The OpenGL Shading Language

An Introduction

What Are Shaders, And Why Should I Care?

- A *programmable* replacement for parts of the fixed function pipeline
- Shaders offer:
    - Opportunity for Improved Visual Quality
    - Algorithm Flexibility
    - Performance Benefits
- The fixed function pipeline is emulated by shaders on current hardware
- Replaced portions of the fixed function pipeline *don’t exist* in new APIs

Types of Shaders

- *Vertex shaders* transform vertices, setup data for fragment shaders
- *Fragment shaders* operate on fragments generated by rasterization
- *Geometry shaders* create geometry on the GPU
- ... More

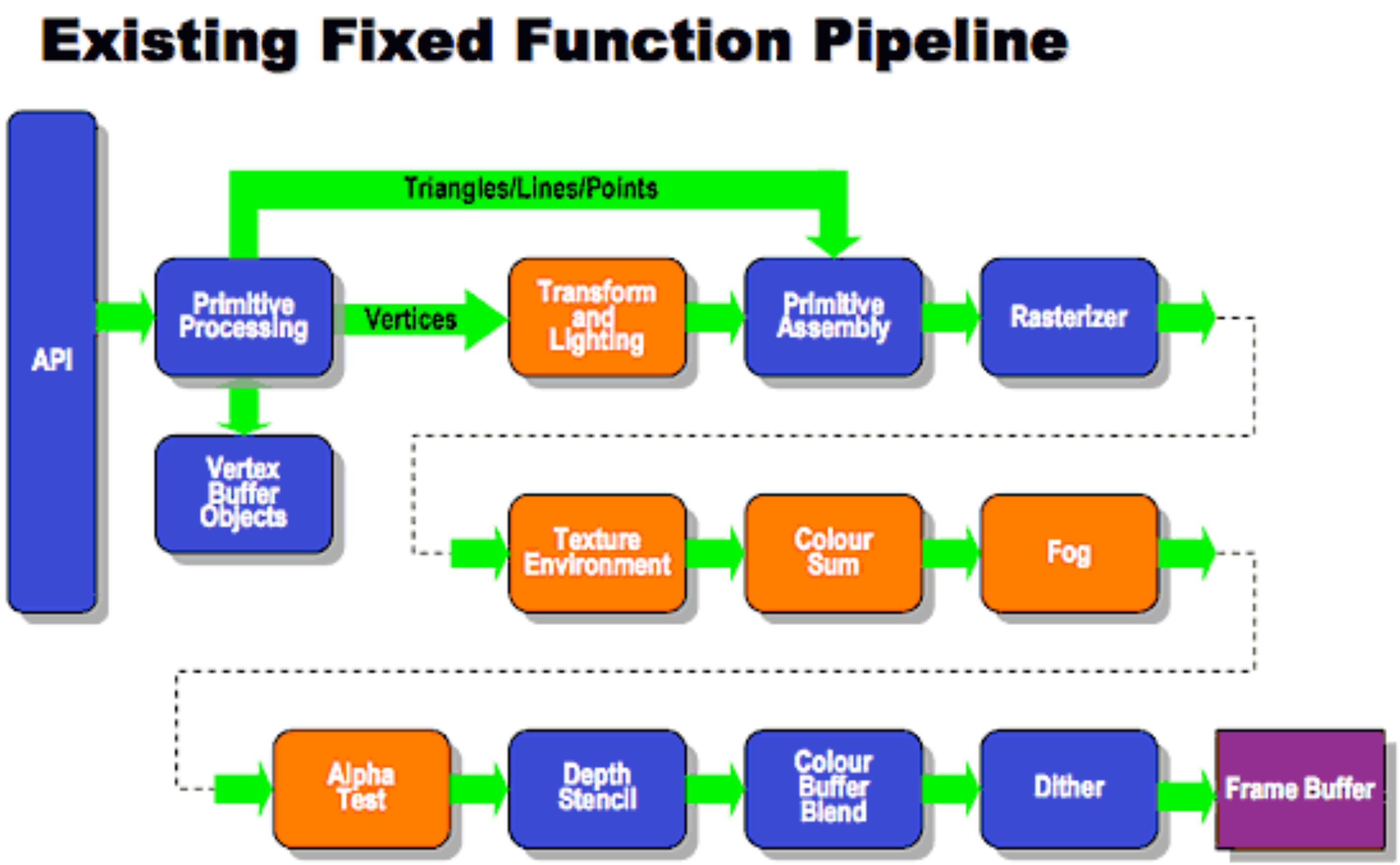
Programs

- A container for compiled shaders
- Provides the foundation to link shaders together

Where Do Shaders Fit In?

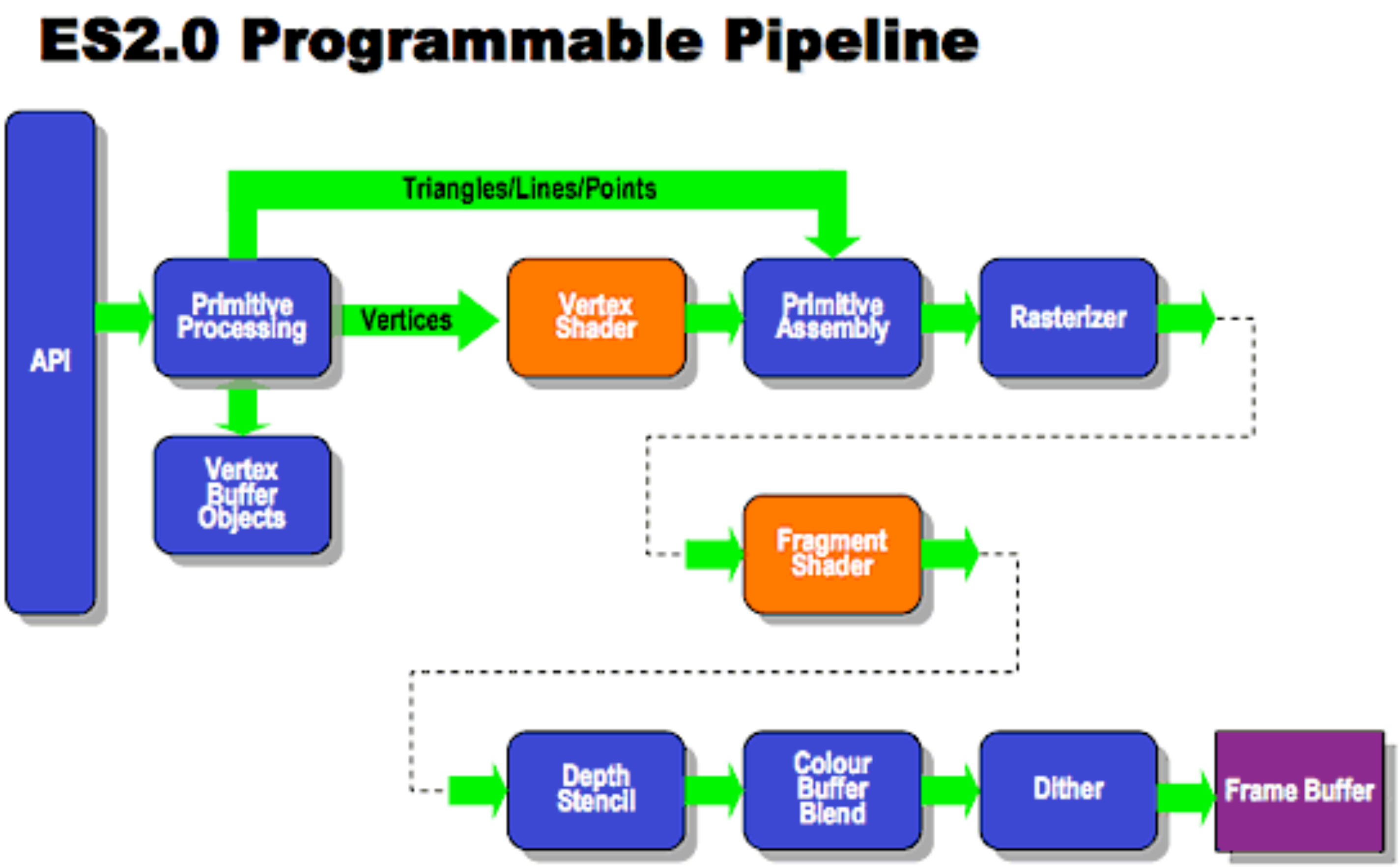
- Lets briefly examine the OpenGL Graphics Pipeline
  - Actually the OpenGL ES Graphics Pipeline
  - Simpler, Similar

Where Do Shaders Fit In?



http://www.khronos.org/opengles/2_X/img/opengles_1x_pipeline.gif

Where Do Shaders Fit In?



http://www.khronos.org/opengles/2_X/img/opengles_20_pipeline.gif

The Vertex Processor

- Common Uses
  - Vertex Transformation
  - Normal Transformation
  - Texture Coordinate Transformation and Generation
  - Animation
  - Setting Up Data For Fragment Shader

The Fragment Processor

- Common Uses
  - Operations on Interpolated Values
  - Texture Application
  - Lighting And Material Application
  - Ray tracing
  - Doing operations per fragment to make pretty pictures

GLSL Syntax

- Borrows syntax from C and C++
- Replaces I/O operations with *qualified* variables, special variables, and texture reads
- Provides booleans, integers and floating point scalar types
- Adds vector and matrix types and operations
- Provides structs and constant-sized arrays
- No pointers, casting, or implicit type promotion
- Shader entry point is called “main”

Branching and Looping

- if-else: Only on newer hardware
- for, while, do-while
- no switch
- no goto
- discard
  - Available only in fragment shaders
  - *Effectively* stops the computation and does not update the frame buffer

Vector Declaration

- vec2, vec3, vec4, bvec2, bvec3, bvec4, ivec2, ivec3, ivec4
- ivec2 A = ivec2(1, 1);
- vec2 B = vec2(A);
- vec3 C = vec3(1.0, 1.0, 1.0);
- vec4 D = vec4(C, 1.0);

Swizzling

- We can access the components of the vector in one of four ways
  - [i], .xyzw, .rgba, .stpq (Equivalent, Use Defined by Semantics)
  - We can "swizzle" vectors to access the components in arbitrary order

```
vec4 A = vec4(1.0, 2.0, 3.0, 4.0).zwyx;  // This is legal
float  B = A.q;       // This is legal
vec4 C = A.rgba;  // This is legal
vec4 D = A.xgbq; // This is illegal
```

  - Assigning to a swizzled vector

```
vec3 E = vec3(0.0);
E.x = A.w;            // This is legal
E.wyxz = A.xxxw; // This is legal
E.xxxx = A.xyzw;  // This is illegal
```

Matrix Declaration

- mat2, mat3, mat4
- Available in GLSL 1.20+
  - mat2x2, mat2x3, mat2x4
  - mat3x2, mat3x3, mat3x4
  - mat4x2, mat4x3, mat4x4
- mat4 = mat4(1.0)
- mat4 = mat4(vec4(1.0), vec4(2.0), vec4(3.0), vec4(4.0));

Matrix “Swizzling”

- We can access the *columns* of a matrix as *vectors* with array syntax

```
mat4 A = mat4(1.0);
vec4 B = A[0];
vec3 C = A[1].xyz;
float  D = A[0][0];
```

Creating And Installing Shaders And Programs

- Create shader object
- Supply source code for shader object
- Compile shader
- Create program object
- Attach shader to program
- Link program
- Use program

Creating And Installing Shaders And Programs

- Create shader object — glCreateShader
- Supply source code for shader object
- Compile shader
- Create program object
- Attach shader to program
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- Use program

Creating And Installing Shaders And Programs

- Create shader object — glCreateShader
- Supply source code for shader object — glShaderSource
- Compile shader
- Create program object
- Attach shader to program
- Link program
- Use program

Creating And Installing Shaders And Programs

• Create shader object	glCreateShader
• Supply source code for shader object	glShaderSource
• Compile shader	glCompileShader
• Create program object	
• Attach shader to program	
• Link program	
• Use program	

Creating And Installing Shaders And Programs

- Create shader object — glCreateShader
- Supply source code for shader object — glShaderSource
- Compile shader — glCompileShader
- Create program object — glCreateProgram
- Attach shader to program
- Link program
- Use program

Creating And Installing Shaders And Programs

• Create shader object	glCreateShader
• Supply source code for shader object	glShaderSource
• Compile shader	glCompileShader
• Create program object	glCreateProgram
• Attach shader to program	glAttachShader
• Link program	
• Use program	

Creating And Installing Shaders And Programs

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Creating And Installing Shaders And Programs

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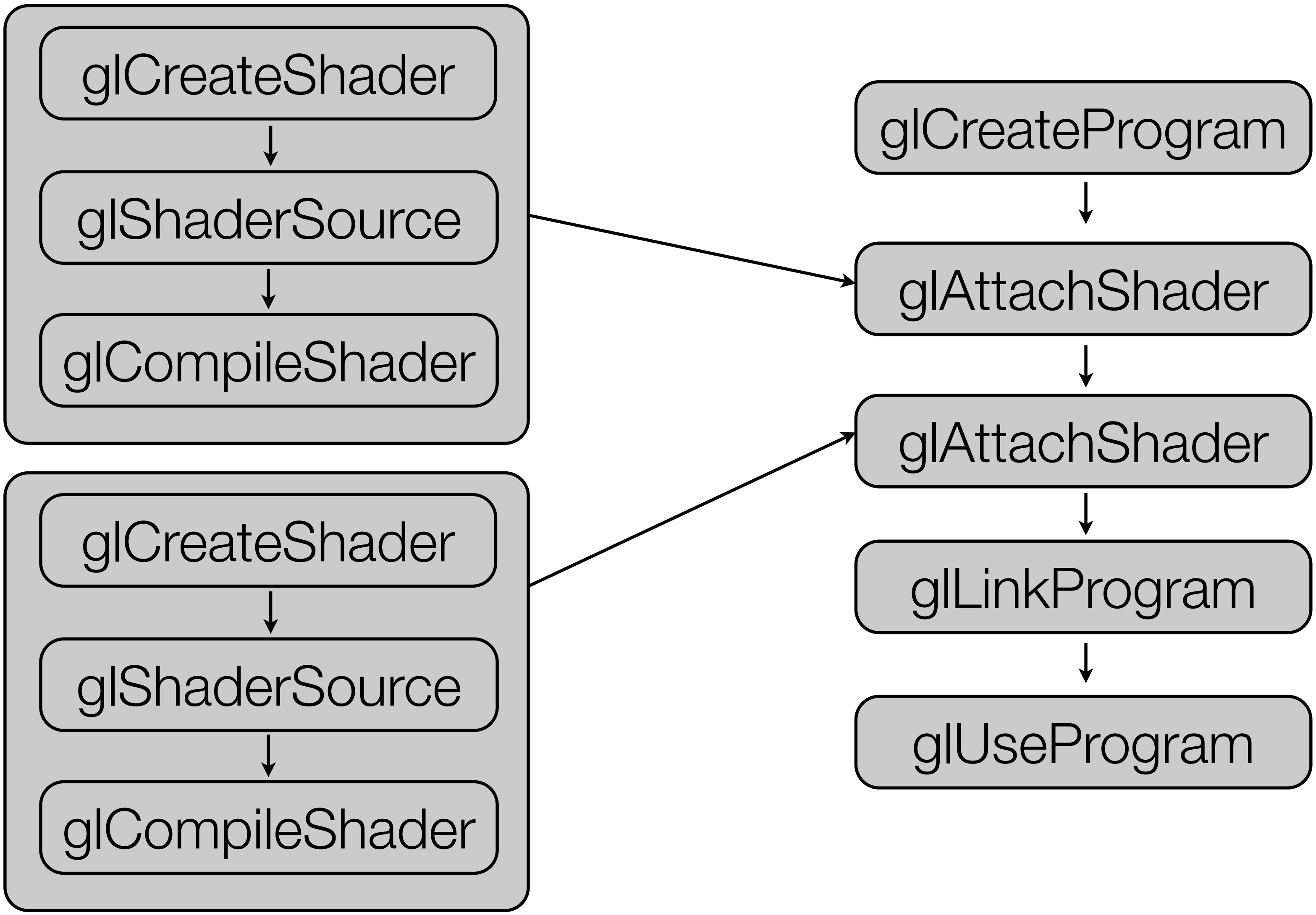
Creating And Installing Shaders And Programs



An Example

```
GLuint program = 0;

const GLchar *vertexSource = "..........";
const GLchar *fragmentSource = ".........."

GLuint vertexShader = glCreateShader(GL_VERTEX_SHADER);
glShaderSource(vertexShader, 1, &vertexSource, 0);
glCompileShader(vertexShader);

GLuint fragmentShader = glCreateShader(GL_FRAGMENT_SHADER);
glShaderSource(fragmentShader, 1, &fragmentSource, 0);
glCompileShader(fragmentShader);

program = glCreateProgram();
glAttachShader(program, vertexShader);
glAttachShader(program, fragmentShader);
glLinkProgram(program);

glUseProgram(program);
```

- Create shader object
- Supply source code for shader object
- Compile shader
- Create program object
- Attach shader to program
- Link program
- Use program

Reporting Compilation and Linking Errors

- glGetShaderInfoLog
  - Retrieve shader compilation errors
- glGetProgramInfoLog
  - Retrieve program linking errors

Getting Error Logs

```
GLsizei maxLength = 1024;
GLsizei length[3] = {0};
GLchar infoLog[3][1024] = {0};

glGetShaderInfoLog(vertexShader,     maxLength, &length[0], infoLog[0]);
glGetShaderInfoLog(fragmentShader, maxLength, &length[1], infoLog[1]);
glGetProgramInfoLog(program,          maxLength, &length[2], infoLog[2]);
```

Anatomy of A Shader

```
// Vertex Shader
void main() {
   gl_Position = gl_Vertex;
}
```

```
// Fragment Shader
void main() {
   gl_FragColor = vec4(1.0, 1.0, 1.0, 1.0);
}
```

- Shader entry point is main
  - returns void, takes no arguments
- How do we get data in and out of our shaders?
  - Qualified variables, special variables and texture reads replace I/O operations

Qualifiers

- Uniform
  - Input to vertex shader from application
  - Information that changes infrequently
- Attribute
  - Input to vertex shader from application
  - Information that changes frequently

Qualifiers

- Varying
  - Output of vertex shader
  - Input to fragment shader
  - Information interpolated between vertices
    - Color
    - Normals
    - Direction To Light Source

Qualifiers And Special Variables

```
// Vertex Shader
void main() {
   gl_Position = gl_Vertex;
}
```

```
// Fragment Shader
void main() {
   gl_FragColor = vec4(1.0, 1.0, 1.0, 1.0);
}
```

- What is the qualifier for gl_Vertex?
- What are the qualifiers for gl_Position and gl_FragColor?

Anatomy Of A Vertex Shader

```
// Vertex Shader
void main() {
   gl_Position = gl_Vertex;
}
```

- A vertex shader *must* write to gl_Position
- A vertex shader can write to gl_PointSize, gl_ClipVertex
- gl_Vertex is an attribute supplying the *untransformed* vertex coordinate
- gl_Position is an special output variable for the *transformed* vertex coordinate

Anatomy Of A Fragment Shader

```
// Fragment Shader
void main() {
   gl_FragColor = vec4(1.0, 1.0, 1.0, 1.0);
}
```

- A fragment shader can write to the following special output variables
  - gl_FragColor to set the color of the fragment
  - gl_FragData[n] to output to a specific render target
  - gl_FragDepth to set the fragment depth

Before We Get Any Further....

- Can I install a vertex shader with no fragment shader, or visa versa?
  - Yes! The fixed function pipeline will be used
- Can I attach multiple vertex or fragment shaders to a program?
  - Yes! But there should only be one main per attached shader type

An Example: Diffuse Shading

- OpenGL computes shading per vertex and interpolates across the surface
- We are going to compute ambient and diffuse shading per fragment
  - No attenuation
  - No specular term
  - Easy to add (try it!)

An Example: Diffuse Shading

- Check List:
  - Transform Vertex and Normal
  - Compute The Vector From Vertex To Light Source
  - Pass Information From Vertex Shader To Fragment Shader
  - Compute Shading

Modifying the Vertex Shader

- Let's modify the vertex program to transform vertices
- We need to multiply the vertex by the modelview and projection matrices

```
// Vertex Shader
void main() {
    gl_Position = gl_Vertex;
}
```

Transforming Vertices

- Let's modify the vertex program to transform vertices

- We need to multiply the vertex by the modelview and projection matrices

```
// Vertex Shader
void main() {
   gl_Position = gl_ProjectionMatrix * gl_ModelViewMatrix * gl_Vertex;
}
```

Built In 4x4 Matrix Provided By OpenGL

- What are the qualifiers for gl_ModelViewMatrix, and gl_ProjectionMatrix?

Transforming Vertices

- Let's modify the vertex program to transform vertices

- We need to multiply the vertex by the modelview and projection matrices

```
// Vertex Shader
void main() {
   gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

Built In 4x4 Matrix Provided By OpenGL

Transforming Normals

- We need to multiply the normal by the normal matrix

```
// Vertex Shader
vec3 frag_Normal;
void main() {
   frag_Normal = gl_NormalMatrix * gl_Normal;
   gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

Calculating The Light Vector

- Light Vector = Light Position - Vertex Position

```
// Vertex Shader
vec3 frag_Light;
vec3 frag_Normal;
void main() {
   frag_Light = gl_LightSource[0].position.xyz - ........;
   frag_Normal = gl_NormalMatrix * gl_Normal;
   gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

- Light Position Is Stored In *Eye Space*
  - *Already multiplied by the modelview matrix!*

Calculating The Light Vector

- Light Vector = Light Position - Vertex Position

```
// Vertex Shader
vec3 frag_Light;
vec3 frag_Normal;
void main() {
   vec4 vertex = gl_ModelViewMatrix * gl_Vertex;
   frag_Light = gl_LightSource[0].position.xyz - vertex.xyz;
   frag_Normal = gl_NormalMatrix * gl_Normal;
   gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

- Now the subtraction is occuring in the same space!

Using The Varying Qualifier

- If mark global variables as “varying” in the vertex shader...

```
// Vertex Shader
varying vec3 frag_Light;
varying vec3 frag_Normal;
void main() {
   vec4 vertex = gl_ModelViewMatrix * gl_Vertex;
   frag_Light = gl_LightSource[0].position.xyz - vertex.xyz;
   frag_Normal = gl_NormalMatrix * gl_Normal;
   gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

Using The Varying Qualifier

- And in the fragment shader, we can pass *interpolated* information
  - Data always moves from vertex shader to fragment shader

```
// Fragment Shader
varying vec3 frag_Light;
varying vec3 frag_Normal;
void main() {
   gl_FragColor = vec4(1.0, 1.0, 1.0, 1.0);
}
```

Using The Varying Qualifier

- We need to calculate diffuse shading
- Formula is:
  - $Light_{Diffuse}$ * $Material_{Diffuse}$ * max(0.0, dot(Normal, Light))
    - Normal is the *normalized* surface normal
    - Light is the *normalized* vector to the light source

Computing Shading

```
// Fragment Shader
varying vec3 frag_Light;
varying vec3 frag_Normal;
void main() {
   vec3 N = normalize(frag_Light);
   vec3 L = normalize(frag_Normal);
   float nDotL = max(0.0, dot(N, L));
   gl_FragColor = vec4(1.0, 1.0, 1.0, 1.0);
}
```

Computing Shading

```
// Fragment Shader
varying vec3 frag_Light;
varying vec3 frag_Normal;
void main() {
   vec3 N = normalize(frag_Light);
   vec3 L = normalize(frag_Normal);
   float nDotL = max(0.0, dot(N, L));
   gl_FragColor = gl_FrontLightProduct[0].diffuse * nDotL;
}
```

Finish The Lighting Model

- Try it yourself!
- Global Ambient + attenuation * (Ambient + Diffuse + Specular)
  - Global Ambient: gl_FrontLightModelProduct.sceneColor
  - Attenuation = 1.0 / A + B * Distance To Light + C * (Distance To Light)^2
    - A, B, C = Look at gl_LightSource[i].constantAttenuation ....
  - Specular = pow (max(0.0, dot(Normal, HalfVector)), shininess)
    - gl_LightSource[i].halfVector, gl_FrontMaterial.shininess

Preparing for GLSL 1.30

- GLSL 1.30 will no longer provide built-in uniforms and attributes
  - We must pass in all values we wish to use
  - Requires less work per state change (Higher Performance)

Using The Uniform Qualifier

- Let's replace gl_ModelViewMatrix and gl_ProjectionMatrix with our own uniform matrices
- We have to
  - Declare two uniform matrices
  - Pass matrix data to the shader
    - glGetUniformLocation
    - glUniformMatrix4f
      - glUniform1f, glUniform2f, ... glUniformMatrix2f, glUniformMatrix3f, ...

Using The Uniform Qualifier

```
// Vertex Shader
uniform mat4 ProjectionMatrix;
uniform mat4 ModelViewMatrix;
void main() {
   gl_Position = ProjectionMatrix * ModelViewMatrix * gl_Vertex;
}
```

Using The Uniform Qualifier

```
// Application Code
float projectionMatrix[16] = ......;
float modelViewMatrix[16] = ......;
GLuint projection = glGetUniformLocation(program, “ProjectionMatrix”);
GLuint modelView = glGetUniformLocation(program, “ModelViewMatrix”);
glUniformMatrix4fv(projection, 1, GL_FALSE, projectionMatrix);
glUniformMatrix4fv(modelView, 1, GL_FALSE, modelViewMatrix);
```

Using Attributes

- Available only in vertex shaders
- Declare global variable as attribute
    - attribute vec4 gl_Vertex;
- A large variety of glVertexAttrib calls
    - Prefer glVertexAttribPointer

glVertexAttribPointer

- Replaces all previous vertex array functionality
- Arguments: index, size, type, normalized, stride, pointer
- size, type, stride and pointer similar to glVertexPointer
- normalized is a boolean
  - If GL_TRUE, values in pointer are mapped between 0 and 1
  - If GL_FALSE, values in pointer are directly converted to floats
- Must call glEnableVertexAttribArray(index) before using....
- What is index?

Attribute Index

- Every attribute has an index
  - A number (like a memory address) that identifies their location
  - We can define that number ourselves
    - glBindAttribLocation(program, index, name)
      - Must be called before calling glLinkProgram
  - We can let OpenGL define it for us
    - glGetAttribLocation(program, name)

Attribute Index

- gl_Vertex is an attribute
- Specified by calling glVertex
- Specified by calling glVertexAttrib* with index 0
- Specified by calling glVertexAttribPointer with index 0
    - Signals the end of data for a given vertex

Using The Attribute Qualifier

- Let's use attributes to submit vertex data
    - We have to declare an attribute
    - We have to pass data to that attribute
        - We will use glVertexAttrib for the demonstation....

Using The Attribute Qualifier

```
// Vertex Shader
uniform mat4 ProjectionMatrix;
uniform mat4 ModelViewMatrix;
attribute vec4 Vertex;
void main() {
   gl_Position = ProjectionMatrix * ModelViewMatrix * Vertex;
}
```

Using The Attribute Qualifier

```
// Application Code
...
glBindAttribLocation(program, 0, "Vertex");
glLinkProgram(program);
...
glBegin(GL_QUADS);
glVertexAttrib4f(0, -10.0f, -10.0f, -25.0f, 1.0f);
glVertexAttrib4f(0,  10.0f, -10.0f, -25.0f, 1.0f);
glVertexAttrib4f(0,  10.0f,  10.0f, -25.0f, 1.0f);
glVertexAttrib4f(0, -10.0f,  10.0f, -25.0f, 1.0f);
glEnd();
```

An Example

- Lets try drawing with glutSolidTeapot
  - We won’t be calling glVertexAttrib
  - But glVertexAttrib with index 0 is the same as calling glVertex

Demo:

What Just Happened?

- We are setting the modelview matrix.....

What Just Happened?

- We are setting the modelview matrix.....
  - before calling glutSolidTeapot
    - glutSolidTeapot calls glRotate
    - Slightly annoying when dealing with glut* objects
    - In general not an issue