Foundations of Computer Graphics

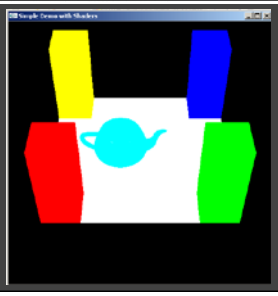
Online Lecture 8: OpenGL 2

Basic Geometry Setup

Ravi Ramamoorthi

Methodology for Lecture

- Make mytest1 more ambitious
- Sequence of steps
- Demo



Review of Last Demo

- Changed floor to all white, added global for teapot and teapotloc, moved geometry to new header file
- Demo 0 [set DEMO to 4 all features]

```
#include <GL/glut.h>
#include "shaders.h"
#include "geometry.h"

int mouseoldx, mouseoldy ; // For mouse motion
GLdouble eyeloc = 2.0 ; // Where to look from; initially 0 -2, 2
GLfloat teapotloc = -0.5 ; // ** NEW ** where the teapot is located
GLint animate = 0 ; // ** NEW ** whether to animate or not
GLuint vertexshader, fragmentshader, shaderprogram ; // shaders
const int DEMO = 0 ; // ** NEW ** To turn on and off features
```

Outline

- Review of demo from last lecture
- *Basic geometry setup for cubes (pillars), colors*
  - *Single geometric object, but multiple colors for pillars*
- Matrix Stacks and Transforms (draw 4 pillars)
- Depth testing (Z-buffering)
- Animation (moving teapot)
- Texture Mapping (wooden floor)

Geometry Basic Setup

```
const int numobjects = 2 ; // number of objects for buffer
const int numperobj  = 3 ;
const int ncolors = 4 ;
GLuint buffers[numperobj*numobjects+ncolors] ; // ** NEW ** List of
   buffers for geometric data
GLuint objects[numobjects] ; // For each object
GLenum PrimType[numobjects] ;
GLsizei NumElems[numobjects] ;
// Floor, Cube Geometry is specified with a vertex array
// The Buffer Offset Macro is from Red Book, page 103, 106
#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, CUBE} ; // For objects, for the floor
```

Cube geometry (for pillars)

```
const GLfloat wd = 0.1 ; const GLfloat ht = 0.5 ;
const GLfloat _cubecol[4][3] = {
  {1.0, 0.0, 0.0}, {0.0, 1.0, 0.0}, {0.0, 0.0, 1.0}, {1.0, 1.0, 0.0} } ;
const GLfloat cubeverts[8][3] = {
  {-wd, -wd, 0.0}, {-wd, wd, 0.0}, {wd, wd, 0.0}, {wd, -wd, 0.0},
  {-wd, -wd, ht}, {wd, -wd, ht}, {wd, wd, ht}, {-wd, wd, ht} } ;
GLfloat cubecol[8][3] ;
const GLubyte cubeinds[6][4] = {
  {0, 1, 2, 3}, // BOTTOM
  {4, 5, 6, 7}, // TOP
  {0, 4, 7, 1}, // LEFT
  {0, 3, 5, 4}, // FRONT
  {3, 2, 6, 5}, // RIGHT
  {1, 7, 6, 2}  // BACK
} ;
```

Cube Geometry (separate Color)

```
// Simple function to set the color separately.  Takes out colors
void initobjectnocol(GLuint object, GLfloat * vert, GLint sizevert,
   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_ELEMENT_ARRAY_BUFFER,buffers[Elements+offset]) ;
   glBufferData(GL_ELEMENT_ARRAY_BUFFER, sizeind, inds,GL_STATIC_DRAW);
   PrimType[object] = type ;
   NumElems[object] = sizeind ;
}
```

Cube Colors

```
// Simple function to init a bunch of color buffers for the cube
void initcolorscube (void) {
  int base = numobjects * numperobj ;
  for (int i = 0 ; i < ncolors ; i++) {
    for (int j = 0 ; j < 8 ; j++)
      for (int k = 0 ; k < 3 ; k++)
        cubecol[j][k] = _cubecol[i][k] ;
    glBindBuffer(GL_ARRAY_BUFFER, buffers[base+i]) ;
    glBufferData(GL_ARRAY_BUFFER, sizeof(cubecol), cubecol ,GL_STATIC_DRAW);
    glColorPointer(3, GL_FLOAT, 0, BUFFER_OFFSET(0)) ;
    glEnableClientState(GL_COLOR_ARRAY) ;       }
}
//in init
initobjectnocol(CUBE, (GLfloat *) cubeverts, sizeof(cubeverts), (GLubyte *)
   cubeinds, sizeof (cubeinds), GL_QUADS) ;
```

Drawing with Cube Colors

```
// And a function to draw with them, similar to drawobject but with color
void drawcolor(GLuint object, GLuint color) {
   int offset = object * numperobj ;
   int base = numobjects * 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[base+color]) ; // Set color
   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)) ; }
```

Foundations of Computer Graphics

Online Lecture 8: OpenGL 2

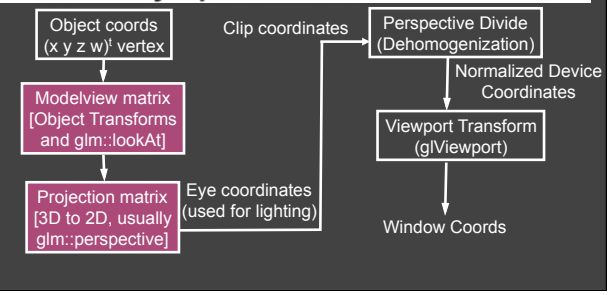
Matrix Stacks and Transforms (Draw 4 Pillars)

Ravi Ramamoorthi

Outline

- Review of demo from last lecture
- Basic geometry setup for cubes (pillars), colors
  - Single geometric object, but multiple colors for pillars
- *Matrix Stacks and Transforms (draw 4 pillars)*
- Depth testing (Z-buffering)
- Animation (moving teapot)
- Texture Mapping (wooden floor)

Summary OpenGL Vertex Transforms



Transformations

Matrix Stacks
- Useful for hierarchically defined figures, placing pillars
- Old OpenGL: glPushMatrix, glPopMatrix, glLoad, glMultMatrixf
- Mytest2 uses old-style stacks. Current recommendation is STL stacks managed yourself. *(You must manage the stack yourself for HW 2).*

Transforms
- Write your own translate, scale, rotate for HW 1 and HW 2
- Careful of OpenGL convetion: In old-style, **Right-multiply** current matrix (last is first applied). glm operators follow this sometimes.

Also gluLookAt (glm::lookAt), gluPerspective (glm::perspective)
- gluLookAt just matrix like any other transform, affecting modelview
- Must come **before in code, after in action** to other transforms
- Why not usually an issue for gluPerspective?

Drawing Pillars 1 (in display)

```
glMatrixMode(GL_MODELVIEW) ;

  // 1st pillar
  glPushMatrix() ;
      glTranslatef(-0.4,-0.4,0.0) ;
      drawcolor(CUBE, 0) ;
  glPopMatrix() ;

  // 2nd pillar
  glPushMatrix() ;
      glTranslatef(0.4,-0.4,0.0) ;
      drawcolor(CUBE, 1) ;
  glPopMatrix() ;
```

Drawing Pillars 2

```
// 3rd pillar
   glPushMatrix() ;
       glTranslatef(0.4,0.4,0.0) ;
       drawcolor(CUBE, 2) ;
   glPopMatrix() ;

   // 4th pillar
   glPushMatrix() ;
       glTranslatef(-0.4,0.4,0.0) ;
       drawcolor(CUBE, 3) ;
   glPopMatrix() ;
```

Demo

- Demo 1
- Does order of drawing matter?
- What if I move floor after pillars in code?
- Is this desirable? If not, what can I do about it?

Foundations of Computer Graphics

Online Lecture 8: OpenGL 2

Depth Testing (Z-Buffering)

Ravi Ramamoorthi

Outline

- Review of demo from last lecture
- Basic geometry setup for cubes (pillars), colors
  - Single geometric object, but multiple colors for pillars
- Matrix Stacks and Transforms (draw 4 pillars)
- *Depth testing (Z-buffering)*
- Animation (moving teapot)
- Texture Mapping (wooden floor)

Double Buffering

- New primitives draw over (replace) old objects
  - Can lead to jerky sensation
- Solution: double buffer. Render into back (off-screen) buffer. When finished, swap buffers to display entire image at once.
- Changes in main and display

```
glutInitDisplayMode (GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);

glutSwapBuffers() ;
glFlush ();
```

Turning on Depth test (Z-buffer)

OpenGL uses a Z-buffer for depth tests

- For each pixel, store nearest Z value (to camera) so far
- If new fragment is closer, it replaces old z, color ["less than" can be over-ridden in fragment program]
- Simple technique to get accurate visibility

Changes in main fn, display to Z-buffer

```
glutInitDisplayMode (GLUT_SINGLE | GLUT_RGB | GLUT_DEPTH);
glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
```

In init function

```
glEnable(GL_DEPTH_TEST) ;
glDepthFunc(GL_LESS) ; // The default option
```

Demo

- Demo 2
- Does order of drawing matter any more?
- What if I change near plane to 0?
- Is this desirable? If not, what can I do about it?

Foundations of Computer Graphics

Online Lecture 8: OpenGL 2

Animation (Moving Teapot)

Ravi Ramamoorthi

Outline

- Review of demo from last lecture
- Basic geometry setup for cubes (pillars), colors
  - Single geometric object, but multiple colors for pillars
- Matrix Stacks and Transforms (draw 4 pillars)
- Depth testing (Z-buffering)
- *Animation (moving teapot)*
- Texture Mapping (wooden floor)

Demo

- Demo 3
- Notice how teapot cycles around
- And that I can pause and restart animation
- And do everything else (zoom etc.) while teapot moves in background

Drawing Teapot (in display)

```
//  ** NEW ** Put a teapot in the middle that animates
    glColor3f(0.0,1.0,1.0) ; // Deprecated command to set the color
    glPushMatrix() ;
    //  I now transform by the teapot translation for animation */
    glTranslatef(teapotloc, 0.0, 0.0) ;

    //  The following two transforms set up and center the teapot
    //  Remember that transforms right-multiply the stack

    glTranslatef(0.0,0.0,0.1) ;
    glRotatef(90.0,1.0,0.0,0.0) ;
    glutSolidTeapot(0.15) ;
    glPopMatrix() ;
```

Simple Animation routine

```
// ** NEW ** in this assignment, is an animation of a teapot
// Hitting p will pause this animation; see keyboard callback

void animation(void) {
  teapotloc = teapotloc + 0.005 ;
  if (teapotloc > 0.5) teapotloc = -0.5 ;
  glutPostRedisplay() ;
}
```

Keyboard callback (p to pause)

```
GLint animate = 0 ; // ** NEW ** whether to animate or not
void keyboard (unsigned char key, int x, int y)
{
  switch (key) {
  case 27:  // Escape to quit
    exit(0) ;
    break ;
  case 'p': // ** NEW ** to pause/restart animation
    animate = !animate ;
      if (animate) glutIdleFunc(animation) ;
      else glutIdleFunc(NULL) ;
    break ;
  default:
    break ;  }
}
```

Foundations of Computer Graphics

Online Lecture 8: OpenGL 2

Texture Mapping (Wooden Floor – mytest3)

Ravi Ramamoorthi

Outline

- Review of demo from last lecture
- Display lists (extend init for pillars)
- Matrix stacks and transforms (draw 4 pillars)
- Depth testing or z-buffering
- Animation (moving teapot)
- *Texture mapping (wooden floor) [mytest3]*

New globals and basic setup

```
GLubyte woodtexture[256][256][3] ; // texture (from grsites.com)
GLuint texNames[1] ; // texture buffer
GLuint istex ;  // blend parameter for texturing
GLuint islight ; // for lighting
GLint texturing = 1 ; // to turn on/off texturing
GLint lighting = 1 ; // to turn on/off lighting

// In Display
 glUniform1i(islight,0) ; // Turn off lighting (except on teapot, later)
 glUniform1i(istex,texturing) ;
 drawtexture(FLOOR,texNames[0]) ; // Texturing floor
 // drawobject(FLOOR) ;
 glUniform1i(istex,0) ; // Other items aren't textured
```

Simple Toggles for Keyboard

```
case 't': // ** NEW ** to turn on/off texturing ;
   texturing = !texturing ;
   glutPostRedisplay() ;
   break ;
case 's': // ** NEW ** to turn on/off shading (always smooth) ;
   lighting = !lighting ;
   glutPostRedisplay() ;
   break ;
```

Adding Visual Detail

- Basic idea: use images instead of more polygons to represent fine scale color variation

Texture Mapping

- Important topic: nearly all objects textured
  - Wood grain, faces, bricks and so on
  - Adds visual detail to scenes
- Can be added in a fragment shader

Polygonal model

With surface texture

Setting up texture

```
inittexture("wood.ppm", shaderprogram) ; // in init()
// Very basic code to read a ppm file
// And then set up buffers for texture coordinates
void inittexture (const char * filename, GLuint program) {
  int i,j,k ;
  FILE * fp ;
  GLint err ;
   assert(fp = fopen(filename,"rb")) ;
   fscanf(fp,"%*s %*d %*d %*d%*c") ;
   for (i = 0 ; i < 256 ; i++)
     for (j = 0 ; j < 256 ; j++)
       for (k = 0 ; k < 3 ; k++)
    fscanf(fp,"%c",&(woodtexture[i][j][k])) ;
   fclose(fp) ;
```

Texture Coordinates

- Each vertex must have a texture coordinate: pointer to texture. Interpolate for pixels (each fragment has st)

```
// Set up Texture Coordinates
  glGenTextures(1, texNames) ;

  glBindBuffer(GL_ARRAY_BUFFER, buffers[numobjects*numperobj+ncolors]) ;
  glBufferData(GL_ARRAY_BUFFER, sizeof (floortex),
  floortex,GL_STATIC_DRAW);
  glActiveTexture(GL_TEXTURE0) ;
  glEnable(GL_TEXTURE_2D) ;
  glTexCoordPointer(2,GL_FLOAT,0,BUFFER_OFFSET(0)) ;
  glEnableClientState(GL_TEXTURE_COORD_ARRAY) ;
  glBindTexture (GL_TEXTURE_2D, texNames[0]) ;
```

Specifying the Texture Image

- glTexImage2D(target, level, components, width height, border, format, type, data)
- target is GL_TEXTURE_2D
- level is (almost always) 0
- components = 3 or 4 (RGB/RGBA)
- width/height MUST be a power of 2
- border = 0 (usually)
- format = GL_RGB or GL_RGBA (usually)
- type = GL_UNSIGNED_BYTE, GL_FLOAT, etc…

Texture Image and Bind to Shader

```
glTexImage2D(GL_TEXTURE_2D,0,GL_RGB, 256, 256, 0, GL_RGB,
  GL_UNSIGNED_BYTE, woodtexture) ;
  glTexParameterf(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR) ;
  glTexParameterf(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR) ;
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT) ;
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT) ;

  // Define a sampler.  See page 709 in red book, 7th ed.
  GLint texsampler ;
  texsampler = glGetUniformLocation(program, "tex") ;
  glUniformli(texsampler,0) ; // Could also be GL_TEXTURE0
  istex = glGetUniformLocation(program,"istex") ;
```

Drawing with Texture

```
void drawtexture(GLuint object, GLuint texture) {
   int offset = object * numperobj ;
   int base = numobjects * numperobj + ncolors ;
   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) ;

// Textures
   ...
```

Drawing with Texture

```
void drawtexture(GLuint object, GLuint texture) {
  ...
// Textures
 glActiveTexture(GL_TEXTURE0) ;
 glEnable(GL_TEXTURE_2D) ;
 glBindTexture(GL_TEXTURE_2D, texture) ;
 glEnableClientState(GL_TEXTURE_COORD_ARRAY) ;
 glBindBuffer(GL_ARRAY_BUFFER, buffers[base]) ; // Texcoords
 glTexCoordPointer(2, GL_FLOAT, 0, BUFFER_OFFSET(0)) ;
 glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, buffers[Elements+offset]) ;
glDrawElements(PrimType[object], NumElems[object],
   GL_UNSIGNED_BYTE, BUFFER_OFFSET(0)) ;
}
```

Final Steps for Drawing (+Demo)

- Vertex shader (just pass on texture coords)

```
gl_TexCoord[0] = gl_MultiTexCoord0 ;
```

- Fragment shader (can be more complex blend)

```
uniform sampler2D tex ;
uniform int istex ;
void main (void)
{
if (istex > 0) gl_FragColor = texture2D(tex, gl_TexCoord[0].st) ;
```