COMP3320 Introduction to OpenGL

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Based on the work provided at `www.learnopengl.com`

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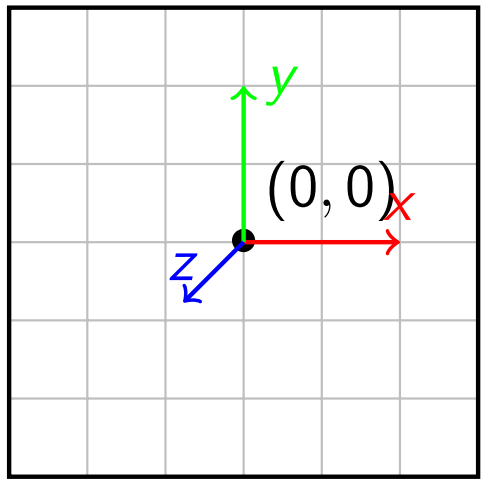
OpenGL Coordinates

- OpenGL uses a right-handed coordinate system
- OpenGL uses normalised device coordinates

$(1, 1)$



$(-1, -1)$

- OpenGL will map the normalised device coordinates to the viewport dimensions
  - $(-1, -1) \rightarrow (0, 0)$
  - $(1, 1) \rightarrow (800, 600)$

OpenGL Coordinate Spaces

- Local Space: 3D coordinates which are local to an object
- World Space: 3D coordinates within the world. The model matrix is used to transform coordinates from local space to world space
- View Space: Also known as camera space or eye space. View space is the camera's perspective of your world. The view matrix is used to transform coordinates from world space to view space
- Clip Space: A projection from view space to normalised device coordinates. The projection matrix is used to perform this projection. OpenGL expects the output of the vertex shader to be in clip space

OpenGL Shaders - Pipeline 1

- Vertex Data: A list of 3D vertex coordinates and associated vertex attributes (we will come back to these later)
- Vertex Shader: Transforms vertex coordinates from model space to clip space
- Shape Assembly: Assembles transformed vertices into a given primitive shape (e.g. triangles)
- Geometry Shader: Transforms shape geometry by emitting new vertices
- Rasterization: Maps primitives to pixel space and creates fragments
- Fragment Shader: Calculates the final colour for a fragment
- Tests and Blending: Performs depth testing and alpha blending

OpenGL Shaders - Pipeline 2

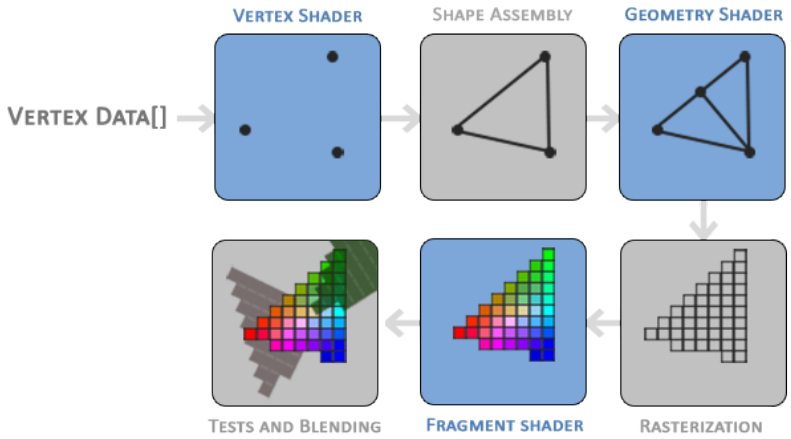


Figure: Graphics pipeline stages.

Image sourced from
`learnopengl.com/Getting-started/Hello-Triangle`

OpenGL Shaders

- Written in OpenGL Shader Language (GLSL)
- A simple vertex shader

```
#version 330 core
layout (location = 0) in vec3 aPosition;
void main() { gl_Position = vec4(aPosition, 1.0); }
```

- A simple fragment shader

```
#version 330 core
out vec4 FragColour;
void main() {
    FragColour = vec4(1.0f, 0.5f, 0.2f, 1.0f);
}
```

- Create a shader using `glCreateShader`
- Attach shader source code using `glShaderSource`
- Compile a shader using `glCompileShader`

OpenGL Shader Programs

- Consists of multiple OpenGL shaders
  - If you have a vertex shader, you must have a fragment shader
  - If you have a fragment shader, you must have a vertex shader
  - Geometry shader is optional
- Create a shader program using `glCreateProgram`
- Attach shaders to the program using `glAttachShader`
- Link attached shaders together into the final program using `glLinkProgram`
- Make a shader program active by using `glUseProgram`

Vertex Buffer Objects

- Stores vertex data in GPU memory
- To create a vertex buffer use `glGenBuffers`
- Program could consist of multiple different vertex buffers. To make a vertex buffer active use `glBindBuffer`
- Vertex data is defined as a list of 3D coordinates (and optionally vertex attributes)

```
float vertices[] = {-0.5f, -0.5f, 0.0f,
                     0.5f, -0.5f, 0.0f,
                     0.0f,  0.5f, 0.0f };
```

- To copy vertex data to GPU memory use `glBufferData`

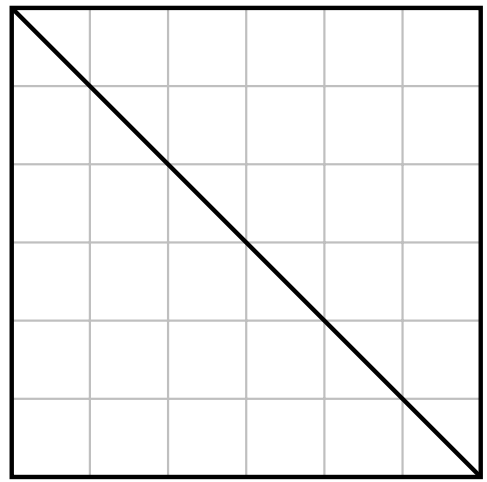
Vertex Array Objects

- Manages vertex buffer objects and vertex attributes
- To create a vertex array use `glGenVertexArrays`
- Program could consist of multiple different vertex arrays. To make a vertex array active use `glBindVertexArray`
- Bind and configure vertex buffer objects after binding the vertex array
- To configure and enable a vertex attribute use `glVertexAttribPointer` followed by `glEnableVertexAttribArray`
- To render a vertex array use `glBindVertexArray` followed by `glDrawArrays` or another OpenGL drawing command

Element Buffer Objects

- Stores indexes into the list of vertex data
- Makes it easy to draw shapes which share vertices
  - An easy example is a square, which contains 2 triangles

$(-0.5, 0.5)$ $(0.5, 0.5)$



$(-0.5, -0.5)$ $(0.5, -0.5)$

  - The naive way to draw this square would be to draw two triangles by specifying six vertices. Two of the vertices would be repeated
  - The better way would be to list the four vertices in the square and use an element buffer object

Element Buffer Objects

- To create an element buffer use `glGenBuffers`
- Program could consist of multiple different element buffers. To make an element buffer active use `glBindBuffer`
- Element data is defined as a list of integer indices

```
float vertices[] = {-0.5f, -0.5f, 0.0f,
                     0.5f, -0.5f, 0.0f,
                     0.5f,  0.5f, 0.0f,
                    -0.5f,  0.5f, 0.0f };
unsigned int indices[] = {0, 1, 3,
                          1, 2, 3 };
```

- To copy index data to GPU memory use `glBufferData`
- To draw an element buffer use `glDrawElements`
- Vertex arrays will also track element buffers