Foundations of Computer Graphics (Spring 2012)

CS 184, Lecture 6: OpenGL 1

http://inst.eecs.berkeley.edu/~cs184

To Do

- HW 1 due on Thu
- Must find partners for HW 2 (if problems, speak to TAs during section). More difficult than HW 1
- Start thinking (now) about HW 2 *and* HW 3.

Demo: Surreal (HW 3)

This Lecture

- Introduction to OpenGL and simple demo code
  - mytest1.cpp ; you compiled mytest3.cpp for HW 0
- I am going to show (maybe write) actual code
  - Online code helps you understand HW 2, HW 3 better
  - ASK QUESTIONS if confused!!
- Simple demo of mytest1
- This lecture deals with very basic OpenGL setup. Next 2 lectures will likely be more interesting

Outline

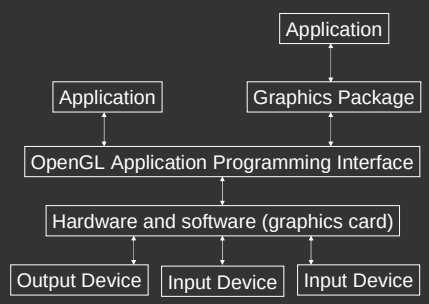
- *Basic idea about OpenGL*
- Basic setup and buffers
- Matrix modes
- Window system interaction and callbacks
- Drawing basic OpenGL primitives
- Initializing Shaders

Best source for OpenGL is the redbook. Of course, this is more a reference manual than a textbook, and you are better off implementing rather reading end to end.

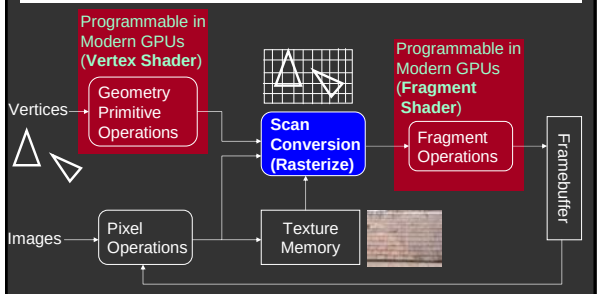
Introduction to OpenGL

- 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 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



OpenGL Rendering Pipeline



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
- Are teaching CS 184 with programmable shaders

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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.
   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
- 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

- Not part of OpenGL
- Toolkits (GLUT) available
- Callback functions for events
  - Keyboard, Mouse, etc.
  - Open, initialize, resize window
  - Similar to other systems (X, Java, etc.)
- 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 ;
  }
}

/* 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)

```
/* Defines a Mouse callback to zoom in and out */
/* This is done by modifying gluLookAt         */
/* The actual motion is in mousedrag           */
/* mouse simply sets state for mousedrag       */
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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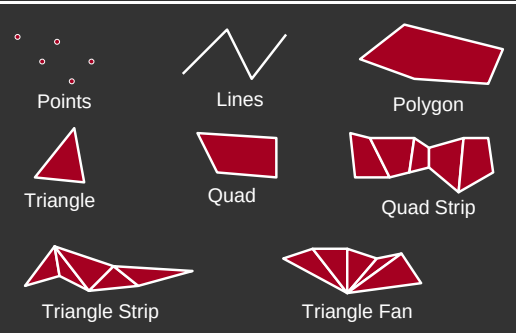
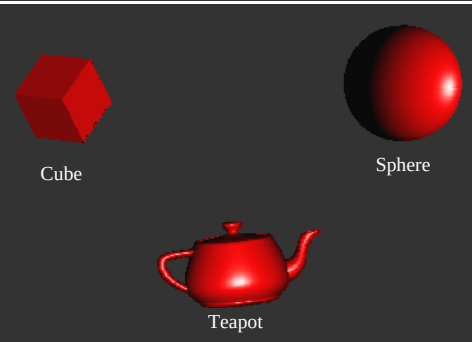
OpenGL Primitives



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



Old OpenGL: Drawing

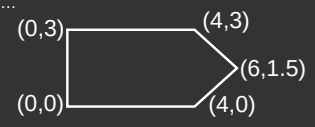
- Enclose vertices between glBegin() … glEnd() pair
  - Can include normal C code and attributes like the colors
  - Inside are commands like glVertex3f, glColor3f
  - Attributes must be set ***before*** the vertex
- Assembly line (pass vertices, transform, shade)
  - These are vertex, fragment shaders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

Old OpenGL: Specifying Geometry

glBegin(GL_POLYGON) ; // Chapter 2 but I do Counter Clock W

- glVertex2f (4.0, 0.0) ;
- glVertex2f (6.0, 1.5) ;
- glVertex2f (4.0, 3.0) ;
- glVertex2f (0.0, 3.0) ;
- glVertex2f (0.0, 0.0) ;
- // glColor, glIndex, glNormal, glTexCoord, … (pp 51,52)
- // glMaterial, glArrayElement, glEvalCoord, … (pp 51,52)
- // Other GL commands invalid between begin and end
- // Can write normal C code…

glEnd() ;

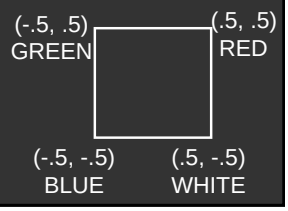


Old OpenGL: Drawing in Display

```
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.
   // The hardware will blend between them.
   // This is a useful debugging trick.  I make sure each vertex
   // appears exactly where I expect it to appear.

   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 () ;
}
```



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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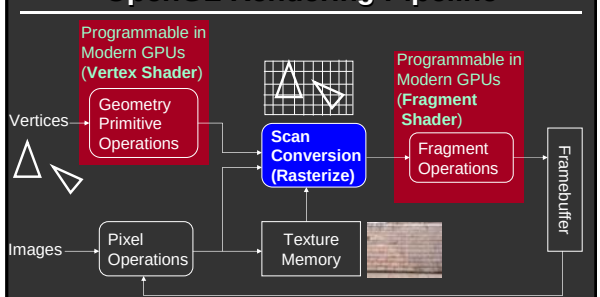
OpenGL Rendering Pipeline



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
- Modern OpenGL is “lite” basically just a rasterizer
  - “Real” action in user-defined vertex, fragment shaders

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 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 ;
}
```