

## Foundations of Computer Graphics

Online Lecture 6: OpenGL 1

*Overview and Motivation*

Ravi Ramamoorthi

## This Lecture

- Introduction to OpenGL and simple demo code
  - mytest1.cpp ; you compiled mytest3.cpp for HW 0
- I am going to show (and write) actual code
  - Code helps you understand HW 2 better
- Simple demo of mytest1
- This lecture deals with very basic OpenGL setup. Next 2 lectures will likely be more interesting

## Outline

- *Basic idea about OpenGL*
- Basic setup and buffers
- Matrix modes
- Window system interaction and callbacks
- Drawing basic OpenGL primitives
- Initializing Shaders

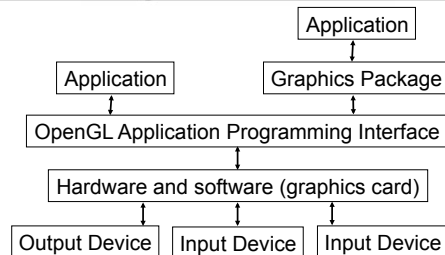
## Introduction to OpenGL

- OpenGL is a graphics *API*
  - Portable software library (platform-independent)
  - Layer between programmer and graphics hardware
  - Uniform instruction set (hides different capabilities)
- OpenGL can fit in many places
  - Between application and graphics system
  - Between higher level API and graphics system

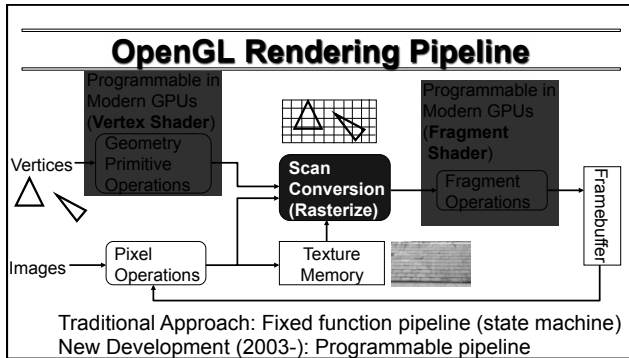
## Why OpenGL?

- Why do we need OpenGL or an API?
  - Encapsulates many basic functions of 2D/3D graphics
  - Think of it as high-level language (C++) for graphics
  - History: Introduced SGI in 92, maintained by Khronos
  - Precursor for DirectX, WebGL, Java3D etc.

## Programmer's View



Slide inspired by Greg Humphreys



## GPUs and Programmability

- Since 2003, can write vertex/pixel shaders
- Fixed function pipeline special type of shader
- Like writing C programs (see GLSL book)
- Performance >> CPU (even used for non-graphics)
- Operate *in parallel* on all vertices or fragments

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*Basic Setup and Buffers, Matrix Modes*

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## Buffers and Window Interactions

- Buffers: Color (front, back, left, right), depth (z), accumulation, stencil. When you draw, you write to some buffer (most simply, front and depth)
- Buffers also used for vertices etc. Buffer data and buffer arrays (will see in creating objects)
- No window system interactions (for portability)
  - But can use GLUT (or Motif, GLX, Tcl/Tk)
  - Callbacks to implement mouse, keyboard interaction

## Basic setup (can copy; slight OS diffs)

```
int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    // Requests the type of buffers (Single, RGB).
    // Think about what buffers you would need...
    glutInitDisplayMode (GLUT_SINGLE | GLUT_RGB);
    // Need to add GLUT_3_2_CORE_PROFILE for Apple/Mac OS
    glutInitWindowSize (500, 500);
    glutInitWindowPosition (100, 100);
    glutCreateWindow ("Simple Demo with Shaders");
    // glewInit(); // GLEW related stuff for non-Apple systems
    init (); // Always initialize first

    // Now, we define callbacks and functions for various tasks.
    ...
}
```

## Basic setup (can copy; slight OS diffs)

```
int main(int argc, char** argv)
{
    ...

    // Now, we define callbacks and functions for various tasks.
    glutDisplayFunc(display);
    glutReshapeFunc(reshape);
    glutKeyboardFunc(keyboard);
    glutMouseFunc(mouse);
    glutMotionFunc(mousedrag);
    glutMainLoop(); // Start the main code
    deleteBuffers(); //Termination. Delete buffers generated in init()
    return 0; /* ANSI C requires main to return int. */
}
```

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## Viewing in OpenGL

- *Inspired by old OpenGL. Now, only best practice, not requirement*
  - You could do your own thing, but this is still the best way to develop viewing
- Viewing consists of two parts
  - Object positioning: *model view* transformation matrix
  - View projection: *projection* transformation matrix
- Old OpenGL (no longer supported/taught in 167x), two matrix stacks
  - GL\_MODELVIEW\_MATRIX, GL\_PROJECTION\_MATRIX
  - Can push and pop matrices onto stacks
- New OpenGL: Use C++ STL templates to make stacks as needed
  - e.g. stack <mat4> modelview; modelview.push(mat4(1.0));
  - GLM libraries replace many deprecated commands. Include mat4

## Viewing in OpenGL

- Convention: camera always at the origin, pointing in the  $-z$  direction
- Transformations move objects relative to the camera
- In old OpenGL, *Matrices are column-major and right-multiply top of stack*. (Last transform in code is first actually applied). In new GLM, similarly (read the assignment notes and documentation).

## Basic initialization code for viewing

```
#include <GL/glut.h> //also <GL/glew.h>; <GLUT/glut.h> for Mac OS
#include <stdlib.h> //also stdio.h, assert.h, glm, others

int mouseoldx, mouseoldy; // For mouse motion
GLfloat eyeloc = 2.0; // Where to look from; initially 0 -2, 2
glm::mat4 projection, modelview; // The mvp matrices themselves

void init (void) {
    /* select clearing color */
    glClearColor (0.0, 0.0, 0.0, 0.0);
    /* initialize viewing values */
    projection = glm::mat4(1.0f); // The identity matrix
    // Think about this. Why is the up vector not normalized?
    modelview = glm::lookAt(glm::vec3(0,-eyeloc,eyeloc),
                           glm::vec3(0,0,0), glm::vec3(0,1,1));
    // (To be cont'd). Geometry and shader set up later ...
}
```

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*Window System Interaction and Callbacks*

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## Window System Interaction

- Not part of OpenGL
  - Toolkits (GLUT) available (also freeglut)
- Callback functions for events (similar to X, Java,)
  - Keyboard, Mouse, etc.
  - Open, initialize, resize window
- Our main func included

```
glutDisplayFunc(display);
glutReshapeFunc(reshape);
glutKeyboardFunc(keyboard);
glutMouseFunc(mouse);
glutMotionFunc(mousedrag);
```

## Basic window interaction code

```
/* Defines what to do when various keys are pressed */
void keyboard (unsigned char key, int x, int y)
{
    switch (key) {
        case 27: // Escape to quit
            exit(0);
            break;
        default:
            break;
    }
}
```

## Basic window interaction code

```
/* Reshapes the window appropriately */
void reshape(int w, int h)
{
    glViewport (0, 0, (GLsizei) w, (GLsizei) h);
    // Note that the field of view takes in a radian angle
    projection = glm::perspective(30.0f / 180.0f * glm::pi<float>(),
        (GLfloat)w / (GLfloat)h, 1.0f, 10.0f);
    glUniformMatrix4fv(projectionPos,1, GL_FALSE, &projection[0][0]);
    // To send the projection matrix to the shader
}
```

## Mouse motion (demo)

```
void mouse(int button, int state, int x, int y) {
    if (button == GLUT_LEFT_BUTTON) {
        if (state == GLUT_UP) { // Do Nothing ;}
        else if (state == GLUT_DOWN) {
            mouseoldx = x ; mouseoldy = y ; // so we can move wrt x , y
        }
    }
    else if (button == GLUT_RIGHT_BUTTON && state == GLUT_DOWN)
    { // Reset gluLookAt
        eyeloc = 2.0 ;
        modelview = glm::lookAt(glm::vec3(0, -eyeloc, eyeloc),
            glm::vec3(0, 0, 0), glm::vec3(0, 1, 1));
        // Send the updated matrix to the shader
        glUniformMatrix4fv(modelviewPos,1,GL_FALSE,&modelview[0][0]);
        glutPostRedisplay() ; // Redraw scene
    }
}
```

## Mouse drag (demo)

```
void mousedrag(int x, int y) {
    int yloc = y - mouseoldy ;    // We will use the y coord to
    zoom in/out
    eyeloc += 0.005*yloc ;        // Where do we look from
    if (eyeloc < 0) eyeloc = 0.0 ;
    mouseoldy = y ;

    /* Set the eye location */
    modelview = glm::lookAt(glm::vec3(0, -eyeloc, eyeloc),
        glm::vec3(0, 0, 0), glm::vec3(0, 1, 1));
    // Send the updated matrix over to the shader
    glUniformMatrix4fv(modelviewPos,1,GL_FALSE,&modelview[0][0]);

    glutPostRedisplay() ; }
```

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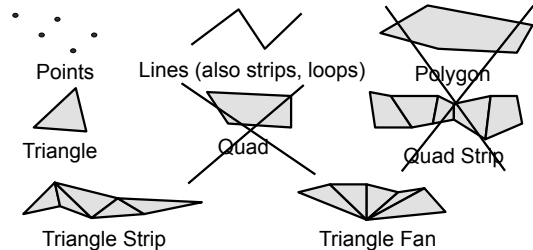
*Drawing Basic OpenGL Primitives*

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## New OpenGL Primitives (fewer)



## Geometry

- Points (GL\_POINTS)  
Stored in Homogeneous coordinates
- Line segments (GL\_LINES)
  - Also (GL\_LINE\_STRIP, GL\_LINE\_LOOP)
- Triangles (GL\_TRIANGLES)
  - Also strips, fans (GL\_TRIANGLE\_STRIP, GL\_TRIANGLE\_FAN)
- More complex primitives (GLUT): Sphere, teapot, cube, ...
  - Must now be converted into triangles (which is what skeleton does)

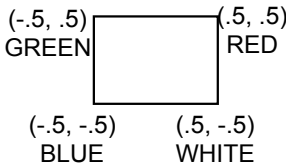
## Old OpenGL: Drawing

- Enclose vertices between glBegin() ... glEnd() pair
  - Can include normal C code and attributes like the colors
  - Inside are commands like glVertex3f, glColor3f
  - Attributes must be set **before** the vertex
- Assembly line (pass vertices, transform, shade)
  - These are vertex, fragment shaders on current GPUs
  - *Immediate Mode*: Sent to server and drawn

## Old OpenGL: Drawing *(not used)*

```
void display(void) {
    glClear (GL_COLOR_BUFFER_BIT);
    // draw polygon (square) of unit length centered at the origin
    // This code draws each vertex in a different color.

    glBegin(GL_POLYGON);
    glColor3f (1.0, 0.0, 0.0);
    glVertex3f (0.5, 0.5, 0.0);
    glColor3f (0.0, 1.0, 0.0);
    glVertex3f (-0.5, 0.5, 0.0);
    glColor3f (0.0, 0.0, 1.0);
    glVertex3f (-0.5, -0.5, 0.0);
    glColor3f (1.0, 1.0, 1.0);
    glVertex3f (0.5, -0.5, 0.0);
    glEnd();
    glFlush ();
}
```



## Old OpenGL: Drawing

- Client-Server model (client generates vertices, server draws) even if on same machine
  - glFlush() forces client to send network packet
  - glFinish() waits for ack, sparingly use synchronization
- New OpenGL: **Vertex Array Objects** (next)

## Modern OpenGL: Floor Specification

```
const GLfloat floorverts[4][3] = {
    {0.5, 0.5, 0.0}, {-0.5, 0.5, 0.0}, {-0.5, -0.5, 0.0}, {0.5, -0.5, 0.0} };
const GLfloat floorcol[4][3] = {
    {1.0, 0.0, 0.0}, {0.0, 1.0, 0.0}, {0.0, 0.0, 1.0}, {1.0, 1.0, 1.0} };
const GLubyte floorinds[1][6] = { {0, 1, 2, 0, 2, 3} }; //triangles
const GLfloat floorverts2[4][3] = {
    {0.5, 0.5, 1.0}, {-0.5, 0.5, 1.0}, {-0.5, -0.5, 1.0}, {0.5, -0.5, 1.0} };
const GLfloat floorcol2[4][3] = {
    {1.0, 0.0, 0.0}, {1.0, 0.0, 0.0}, {1.0, 0.0, 0.0}, {1.0, 0.0, 0.0} };
const GLubyte floorinds2[1][6] = { {0, 1, 2, 0, 2, 3} };
//triangles
```

## Modern OpenGL: Vertex Array Objects

```
const int numobjects = 2 ; // number of objects for buffer
const int numperobj = 3 ; // Vertices, colors, indices
GLuint VAOs[numobjects]; // A Vertex Array Object per object
GLuint buffers[numperobj*numobjects]; // List of buffers geometric data
GLuint objects[numobjects]; // For each object
GLenum PrimType[numobjects]; // Primitive Type (triangles, strips)
GLsizei NumElems[numobjects]; // Number of geometric elements

// Floor Geometry is specified with a vertex array
enum {Vertices, Colors, Elements}; // For arrays for object
enum {FLOOR, FLOOR2}; // For objects, for the floor

//-----In init below (creates buffer objects for later use)-----
```

## Modern OpenGL: Vertex Array Objects

```
const int numobjects = 2 ; // number of objects for buffer
const int numperobj = 3 ; // Vertices, colors, indices
GLuint VAOs[numobjects]; // A Vertex Array Object per object
GLuint buffers[numperobj*numobjects]; // List of buffers geometric data
//...
//-----In init below (creates buffer objects for later use)-----
glGenVertexArrays(numobjects, VAOs); //create unique identifiers
glGenBuffers(numperobj*numobjects, buffers); //and for buffers

void deleteBuffers() { // Like a destructor
    glDeleteVertexArrays(numobjects, VAOs);
    glDeleteBuffers(numperobj*numobjects, buffers);
}
```

## Modern OpenGL: Initialize Buffers

```
void initobject (GLuint object, GLfloat * vert, GLint sizevert, GLfloat *
    col, GLint sizecol, GLubyte * inds, GLint sizeind, GLenum type) {
    int offset = object * numperobj;
    glBindVertexArray(VAOs[object]);
    glBindBuffer(GL_ARRAY_BUFFER, buffers[Vertices+offset]);
    glBufferData(GL_ARRAY_BUFFER, sizevert, vert, GL_STATIC_DRAW);
    // Use layout location 0 for the vertices
    glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(GLfloat), 0);
    glBindBuffer(GL_ARRAY_BUFFER, buffers[Colors+offset]);
    glBufferData(GL_ARRAY_BUFFER, sizecol, col, GL_STATIC_DRAW);
    // Use layout location 1 for the colors
    //...
}
```

## Modern OpenGL: Initialize Buffers

```
void initobject (GLuint object, GLfloat * vert, GLint sizevert, GLfloat *
col, GLint sizecol, GLubyte * inds, GLint sizeind, GLenum type) {
// ...
// Use layout location 1 for the colors
glEnableVertexAttribArray(1);
glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(GLfloat), 0);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, buffers[Elements+offset]) ;
glBufferData(GL_ELEMENT_ARRAY_BUFFER, sizeind, inds, GL_STATIC_DRAW);
PrimType[object] = type;
NumElems[object] = sizeind;
// Prevent further modification of this VAO by unbinding it
glBindVertexArray(0);
}
```

## Modern OpenGL: Draw Vertex Object

```
void drawobject(GLuint object) {
glBindVertexArray(VAOs[object]);
glDrawElements(PrimType[object], NumElems[object],
GL_UNSIGNED_BYTE, 0);
glBindVertexArray(0); //unbind
}

void display(void) {
glClear (GL_COLOR_BUFFER_BIT); // clear all pixels
drawobject(FLOOR) ;
drawobject(FLOOR2) ;
glFlush ();
// start processing buffered OpenGL commands
}
```

## Initialization for Drawing, Shading

```
#include "shaders.h"
GLuint vertexshader, fragmentshader, shaderprogram ; // shaders
// Initialization in init() for Drawing
glGenVertexArrays(numobjects, VAOs) ;
glGenBuffers(numobj*numobjects, buffers) ;
initobject(FLOOR, (GLfloat *) floorverts, sizeof(floorverts), (GLfloat
*) floorcol, sizeof (floorcol), (GLubyte *) floorinds, sizeof
(floorinds), GL_TRIANGLES) ;
initobject(FLOOR2, (GLfloat *) floorverts2, sizeof(floorverts2),
(GLfloat *) floorcol2, sizeof (floorcol2), (GLubyte *) floorinds2,
sizeof (floorinds2), GL_TRIANGLES) ;
// In init() for Shaders, discussed next
vertexshader = initshaders(GL_VERTEX_SHADER, "shaders/nop.vert") ;
fragmentshader = initshaders(GL_FRAGMENT_SHADER, "shaders/nop.frag") ;
shaderprogram = initprogram(vertexshader, fragmentshader) ;
```

## Demo (change colors)

## Foundations of Computer Graphics

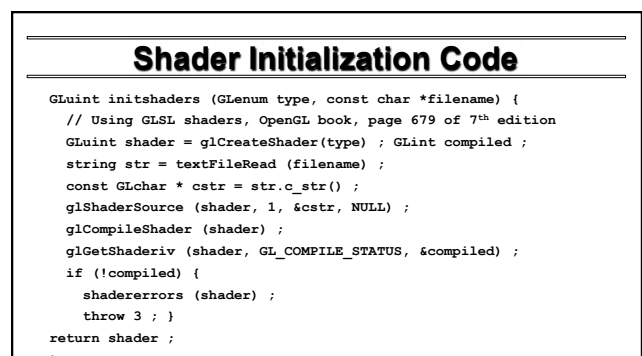
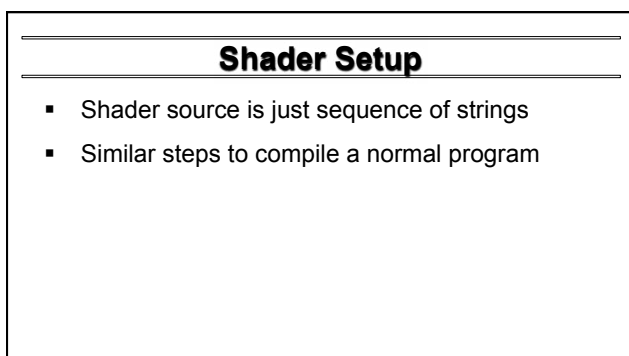
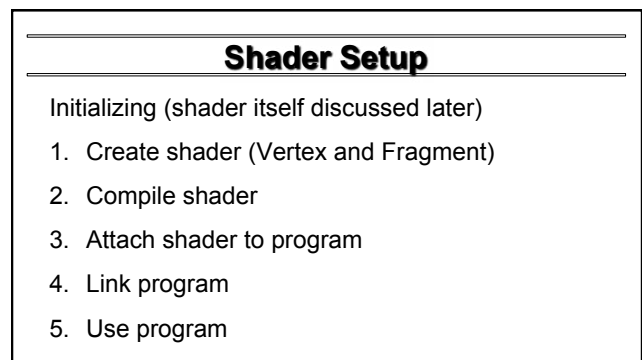
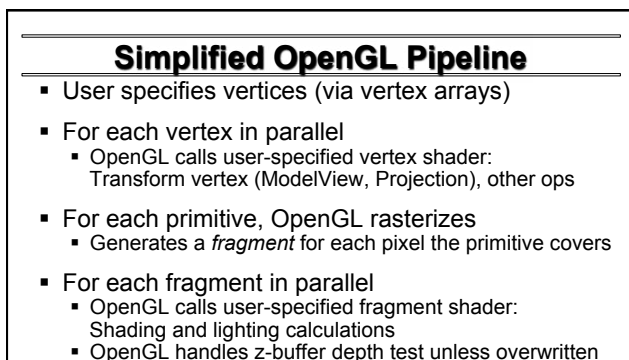
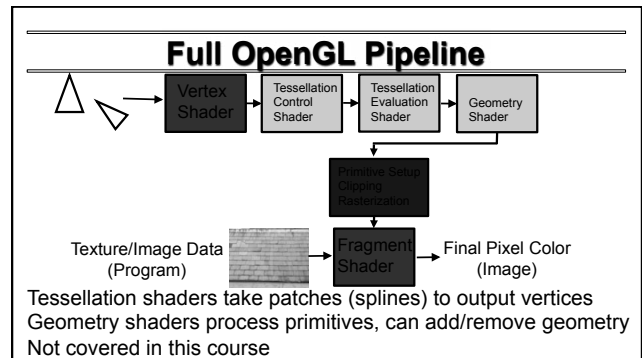
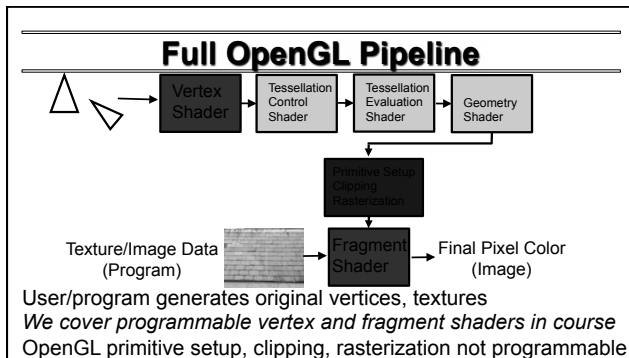
Online Lecture 6: OpenGL 1

*Initializing Shaders*

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## Linking Shader Program

```
GLuint initprogram (GLuint vertexshader, GLuint fragmentshader) {
    GLuint program = glCreateProgram() ;
    GLint linked ;
    glAttachShader(program, vertexshader) ;
    glAttachShader(program, fragmentshader) ;
    glLinkProgram(program) ;
    glGetProgramiv(program, GL_LINK_STATUS, &linked) ;
    if (linked) glUseProgram(program) ;
    else {
        programerrors(program) ;
        throw 4 ; }
    cout<<"Shader program successfully attached and linked." << endl;
    return program ; }
```

## Basic (nop) vertex shader

- In shaders/ nop.vert.glsl nop.frag.glsl
  - Written in GLSL (GL Shading Language)
  - Vertex Shader (out values interpolated to fragment)

```
# version 330 core
// Do not modify the above version directive to anything older.
// Shader inputs
layout (location = 0) in vec3 position;
layout (location = 1) in vec3 color;
// Shader outputs, if any
out vec3 Color;
// Uniform variables
uniform mat4 modelview;
uniform mat4 projection;
void main() {
    // ...
}
```

## Basic (nop) vertex shader

- In shaders/ nop.vert.glsl nop.frag.glsl
  - Written in GLSL (GL Shading Language)
  - Vertex Shader (out values interpolated to fragment)

```
# version 330 core
layout (location = 0) in vec3 position;
layout (location = 1) in vec3 color;
// Shader outputs, if any
out vec3 Color;
// Uniform variables
uniform mat4 modelview;
uniform mat4 projection;
void main() {
    gl_Position = projection * modelview * vec4(position, 1.0f);
    Color = color; // Just forward this color to the fragment shader
}
```

## Basic (nop) fragment shader

```
# version 330 core
// Do not modify the version directive to anything older than 330.
// Fragment shader inputs are outputs of same name from vertex shader
in vec3 Color;
// Uniform variables (none)

// Output
out vec4 fragColor;
void main (void)
{
    fragColor = vec4(Color, 1.0f);
}
```