Programming with OpenGL

Part 1: Background

Objectives

- Development of the OpenGL API
- OpenGL Architecture
  - OpenGL as a state machine
- Functions
  - Types
  - Formats
- Simple program

Early History of APIs

- IFIPS (1973) formed two committees to come up with a standard graphics API
  - Graphical Kernel System (GKS)
    - 2D but contained good workstation model
  - Core
    - Both 2D and 3D
  - GKS adopted as IS0 and later ANSI standard (1980s)
- GKS not easily extended to 3D (GKS-3D)
  - Far behind hardware development

PHIGS and X

- Programmers Hierarchical Graphics System (PHIGS)
  - Arose from CAD community
  - Database model with retained graphics (structures)
- X Window System
  - DEC/MIT effort
  - Client-server architecture with graphics
- PEX combined the two
  - Not easy to use (all the defects of each)

SGI and GL

- Silicon Graphics (SGI) revolutionized the graphics workstation by implementing the pipeline in hardware (1982)
- To access the system, application programmers used a library called GL
- With GL, it was relatively simple to program three dimensional interactive applications

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 Evolution

- Controlled by an Architectural Review Board (ARB)
  - Members include SGI, Microsoft, Nvidia, HP, 3DLabs, IBM,…….
  - Relatively stable (present version 2.0)
    - Evolution reflects new hardware capabilities
      - 3D texture mapping and texture objects
      - Vertex programs
  - Allows for platform specific features through extensions

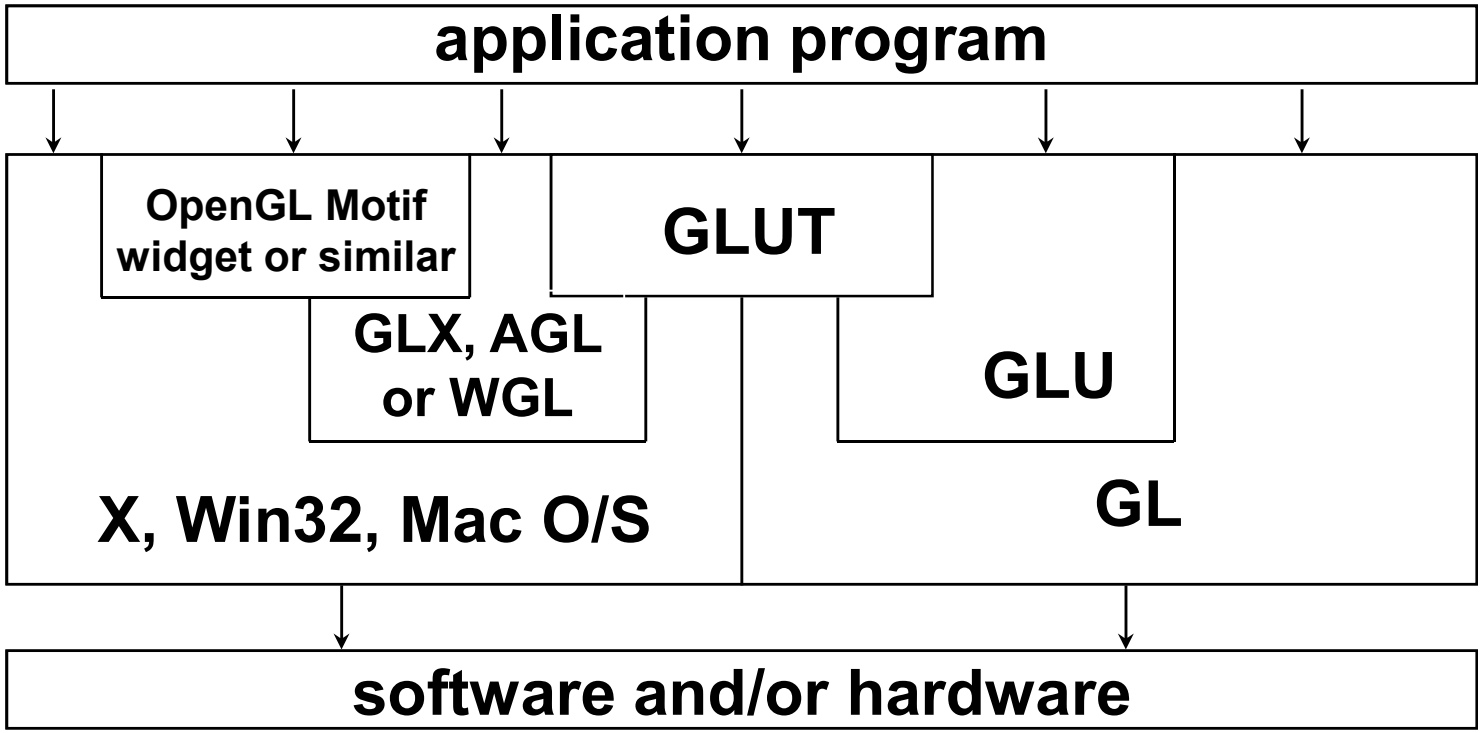
OpenGL Libraries

- 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

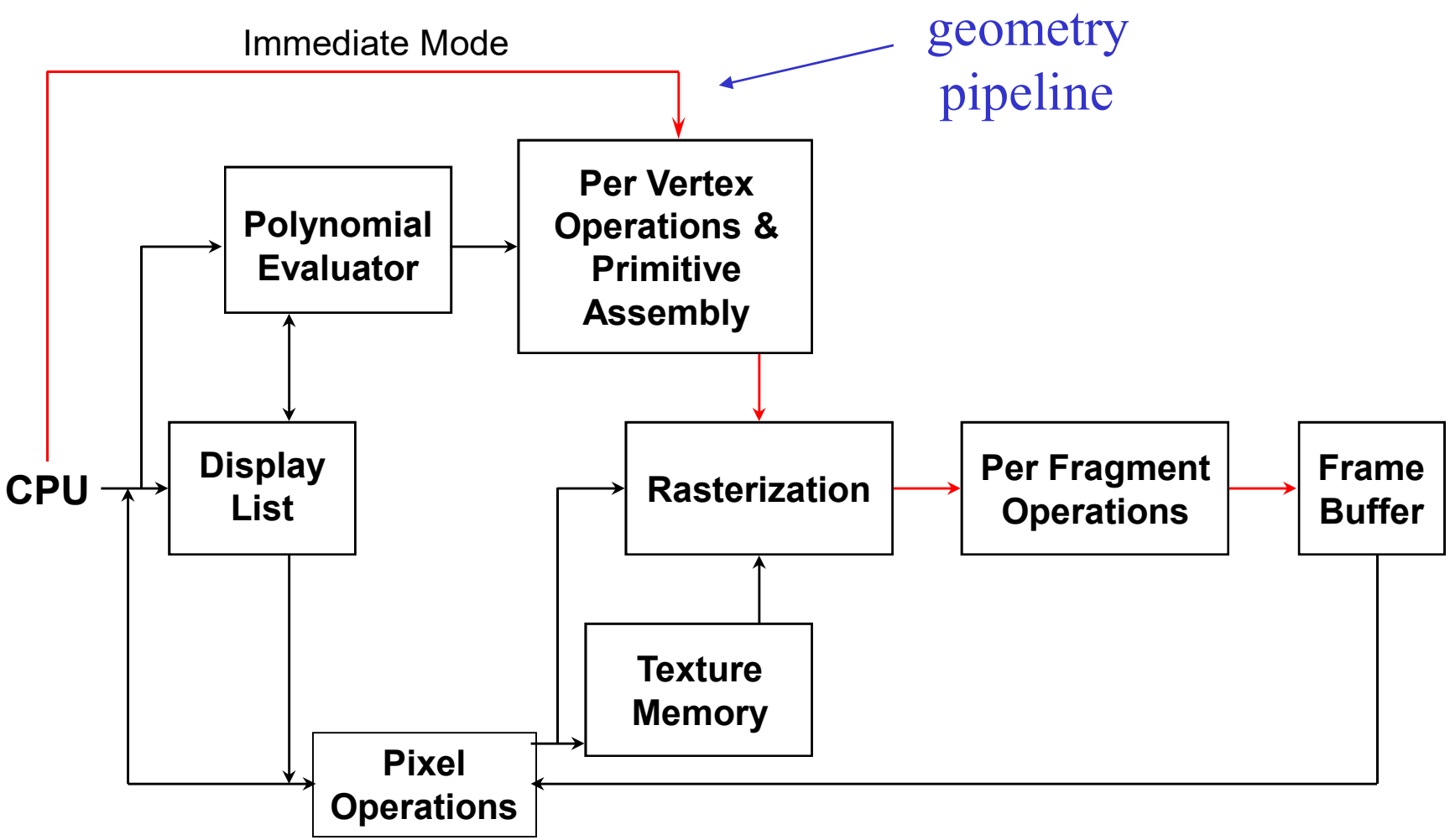
GLUT

- 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

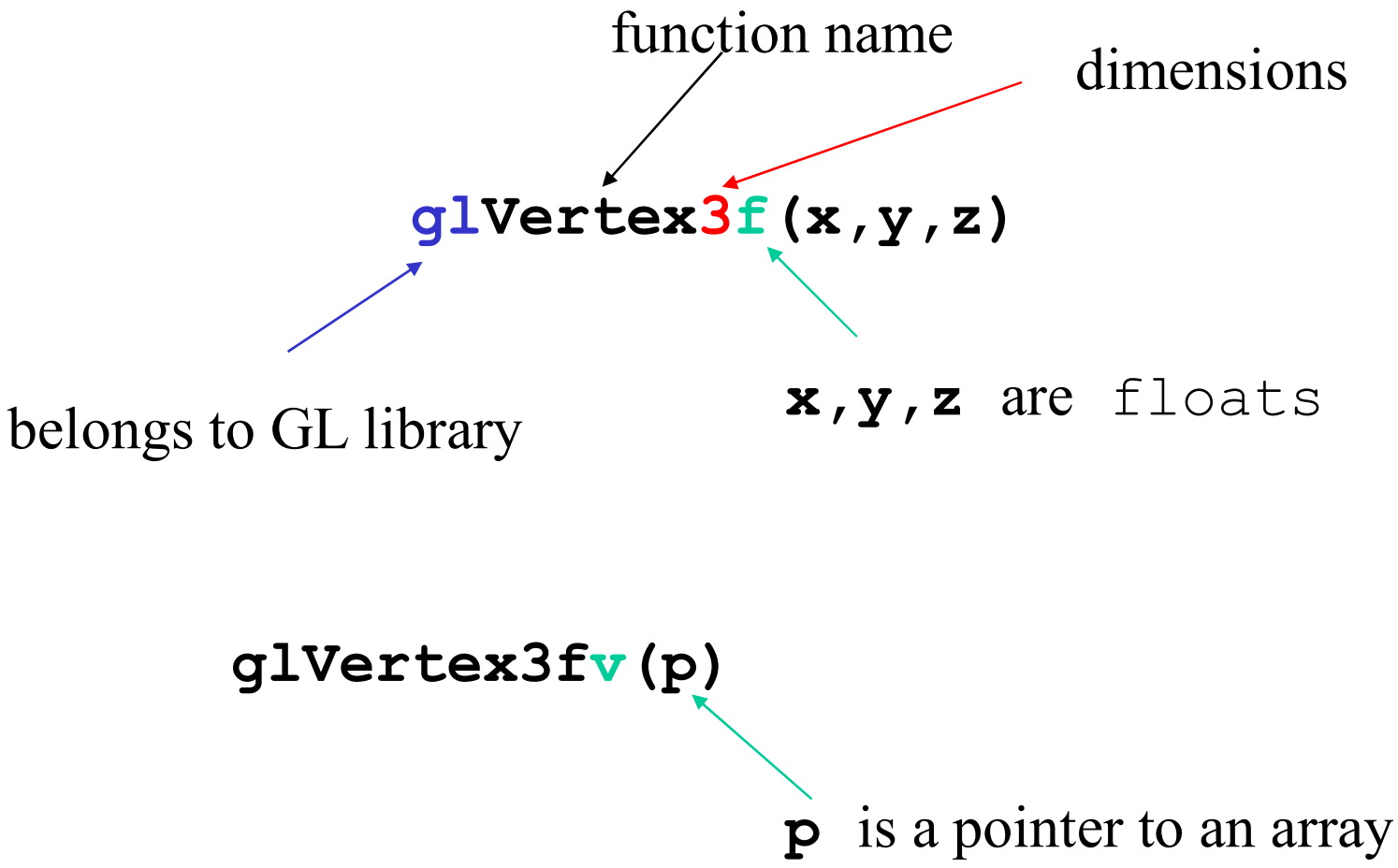
OpenGL State

- 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

Lack of Object Orientation

- 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

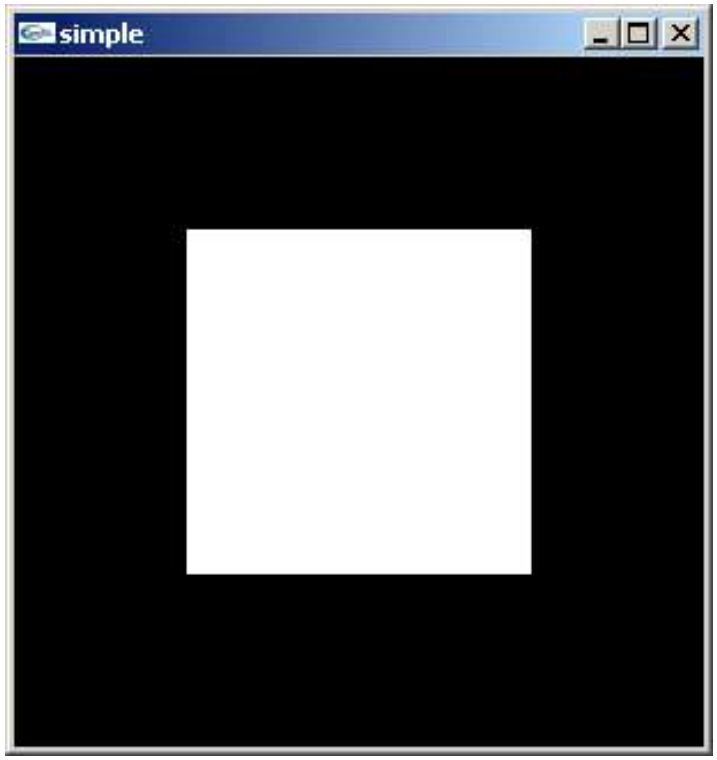


OpenGL #defines

- 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

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

Notes on compilation

- See website and ftp for examples
- 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

Compilation on Windows

- Visual C++
  - Get glut.h, glut32.lib and glut32.dll from web
  - Create a console application
  - Add opengl32.lib, glut32.lib, glut32.lib to project settings (under link tab)
- Borland C similar
- Cygwin (linux under Windows)
  - Can use gcc and similar makefile to linux
  - Use –lopengl32 –lglu32 –lglut32 flags

Programming with OpenGL

Part 2: Complete Programs

Objectives

- Refine the first program
  - Alter the default values
  - Introduce a standard program structure
- Simple viewing
  - Two-dimensional viewing as a special case of three-dimensional viewing
- Fundamental OpenGL primitives
- Attributes

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

- In this version, we shall see the same output but we have defined all the relevant state values through function calls using the default values
- In particular, we set
  - Colors
  - Viewing conditions
  - Window properties

main.c

```
#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

```
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);
}
```

black clear color

opaque window

fill/draw with white

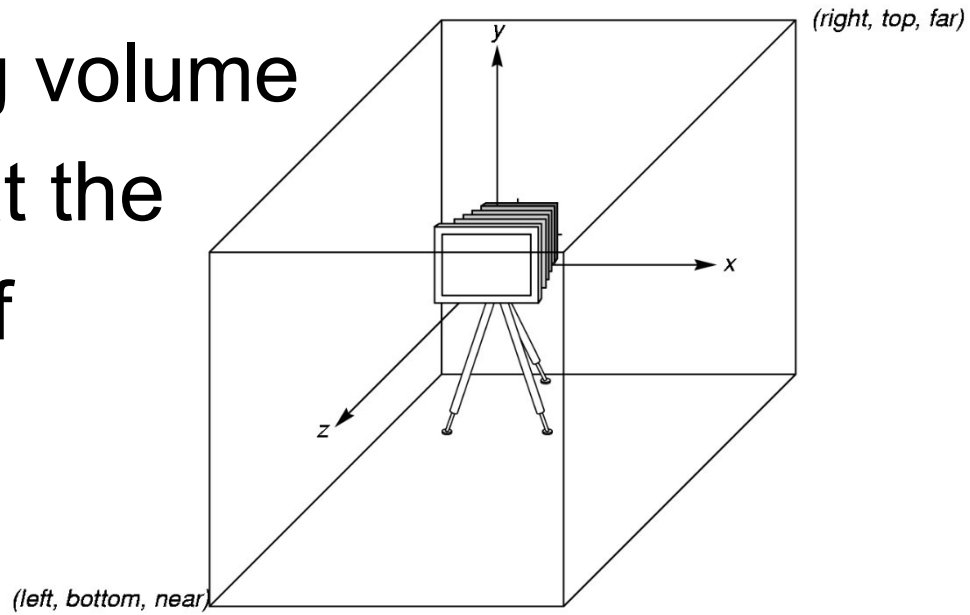
viewing volume

Coordinate Systems

- 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

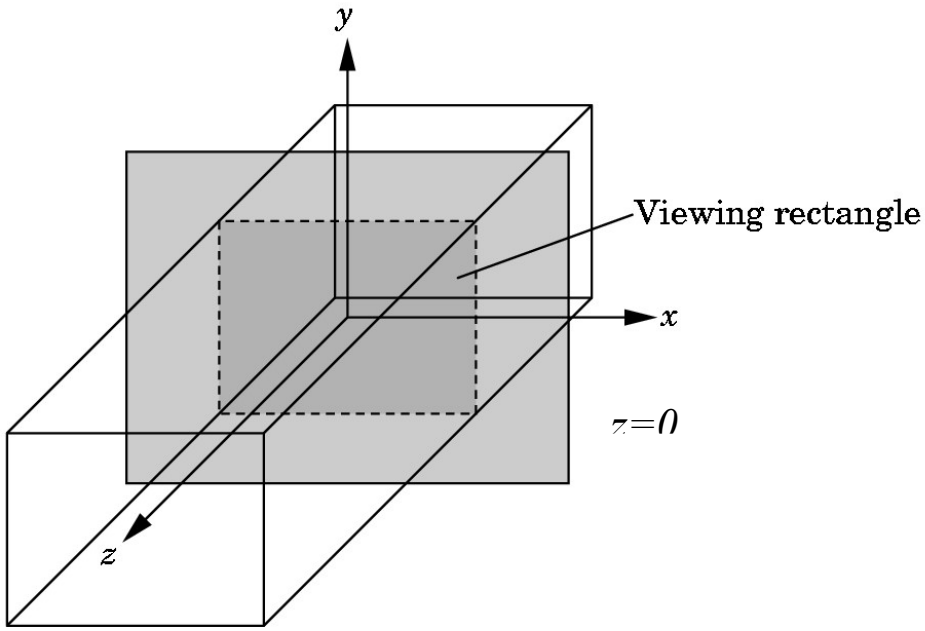
OpenGL Camera

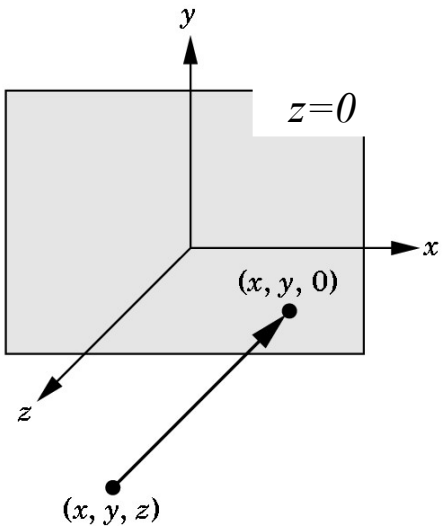
- OpenGL places a camera at the origin in object space pointing in the negative z direction
- The default viewing volume is a box centered at the origin with a side of length 2



Orthographic Viewing

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





Transformations and 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);
```

Two- and three-dimensional viewing

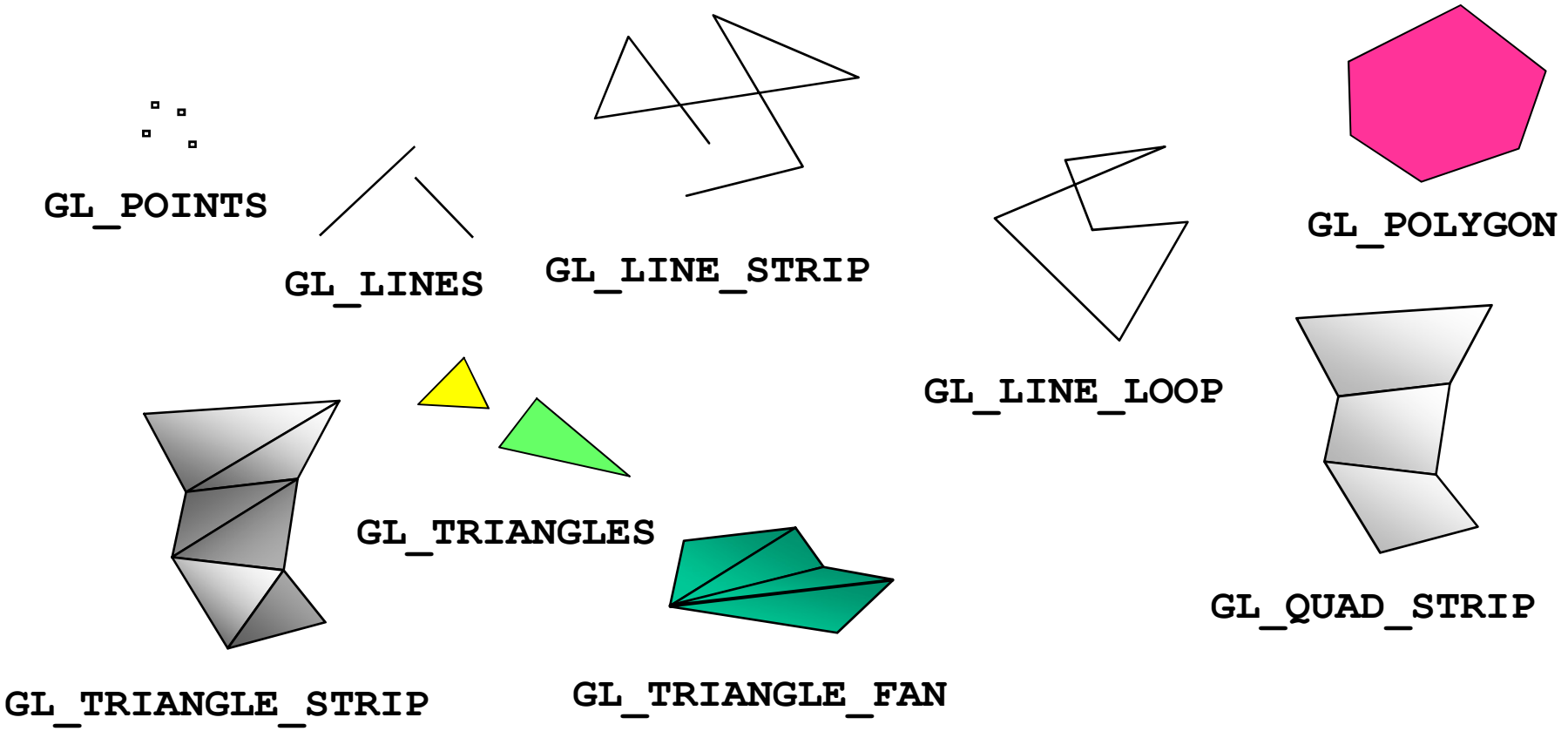
- In **`glOrtho(left, right, bottom, top, near, far)`** the near and far distances are measured from the camera
- Two-dimensional vertex commands place all vertices in the plane z=0
- If the application is in two dimensions, we can use the function

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

mydisplay.c

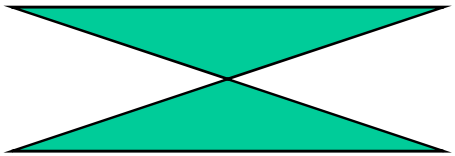
```
void mydisplay()
{
 glClear(GL_COLOR_BUFFER_BIT);
 glBegin(GL_POLYGON);
     glVertex2f(-0.5, -0.5);
     glVertex2f(-0.5, 0.5);
     glVertex2f(0.5, 0.5);
     glVertex2f(0.5, -0.5);
 glEnd();
 glFlush();
}
```

OpenGL Primitives



Polygon Issues

- 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

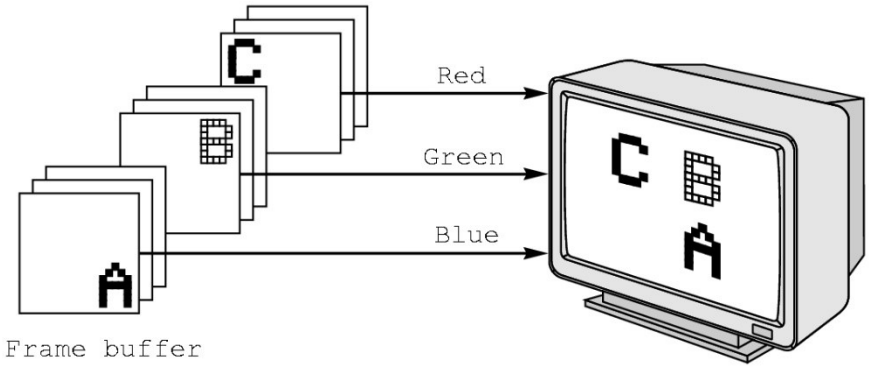
nonconvex polygon

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

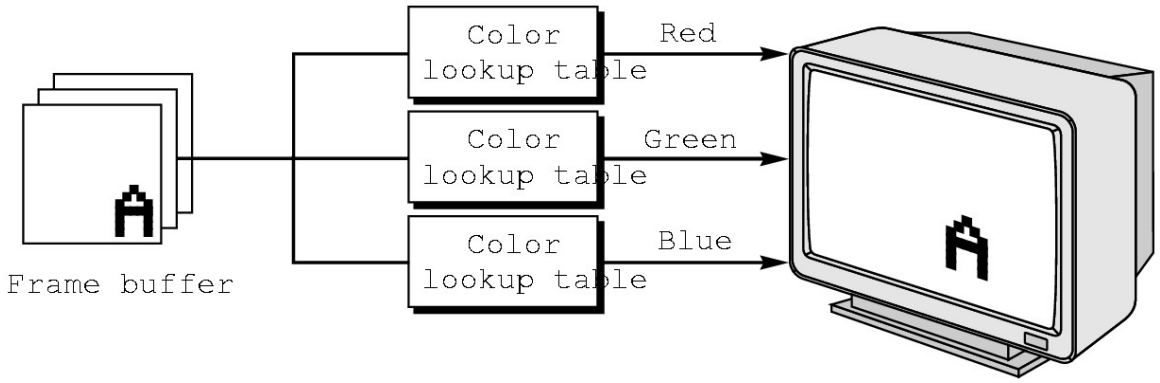
RGB color

- 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

- Colors are indices into tables of RGB values
- Requires less memory
  - indices usually 8 bits
  - not as important now
    - Memory inexpensive
    - Need more colors for shading



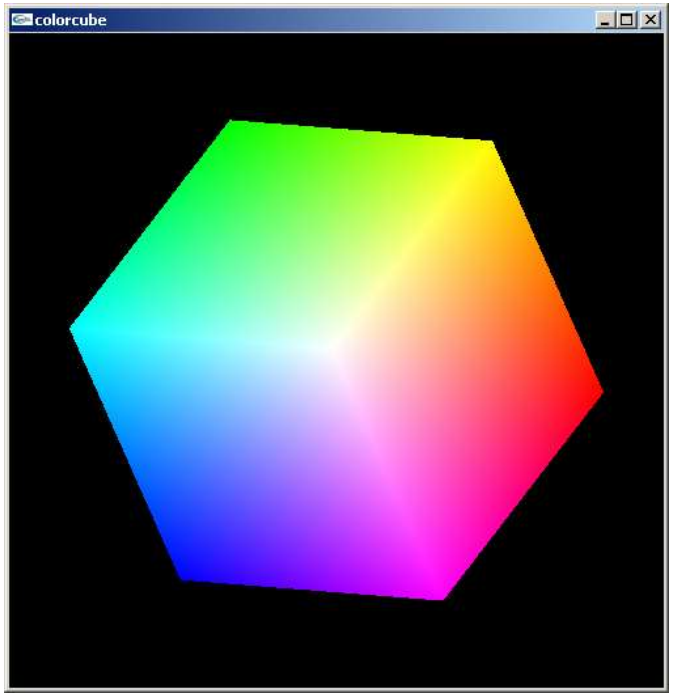
Color and State

- 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

- 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)