Foundations of Computer Graphics

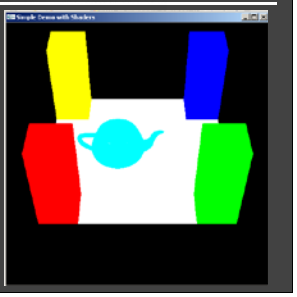
Online Lecture 8: OpenGL 2

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> //also <GL/glew.h>; <GLUT/glut.h> for Mac OS
#include "shaders.h"
#include "geometry.h"

int mouseoldx, mouseoldy ; // For mouse motion
GLfloat 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

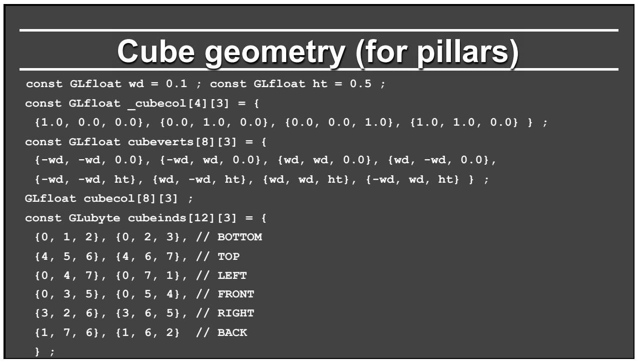
- Review of demo from last lecture
- *Basic geometry setup for cubes (pillars), colors*
  - *Single geometric object, but multiple colors for pillars*
- Matrix Stacks and Transforms (draw 4 pillars)
- Depth testing (Z-buffering)
- Animation (moving teapot)
- Texture Mapping (wooden floor)

Geometry Basic Setup 1

```
const int numobjects = 2 ; // number of objects for buffer
const int numperobj  = 3 ;
const int ncolors = 4 ;
GLUint VAOs[numobjects+ncolors], teapotVAO; // VAO for each object
GLuint buffers[numperobj*numobjects+ncolors], teapotbuffers[3] ;
GLuint objects[numobjects] ; // ** NEW ** For each object
GLenum PrimType[numobjects] ;
GLsizei NumElems[numobjects] ;
std::vector <glm::vec3> teapotVertices; // For geometry of the teapot
std::vector <glm::vec3> teapotNormals;
std::vector <unsigned int> teapotIndices;
// To be used as a matrix stack for the modelview.
std::vector <glm::mat4> modelviewStack;
```

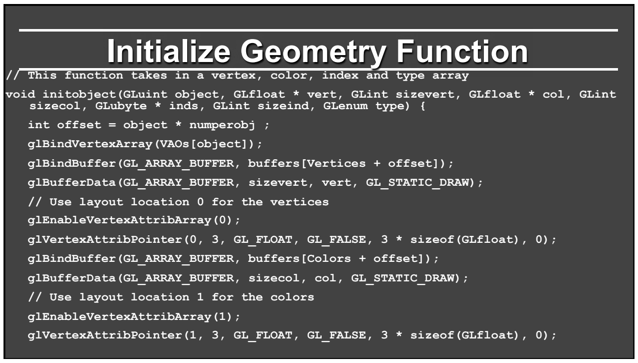
Geometry Basic Setup 2

```
// ** NEW ** Floor Geometry is specified with a vertex array
// ** NEW ** Same for other Geometry

enum {Vertices, Colors, Elements} ; // For arrays for object
enum {FLOOR, CUBE} ; // For objects, for the floor

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, 1.0, 1.0}, {1.0, 1.0, 1.0}, {1.0, 1.0, 1.0}, {1.0, 1.0, 1.0}} ;
const GLubyte floorinds[1][6] = { {0, 1, 2, 0, 2, 3} } ;
const GLfloat floortex[4][2] = {
  {1.0, 1.0}, {0.0, 1.0}, {0.0, 0.0}, {1.0, 0.0} } ;
```



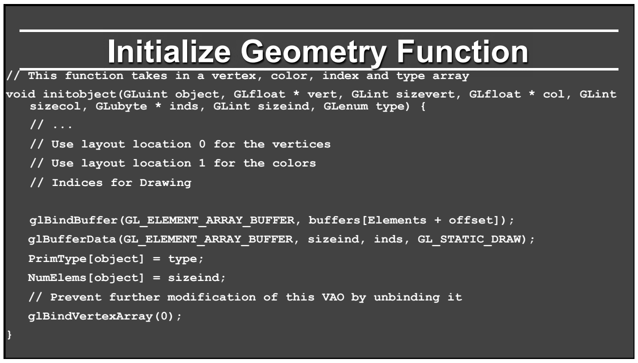
Cube geometry (for pillars)

```
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[12][3] = {
 {0, 1, 2}, {0, 2, 3}, // BOTTOM
 {4, 5, 6}, {4, 6, 7}, // TOP
 {0, 4, 7}, {0, 7, 1}, // LEFT
 {0, 3, 5}, {0, 5, 4}, // FRONT
 {3, 2, 6}, {3, 6, 5}, // RIGHT
 {1, 7, 6}, {1, 6, 2}  // BACK
 } ;
```



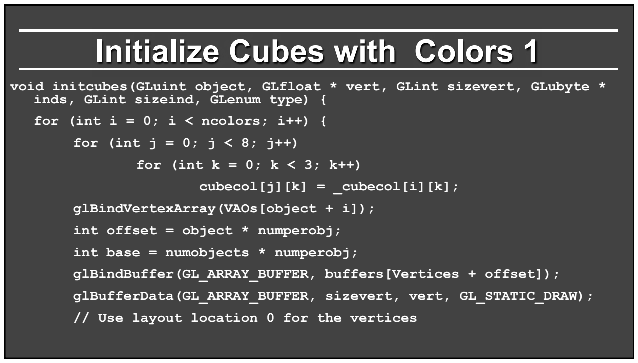
Initialize Geometry Function

```
// This function takes in a vertex, color, index and type array
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
   glEnableVertexAttribArray(0);
   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
   glEnableVertexAttribArray(1);
   glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(GLfloat), 0);
```



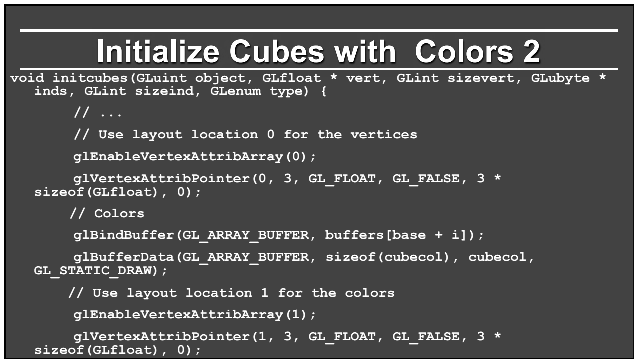
Initialize Geometry Function

```
// This function takes in a vertex, color, index and type array
void initobject(GLuint object, GLfloat * vert, GLint sizevert, GLfloat * col, GLint
   sizecol, GLubyte * inds, GLint sizeind, GLenum type) {
   // ...
   // Use layout location 0 for the vertices
   // Use layout location 1 for the colors
   // Indices for Drawing

   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);
}
```



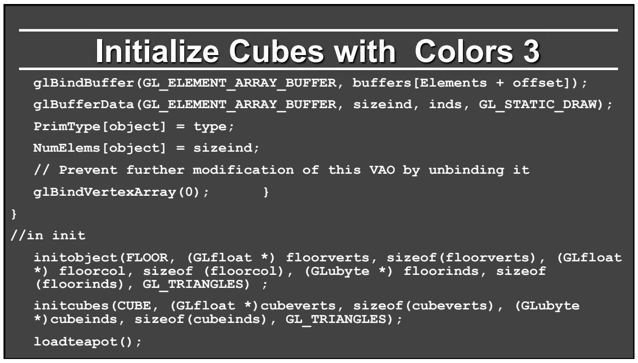
Initialize Cubes with Colors 1

```
void initcubes(GLuint object, GLfloat * vert, GLint sizevert, GLubyte *
   inds, GLint sizeind, GLenum type) {
   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];
        glBindVertexArray(VAOs[object + i]);
        int offset = object * numperobj;
        int base = numobjects * numperobj;
        glBindBuffer(GL_ARRAY_BUFFER, buffers[Vertices + offset]);
        glBufferData(GL_ARRAY_BUFFER, sizevert, vert, GL_STATIC_DRAW);
        // Use layout location 0 for the vertices
```



Initialize Cubes with Colors 2

```
void initcubes(GLuint object, GLfloat * vert, GLint sizevert, GLubyte *
   inds, GLint sizeind, GLenum type) {
        // ...
        // Use layout location 0 for the vertices
        glEnableVertexAttribArray(0);
        glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 3 *
  sizeof(GLfloat), 0);
       // Colors
        glBindBuffer(GL_ARRAY_BUFFER, buffers[base + i]);
        glBufferData(GL_ARRAY_BUFFER, sizeof(cubecol), cubecol,
  GL_STATIC_DRAW);
      // Use layout location 1 for the colors
        glEnableVertexAttribArray(1);
        glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 3 *
  sizeof(GLfloat), 0);
```



Initialize Cubes with Colors 3

```
   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);      }
}
//in init
   initobject(FLOOR, (GLfloat *) floorverts, sizeof(floorverts), (GLfloat
   *) floorcol, sizeof (floorcol), (GLubyte *) floorinds, sizeof
   (floorinds), GL_TRIANGLES) ;
   initcubes(CUBE, (GLfloat *)cubeverts, sizeof(cubeverts), (GLubyte
   *)cubeinds, sizeof(cubeinds), GL_TRIANGLES);
   loadteapot();
```

Drawing with/without Colors

```
// And a function to draw with them, similar to drawobject but with color
void drawcolor(GLuint object, GLuint color) {
   glBindVertexArray(VAOs[object + color]);
   glDrawElements(PrimType[object], NumElems[object], GL_UNSIGNED_BYTE, 0);
   glBindVertexArray(0);
}
void drawobject(GLuint object) {
   glBindVertexArray(VAOs[object]);
   glDrawElements(PrimType[object], NumElems[object], GL_UNSIGNED_BYTE, 0);
   glBindVertexArray(0);
}

void loadteapot() // See source code for details if interested
```

Foundations of Computer Graphics

Online Lecture 8: OpenGL 2

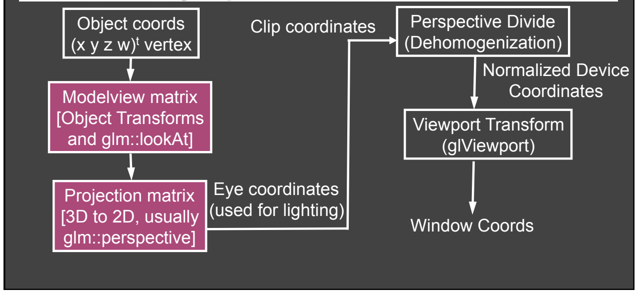
Matrix Stacks and Transforms (Draw 4 Pillars)

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

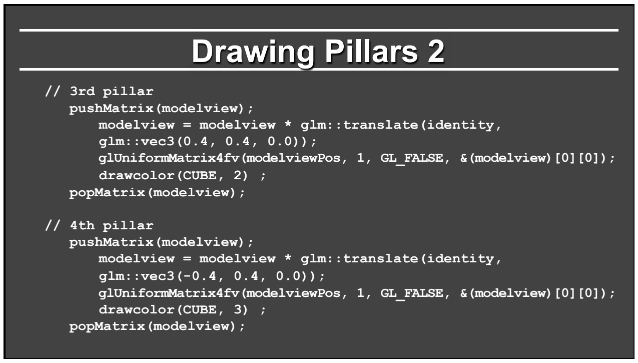
Matrix Stacks
- Useful for hierarchically defined figures, placing pillars
- Old OpenGL: glPushMatrix, glPopMatrix, glLoad, glMultMatrixf
- Current recommendation is STL stacks managed yourself, which is done in mytest2. *(You must manage the stack yourself for HW 2).*

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

Also gluLookAt (glm::lookAt), gluPerspective (glm::perspective)
- Remember just matrix like any other transform, affecting modelview
- See mytest for how to best implement these ideas

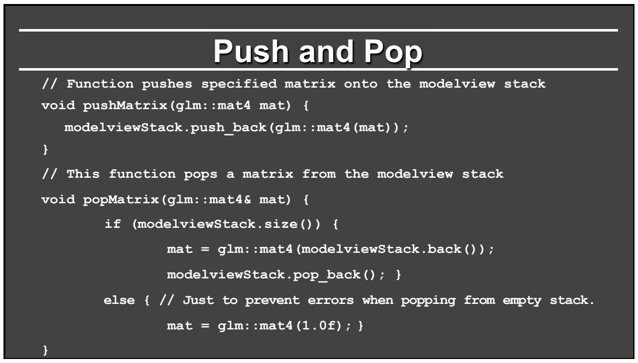
Drawing Pillars 1 (in display)

```
// 1st pillar: Right-multiply modelview as in old OpenGL
pushMatrix(modelview) ;  // push/pop functions for stack
     modelview = modelview * glm::translate(identity, glm::vec3(-0.4,
     -0.4, 0.0)) ;  // build translation matrix
     glUniformMatrix4fv(modelviewPos, 1, GL_FALSE, &(modelview)[0][0]);
     drawcolor(CUBE, 0) ;
popMatrix(modelview) ;
// 2nd pillar
pushMatrix(modelview) ;
    modelview = modelview * glm::translate(identity, glm::vec3(0.4,
     -0.4, 0.0)) ;  // build translation matrix
    glUniformMatrix4fv(modelviewPos, 1, GL_FALSE, &(modelview)[0][0]);
    drawcolor(CUBE, 1) ;
popMatrix(modelview) ;
```



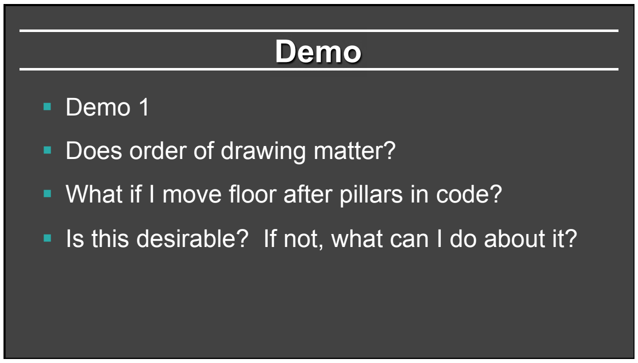
Drawing Pillars 2

```
// 3rd pillar
   pushMatrix(modelview);
       modelview = modelview * glm::translate(identity,
       glm::vec3(0.4, 0.4, 0.0));
       glUniformMatrix4fv(modelviewPos, 1, GL_FALSE, &(modelview)[0][0]);
       drawcolor(CUBE, 2) ;
   popMatrix(modelview);

// 4th pillar
   pushMatrix(modelview);
       modelview = modelview * glm::translate(identity,
       glm::vec3(-0.4, 0.4, 0.0));
       glUniformMatrix4fv(modelviewPos, 1, GL_FALSE, &(modelview)[0][0]);
       drawcolor(CUBE, 3) ;
   popMatrix(modelview);
```



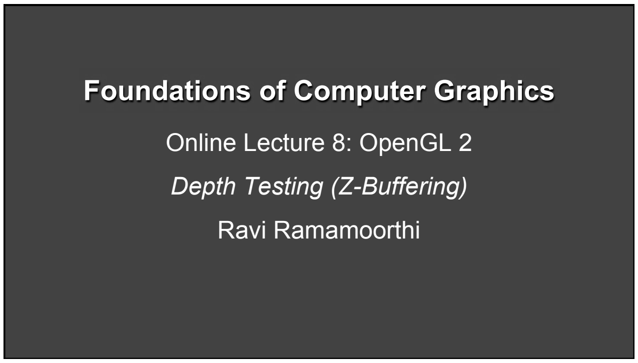
Push and Pop

```
// Function pushes specified matrix onto the modelview stack
void pushMatrix(glm::mat4 mat) {
   modelviewStack.push_back(glm::mat4(mat));
}
// This function pops a matrix from the modelview stack
void popMatrix(glm::mat4& mat) {
        if (modelviewStack.size()) {
                mat = glm::mat4(modelviewStack.back());
                modelviewStack.pop_back(); }
        else { // Just to prevent errors when popping from empty stack.
                mat = glm::mat4(1.0f); }
}
```



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?

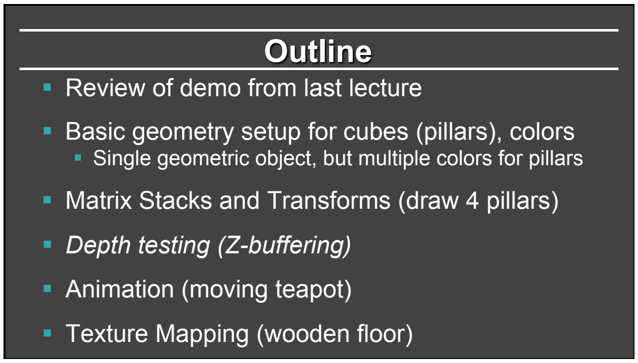


Foundations of Computer Graphics

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
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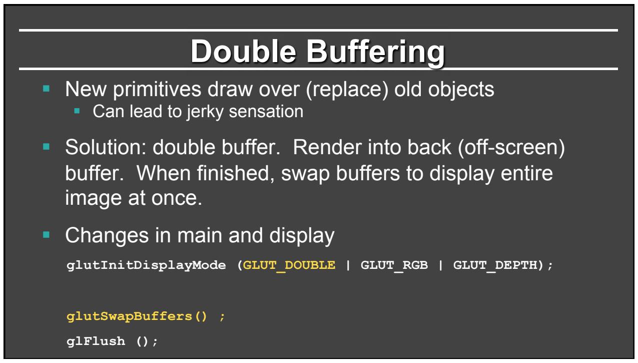
- Matrix Stacks and Transforms (draw 4 pillars)
- *Depth testing (Z-buffering)*
- Animation (moving teapot)
- Texture Mapping (wooden floor)

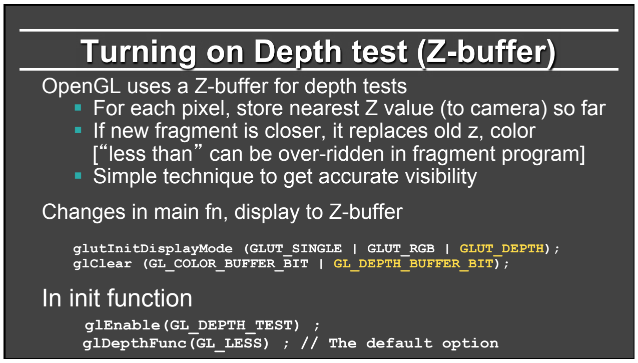


Double Buffering

- 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

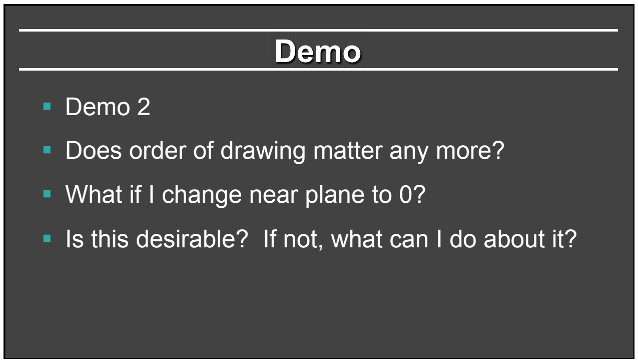
- For each pixel, store nearest Z value (to camera) so far
- If new fragment is closer, it replaces old z, color [“less than” can be over-ridden in fragment program]
- Simple technique to get accurate visibility

Changes in main fn, display to Z-buffer

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

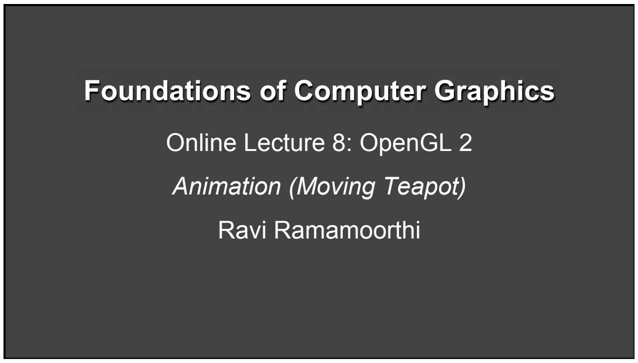
In init function

```
 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?

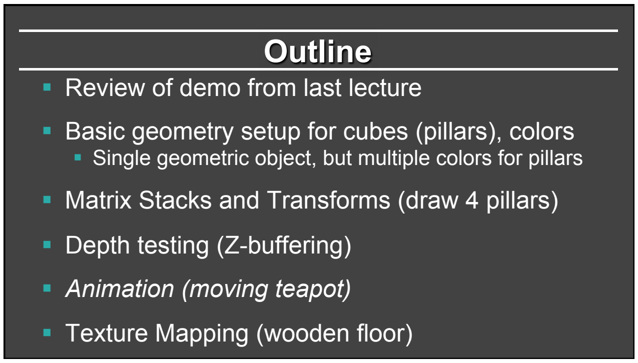


Foundations of Computer Graphics

Online Lecture 8: OpenGL 2

Animation (Moving Teapot)

Ravi Ramamoorthi



Outline

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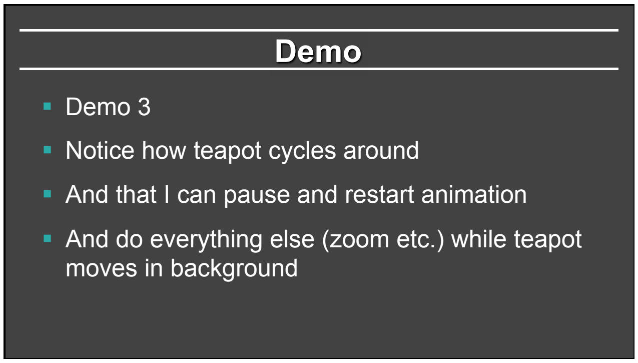
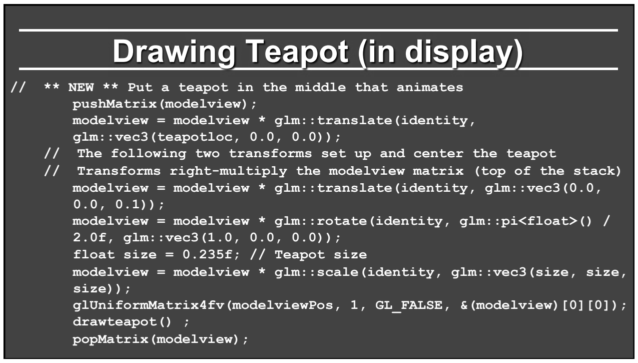


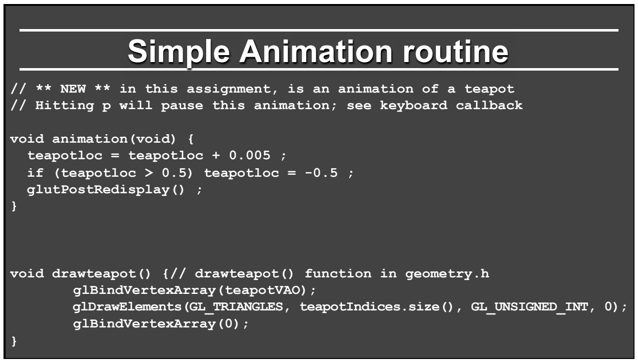
Demo

- 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



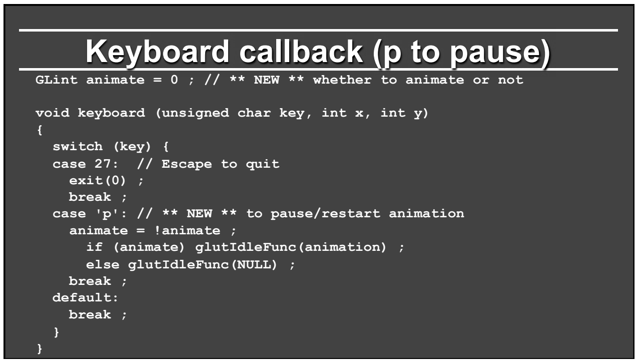
Drawing Teapot (in display)

```
//  ** NEW ** Put a teapot in the middle that animates
      pushMatrix(modelview);
      modelview = modelview * glm::translate(identity,
      glm::vec3(teapotloc, 0.0, 0.0));
   //  The following two transforms set up and center the teapot
   //  Transforms right-multiply the modelview matrix (top of the stack)
      modelview = modelview * glm::translate(identity, glm::vec3(0.0,
      0.0, 0.1));
      modelview = modelview * glm::rotate(identity, glm::pi<float>() /
      2.0f, glm::vec3(1.0, 0.0, 0.0));
      float size = 0.235f; // Teapot size
      modelview = modelview * glm::scale(identity, glm::vec3(size, size,
      size));
      glUniformMatrix4fv(modelviewPos, 1, GL_FALSE, &(modelview)[0][0]);
      drawteapot() ;
      popMatrix(modelview);
```



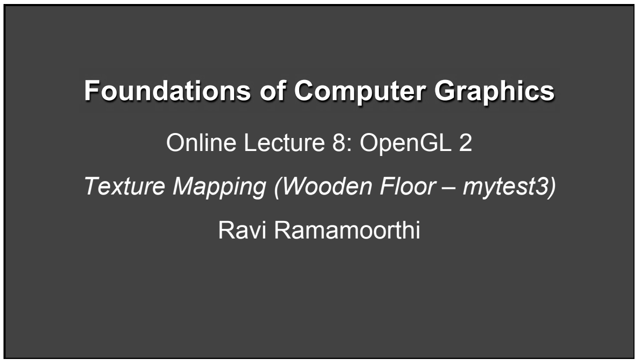
Simple Animation routine

```
// ** 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() ;
}



void drawteapot() {// drawteapot() function in geometry.h
        glBindVertexArray(teapotVAO);
        glDrawElements(GL_TRIANGLES, teapotIndices.size(), GL_UNSIGNED_INT, 0);
        glBindVertexArray(0);
}
```



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 ;
  }
}
```

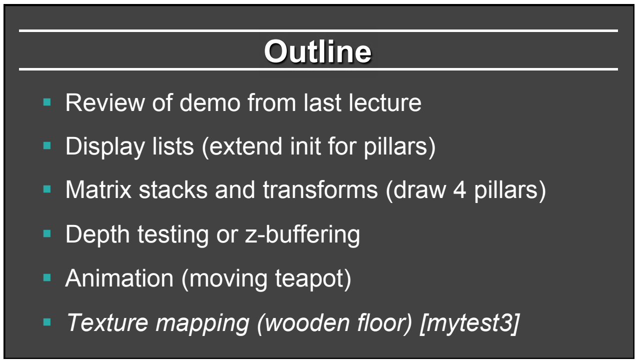


Foundations of Computer Graphics

Online Lecture 8: OpenGL 2

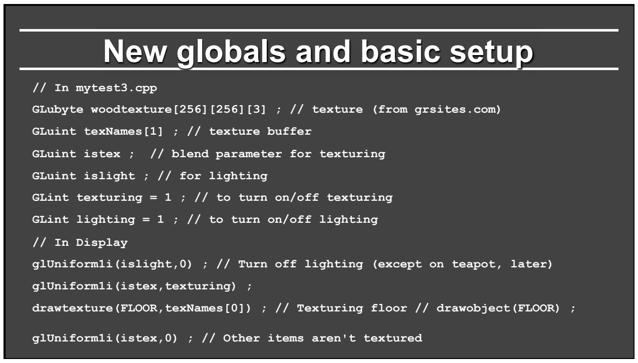
Texture Mapping (Wooden Floor – mytest3)

Ravi Ramamoorthi



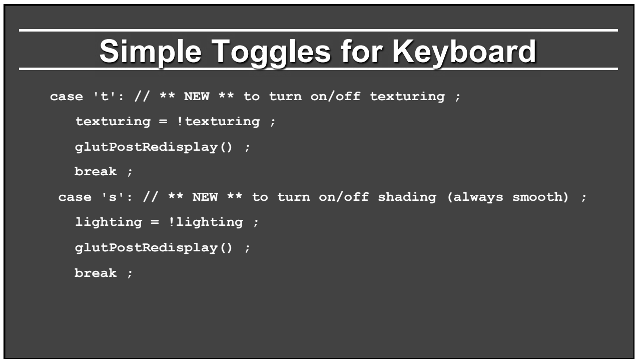
Outline

- 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]*



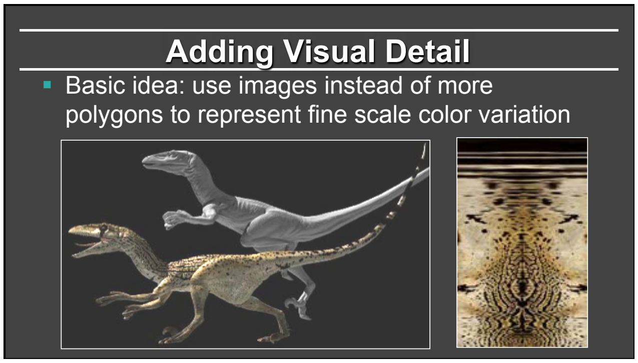
New globals and basic setup

```
// In mytest3.cpp
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
```



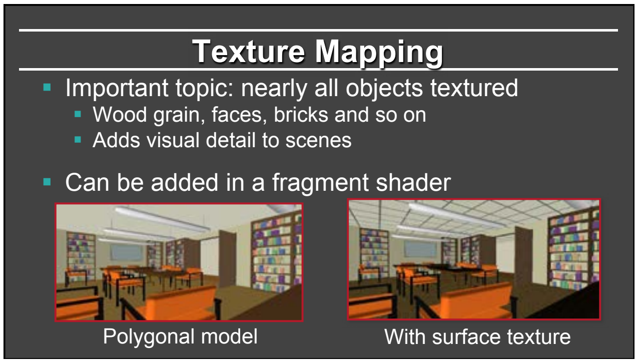
Simple Toggles for Keyboard

```
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

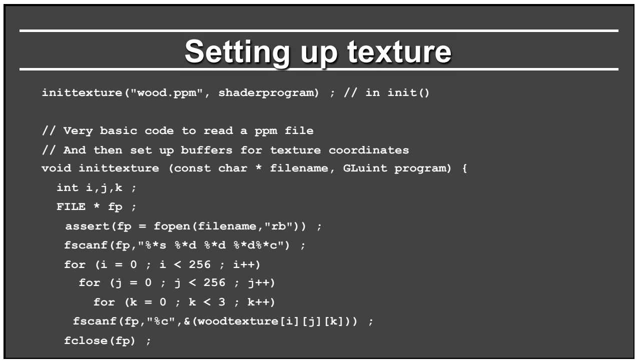


Texture Mapping

- 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

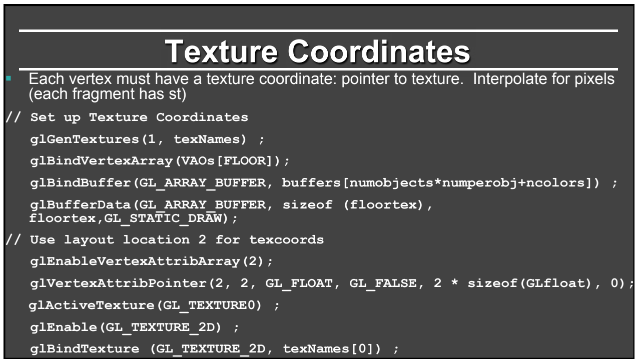
Polygonal model

With surface texture



Setting up texture

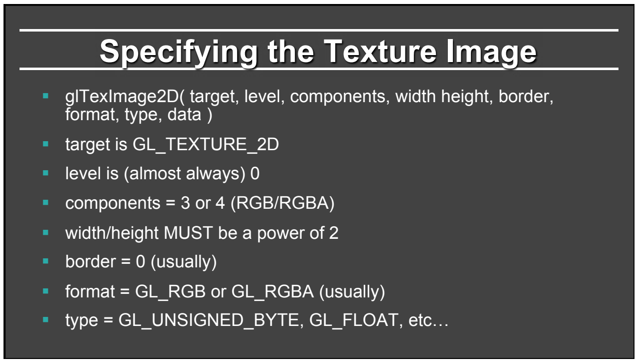
```
inittexture("wood.ppm", shaderprogram) ; // in init()

// 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 ;
   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

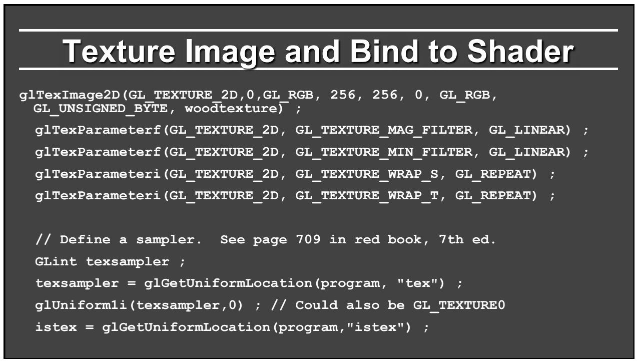
- Each vertex must have a texture coordinate: pointer to texture. Interpolate for pixels (each fragment has st)

```
// Set up Texture Coordinates
   glGenTextures(1, texNames) ;
   glBindVertexArray(VAOs[FLOOR]);
   glBindBuffer(GL_ARRAY_BUFFER, buffers[numobjects*numperobj+ncolors]) ;
   glBufferData(GL_ARRAY_BUFFER, sizeof (floortex),
   floortex,GL_STATIC_DRAW);
// Use layout location 2 for texcoords
   glEnableVertexAttribArray(2);
   glVertexAttribPointer(2, 2, GL_FLOAT, GL_FALSE, 2 * sizeof(GLfloat), 0);
   glActiveTexture(GL_TEXTURE0) ;
   glEnable(GL_TEXTURE_2D) ;
   glBindTexture (GL_TEXTURE_2D, texNames[0]) ;
```



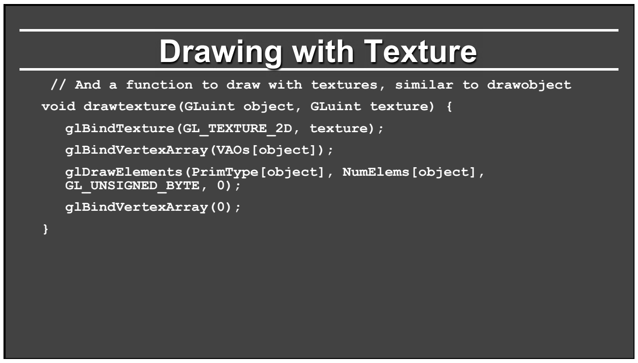
Specifying the Texture Image

- 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…



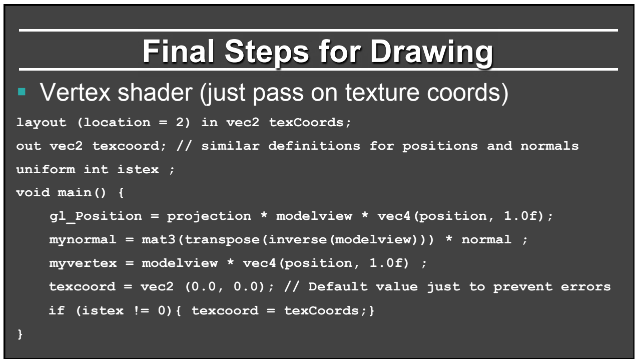
Texture Image and Bind to Shader

```
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") ;
  glUniform1i(texsampler,0) ; // Could also be GL_TEXTURE0
  istex = glGetUniformLocation(program,"istex") ;
```



Drawing with Texture

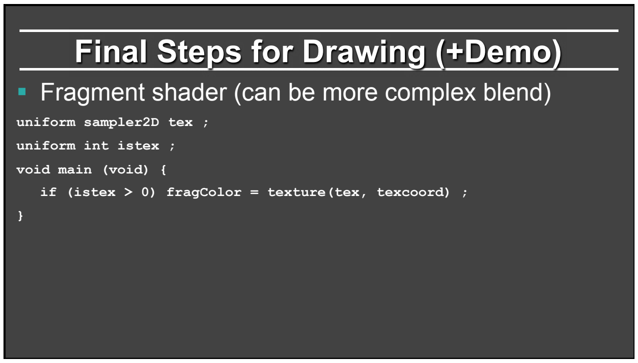
```
  // And a function to draw with textures, similar to drawobject
 void drawtexture(GLuint object, GLuint texture) {
    glBindTexture(GL_TEXTURE_2D, texture);
    glBindVertexArray(VAOs[object]);
    glDrawElements(PrimType[object], NumElems[object],
    GL_UNSIGNED_BYTE, 0);
    glBindVertexArray(0);
 }
```



Final Steps for Drawing

- Vertex shader (just pass on texture coords)

```
layout (location = 2) in vec2 texCoords;
out vec2 texcoord; // similar definitions for positions and normals
uniform int istex ;
void main() {
    gl_Position = projection * modelview * vec4(position, 1.0f);
    mynormal = mat3(transpose(inverse(modelview))) * normal ;
    myvertex = modelview * vec4(position, 1.0f) ;
    texcoord = vec2 (0.0, 0.0); // Default value just to prevent errors
    if (istex != 0){ texcoord = texCoords;}
}
```



Final Steps for Drawing (+Demo)

- Fragment shader (can be more complex blend)

```
uniform sampler2D tex ;
uniform int istex ;
void main (void) {
   if (istex > 0) fragColor = texture(tex, texcoord) ;
}
```