Programming with OpenGL
Part 5: More GLSL

CS 432 Interactive Computer Graphics
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Objectives

- Coupling shaders to applications
  - Reading
  - Compiling
  - Linking
- Vertex Attributes
- Setting up uniform variables
- Example applications

Linking Shaders with Application

- Read shaders
- Compile shaders
- Create a program object
- Link everything together
- Link variables in application with variables in shaders
  - Vertex attributes
  - Uniform variables

Program Object

- Container for shaders
  - Can contain multiple shaders
  - Other GLSL functions

```
GLuint myProgObj;
myProgObj = glCreateProgram();
 /* define shader objects here */
glUseProgram(myProgObj);
glLinkProgram(myProgObj);
```

Reading a Shader

- Shaders are added to the program object and compiled
- Usual method of passing a shader is as a null-terminated string using the function **`glShaderSource`**
- If the shader is in a file, we can write a reader to convert the file to a string

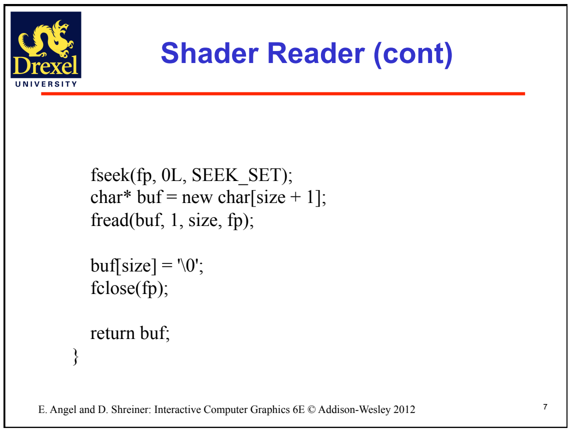
Shader Reader

```
#include <stdio.h>

static char*
readShaderSource(const char* shaderFile)
{
    FILE* fp = fopen(shaderFile, "r");

    if ( fp == NULL ) { return NULL; }

    fseek(fp, 0L, SEEK_END);
    long size = ftell(fp);
```



Shader Reader (cont)

```
      fseek(fp, 0L, SEEK_SET);
      char* buf = new char[size + 1];
      fread(buf, 1, size, fp);

      buf[size] = '\0';
      fclose(fp);

      return buf;
   }
```

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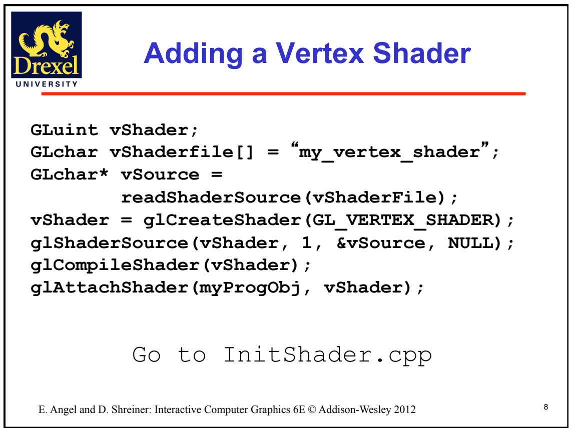

Adding a Vertex Shader

```
GLuint vShader;
GLchar vShaderfile[] = “my_vertex_shader”;
GLchar* vSource =
        readShaderSource(vShaderFile);
vShader = glCreateShader(GL_VERTEX_SHADER);
glShaderSource(vShader, 1, &vSource, NULL);
glCompileShader(vShader);
glAttachShader(myProgObj, vShader);
```

Go to InitShader.cpp

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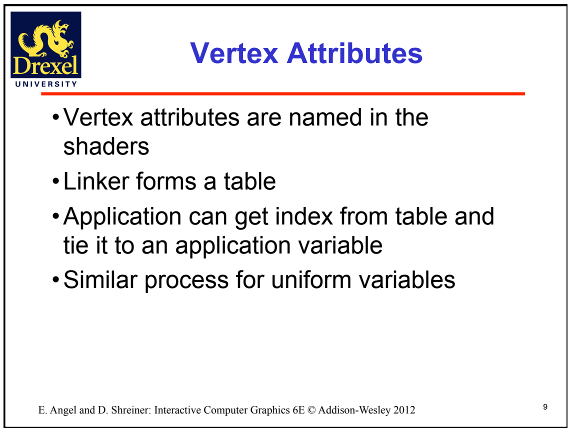

Vertex Attributes

- Vertex attributes are named in the shaders
- Linker forms a table
- Application can get index from table and tie it to an application variable
- Similar process for uniform variables

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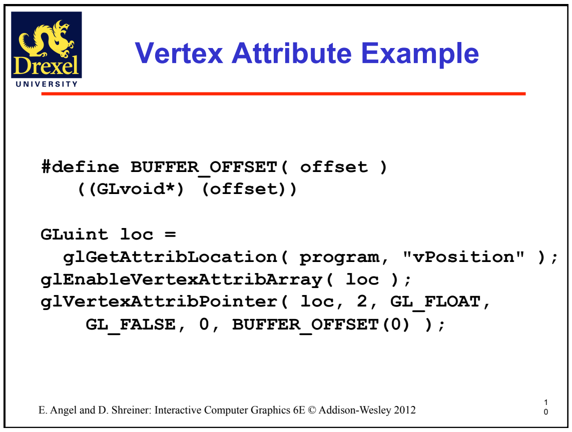

Vertex Attribute Example

```
#define BUFFER_OFFSET( offset )
   ((GLvoid*) (offset))

GLuint loc =
  glGetAttribLocation( program, "vPosition" );
glEnableVertexAttribArray( loc );
glVertexAttribPointer( loc, 2, GL_FLOAT,
    GL_FALSE, 0, BUFFER_OFFSET(0) );
```

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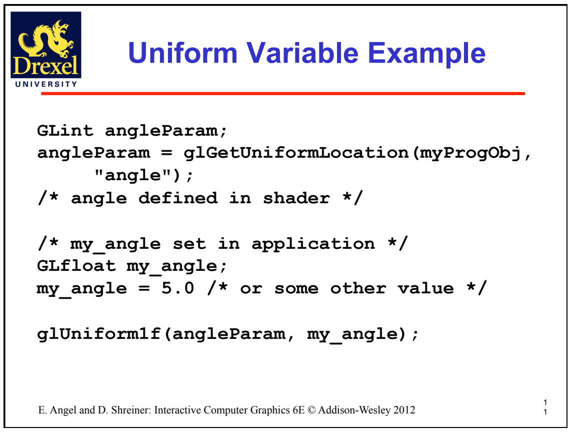

Uniform Variable Example

```
GLint angleParam;
angleParam = glGetUniformLocation(myProgObj,
     "angle");
/* angle defined in shader */

/* my_angle set in application */
GLfloat my_angle;
my_angle = 5.0 /* or some other value */

glUniform1f(angleParam, my_angle);
```

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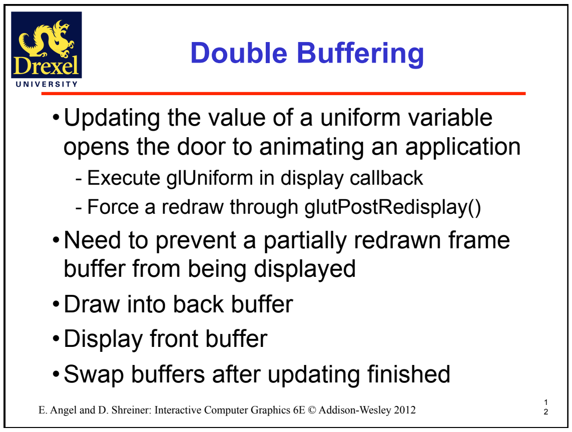

Double Buffering

- Updating the value of a uniform variable opens the door to animating an application
  - Execute glUniform in display callback
  - Force a redraw through glutPostRedisplay()
- Need to prevent a partially redrawn frame buffer from being displayed
- Draw into back buffer
- Display front buffer
- Swap buffers after updating finished

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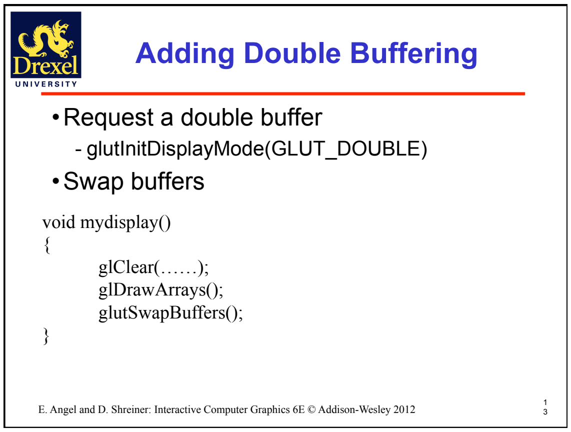
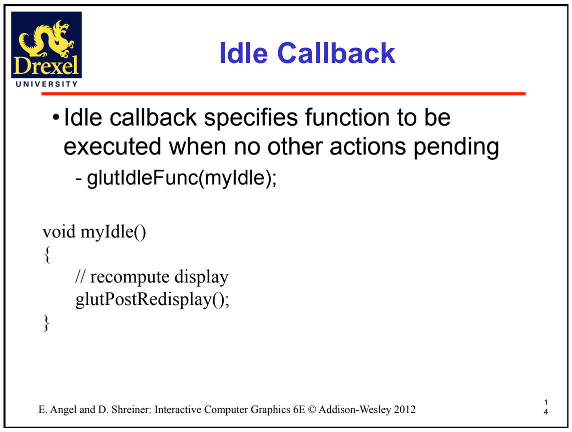


Adding Double Buffering

- Request a double buffer
  - glutInitDisplayMode(GLUT_DOUBLE)
- Swap buffers

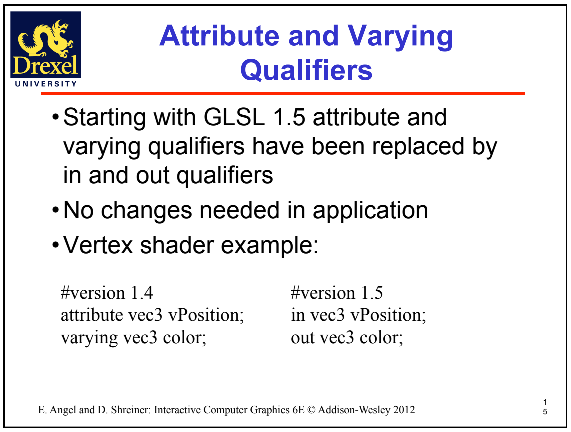
```
void mydisplay()
{
        glClear(……);
        glDrawArrays();
        glutSwapBuffers();
}
```



Idle Callback

- Idle callback specifies function to be executed when no other actions pending
  - glutIdleFunc(myIdle);

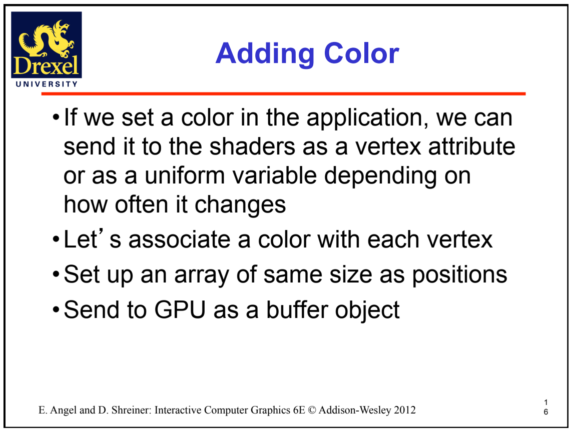
```
void myIdle()
{
    // recompute display
    glutPostRedisplay();
}
```



Attribute and Varying Qualifiers

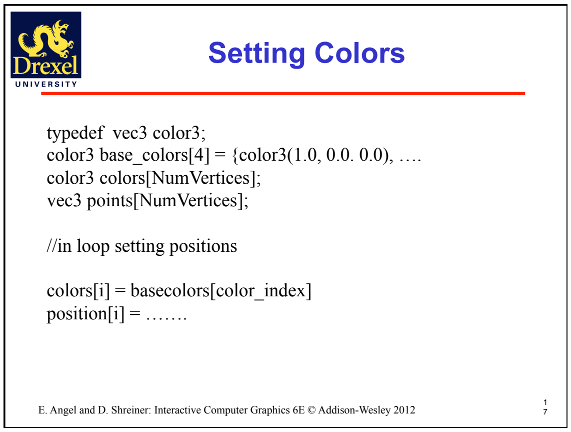
- Starting with GLSL 1.5 attribute and varying qualifiers have been replaced by in and out qualifiers
- No changes needed in application
- Vertex shader example:

```
#version 1.4                    #version 1.5
attribute vec3 vPosition;       in vec3 vPosition;
varying vec3 color;             out vec3 color;
```



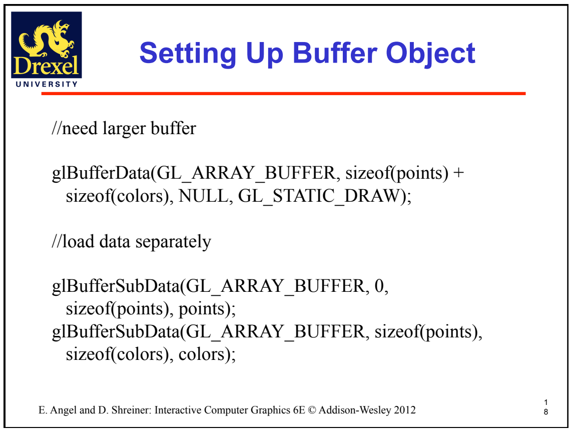
Adding Color

- If we set a color in the application, we can send it to the shaders as a vertex attribute or as a uniform variable depending on how often it changes
- Let' s associate a color with each vertex
- Set up an array of same size as positions
- Send to GPU as a buffer object



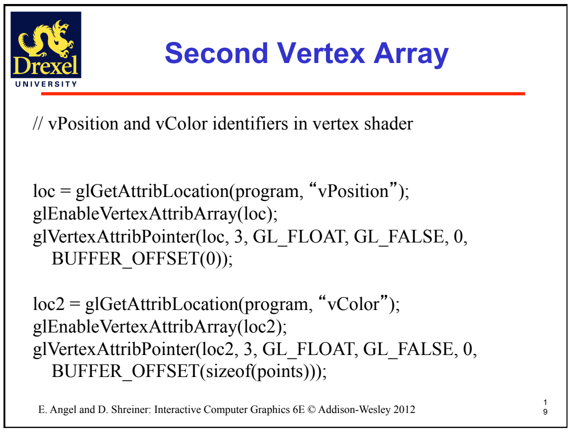
Setting Colors

```
typedef  vec3 color3;
color3 base_colors[4] = {color3(1.0, 0.0. 0.0), ….
color3 colors[NumVertices];
vec3 points[NumVertices];

//in loop setting positions

colors[i] = basecolors[color_index]
position[i] = …….
```



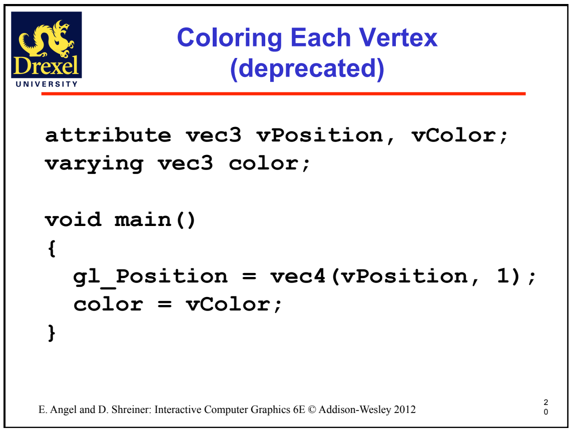
Setting Up Buffer Object

```
//need larger buffer

glBufferData(GL_ARRAY_BUFFER, sizeof(points) +
  sizeof(colors), NULL, GL_STATIC_DRAW);

//load data separately

glBufferSubData(GL_ARRAY_BUFFER, 0,
  sizeof(points), points);
glBufferSubData(GL_ARRAY_BUFFER, sizeof(points),
  sizeof(colors), colors);
```



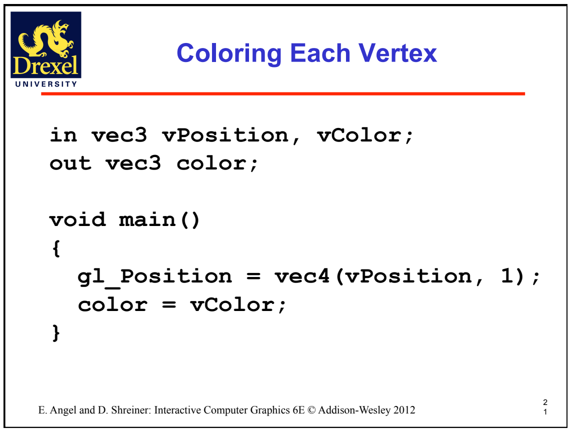
Second Vertex Array

```
// vPosition and vColor identifiers in vertex shader


loc = glGetAttribLocation(program, “vPosition”);
glEnableVertexAttribArray(loc);
glVertexAttribPointer(loc, 3, GL_FLOAT, GL_FALSE, 0,
   BUFFER_OFFSET(0));

loc2 = glGetAttribLocation(program, “vColor”);
glEnableVertexAttribArray(loc2);
glVertexAttribPointer(loc2, 3, GL_FLOAT, GL_FALSE, 0,
   BUFFER_OFFSET(sizeof(points)));
```



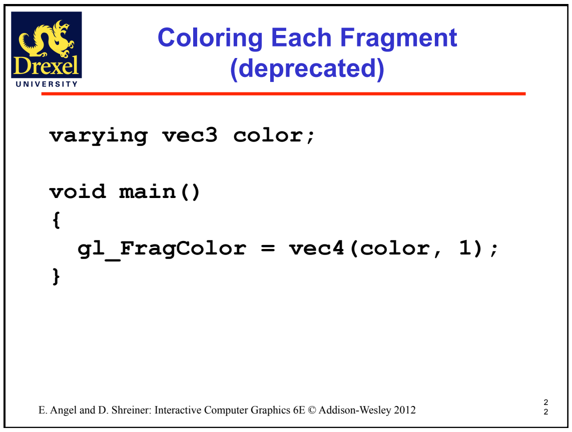
Coloring Each Vertex (deprecated)

```
attribute vec3 vPosition, vColor;
varying vec3 color;

void main()
{
  gl_Position = vec4(vPosition, 1);
  color = vColor;
}
```



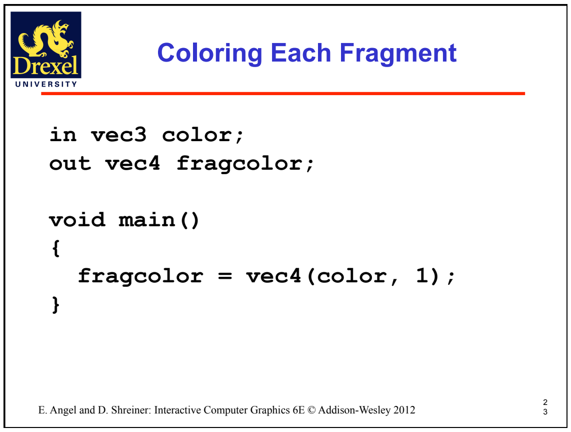
Coloring Each Vertex

```
in vec3 vPosition, vColor;
out vec3 color;

void main()
{
  gl_Position = vec4(vPosition, 1);
  color = vColor;
}
```



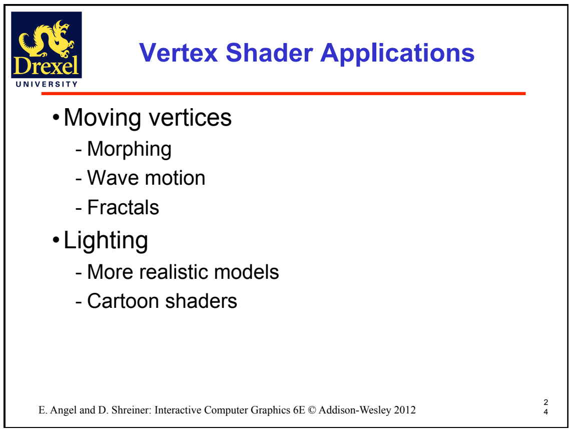
Coloring Each Fragment (deprecated)

```
varying vec3 color;

void main()
{
  gl_FragColor = vec4(color, 1);
}
```



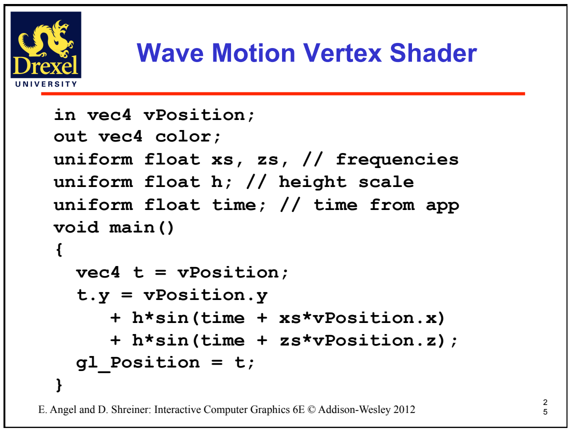
Coloring Each Fragment

```
in vec3 color;
out vec4 fragcolor;

void main()
{
  fragcolor = vec4(color, 1);
}
```



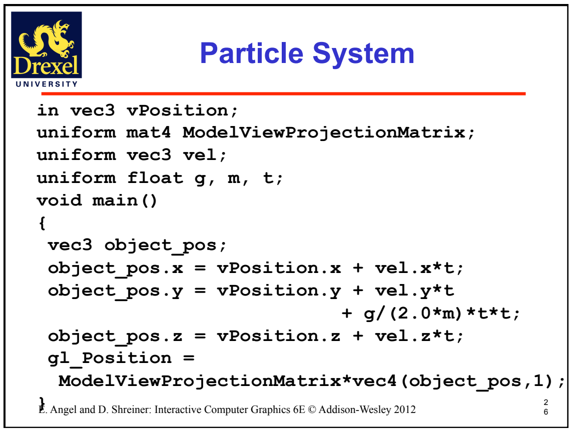
Vertex Shader Applications

- Moving vertices
  - Morphing
  - Wave motion
  - Fractals
- Lighting
  - More realistic models
  - Cartoon shaders



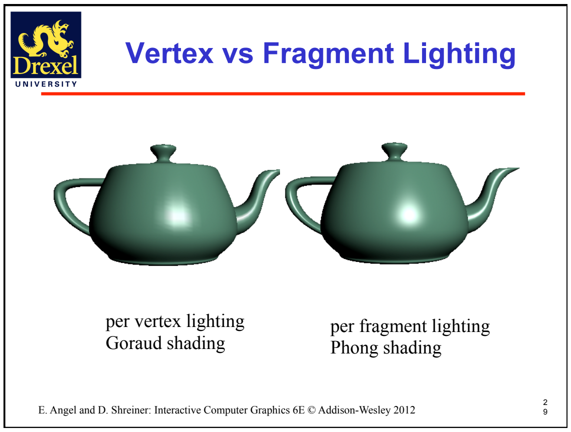
Wave Motion Vertex Shader

```
in vec4 vPosition;
out vec4 color;
uniform float xs, zs, // frequencies
uniform float h; // height scale
uniform float time; // time from app
void main()
{
  vec4 t = vPosition;
  t.y = vPosition.y
     + h*sin(time + xs*vPosition.x)
     + h*sin(time + zs*vPosition.z);
  gl_Position = t;
}
```



Particle System

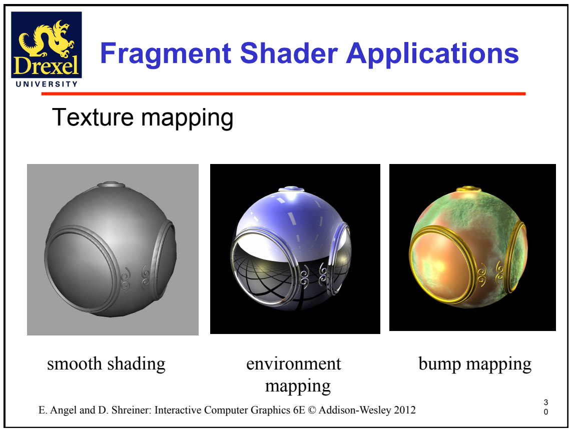
```
in vec3 vPosition;
uniform mat4 ModelViewProjectionMatrix;
uniform vec3 vel;
uniform float g, m, t;
void main()
{
 vec3 object_pos;
 object_pos.x = vPosition.x + vel.x*t;
 object_pos.y = vPosition.y + vel.y*t
                            + g/(2.0*m)*t*t;
 object_pos.z = vPosition.z + vel.z*t;
 gl_Position =
  ModelViewProjectionMatrix*vec4(object_pos,1);
}
```



Vertex vs Fragment Lighting

per vertex lighting
Goraud shading

per fragment lighting
Phong shading



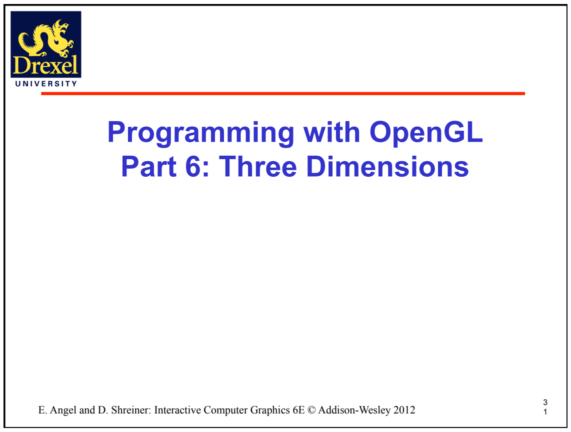
Fragment Shader Applications

Texture mapping

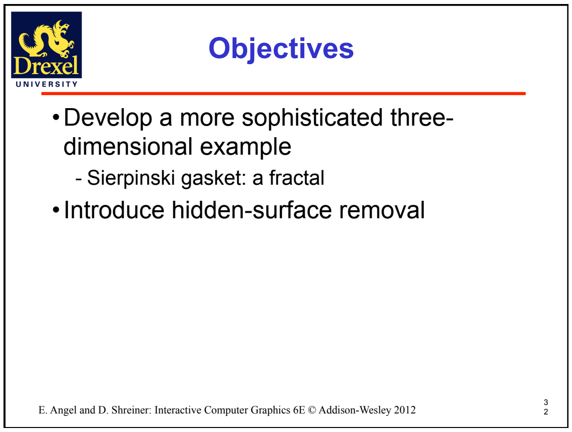
smooth shading

environment mapping

bump mapping



Programming with OpenGL Part 6: Three Dimensions



Objectives

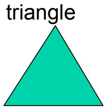
- Develop a more sophisticated three-dimensional example
  - Sierpinski gasket: a fractal
- Introduce hidden-surface removal

Three-dimensional Applications

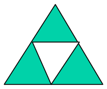
- In OpenGL, two-dimensional applications are a special case of three-dimensional graphics
- Going to 3D
  - Not much changes
  - Use `vec3, glUniform3f`
  - Have to worry about the order in which primitives are rendered or use hidden-surface removal

Sierpinski Gasket (2D)

- Start with a triangle



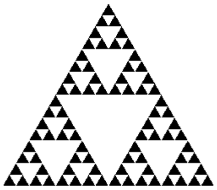
- Connect bisectors of sides and remove central triangle



- Repeat

Example

- Five subdivisions



The gasket as a fractal

- Consider the filled area (black) and the perimeter (the length of all the lines around the filled triangles)
- As we continue subdividing
  - the area goes to zero
  - but the perimeter goes to infinity
- This is not an ordinary geometric object
  - It is neither two- nor three-dimensional
- It is a *fractal* (fractional dimension) object

Gasket Program

```
#include <GL/glut.h>

/* initial triangle */

point2 v[3] ={point2(-1.0, -0.58),
              point2(1.0, -0.58),
              point2 (0.0, 1.15)};

int n; /* number of recursive steps */
```

Draw one triangle

```
void triangle( point2 a, point2 b, point2 c)

/* display one triangle  */
{
    //  static int i =0;  // This doesn't
                          // make sense
      points[i] = a;
      i++;
      points[i] = b;
      i++;
      points[i] = c;
      i++;
}
```

Triangle Subdivision

```
void divide_triangle(point2 a, point2 b, point2 c, int m)
{
/* triangle subdivision using vertex numbers */
    point2 ab, ac, bc;
    if(m>0)
    {
        ab = (a + b )/2;
        ac = (a + c)/2;
        bc = (b + c)/2;
        divide_triangle(a, ab, ac, m-1);
        divide_triangle(c, ac, bc, m-1);
        divide_triangle(b, bc, ac, m-1);
    }
    else(triangle(a,b,c));
 /* draw triangle at end of recursion */
}
```

display and init Functions

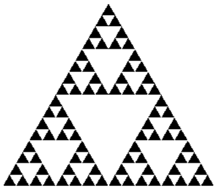
```
void display()
{
    glClear(GL_COLOR_BUFFER_BIT);
    glDrawArrays(GL_TRIANGLES, 0, NumVertices);
    glFlush();
}

void myinit()
{
    vec2 v[3] = {point2(……
    .
    .
    divide_triangles(v[0], v[1], v[2], n);
    .
    .
}
```

main Function

```
int main(int argc, char **argv)
{
    n=4;
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_SINGLE|GLUT_RGB);
    glutInitWindowSize(500, 500);
    glutCreateWindow("2D Gasket");
    glutDisplayFunc(display);
    myinit();
    glutMainLoop();
}
```

Example

- Five subdivisions



Moving to 3D

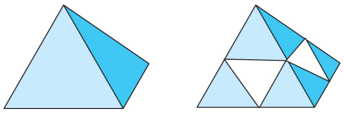
- We can easily make the program three-dimensional by using

```
point3 v[3]
```

and we start with a tetrahedron

3D Gasket

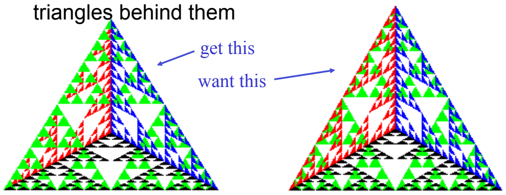
- We can subdivide each of the four faces



- Appears as if we remove a solid tetrahedron from the center leaving four smaller tetrahedra
- Code almost identical to 2D example

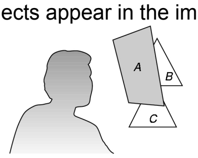
Almost Correct

- Because the triangles are drawn in the order they are specified in the program, the front triangles are not always rendered in front of triangles behind them



Hidden-Surface Removal

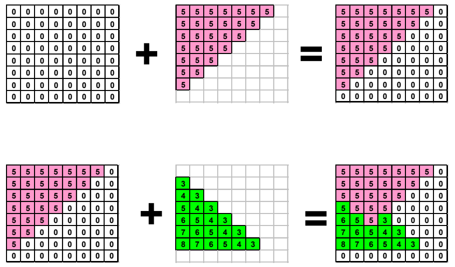
- We want to see only those surfaces in front of other surfaces
- OpenGL uses a *hidden-surface* method called the *z*-buffer algorithm that saves depth information as objects are rendered so that only the front objects appear in the image



Z-buffering

- Z-buffering (depth-buffering) is a visible surface detection algorithm
- Implementable in hardware and software
- Requires data structure (z-buffer) in addition to frame buffer.
- Z-buffer stores values [0 .. ZMAX] corresponding to depth of each point.
- If the point is closer than one in the buffers, it will replace the buffered values

Z-buffering



0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0

+

5	5	5	5	5	5	5	
5	5	5	5	5	5		
5	5	5	5	5			
5	5	5	5				
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5	5						
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5	5	5	5	5	5	5	0
5	5	5	5	5	5	0	0
5	5	5	5	5	0	0	0
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5	5	5	0	0	0	0	0
5	5	0	0	0	0	0	0
5	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

5	5	5	5	5	5	5	0
5	5	5	5	5	5	0	0
5	5	5	5	5	0	0	0
5	5	5	5	0	0	0	0
5	5	5	0	0	0	0	0
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+

3							
4	3						
5	4	3					
6	5	4	3				
7	6	5	4	3			
8	7	6	5	4	3		

=

5	5	5	5	5	5	5	0
5	5	5	5	5	5	0	0
5	5	5	5	5	0	0	0
5	5	5	5	0	0	0	0
6	5	5	3	0	0	0	0
7	6	5	4	3	0	0	0
8	7	6	5	4	3	0	0
0	0	0	0	0	0	0	0

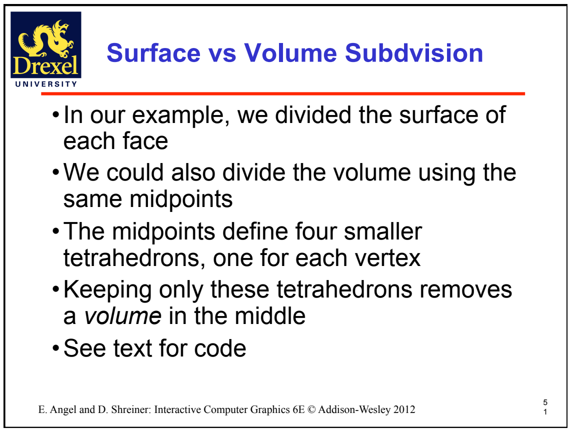
1994 Foley/VanDam/Finer/Huges/Phillips ICG

Z-buffering w/ front/back clipping

```
for (y = 0; y < YMAX; y++)
  for (x = 0; x < XMAX; x++) {
          F[x][y] = BACKGROUND_VALUE;
          Z[x][y] = -1;  /* Back value in NPC */
  }
for (each polygon)
  for (each pixel in polygon's projection) {
          pz = polygon's z-value at pixel coordinates (x,y)
          if (pz < FRONT && pz > Z[x][y]) {  /* New point is behind front
                                  plane & closer than previous point */
                  Z[x][y] = pz;
                  F[x][y] = polygon's color at pixel coordinates (x,y)
          }
  }
```

Using the *z*-buffer algorithm

- It must be
  - Requested in `main.c`
    - `glutInitDisplayMode (GLUT_SINGLE | GLUT_RGB | GLUT_DEPTH)`
  - Enabled in `init.c`
    - `glEnable(GL_DEPTH_TEST)`
  - Cleared in the display callback
    - `glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT)`



Surface vs Volume Subdvision

- In our example, we divided the surface of each face
- We could also divide the volume using the same midpoints
- The midpoints define four smaller tetrahedrons, one for each vertex
- Keeping only these tetrahedrons removes a *volume* in the middle
- See text for code

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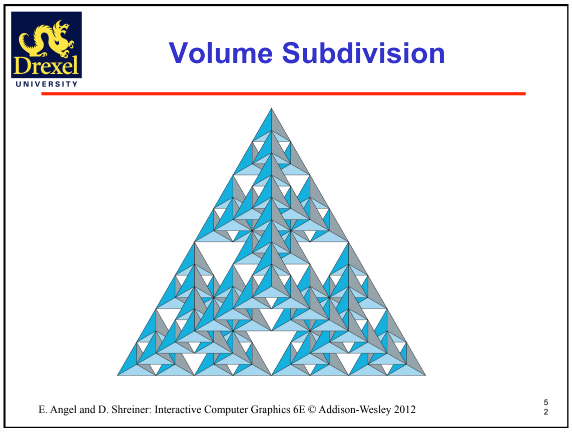

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