for accumulating a series of images into a final composed image. None of these are default buffers.

We need to create the characteristics of our window. A call to glutInitWindowSize() will be used to specify the size, in pixels, of your initial window. The arguments indicate the height and width (in pixels) of the requested window. Similarly, glutInitWindowPosition() is used to specify the screen location for the upper-left corner of your initial window. The arguments, x and y, indicate the location of the window relative to the entire display.

1.6 Creating a Window

To actually create a window, the with the previously set characteristics (display mode, size, location, etc), the programmer uses the glutCreateWindow() command. The command takes a string as a parameter which may appear in the title bar if the window system you are using supports it. The window is not actually displayed until the glutMainLoop() is entered.

1.7 Display Function

The glutDisplayFunc() procedure is the first and most important event callback function you will see. A callback function is one where a programmer-specified routine can be registered to be called in response to a specific type of event. For example, the argument of glutDisplayFunc() is the function that is called whenever GLUT determines that the contents of

the window needs to be redisplayed. Therefore, you should put all the routines that you need to draw a scene in this display callback function.

1.8 Reshape Function

The glutReshapeFunc() is a callback function that specifies the function that is called whenever the window is resized or moved. Typically, the function that is called when needed by the reshape function displays the window to the new size and redefines the viewing characteristics as desired. If glutReshapeFunc() is not called, a default reshape function is called which sets the view to minimize distortion and sets the display to the new height and width.

1.9 Main Loop

The very last thing you must do is call glutMainLoop(). All windows that have been created can now be shown, and rendering those windows is now effective. The program will now be able to handle events as they occur (mouse clicks, window resizing, etc). In addition, the registered display callback (from our glutDisplayFunc()) is triggered. Once this loop is entered, it is never exited!

Geometric Objects used in graphics

2.1 Point, Lines and Polygons

Each geometric object is described by a set of vertices and the type of primitive to be drawn. A vertex is no more than a point defined in three dimensional space. Whether and how these vertices are connected is determined by the primitive type. Every geometric object is ultimately described as an ordered set of vertices. We use the glVertex*() command to specify a vertex. The '*' is used to indicate that there are variations to the base command glVertex().

Some OpenGL command names have one, two, or three letters at the end to denote the number and type of parameters to the command. The first character indicates the number of values of the indicated type that must be presented to the command. The second character indicates the specific type of the arguments. The final character, if present, is 'v', indicating that the command takes a pointer to an array (a vector) of values rather than a series of individual agreements.

For example, in the command glVertex3fv(), '3' is used to indicate three arguments, 'f' is used to indicate the arguments are floating point, and 'v' indicates that the arguments are in vector format.

Points: A point is represented by a single vertex. Vertices specified by the user as two-dimensional (only x- and y-coordinates) are assigned a z-coordinate equal to zero. To control the size of a rendered point, use glPointSize() and supply the desired size in pixels as the argument. The default is as 1 pixel by 1 pixel point. If the width specified is 2.0, the point will be a square of 2 by 2 pixels. glVertex*() is used to describe a point, but it is only effective between a glBegin() and a glEnd() pair. The argument passed to glBegin() determines what sort of geometric primitive is constructed from the vertices.

Lines: In OpenGL, the term line refers to a line segment, not the mathematician's version that extends to infinity in both directions. The easiest way to specify a line is in terms of the vertices at the endpoints. As with the points above, the argument passed to glBegin() tells it what to do with the vertices. The option for lines includes:

GL_LINES: Draws a series of unconnected line segments drawn between each set of vertices. An extraneous vertex is ignored.
GL_LINE_STRIP: Draws a line segment from the first vertex to the last. Lines can intersect arbitrarily.

GL_LINE_LOOP: Same as GL_STRIP, except that a final line segment is drawn from the last vertex back to the first.

With OpenGL, the description of the shape of an object being drawn is independent of the description of its color. When a particular geometric object is drawn, it's drawn using the currently specified coloring scheme. In general, an OpenGL programmer first sets the color, using glColor*() and then draws the objects. Until the color is changed, all objects are drawn in that color or using that color scheme.

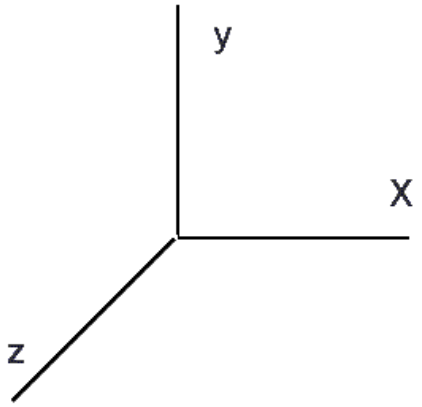
Polygons: Polygons are the areas enclosed by single closed loops of line segments, where the line segments are specified by the vertices at their endpoints. Polygons are typically drawn with the pixels in the interior filled in, but you can also draw them as outlines or a set of points. In OpenGL, there are a few restrictions on what constitutes a primitive polygon. For example, the edges of a polygon cannot intersect and they must be convex (no indentations). There are special commands for a three-sided (triangle) and four-sided (quadrilateral) polygons, glBegin(GL_TRIANGLES) and glBegin(GL_QUADS), respectively. However, the general case of a polygon can be defined using glBegin(GL_POLYGON).

2.2 Drawing 3-D Objects

GLUT has a series of drawing routines that are used to create three-dimensional models. This means we don't have to reproduce the code necessary to draw these models in each program. These routines render all their graphics in immediate mode. Each object comes in two flavors, wire or solid. Available objects are:

2.3 Transformations

A modeling transformation is used to position and orient the model. For example, you can rotate, translate, or scale the model - or some combination of these operations. To make an object appear further away from the viewer, two options are available - the viewer can move closer to the object or the object can be moved further away from the viewer. Moving the viewer will be discussed later when we talk about viewing transformations. For right now, we will keep the default "camera" location at the origin, pointing toward the negative z-axis, which goes into the screen perpendicular to the viewing plane.



When transformations are performed, a series of matrix multiplications are actually performed to affect the position, orientation, and scaling of the model. You must, however, think of these matrix multiplications occuring in the opposite order from how they appear in the code. The order of transformations is critical. If you perform transformation A and then perform transformation B, you almost always get something different than if you do them in the opposite order.

Scaling: The scaling command glScale() multiplies the current matrix by a matrix that stretches, shrinks, or reflects an object along the axes. Each x-, y-, and z-coordinate of every point in the object is multiplied by the corresponding argument x, y, or z. The glScale*() is the only one of the three modeling transformations that changes the apparent size of an object: scaling with values greater than 1.0 stretches an object, and using values less than 1.0 shrinks it. Scaling with a -1.0 value reflects an object across an axis.

Translation: The translation command glTranslate() multiplies the current matrix by a matrix that moves (translates) an object by the given x-, y-, and z-values.

Rotation: The rotation command glRotate() multiplies the current matrix that rotates an object in a counterclockwise direction about the ray from the origin through the point (x,y,z). The angle parameter specifies the angle of rotation in degrees. An object that lies farther from the axis of rotation is more dramatically rotated (has a larger orbit) than an object drawn near the axis.

Sample Programs

Sample Program: 01

```
/* A basic Open GL window*/
#include<GL/glut.h>
void display (void)
{
      glClearColor (0.0,0.0,0.0,1.0);
      glClear (GL_COLOR_BUFFER_BIT);
      glLoadIdentity ();
      gluLookAt (0.0,0.0,5.0,0.0,0.0,0.0,0.0,1.0,0.0);
      glFlush ();
}
int main (int argc,char **argv)
{
      glutInit (&argc,argv);
      glutInitDisplayMode (GLUT_SINGLE);
      glutInitWindowSize (500,500);
      glutInitWindowPosition (100,100);
      glutCreateWindow ("A basic open GL window");
      glutDisplayFunc (display);
      glutMainLoop ();
      return 0;
}
```

Sample Program: 02

```
/*Program to create a teapot*/
#include<GL/glut.h>

void cube(void)
{
      glutWireTeapot(2);
}

void display(void)
{

       glClearColor(0.0,0.0,0.0,1.0);
       glClear(GL_COLOR_BUFFER_BIT);
       glLoadIdentity();
       gluLookAt(0.0,0.0,5.0,0.0,0.0,0.0,0.0,1.0,0.0);
       cube();
       glFlush();
}

void reshape(int w,int h)
{
      glViewport(0,0,(GLsizei)w,(GLsizei)h);
      glMatrixMode(GL_PROJECTION);
      glLoadIdentity();
      gluPerspective(60,(GLfloat)w/(GLfloat)h,1.0,100.0);
      glMatrixMode(GL_MODELVIEW);
}

int main(int agrc,char**agrv)
```

```
{
            glutInit(&agrc,agrv);
            glutInitDisplayMode(GLUT_SINGLE);
            glutInitWindowSize(500,500);
            glutInitWindowPosition(100,100);
            glutCreateWindow("A basic OpenGL Window");
            glutDisplayFunc(display);
            glutReshapeFunc(reshape);
            glutMainLoop();
            return 0;
}
```

Sample Program: 03

```
/* Program to create a cube*/
#include<GL/glut.h>

void cube(void)
{
      glutWireCube(2);
}

void display(void)
{

      glClearColor(0.0,0.0,0.0,1.0);
      glClear(GL_COLOR_BUFFER_BIT);
      glLoadIdentity();
      gluLookAt(0.0,0.0,5.0,0.0,0.0,0.0,0.0,1.0,0.0);
      cube();
      glFlush();
}

void reshape(int w,int h)
{
      glViewport(0,0,(GLsizei)w,(GLsizei)h);
      glMatrixMode(GL_PROJECTION);
      glLoadIdentity();
      gluPerspective(60,(GLfloat)w/(GLfloat)h,1.0,100.0);
      glMatrixMode(GL_MODELVIEW);
}

int main(int agrc,char** agrv)
{
      glutInit(&agrc,agrv);
      glutInitDisplayMode(GLUT_SINGLE);
      glutInitWindowSize(500,500);
      glutInitWindowPosition(100,100);
      glutCreateWindow("A basic OpenGL Window");
      glutDisplayFunc(display);
      glutReshapeFunc(reshape);
      glutMainLoop();
      return 0;
}
```

Sample Program: 04

```
/*point.c
/* Program to draw/display points */
#include<GL/glut.h>
#include<stdlib.h>
void myInit(void)
{
      glClearColor(2.0,2.0,2.0,4.0);
      glColor3f(0.0f,0.0f,0.0f);
      glPointSize(4.0);
      glMatrixMode(GL_PROJECTION);
      glLoadIdentity();
      gluOrtho2D(0.0,640.0,0.0,480.0);
}
void display(void)
{
      glClear(GL_COLOR_BUFFER_BIT);
      glBegin(GL_POINTS);
      glVertex2i(100,200);
      glVertex2i(400,200);
      glVertex2i(200,100);
      glVertex2i(200,400);
      glEnd();
      glFlush();
}
void main(int argc, char** argv)
{
      glutInit(&argc,argv);
      glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
      glutInitWindowSize(500,500);
      glutInitWindowPosition(100,150);
      glutCreateWindow("My First Attempt");
      glutDisplayFunc(display);
      myInit();
      glutMainLoop();
}
```

Sample Program: 05

/*program to implement horizontal and vertical lines*/

```
#include<GL/glut.h>
#include<stdlib.h>
void myInit(void)
{
      glClearColor(2.0,2.0,2.0,4.0);
      glColor3f(0.0f,0.0f,0.0f);
      glLineWidth(4.0);
      glMatrixMode(GL_PROJECTION);
      glLoadIdentity();
      gluOrtho2D(0.0,640.0,0.0,480.0);
}
void drawLineInt(GLint x1,GLint y1,GLint x2,GLint y2)
{
      glBegin(GL_LINES);
      glVertex2i(x1,y1);
      glVertex2i(x2,y2);
      glEnd();
}
```

```
void display(void)
{
      glClear(GL_COLOR_BUFFER_BIT);
      glBegin(GL_LINES);
      glVertex2i(100,200);
      glVertex2i(400,200);
      glVertex2i(200,100);
      glVertex2i(200,400);
      glEnd();
      glFlush();
}
void main(int argc, char** argv)
{
      glutInit(&argc,argv);
      glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
      glutInitWindowSize(500,500);
      glutInitWindowPosition(100,150);
      glutCreateWindow("My First Attempt");
      glutDisplayFunc(display);
      myInit();
      drawLineInt(100,200,40,60);
      glutMainLoop();
}
```

LAB PROGRAMS:

Program No: 01 **Date:**

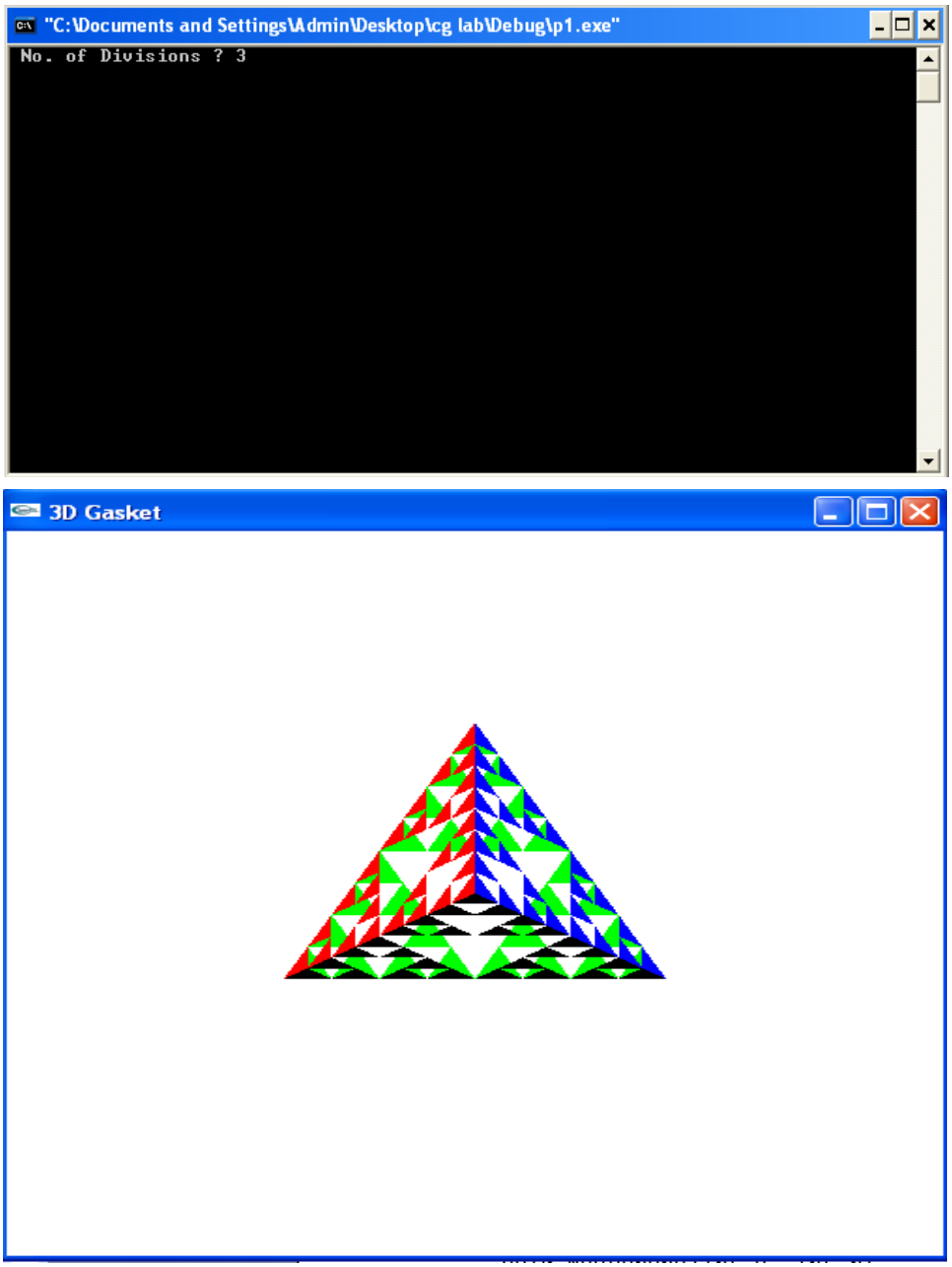
Tetrahedron to from 3D Sierpinski gasket

AIM: - Program to recursively subdivide a tetrahedron to from 3D Sierpinski gasket. The number of recursive steps is to be specified by the user.

```
/* Recursive subdivision of tetrahedron to form 3D Sierpinski gasket */
//tetra_vtu.cpp

#include <stdlib.h>
#include <stdio.h>
#include <GL/glut.h>

typedef float point[3];

/* initial tetrahedron */

point v[]={{0.0, 0.0, 1.0}, {0.0, 0.942809, -0.33333},{-0.816497, -0.471405,
           -0.333333}, {0.816497, -0.471405, -0.333333}};

static GLfloat theta[] = {0.0,0.0,0.0};

int n;

void triangle( point a, point b, point c)

/* display one triangle using a line loop for wire frame, a single normal for
constant shading, or three normals for interpolative shading */

{
    glBegin(GL_POLYGON); /*glBegain(GL_TRIANGLES);*/
       glVertex3fv(a);
       glVertex3fv(b);
       glVertex3fv(c);
    glEnd();
}

void divide_triangle(point a, point b, point c, int m)
{
/* triangle subdivision using vertex numbers
righthand rule applied to create outward pointing faces */

    point v1, v2, v3;
    int j;
    if(m>0)
    {
        for(j=0; j<3; j++) v1[j]=(a[j]+b[j])/2;
        for(j=0; j<3; j++) v2[j]=(a[j]+c[j])/2;
        for(j=0; j<3; j++) v3[j]=(b[j]+c[j])/2;
        divide_triangle(a, v1, v2, m-1);
        divide_triangle(c, v2, v3, m-1);
        divide_triangle(b, v3, v1, m-1);
    }
    else(triangle(a,b,c)); /* draw triangle at end of recursion */
}
```

```
void tetrahedron( int m)
{

/* Apply triangle subdivision to faces of tetrahedron */

      glColor3f(1.0,0.0,0.0);
    divide_triangle(v[0], v[1], v[2], m);
      glColor3f(0.0,1.0,0.0);
    divide_triangle(v[3], v[2], v[1], m);
      glColor3f(0.0,0.0,1.0);
    divide_triangle(v[0], v[3], v[1], m);
      glColor3f(0.0,0.0,0.0);
    divide_triangle(v[0], v[2], v[3], m);
}

void display(void)
{


    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
    glLoadIdentity();
    tetrahedron(n);
    glFlush();
}

void myReshape(int w, int h)
{
    glViewport(0, 0, w, h);
    glMatrixMode(GL_PROJECTION);
    glLoadIdentity();
    if (w <= h)
        glOrtho(-2.0, 2.0, -2.0 * (GLfloat) h / (GLfloat) w,
            2.0 * (GLfloat) h / (GLfloat) w, -10.0, 10.0);

    glMatrixMode(GL_MODELVIEW);
    glutPostRedisplay();
}


void main(int argc, char **argv)
{
    //n=atoi(argv[1]);
    printf(" No. of Divisions ? ");
    scanf("%d",&n);
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB | GLUT_DEPTH);
    glutInitWindowSize(500, 500);
    glutCreateWindow("3D Gasket");
    glutReshapeFunc(myReshape);
    glutDisplayFunc(display);
    glEnable(GL_DEPTH_TEST);
    glClearColor (1.0, 1.0, 1.0, 1.0);
    glutMainLoop();
}
```

Output:-



Date: **Signature of the staff**

Program No: 02 **Date:**

Liang-Barsky line clipping

AIM: - Program to implement Liang-Barsky line clipping algorithm

Algorithm

1. Set $t_{min} = 0$ and $t_{max} = 1$
2. Calculate the values of tL, tR, tT, and tB (tvalues).
   - ✓ if $t < t_{min}$ or $t > t_{max}$ ignore it and go to the next edge
   - ✓ otherwise classify the **t**value as entering or exiting value (using inner product to classify)
   - ✓ if **t** is entering value set $t_{min} = t$; if **t** is exiting value set $t_{max} = t$
3. If $t_{min} < t_{max}$ then **draw a line** from (x1 + dx*tmin, y1 + dy*tmin) to (x1 + dx*tmax, y1 + dy*tmax)
4. If the line crosses over the window, you will see (x1 + dx*tmin, y1 + dy*tmin) and (x1 + dx*tmax, y1 + dy*tmax) are intersection between line and edge.

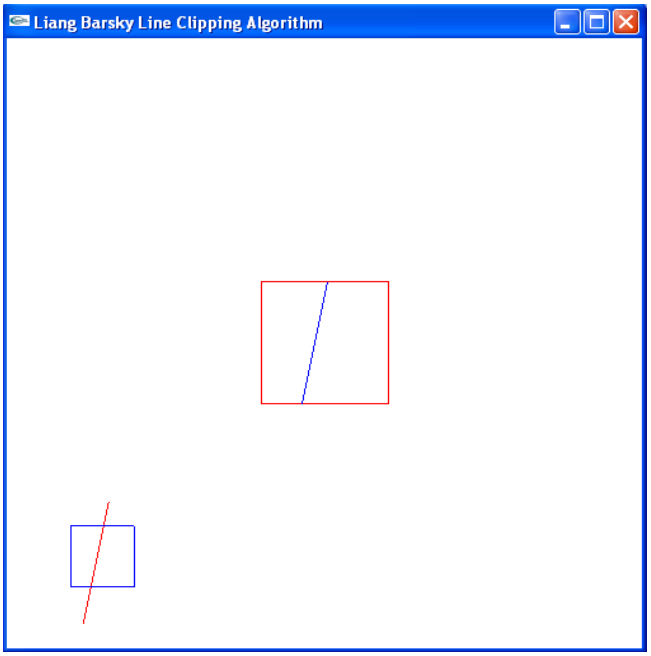
Program

```
// Liang-Barsky Line Clipping Algorithm with Window to viewport Mapping */
#include <stdio.h>
#include <GL/glut.h>

double xmin=50,ymin=50, xmax=100,ymax=100; // Window boundaries
double xvmin=200,yvmin=200,xvmax=300,yvmax=300; // Viewport boundaries

int cliptest(double p, double q, double *t1, double *t2)
{
      double t=q/p;
  if(p < 0.0)     // potentially enry point, update te
  {     if( t > *t1) *t1=t;
        if( t > *t2) return(false); // line portion is outside
  }
  else
  if(p > 0.0)     //  Potentially leaving point, update tl
  {     if( t < *t2) *t2=t;
        if( t < *t1) return(false); // line portion is outside
  }
  else
        if(p == 0.0)
        {           if( q < 0.0) return(false); // line parallel to edge but
outside
        }
 return(true);
}
```

```
void LiangBarskyLineClipAndDraw (double x0, double y0,double x1, double y1)
{
      double dx=x1-x0, dy=y1-y0, te=0.0, tl=1.0;
      if(cliptest(-dx,x0-xmin,&te,&tl))  // inside test wrt left edge
      if(cliptest(dx,xmax-x0,&te,&tl)) // inside test wrt right edge
      if(cliptest(-dy,y0-ymin,&te,&tl)) // inside test wrt bottom edge
      if(cliptest(dy,ymax-y0,&te,&tl)) // inside test wrt top edge
      {
            if( tl < 1.0 )
            {
                  x1 = x0 + tl*dx;
                  y1 = y0 + tl*dy;
            }
            if( te > 0.0 )
            {   x0 = x0 + te*dx;
                  y0 = y0 + te*dy;
            }
                 // Window to viewport mappings
            double sx=(xvmax-xvmin)/(xmax-xmin); // Scale parameters
            double sy=(yvmax-yvmin)/(ymax-ymin);
            double vx0=xvmin+(x0-xmin)*sx;
            double vy0=yvmin+(y0-ymin)*sy;
            double vx1=xvmin+(x1-xmin)*sx;
            double vy1=yvmin+(y1-ymin)*sy;
                  //draw a red colored viewport
            glColor3f(1.0, 0.0, 0.0);
            glBegin(GL_LINE_LOOP);
                  glVertex2f(xvmin, yvmin);
                  glVertex2f(xvmax, yvmin);
                  glVertex2f(xvmax, yvmax);
                  glVertex2f(xvmin, yvmax);
            glEnd();
            glColor3f(0.0,0.0,1.0); // draw blue colored clipped line
            glBegin(GL_LINES);
                  glVertex2d (vx0, vy0);
                  glVertex2d (vx1, vy1);
            glEnd();
      }
      }// end of line clipping

void display()
{
      double x0=60,y0=20,x1=80,y1=120;
      glClear(GL_COLOR_BUFFER_BIT);
      /*draw the line with red color*/
      glColor3f(1.0,0.0,0.0);
      /*bres(120,20,340,250);*/
      glBegin(GL_LINES);
      glVertex2d (x0, y0);
      glVertex2d (x1, y1);
      glEnd();
      /*draw a blue colored window*/
      glColor3f(0.0, 0.0, 1.0);
      glBegin(GL_LINE_LOOP);
      glVertex2f(xmin, ymin);
      glVertex2f(xmax, ymin);
      glVertex2f(xmax, ymax);
      glVertex2f(xmin, ymax);
      glEnd();
      LiangBarskyLineClipAndDraw(x0,y0,x1,y1);
      glFlush();
}
```

```
void myinit()
{
	glClearColor(1.0,1.0,1.0,1.0);
	glColor3f(1.0,0.0,0.0);
	glPointSize(1.0);
	glMatrixMode(GL_PROJECTION);
	glLoadIdentity();
	gluOrtho2D(0.0,499.0,0.0,499.0);
}
void main(int argc, char** argv)
{
	//int x1, x2, y1, y2;
	//printf("Enter End points:");
	//scanf("%d%d%d%d", &x1,&x2,&y1,&y2);
	glutInit(&argc,argv);
	glutInitDisplayMode(GLUT_SINGLE|GLUT_RGB);
	glutInitWindowSize(500,500);
	glutInitWindowPosition(0,0);
	glutCreateWindow("Liang Barsky Line Clipping Algorithm");
	glutDisplayFunc(display);
	myinit();
	glutMainLoop();
}
```

Output:-



Date: **Signature of the staff**

Program No: 03 **Date:**

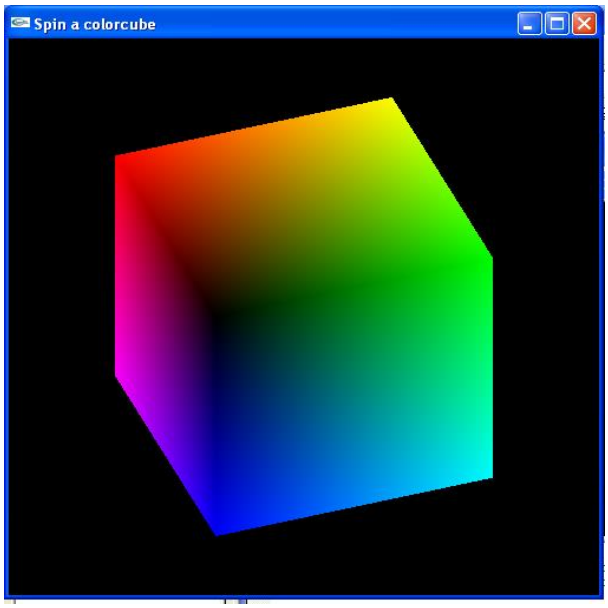
3D - Color Cube

AIM: - Program to draw a color cube and spin it using OpenGL transformation matrices

```
/* Rotating cube with color interpolation */

#include <stdlib.h>
#include <GL/glut.h>
      GLfloat vertices[] = {-1.0,-1.0,-1.0,1.0,-1.0,-1.0,
                            1.0,1.0,-1.0, -1.0,1.0,-1.0, -1.0,-1.0,1.0,
                            1.0,-1.0,1.0, 1.0,1.0,1.0, -1.0,1.0,1.0};

      GLfloat colors[] = {0.0,0.0,0.0,1.0,0.0,0.0,
                            1.0,1.0,0.0, 0.0,1.0,0.0, 0.0,0.0,1.0,
                            1.0,0.0,1.0, 1.0,1.0,1.0, 0.0,1.0,1.0};

    GLubyte cubeIndices[]={0,3,2,1,2,3,7,6,0,4,7,3,1,2,6,5,4,5,6,7,0,1,5,4};

static GLfloat theta[] = {0.0,0.0,0.0};
static GLint axis = 2;

void display(void)
{
/* display callback, clear frame buffer and z buffer,
   rotate cube and draw, swap buffers */

      glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
      glLoadIdentity();
      glRotatef(theta[0], 1.0, 0.0, 0.0);
      glRotatef(theta[1], 0.0, 1.0, 0.0);
      glRotatef(theta[2], 0.0, 0.0, 1.0);
      glDrawElements(GL_QUADS, 24, GL_UNSIGNED_BYTE, cubeIndices);
      /*glBegin(GL_LINES);
      glVertex3f(0.0,0.0,0.0);
      glVertex3f(1.0,1.0,1.0);
      glEnd(); */
      glFlush();
      glutSwapBuffers();
}

void spinCube()
{
/* Idle callback, spin cube 2 degrees about selected axis */

      theta[axis] += 2.0;
      if( theta[axis] > 360.0 ) theta[axis] -= 360.0;
      glutPostRedisplay();
}

void mouse(int btn, int state, int x, int y)
{

/* mouse callback, selects an axis about which to rotate */

      if(btn==GLUT_LEFT_BUTTON && state == GLUT_DOWN) axis = 0;
      if(btn==GLUT_MIDDLE_BUTTON && state == GLUT_DOWN) axis = 1;
      if(btn==GLUT_RIGHT_BUTTON && state == GLUT_DOWN) axis = 2;
}
```

```
void myReshape(int w, int h)
{
    glViewport(0, 0, w, h);
    glMatrixMode(GL_PROJECTION);
    glLoadIdentity();
        glOrtho(-2.0, 2.0, -2.0, 2.0, -10.0, 10.0);
    glMatrixMode(GL_MODELVIEW);
}

Void main(int argc, char **argv)
{

/* need both double buffering and z buffer */
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);
    glutInitWindowSize(500, 500);
    glutCreateWindow("Spin a colorcube");
    glutReshapeFunc(myReshape);
    glutDisplayFunc(display);
    glutIdleFunc(spinCube);
    glutMouseFunc(mouse);
    glEnable(GL_DEPTH_TEST); /* Enable hidden--surface--removal */
    glEnableClientState(GL_COLOR_ARRAY);
    glEnableClientState(GL_VERTEX_ARRAY);
    glVertexPointer(3, GL_FLOAT, 0, vertices);
    glColorPointer(3,GL_FLOAT, 0, colors);
    glColor3f(1.0,1.0,1.0);
    glutMainLoop();
}
```

Output:-



Date: **Signature of the staff**

Program No: 04 **Date:**

2D - House

AIM: - Program to create a house like figure and rotate it about a given fixed point using OpenGL functions

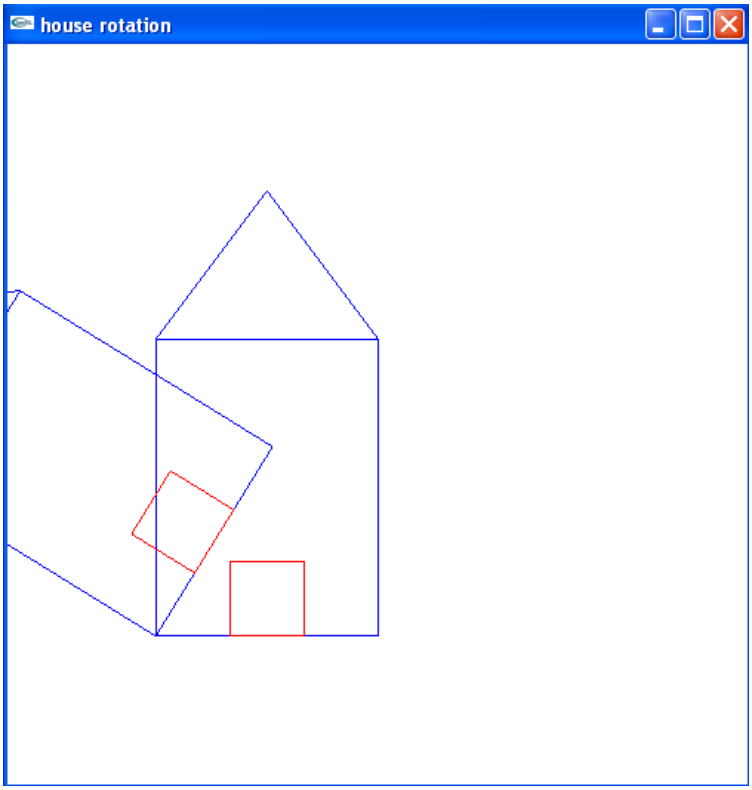
```
// Progam to draw a house and rotate about the pivot point
#include <stdio.h>
#include <math.h>
#include <GL/glut.h>
#define PI 3.1425
GLfloat house[3][9]={{100.0,100.0,175.0,250.0,250.0,150.0,150.0,200.0,200.0},
             {100.0,300.0,400.0,300.0,100.0,100.0,150.0,150.0,100.0},
             {1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0}};
      GLfloat rot_mat[3][3]={{0},{0},{0}};
      GLfloat result[3][9]={{0}, {0}, {0}};
      GLfloat h=100.0; // Pivot point
      GLfloat k=100.0;
      GLfloat theta;
void multiply()
{        /* Rotation MATRIX and Object Matrix => Resultant Transformed House*/
      int i,j,l;
      for(i=0;i<3;i++)
            for(j=0;j<9;j++)
            {
                  result[i][j]=0;
                  for(l=0;l<3;l++)
                  result[i][j]=result[i][j]+rot_mat[i][l]*house[l][j];
            }
}
void rotate()
{
      GLfloat m,n;   // Build the rotation matrix
      m=-h*(cos(theta)-1)+k*(sin(theta));
      n=-k*(cos(theta)-1)-h*(sin(theta));
      rot_mat[0][0]=cos(theta);
      rot_mat[0][1]=-sin(theta);
      rot_mat[0][2]=m;
      rot_mat[1][0]=sin(theta);
      rot_mat[1][1]=cos(theta);
      rot_mat[1][2]=n;
      rot_mat[2][0]=0;
      rot_mat[2][1]=0;
      rot_mat[2][2]=1;
      /*multiply the two matrices: Rotation Matrix * Objet Matrix(house)*/
      multiply();
}
void drawhouse()
{
  glColor3f(0.0, 0.0, 1.0);

  glBegin(GL_LINE_LOOP);
  glVertex2f(house[0][0],house[1][0]);
  glVertex2f(house[0][1],house[1][1]);
  glVertex2f(house[0][3],house[1][3]);
  glVertex2f(house[0][4],house[1][4]);
  glEnd();
  glColor3f(1.0,0.0,0.0);
  glBegin(GL_LINE_LOOP);
  glVertex2f(house[0][5],house[1][5]);
```

```
  glVertex2f(house[0][6],house[1][6]);
  glVertex2f(house[0][7],house[1][7]);
  glVertex2f(house[0][8],house[1][8]);
  glEnd();
  glColor3f(0.0, 0.0, 1.0);
  glBegin(GL_LINE_LOOP);
  glVertex2f(house[0][1],house[1][1]);
  glVertex2f(house[0][2],house[1][2]);
  glVertex2f(house[0][3],house[1][3]);
  glEnd();
}
void drawrotatedhouse()
{
glColor3f(0.0, 0.0, 1.0);

  glBegin(GL_LINE_LOOP);
  glVertex2f(result[0][0],result[1][0]);
  glVertex2f(result[0][1],result[1][1]);
  glVertex2f(result[0][3],result[1][3]);
  glVertex2f(result[0][4],result[1][4]);
  glEnd();
  glColor3f(1.0,0.0,0.0);
  glBegin(GL_LINE_LOOP);
  glVertex2f(result[0][5],result[1][5]);
  glVertex2f(result[0][6],result[1][6]);
  glVertex2f(result[0][7],result[1][7]);
  glVertex2f(result[0][8],result[1][8]);
  glEnd();
  glColor3f(0.0, 0.0, 1.0);
  glBegin(GL_LINE_LOOP);
  glVertex2f(result[0][1],result[1][1]);
  glVertex2f(result[0][2],result[1][2]);
  glVertex2f(result[0][3],result[1][3]);
  glEnd();

}

void display()
{

      glClear(GL_COLOR_BUFFER_BIT);
      drawhouse();
      rotate();
      drawrotatedhouse();
      glFlush();
}

void myinit()
{
      glClearColor(1.0,1.0,1.0,1.0);
      glColor3f(1.0,0.0,0.0);
      glPointSize(1.0);
      glMatrixMode(GL_PROJECTION);
      glLoadIdentity();
      gluOrtho2D(0.0,499.0,0.0,499.0);
}


void main(int argc, char** argv)
{

      printf("Enter the rotation angle\n");
```

```
        scanf("%f", &theta);
        theta= theta*PI/180;
        glutInit(&argc,argv);
        glutInitDisplayMode(GLUT_SINGLE|GLUT_RGB);
        glutInitWindowSize(500,500);
        glutInitWindowPosition(0,0);
        glutCreateWindow("house rotation");
        glutDisplayFunc(display);
        myinit();
        glutMainLoop();
}
```

Output:-

In command prompt enter the rotation angle=45 result look as below…



Date: **Signature of the staff**

Program No: 05 **Date:**

Cohen-Sutherland line-clipping

AIM: - Program to implement the Cohen-Sutherland line-clipping algorithm. Make provision to specify the input line, window for clipping and view port for displaying the clipped image

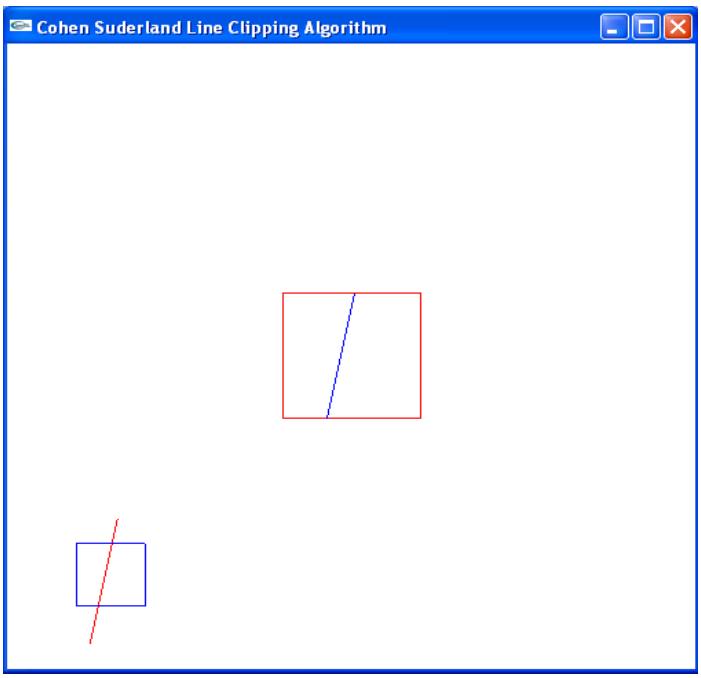
```
/* Cohen-Suderland Line Clipping Algorithm with Window to viewport Mapping */
#include <stdio.h>
#include <GL/glut.h>
#define outcode int
double xmin=50,ymin=50, xmax=100,ymax=100; // Window boundaries
double xvmin=200,yvmin=200,xvmax=300,yvmax=300; // Viewport boundaries
/*bit codes for the right, left, top, & bottom*/
const int INSIDE = 0;               //0000
const int LEFT = 1;                 //0001
const int RIGHT = 2;                //0010
const int BOTTOM = 4;               //0100
const int TOP = 8;                  //1000
/*used to compute bit codes of a point*/
outcode ComputeOutCode (double x, double y);

/*Cohen-Sutherland clipping algorithm clips a line from*/
/*P0 = (x0, y0) to P1 = (x1, y1) against a rectangle with */
/*diagonal from (xmin, ymin) to (xmax, ymax).*/
void CohenSutherlandLineClipAndDraw (double x0, double y0,double x1, double
y1)
{
      /*Outcodes for P0, P1, and whatever point lies outside the clip
rectangle*/
      outcode outcode0, outcode1, outcodeOut;
      bool accept = false, done = false;

      /*compute outcodes*/
      outcode0 = ComputeOutCode (x0, y0);
      outcode1 = ComputeOutCode (x1, y1);

      do{
            if (!(outcode0 | outcode1))  /*logical or is 0 Trivially accept &
exit*/
            {
                  accept = true;
                  done = true;
            }
            else if (outcode0 & outcode1) /*logical and is not 0. Trivially
reject and exit*/
                  done = true;
            else
            {
                  //failed both tests, so calculate the line segment to clip
                  //from an outside point to an intersection with clip edge
                  double x, y;

                  //At least one endpoint is outside the clip rectangle; pick
it.
                  outcodeOut = outcode0? outcode0: outcode1;

                  //Now find the intersection point;
```

```
                  //use formulas y = y0 + slope * (x - x0), x = x0 +
(1/slope)* (y - y0)
                  if (outcodeOut & TOP)           //point is above the clip
rectangle
                  {
                        x = x0 + (x1 - x0) * (ymax - y0)/(y1 - y0);
                        y = ymax;
                  }
                  else if (outcodeOut & BOTTOM)  //point is below the clip
rectangle
                  {
                        x = x0 + (x1 - x0) * (ymin - y0)/(y1 - y0);
                        y = ymin;
                  }
                  else if (outcodeOut & RIGHT)   //point is to the right of
clip rectangle
                  {
                        y = y0 + (y1 - y0) * (xmax - x0)/(x1 - x0);
                        x = xmax;
                  }
                  else                           //point is to the left of
clip rectangle
                  {
                        y = y0 + (y1 - y0) * (xmin - x0)/(x1 - x0);
                        x = xmin;
                  }

                  //Now we move outside point to intersection point to clip
                  //and get ready for next pass.
                  if (outcodeOut == outcode0)
                  {
                        x0 = x;
                        y0 = y;
                        outcode0 = ComputeOutCode (x0, y0);
                  }
                  else
                  {
                        x1 = x;
                        y1 = y;
                        outcode1 = ComputeOutCode (x1, y1);
                  }
            }
      }while (!done);

      if (accept)
      {                 /* Window to viewport mappings*/
            double sx=(xvmax-xvmin)/(xmax-xmin); /*Scale parameters*/
            double sy=(yvmax-yvmin)/(ymax-ymin);
            double vx0=xvmin+(x0-xmin)*sx;
            double vy0=yvmin+(y0-ymin)*sy;
            double vx1=xvmin+(x1-xmin)*sx;
            double vy1=yvmin+(y1-ymin)*sy;
                  /*draw a red colored viewport*/
            glColor3f(1.0, 0.0, 0.0);
            glBegin(GL_LINE_LOOP);
                  glVertex2f(xvmin, yvmin);
                  glVertex2f(xvmax, yvmin);
                  glVertex2f(xvmax, yvmax);
                  glVertex2f(xvmin, yvmax);
            glEnd();
            glColor3f(0.0,0.0,1.0); //draw blue colored clipped line
            glBegin(GL_LINES);
```

```
                glVertex2d (vx0, vy0);
                glVertex2d (vx1, vy1);
            glEnd();
      }
}

/*Compute the bit code for a point (x, y) using the clip rectangle
bounded diagonally by (xmin, ymin), and (xmax, ymax)*/

outcode ComputeOutCode (double x, double y)
{
      outcode code = 0;
      if (y > ymax)              //above the clip window
            code |= TOP;
      else if (y < ymin)         //below the clip window
            code |= BOTTOM;
      if (x > xmax)              //to the right of clip window
            code |= RIGHT;
      else if (x < xmin)         //to the left of clip window
            code |= LEFT;
      return code;
}

void display()
{
      double x0=60,y0=20,x1=80,y1=120;
      glClear(GL_COLOR_BUFFER_BIT);
      //draw the line with red color
      glColor3f(1.0,0.0,0.0);
      //bres(120,20,340,250);
      glBegin(GL_LINES);
            glVertex2d (x0, y0);
            glVertex2d (x1, y1);
            glEnd();

      //draw a blue colored window
      glColor3f(0.0, 0.0, 1.0);

      glBegin(GL_LINE_LOOP);
        glVertex2f(xmin, ymin);
        glVertex2f(xmax, ymin);
        glVertex2f(xmax, ymax);
        glVertex2f(xmin, ymax);
      glEnd();
      CohenSutherlandLineClipAndDraw(x0,y0,x1,y1);
      glFlush();
}

void myinit()
{
      glClearColor(1.0,1.0,1.0,1.0);
      glColor3f(1.0,0.0,0.0);
      glPointSize(1.0);
      glMatrixMode(GL_PROJECTION);
      glLoadIdentity();
      gluOrtho2D(0.0,499.0,0.0,499.0);
}

void main(int argc, char** argv)
{
      //int x1, x2, y1, y2;
      //printf("Enter End points:");
```

```
        //scanf("%d%d%d%d", &x1,&x2,&y1,&y2);

        glutInit(&argc,argv);
        glutInitDisplayMode(GLUT_SINGLE|GLUT_RGB);
        glutInitWindowSize(500,500);
        glutInitWindowPosition(0,0);
        glutCreateWindow("Cohen Suderland Line Clipping Algorithm");
        glutDisplayFunc(display);
        myinit();
        glutMainLoop();
}
```

Output:-



Date: **Signature of the staff**

Program No: 06 **Date:**

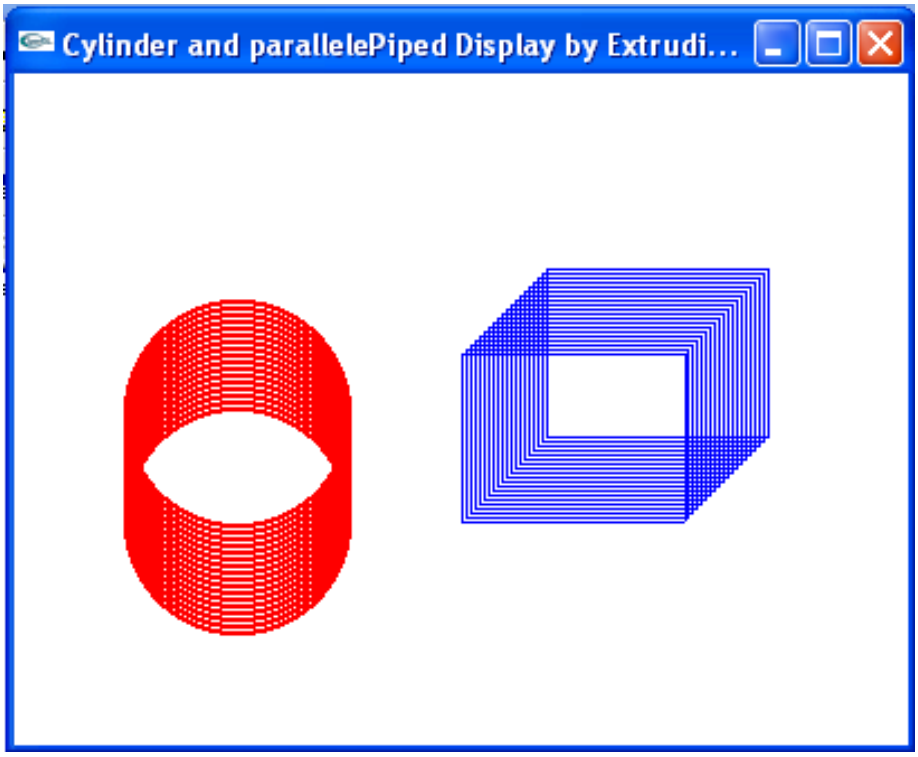
Cylinder and Parallelepiped object

AIM: -Program to create a cylinder and a parallelepiped by extruding a circle and quadrilateral respectively. Allow the user to specify the circle and the quadrilateral.

```
//Cylinder and Parallelepiped by extruding Circle and Quadrilateral
//cyl_pp_vtu.cpp
#include <GL/glut.h>
#include <math.h>
#include <stdio.h>

void draw_pixel(GLint cx, GLint cy)
{    glColor3f(1.0,0.0,0.0);
       glBegin(GL_POINTS);
       glVertex2i(cx,cy);
       glEnd();
}

void plotpixels(GLint h, GLint k, GLint x, GLint y)
{
      draw_pixel(x+h,y+k);
      draw_pixel(-x+h,y+k);
      draw_pixel(x+h,-y+k);
      draw_pixel(-x+h,-y+k);
      draw_pixel(y+h,x+k);
      draw_pixel(-y+h,x+k);
      draw_pixel(y+h,-x+k);
      draw_pixel(-y+h,-x+k);
}
void Circle_draw(GLint h, GLint k, GLint r)  // Midpoint Circle Drawing
Algorithm
{
       GLint d =  1-r, x=0, y=r;
       while(y > x)
       {
             plotpixels(h,k,x,y);
             if(d < 0) d+=2*x+3;
             else
             {
                  d+=2*(x-y)+5;
                  --y;
             }
             ++x;
       }
       plotpixels(h,k,x,y);
}

void Cylinder_draw()
{
      GLint xc=100, yc=100, r=50;
      GLint i,n=50;
      for(i=0;i<n;i+=3)
      {
      Circle_draw(xc,yc+i,r);
      }
}
```

```
void parallelepiped(int x1,  int x2,int y1, int y2, int y3, int y4)
{

      glColor3f(0.0, 0.0, 1.0);
      glPointSize(2.0);
      glBegin(GL_LINE_LOOP);
      glVertex2i(x1,y1);
      glVertex2i(x2,y3);
      glVertex2i(x2,y4);
      glVertex2i(x1,y2);
      glEnd();
}

void parallelepiped_draw()
{
       x1=200,x2=300,y1=100,y2=175,y3=100,y4=175;
       GLint i,n=40;
       for(i=0;i<n;i+=2)
       {
            parallelepiped(x1+i,x2+i,y1+i,y2+i,y3+i,y4+i);
       }

}

void init(void)
{
      glClearColor(1.0,1.0,1.0,0.0);  // Set display window color to white
      glMatrixMode(GL_PROJECTION);  // Set Projection parameters
      gluOrtho2D(0.0,400.0,0.0,300.0);
}
void display(void)
{     glClear(GL_COLOR_BUFFER_BIT);  // Clear Display Window
      glColor3f(1.0,0.0,0.0); // Set circle color to red  (R G B)
      glPointSize(2.0);
      Cylinder_draw(); // Call cylinder
      parallelepiped_draw();// call parallelepiped
      glFlush(); // Process all OpenGL routines as quickly as possible
}

void main(int argc, char **argv)
{
      glutInit(&argc,argv); // Initialize GLUT
      glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB); // Set Display mode
      glutInitWindowPosition(50,50);  // Set top left window position
      glutInitWindowSize(400,300); // Set Display window width and height
      glutCreateWindow("Cylinder and parallelePiped Display by Extruding
                        Circle and Quadrilaterl "); // Create Display Window
      init();
      glutDisplayFunc(display); // Send the graphics to Display Window
      glutMainLoop();
}
```

Output:-



Date: **Signature of the staff**

Program No: 07 **Date:**

3D – Tea pot

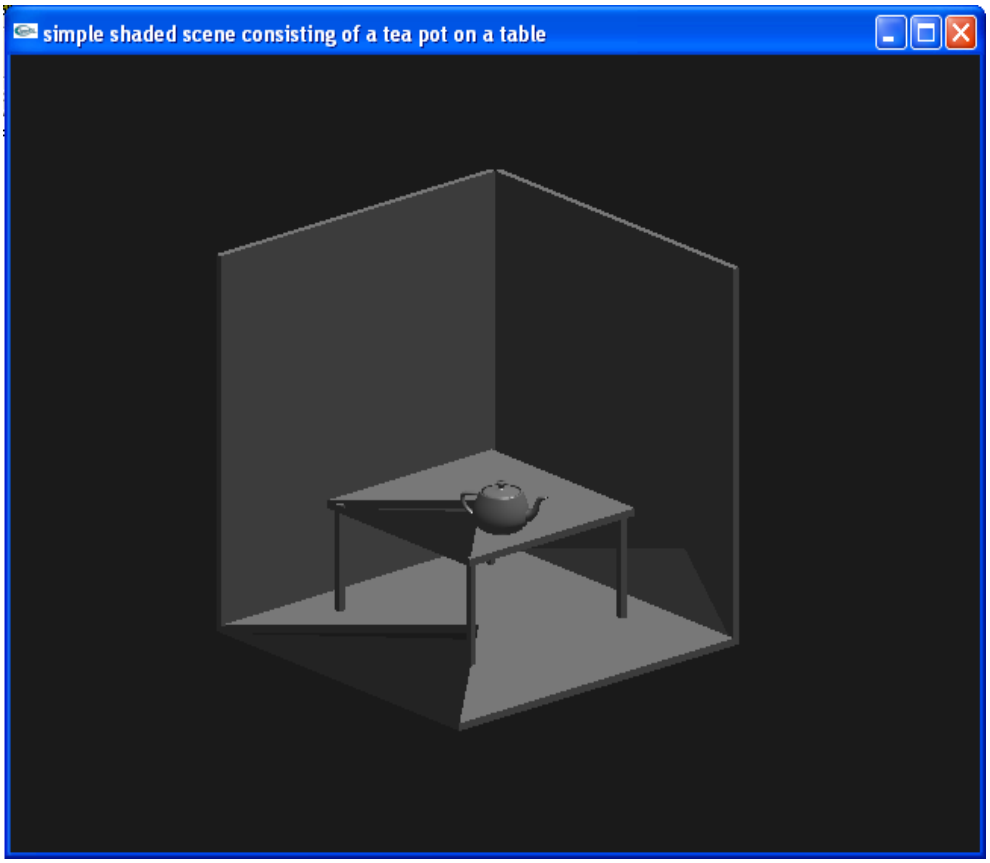
AIM: - Program, using OpenGL functions, to draw a simple shaded scene consisting of a tea pot on a table. Define suitably the position and properties of the light source along with the properties of the properties of the surfaces of the solid object used in the scene.

```
/* simple shaded scene consisting of a tea pot on a table */
#include <GL/glut.h>

void wall (double thickness)
{
      //draw thin wall with top = xz-plane, corner at origin
      glPushMatrix();
      glTranslated (0.5, 0.5 * thickness, 0.5);
      glScaled (1.0, thickness, 1.0);
      glutSolidCube (1.0);
      glPopMatrix();
}

//draw one table leg
void tableLeg (double thick, double len)
{
      glPushMatrix();
      glTranslated (0, len/2, 0);
      glScaled (thick, len, thick);
      glutSolidCube (1.0);
      glPopMatrix();
}

void table (double topWid, double topThick, double legThick, double legLen)
{
      //draw the table - a top and four legs
      //draw the top first
      glPushMatrix();
      glTranslated (0, legLen, 0);
      glScaled(topWid, topThick, topWid);
      glutSolidCube (1.0);
      glPopMatrix();
      double dist = 0.95 * topWid/2.0 - legThick/2.0;
      glPushMatrix();
      glTranslated (dist, 0, dist);
      tableLeg (legThick, legLen);
      glTranslated (0.0, 0.0, -2 * dist);
      tableLeg (legThick, legLen);
      glTranslated (-2*dist, 0, 2 *dist);
      tableLeg (legThick, legLen);
      glTranslated(0, 0, -2*dist);
      tableLeg (legThick, legLen);
      glPopMatrix();
}

void displaySolid (void)
{
      //set properties of the surface material
      GLfloat mat_ambient[] = {0.7f, 0.7f, 0.7f, 1.0f}; // gray
      GLfloat mat_diffuse[] = {.5f, .5f, .5f, 1.0f};
```

```
	GLfloat mat_specular[] = {1.0f, 1.0f, 1.0f, 1.0f};
	GLfloat mat_shininess[] = {50.0f};
	glMaterialfv (GL_FRONT, GL_AMBIENT, mat_ambient);
	glMaterialfv (GL_FRONT, GL_DIFFUSE, mat_diffuse);
	glMaterialfv (GL_FRONT, GL_SPECULAR, mat_specular);
	glMaterialfv (GL_FRONT, GL_SHININESS, mat_shininess);

	//set the light source properties
	GLfloat lightIntensity[] = {0.7f, 0.7f, 0.7f, 1.0f};
	GLfloat light_position[] = {2.0f, 6.0f, 3.0f, 0.0f};
	glLightfv (GL_LIGHT0, GL_POSITION, light_position);
	glLightfv (GL_LIGHT0, GL_DIFFUSE, lightIntensity);

	//set the camera
	glMatrixMode (GL_PROJECTION);
	glLoadIdentity();
	double winHt = 1.0; //half-height of window
	glOrtho (-winHt * 64/48.0, winHt*64/48.0, -winHt, winHt, 0.1, 100.0);
	glMatrixMode (GL_MODELVIEW);
	glLoadIdentity();
	gluLookAt (2.3, 1.3, 2.0, 0.0, 0.25, 0.0, 0.0, 1.0, 0.0);

	//start drawing
	glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
	glPushMatrix();
	glTranslated (0.4, 0.4, 0.6);
	glRotated (45, 0, 0, 1);
	glScaled (0.08, 0.08, 0.08);

	glPopMatrix();

	glPushMatrix();
	glTranslated (0.6, 0.38, 0.5);
	glRotated (30, 0, 1, 0);
	glutSolidTeapot (0.08);
	glPopMatrix ();
	glPushMatrix();
	glTranslated (0.25, 0.42, 0.35);
	//glutSolidSphere (0.1, 15, 15);
	glPopMatrix();
	glPushMatrix();
	glTranslated (0.4, 0, 0.4);
	table (0.6, 0.02, 0.02, 0.3);
	glPopMatrix();
	wall (0.02);
	glPushMatrix();
	glRotated (90.0, 0.0, 0.0, 1.0);
	wall (0.02);
	glPopMatrix();
	glPushMatrix();
	glRotated (-90.0, 1.0, 0.0, 0.0);
	wall (0.02);
	glPopMatrix();

	glFlush();
}

void main (int argc, char ** argv)
{
	glutInit (&argc, argv);
	glutInitDisplayMode (GLUT_SINGLE|GLUT_RGB|GLUT_DEPTH);
	glutInitWindowSize (640, 480);
```

```
        glutInitWindowPosition (100, 100);
        glutCreateWindow ("simple shaded scene consisting of a tea pot on a
table");
        glutDisplayFunc (displaySolid);
        glEnable (GL_LIGHTING);
        glEnable (GL_LIGHT0);
        glShadeModel (GL_SMOOTH);
        glEnable (GL_DEPTH_TEST);
        glEnable (GL_NORMALIZE);
        glClearColor (0.1, 0.1, 0.1, 0.0);
        glViewport (0, 0, 640, 480);
        glutMainLoop();
}
```

Output:-



Date: **Signature of the staff**

Program No: 08 **Date:**

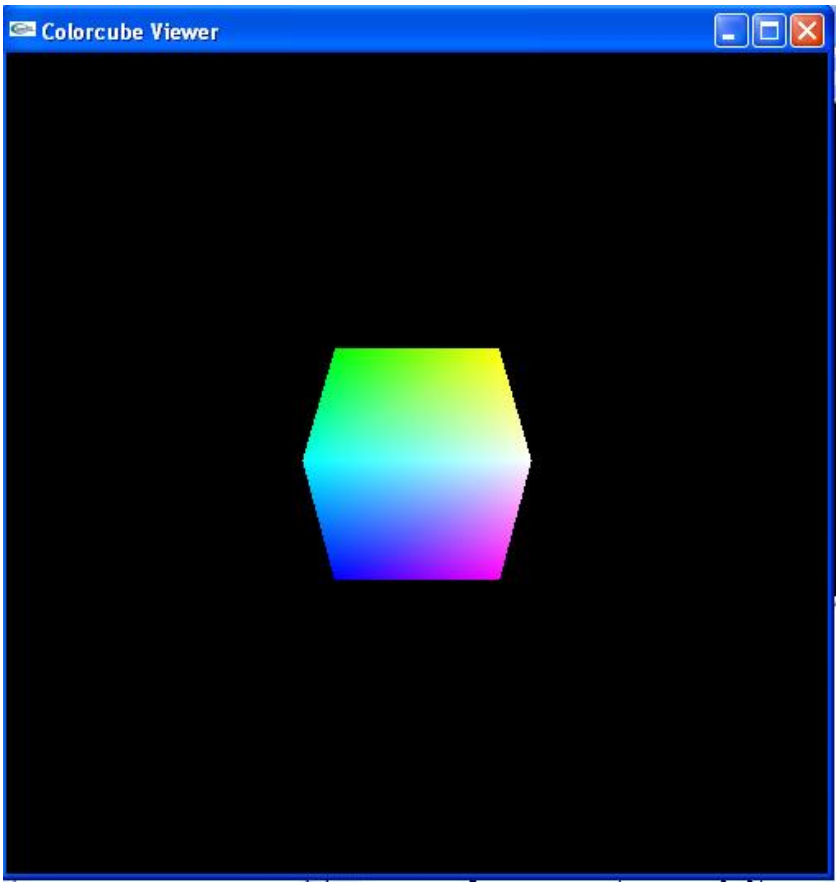
Color cube and user to allow the camera

AIM: - Program to draw a color cube and allow the user to move the camera suitably to experiment with perspective viewing. Use OpenGL functions.

```
    /* Rotating cube with viewer movement */

    /* We use the Lookat function in the display callback to point
    the viewer, whose position can be altered by the x,X,y,Y,z, and Z keys.
    The perspective view is set in the reshape callback */

#include <stdlib.h>
#include <GL/glut.h>

      GLfloat vertices[][3] = {{-1.0,-1.0,-1.0},{1.0,-1.0,-1.0},
      {1.0,1.0,-1.0}, {-1.0,1.0,-1.0}, {-1.0,-1.0,1.0},
      {1.0,-1.0,1.0}, {1.0,1.0,1.0}, {-1.0,1.0,1.0}};

      GLfloat colors[][3] = {{0.0,0.0,0.0},{1.0,0.0,0.0},
      {1.0,1.0,0.0}, {0.0,1.0,0.0}, {0.0,0.0,1.0},
      {1.0,0.0,1.0}, {1.0,1.0,1.0}, {0.0,1.0,1.0}};

void polygon(int a, int b, int c , int d)
{
      glBegin(GL_POLYGON);
            glColor3fv(colors[a]);
            glVertex3fv(vertices[a]);
            glColor3fv(colors[b]);
            glVertex3fv(vertices[b]);
            glColor3fv(colors[c]);
            glVertex3fv(vertices[c]);
            glColor3fv(colors[d]);
            glVertex3fv(vertices[d]);
      glEnd();
}

void colorcube()
{
      polygon(0,3,2,1);
      polygon(2,3,7,6);
      polygon(0,4,7,3);
      polygon(1,2,6,5);
      polygon(4,5,6,7);
      polygon(0,1,5,4);
}

static GLfloat theta[] = {0.0,0.0,0.0};
static GLint axis = 2;
static GLdouble viewer[]= {0.0, 0.0, 5.0};

void display(void)
{
      glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
      glLoadIdentity();
      gluLookAt(viewer[0],viewer[1],viewer[2], 0.0, 0.0, 0.0, 0.0, 1.0, 0.0);
      glRotatef(theta[0], 1.0, 0.0, 0.0);
      glRotatef(theta[1], 0.0, 1.0, 0.0);
      glRotatef(theta[2], 0.0, 0.0, 1.0);
```

```
      colorcube();
      glFlush();
      glutSwapBuffers();
}

void mouse(int btn, int state, int x, int y)
{
      if(btn==GLUT_LEFT_BUTTON && state == GLUT_DOWN) axis = 0;
      if(btn==GLUT_MIDDLE_BUTTON && state == GLUT_DOWN) axis = 1;
      if(btn==GLUT_RIGHT_BUTTON && state == GLUT_DOWN) axis = 2;
      theta[axis] += 2.0;
      if( theta[axis] > 360.0 ) theta[axis] -= 360.0;
      display();
}

void keys(unsigned char key, int x, int y)
{


   if(key == 'x') viewer[0]-= 1.0;
   if(key == 'X') viewer[0]+= 1.0;
   if(key == 'y') viewer[1]-= 1.0;
   if(key == 'Y') viewer[1]+= 1.0;
   if(key == 'z') viewer[2]-= 1.0;
   if(key == 'Z') viewer[2]+= 1.0;
   display();
}

void myReshape(int w, int h)
{
      glViewport(0, 0, w, h);
      glMatrixMode(GL_PROJECTION);
      glLoadIdentity();
      if(w<=h) glFrustum(-2.0, 2.0, -2.0 * (GLfloat) h/ (GLfloat) w,
       2.0* (GLfloat) h / (GLfloat) w, 2.0, 20.0);
      glMatrixMode(GL_MODELVIEW);
}

void  main(int argc, char **argv)
{
      glutInit(&argc, argv);
      glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);
      glutInitWindowSize(500, 500);
      glutCreateWindow("Colorcube Viewer");
      glutReshapeFunc(myReshape);
      glutDisplayFunc(display);
      glutMouseFunc(mouse);
      glutKeyboardFunc(keys);
      glEnable(GL_DEPTH_TEST);
      glutMainLoop();
}
```

Output:-



Date: **Signature of the staff**

Program No: 09 **Date:**

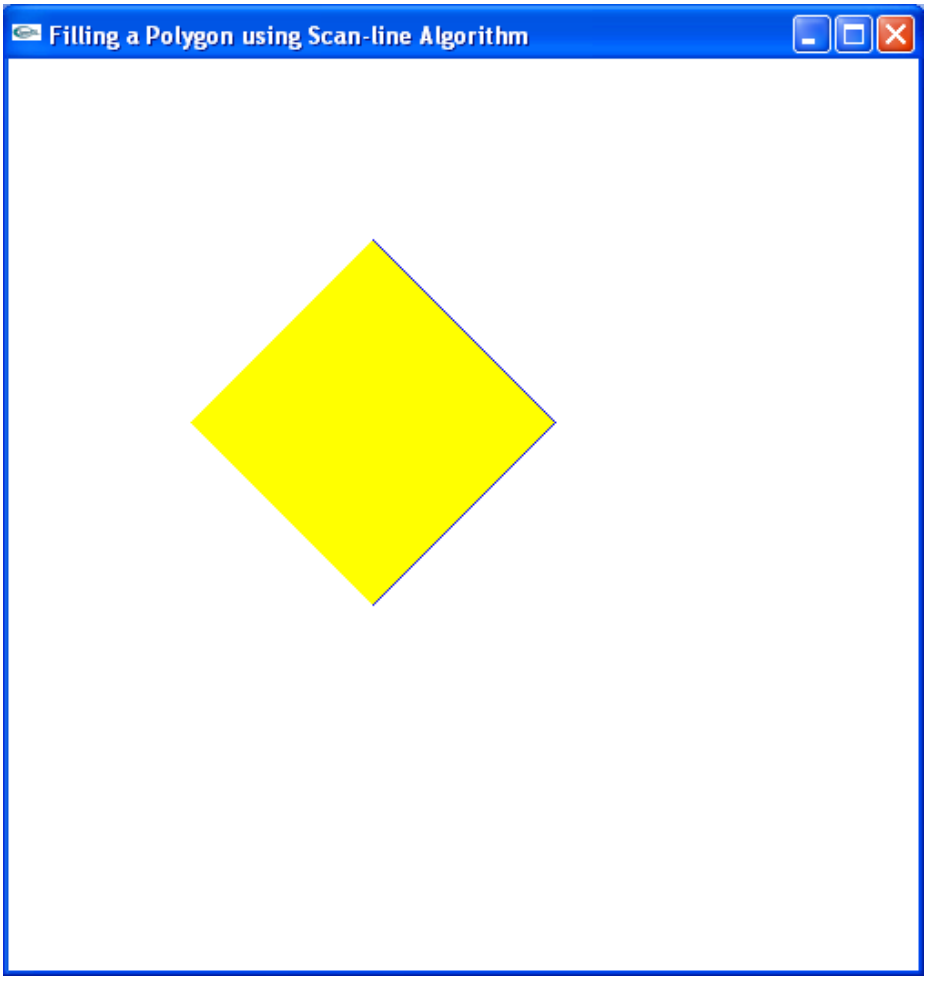
Polygon using scan-line area filling algorithm

AIM: - Program to fill any given polygon using scan-line area filling algorithm. (Use appropriate data structures.)

```
// Scan-Line algorithm for filling a polygon
#define BLACK 0
#include <stdlib.h>
#include <stdio.h>
#include <GL/glut.h>
float x1,x2,x3,x4,y1,y2,y3,y4;
void edgedetect(float x1,float y1,float x2,float y2,int *le,int *re)
{
float mx,x,temp;
int i;
      if((y2-y1)<0)
      {
            temp=y1;y1=y2;y2=temp;
            temp=x1;x1=x2;x2=temp;
      }
      if((y2-y1)!=0)
            mx=(x2-x1)/(y2-y1);
      else
            mx=x2-x1;
      x=x1;
      for(i=y1;i<=y2;i++)
      {
            if(x<(float)le[i])
                  le[i]=(int)x;
            if(x>(float)re[i])
                  re[i]=(int)x;
            x+=mx;
      }
}
void draw_pixel(int x,int y,int value)
{
      glColor3f(1.0,1.0,0.0);
      glBegin(GL_POINTS);
      glVertex2i(x,y);
      glEnd();
}
void scanfill(float x1,float y1,float x2,float y2,float x3,float y3,float
x4,float y4)
{
      int le[500],re[500];
      int i,y;
      for(i=0;i<500;i++)
      {
            le[i]=500;
            re[i]=0;
      }
      edgedetect(x1,y1,x2,y2,le,re);
      edgedetect(x2,y2,x3,y3,le,re);
      edgedetect(x3,y3,x4,y4,le,re);
      edgedetect(x4,y4,x1,y1,le,re);
      for(y=0;y<500;y++)
      {
```

```
            if(le[y]<=re[y])
                  for(i=(int)le[y];i<(int)re[y];i++)
                        draw_pixel(i,y,BLACK);
      }

}
void display()
{
x1=200.0;y1=200.0;x2=100.0;y2=300.0;x3=200.0;y3=400.0;x4=300.0;y4=300.0;

glClear(GL_COLOR_BUFFER_BIT);
glColor3f(0.0, 0.0, 1.0);
glBegin(GL_LINE_LOOP);
  glVertex2f(x1,y1);
  glVertex2f(x2,y2);
  glVertex2f(x3,y3);
  glVertex2f(x4,y4);
  glEnd();
  scanfill(x1,y1,x2,y2,x3,y3,x4,y4);

glFlush();
}

void myinit()
{
      glClearColor(1.0,1.0,1.0,1.0);
      glColor3f(1.0,0.0,0.0);
      glPointSize(1.0);
      glMatrixMode(GL_PROJECTION);
      glLoadIdentity();
      gluOrtho2D(0.0,499.0,0.0,499.0);
}

void main(int argc, char** argv)
{
      glutInit(&argc,argv);
      glutInitDisplayMode(GLUT_SINGLE|GLUT_RGB);
      glutInitWindowSize(500,500);
      glutInitWindowPosition(0,0);
      glutCreateWindow("Filling a Polygon using Scan-line Algorithm");
      glutDisplayFunc(display);
      myinit();
      glutMainLoop();
}
```

Output:-



Date: **Signature of the staff**

Program No: 10 **Date:**

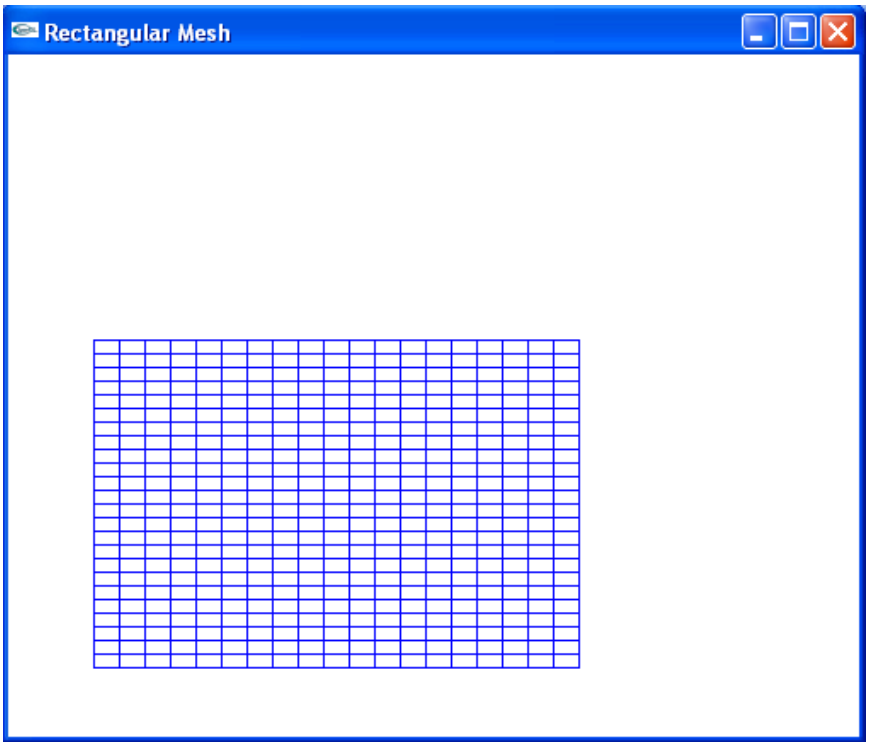
Rectangular mesh

AIM: - Program to display a set of values { fij } as a rectangular mesh.

```
// rect_mesh_vtu.cpp
// Rectangular Mesh using set of points f(i,j)=f(xi,yi) where xi=x0+i*dx,
yi=y0+j*dy
#include <stdlib.h> // standard definitions
#include <GL/glut.h> // GLUT
#define maxx 20
#define maxy 25
#define dx 15
#define dy 10

GLfloat x[maxx]={0.0},y[maxy]={0.0};
GLfloat x0=50,y0=50;  // initial values for x, y
GLint i,j;
void init()
{
    glClearColor(1.0,1.0,1.0,1.0);
      glColor3f(1.0,0.0,0.0);
      glPointSize(5.0);
      glMatrixMode(GL_PROJECTION);
      glLoadIdentity();
      gluOrtho2D(0.0,499.0,0.0,499.0);
      glutPostRedisplay();          // request redisplay
}

void display(void)

{
/* clear window */
       glClear(GL_COLOR_BUFFER_BIT);
       glColor3f(0.0, 0.0, 1.0);                 // set color to blue
/* draw rectangles */
       for(i=0;i<maxx;i++)
             x[i]=x0+i*dx;    // compute x[i]
            for(j=0;j<maxy;j++)
                  y[j]=y0+j*dy;  // compute y[i]

            glColor3f(0.0, 0.0, 1.0);
            for(i=0;i<maxx-1;i++)
            for(j=0;j<maxy-1;j++)
            {
                  glColor3f(0.0, 0.0, 1.0);
            glBegin(GL_LINE_LOOP);
            glVertex2f(x[i],y[j]);
            glVertex2f(x[i],y[j+1]);
            glVertex2f(x[i+1],y[j+1]);
            glVertex2f(x[i+1],y[j]);
            glEnd();
            glFlush();
            }
      glFlush();

}
```

```
void main(int argc, char** argv)
{
     glutInit(&argc, argv); // OpenGL initializations
     glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);// single buffering and RGB
     glutInitWindowSize(500, 400); // create a 500x400 window
     glutInitWindowPosition(0, 0); // ...in the upper left
     glutCreateWindow("Rectangular Mesh"); // create the window
     glutDisplayFunc(display); // setup callbacks
     init();
     glutMainLoop(); // start it running
}
```

Output:-



Date: **Signature of the staff**

References

1. Edward Angel: Interactive Computer Graphics A Top-Down Approach with OpenGL, 5th Edition, Addison-Wesley, 2008.
2. F.S. Hill,Jr.: Computer Graphics Using OpenGL, 2nd Edition, Pearson education, 2001.
3. James D Foley, Andries Van Dam, Steven K Feiner, John F Hughes, Computer Graphics, Addison-wesley 1997.
4. Donald Hearn and Pauline Baker: Computer Graphics- OpenGL Version, 2nd Edition, Pearson Education, 2003.

Annexures

Basic 2D Drawing

glBegin (mode);

glBegin — delimit the vertices of a primitive or a group of like primitives

Mode

Specifies the primitive or primitives that will be created from vertices presented between glBegin and the subsequent glEnd. Ten symbolic constants are accepted: GL_POINTS, GL_LINES, GL_LINE_STRIP, GL_LINE_LOOP, GL_TRIANGLES, GL_TRIANGLE_STRIP, GL_TRIANGLE_FAN, GL_QUADS,GL_QUAD_STRIP, and GL_POLYGON.

Lines of zero length are not visible.

A vertex is considered to be just a location with zero mass.

Only 10 of the OpenGL functions are legal for use between glBegin and glEnd.

Some Primitive Attributes

glClearColor (red, green, blue, alpha); - Default = (0.0, 0.0, 0.0, 0.0)

glColor3f (red, green, blue); - Default = (1.0, 1.0, 1.0)

glLineWidth (width); - Default = (1.0)

glLineStipple (factor, pattern) - Default = (1, 0xffff)

glEnable (GL_LINE_STIPPLE);

glPolygonMode (face, mode) - Default = (GL_FRONT_AND_BACK, GL_FILL)

glPointSize (size); - Default = (1.0)

Obtaining Values of OpenGL State Variables

glGetBooleanv (paramname, *paramlist);

glGetDoublev (paramname, *paramlist);

glGetFloatv (paramname, *paramlist);

glGetIntegerv (paramname, *paramlist);

Saving and Restoring Attributes

glPushAttrib (group);
glPopAttrib ( );

Where group = GL_CURRENT_BIT, GL_ENABLE_BIT, GL_LINE_BIT, GL_POLYGON_BIT, etc.

Projection Transformations

glMatrixMode (mode);

glMatrixMode — specify which matrix is the current matrix

Mode - Specifies which matrix stack is the target for subsequent matrix operations. Three values are accepted: GL_MODELVIEW, GL_PROJECTION, and GL_TEXTURE. The initial value is GL_MODELVIEW. Additionally, if the GL_ARB_imaging extension is supported, GL_COLOR is also accepted.

glLoadIdentity ( );

glLoadIdentity — replace the current matrix with the identity matrix.

glLoadIdentity replaces the current matrix with the identity matrix. It is semantically equivalent to calling glLoadMatrix with the identity matrix.

1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 but in some cases it is more efficient.

glFrustrum( )— multiply the current matrix by a perspective matrix

glFrustum (left, right, bottom, top, near, far);

left, right

Specify the coordinates for the left and right vertical clipping planes.

bottom, top

Specify the coordinates for the bottom and top horizontal clipping planes.

nearVal, farVal

Specify the distances to the near and far depth clipping planes. Both distances must be positive.

gluPerspective ( )-set up a perspective projection matrix

gluPerspective (fov, aspect, near, far);

fovy

Specifies the field of view angle, in degrees, in the *y* direction.

aspect

Specifies the aspect ratio that determines the field of view in the *x* direction. The aspect ratio is the ratio of *x* (width) to *y* (height).

zNear

Specifies the distance from the viewer to the near clipping plane (always positive).

zFar

Specifies the distance from the viewer to the far clipping plane (always positive).

glOrtho( ) - multiply the current matrix with an orthographic matrix.

glOrtho (left, right, bottom, top, near, far); - Default = (-1.0, 1.0, -1.0, 1.0, -1.0, 1.0)

gluOrtho2D - define a 2D orthographic projection matrix.

gluOrtho2D (left, right, bottom, top);

Modelview Transformations

glMatrixMode (GL_MODELVIEW);
glLoadIdentity ( );
gluLookAt (eye_x, eye_y, eye_z, at_x, at_y, at_z, up_x, up_y, up_z);
glTranslatef (dx, dy, dz);
glScalef (sx, sy, sz);
glRotatef (angle, axisx, axisy, axisz);

Writing Bitmapped Text

glPixelStorei (GL_UNPACK_ALIGNMENT, 1);
glColor3f (red, green, blue);
glRasterPos2f (x, y);
glutBitmapCharacter (font, character);

where font = GLUT_BITMAP_8_BY_13, GLUT_BITMAP_HELVETICA_10, etc.

Managing the Frame Buffer

glutInit (&argc, argv) - Initialize OpenGLUT data structures.

glutInitDisplayMode (mode) - sets the initial display mode.

Mode

Display mode, normally the bitwise OR-ing of GLUT display mode bit masks. See values below:

GLUT_RGBA
Bit mask to select an RGBA mode window. This is the default if neither GLUT_RGBA nor GLUT_INDEX are specified.

GLUT_RGB
An alias for GLUT_RGBA.

GLUT_INDEX
Bit mask to select a color index mode window. This overrides GLUT_RGBA if it is also specified.

GLUT_SINGLE
Bit mask to select a single buffered window. This is the default if neither GLUT_DOUBLE or GLUT_SINGLE are specified.

GLUT_DOUBLE
Bit mask to select a double buffered window. This overrides GLUT_SINGLE if it is also specified.

GLUT_ACCUM
Bit mask to request a window with an accumulation buffer.

GLUT_ALPHA
Bit mask to request a window with an alpha component to the color buffer(s).

GLUT_DEPTH
Bit mask to request a window with a depth buffer.

GLUT_STENCIL
Bit mask to request a window with a stencil buffer.

glutInitWindowSize (width, height);

glutInitWindowPosition (x, y);

glutCreateWindow (label);

glClear (GL_COLOR_BUFFER_BIT);

glutSwapBuffers ( ) - glutSwapBuffers swaps the buffers of the *current window* if double buffered.

where mode = GLUT_SINGLE or GLUT_DOUBLE.

Registering Callbacks

glutDisplayFunc (callback);

glutReshapeFunc (callback);

glutDisplayFunc (callback);

glutMotionFunc (callback);

glutPassiveMotionFunc (callback);

glutMouseFunc (callback);

glutKeyboardFunc (callback);

id = glutCreateMenu (callback);

glutMainLoop ( );

Display Lists

glNewList (number, GL_COMPILE);

glEndList ( );

glCallList (number);

glDeleteLists (number, 1);

Managing Menus

id = glutCreateMenu (callback);

glutDestroyMenu (id);

glutAddMenuEntry (label, number);

glutAttachMenu (button);

glutDetachMenu (button);

where button = GLUT_RIGHT_BUTTON or GLUT_LEFT_BUTTON.

Viva Questions & Answers

1. Define Computer graphics?
   Computer graphics are graphics created by computers and, more generally, the representation and manipulation of pictorial data by a computer

2. Define Computer Animation?
   Computer animation is the art of creating moving images via the use of computers. It is a subfield of **computer graphics** and animation

3. Define Pixel?
   The word *pixel* is based on a contraction of *pix* ("pictures") and *el* (for "element"). Pixels are normally arranged in a 2-dimensional grid, and are often represented using dots, squares, or rectangles

4. Define Raster graphics?
   Raster Graphics, which is the representation of images as an array of pixels, as it is typically used for the representation of photographic images.

5. Define Image?
   An **image** (from Latin *imago*) is an artifact, usually two-dimensional (a **picture**), that has a similar appearance to some subject—usually a physical object or a person.

6. Define Rendering?
   Rendering is the process of generating an image from a model, by means of computer programs.

7. Define Ray Tracing?
   Ray tracing is a technique for generating an image by tracing the path of light through pixels in an image plane.

8. Define Projection?
   Projection is a method of mapping points to a plane.

9. Define 3D Projection?
   3D projection is a method of mapping three dimensional points to a two dimensional plane.

10. Define Texture Mapping?
    Texture mapping is a method for adding detail, surface texture, or color to a computer-generated graphic or 3D model.

11. Define Vector Graphics?
    Vector graphics formats are complementary to raster graphics, which is the representation of images as an array of pixels, as it is typically used for the representation of photographic images.

12. Define Pinhole camera model?
    The **pinhole camera model** describes the mathematical relationship between the coordinates of a 3D point and its projection onto the image plane of an *ideal* pinhole

camera, where the camera aperture is described as a point and no lenses are used to focus light.

13. Define digital image?
    A **digital image** is a representation of a two-dimensional image using ones and zeros (binary). Without qualifications, the term "digital image" usually refers to raster images.

14. Define Grayscale?
    A **grayscale** or **greyscale** digital image is an image in which the value of each pixel is a single sample, that is, it carries only intensity information.

15. Define Pinhole Camera?
    A **pinhole camera** is a very simple camera with no lens and a single very small aperture. Simply explained, it is a light-proof box with a small hole in one side.

16. Define CCD?
    A **charge-coupled device** (**CCD**) is an analog shift register that enables the transportation of analog signals (electric charges) through successive stages (capacitors), controlled by a clock signa.

17. Define Image Resolution?
    Image resolution describes the detail an image holds. The term applies equally to digital images, film images, and other types of images. Higher resolution means more image detail.

18. Define Wavelength?
    Wavelength is the distance between repeating units of a propagating wave of a given frequency.

19. What is an Electromagnetic Spectrum?
    The **electromagnetic (EM) spectrum** is the range of all possible electromagnetic radiation frequencies. The "electromagnetic spectrum" (usually just *spectrum*) of an object is the characteristic distribution of electromagnetic radiation from that particular object.

20. Define Halftone?
    Halftone is the reprographic technique that simulates continuous tone imagery through the use of dots, varying either in size or in spacing. 'Halftone' can also be used to refer specifically to the image that is produced by this process.

21. Define WCS?
    World Coordinate Systems. While every point in the FITS data array can be located in the coordinate system determined by the array axes. **World Coordinate** Systems (WCS) are any **coordinate** systems that describe the physical **coordinate** associated with a data array, such as sky **coordinates.**

22. What is OpenGL?
    OpenGL(R) is the software interface for graphics hardware that allows graphics programmers to produce high-quality color images of 3D objects. OpenGL is a rendering only, vendor neutral API providing 2D and 3D graphics functions, including modeling, transformations, color, lighting, smooth shading, as well as advanced features like texture

mapping, NURBS, fog, alpha blending and motion blur. OpenGL works in both immediate and retained (display list) graphics modes.
OpenGL is window system and operating system independent. OpenGL has been integrated with Windows NT and with the X Window System under UNIX. Also, OpenGL is network transparent. A defined common extension to the X Window System allows an OpenGL client on one vendor's platform to run across a network to another vendor's OpenGL server

23. What hardware supports the OpenGL API?

    Many vendors have developed or are developing implementations of the OpenGL API for a variety of embedded hardware devices including aircraft avionics, PDAs (personal digital assistants such as Palm™), cellular phones, game consoles (Sony Playstation® 2), television set-top boxes, and display devices (X-Terms and network computers). The small size of the OpenGL API, its open nature, and now free use of the sample implementation make the OpenGL API an ideal graphics library for these types of applications.

24. What are the benefits of OpenGL for hardware and software developers?

    - Industry standard
    - Reliable and portable.
    - Evolving.
    - Scalable.
    - Easy to use.
    - Well-documented**.**

25. What is the GLUT Toolkit?
    GLUT is a portable toolkit which performs window and event operations to support OpenGL rendering

26. How does the camera work in OpenGL?
    As far as OpenGL is concerned, there is no camera. More specifically, the camera is always located at the eye space coordinate (0.0, 0.0, 0.0). To give the appearance of moving the camera, your OpenGL application must move the scene with the inverse of the camera transformation by placing it on the MODELVIEW matrix. This is commonly referred to as the viewing transformation. In practice this is mathematically equivalent to a camera transformation but more efficient because model transformations and camera transformations are concatenated to a single matrix. As a result though, certain operations must be performed when the camera and only the camera is on the MODELVIEW matrix. For example to position a light source in world space it most be positioned while the viewing transformation and only the viewing transformation is applied to the MODELVIEW matrix.

27. How do I implement a zoom operation?

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. For example, your program might maintain a zoom factor based on user input, which is a floating-point number. When set to a value of 1.0, no zooming takes place. Larger values result in greater zooming or a more restricted field of view, while smaller values cause the opposite to occur.

28. How do I get a specified point (XYZ) to appear at the center of the scene?

    gluLookAt() is the easiest way to do this. Simply set the X, Y, and Z values of your point as the fourth, fifth, and sixth parameters to gluLookAt ().

29. Define Instruction Pipeline?

    An **instruction pipeline** is a technique used in the design of computers and other digital electronic devices to increase their instruction throughput (the number of instructions that can be executed in a unit of time).

30. Define Geometric Pipeline?

    Geometric manipulation of modeling primitives, such as that performed by a **Geometry Pipeline**, is the first stage in computer graphics systems which perform image generation based on geometric models.

31. Define Perspective Projection?

    Perspective (from Latin *perspicere*, to see through) in the graphic arts, such as drawing, is an approximate representation, on a flat surface (such as paper), of an image as it is perceived by the eye. The two most characteristic features of perspective are that objects are drawn.