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

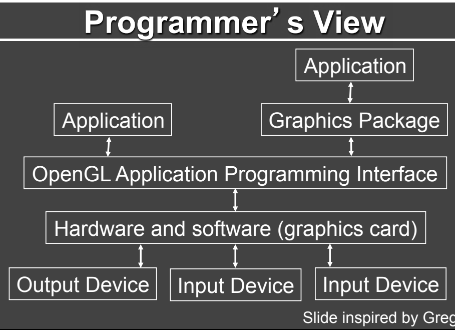
Introduction to OpenGL

- 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?

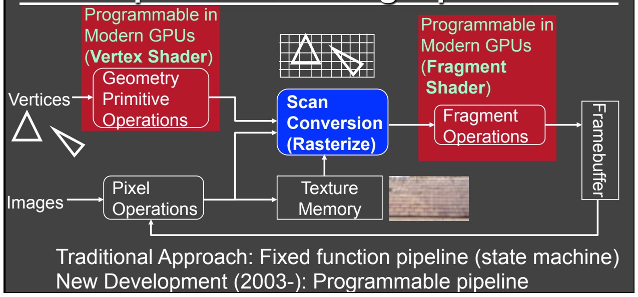
- Why do we need OpenGL or an API?
  - Encapsulates many basic functions of 2D/3D graphics
  - Think of it as high-level language (C++) for graphics
  - History: Introduced SGI in 92, maintained by Khronos
  - Precursor for DirectX, WebGL, Java3D etc.

Programmer’s View


Application
Application
Graphics Package
OpenGL Application Programming Interface
Hardware and software (graphics card)
Output Device
Input Device
Input Device

Slide inspired by Greg Humphreys

OpenGL Rendering Pipeline


Programmable in Modern GPUs (Vertex Shader)
Vertices
Geometry Primitive Operations
Scan Conversion (Rasterize)
Programmable in Modern GPUs (Fragment Shader)
Fragment Operations
Framebuffer
Images
Pixel Operations
Texture Memory

Traditional Approach: Fixed function pipeline (state machine)
New Development (2003-): Programmable pipeline

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

Ravi Ramamoorthi

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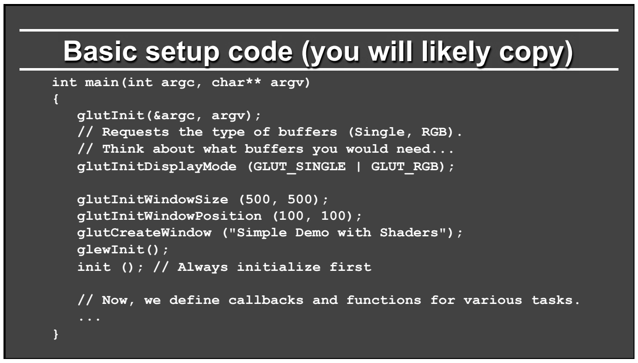
Buffers and Window Interactions

- Buffers: Color (front, back, left, right), depth (z), accumulation, stencil. When you draw, you write to some buffer (most simply, front and depth)
- No window system interactions (for portability)
  - But can use GLUT (or Motif, GLX, Tcl/Tk)
  - Callbacks to implement mouse, keyboard interaction

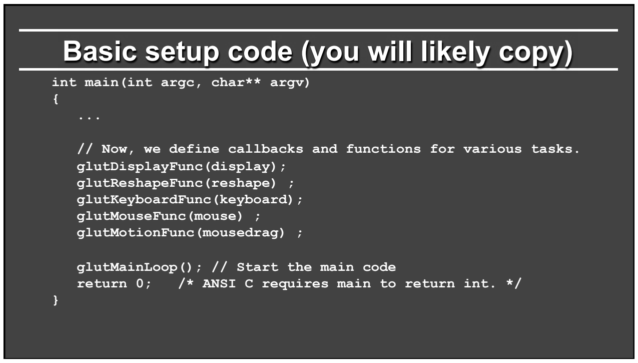


Basic setup code (you will likely copy)

```
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);

   glutInitWindowSize (500, 500);
   glutInitWindowPosition (100, 100);
   glutCreateWindow ("Simple Demo with Shaders");
   glewInit();
   init (); // Always initialize first

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

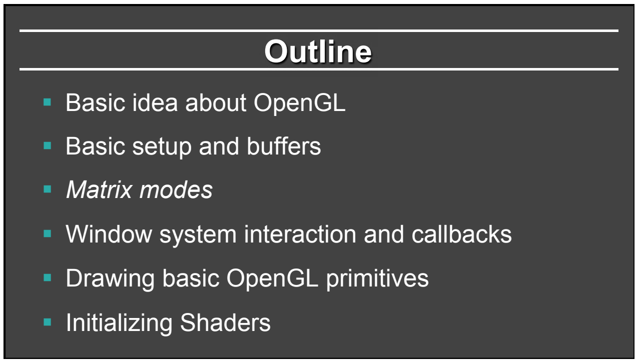


Basic setup code (you will likely copy)

```
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
   return 0;   /* ANSI C requires main to return int. */
}
```



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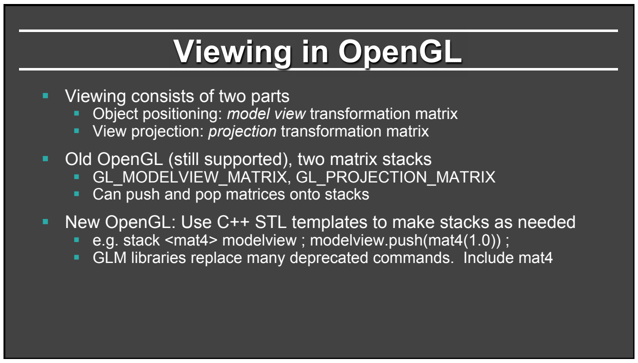
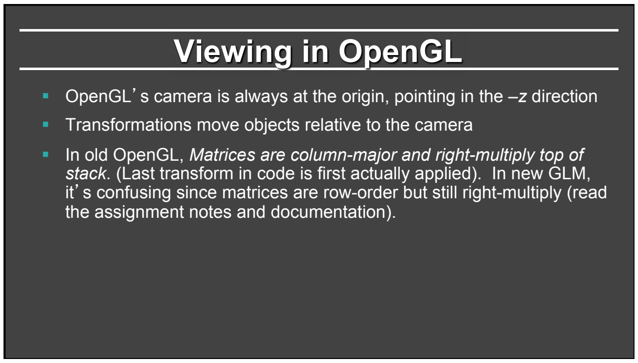


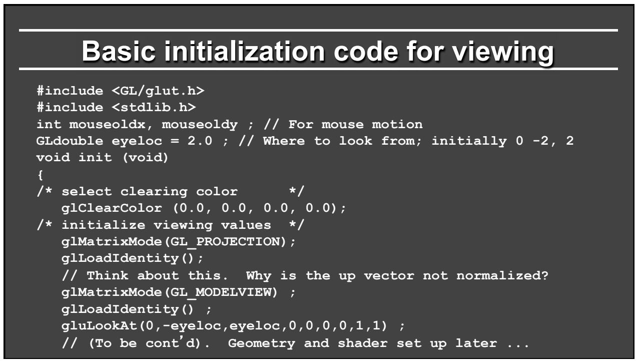
Viewing in OpenGL

- Viewing consists of two parts
  - Object positioning: *model view* transformation matrix
  - View projection: *projection* transformation matrix
- Old OpenGL (still supported), 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

- OpenGL's camera is 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, it's confusing since matrices are row-order but still right-multiply (read the assignment notes and documentation).



Basic initialization code for viewing

```
#include <GL/glut.h>
#include <stdlib.h>
int mouseoldx, mouseoldy ; // For mouse motion
GLdouble eyeloc = 2.0 ; // Where to look from; initially 0 -2, 2
void init (void)
{
/* select clearing color      */
   glClearColor (0.0, 0.0, 0.0, 0.0);
/* initialize viewing values  */
   glMatrixMode(GL_PROJECTION);
   glLoadIdentity();
   // Think about this.  Why is the up vector not normalized?
   glMatrixMode(GL_MODELVIEW) ;
   glLoadIdentity() ;
   gluLookAt(0,-eyeloc,eyeloc,0,0,0,0,1,1) ;
   // (To be cont'd).  Geometry and shader set up later ...
```

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Window System Interaction and Callbacks

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Outline

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Window System Interaction

- Not part of OpenGL
  - Toolkits (GLUT) available
- 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 ;
  }
}
```

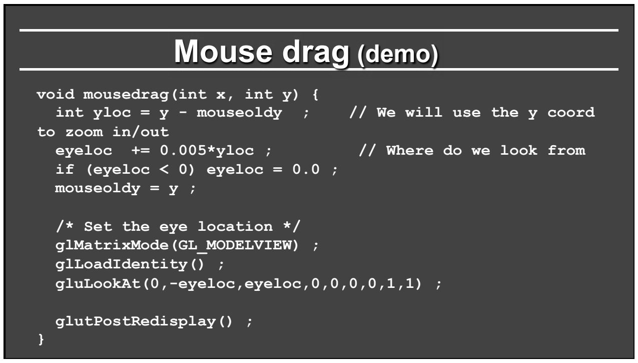
Basic window interaction code

```
/* Reshapes the window appropriately */
void reshape(int w, int h)
{
   glViewport (0, 0, (GLsizei) w, (GLsizei) h);
   glMatrixMode(GL_PROJECTION);
   glLoadIdentity();

   gluPerspective(30.0, (GLdouble)w/(GLdouble)h, 1.0, 10.0) ;
}
```

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 ;
      glMatrixMode(GL_MODELVIEW) ;
      glLoadIdentity() ;
      gluLookAt(0,-eyeloc,eyeloc,0,0,0,0,1,1) ;
      glutPostRedisplay() ;
    }
}
```

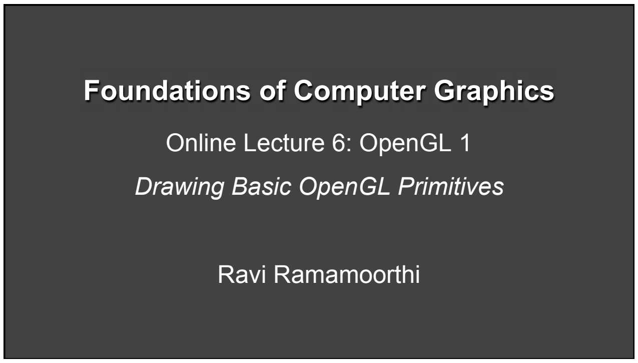


Mouse drag (demo)

```
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 */
  glMatrixMode(GL_MODELVIEW) ;
  glLoadIdentity() ;
  gluLookAt(0,-eyeloc,eyeloc,0,0,0,0,1,1) ;

  glutPostRedisplay() ;
}
```



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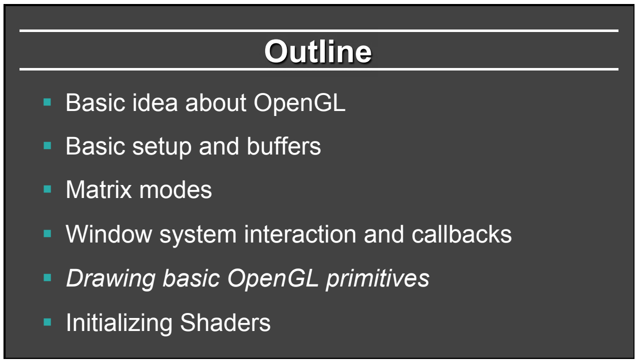
Drawing Basic OpenGL Primitives

Ravi Ramamoorthi



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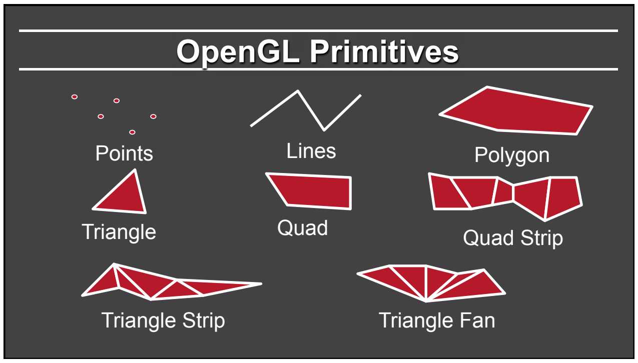


OpenGL Primitives

Points

Lines

Polygon

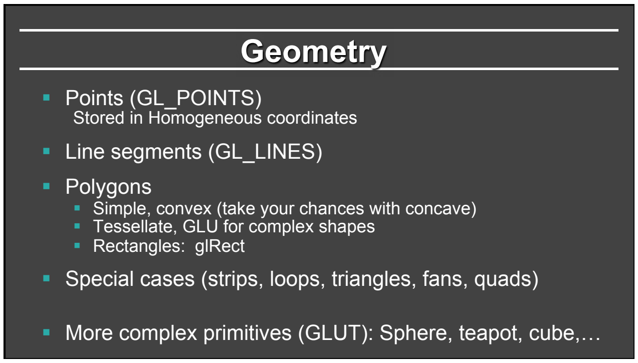
Triangle

Quad

Quad Strip

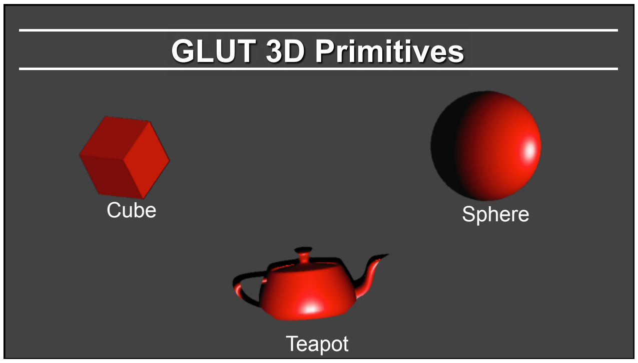
Triangle Strip

Triangle Fan



Geometry

- Points (GL_POINTS)
  Stored in Homogeneous coordinates
- Line segments (GL_LINES)
- Polygons
  - Simple, convex (take your chances with concave)
  - Tessellate, GLU for complex shapes
  - Rectangles: glRect
- Special cases (strips, loops, triangles, fans, quads)
- More complex primitives (GLUT): Sphere, teapot, cube,…



GLUT 3D Primitives

Cube

Sphere

Teapot

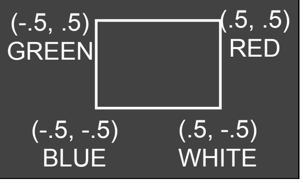
Old OpenGL: Drawing

- 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 in Display

```
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 Buffer Objects** (next)

Modern OpenGL: Floor Specification

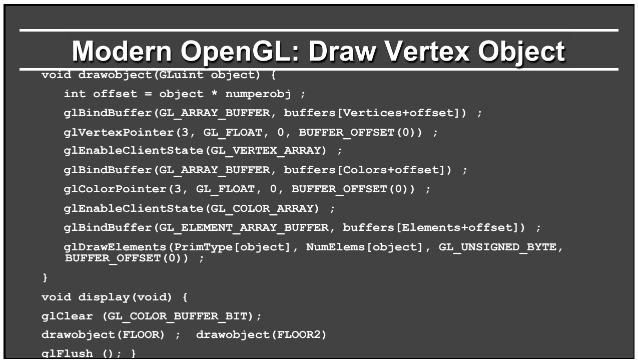
```
const GLfloat floorverts[4][3] = {
  {0.5, 0.5, 0.0},{-0.5, 0.5, 0.0},{-0.5, -0.5, 0.0}, {0.5, -0.5, 0.0}} ;
const GLfloat floorcol[4][3] = {
  {1.0, 0.0, 0.0},{0.0, 1.0, 0.0},{0.0, 0.0, 1.0},{1.0, 1.0, 1.0}} ;
const GLubyte floorinds[1][4] = { {0, 1, 2, 3} } ;
const GLfloat floorverts2[4][3] = {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

Modern OpenGL: Vertex Buffer Objects

```
const int numobjects = 2 ;  // number of objects for buffer
const int numperobj  = 3 ;  // Vertices, colors, indices
GLuint buffers[numperobj] ; // List of buffers for geometric data
GLuint objects[numobjects]; // For each object
GLenum PrimType[numobjects];// Primitive Type (quads, polygons)
GLsizei NumElems[numobjects] ; // Number of geometric elements
// Floor Geometry is specified with a vertex array
// The Buffer Offset Macro is from Red Book, page 103, 106
// Note for more complex objects the indices must be integers, not bytes.
#define BUFFER_OFFSET(bytes) ((GLubyte *) NULL + (bytes))
#define NumberOf(array) (sizeof(array)/sizeof(array[0]))
enum {Vertices, Colors, Elements} ; // For arrays for object
enum {FLOOR, FLOOR2} ; // For objects, for the floor
```

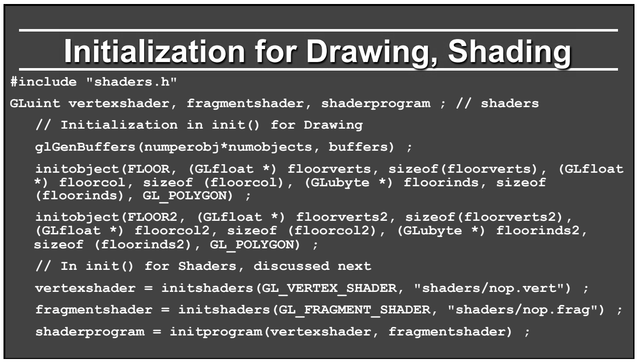
Modern OpenGL: Initialize Buffers

```
void initobject (GLuint object, GLfloat * vert, GLint sizevert, GLfloat *
   col, GLint sizecol, GLubyte * inds, GLint sizeind, GLenum type) {
   int offset = object * numperobj ;
   glBindBuffer(GL_ARRAY_BUFFER, buffers[Vertices+offset]) ;
   glBufferData(GL_ARRAY_BUFFER, sizevert, vert,GL_STATIC_DRAW);
   glVertexPointer(3, GL_FLOAT, 0, BUFFER_OFFSET(0)) ;
   glEnableClientState(GL_VERTEX_ARRAY) ;
   glBindBuffer(GL_ARRAY_BUFFER, buffers[Colors+offset]) ;
   glBufferData(GL_ARRAY_BUFFER, sizecol, col,GL_STATIC_DRAW);
   glColorPointer(3, GL_FLOAT, 0, BUFFER_OFFSET(0)) ;
   glEnableClientState(GL_COLOR_ARRAY) ;
   glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, buffers[Elements+offset]) ;
   glBufferData(GL_ELEMENT_ARRAY_BUFFER, sizeind, inds,GL_STATIC_DRAW);
   PrimType[object] = type ;
   NumElems[object] = sizeind ; }
```



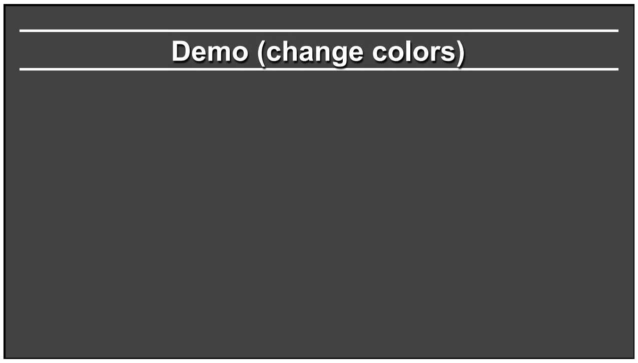
Modern OpenGL: Draw Vertex Object

```
void drawobject(GLuint object) {
   int offset = object * numperobj ;
   glBindBuffer(GL_ARRAY_BUFFER, buffers[Vertices+offset]) ;
   glVertexPointer(3, GL_FLOAT, 0, BUFFER_OFFSET(0)) ;
   glEnableClientState(GL_VERTEX_ARRAY) ;
   glBindBuffer(GL_ARRAY_BUFFER, buffers[Colors+offset]) ;
   glColorPointer(3, GL_FLOAT, 0, BUFFER_OFFSET(0)) ;
   glEnableClientState(GL_COLOR_ARRAY) ;
   glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, buffers[Elements+offset]) ;
   glDrawElements(PrimType[object], NumElems[object], GL_UNSIGNED_BYTE,
   BUFFER_OFFSET(0)) ;
}
void display(void) {
glClear (GL_COLOR_BUFFER_BIT);
drawobject(FLOOR) ;  drawobject(FLOOR2)
glFlush (); }
```

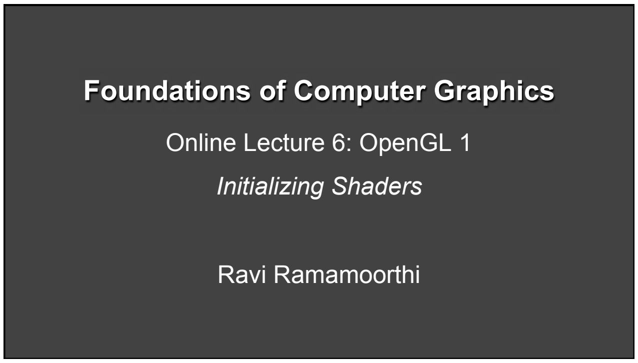


Initialization for Drawing, Shading

```
#include "shaders.h"
GLuint vertexshader, fragmentshader, shaderprogram ; // shaders
   // Initialization in init() for Drawing
   glGenBuffers(numperobj*numobjects, buffers) ;
   initobject(FLOOR, (GLfloat *) floorverts, sizeof(floorverts), (GLfloat
   *) floorcol, sizeof (floorcol), (GLubyte *) floorinds, sizeof
   (floorinds), GL_POLYGON) ;
   initobject(FLOOR2, (GLfloat *) floorverts2, sizeof(floorverts2),
   (GLfloat *) floorcol2, sizeof (floorcol2), (GLubyte *) floorinds2,
   sizeof (floorinds2), GL_POLYGON) ;
   // 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)



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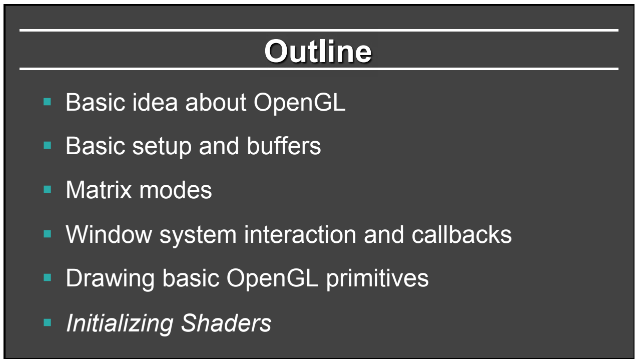
Initializing Shaders

Ravi Ramamoorthi



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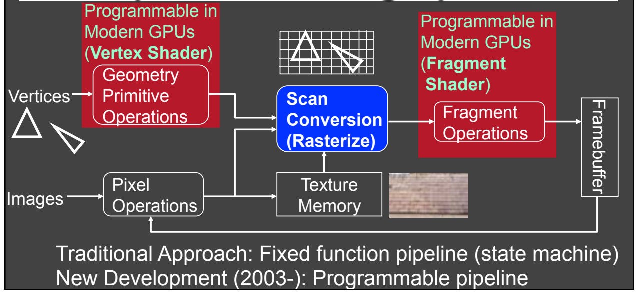
OpenGL Rendering Pipeline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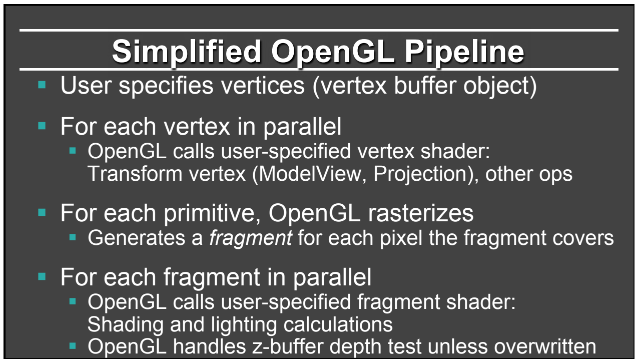
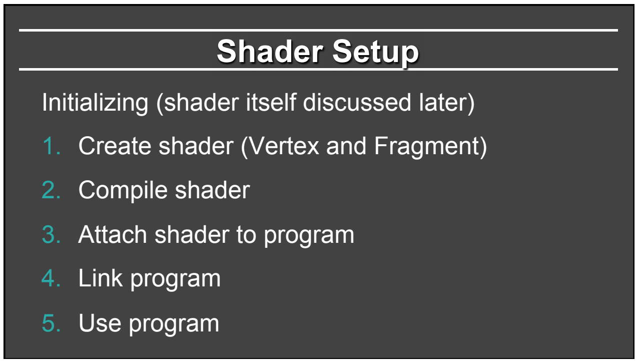
Traditional Approach: Fixed function pipeline (state machine)
New Development (2003-): Programmable pipeline



Simplified OpenGL Pipeline

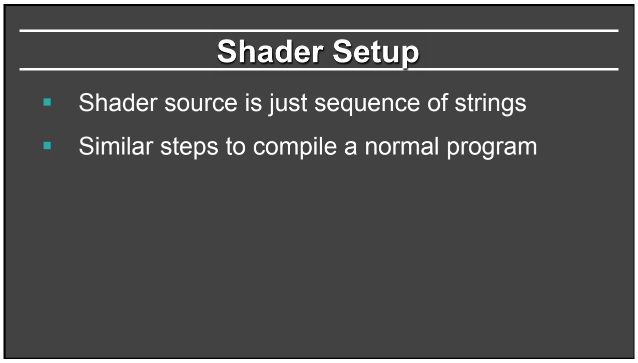
- User specifies vertices (vertex buffer object)
- For each vertex in parallel
  - OpenGL calls user-specified vertex shader: Transform vertex (ModelView, Projection), other ops
- For each primitive, OpenGL rasterizes
  - Generates a *fragment* for each pixel the fragment covers
- For each fragment in parallel
  - OpenGL calls user-specified fragment shader: Shading and lighting calculations
  - OpenGL handles z-buffer depth test unless overwritten



Shader Setup

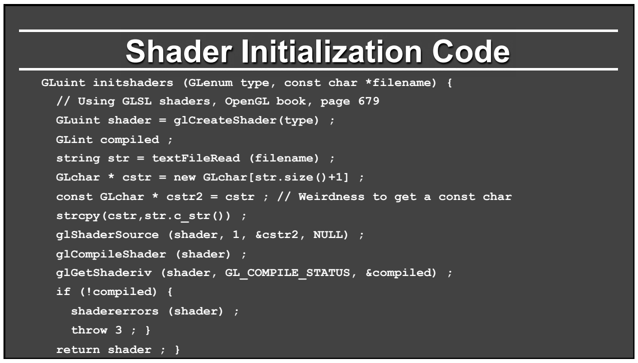
Initializing (shader itself discussed later)

1. Create shader (Vertex and Fragment)
2. Compile shader
3. Attach shader to program
4. Link program
5. Use program



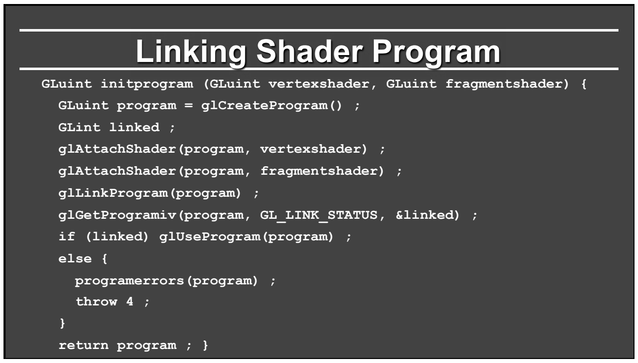
Shader Setup

- Shader source is just sequence of strings
- Similar steps to compile a normal program



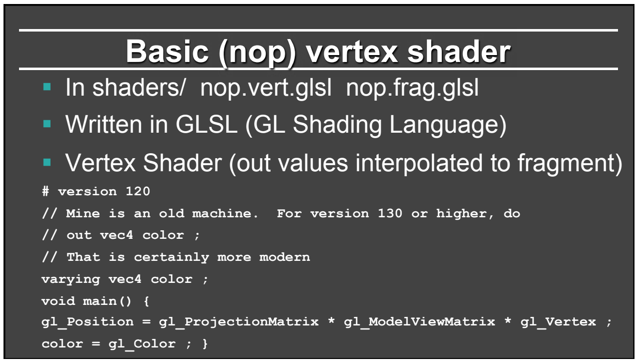
Shader Initialization Code

```
GLuint initshaders (GLenum type, const char *filename) {
  // Using GLSL shaders, OpenGL book, page 679
  GLuint shader = glCreateShader(type) ;
  GLint compiled ;
  string str = textFileRead (filename) ;
  GLchar * cstr = new GLchar[str.size()+1] ;
  const GLchar * cstr2 = cstr ; // Weirdness to get a const char
  strcpy(cstr,str.c_str()) ;
  glShaderSource (shader, 1, &cstr2, NULL) ;
  glCompileShader (shader) ;
  glGetShaderiv (shader, GL_COMPILE_STATUS, &compiled) ;
  if (!compiled) {
    shadererrors (shader) ;
    throw 3 ; }
  return shader ; }
```



Linking Shader Program

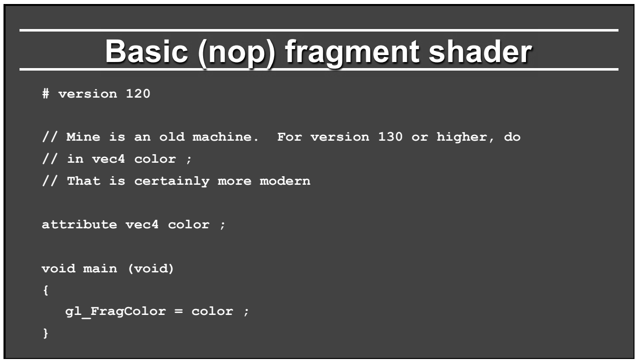
```
GLuint initprogram (GLuint vertexshader, GLuint fragmentshader) {
  GLuint program = glCreateProgram() ;
  GLint linked ;
  glAttachShader(program, vertexshader) ;
  glAttachShader(program, fragmentshader) ;
  glLinkProgram(program) ;
  glGetProgramiv(program, GL_LINK_STATUS, &linked) ;
  if (linked) glUseProgram(program) ;
  else {
    programerrors(program) ;
    throw 4 ;
  }
  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 120
// Mine is an old machine.  For version 130 or higher, do
// out vec4 color ;
// That is certainly more modern
varying vec4 color ;
void main() {
gl_Position = gl_ProjectionMatrix * gl_ModelViewMatrix * gl_Vertex ;
color = gl_Color ; }
```



Basic (nop) fragment shader

```
# version 120

// Mine is an old machine.  For version 130 or higher, do
// in vec4 color ;
// That is certainly more modern

attribute vec4 color ;

void main (void)
{
   gl_FragColor = color ;
}
```