CS 248
OpenGL Help Session

CS248
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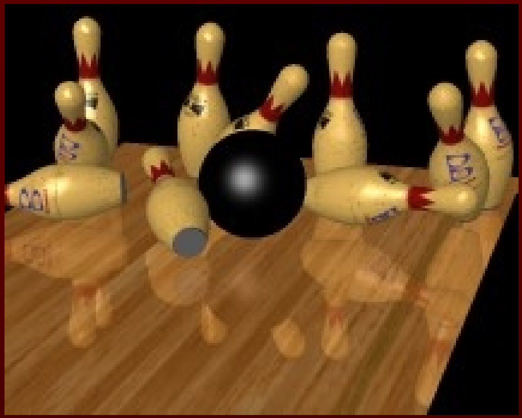
Overview

- **Basic primitives and rendering in OpenGL**
- **Transformations and viewing**
- **GLUT and the interaction / display loop**
- **More primitives and rendering**
- **Development tips**

Note: all page references refer to the *OpenGL Programming Guide, 3rd Edition ver. 1.2* (aka “The Red Book”) unless noted otherwise.

Getting Started…

- **OpenGL is a cross platform 3D graphics library that takes advantage of specialized graphics hardware.**



Two scenes rendered with a shading language developed at Stanford.

• Read the Red Book! It's a great resource and is very readable.

• OpenGL is a *state* machine: polygons are affected by the current color, transformation, drawing mode, etc.

Specifying Object Vertices (Ch.2 p.42)

- **Every object is specified by vertices**

  `glVertex3f (2.0, 4.1, 6.0);` // specifies a vertex at the x, y, z coordinate (2.0, 4.1, 6.0).
  // The “3f” means 3 floating point coordinates.

  - **Other examples:**

    ```
    glVertex2i (4, 5);           // 2 integers for x and y.  z = 0.
    glVertex3fv (vector);        // float vector[3] = {5.0, 3.2, 5.0};
    ```

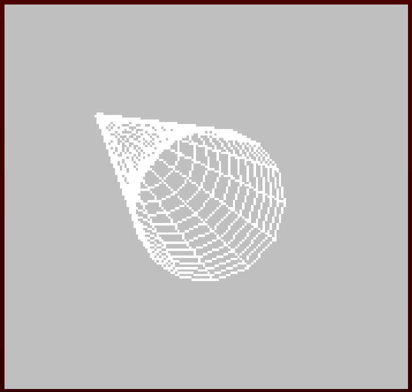
- **Current color affects any vertices**
  - `glColor3f (0.0, 0.5, 1.0);` // no Red, half-intensity Green, full-intensity Blue

- **Vertices are specified only between `glBegin(`*`mode`*`)` and `glEnd()`, usually in a counter-clockwise order for polygons.**
  - ```
    glBegin (GL_TRIANGLES);
      glVertex2i (0, 0);
      glVertex2i (2, 0);
      glVertex2i (1, 1);
    glEnd();
    ```
    ```

Primitive Types in glBegin (Ch.2, p.44)

- Points GL_POINTS
- Lines GL_LINES, GL_LINE_STRIP, GL_LINE_LOOP
- Triangles GL_TRIANGLES, GL_TRIANGLE_STRIP, GL_TRIANGLE_FAN
- Quads GL_QUADS, GL_QUAD_STRIP
- Polygons GL_POLYGON

```
glBegin(GL_LINES);
  [lots of glVertex calls];
glEnd();
```



```
glBegin(GL_QUADS);
  [lots of glVertex calls];
glEnd();
```

(show page 45)

Transformations and Viewing (Ch.3)

OpenGL has 3 different matrix modes:

- GL_MODELVIEW
- GL_PROJECTION
- GL_TEXTURE
- For example, choose to act on the projection matrix with:

```
glMatrixMode(GL_PROJECTION);
```

- **The *Modelview* matrix is used for your object transformations.**
- **The *Projection* matrix sets up the perspective transformation. It is usually set once at the beginning of your program.**
- **The *Texture* matrix can be used to warp textures (not commonly used).**

OpenGL: Modelview matrix

- **Transforms the viewpoint and objects within the scene.**
- **Example:**

```
glMatrixMode(GL_MODELVIEW);// set the current matrix
glLoadIdentity();          // load the identity matrix
glTranslatef(10.5, 0, 0);  // translate 10.5 units along x-axis
glRotatef(45, 0, 0, 1);    // rotate 45 degrees CCW around z-axis
DrawCube();                // cube is defined centered around origin
```

- **Where will this end up?**
- **Answer: on the x-axis, rotated 45 degrees CCW. First image on page 107, fig 3-4.**

  Remember that the operations are right multiplied, so the transformation just before `DrawCube()` takes effect first.

- **You can use `gluLookAt(…)` (page 119) in addition to rotations and translations to affect the viewpoint.**

OpenGL: Projection Matrix

- **Sets up a perspective projection. (page 123)**
- **A few available options:**
  - **`glFrustrum (...);`** // sets up a user defined viewing frustrum
  - **`gluPerspective (fovy, aspect, near, far);`**
    // calculates viewing frustrum for you, given field-of-view in degrees, aspect ratio, and near and far clipping planes.
  - **`glOrtho (...);`** // creates orthographic (parallel) projection. Useful for 2D rendering.
- **Example:**

```
glMatrixMode(GL_PROJECTION);
glLoadIdentity();
gluPerspective(64, (float)windowWidth / (float)windowHeight, 4, 4096);
```

GLUT – OpenGL Utility Toolkit (Appendix D)

- **GLUT is a library that handles system events and windowing across multiple platforms, and also provides some nice utilities. We *strongly* suggest you use it. Find it from the proj3 web page.**

Starting up:

```
int main (int argc, char *argv[])
{
   glutInit(&argc, argv);
   glutInitDisplayMode (GLUT_DEPTH | GLUT_DOUBLE | GLUT_RGBA);
   glutInitWindowSize (windowWidth, windowHeight);
   glutInitWindowPosition (0, 0);
   glutCreateWindow (“248 Video Game!");

   SetStates();            // Initialize any rendering states (your code).
   RegisterCallbacks();    // Set up event callbacks (your code, coming up).

   glutMainLoop();         // Transfer control to GLUT. Doesn’t return.
   return 0;
}
```

Setting Up Rendering States

- **OpenGL is a *state* machine: polygons are affected by the current color, transformation, drawing mode, etc.**
- **Enable and disable features such as lighting, texturing, and alpha blending.**
  - `glEnable (GL_LIGHTING);  // enable lighting (disabled by default)`
- **Forgetting to enable something is a common source of bugs! Make sure you enable any features that you need (list of defaults is in Appendix B).**

GLUT Event Callbacks

- Register functions that are called when certain events occur.

Examples:

```
glutDisplayFunc( Display );                // called when its time to draw
glutKeyboardFunc( Keyboard );              // receives key input
glutReshapeFunc( Reshape );                // called when window reshapes
glutMouseFunc( Mouse );                    // called when button changes
glutPassiveMotionFunc( PassiveFunc );      // mouse moves, no buttons
glutMotionFunc( MouseDraggedFunc );        // mouse moves, some buttons
glutIdleFunc( Idle );                      // called whenever idle
```

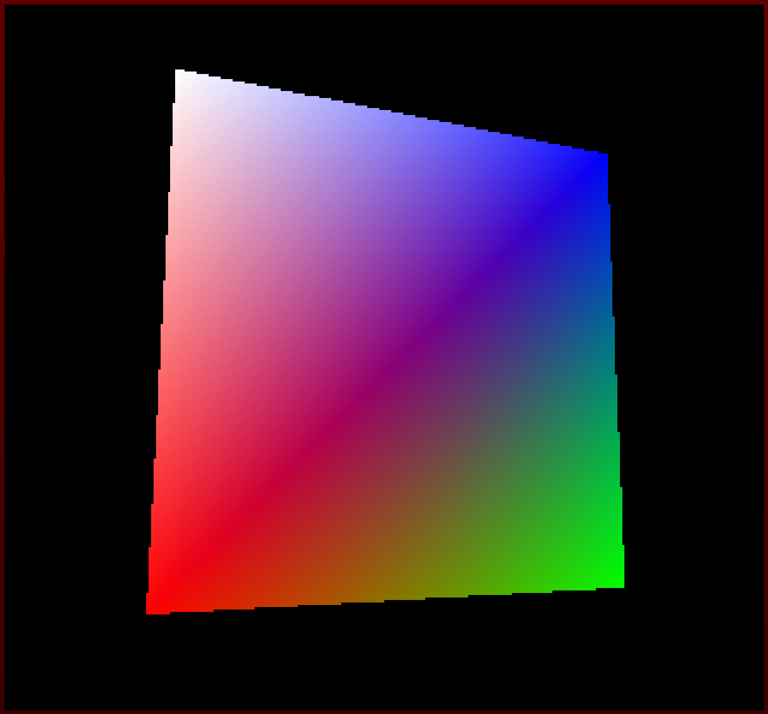
OpenGL – Depth Buffer, Double Buffer

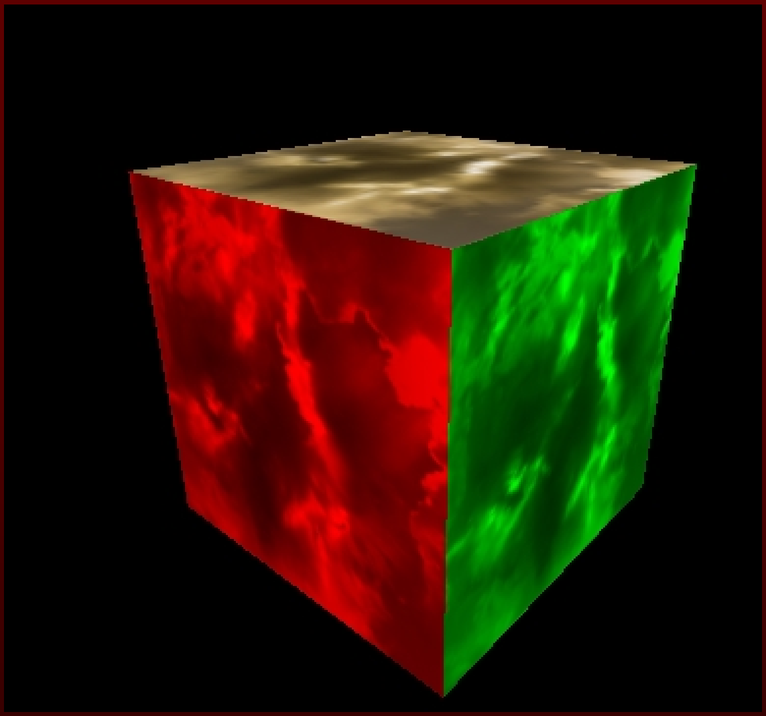
- **Buffers store color and depth**
  - Allows Hidden Surface Removal, so there is proper ordering of objects in 3D space. This will be discussed later in the course.
- **Double buffering:**
  - Draw on *back* buffer while *front* buffer is being displayed.
  - When finished drawing, swap the two, and begin work on the new back buffer.
  - `glutSwapBuffers();  // called at the end of rendering`
- **Clearing the buffers:**

```
// Clear to this color when screen is cleared.
glClearColor (0.0, 0.0, 0.0, 0.0);

// Clear color and depth buffers.
glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
```

GLUT – Code Demo





OpenGL: Normals and Lighting

- **OpenGL can simulate lighting for you, given some information on the geometry. Specify vertex normals as you specify geometry.**
- **Normal vectors should be of unit length (normalized) in most cases.**

```
// each vertex has a different normal here
glColor3f (0.8, 1.0, 0.5);
glBegin(GL_TRIANGLES);
     glNormal3fv (n0);
     glVertex3fv (v0);
     glNormal3fv (n1);
     glVertex3fv (v1);
     glNormal3fv (n2);
     glVertex3fv (v2);
glEnd();

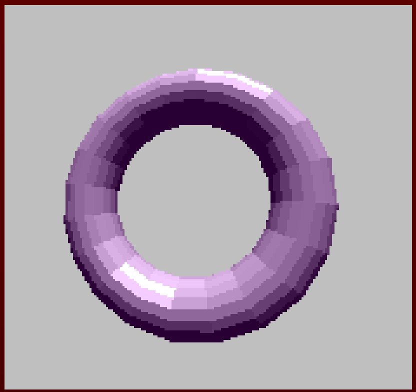
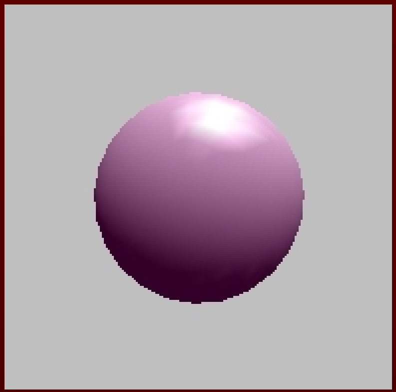
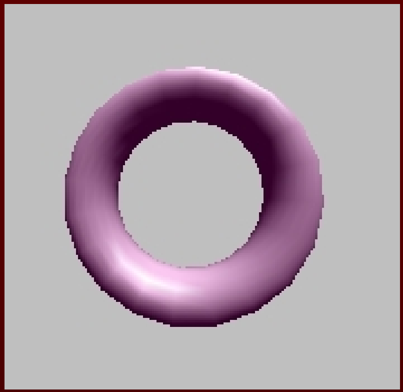
// all vertices have the same normal here
glBegin(GL_TRIANGLES);
     glNormal3fv (n0);
     glVertex3fv (v0);
     glVertex3fv (v1);
     glVertex3fv (v2);
glEnd();
```

OpenGL: Lighting (Ch.5 p.173)

- **`glEnable (GL_LIGHTING);`**
- **OpenGL supports a minimum of 8 lights.**
  - ```
    glEnable (GL_LIGHT0);
    ...
    glEnable (GL_LIGHT7);
    ```
- Lights have a position, type, and color, among other things.
- Position:
  - ```
    float light0Position[4] = {1.0, 0.0, 4.0, 1.0};
    glLightfv (GL_LIGHT0, GL_POSITION, light0Position);
    ```
- Types of lights are point light, directional light, and spotlight. The fourth component of position (1.0 above) determines the type. 0 is for directional lights, 1 is for point/spot lights. (page 187)
- Color has a few components: Ambient, Diffuse, Specular. Read about them in the text.

OpenGL: Lighting (cont.)

- **OpenGL supports 2 basic shading models: flat and smooth.**
  - `glShadeModel(GL_FLAT);` `glShadeModel(GL_SMOOTH);`

- Lighting calculations can be expensive, so investigate other options (ie lightmaps) if needed.

OpenGL: Material Properties (Ch.5)

- **You can specify different material properties for different polygons, changing the effect of lights.**
  - Use `glMaterial*(GLenum face, GLenum pname, TYPE param);`
- **Some properties (`pname`), page 202:**
  - GL_AMBIENT: Ambient color of material
  - GL_DIFFUSE: Diffuse color of material
  - GL_SPECULAR: Specular component (for highlights)
  - GL_SHININESS: Specular exponent (intensity of highlight)
- **Color plate 17 in the book shows a few examples.**

OpenGL: Texturing

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- **Loading your data**
  - this can come from an image: ppm, tiff
  - create at run time
  - final result is always an array
- **Setting texture state**
  - creating texture names, scaling the image/data, building Mipmaps, setting filters, etc.
- **Mapping the texture to the polygon**
  - specify s,t coordinates for polygon vertices

OpenGL: Texturing

- **Loading your data**
  - this can come from an image: ppm, tiff
    - libtiff, libppm, etc.
    - remember the ordering of color channels and bits per channel! ie: RGBA, or AGBR, 32 bits or 8 bits?
    - You can tell OpenGL how to read your data by setting certain texture state (see next slide)
  - create at run time
    - procedural textures, 3D textures, adding specular highlights
  - final result is always an array

OpenGL: Texturing

- **Setting texture state**
  - create texture names
    - `glGenTextures(int num, int* texNames)`
    - `glBindTexture(GL_TEXTURE_2D, texName);`
  - Tell OpenGL how to read your array
    - `glPixelStorei(GL_UNPACK_SWAP_BYTES, int num);`
    - `glPixelStorei(GL_UNPACK_ALIGNMENT, int num);`
  - Scale your array to be $2^n+2(b)$, b = {0,1} if you have a border or not
    - `gluScaleImage(GL_RGBA, w0, h0, GL_UNSIGNED_BYTE, img, w1, h1, GL_UNSIGNED_BYTE, imgScaled)`
    - `gluBuild2DMipmaps(GL_TEXTURE_2D, GL_RGBA, w0, h0, GL_RGBA, GL_UNSIGNED_BYTE, img);`

OpenGL: Texturing

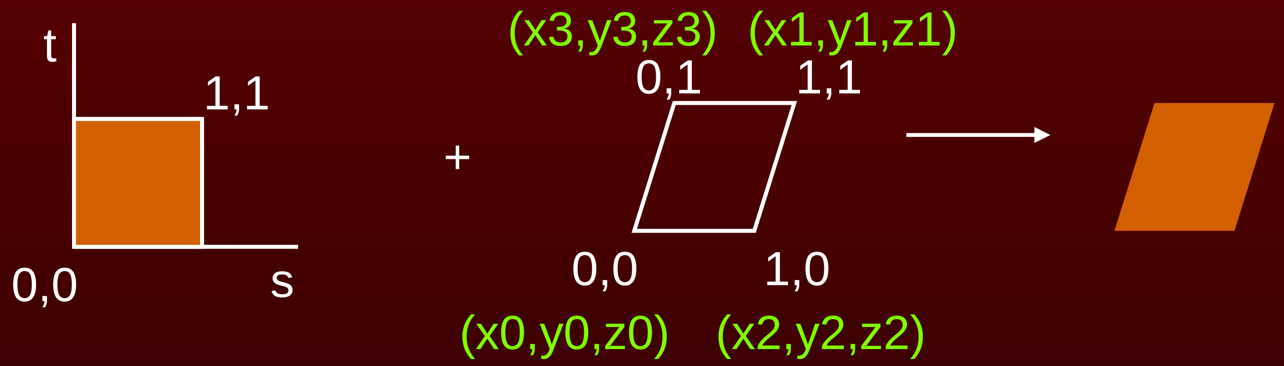
- **Setting texture state (cont)**
  - Tell OpenGL what to do when the s,t values are not within [0,1]x[0,1] range.
    - `glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP);`
    - `glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_CLAMP);`
    - GL_CLAMP: any values larger than 1.0 are clamped to 1.0
    - GL_REPEAT: wrap larger values to the beginning of the texture (see OpenGL book, pg 411)
  - Set the filters for minification/magnification
    - `glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_NEAREST);`
    - other parameters: GL_LINEAR, other mipmap options

OpenGL: Texturing

- **Setting texture state (cont)**
  - Tell OpenGL about your data array (image, etc.)
    - **`glTexImage2D(GL_TEXTURE_2D, int lod, int num_components, width, height, border, format_of_data_pixel, size_of_each_channel, img_array)`**
    - If you used to **`gluBuild2DMipmaps`** scale your image and create a multi-resolution pyramid of textures, then you do NOT need to use **`glTexImage2D`**. The **`gluBuild2DMipmaps`** command will already tell OpenGL about your array.

OpenGL: Texturing

- **Mapping the texture to the polygon**
  - specify (s,t) texture coordinates for (x,y,z) polygon vertices
  - texture coordinates (s,t) are from 0,1:



- `glTexCoord2f(s,t);`

OpenGL: Texturing

- Let’s look at code!

OpenGL: Texturing

- Advanced Texture techniques
  - Multitextures
  - automatic texture generation
    - Let OpenGL determine texture coordinates for you
  - Environment Mapping
  - Texture matrix stack

OpenGL: Alpha Blending

- When enabled, OpenGL uses the alpha channel to blend a new fragment's color value with a color in the framebuffer

+ =

?

New color (r1,g1,b1,a1) "source"

Color in framebuffer (r0,g0,b0,a0) "destination"

(r',g',b',a')

r' = a1*r1 + (1-a1)*r0

```
glEnable(GL_BLEND);
glBlendFunc(GL_ONE, GL_ZERO);
…draw green square …
glBlendFunc(GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA);
…draw brown square with alpha = 0.5…
```

OpenGL: Alpha Blending AND Textures

- Alpha blending with multiple textures
  - one way to do multi-pass rendering
  - number of “texture passes” over a polygon is independent of the maximum number of multi-texture units on the graphics card
    - GeForce 2 has only 2 texture units!
  - slower because geometry is sent n times to the card for n texture passes
  - demo and code if you want to see it

Development

- **On Windows:**
  - Download the GLUT libraries (linked off the proj3 webpage).
  - You want to link your project with: opengl32.lib, glut32.lib, and glu32.lib. This is under Project->Settings->Link in MS Visual Studio.
- **On Linux:**
  - GLUT is already installed on the graphics lab PCs.
  - In your Makefile, compile with flags: -L/usr/lib -lGL -lGLU –lglut

- Call glutReportErrors() once each display loop for debugging.
  - This will report any errors that may have occurred during rendering, such as an illegal operation in a glBegin/glEnd pair.

Questions?