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

```cpp
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

```c
#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);
    fp = fopen(shaderFile, "r");
    fseek(fp, size, SEEK_SET);
    char* shader = (char*)malloc((size + 1) * sizeof(char));
    if(shader == NULL) {
        free(shader);
        return NULL;
    }
    size = fread(shader, 1, size, fp);
    shader[size] = 0;
    return shader;
}
```
Shader Reader (cont)

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

Adding a Vertex Shader

```c
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

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

Vertex Attribute Example

```c
#define BUFFER_OFFSET( offset )
((GLvoid*) (offset))
GLuint loc =
glGetAttribLocation( program, "vPosition" );
glEnableVertexAttribArray( loc );
glVertexAttribPointer( loc, 2, GL_FLOAT,
GL_FALSE, 0, BUFFER_OFFSET(0) );
```

Uniform Variable Example

```c
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);
```

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
Adding Double Buffering

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

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

Idle Callback

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

```c
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:

```c
#version 1.4
attribute vec3 vPosition;
varying vec3 color;

#version 1.5
in vec3 vPosition;
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

```c
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] = …….```

```c
// 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);
```

Setting Colors

```c
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

```c
// 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 = glGetUniformLocation(program, "vPosition");
glEnableVertexAttribArray(loc);
gVertexAttribPointer(loc, 3, GL_FLOAT, GL_FALSE, 0, BUFFER_OFFSET(0));

loc2 = glGetUniformLocation(program, "vColor");
glEnableVertexAttribArray(loc2);
gVertexAttribPointer(loc2, 3, GL_FLOAT, GL_FALSE, 0, BUFFER_OFFSET(sizeof(points)));

Coloring Each Vertex

in vec3 vPosition, vColor;
out vec3 color;

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

Coloring Each Fragment

in vec3 color;
out vec4 fragcolor;

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

Drawing Data in Buffers

void mydisplay()
{
  glClear(……);
  glDrawArrays(GL_TRIANGLES,…);
  glutSwapBuffers();
}

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 + xs*vPosition.z);
  gl_Position = t;
}
Particle System

```cpp
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 (Gouraud shading)
- Per fragment lighting (Phong shading)

Fragment Shader Applications

- Texture mapping
- Procedural textures
- Environment mapping
- Bump mapping

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

```c
#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

```c
static int i = 0;
void triangle( point2 a, point2 b, point2 c)
/* display one triangle */
{
    points[i] = a;
    i++;
    points[i] = b;
    i++;
    points[i] = c;
    i++;
}
```

Triange Subdivision

```c
void divide_triangle(point2 a, point2 b, point2 c, int m)
/* triangle subdivision using vertex numbers */
    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

```c
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

```c
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 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 Subdivision

- 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.
Volume Subdivision