Shaders

Part 2

The **GPU** pipeline

The **GPU** pipeline

The **vertex** shader

A **program** that **transforms** the properties of
every vertex passed to the GPU
and passes data to the fragment shader.

The vertex shader is where the **model**, **view** and **projection** matrices are applied to the **vertex**.

Lesson 47: NeHe & Owen Bourne's Cg Vertex Shader Tutorial

The **fragment** shader

A program that **returns the color of each pixel** when geometry is rasterized on the GPU.

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The final **shader program** is a combination of a **vertex** and a **fragment** shader.

GLSL

Open**GL** **S**hading **L**anguage

Anatomy of a simple **GLSL** vertex shader.

```
attribute vec4 position;
attribute vec2 texCoord;

uniform mat4 modelMatrix;
uniform mat4 viewMatrix;
uniform mat4 projectionMatrix;

varying vec2 texCoordVar;

void main()
{
    vec4 p = viewMatrix * modelMatrix  * position;
    texCoordVar = texCoord;
    gl_Position = projectionMatrix * p;
}
```

Anatomy of a simple **GLSL** vertex shader.

```
attribute vec4 position;
attribute vec2 texCoord;
```

ATTRIBUTES

```
uniform mat4 modelMatrix;
uniform mat4 viewMatrix;
uniform mat4 projectionMatrix;
```

UNIFORMS

```
varying vec2 texCoordVar;
```

VARYING VARIABLES

```
void main()
{
    vec4 p = viewMatrix * modelMatrix  * position;
    texCoordVar = texCoord;
    gl_Position = projectionMatrix * p;
}
```

Anatomy of a simple **GLSL** fragment shader.

```
uniform sampler2D diffuse;

varying vec2 texCoordVar;

void main() {
    gl_FragColor = texture2D(diffuse, texCoordVar);
}
```

Anatomy of a simple **GLSL** fragment shader.

```
uniform sampler2D diffuse;
```

UNIFORMS

```
varying vec2 texCoordVar;
```

VARYING VARIABLES

```
void main() {
    gl_FragColor = texture2D(diffuse, texCoordVar);
}
```

Using shaders in **OpenGL**.

Loading and **compiling** vertex and fragment **shaders**.

vertex_shader.glsl

```
attribute vec4 position;
attribute vec2 texCoord;

uniform mat4 modelMatrix;
uniform mat4 viewMatrix;
uniform mat4 projectionMatrix;

varying vec2 texCoordVar;

void main()
{
    vec4 p = viewMatrix * modelMatrix  * position;
    texCoordVar = texCoord;
    gl_Position = projectionMatrix * p;
}
```

fragment_shader.glsl

```
uniform sampler2D diffuse;

varying vec2 texCoordVar;

void main() {
    gl_FragColor = texture2D(diffuse, texCoordVar);
}
```

Load our shader files into an **std::string.**

```
std::ifstream infile("vertex_shader.frag");
if(infile.fail()) {
    std::cout << "Error opening shader file" << std::endl;
}
std::stringstream buffer;
buffer << infile.rdbuf();
std::string vertexShader = buffer.str();
```

Creating and **compiling** a shader from string.

Use **GL_VERTEX_SHADER** for vertex shader.

```
GLuint vertexShaderID = glCreateShader(GL_VERTEX_SHADER);

const char *vertexShaderString = vertexShader.c_str();
int vertexShaderStringLength = vertexShader.size();

glShaderSource(vertexShaderID, 1, &vertexShaderString, & vertexShaderStringLength);
glCompileShader(vertexShaderID);
```

Use **GL_FRAGMENT_SHADER** for fragment shader.

```
GLuint fragmentShaderID = glCreateShader(GL_FRAGMENT_SHADER);

const char *fragmentShaderString = fragmentShader.c_str();
int fragmentShaderStringLength = fragmentShader.size();

glShaderSource(fragmentShaderID, 1, &fragmentShaderString, &fragmentShaderStringLength);
glCompileShader(fragmentShaderID);
```

Creating and **linking** the shader program from the fragment and vertex shaders.

```
GLuint exampleProgram = glCreateProgram();
glAttachShader(exampleProgram, vertexShaderID);
glAttachShader(exampleProgram, fragmentShaderID);
glLinkProgram(exampleProgram);
```

Get references to the **attribute** and **uniform locations** of the shader program so we can **pass data to it**.

```
attribute vec4 position;
attribute vec2 texCoord;
```

ATTRIBUTES

```
uniform mat4 modelMatrix;
uniform mat4 viewMatrix;
uniform mat4 projectionMatrix;
```

UNIFORMS

Uniforms

```
GLint projectionMatrixUniform = glGetUniformLocation(exampleProgram, "projectionMatrix");
GLint modelMatrixUniform = glGetUniformLocation(exampleProgram, "modelMatrix");
GLint viewMatrixUniform = glGetUniformLocation(exampleProgram, "viewMatrix");
```

Attributes

```
GLuint positionAttribute = glGetAttribLocation(exampleProgram, "position");
GLuint texCoordAttribute = glGetAttribLocation(exampleProgram, "texCoord");
```

Drawing using our **shader program**.

Tell **OpenGL** to use our **program**.

```
glUseProgram(exampleProgram);
```

Bind our model, view and projection matrices.

```
glUniformMatrix4fv(projectionMatrixUniform, 1, GL_FALSE, projectionMatrix.ml);
glUniformMatrix4fv(modelMatrixUniform, 1, GL_FALSE, modelMatrix.ml);
glUniformMatrix4fv(viewMatrixUniform, 1, GL_FALSE, viewMatrix.ml);
```

Bind **shader attributes**.

```
float vertices[] = {-0.5, 0.5, -0.5, -0.5, 0.5, -0.5, -0.5, 0.5, 0.5, -0.5, 0.5, 0.5};
glVertexAttribPointer(program.positionAttribute, 2, GL_FLOAT, false, 0, vertices);
glEnableVertexAttribArray(program.positionAttribute);

float texCoords[] = {0.0, 0.0, 0.0, 1.0, 1.0, 1.0, 0.0, 0.0, 1.0, 1.0, 1.0, 0.0};
glVertexAttribPointer(program.texCoordAttribute, 2, GL_FLOAT, false, 0, texCoords);
glEnableVertexAttribArray(program.texCoordAttribute);

glDrawArrays(GL_TRIANGLES, 0, 6);
```

Catching **GLSL errors** when compiling shaders.

After calling **glCompileShader** you can check if it failed to compile and get a readable error message.

```
GLint compileSuccess;
glGetShaderiv(vertexShaderID, GL_COMPILE_STATUS, &compileSuccess);
if (compileSuccess == GL_FALSE) {

        GLchar messages[256];
        glGetShaderInfoLog(shaderID, sizeof(messages), 0, &messages[0]);
        std::cout << messages << std::endl;

}
```

Intro to basic **GLSL**

Basic Types

void	no function return value or empty parameter list
bool	Boolean
int	signed integer
float	floating scalar
vec2, vec3, vec4	n-component floating point vector
bvec2, bvec3, bvec4	Boolean vector
ivec2, ivec3, ivec4	signed integer vector
mat2, mat3, mat4	2x2, 3x3, 4x4 float matrix
sampler2D	access a 2D texture
samplerCube	access cube mapped texture

Vertex shader must set **gl_Position** (which is a homogenized **vec4** coordinate) to set the final position of the vertex being drawn.

If it is passing any **varying** data to the pixel shader, it must set those as well.

```
attribute vec4 position;
attribute vec2 texCoord;

uniform mat4 modelMatrix;
uniform mat4 viewMatrix;
uniform mat4 projectionMatrix;

varying vec2 texCoordVar;

void main()
{
    vec4 p = viewMatrix * modelMatrix  * position;
    texCoordVar = texCoord;
    gl_Position = projectionMatrix * p;
}
```

Fragment shader must set **gl_FragColor** (which is a **vec4 RGBA color value**) to set the final color of the pixel being rendered.

The **texture2D** function is built in and takes a **sampler2D** texture and a **vec2** UV coordinate and returns a **vec4 RGBA** color from that texture at that coordinate.

```
uniform sampler2D diffuse;

varying vec2 texCoordVar;

void main() {
    gl_FragColor = texture2D(diffuse, texCoordVar);
}
```

Simple **shader examples**.

Inverting texture color.

```
uniform sampler2D texture;

varying vec2 texCoordVar;

void main()
{
    vec4 finalColor = 1.0 - texture2D( texture, texCoordVar);
    finalColor.a = texture2D( texture, texCoordVar).a;
    gl_FragColor = finalColor;
}
```

Making a texture **black and white**.

```
uniform sampler2D texture;

varying vec2 texCoordVar;

void main()
{
    vec4 texColor = texture2D( texture, texCoordVar);
    vec4 finalColor = vec4((texColor.r + texColor.g + texColor.b)/3.0);
    finalColor.a = texture2D( texture, texCoordVar).a;
    gl_FragColor = finalColor;
}
```

Functions in GLSL

Built-In Functions

Angle & Trigonometry Functions [8.1]

Component-wise operation. Parameters specified as *angle* are assumed to be in units of radians. T is float, vec2, vec3, vec4.

T **radians**(T *degrees*)	degrees to radians
T **degrees**(T *radians*)	radians to degrees
T **sin**(T *angle*)	sine
T **cos**(T *angle*)	cosine
T **tan**(T *angle*)	tangent
T **asin**(T *x*)	arc sine
T **acos**(T *x*)	arc cosine
T **atan**(T *y*, T *x*) T **atan**(T *y_over_x*)	arc tangent

Exponential Functions [8.2]

Component-wise operation. T is float, vec2, vec3, vec4.

T **pow**(T *x*, T *y*)	x^y
T **exp**(T *x*)	e^x
T **log**(T *x*)	ln
T **exp2**(T *x*)	2^x
T **log2**(T *x*)	$\log_2$
T **sqrt**(T *x*)	square root
T **inversesqrt**(T *x*)	inverse square root

Common Functions [8.3]

Component-wise operation. T is float, vec2, vec3, vec4.

T **abs**(T *x*)	absolute value
T **sign**(T *x*)	returns -1.0, 0.0, or 1.0
T **floor**(T *x*)	nearest integer <= *x*
T **ceil**(T *x*)	nearest integer >= *x*
T **fract**(T *x*)	*x* - **floor**(*x*)
T **mod**(T *x*, T *y*) T **mod**(T *x*, float *y*)	modulus
T **min**(T *x*, T *y*) T **min**(T *x*, float *y*)	minimum value
T **max**(T *x*, T *y*) T **max**(T *x*, float *y*)	maximum value
T **clamp**(T *x*, T *minVal*, T *maxVal*) T **clamp**(T *x*, float *minVal*, float *maxVal*)	**min**(**max**(*x*, **minVal**), **maxVal**)
T **mix**(T *x*, T *y*, T *a*) T **mix**(T *x*, T *y*, float *a*)	linear blend of *x* and *y*
T **step**(T *edge*, T *x*) T **step**(float *edge*, T *x*)	0.0 if *x* < *edge*, else 1.0
T **smoothstep**(T *edge0*, T *edge1*, T *x*) T **smoothstep**(float *edge0*, float *edge1*, T *x*)	clip and smooth

Geometric Functions [8.4]

These functions operate on vectors as vectors, not component-wise. T is float, vec2, vec3, vec4.

float **length**(T *x*)	length of vector
float **distance**(T *p0*, T *p1*)	distance between points
float **dot**(T *x*, T *y*)	dot product
vec3 **cross**(vec3 *x*, vec3 *y*)	cross product
T **normalize**(T *x*)	normalize vector to length 1
T **faceforward**(T *N*, T *I*, T *Nref*)	returns *N* if **dot**(*Nref*, *I*) < 0, else -*N*
T **reflect**(T *I*, T *N*)	reflection direction *I* - 2 * **dot**(*N*,*I*) * *N*
T **refract**(T *I*, T *N*, float *eta*)	refraction vector

Matrix Functions [8.5]

Type mat is any matrix type.

mat **matrixCompMult**(mat *x*, mat *y*)	multiply *x* by *y* component-wise

Vector Relational Functions [8.6]

Compare *x* and *y* component-wise. Sizes of input and return vectors for a particular call must match. Type bvec is bvec*n*; vec is vec*n*; ivec is ivec*n* (where *n* is 2, 3, or 4). T is the union of vec and ivec.

bvec **lessThan**(T *x*, T *y*)	x < y
bvec **lessThanEqual**(T *x*, T *y*)	x <= y
bvec **greaterThan**(T *x*, T *y*)	x > y
bvec **greaterThanEqual**(T *x*, T *y*)	x >= y
bvec **equal**(T *x*, T *y*) bvec **equal**(bvec *x*, bvec *y*)	x == y
bvec **notEqual**(T *x*, T *y*) bvec **notEqual**(bvec *x*, bvec *y*)	x!= y
bool **any**(bvec *x*)	true if any component of *x* is true
bool **all**(bvec *x*)	true if all components of *x* are true
bvec **not**(bvec *x*)	logical complement of *x*

Texture Lookup Functions [8.7]

Available only in vertex shaders.

vec4 **texture2DLod**(sampler2D *sampler*, vec2 *coord*, float *lod*)
vec4 **texture2DProjLod**(sampler2D *sampler*, vec3 *coord*, float *lod*)
vec4 **texture2DProjLod**(sampler2D *sampler*, vec4 *coord*, float *lod*)
vec4 **textureCubeLod**(samplerCube *sampler*, vec3 *coord*, float *lod*)

Available only in fragment shaders.

vec4 **texture2D**(sampler2D *sampler*, vec2 *coord*, float *bias*)
vec4 **texture2DProj**(sampler2D *sampler*, vec3 *coord*, float *bias*)
vec4 **texture2DProj**(sampler2D *sampler*, vec4 *coord*, float *bias*)
vec4 **textureCube**(samplerCube *sampler*, vec3 *coord*, float *bias*)

Available in vertex and fragment shaders.

vec4 **texture2D**(sampler2D *sampler*, vec2 *coord*)
vec4 **texture2DProj**(sampler2D *sampler*, vec3 *coord*)
vec4 **texture2DProj**(sampler2D *sampler*, vec4 *coord*)
vec4 **textureCube**(samplerCube *sampler*, vec3 *coord*)

Saturation function example.

```
uniform sampler2D texture;
varying vec2 texCoordVar;

vec3 saturation_func(vec3 rgb, float adjustment)
{
    const vec3 W = vec3(0.2125, 0.7154, 0.0721);
    vec3 intensity = vec3(dot(rgb, W));
    return mix(intensity, rgb, adjustment);
}

void main()
{
    vec4 finalColor;
    finalColor.rgb = saturation_func(texture2D( texture, texCoordVar).rgb, 2.0);
    finalColor.a = texture2D( texture, texCoordVar).a;
    gl_FragColor = finalColor;
}
```

Passing **variables** as **uniforms**.

Example: passing the saturation value from our **C++** code.

```
uniform sampler2D texture;
uniform float saturationAmount;
varying vec2 texCoordVar;

vec3 saturation_func(vec3 rgb, float adjustment)
{
    const vec3 W = vec3(0.2125, 0.7154, 0.0721);
    vec3 intensity = vec3(dot(rgb, W));
    return mix(intensity, rgb, adjustment);
}

void main()
{
    vec4 finalColor;
    finalColor.xyz = saturation_func(texture2D( texture, texCoordVar).xyz, saturationAmount);
    finalColor.a = texture2D( texture, texCoordVar).a;
    gl_FragColor = finalColor;
}
```

Get the saturation amount **uniform location**.

```
GLint saturationAmountUniform = glGetUniformLocation(exampleProgram, "saturationAmount");
```

Before rendering, bind a value to it.

```
glUniform1f(saturationAmountUniform, 2.0f);
```

Some **GLSL types** and their corresponding C++ **uniform binding functions**.

float - **glUniform1f**(location, value);
vec2 - **glUniform2f**(location, value1, value2);
vec3 - **glUniform3f**(location, value1, value2, value3);
vec4 - **glUniform4f**(location, value1, value2, value3, value4);

Example: **scrolling** a texture.

```
uniform sampler2D texture;
uniform vec2 scroll;
varying vec2 texCoordVar;

void main()
{
    gl_FragColor = texture2D( texture, texCoordVar + scroll);
}
```

Get the scroll amount **uniform location**.

```
GLint scrollUniform = glGetUniformLocation(exampleProgram, "scroll");
```

Before rendering, bind a value to it.

```
glUniform2f(scrollUniform, ticks, 0.0f);
```

Final project requirements.

- Must have a title screen and proper states for game over, etc.
- Must have a way to quit the game.
- Must have music and sound effects.
- Must have at least 3 different levels or be procedurally generated.
- Must be either local multiplayer or have AI (or both!).
- Must have at least some animation or particle effects.

Bonus points for...

- Getting it running on your phone.
- Having 3D elements.
- Having shader effects.

(we haven’t covered any of this yet!)