Computer Graphics (Fall 2006)

COMS 4160, Lecture 11: OpenGL 2

http://www.cs.columbia.edu/~cs4160

To Do

- Start working on HW 3. Milestones due in 1 week.
- Can leverage many sources (Red book, excellent online documentation, see links class website)
- And programs shown in class (try reading, compiling, understanding source code)
- It is a good idea to copy (and modify) relevant segments
- (Very) tough to get started, but lots of fun afterwards

Methodology for Lecture

- Make demo from last lecture more ambitious
- Questions on some changes and potential problems
- I will run through sequence of steps with demos
- Demo 4160-opengl\opengl2\opengl2-orig.exe

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)

Best source for OpenGL is the redbook (in this lecture, chapters 3, 7 and early part of 9) . Of course, this is more a reference manual than a textbook, and you are better off implementing rather reading end to end. Though if you do have time, the book is actually quite readable

Review of Last Demo

- Changed floor to all white, added global for display lists (talked about next) and included some new files
- Demo 0 (in Visual Studio)

```
#include <GL/glut.h>
#include <stdio.h> // ** NEW ** for loading the texture
#include <stdlib.h>
#include <assert.h> // ** NEW ** for errors

int mouseoldx, mouseoldy ; // For mouse motion
GLdouble eyeloc = 2.0 ; // Where to look from; initially 0 -2, 2
GLuint pillar ; // ** NEW ** For the display list for the pillars
```

Immediate vs. Retained Mode

Immediate Mode

- Primitives sent to display as soon as specified (default)
- Graphics system has no memory of drawn primitives

Retained Mode

- Primitives placed in ***display lists***
- Display lists can be kept on the graphics server
- Can be redisplayed with different graphics state
- Almost always a performance win

We will add 4 pillars using a display list for a single pillar, with changed attributes (transform, color)

Display List Initialization (in init)

```
// This uses gluCylinder.  The glu primitives are
// sometimes useful.
// The GLU library is described in chapter 11.  We need only
// a small part of it.

   cyl = gluNewQuadric() ;

   /* This part sets up a display list for the pillars.
      Refer to chapter 7 for more details */

   pillar = glGenLists(1) ;
   glNewList(pillar, GL_COMPILE) ;
   gluCylinder (cyl, 0.1, 0.1, .5, 10, 10) ;
   glEndList() ;
```

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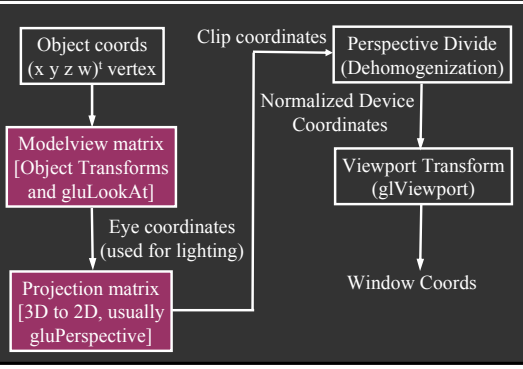
Red Book, Chapter 3

Summary OpenGL Vertex Transforms



Transformations

Matrix Stacks
- glPushMatrix, glPopMatrix, glLoad, glMultMatrixf
- Useful for Hierarchically defined figures, placing pillars

Transforms
- glTranslatef(x,y,z) ; glRotatef(θ,x,y,z) ; glScalef(x,y,z)
- **Right-multiply** current matrix (last is first applied)

Also gluLookAt, gluPerspective
- Remember gluLookAt just matrix like any other transform, affecting modelview
- Must come **before in code, after in action** to other transfs
- Why not usually an issue for gluPerspective?

Complete Viewing Example

```
//Projection first (order doesn't matter)
glMatrixMode( GL_PROJECTION );
glLoadIdentity();
gluPerspective( 60, 1, 1, 100 );

//Now object transformations
glMatrixMode( GL_MODELVIEW );
glLoadIdentity();
gluLookAt( 10, 10, 10, 1, 2, 3, 0, 0, 1 ) ;
glTranslatef( 1, 1, 1 );
glRotatef( 90, 1, 0, 0 );
DrawObject();
```

Drawing Pillars 1 (in display)

```
/* Note the use of matrix stacks and push and pop */
   glMatrixMode(GL_MODELVIEW) ;

   /* Draw first pillar by Translating */
   glPushMatrix() ;
      glTranslatef(0.4, 0.4, 0.0) ;
      glColor3f(1.0, 1.0, 0.0) ;
      glCallList(pillar) ;
   glPopMatrix() ;

   /* Draw second pillar by Translating */
   glPushMatrix() ;
      glTranslatef(-0.4, 0.4, 0.0) ;
      glColor3f(1.0, 0.0, 0.0) ;
      glCallList(pillar) ;
   glPopMatrix() ;
```

Drawing Pillars 2

```
/* Draw third pillar by Translating */
   glPushMatrix() ;
      glTranslatef(-0.4, -0.4, 0.0) ;
      glColor3f(0.0, 1.0, 0.0) ;
      glCallList(pillar) ;
   glPopMatrix() ;

   /* Draw fourth pillar by Translating */
   glPushMatrix() ;
      glTranslatef(0.4, -0.4, 0.0) ;
      glColor3f(0.0, 0.0, 1.0) ;
      glCallList(pillar) ;
   glPopMatrix() ;
```

Demo

- Demo 1 (in visual studio)
- 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?

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- Review of demo from last lecture
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- *Depth testing or z-buffering (state management too)*
- Animation (moving teapot)
- Texture mapping (wooden floor)

State

- OpenGL is a big state machine
- State encapsulates control for operations like:
  - Lighting
  - Shading
  - Texture Mapping
  - Depth testing
- Boolean state settings can be turned on and off with glEnable and glDisable
- Anything that can be set can be queried using glGet

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
- Simple technique to get accurate visibility
- (Be sure you know what fragments and pixels are)

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 (in visual studio)
- 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?

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Demo

- Demo 3 (in visual studio)
- 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)

```
GLdouble teapotloc = -0.5 ; // global variable set before
 /*  ** NEW ** Put a teapot in the middle that animates */
   glColor3f(0.0,1.0,1.0) ;
   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

```
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 ;
  }
}
```

Double Buffering

- New primitives draw over (replace) old objects
- Can lead to jerky sensation
- Solution: double buffer. Render into back (offscreen) 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 ();
```

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- *Texture mapping (wooden floor)*

Initial part of GL chapter 9, Demo 4

Texture Mapping

- Textures are *images* applied to objects
- Texture modifies the color assignment to a fragment
  - Texture color can modify the material color used in the shading model, or it can be a decal
- Use glTexCoord to assign a texture coordinate to a vertex

Texture Mapping Example

```
glBegin( GL_QUADS );
  glTexCoord2f( 0, 0 );
  glVertex3f( a, b, c );
  glTexCoord2f( 1, 0 );
  glVertex3f( a, b, d );
  glTexCoord2f( 1, 1 );
  glVertex3f( a, e, d );
  glTexCoord2f( 0, 1 );
  glVertex3f( a, e, c );
glEnd();
```

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…

More on Texture (very briefly)

- Optimizations for efficiency
- Mipmapping
- Filtering
- Texture Coordinate generation
- Texture Matrix
- Environment Mapping

If very ambitious, read all of chapter 9

Setting up texture (in init)

```
/* ** New for demo 2 ** setup for textures */
  /* First, read this simple ppm file in */
  assert(fp = fopen("wood.ppm","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) ;

  /* Now, set up all the stuff for texturing, per red book */
  glGenTextures(1, &texName) ;
  glBindTexture(GL_TEXTURE_2D, texName) ;
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT) ;
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT) ;
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_NEAREST) ;
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST) ;
  glTexImage2D(GL_TEXTURE_2D,0,GL_RGB, 256, 256, 0, GL_RGB,
GL_UNSIGNED_BYTE, woodtexture) ;
```

Rendering with texture (in display)

```
  /* As a final step, I modify this for texture mapping * NEW * */
   /* Consult chapter 9 for the explanation of the various options */
   /* Note addition of texture coordinates, and the glue to add
texturing */
   /* Also note some effort to find the error if any */

   glEnable(GL_TEXTURE_2D) ;
   glTexEnvf(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_REPLACE) ;
   glBindTexture(GL_TEXTURE_2D, texName) ;
   glColor3f(1.0,1.0,1.0) ;
   err = glGetError() ; assert(err == GL_NO_ERROR) ;
   glBegin(GL_POLYGON) ;
      glTexCoord2f(1.0, 1.0) ; glVertex3f (0.5, 0.5, 0.0);
      glTexCoord2f(0.0,1.0) ; glVertex3f (-0.5, 0.5, 0.0);
      glTexCoord2f(0.0,0.0); glVertex3f (-0.5, -0.5, 0.0);
      glTexCoord2f(1.0,0.0) ; glVertex3f (0.5, -0.5, 0.0);
   glEnd() ;
   err = glGetError() ; assert(err == GL_NO_ERROR) ;
   glDisable(GL_TEXTURE_2D) ;
```