Introduction to OpenGL

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CS 456 Computer Graphics

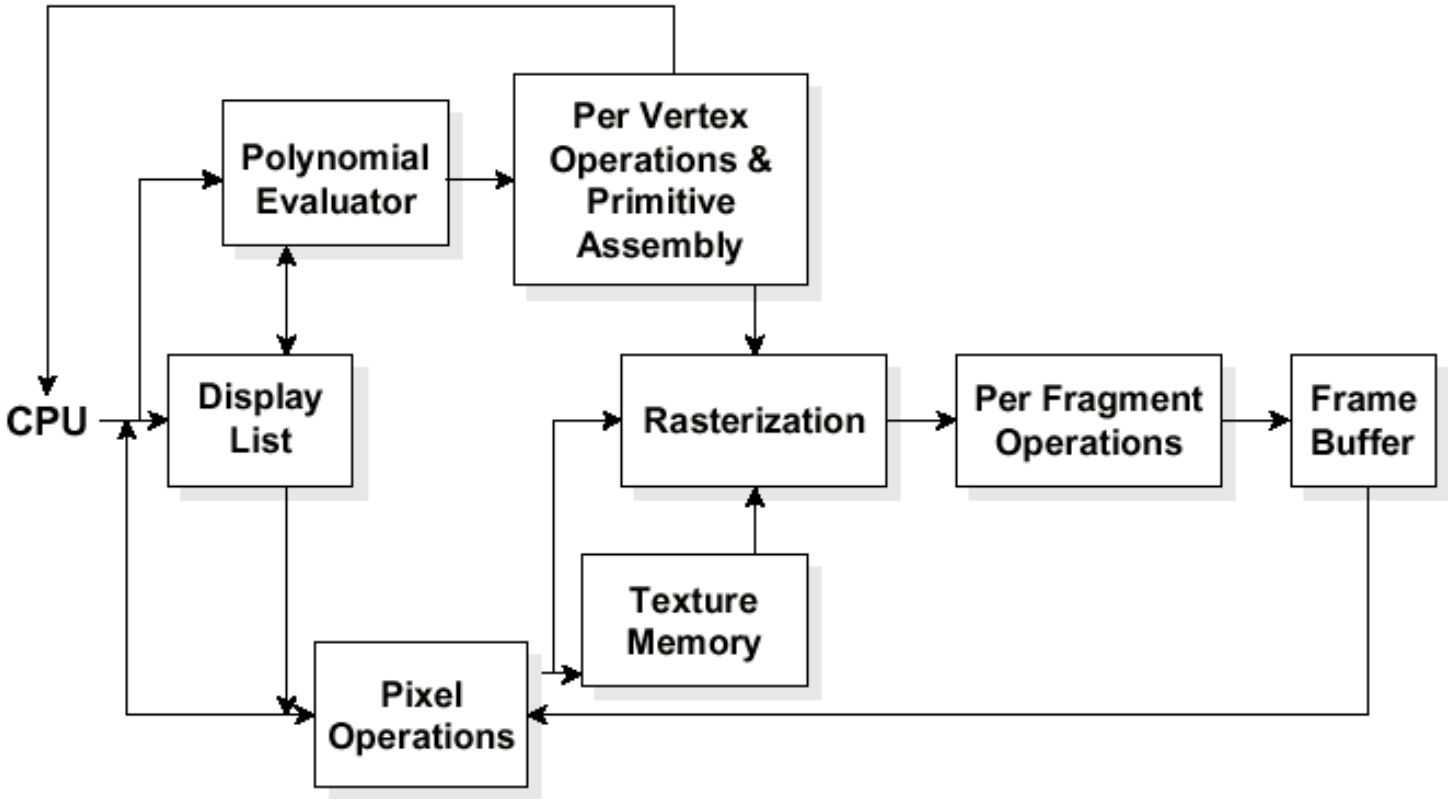
OpenGL and GLUT Overview

- What is OpenGL & what can it do for me?
- OpenGL in windowing systems
- Why GLUT
- GLUT program template

What Is OpenGL?

- Graphics rendering API
  - high-quality color images composed of geometric and image primitives
  - window system independent
  - operating system independent

OpenGL Architecture



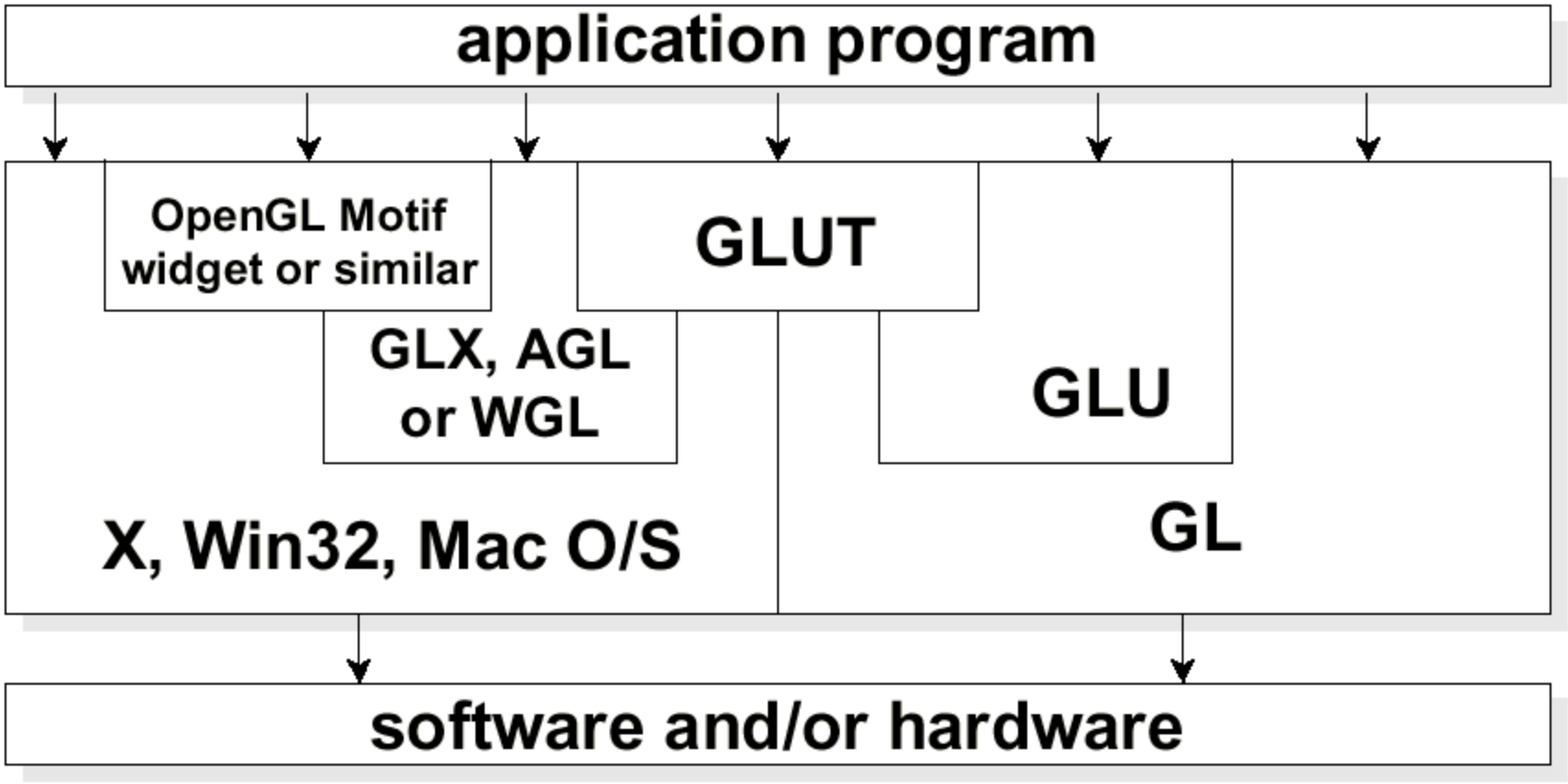
OpenGL as a Renderer

- Geometric primitives
  - points, lines and polygons
  - Image Primitives
  - images and bitmaps
- separate pipeline for images and geometry
  - linked through texture mapping
- Rendering depends on state
  - colors, materials, light sources, etc.

Relate APIs

- AGL, GLX, WGL
  - glue between OpenGL and windowing systems
- GLU (OpenGL Utility Library)
  - part of OpenGL
  - NURBS, tessellators, quadric shapes, etc
- GLUT (OpenGL Utility Toolkit)
  - portable windowing API
  - not officially part of OpenGL

OpenGL and Related APIs



Preliminaries

- Header Files
  - #include <GL gl.h>
  - #include <GL glu.h>
  - #include <GL glut.h>
- Libraries
- Enumerated types
- OpenGL defines numerous types for compatibility
  - GLfloat, GLint, GLenum, etc.

GLUT Basics

- Application Structure: event driven
- Configure and open window
- Initialize OpenGL state
- Register input callback functions
  - render
  - resize
  - input: keyboard, mouse, etc.
- Enter event processing loop

Sample Program

```
void main( int argc, char** argv )
{
   int mode = GLUT_RGB|GLUT_DOUBLE;
   glutInitDisplayMode( mode );
   glutCreateWindow( argv[0] );
   init(); // initiate OpenGL states, program
     variables
   glutDisplayFunc( display );  // register
     callback routines
   glutReshapeFunc( resize );
   glutKeyboardFunc( key );
   glutIdleFunc( idle );
   glutMainLoop(); // enter the event-driven loop
}
```

OpenGL Initialization

- Set up whatever state you're going to use

```
void init( void )
{
   glClearColor( 0.0, 0.0, 0.0, 1.0 );
   glClearDepth( 1.0 );
   glEnable( GL_LIGHT0 );
   glEnable( GL_LIGHTING );
   glEnable( GL_DEPTH_TEST );
}
```

GLUT Callback Functions

- Routine to call when something happens
  - window resize or redraw
  - user input
  - animation
- “Register” callbacks with GLU
  - **`glutDisplayFunc( display );`**
  - **`glutIdleFunc( idle );`**
  - **`glutKeyboardFunc( keyboard );`**

Rendering Callback

- Do all of our drawing here

```
glutDisplayFunc( display );
void display( void )
{
   glClear( GL_COLOR_BUFFER_BIT );
   glBegin( GL_TRIANGLE );
      glVertex3fv( v[0] );
      glVertex3fv( v[1] );
      glVertex3fv( v[2] );
   glEnd();
   glutSwapBuffers();
}
```

Idle Callbacks

- Use for animation and continuous update

```
glutIdleFunc( idle );
void idle( void )
{
   t +=dt;
   glutPostRedisplay();
}
```

User Input Callbacks

- Process user input

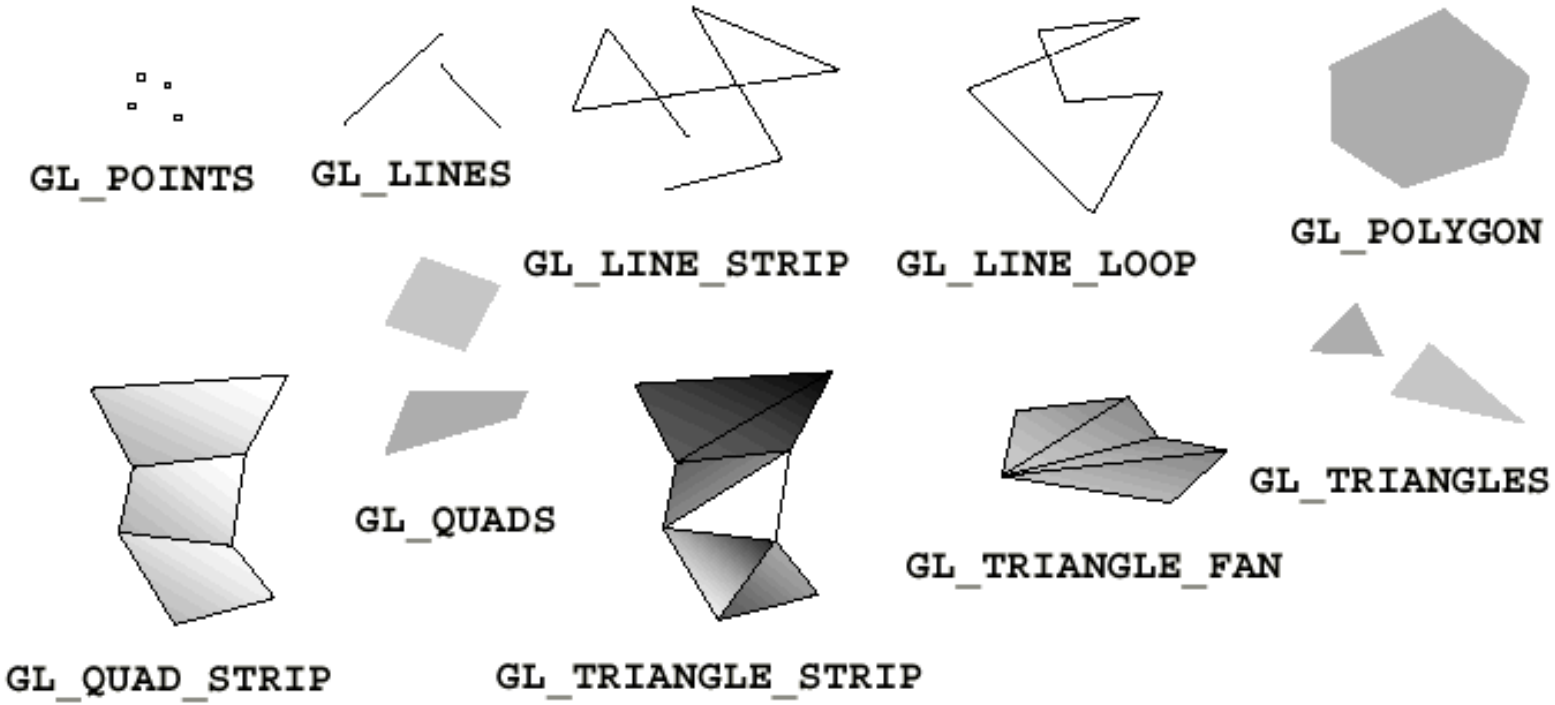
```
glutKeyboardFunc( keyboard );
void keyboard( char key, int x, int y )
{
   switch( key ) {
      case ‘q’ : case ‘Q’ :
         exit( EXIT_SUCCESS );
         break;
      case ‘r’ : case ‘R’ :
         rotate = GL_TRUE;
         break;
      }
}
```

Elementary Rendering

- Geometric Primitives
- Managing OpenGL State
- OpenGL Buffers

OpenGL Geometric Primitives

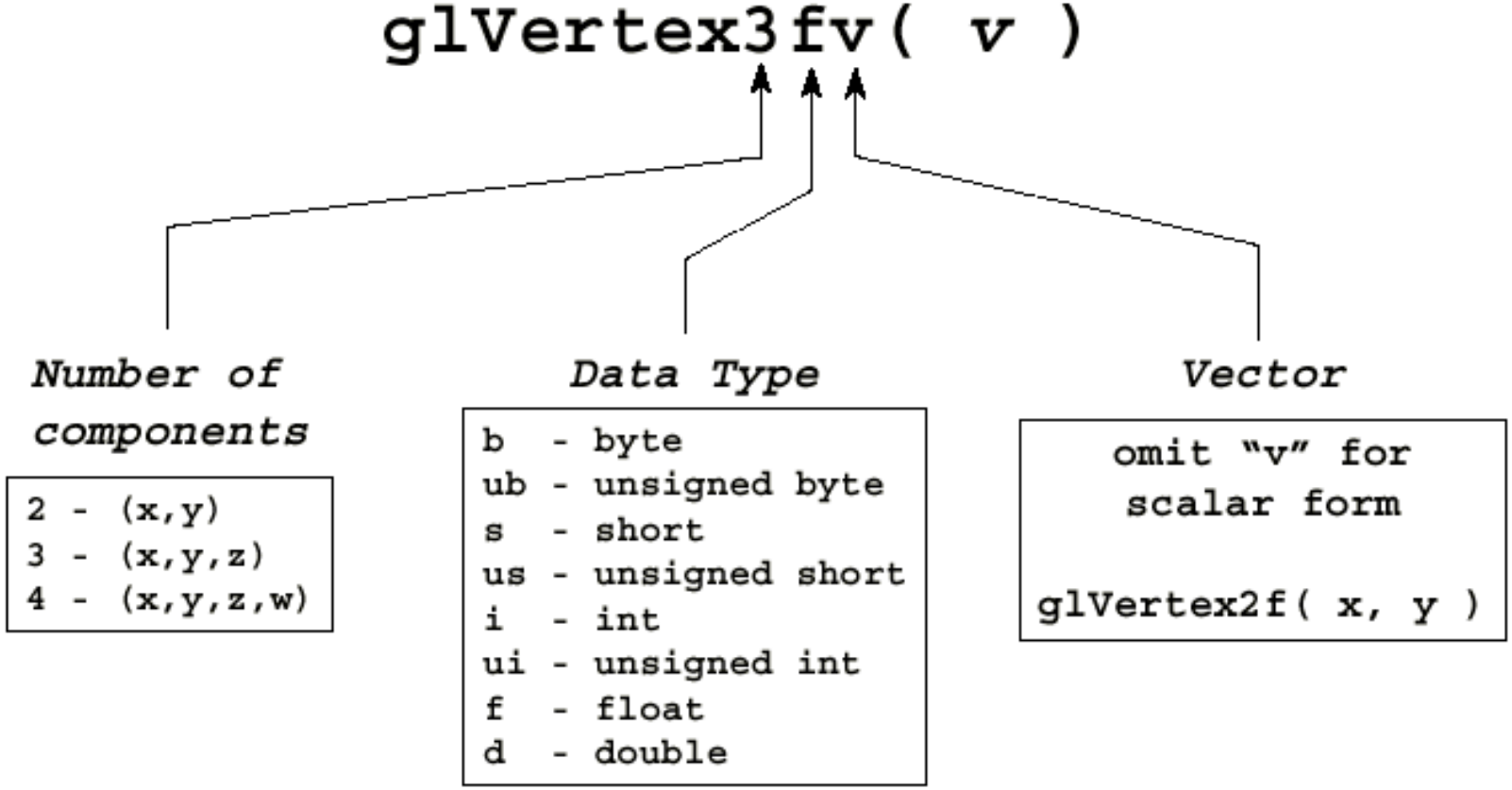
- All geometric primitives are specified by vertices



Simple Example

```
void drawRhombus( GLfloat color[] )
{
   glBegin( GL_QUADS );
      glColor3fv( color );
      glVertex2f( 0.0, 0.0 );
      glVertex2f( 1.0, 0.0 );
      glVertex2f( 1.5, 1.118 );
      glVertex2f( 0.5, 1.118 );
   glEnd();
}
```

OpenGL Command Formats



Specifying Geometric Primitives

- Primitives are specified using

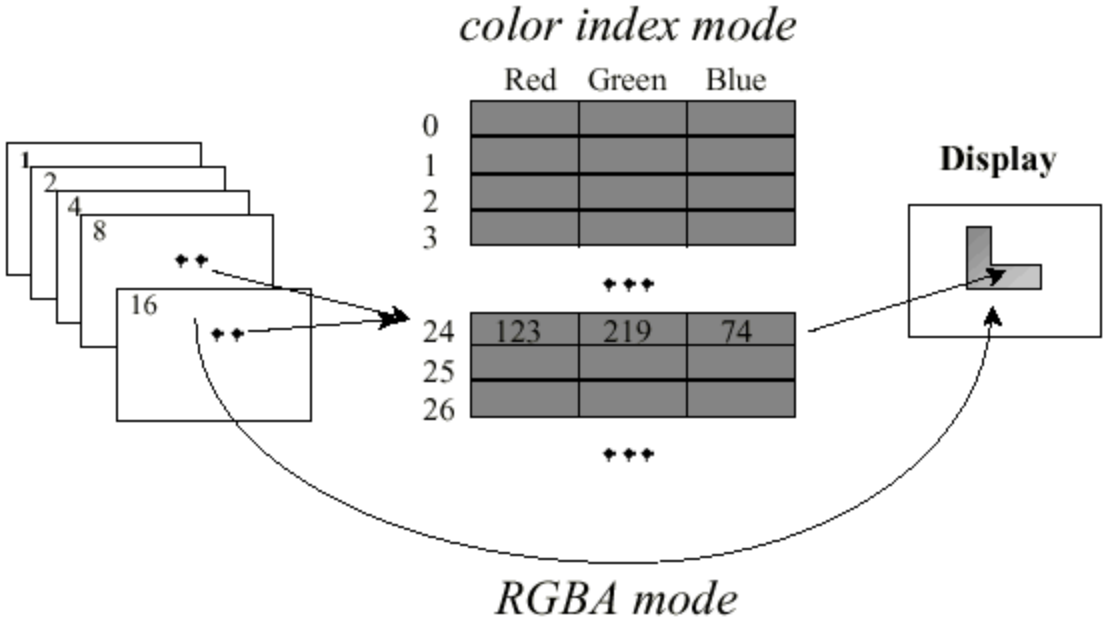
```
glBegin( primType );
glEnd();
```

- primType determines how vertices are combined

```
GLfloat red, greed, blue;
Glfloat coords[3];
glBegin( primType );
    for (i =0;i <nVerts; ++i ) {
    glColor3f( red, green, blue );
    glVertex3fv( coords );
    }
glEnd();
```

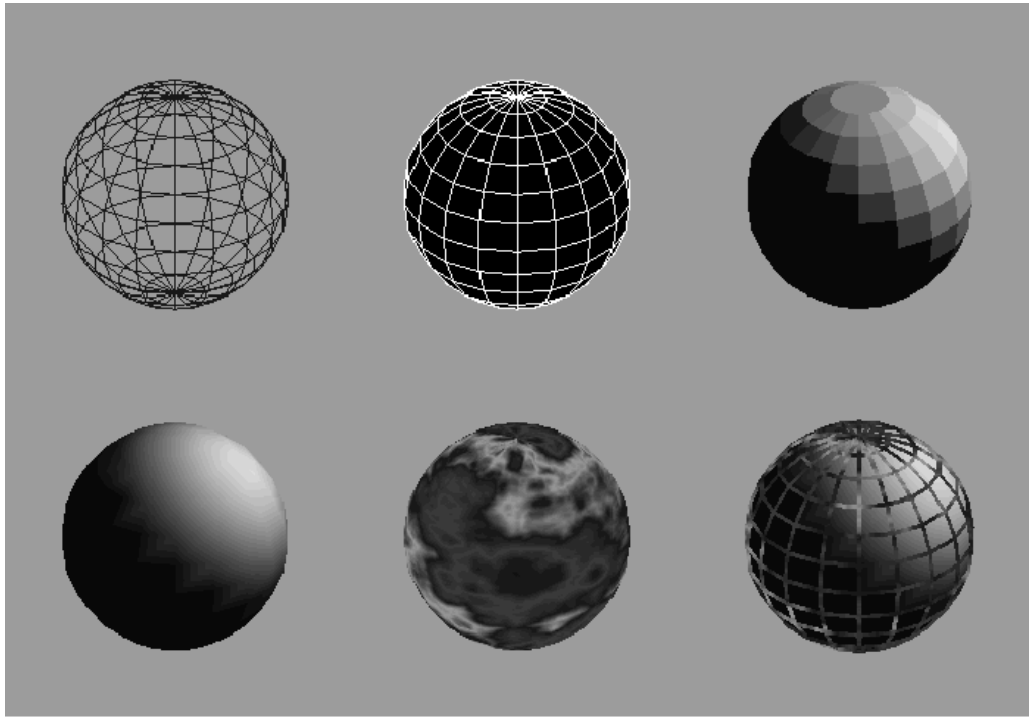
OpenGL Color Model

- Both RGBA (true color) and Color Index



Controlling Rendering

- Appearance
- From Wireframe to Texture mapped



OpenGL’s State Machine

- All rendering attributes are encapsulated in the OpenGL State
  - rendering styles
  - shading
  - lighting
  - texture mapping

Manipulating OpenGL State

- Appearance is controlled by current state

  for each (primitive to render) {

  update OpenGL state

  render primitive

  }

- manipulating vertex attributes is most common way to manipulate state
  - **`glColor*() / glIndex*()`**
  - **`glNormal*()`**
  - **`glTexCoord*()`**

Controlling current state

- Setting State

```
glPointSize( size );
glLineStipple( repeat, pattern );
glShadeModel( GL_ SMOOTH );
```

- Enabling Features

```
glEnable( GL_ LIGHTING );
glDisable( GL_TEXTURE_2D );
```

Transformations in OpenGL

- Modeling
- Viewing
  - orient camera
  - projection
- Animation
- Map to screen

Coordinate Systems and Transformations

- Steps in Forming an Image
  - specify geometry (world coordinates)
  - specify camera (camera coordinates)
  - project (window coordinates)
  - map to viewport (screen coordinates)
- Each step uses transformations
- Every transformation is equivalent to a change in coordinate systems

3D Transformations

- A vertex is transformed by 4 x 4 matrices
- all affine operation are matrix multiplication
- matrices are stored column-major in OGL
- matrices are always post-multiplied

Except in perspective projection, the fourth row = (0,0,0,1), w left unchanged.

OpenGL uses stacks of matrices, the programmer must remember that the last matrix specified is the first applied.

$$\mathbf{M} = \begin{bmatrix} m_0 & m_4 & m_8 & m_{12} \\ m_1 & m_5 & m_9 & m_{13} \\ m_2 & m_6 & m_{10} & m_{14} \\ m_3 & m_7 & m_{11} & m_{15} \end{bmatrix}$$

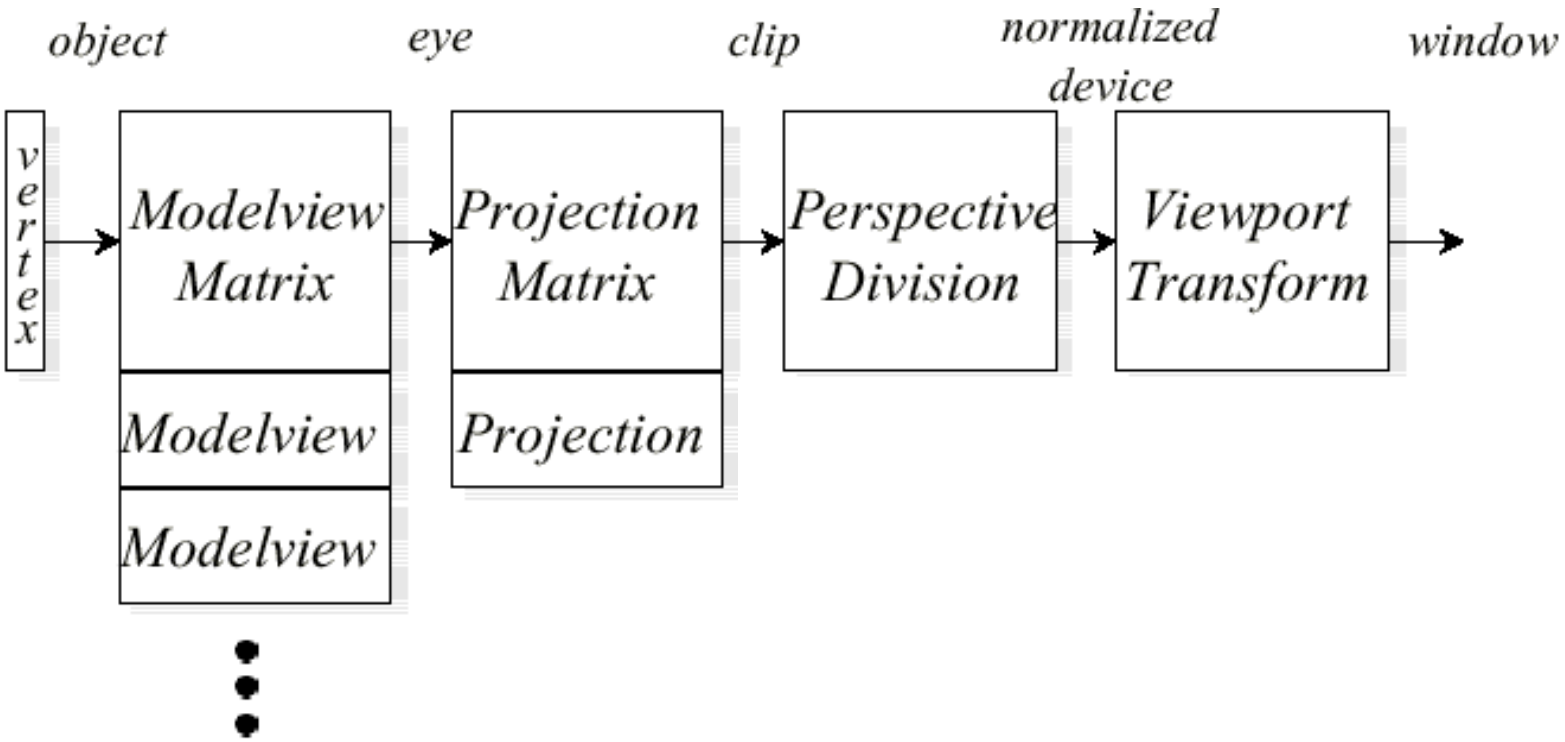
Specifying Transformations

- Programmer has two styles of specifying transformations
  - specify matrices **`glLoadMatrix, glMultMatri`**x
  - specify operation **`glRotate, glOrth`**o
- Programmer does not have to remember the exact matrices
- check appendix of Red Book

Programming Transformations

- Prior to rendering, view, locate, and orient:
  - eye/camera position
  - 3D geometry
- Manage the matrices
  - including matrix stack
- Combine (composite) transformations
- Transformation matrices are part of the state, they must be defined prior to any vertices to which they are to apply.
- OpenGL provides matrix stacks for each type of supported matrix (ModelView, projection, texture) to store matrices.

Transformation Pipeline



Matrix Operations

- Specify Current Matrix Stack
  - **`glMatrixMode( GL_MODELVIEW or GL_PROJECTION )`**
- Other Matrix or Stack Operation
  - **`glLoadIdentity() glPushMatrix() glPopMatrix()`**
- Viewport
  - usually same as window size
  - viewport aspect ratio should be same as projection transformation or resulting image may be distorted
  - **`glViewport( x, y, width, height )`**

Projection Transformation

- Perspective projection
  - **`gluPerspective( fovy, aspect, zNear, zFar )`**
  - **`glFrustum( left, right, bottom, top, zNear, zFar )`** (very rarely used)
- Orthographic parallel projection
  - **`glOrtho( left, right, bottom, top, zNear, zFar)`**
  - **`gluOrtho2D( left, right, bottom, top )`**
  - calls **`glOrtho`** with z values near zero
- *Warning:* for `gluPerspective()` or `glFrustum()`, don't use zero for `zNear`!

Applying Projection

- Transformations
- Typical use (orthographic projection)

```
glMatrixMode( GL_PROJECTION );
glLoadIdentity();
glOrtho( left, right, bottom, top, zNear,
  zFar );
```

Viewing Transformations

- Position the camera/eye in the scene
- To “fly through” a scene
- change viewing transformation and redraw scene

```
gluLookAt( eye x ,eye y ,eye z ,
           aim x ,aim y ,aim z ,
           up x ,up y ,up z )
```

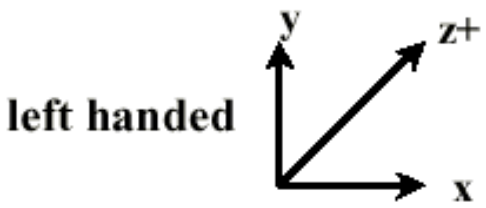
- up vector determines unique orientation
- careful of degenerate positions

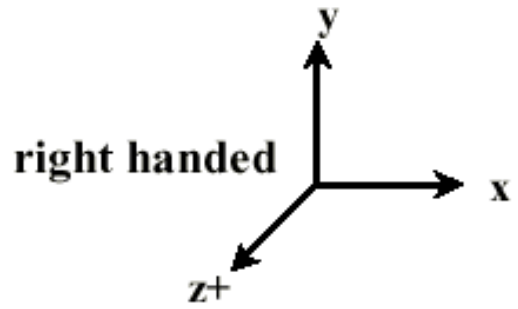
Modeling Transformations

- Move object
  - **`glTranslate{fd}( x, y, z )`**
- Rotate object aro nd arbitrary axis
  - **`glRotate{fd}( angle, x, y, z )`**
  - angle is in degrees
- Dilate (stretch or shrink) object
  - **`glScale{fd}( x, y, z )`**

Projection is left handed

- Projection transformation (**`gluPerspective, glOrtho`**) are left handed
  - think of **`zNear`** and **`zFar`** as distance from view point
- Everything else is right handed, including the vertexes to be rendered





Common Transformation Usage

- Example of **`resize()`** routine
  - restate projection & viewing transformations
- Usually called when window resized
- Registered a callback for **`glutReshapeFunc()`**

resize(): Perspective & LookAt

```
void resize( int w, int h )
{
   glViewport( 0, 0, (GLsizei) w, (GLsizei)
     h );
   glMatrixMode( GL_PROJECTION );
   glLoadIdentity();
   gluPerspective( 65.0, (GLfloat) w / h,
         1.0, 100.0 );
   glMatrixMode( GL_MODELVIEW );
   glLoadIdentity();
   gluLookAt( 0.0, 0.0, 5.0,
         0.0, 0.0, 0.0,
         0.0, 1.0, 0.0 );
}
```