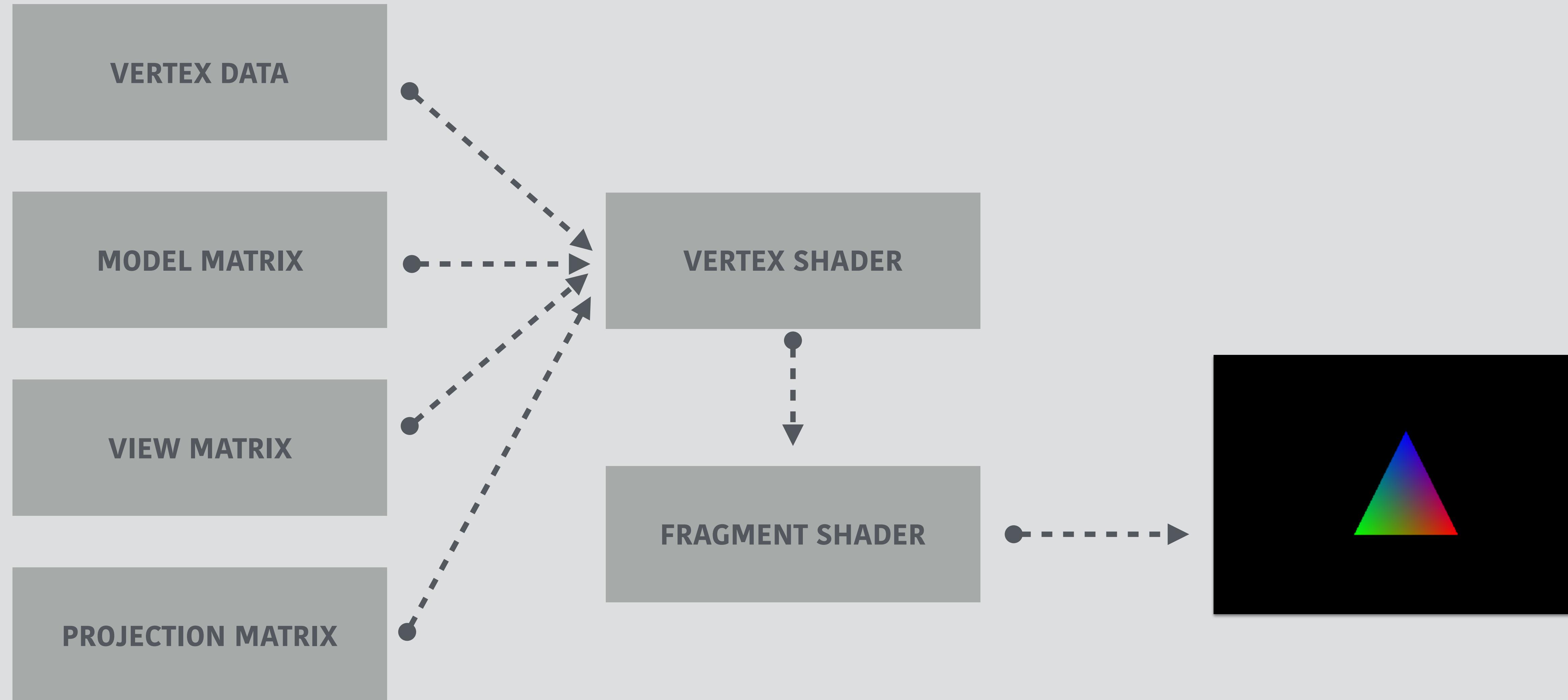


Shaders

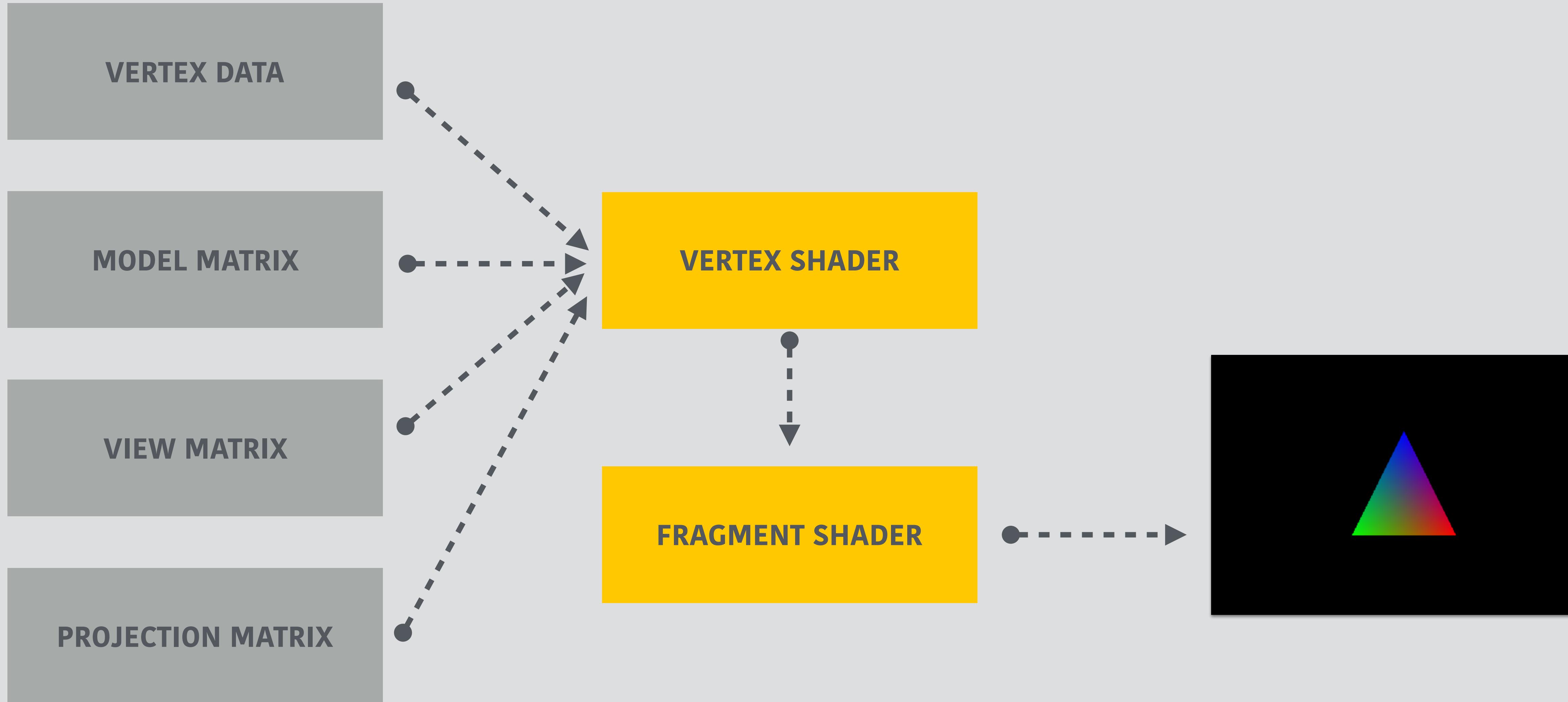
Part 1



The GPU pipeline



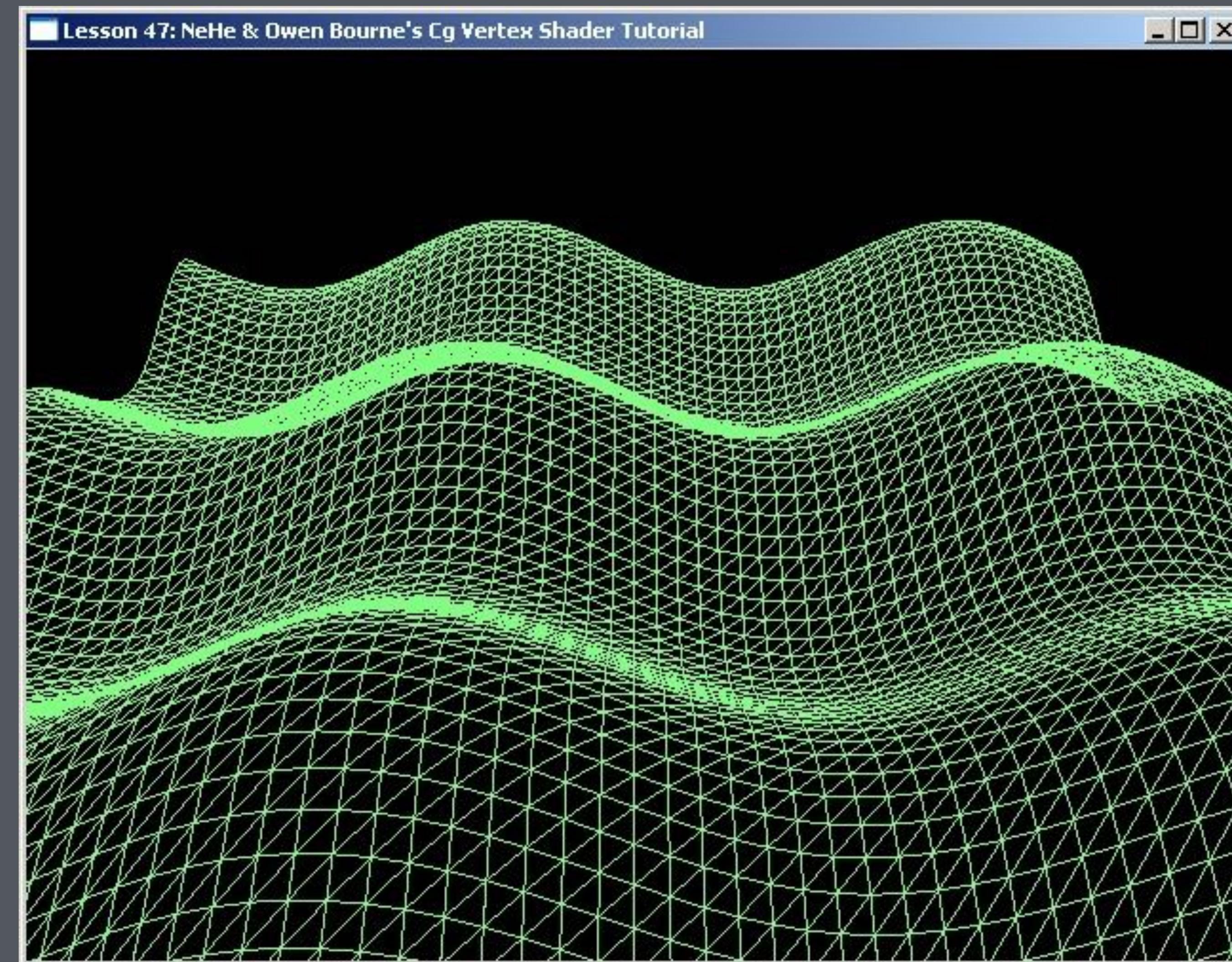
The GPU pipeline

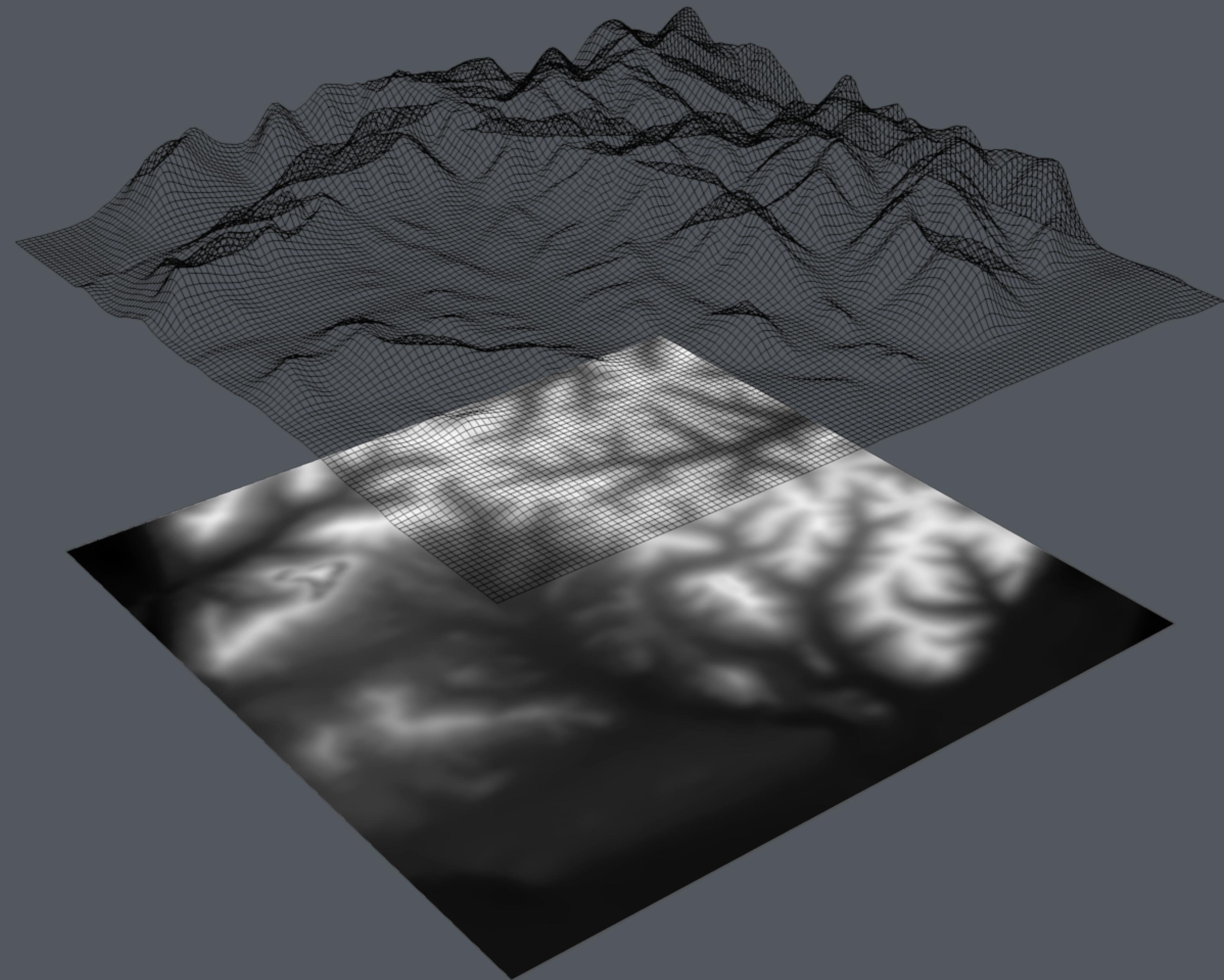


The vertex shader

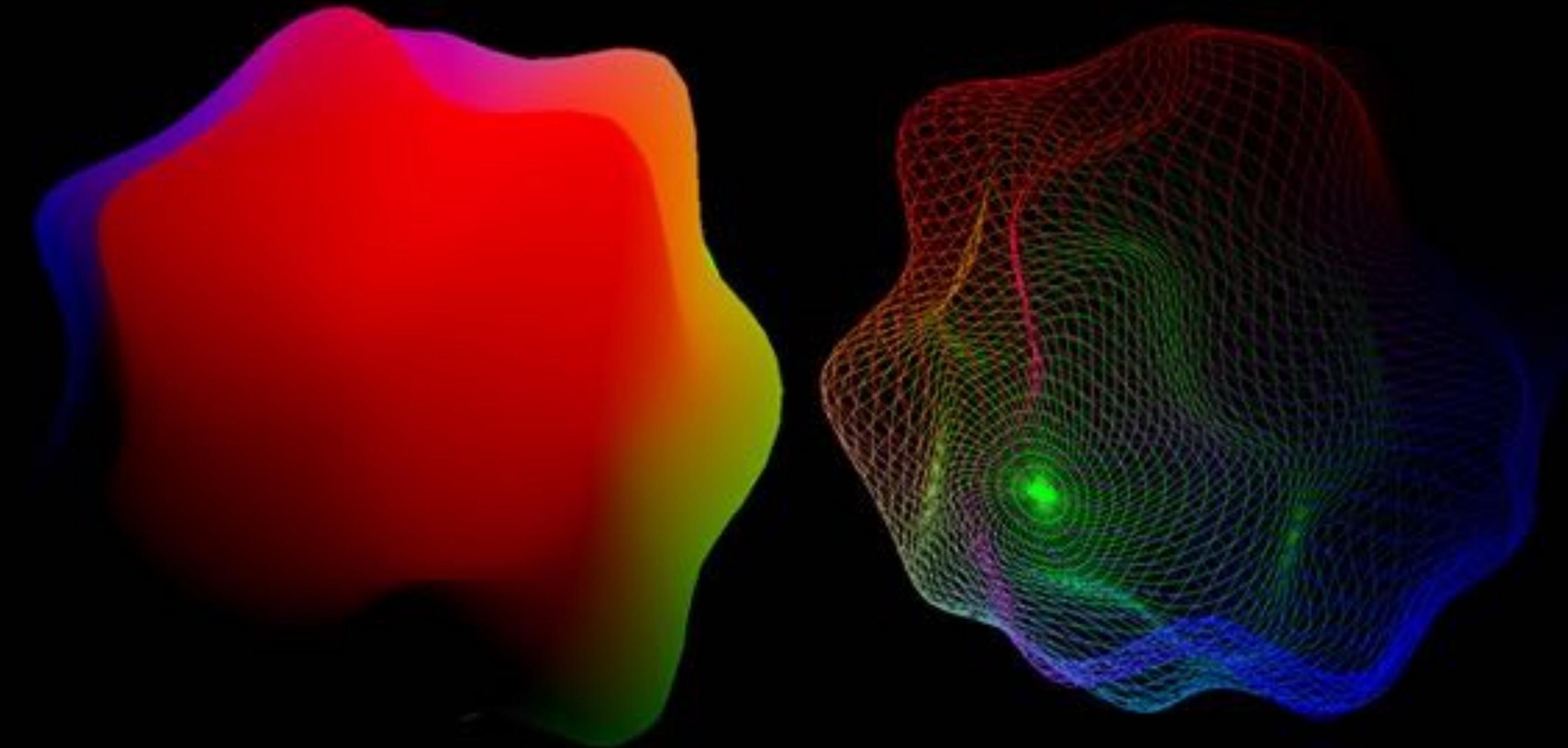
A program that transforms the properties of
every vertex passed to the GPU
and passes data to the fragment shader.

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



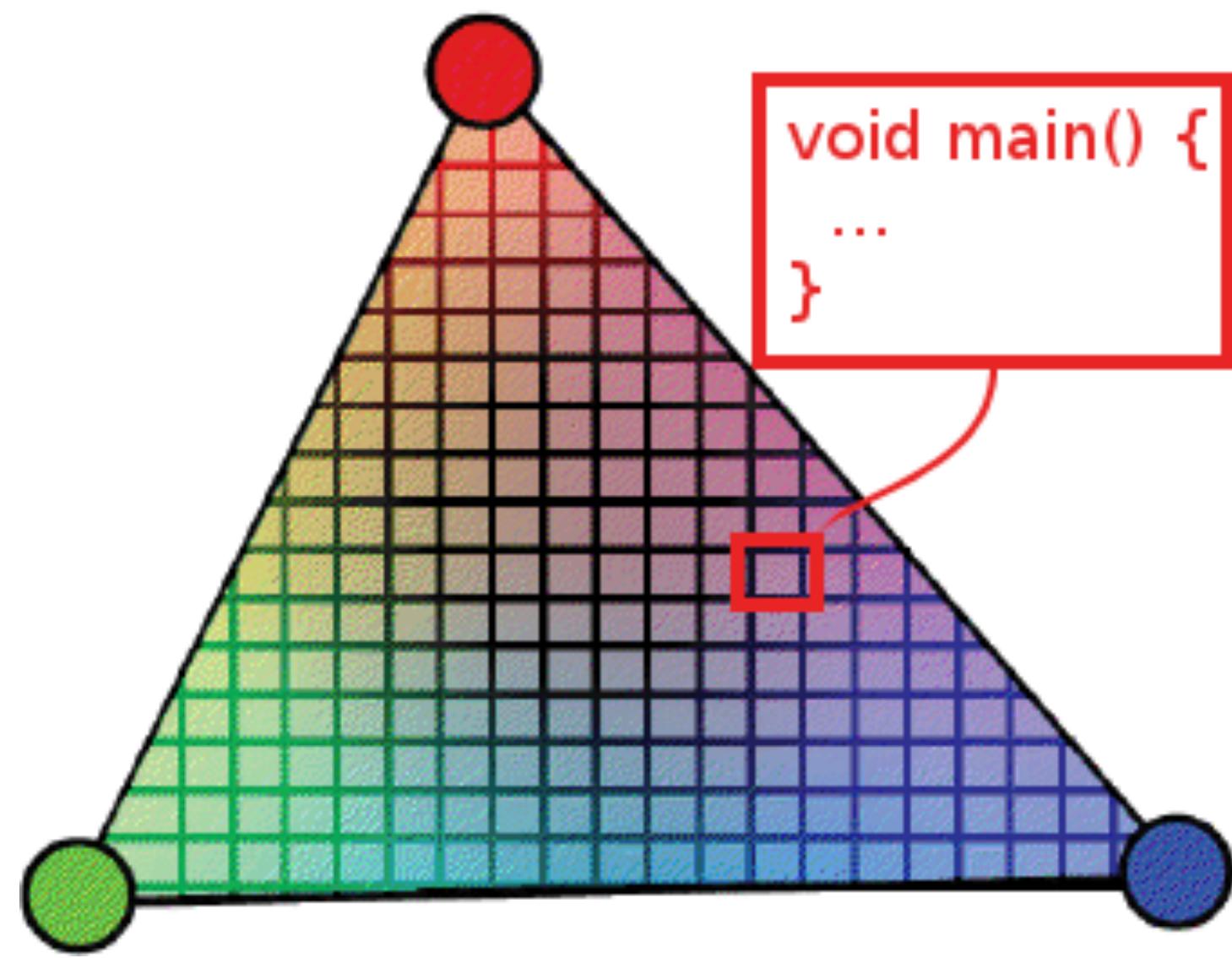
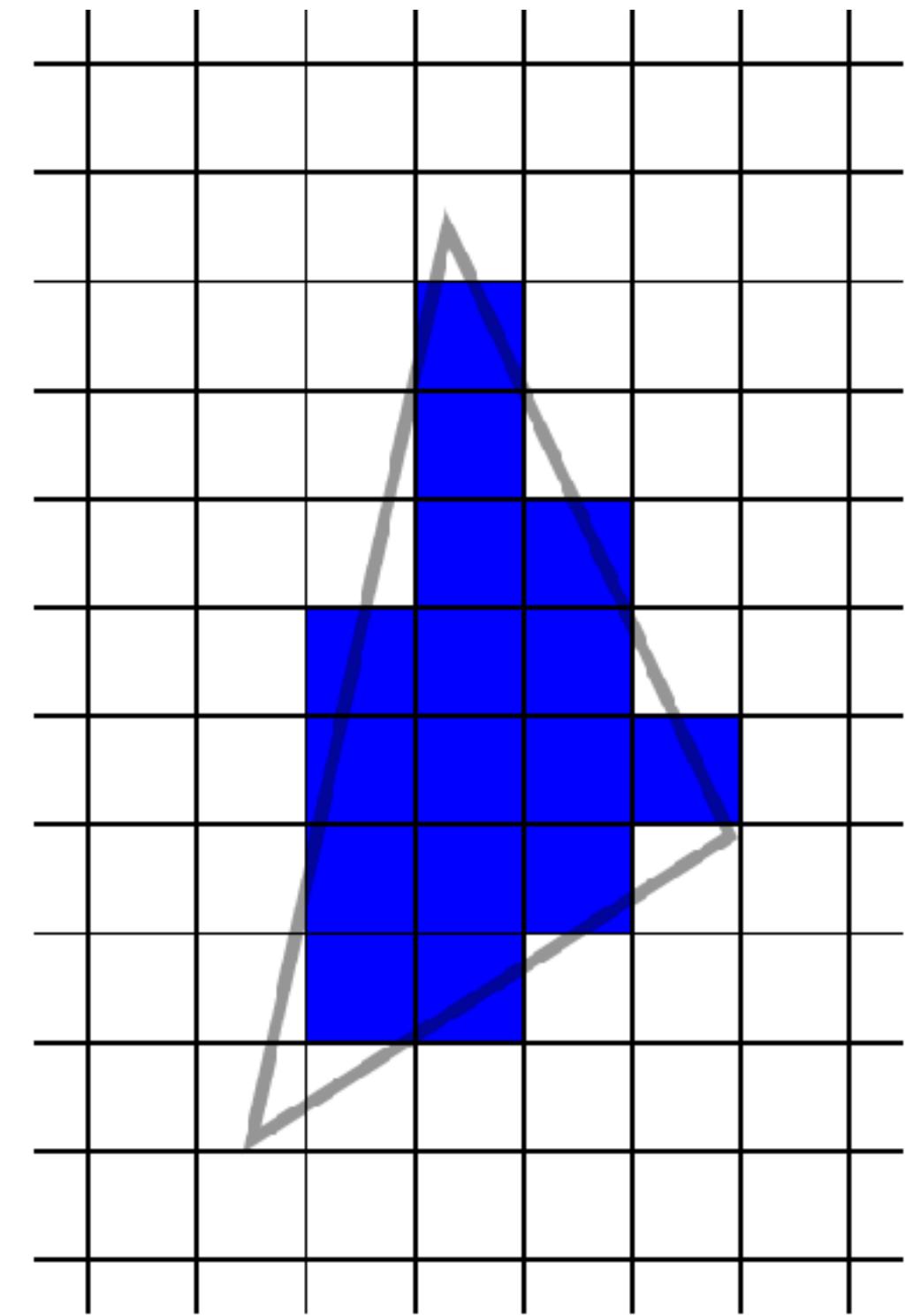
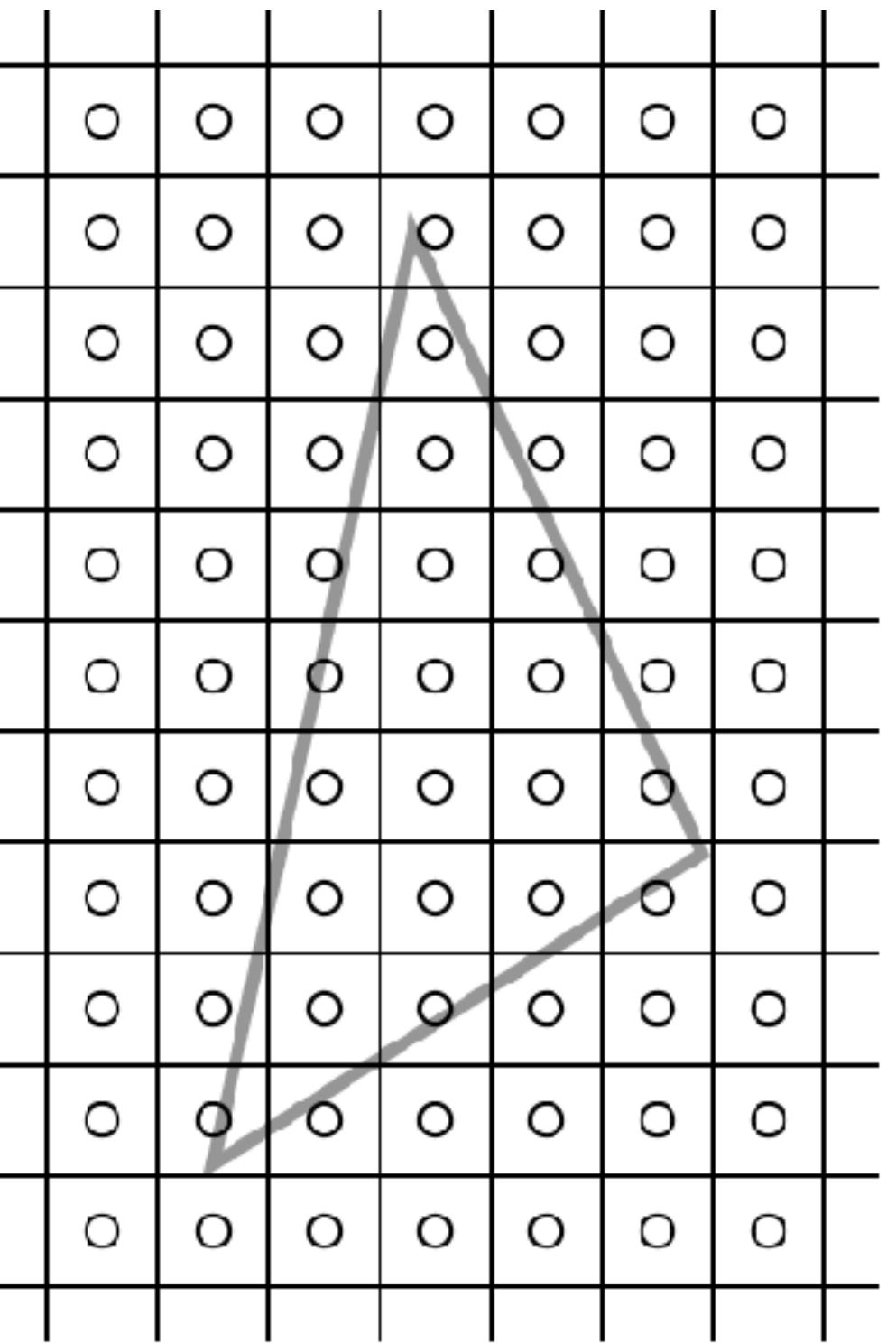
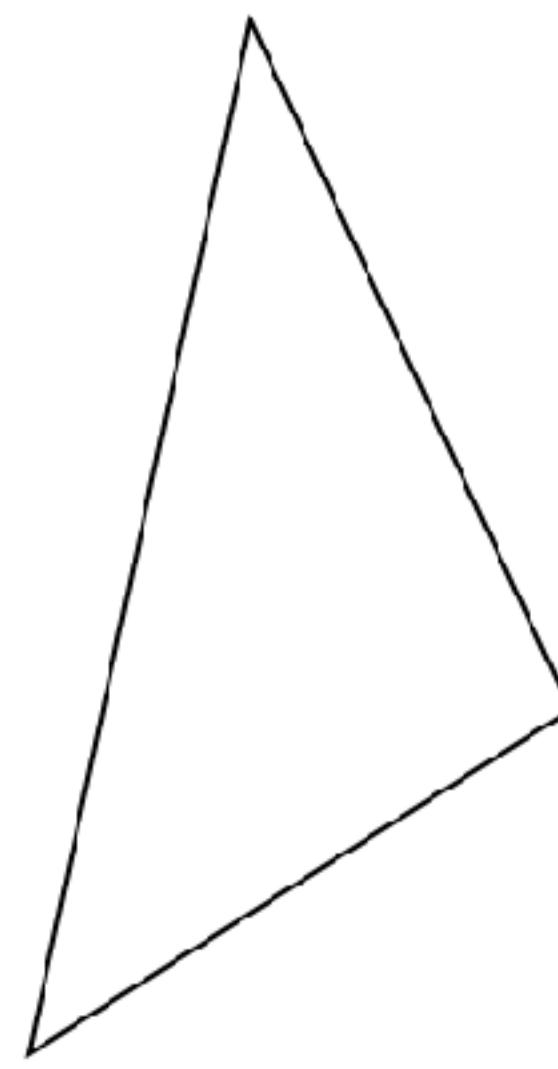


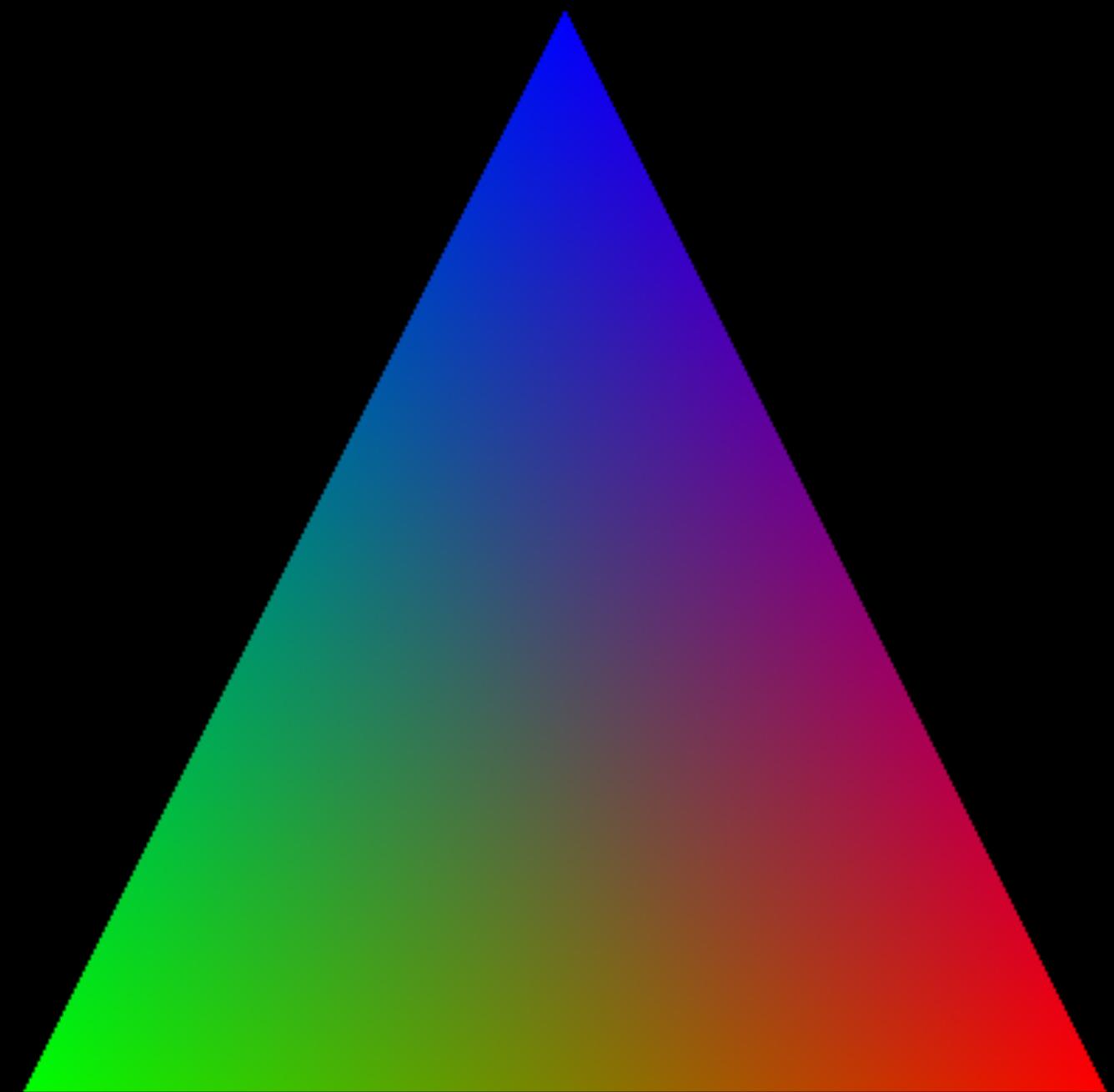


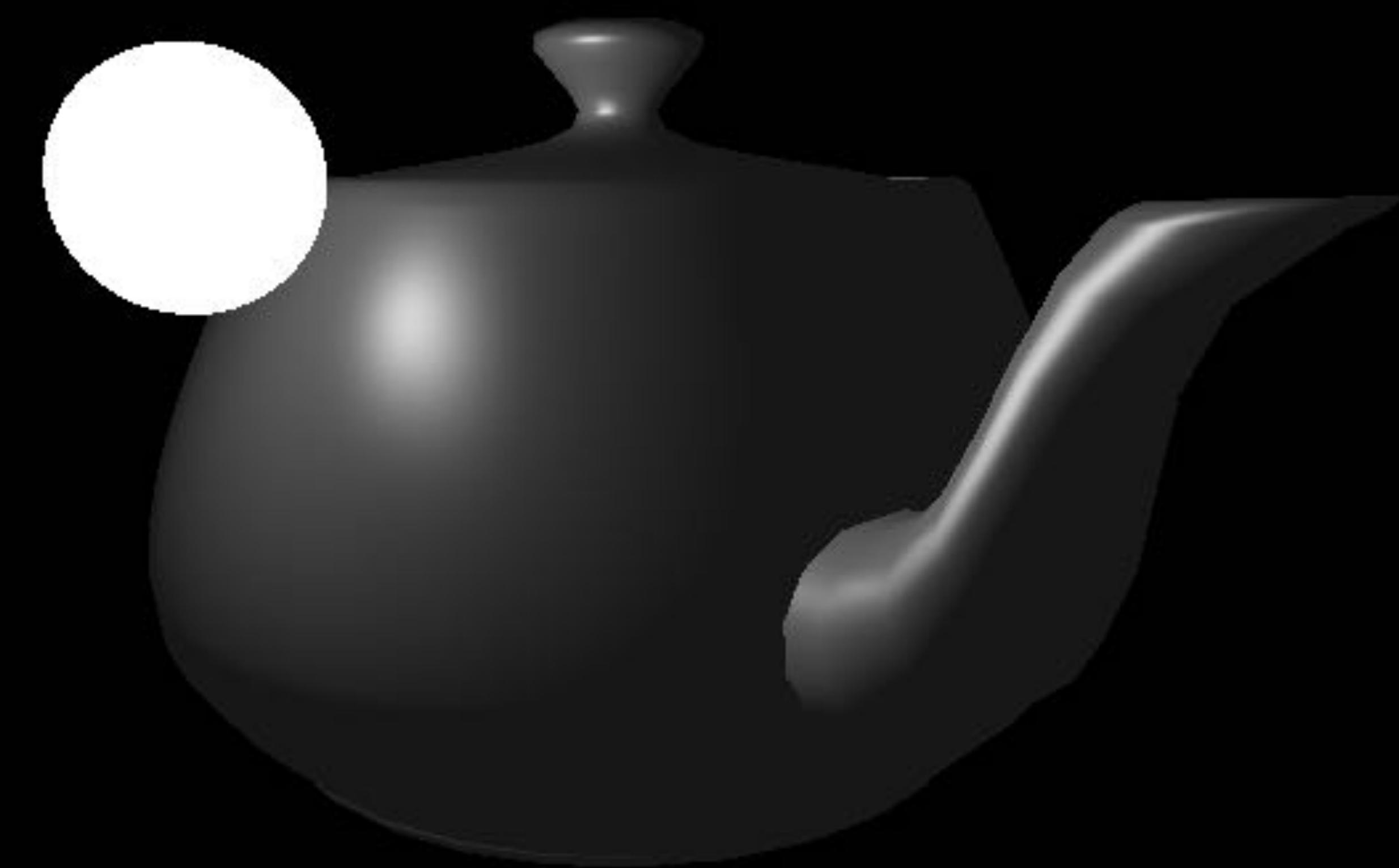


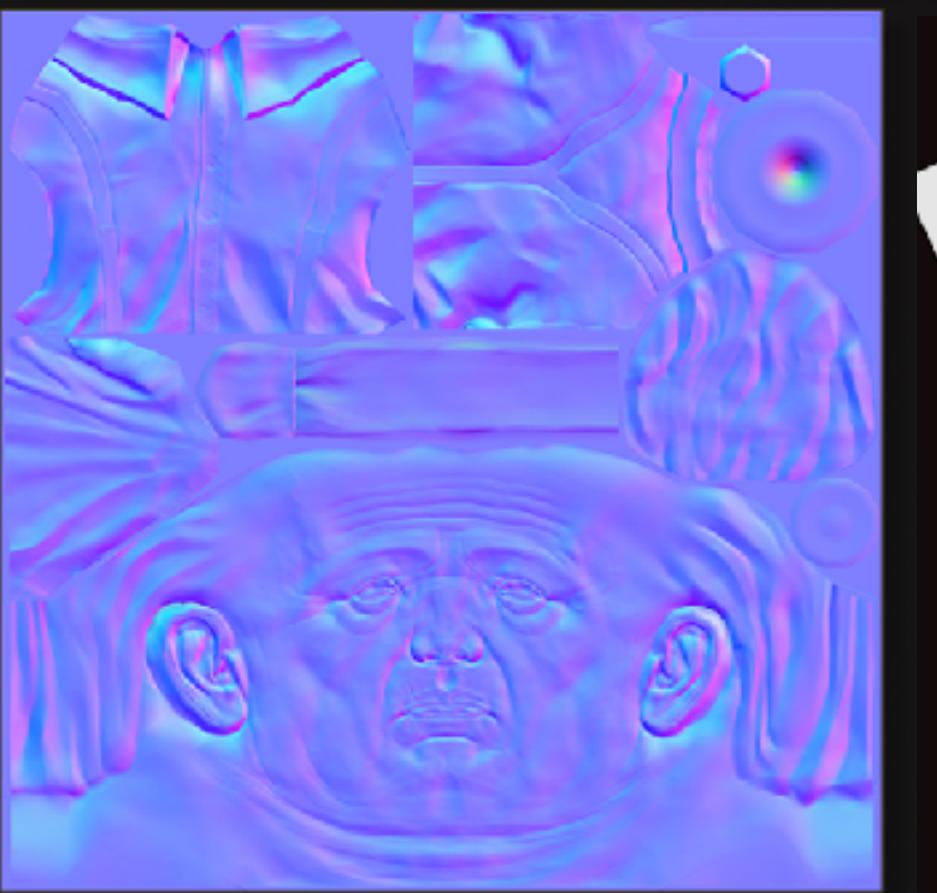
The fragment shader

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









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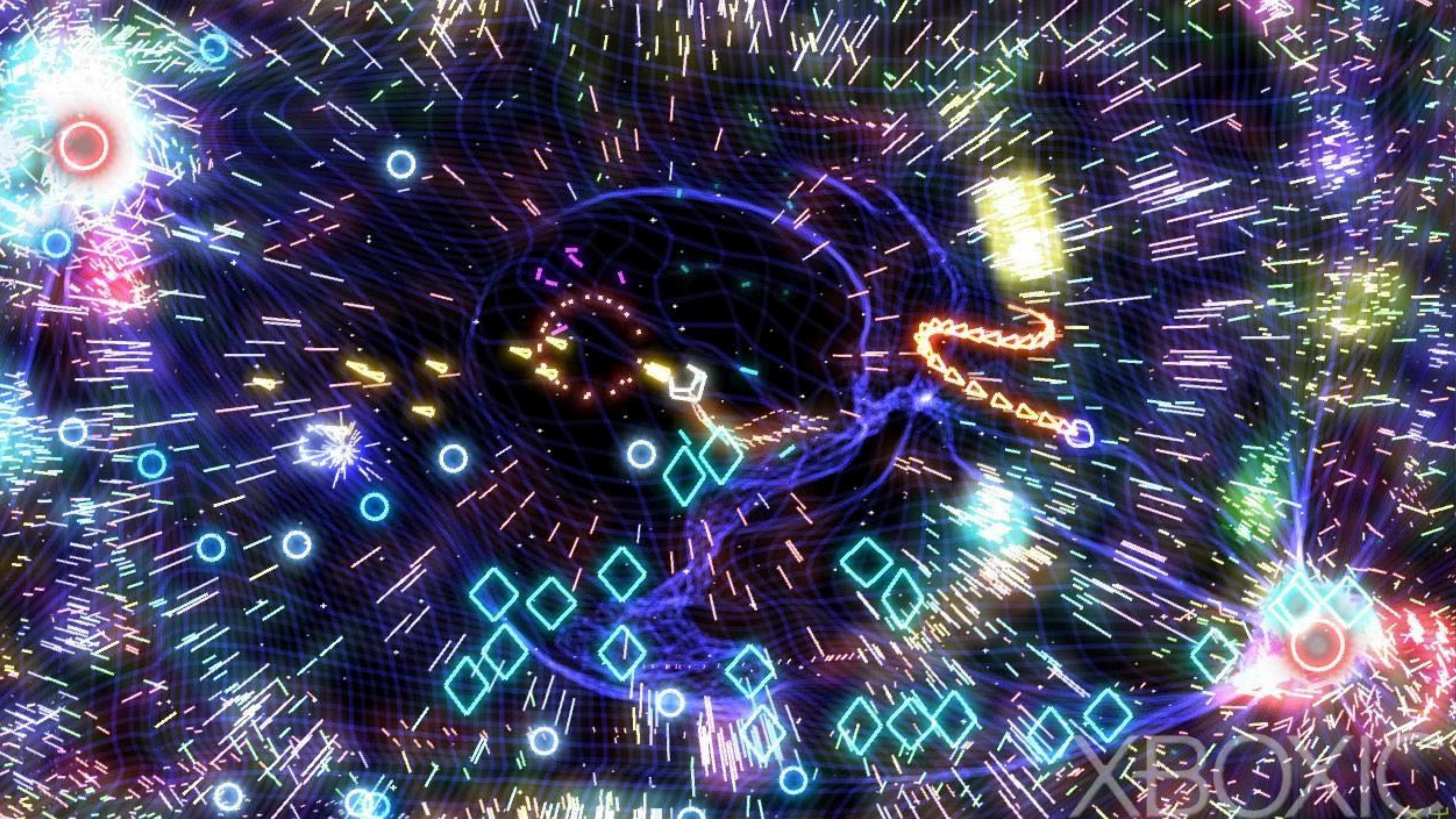




4 4 4

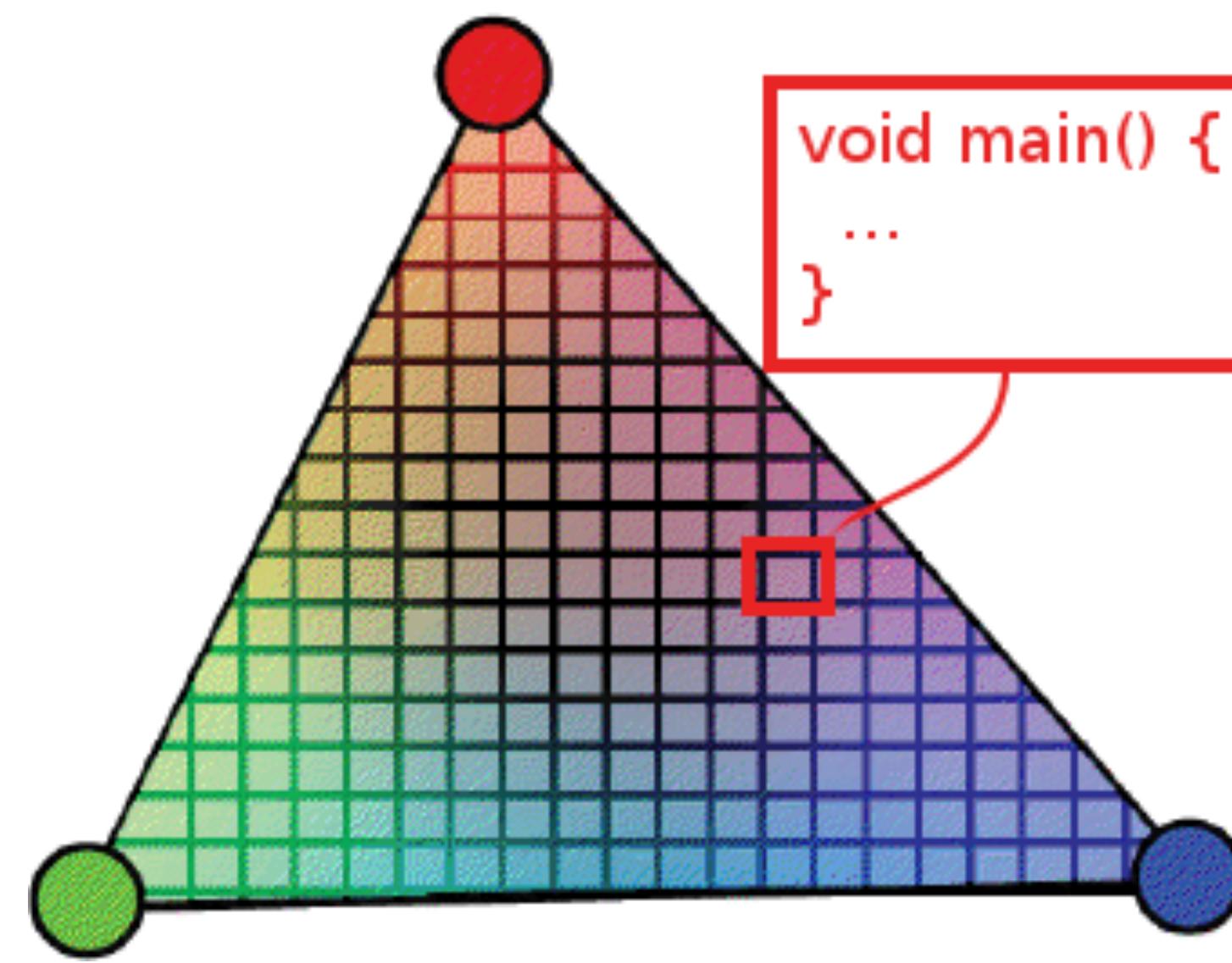
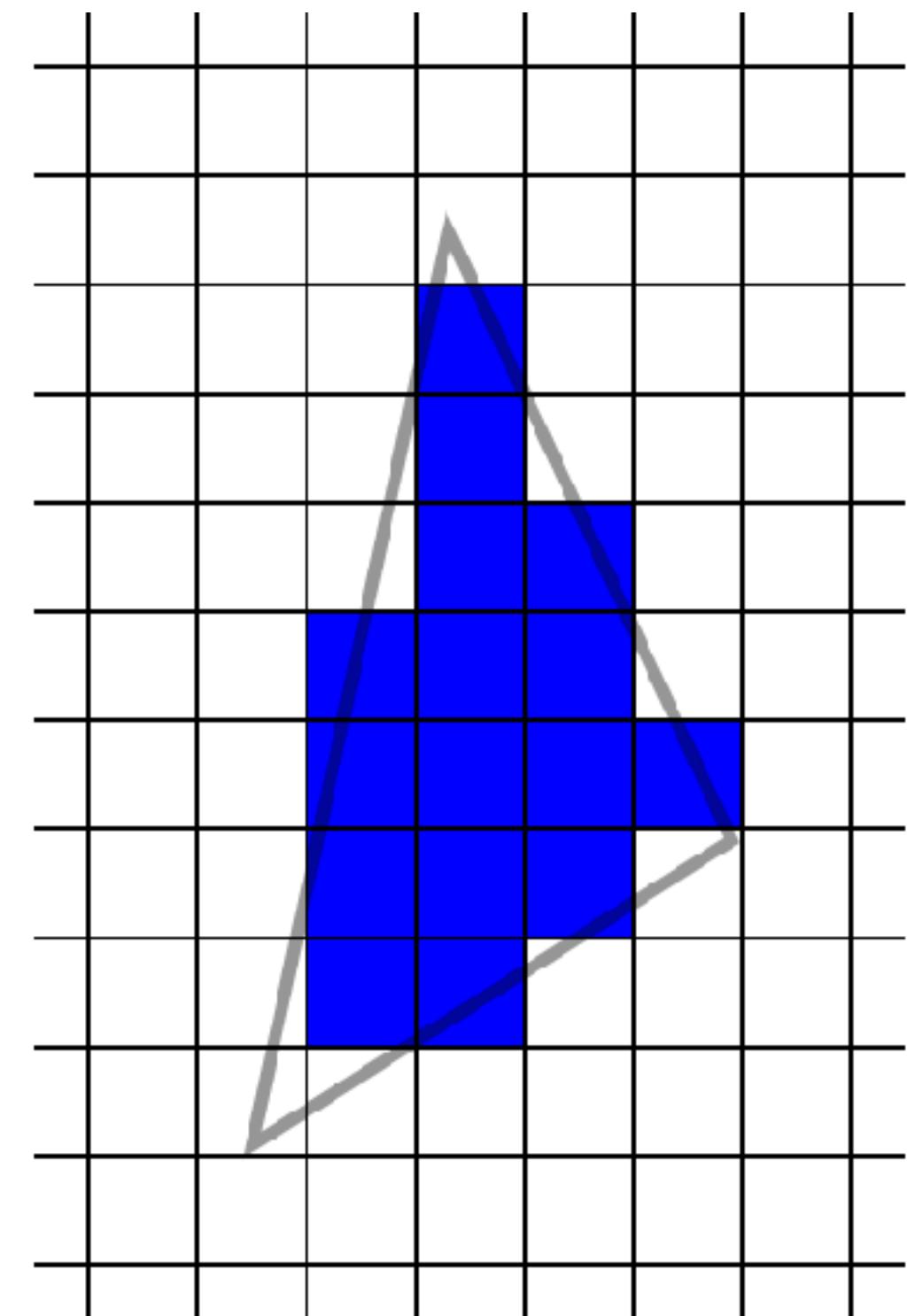
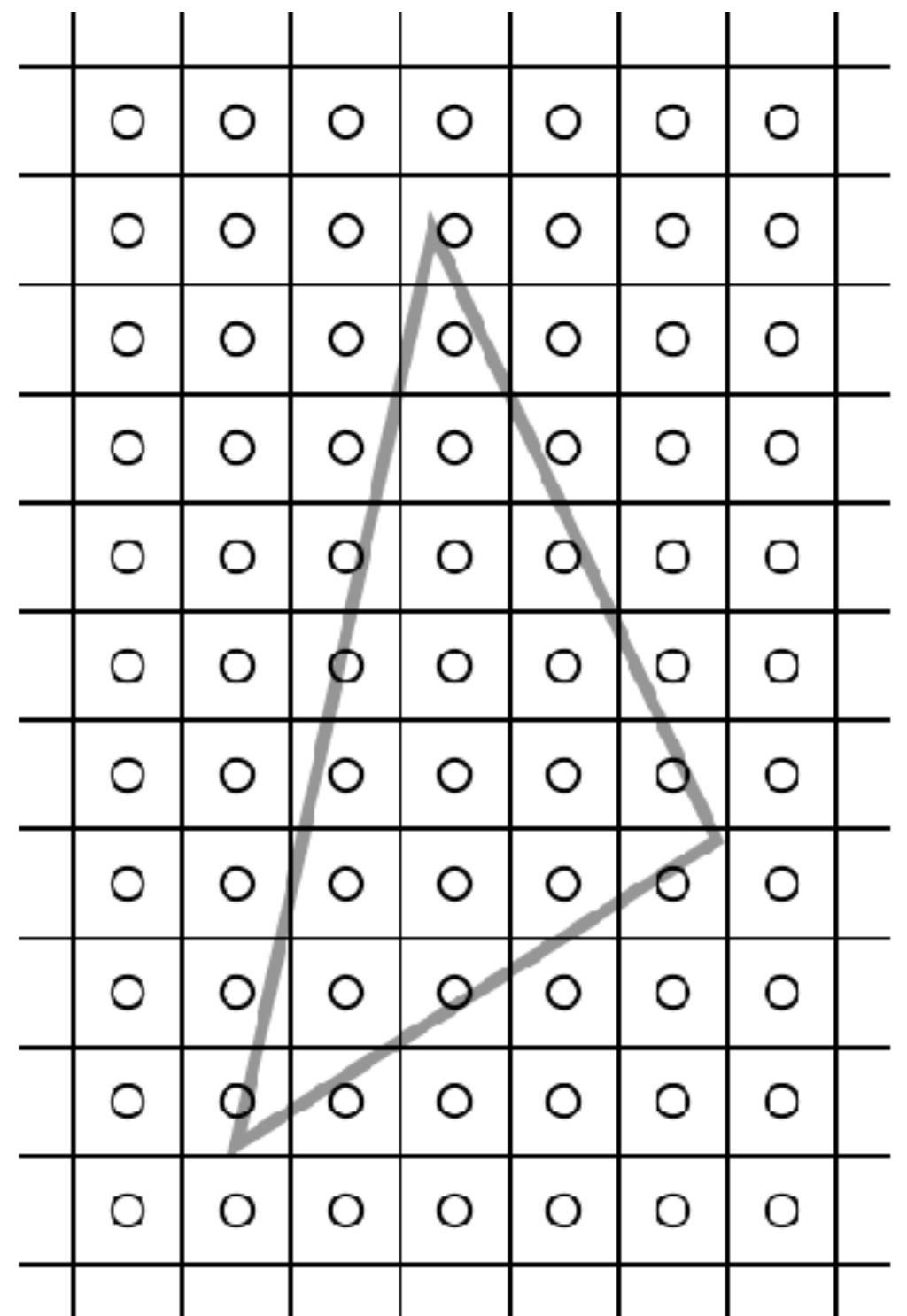
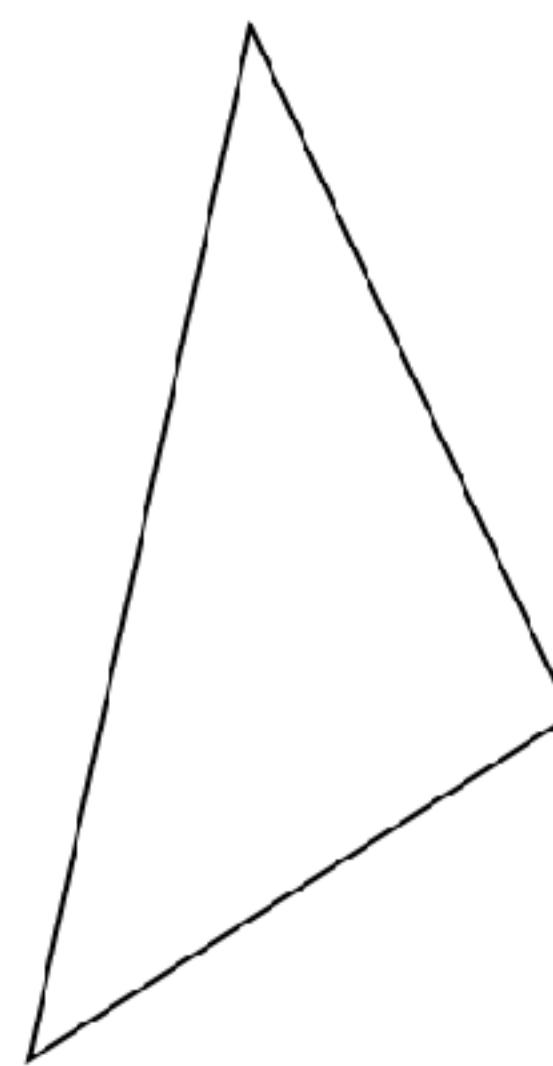
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The final shader program is a combination
of a vertex and a fragment shader.

Relationship between vertex and
fragment shaders.



GLSL

OpenGL Shading Language

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;  
  
varying vec2 texCoordVar;  
  
void main() {  
    gl_FragColor = texture2D(diffuse, texCoordVar);  
}
```

UNIFORMS

VARYING VARIABLES

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[0][0]);  
glUniformMatrix4fv(modelMatrixUniform, 1, GL_FALSE, &modelMatrix[0][0]);  
glUniformMatrix4fv(viewMatrixUniform, 1, GL_FALSE, &viewMatrix[0][0]);
```

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(positionAttribute, 2, GL_FLOAT, false, 0, vertices);  
 glEnableVertexAttribArray(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(texCoordAttribute, 2, GL_FLOAT, false, 0, texCoords);  
 glEnableVertexAttribArray(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 homogeneous `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 <i>degrees</i>)	degrees to radians
T degrees (T <i>radians</i>)	radians to degrees
T sin (T <i>angle</i>)	sine
T cos (T <i>angle</i>)	cosine
T tan (T <i>angle</i>)	tangent
T asin (T <i>x</i>)	arc sine
T acos (T <i>x</i>)	arc cosine
T atan (T <i>y</i> , T <i>x</i>)	arc tangent
T atan (T <i>y_over_x</i>)	

Exponential Functions [8.2]

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

T pow (T <i>x</i> , T <i>y</i>)	x^y
T exp (T <i>x</i>)	e^x
T log (T <i>x</i>)	\ln
T exp2 (T <i>x</i>)	2^x
T log2 (T <i>x</i>)	\log_2
T sqrt (T <i>x</i>)	square root
T inversesqrt (T <i>x</i>)	inverse square root

Common Functions [8.3]

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

T abs (T <i>x</i>)	absolute value
T sign (T <i>x</i>)	returns -1.0, 0.0, or 1.0
T floor (T <i>x</i>)	nearest integer $\leq x$
T ceil (T <i>x</i>)	nearest integer $\geq x$
T fract (T <i>x</i>)	$x - \text{floor}(x)$
T mod (T <i>x</i> , T <i>y</i>)	modulus
T mod (T <i>x</i> , float <i>y</i>)	
T min (T <i>x</i> , T <i>y</i>)	minimum value
T min (T <i>x</i> , float <i>y</i>)	
T max (T <i>x</i> , T <i>y</i>)	maximum value
T max (T <i>x</i> , float <i>y</i>)	
T clamp (T <i>x</i> , T <i>minVal</i> , T <i>maxVal</i>)	
T clamp (T <i>x</i> , float <i>minVal</i> , float <i>maxVal</i>)	$\min(\max(x, \text{minVal}), \text{maxVal})$
T mix (T <i>x</i> , T <i>y</i> , T <i>a</i>)	linear blend of <i>x</i> and <i>y</i>
T mix (T <i>x</i> , T <i>y</i> , float <i>a</i>)	
T step (T <i>edge</i> , T <i>x</i>)	0.0 if $x < \text{edge}$, else 1.0
T step (float <i>edge</i> , T <i>x</i>)	
T smoothstep (T <i>edge0</i> , T <i>edge1</i> , T <i>x</i>)	
T smoothstep (float <i>edge0</i> , float <i>edge1</i> , T <i>x</i>)	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 <i>x</i>)	length of vector
float distance (T <i>p0</i> , T <i>p1</i>)	distance between points
float dot (T <i>x</i> , T <i>y</i>)	dot product
vec3 cross (vec3 <i>x</i> , vec3 <i>y</i>)	cross product
T normalize (T <i>x</i>)	normalize vector to length 1
T faceforward (T <i>N</i> , T <i>I</i> , T <i>Nref</i>)	returns <i>N</i> if $\text{dot}(N_{\text{ref}}, I) < 0$, else - <i>N</i>
T reflect (T <i>I</i> , T <i>N</i>)	reflection direction $I - 2 * \text{dot}(N, I) * N$
T refract (T <i>I</i> , T <i>N</i> , float <i>eta</i>)	refraction vector

Matrix Functions [8.5]

Type mat is any matrix type.

mat matrixCompMult (mat <i>x</i> , mat <i>y</i>)	multiply <i>x</i> by <i>y</i> 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 bvecn; vec is vecn; ivec is ivec n (where n is 2, 3, or 4). T is the union of vec and ivec.

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

Texture Lookup Functions [8.7]

Available only in vertex shaders.

vec4 texture2DLod (sampler2D <i> sampler</i> , vec2 <i>coord</i> , float <i>lod</i>)	
vec4 texture2DProjLod (sampler2D <i> sampler</i> , vec3 <i>coord</i> , float <i>lod</i>)	
vec4 texture2DProjLod (sampler2D <i> sampler</i> , vec4 <i>coord</i> , float <i>lod</i>)	
vec4 textureCubeLod (samplerCube <i> sampler</i> , vec3 <i>coord</i> , float <i>lod</i>)	

Available only in fragment shaders.

vec4 texture2D (sampler2D <i> sampler</i> , vec2 <i>coord</i> , float <i>bias</i>)	
vec4 texture2DProj (sampler2D <i> sampler</i> , vec3 <i>coord</i> , float <i>bias</i>)	
vec4 texture2DProj (sampler2D <i> sampler</i> , vec4 <i>coord</i> , float <i>bias</i>)	
vec4 textureCube (samplerCube <i> sampler</i> , vec3 <i>coord</i> , float <i>bias</i>)	

Available in vertex and fragment shaders.

vec4 texture2D (sampler2D <i> sampler</i> , vec2 <i>coord</i>)	
vec4 texture2DProj (sampler2D <i> sampler</i> , vec3 <i>coord</i>)	
vec4 texture2DProj (sampler2D <i> sampler</i> , vec4 <i>coord</i>)	
vec4 textureCube (samplerCube <i> sampler</i> , vec3 <i>coord</i>)	

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);
```