Lecture 3

Programming with OpenGL + GLUT

OpenGL

The success of GL lead to OpenGL (1992), a platform-independent API that was

- Easy to use
- Close enough to the hardware to get excellent performance
- Focus on rendering
- Omitted windowing and input to avoid window system dependencies

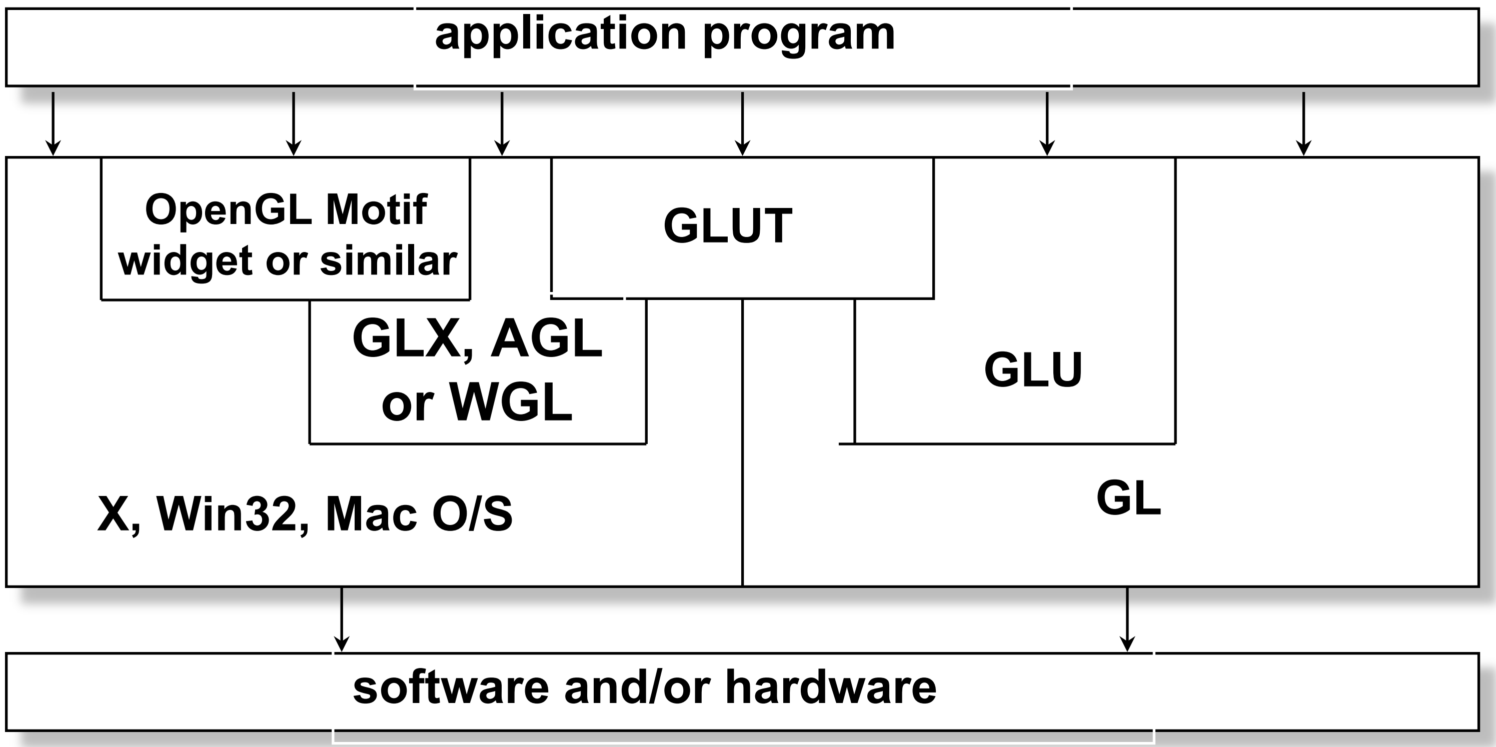
OpenGL Libraries

- OpenGL core library
  - OpenGL32 on Windows
  - GL on most unix/linux systems (libGL.a)
- OpenGL Utility Library (GLU)
  - Provides functionality in OpenGL core but avoids having to rewrite code
- Links with window system
  - GLX for X window systems
  - WGL for Windows
  - AGL for Macintosh

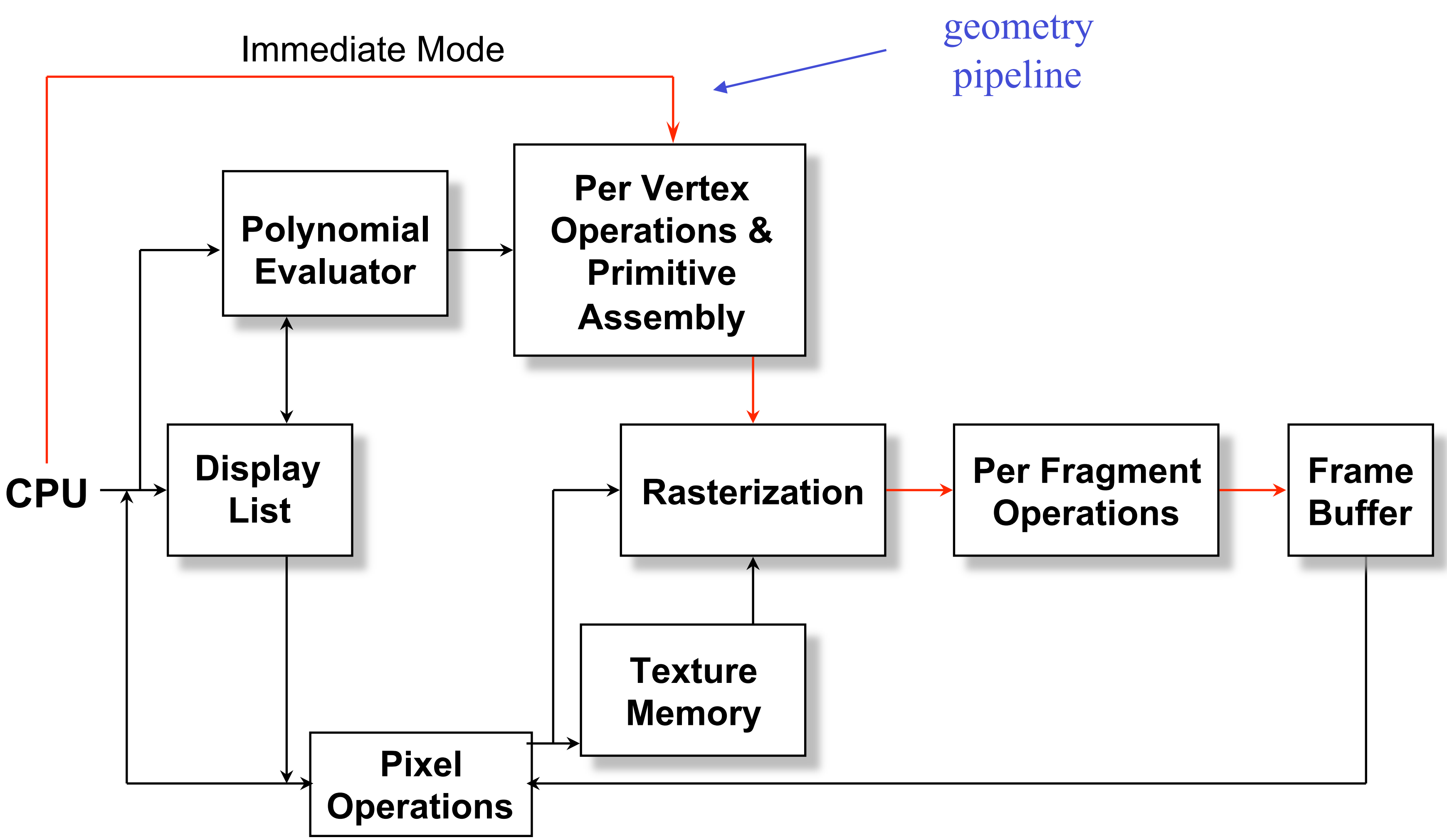
GLUT

- OpenGL Utility Toolkit (GLUT)
  - Provides functionality common to all window systems
    - Open a window
    - Get input from mouse and keyboard
    - Menus
    - Event-driven
  - Code is portable but GLUT lacks the functionality of a good toolkit for a specific platform
    - No slide bars

Software Organization



OpenGL Architecture



OpenGL Functions

- Primitives
  - Points
  - Line Segments
  - Polygons
- Attributes
- Transformations
  - Viewing
  - Modeling
- Control (GLUT)
- Input (GLUT)
- Query

OpenGL State

- OpenGL is a state machine
- OpenGL functions are of two types
  - Primitive generating
    - Can cause output if primitive is visible
    - How vertices are processed and appearance of primitive are controlled by the state
  - State changing
    - Transformation functions
    - Attribute functions

Not Object Oriented

- OpenGL is not object oriented so that there are multiple functions for a given logical function
  - `glVertex3f`
  - `glVertex2i`
  - `glVertex3dv`
- Underlying storage mode is the same
- Easy to create overloaded functions in C++ but issue is efficiency

OpenGL Function Format

function name

dimensions

glVertex3f(x,y,z)

belongs to GL library

x,y,z are **floats**

glVertex3fv(p)

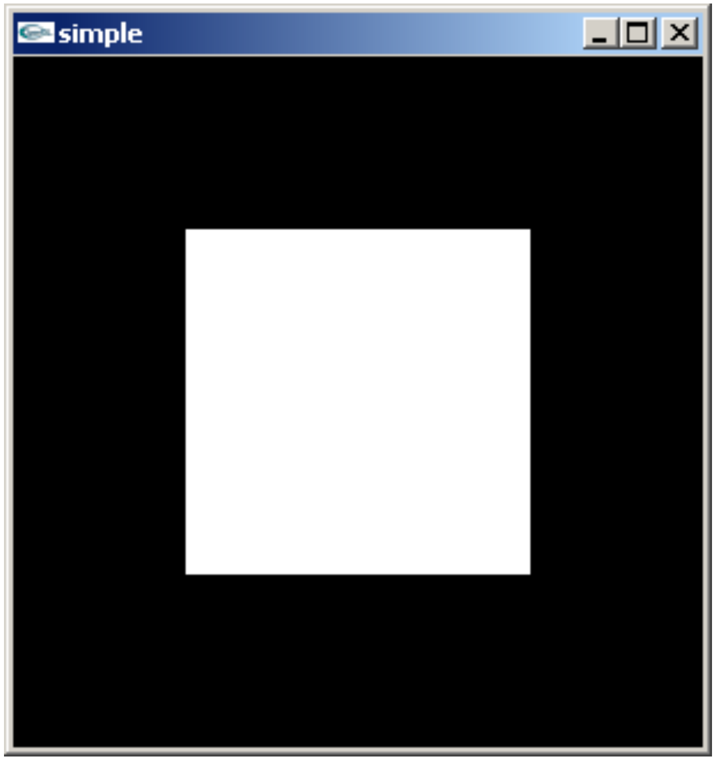
p is a pointer to an array

OpenGL #defines

- Most constants are defined in the include files **`gl.h`**, **`glu.h`** and **`glut.h`**
  - Note **`#include <GL/glut.h>`** should automatically include the others
  - Examples
  - **`glBegin(GL_POLYGON)`**
  - **`glClear(GL_COLOR_BUFFER_BIT)`**
- include files also define OpenGL data types: **`GLfloat`**, **`GLdouble`**,….

A Simple Program

Generate a square on a solid background



Simple.c

```
#include <GL/glut.h>
void mydisplay(){
    glClear(GL_COLOR_BUFFER_BIT);
        glBegin(GL_POLYGON);
                glVertex2f(-0.5, -0.5);
                glVertex2f(-0.5, 0.5);
                glVertex2f(0.5, 0.5);
                glVertex2f(0.5, -0.5);
        glEnd();
        glFlush();
}
int main(int argc, char** argv){
        glutCreateWindow("simple");
        glutDisplayFunc(mydisplay);
        glutMainLoop();
}
```

Event Loop

- Note that the program defines a *display callback* function named **`mydisplay`**
  - Every glut program must have a display callback
  - The display callback is executed whenever OpenGL decides the display must be refreshed, for example when the window is opened
  - The **`main`** function ends with the program entering an event loop

Compilation Notes

- See website and starter code of Project 1 for example
- Unix/linux
  - Include files usually in …/include/GL
  - Compile with –lglut –lglu –lgl loader flags
  - May have to add –L flag for X libraries
  - Mesa implementation included with most linux distributions
  - Check web for latest versions of Mesa and GLUT

Defaults

- `simple.c` is too simple
- Makes heavy use of state variable default values for
  - Viewing
  - Colors
  - Window parameters
- Next version will make the defaults more explicit

OpenGL Program Structure

- Most OpenGL programs have a similar structure that consists of the following functions
  - **`main()`**:
    - defines the callback functions
    - opens one or more windows with the required properties
    - enters event loop (last executable statement)
  - **`init()`**: sets the state variables
    - Viewing
    - Attributes
  - callbacks
    - Display function
    - Input and window functions

Simple.c (revisited)

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

int main(int argc, char** argv)
{
 glutInit(&argc,argv);
 glutInitDisplayMode(GLUT_SINGLE|GLUT_RGB);
 glutInitWindowSize(500,500);
 glutInitWindowPosition(0,0);
 glutCreateWindow("simple");
 glutDisplayFunc(mydisplay);

 init();

 glutMainLoop();
}
```

includes **gl.h**

define window properties

display callback

set OpenGL state

enter event loop

GLUT functions

- **`glutInit`** allows application to get command line arguments and initializes system
- **`gluInitDisplayMode`** requests properties for the window (the *rendering context*)
  - RGB color
  - Single buffering
  - Properties logically ORed together
- **`glutWindowSize`** in pixels
- **`glutWindowPosition`** from top-left corner of display
- **`glutCreateWindow`** create window with title "simple"
- **`glutDisplayFunc`** display callback
- **`glutMainLoop`** enter infinite event loop

Init.c

black clear color

opaque window

```
void init()
{
 glClearColor (0.0, 0.0, 0.0, 1.0);

 glColor3f(1.0, 1.0, 1.0);

 glMatrixMode (GL_PROJECTION);
 glLoadIdentity ();
 glOrtho(-1.0, 1.0, -1.0, 1.0, -1.0, 1.0);
}
```

fill/draw with white

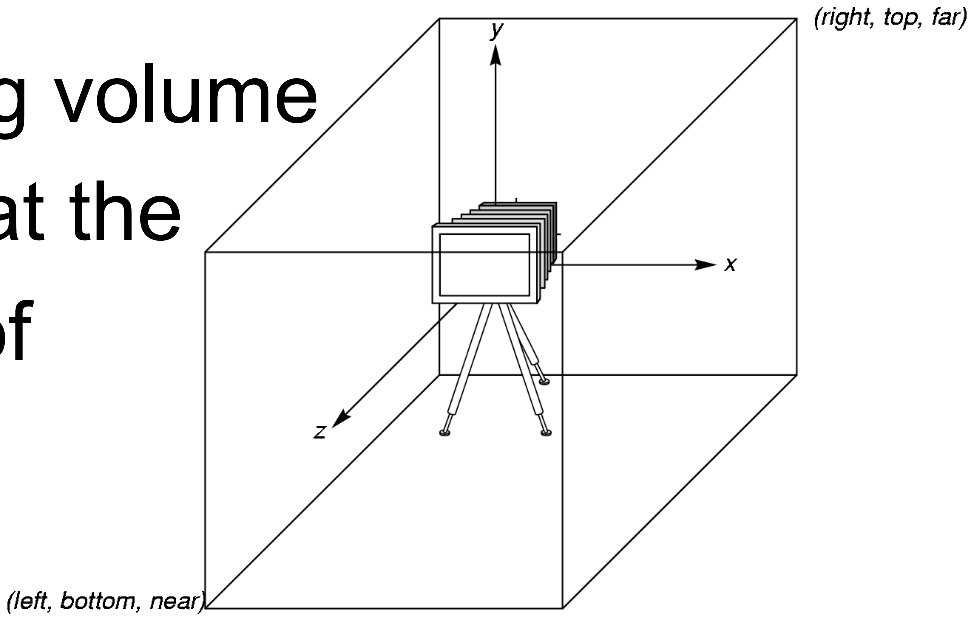
viewing volume

Coordinate Systems in OpenGL

- The units in **`glVertex`** are determined by the application and are called *object* or *problem coordinates*
- The viewing specifications are also in object coordinates and it is the size of the viewing volume that determines what will appear in the image
- Internally, OpenGL will convert to *camera (eye) coordinates* and later to *screen coordinates*
- OpenGL also uses some internal representations that usually are not visible to the application

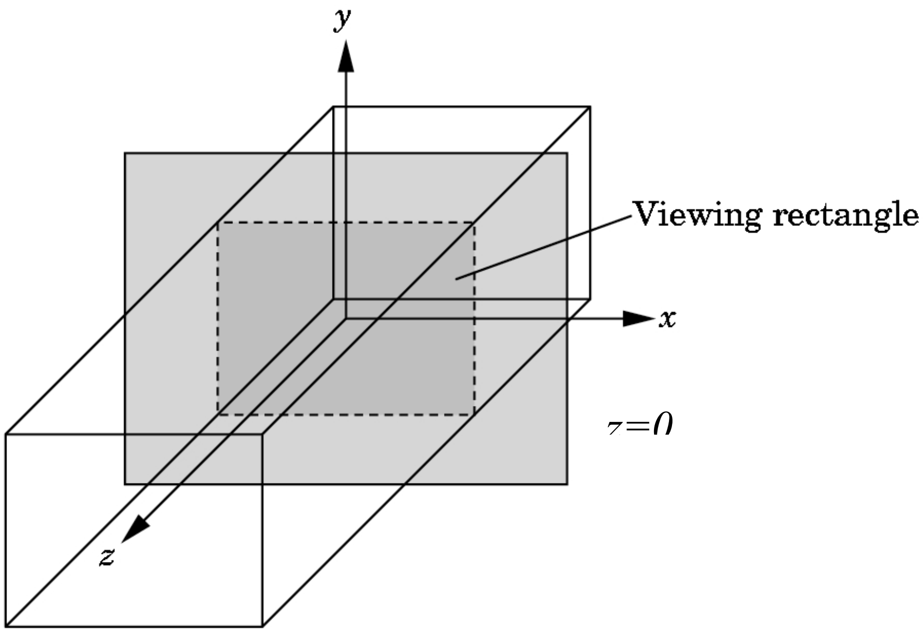
OpenGL Camera I

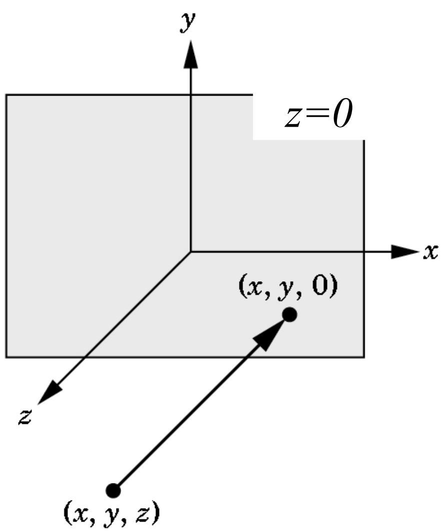
- OpenGL places a camera at the origin in object space pointing in the negative z direction
- The default viewing volume is a box centered at the origin with a side of length 2



Orthographic Viewing

In the default orthographic view, points are projected forward along the z axis onto the plane $z=0$





Transformations & Viewing

- In OpenGL, projection is carried out by a projection matrix (transformation)
- There is only one set of transformation functions so we must set the matrix mode first

```
glMatrixMode (GL_PROJECTION)
```

- Transformation functions are incremental so we start with an identity matrix and alter it with a projection matrix that gives the view volume

```
glLoadIdentity();
glOrtho(-1.0, 1.0, -1.0, 1.0, -1.0, 1.0);
```

2D/3D Viewing

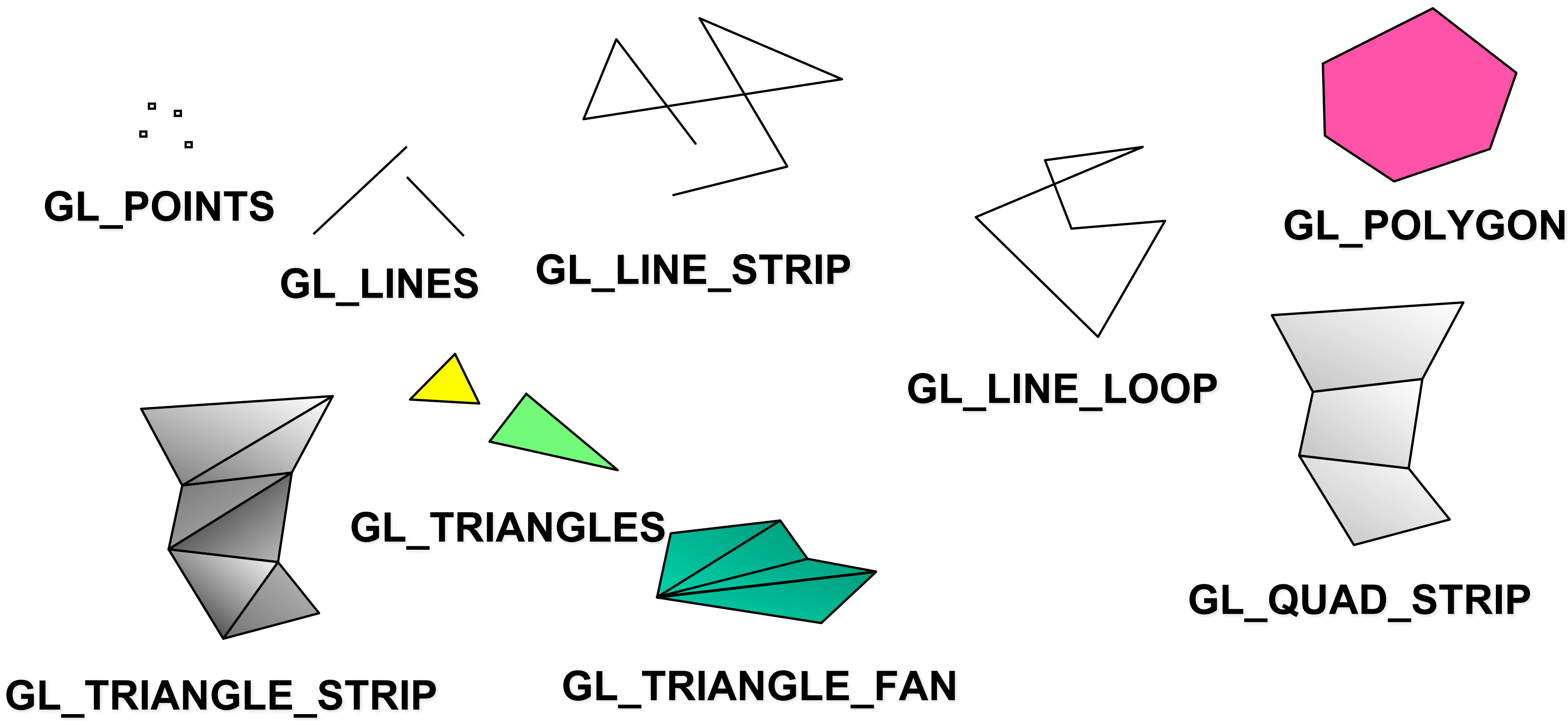
- In **`glOrtho(left, right, bottom, top, near, far)`** the near and far distances are measured from the camera
- Two-dimensional vertex commands place all vertices in the plane z=0
- If the application is in two dimensions, we can use the function

  `gluOrtho2D(left, right,bottom,top)`
- In two dimensions, the view or clipping volume becomes a *clipping window*

Mydisplay.c

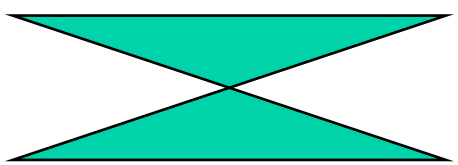
```c
void mydisplay()
{
 glClear(GL_COLOR_BUFFER_BIT);
 glBegin(GL_POLYGON);
        glVertex2f(-0.5, -0.5);
        glVertex2f(-0.5, 0.5);
        glVertex2f(0.5, 0.5);
        glVertex2f(0.5, -0.5);
 glEnd();
 glFlush();
}
```

OpenGL Geometry Primitives

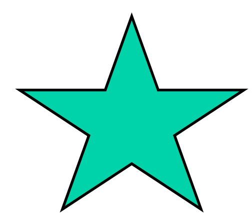


Polygons in OpenGL

- OpenGL will only display polygons correctly that are
  - Simple: edges cannot cross
  - Convex: All points on line segment between two points in a polygon are also in the polygon
  - Flat: all vertices are in the same plane
- User program can check if above true
  - OpenGL will produce output if these conditions are violated but it may not be what is desired
- Triangles satisfy all conditions



nonsimple polygon



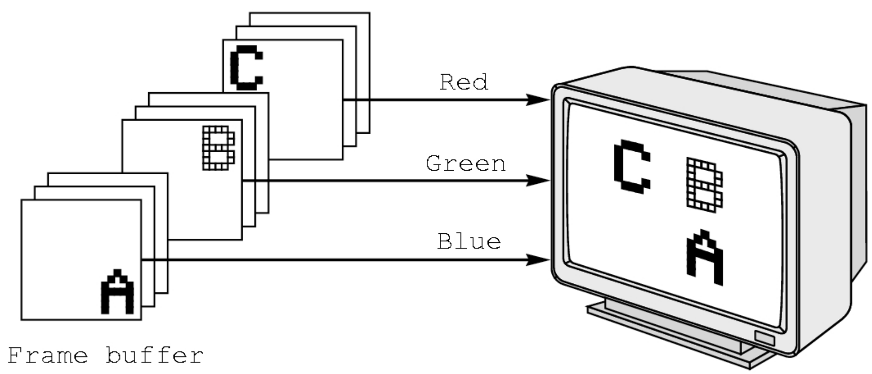
nonconvex polygon

Attributes

- Attributes are part of the OpenGL state and determine the appearance of objects
  - Color (points, lines, polygons)
  - Size and width (points, lines)
  - Stipple pattern (lines, polygons)
  - Polygon mode
    - Display as filled: solid color or stipple pattern
    - Display edges
    - Display vertices

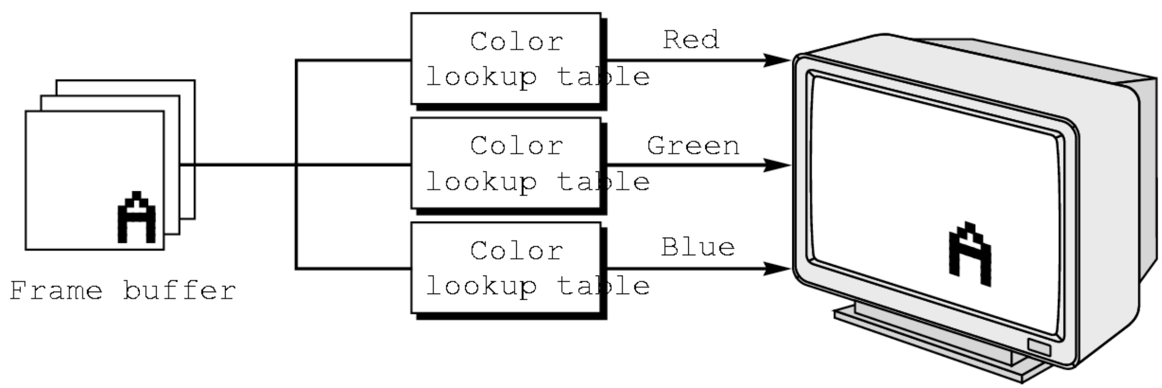
RGB Color in OpenGL

- Each color component is stored separately in the frame buffer
- Usually 8 bits per component in buffer
- Note in **`glColor3f`** the color values range from 0.0 (none) to 1.0 (all), whereas in **`glColor3ub`** the values range from 0 to 255



Indexed Color in OpenGL

- Colors are indices into tables of RGB values
- Requires less memory
  - indices usually 8 bits
  - Use when need more colors for shading



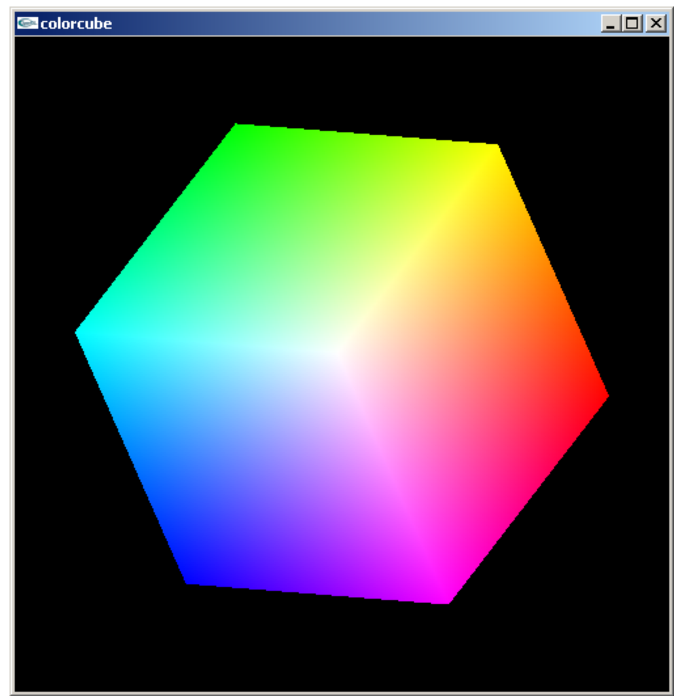
Colors & State

- The color as set by **`glColor`** becomes part of the state and will be used until changed
  - Colors and other attributes are not part of the object but are assigned when the object is rendered
- We can create conceptual *vertex colors* by code such as

```
glColor
glVertex
glColor
glVertex
```

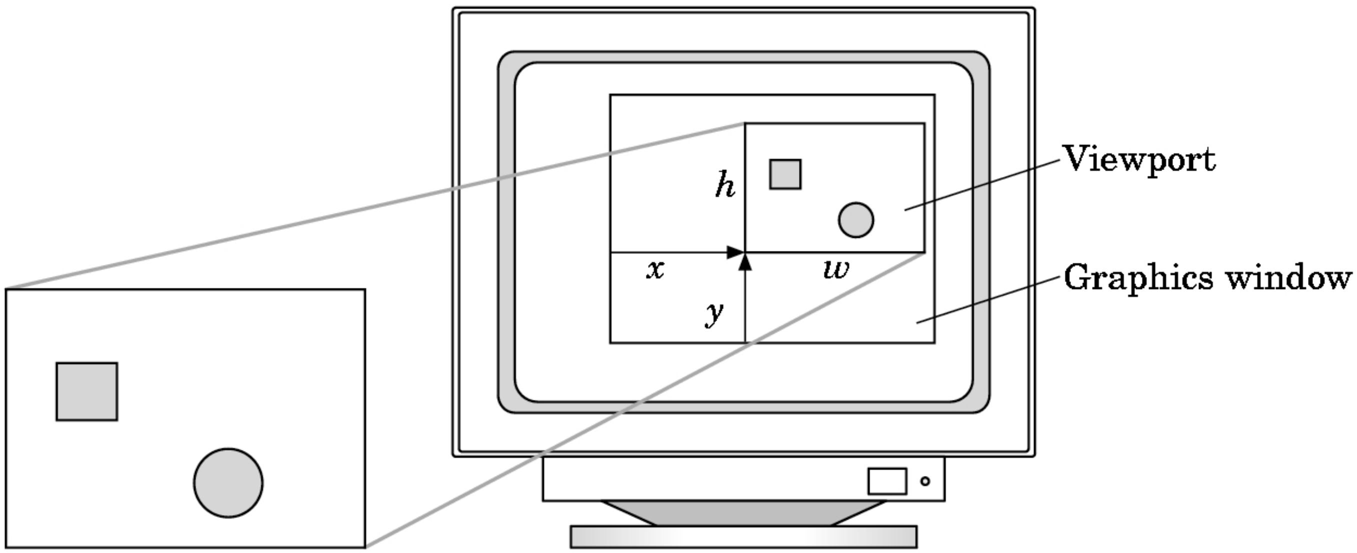
Smooth Color in OpenGL

- Default is *smooth* shading
  - OpenGL interpolates vertex colors across visible polygons
- Alternative is *flat shading*
  - Color of first vertex determines fill color
- **`glShadeModel`** **`(GL_SMOOTH)`** or **`GL_FLAT`**



Viewports

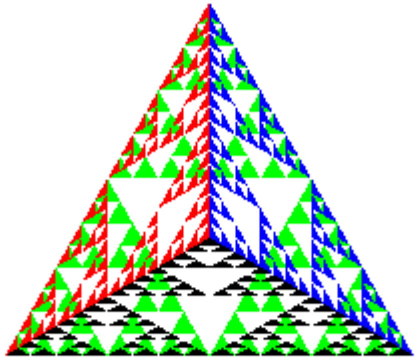
- Do not have use the entire window for the image: **`glViewport(x,y,w,h)`**
- Values in pixels (screen coordinates)



3D Applications in OpenGL

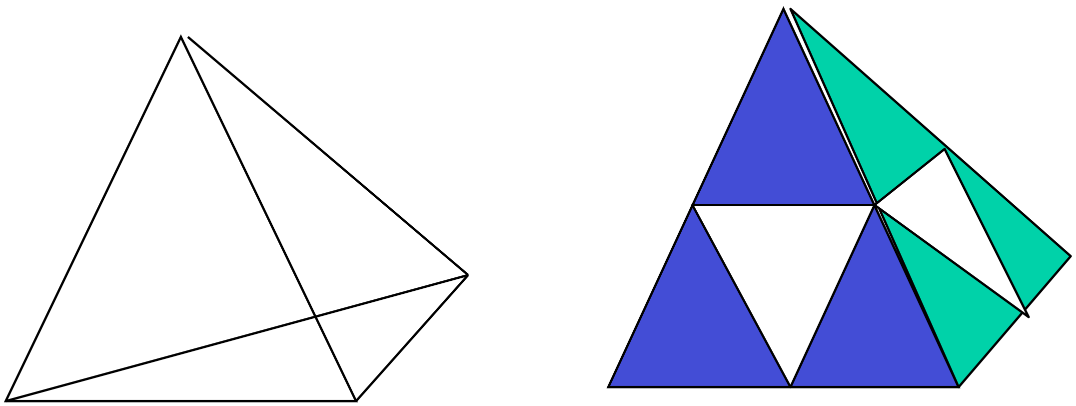
- In OpenGL, two-dimensional applications are a special case of three-dimensional graphics
- Going to 3D
  - Not much changes
  - Use **`glVertex3*( )`**
  - Have to worry about the order in which polygons are drawn or use hidden-surface removal
  - Polygons should be simple, convex, flat

3D Sierpinski Gasket



5 iterations

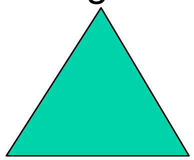
- Subdivide each of the four faces



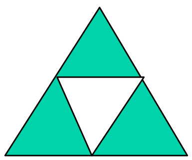
- Appears as if we remove a solid tetrahedron from the center leaving four smaller tetrahedra

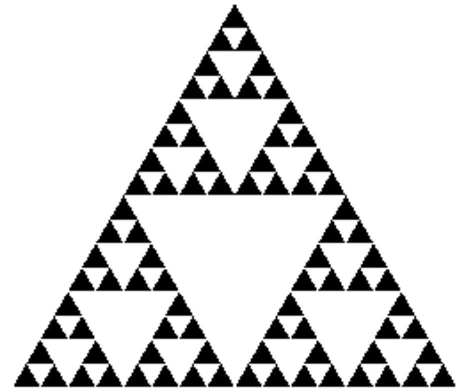
2D Triangle Subdivision

- Start with a triangle



- Connect bisectors of sides and remove central triangle





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

/* initial triangle */

GLfloat v[3][2]={{-1.0, -0.58},
           {1.0, -0.58}, {0.0, 1.15}};

void triangle( GLfloat *a, GLfloat *b,
 GLfloat *c)

/* display one triangle  */
{
      glVertex2fv(a);
      glVertex2fv(b);
      glVertex2fv(c);
}
```

```
void divide_triangle(GLfloat *a, GLfloat *b, GLfloat *c
 int m)
{
/* triangle subdivision using vertex numbers */
    point2 v0, v1, v2;
    int j;
    if(m>0)
     {
        for(j=0; j<2; j++) v0[j]=(a[j]+b[j])/2;
        for(j=0; j<2; j++) v1[j]=(a[j]+c[j])/2;
        for(j=0; j<2; j++) v2[j]=(b[j]+c[j])/2;
        divide_triangle(a, v0, v1, m-1);
        divide_triangle(c, v1, v2, m-1);
        divide_triangle(b, v2, v0, m-1);
    }
    else(triangle(a,b,c));
 /* draw triangle at end of recursion */
}
```

3D Triangle/Tetrahedron Subdivision

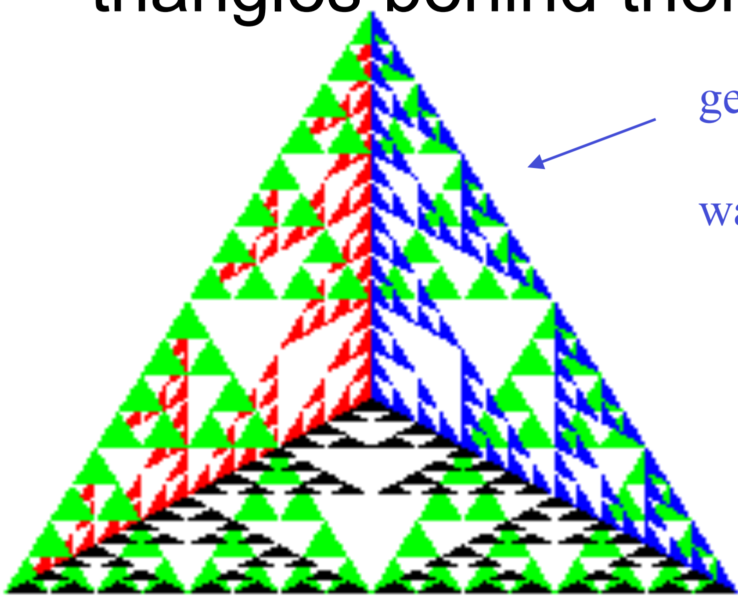
```
void triangle( GLfloat *a, GLfloat *b,
 GLfloat *c)
{
     glVertex3fv(a);
     glVertex3fv(b);
     glVertex3fv(c);
}
```

```
void divide_triangle(GLfloat *a, GLfloat *b,
 GLfloat *c, int m)
{
    GLfloat v1[3], v2[3], v3[3];
    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));
}
```

```
void tetrahedron( int m)
{
    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);
}
```

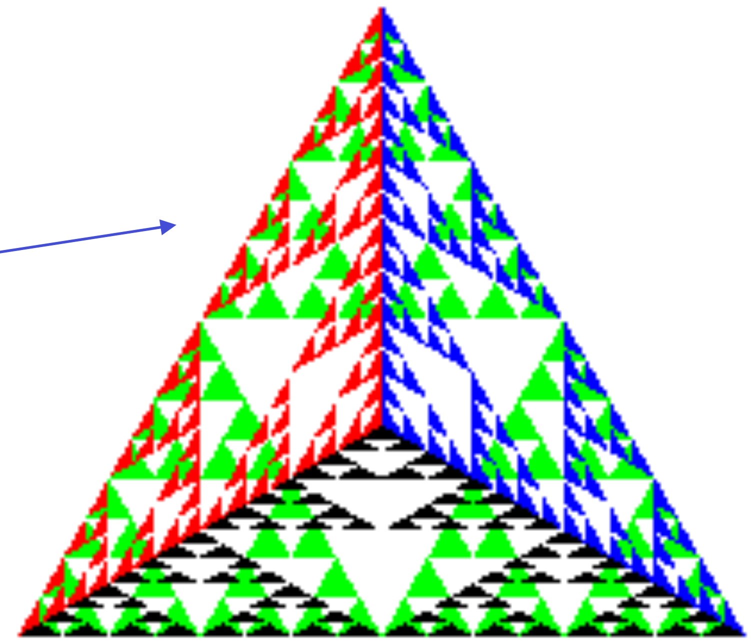
Almost Correct

- Because the triangles are drawn in the order they are defined in the program, the front triangles are not always rendered in front of triangles behind them



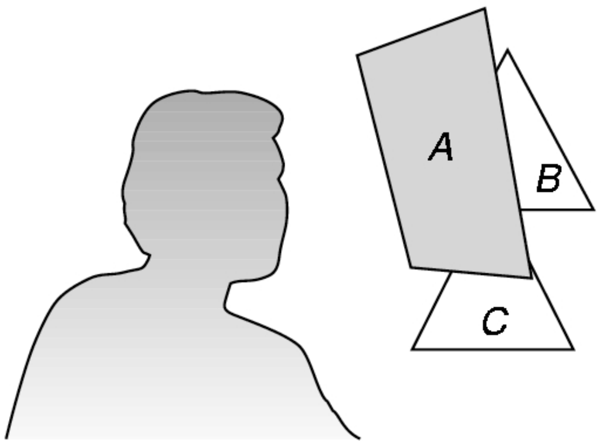
get this

want this



Hidden Surface Removal

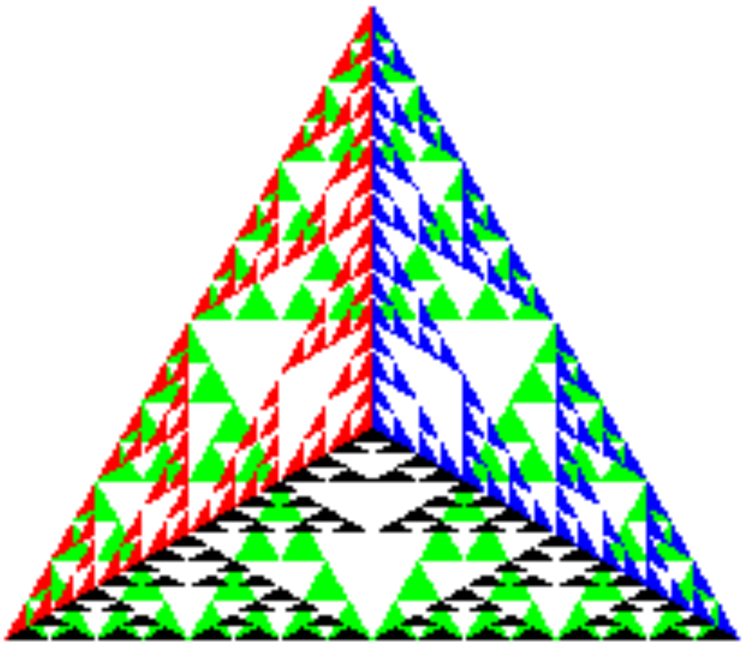
- We want to see only those surfaces in front of other surfaces
- OpenGL uses a *hidden-surface* method called the *z*-buffer algorithm that saves depth information as objects are rendered so that only the front objects appear in the image

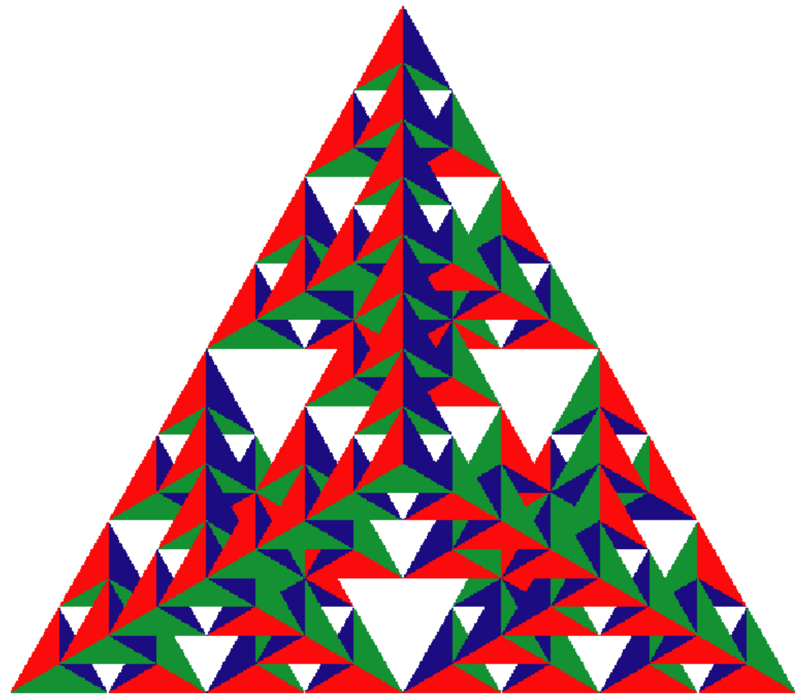


Using the Z-buffer algorithm

- The algorithm uses an extra buffer, the z-buffer, to store depth information as geometry travels down the pipeline
- It must be
  - Requested in **`main.c`**
    - **`glutInitDisplayMode (GLUT_SINGLE | GLUT_RGB | GLUT_DEPTH)`**
  - Enabled in **`init.c`**
    - **`glEnable(GL_DEPTH_TEST)`**
  - Cleared in the display callback
    - **`glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT)`**

Surface/Volume Subdivison





For complete 3D program please see pg. 693 - 695 of text