Computer Graphics and OpenGL

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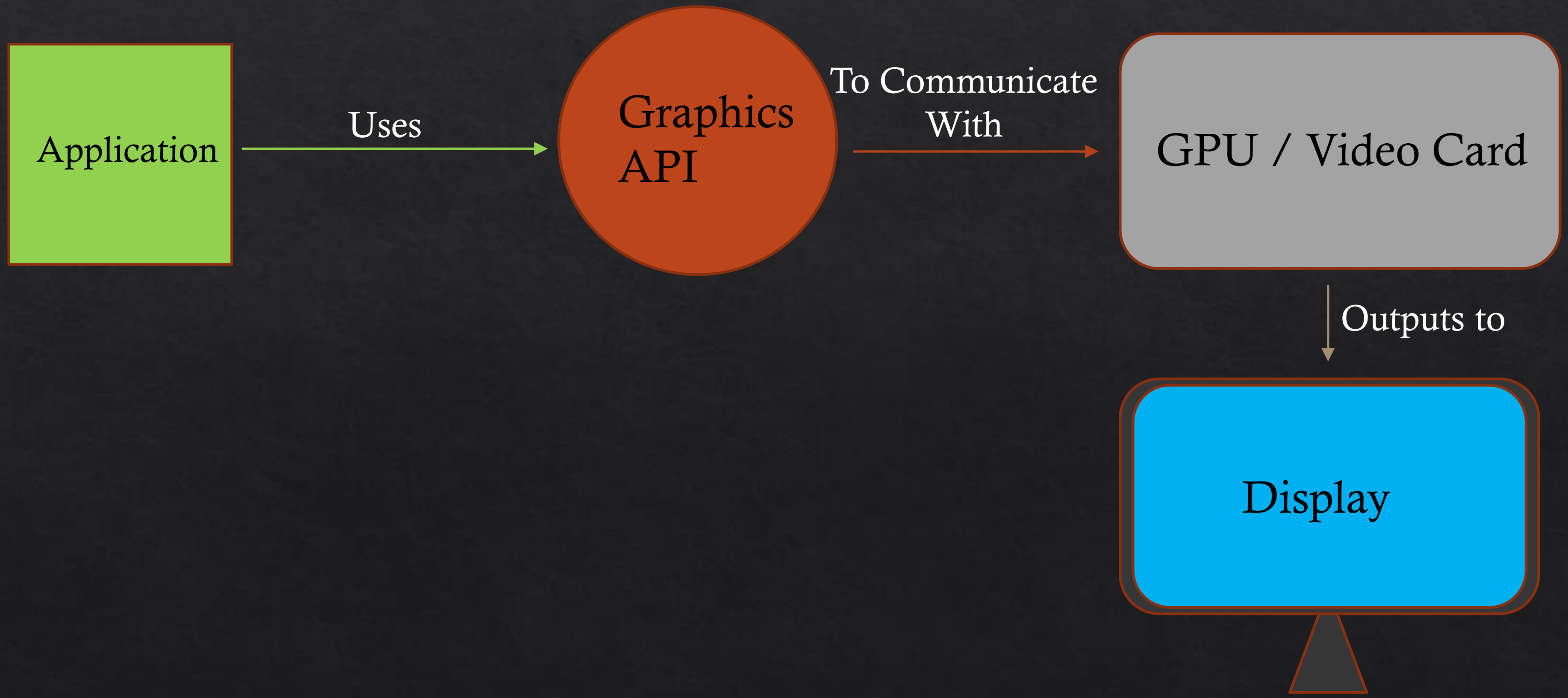
Overview

- General Overview of Computer Graphics
- OpenGL and some alternatives
- How OpenGL works
- An Example
- References

How Computers Output Graphics

- In General



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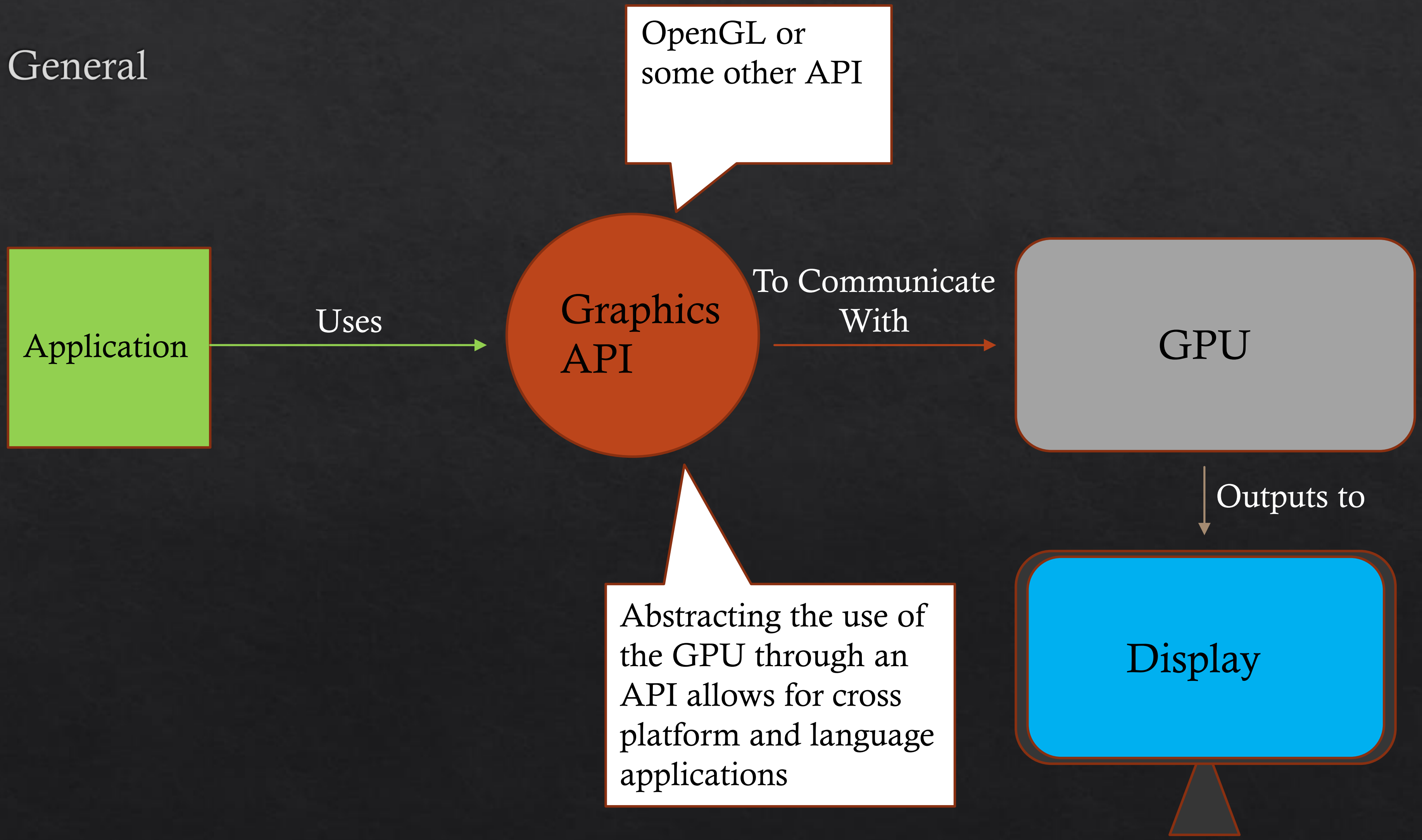

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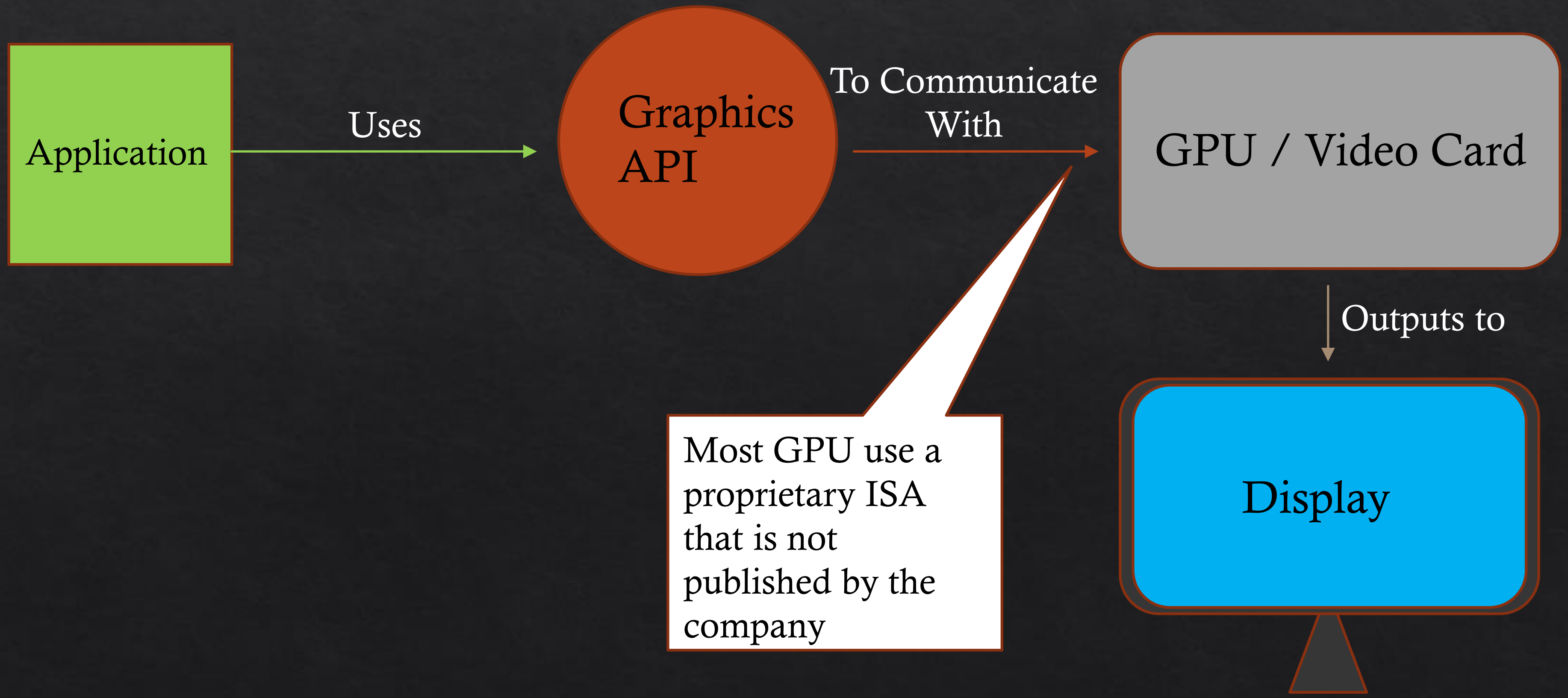

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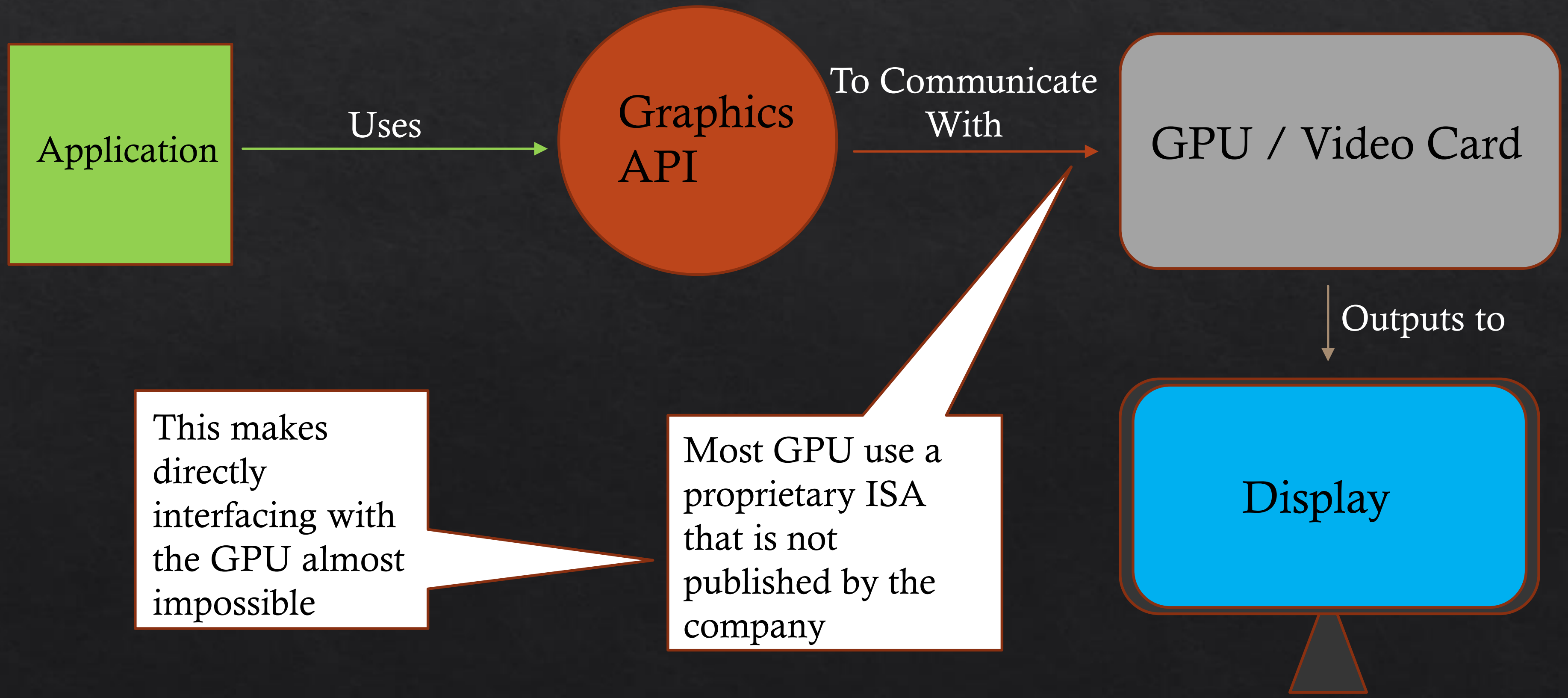

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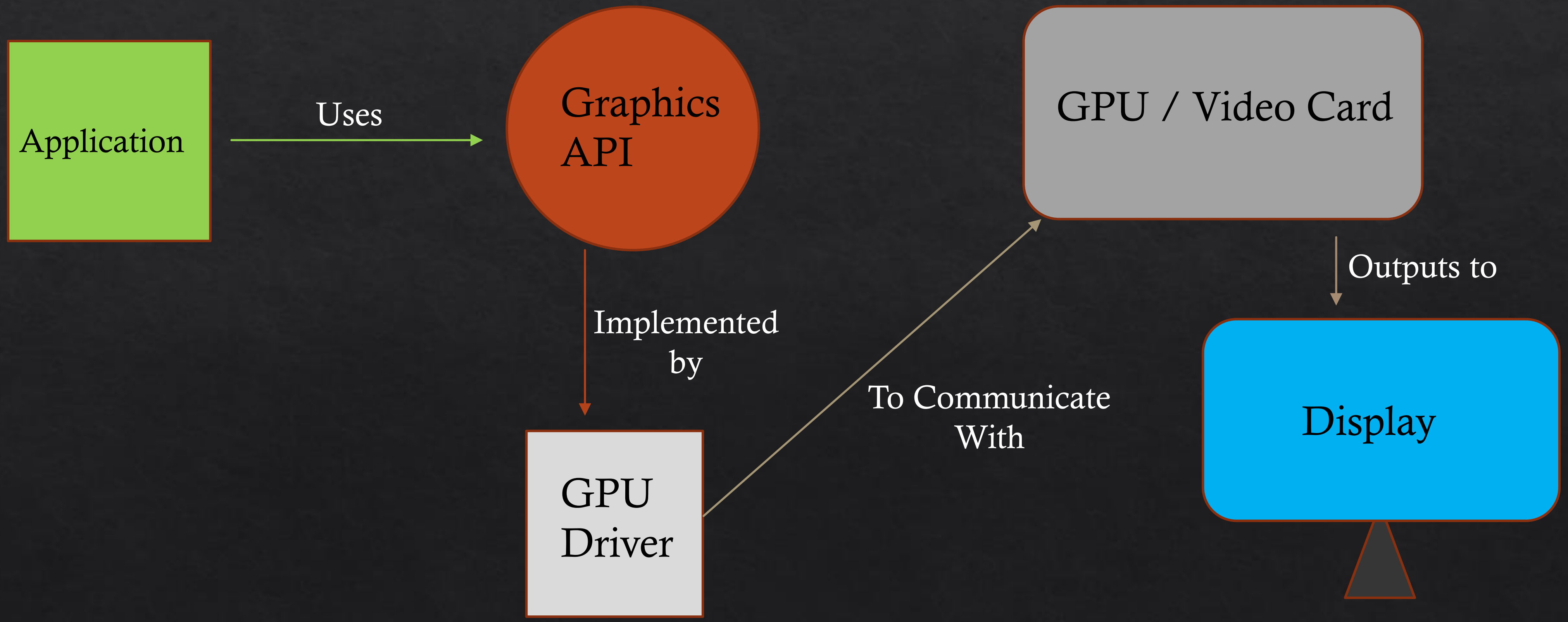

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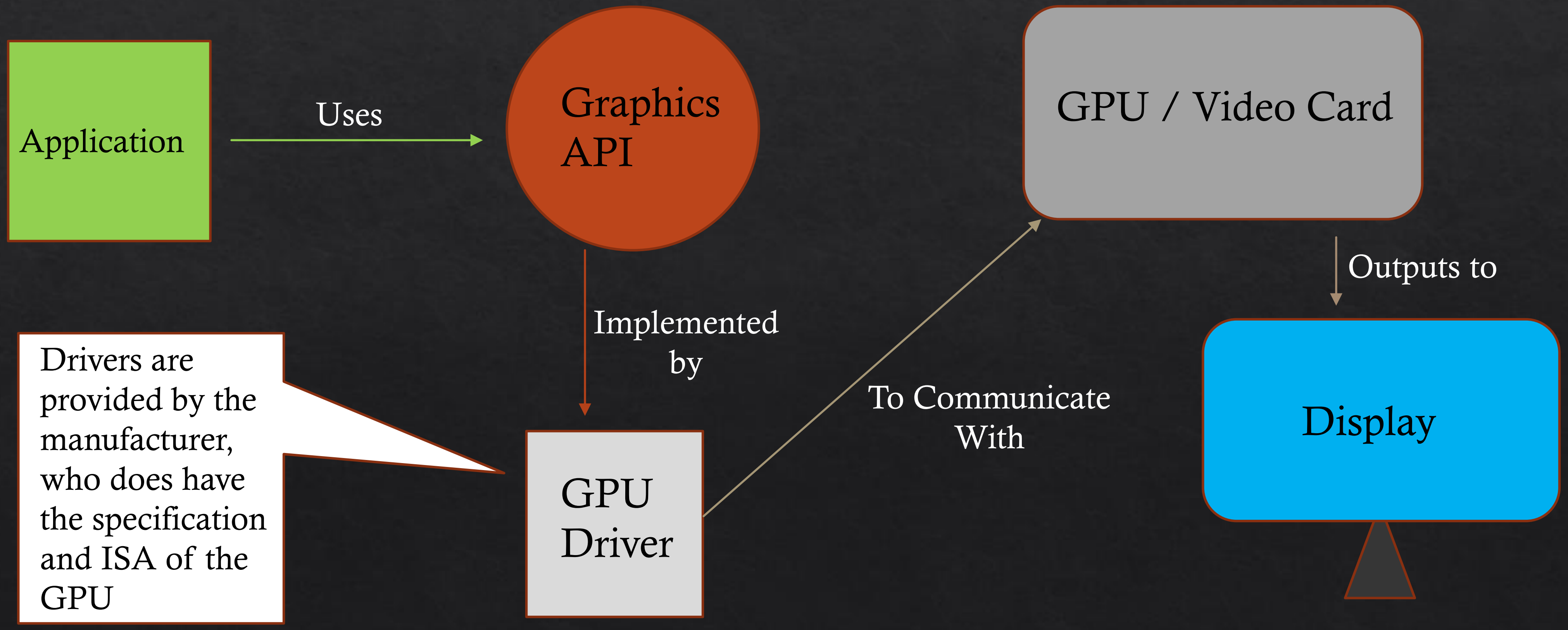

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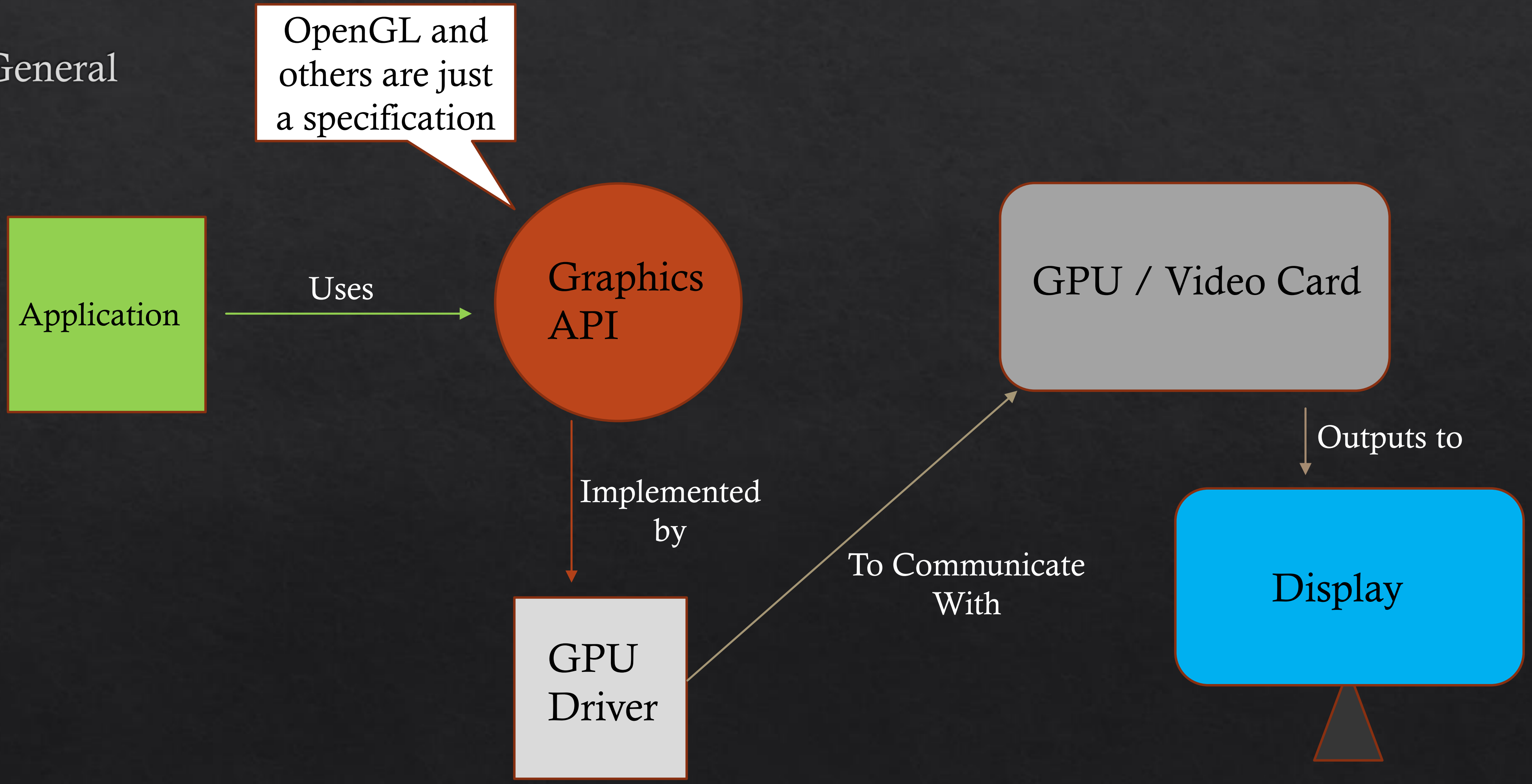

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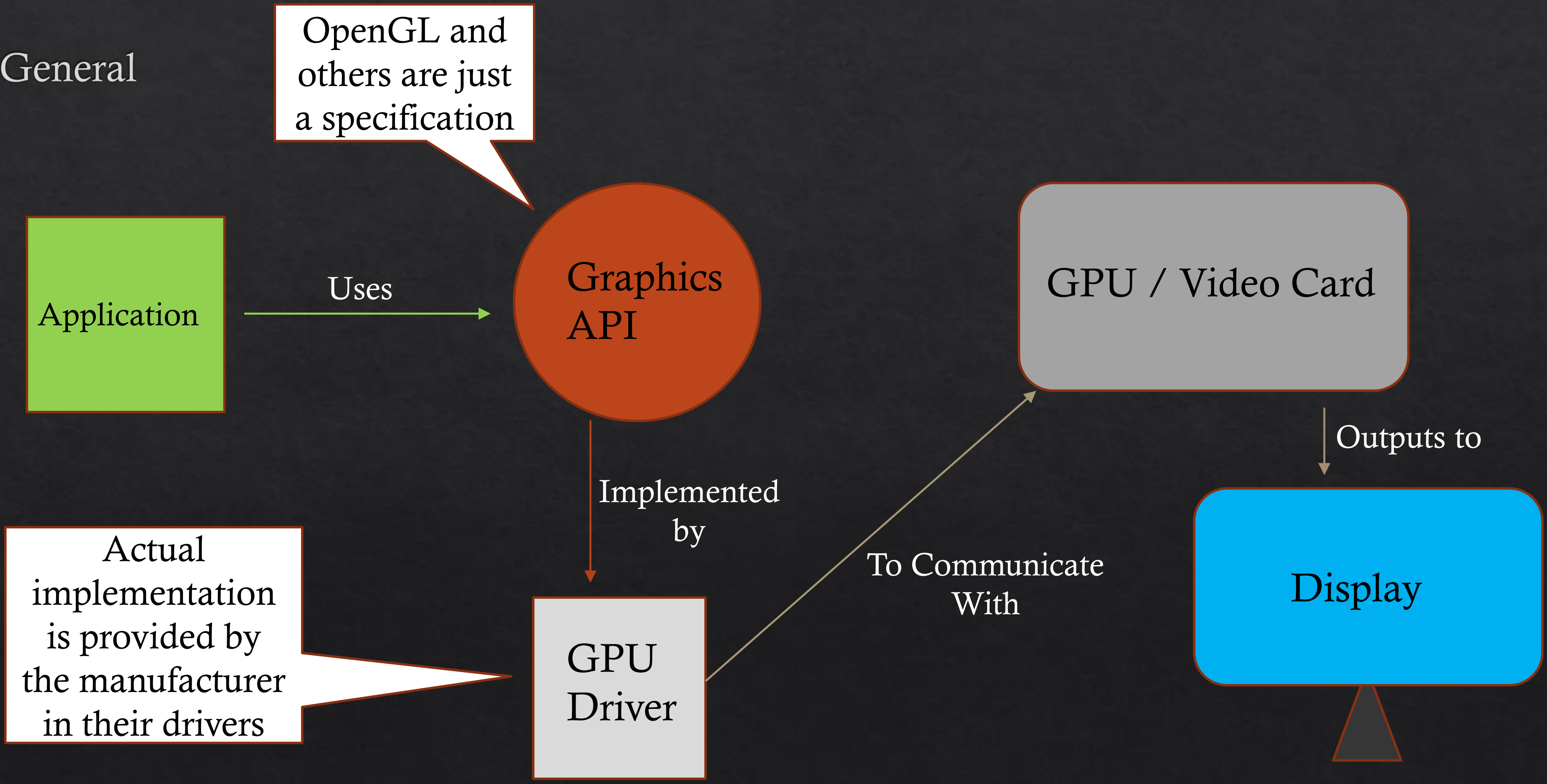

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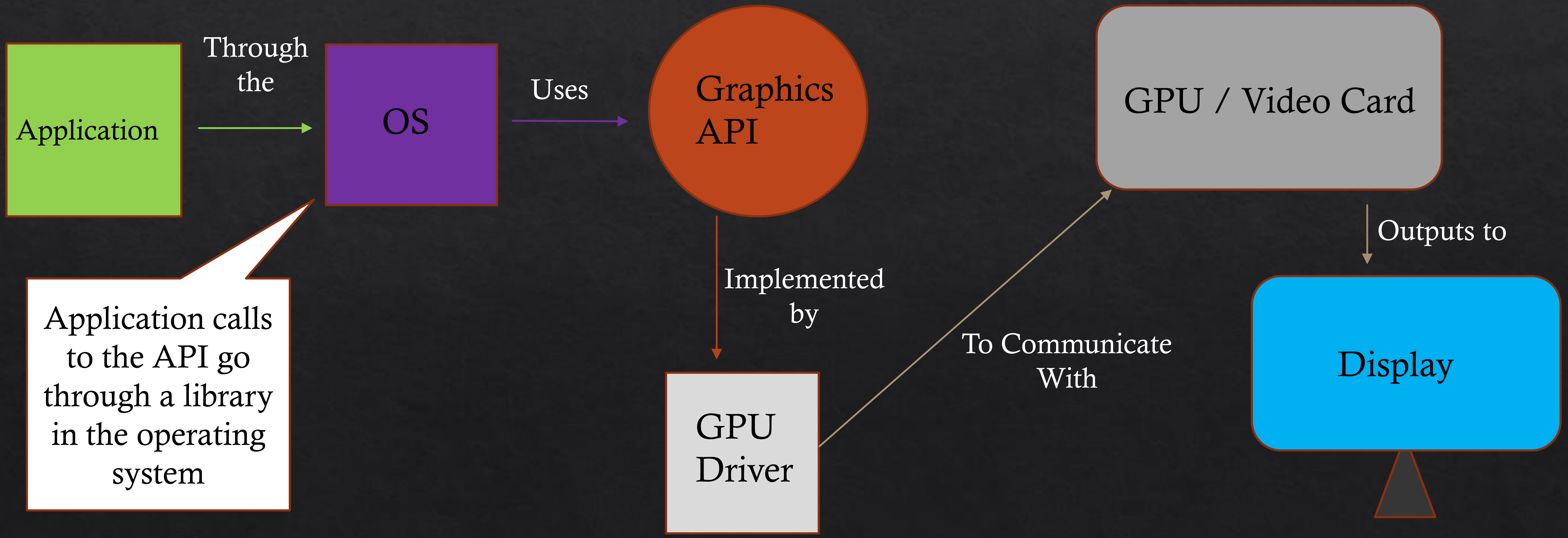

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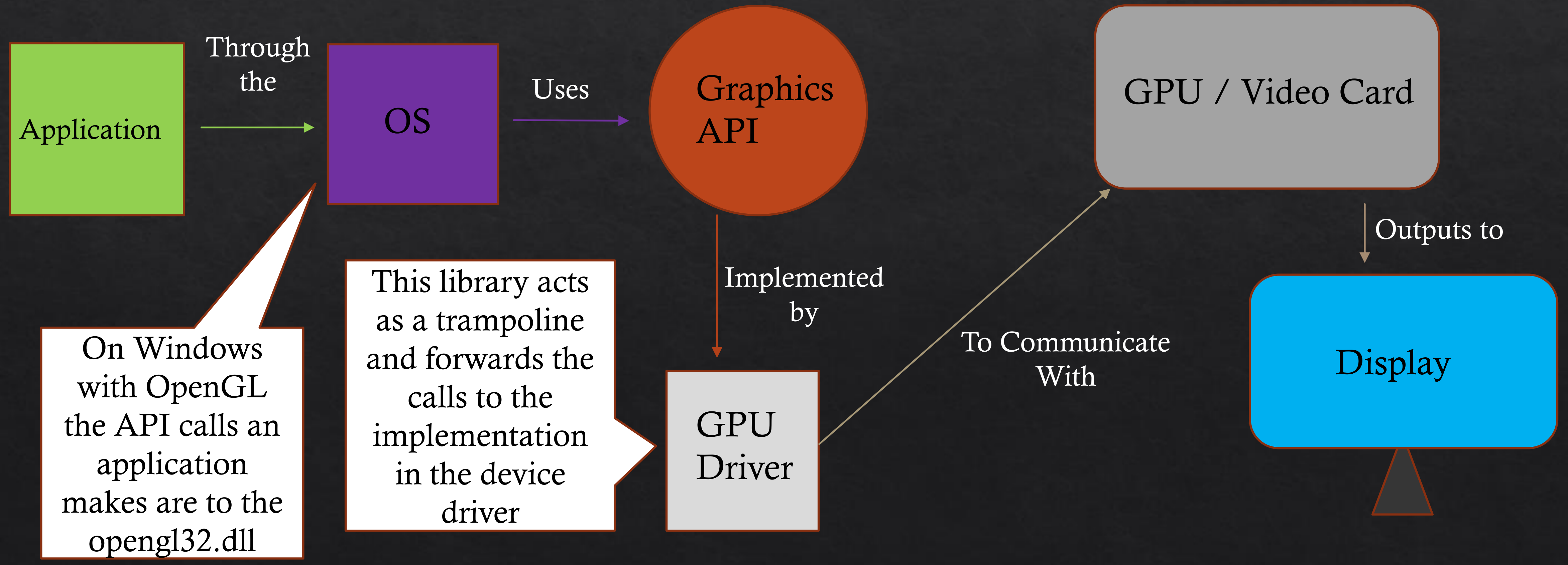

What is OpenGL

- Application Programmer Interface
- Specification not an Implementation
- Cross-Platform (OS)
- Cross-Language
- Specification is maintained by the **Khronos Group** consortium
- Widely used across all platforms and applications

Other Graphics APIs – Direct3d

- Microsoft's 3D graphics API
- 3D graphics API within the DirectX libraries
- Is widely used in for video games
- Only available on Windows

Other Graphics APIs - Vulcan

- Also maintained by the Khronos Group
- Developed to be the successor of OpenGL
- Provide a lower-level API giving more direct access to the GPU
- Improved performance over OpenGL
- Specification was released in 2016
- Starting to see wider adoption across the industry

Computer Graphics Without an API?

- It is entirely possible to calculate an image and display within a window
- On windows it would require an operating system call like **BitBLt**
- Windows also provides the graphic device interface (GDI)
  - Allows the users simple access to graphical programing without using the GPU or video card
  - Cannot do 3D graphics
  - Struggles with 2D animation
- Generally everything displayed on the monitor is at least piped through the GPU / Video Card

General Computing APIs

- GPU's are extremely useful for computing outside of graphics
- Until fairly recently, utilizing GPUs was done by bending OpenGL to accomplish the task
- OpenCL is focused on heterogeneous computing
  - Is also maintained by the Khronos Group
- Cuda is focused on general purpose use of GPUs
  - Maintained by and only functions on GPUs manufactured by Nvidia

How OpenGL Works

- OpenGL is a large state machine
- A large collection of variables define how OpenGL should currently operate
- For example, to change OpenGL from drawing triangles to lines we change the context variable that defines how it should draw
- The current state of OpenGL is called the context

How OpenGL Works

- The Birds Eye View of steps to operating OpenGL
  - Create a Window
  - Create an OpenGL context
  - Give OpenGL data to render
  - Set OpenGL to the desired context
  - Have OpenGL render

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OpenGL cannot operate without a window

OpenGL Objects

- The context and data OpenGL is working with are controlled by OpenGL objects
- Objects are an abstraction that allows for easier translation to higher languages
- OpenGL libraries are usually implemented in C, so objects can be thought of as more as structs

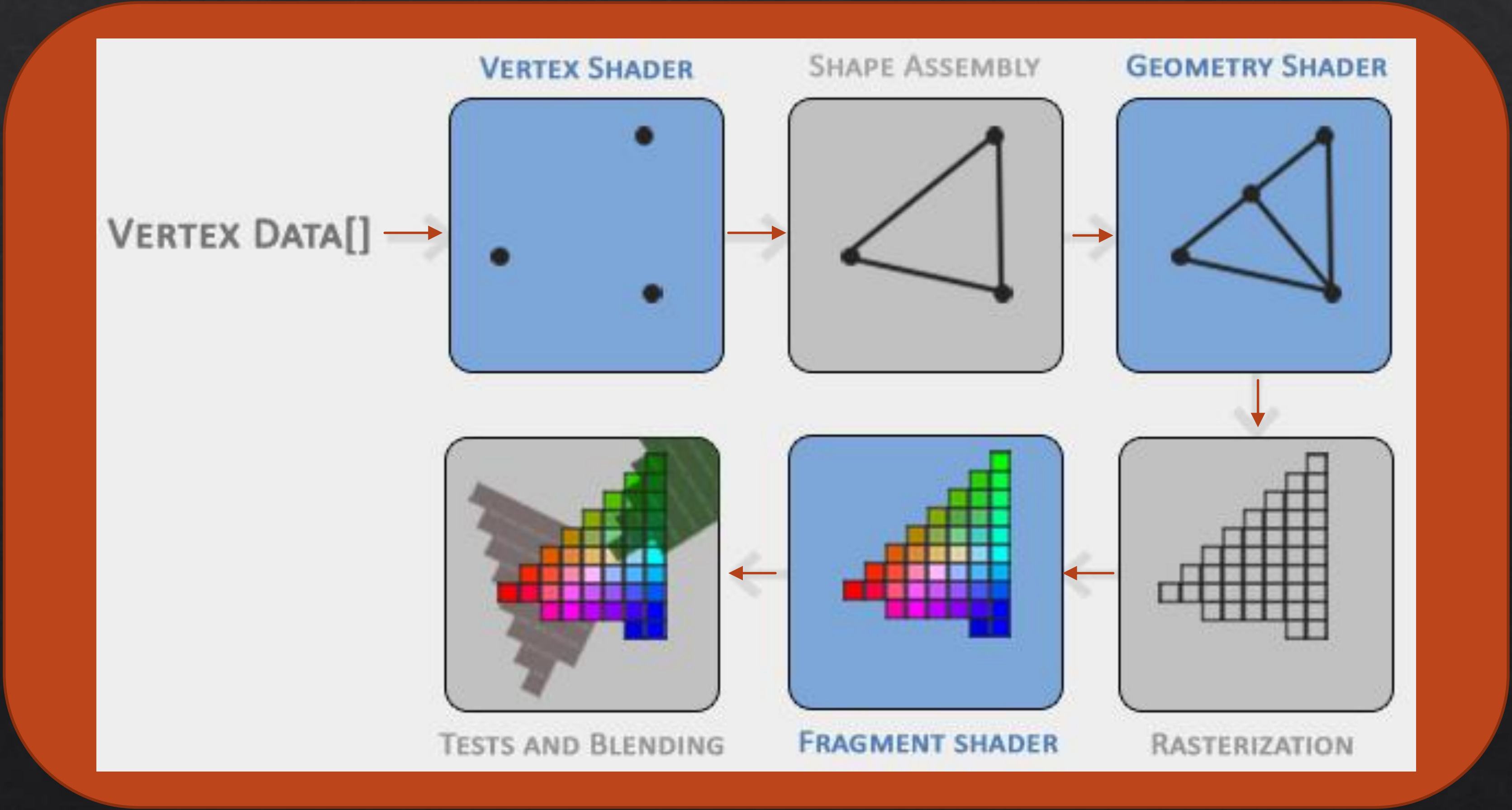
OpenGL Objects

- Creating and using an object involves the following workflow

```
// create object
unsigned int objectId = 0;
glGenObject(1, &objectId);
// bind/assign object to context
glBindObject(GL_WINDOW_TARGET, objectId);
// set options of object currently bound to GL_WINDOW_TARGET
glSetObjectOption(GL_WINDOW_TARGET, GL_OPTION_WINDOW_WIDTH,  800);
glSetObjectOption(GL_WINDOW_TARGET, GL_OPTION_WINDOW_HEIGHT, 600);
// set context target back to default
glBindObject(GL_WINDOW_TARGET, 0);
```

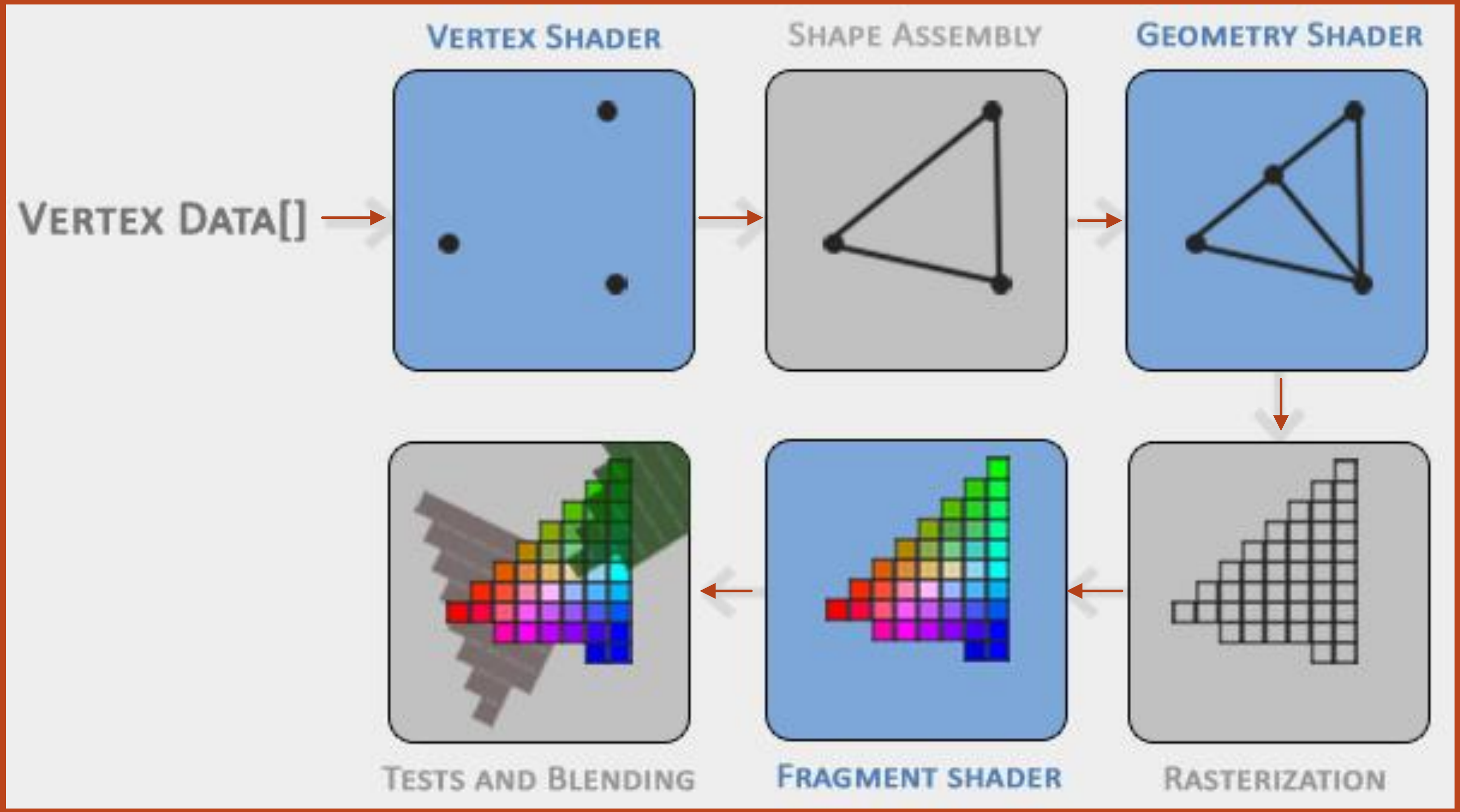
The OpenGL Graphics Pipeline

- Well a simplified version of it



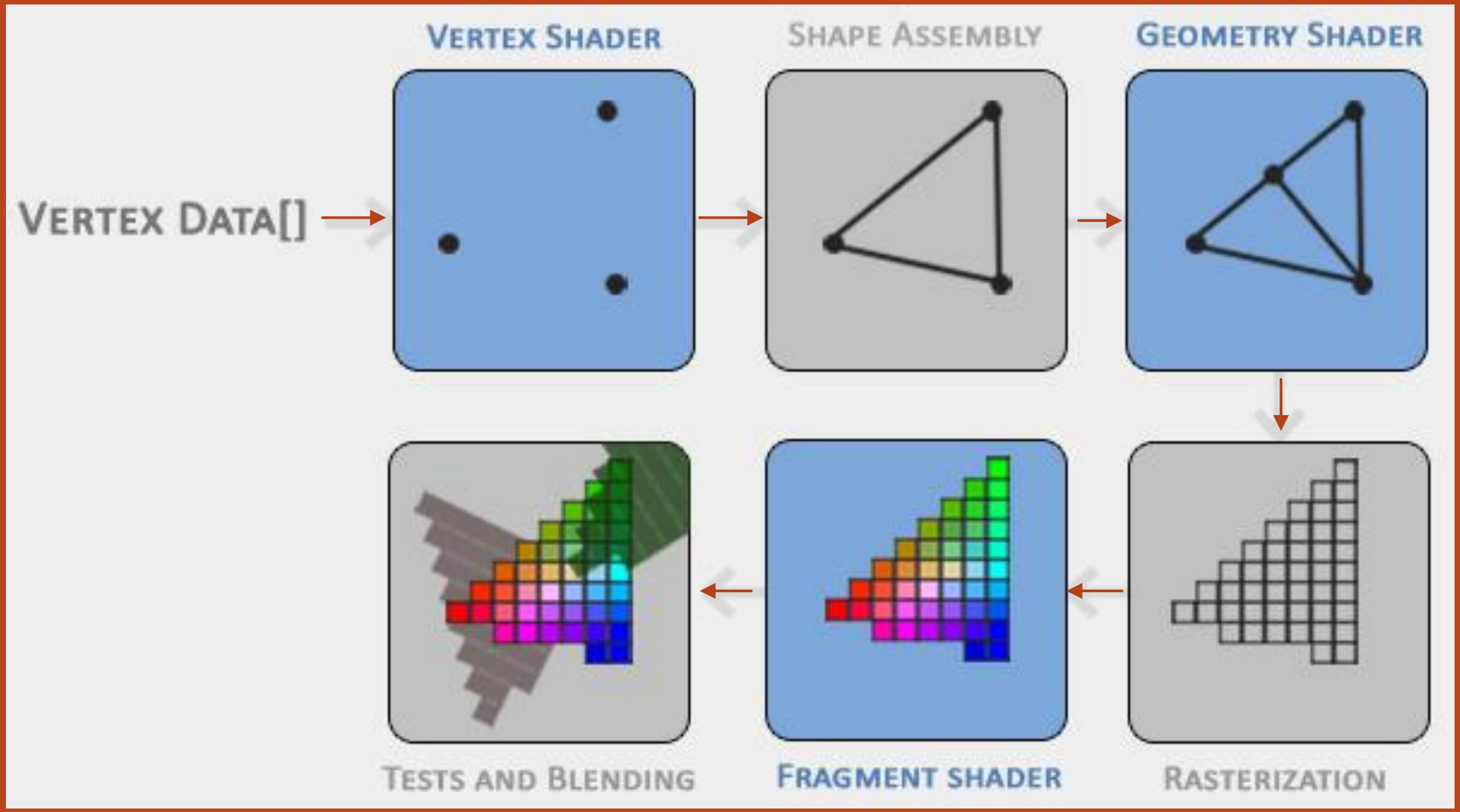
The OpenGL Graphics Pipeline

- The output of each step is input to the next step
- A small program is run on a processing core for each step of the pipeline
- These programs are called shaders



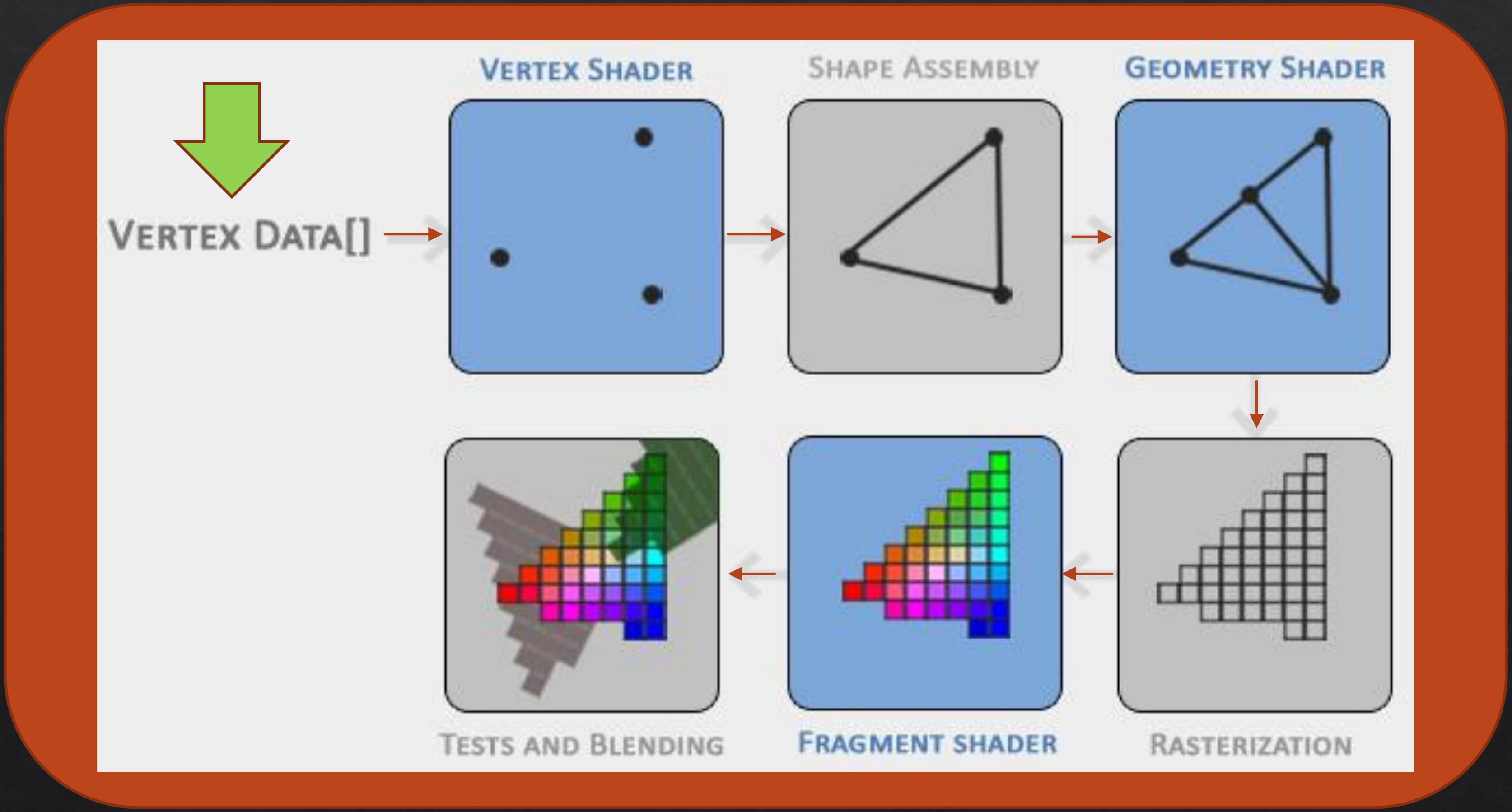
The OpenGL Graphics Pipeline

- The vertex data fed in initially consist usually of 3 or 4 vector coordinates
- This is done with the OpenGL Shading Language
- GLSL



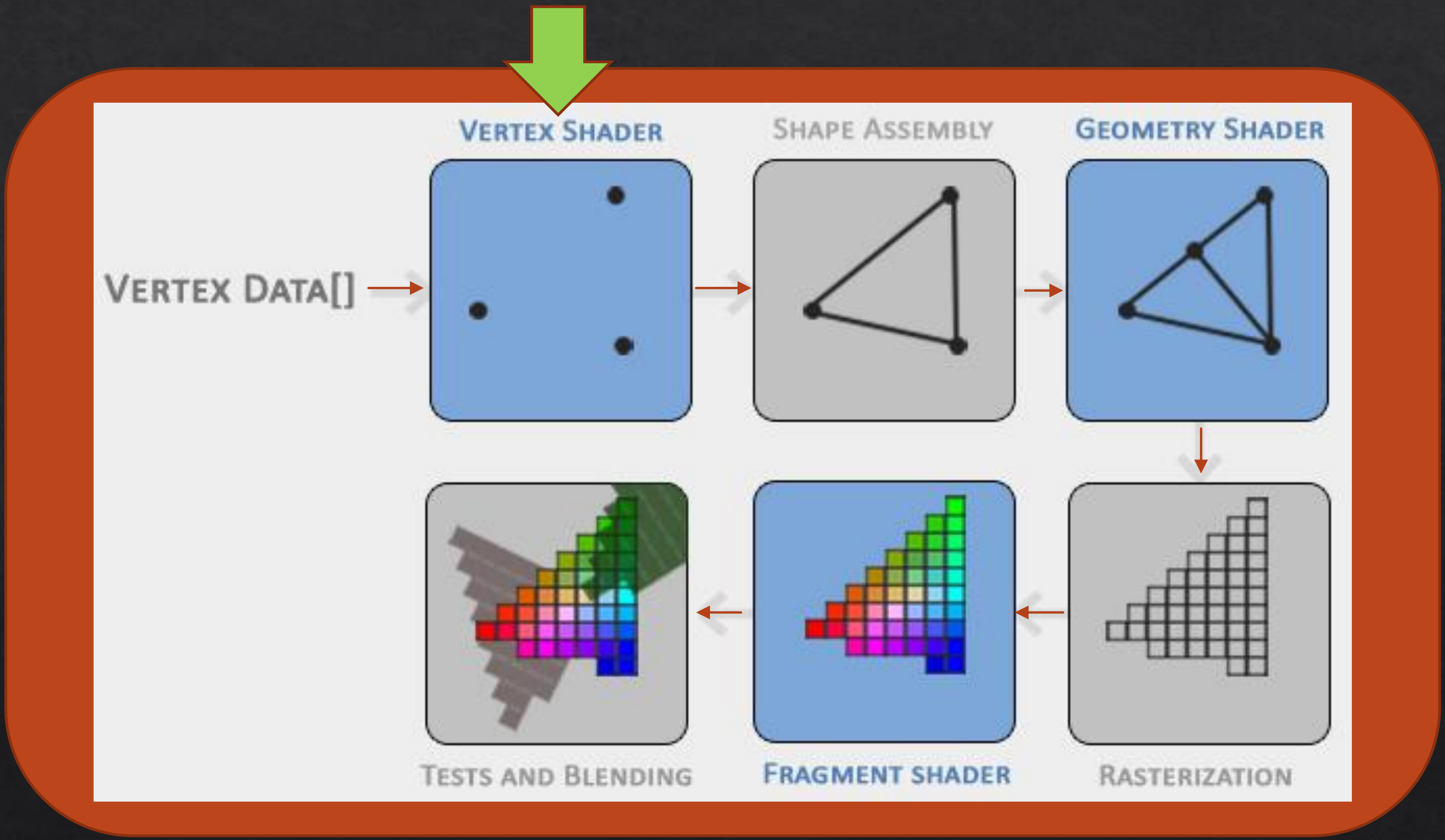
The OpenGL Graphics Pipeline

- The vertex data is an array of coordinates representing points in 3d space



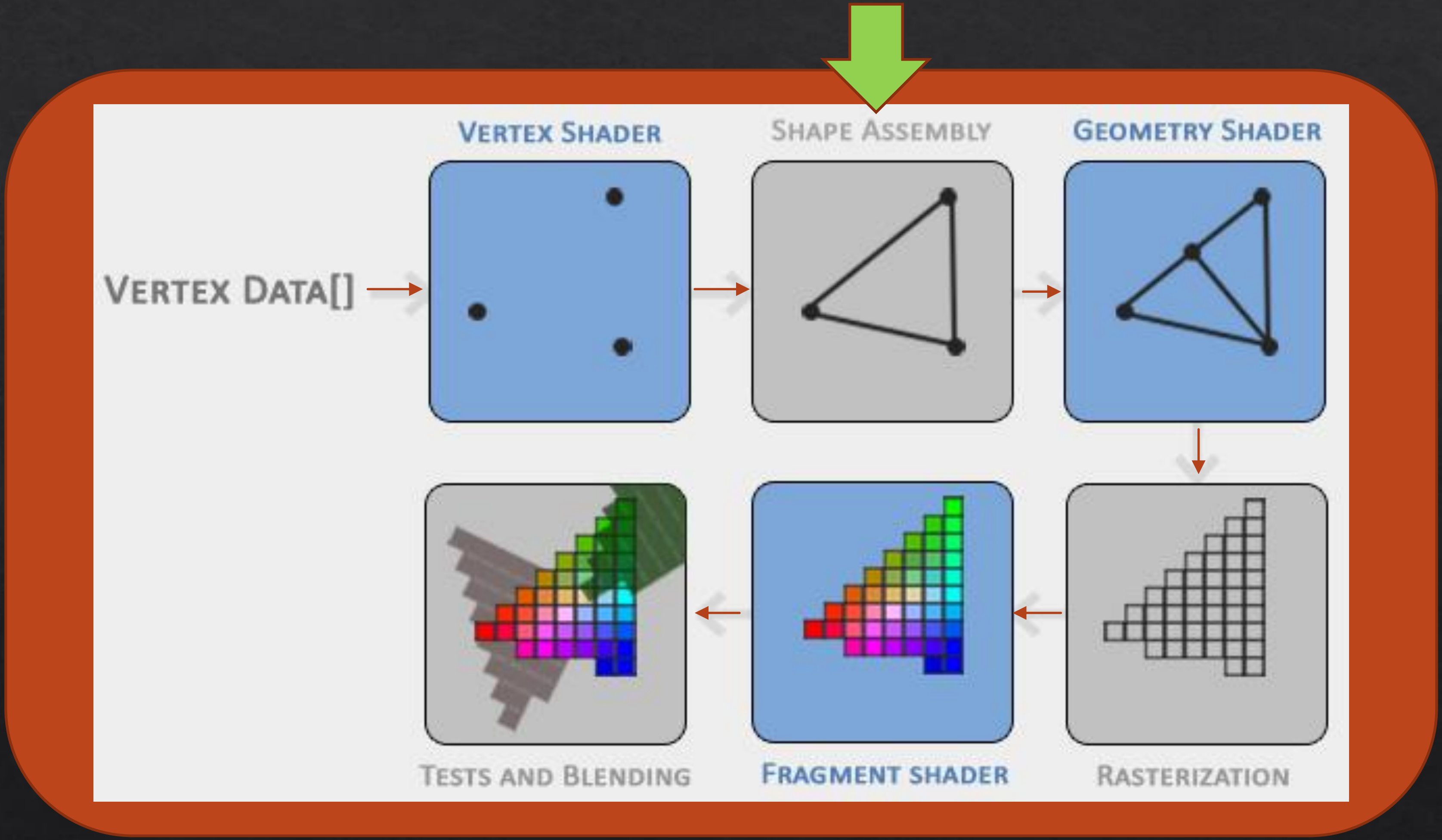
The OpenGL Graphics Pipeline

- The vertex shader is provided by the user
- Its purpose is to calculate 3d transformations that occur



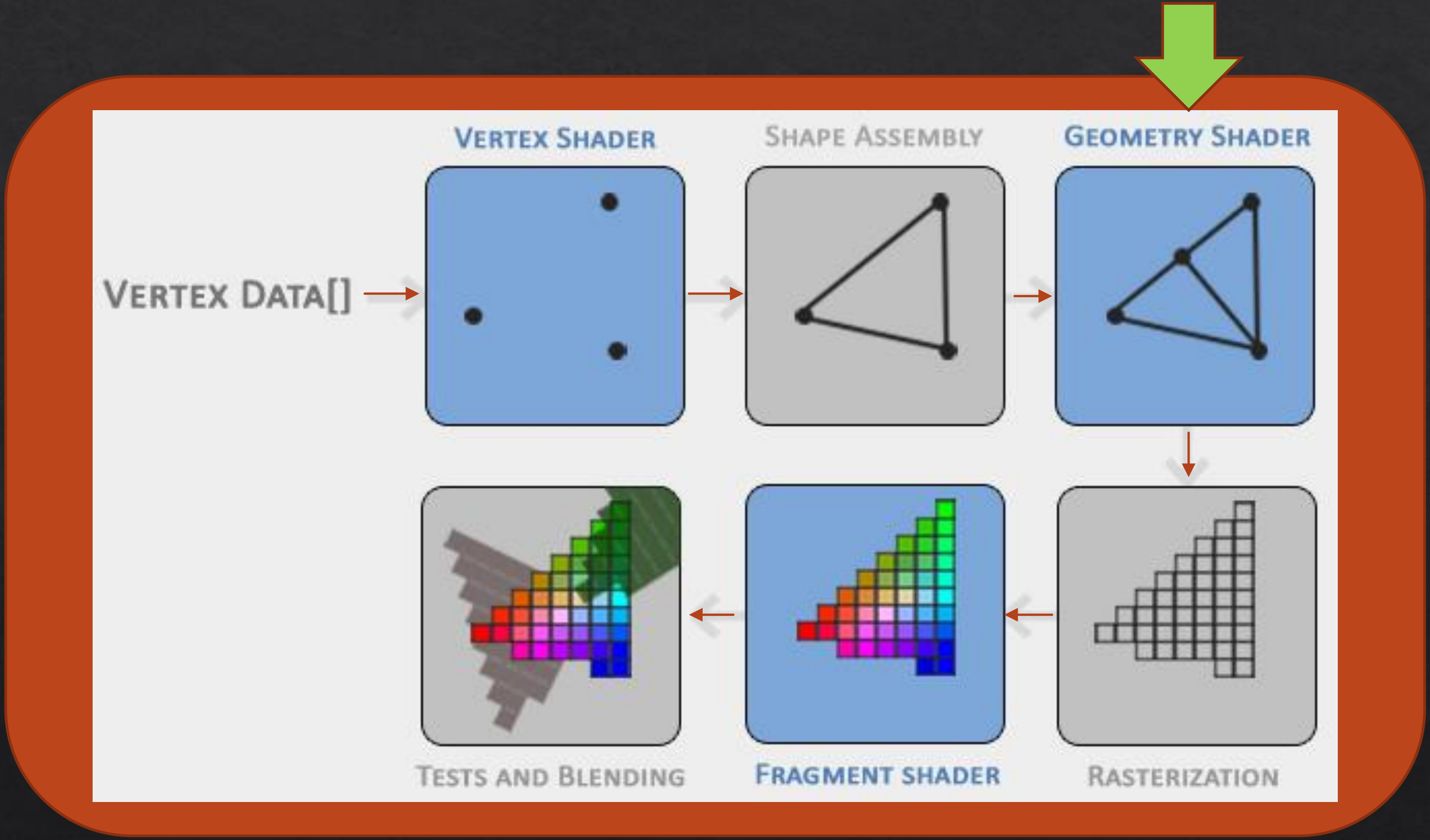
The OpenGL Graphics

- Shape assembly links the 3d points it is provided into primitive shapes
- These shapes are most often triangles in OpenGL
- They can be lines or the 3d points can be left alone



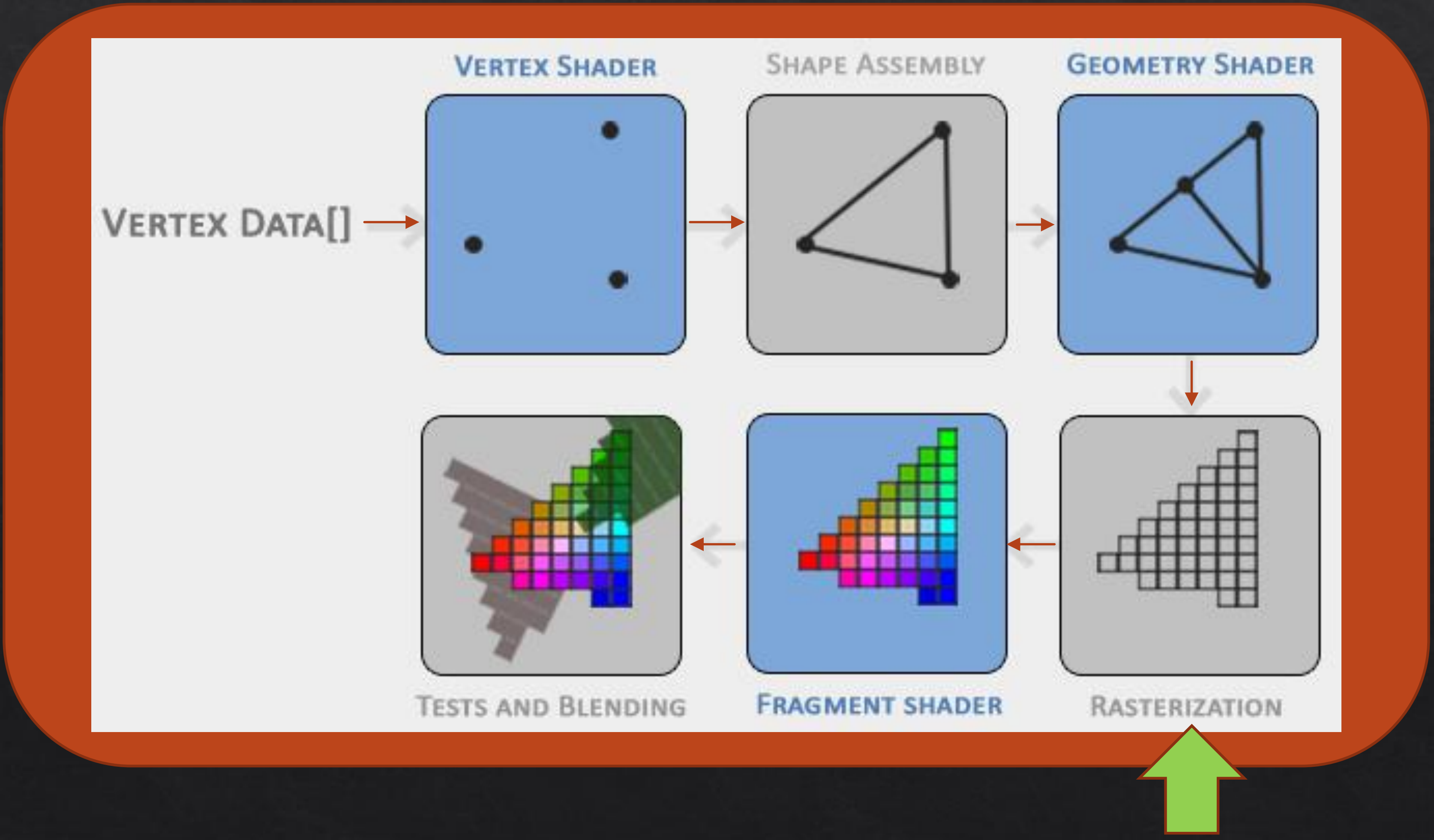
The OpenGL Graphics Pipeline

- The Geometry shader takes primitive shapes and can form more complex ones
- It can be defined by the developer but has a default shader program as well



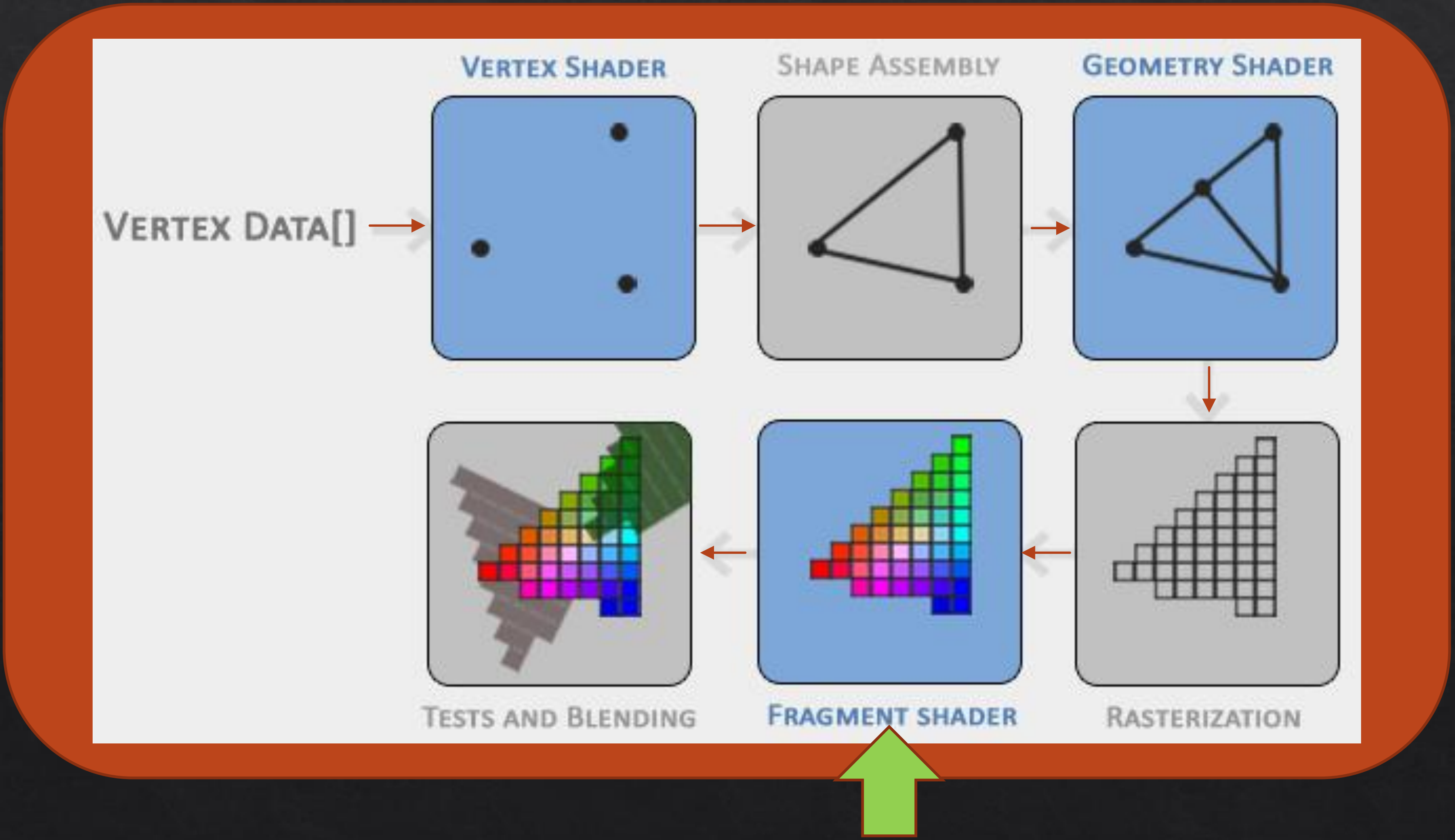
The OpenGL Graphics Pipeline - Data

- Rasterization maps the primitive shapes to their corresponding pixels on the final display
- It also performs clipping, removing ay primitive shapes outside of the display, increasing performance



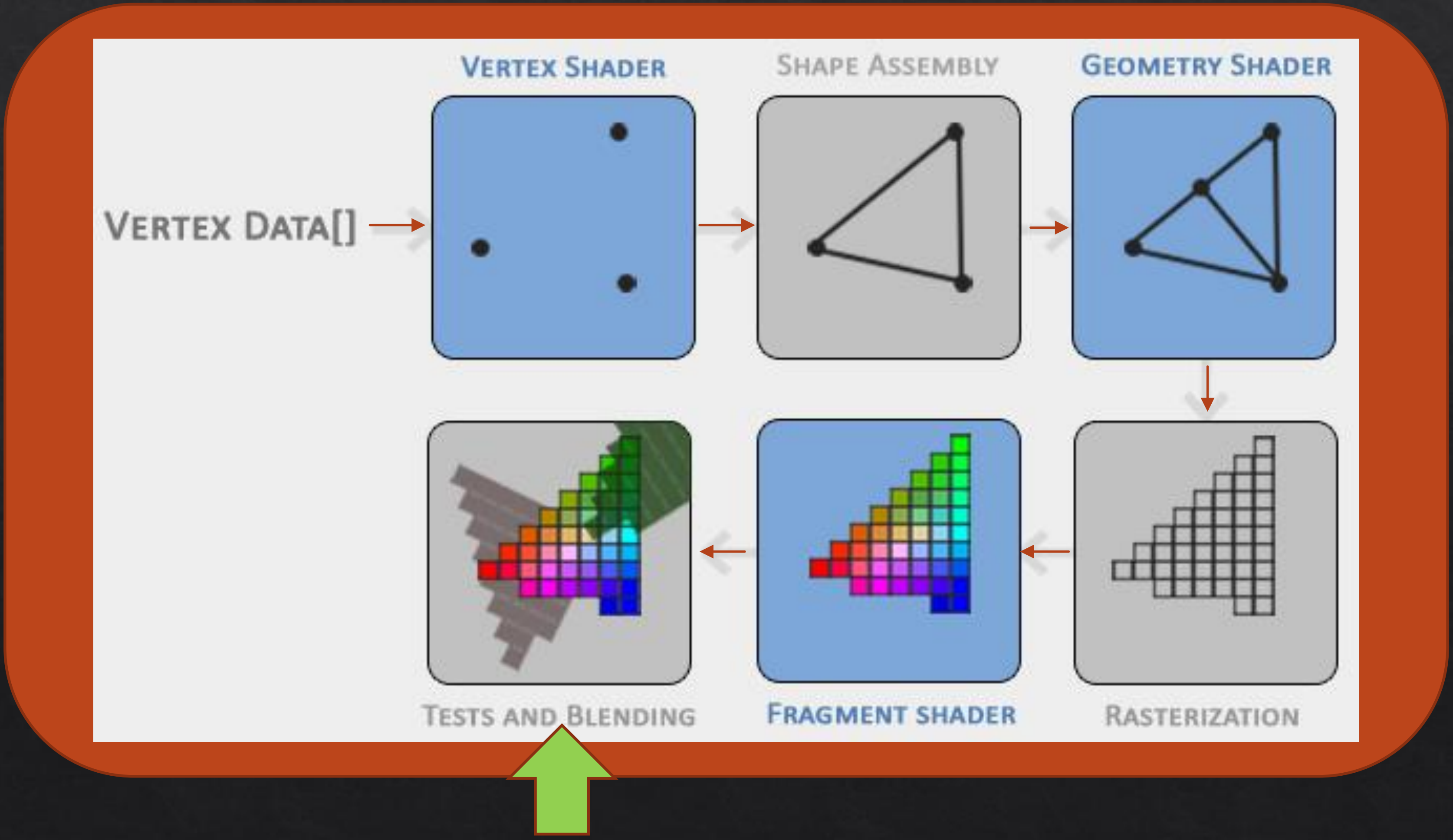
The OpenGL Graphics Pipeline - Data

- The fragment shader decides what color each pixel is going to be
- This shader needs to be defined by the developer
- Calculations like light, shadows, color of light, etc would be performed here



The OpenGL Graphics Pipeline - Data

- Tests and Blending checks what pixels are behind other pixels
- It also applies opacity to pixels



Example: Drawing a Triangle

- Steps
  1. Create a window and OpenGL context
  2. Send OpenGL data
  3. Create a Vertex shader and Fragment shader
  4. Tell OpenGL how to read our data
  5. Set the Context for the rendering
  6. Render the triangle
- Code will be shown when helpful
- This example was done using C++

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Create A Window and OpenGL Context

- Can be done with a library called **GLFW**
- It will perform all the necessary OS calls to set up a window and context
- GLFW also accounts for user input like window resizing or escapes
- There are many alternatives to **GLFW**

Create A Window and OpenGL Context

- With hand waving, GLFW is used to:
  - **Create a window**
  - **Create an OpenGL context**
  - **Handle if the user resizes the window**
  - **Handle if the user quits**
  - **Handle the render loop**
- The code is long and not that interesting

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These last two steps are performed repeatedly within the render loop

Send OpenGL data

- Here is the data we are going to send OpenGL

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

- It consists of three 3d points
- Even though we are only drawing a 2d triangle, OpenGL only works in 3d

Send OpenGL data

- Data is sent to the GPU and set to the current context through objects
- To do this create a buffer object

```
unsigned int VBO;
glGenBuffers(1, &VBO);
```

- Bind it to the OpenGL context variable GL_ARRAY_BUFFER

```
glBindBuffer(GL_ARRAY_BUFFER, VBO);
```

- Then put the data into the buffer currently bound to GL_ARRAY_BUFFER

```
glBufferData(GL_ARRAY_BUFFER, sizeof(vertices), vertices, GL_STATIC_DRAW);
```

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Create a Vertex and Fragment shader

- The Vertex and Fragment shaders need to be provided by the developer

Create a Vertex and Fragment shader

- The Vertex shader will work as a pipe

```
#version 330 core
layout (location = 0) in vec3 aPos;

void main()
{
    gl_Position = vec4(aPos.x, aPos.y, aPos.z, 1.0);
}
```

- Taking the input and sending it to the output

Create a Vertex and Fragment shader

- The Fragment shader will just output the color orange

```
#version 330 core
out vec4 FragColor;

void main()
{
    FragColor = vec4(1.0f, 0.5f, 0.2f, 1.0f);
}
```

Create a Vertex and Fragment shader

- To compile the shaders you create a shader object

```
unsigned int vertexShader;
vertexShader = glCreateShader(GL_VERTEX_SHADER);
```

- The code is then given to the shader object in the form of C string

```
const char *vertexShaderSource = "#version 330 core\n"
    "layout (location = 0) in vec3 aPos;\n"
    "void main()\n"
    "{\n"
    "   gl_Position = vec4(aPos.x, aPos.y, aPos.z, 1.0);\n"
    "}\0";
```

- And compiled

```
glShaderSource(vertexShader, 1, &vertexShaderSource, NULL);
glCompileShader(vertexShader);
```

Create a Vertex and Fragment shader

- After the shaders are compiled they are linked into a program

```
unsigned int shaderProgram;
shaderProgram = glCreateProgram();
```

```
glAttachShader(shaderProgram, vertexShader);
glAttachShader(shaderProgram, fragmentShader);
glLinkProgram(shaderProgram);
```

- And are ready for use

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Tell OpenGL how to read the data

- The vertices data did not need to be formatted this way

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

- OpenGL does not specify how vertex attributes should be inputted to the vertex shader
- So we need to tell it how to read the data given

Tell OpenGL how to read the data

- This is done through a vertex attribute pointer

```
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(float), (void*)0);
glEnableVertexAttribArray(0);
```

Tell OpenGL how to read the data

- This is done through a vertex attribute pointer

```
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(float), (void*)0);
glEnableVertexAttribArray(0);
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```
glBindBuffer(GL_ARRAY_BUFFER, VBO);
```

- This links the currently bound array buffer

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void main()
{
    gl_Position = vec4(aPos.x, aPos.y, aPos.z, 1.0);
}
```

- This links the currently bound array buffer to the input variables of the vertex shader

Tell OpenGL how to read the data

- This is done through a vertex attribute pointer

```
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(float), (void*)0);
glEnableVertexAttribArray(0);
```

- It also specifies how the data should be interpreted

Tell OpenGL how to read the data

- We can have multiple Vertex buffer objects, each with multiple vertex attribute pointers
- This could be a nightmare to manager
- To track all of this OpenGL gives Vertex Array Objects
- VAO’s automatically keep track of the connections between VBOs and attribute pointers
- OpenGL will not render without them

Tell OpenGL how to read the data

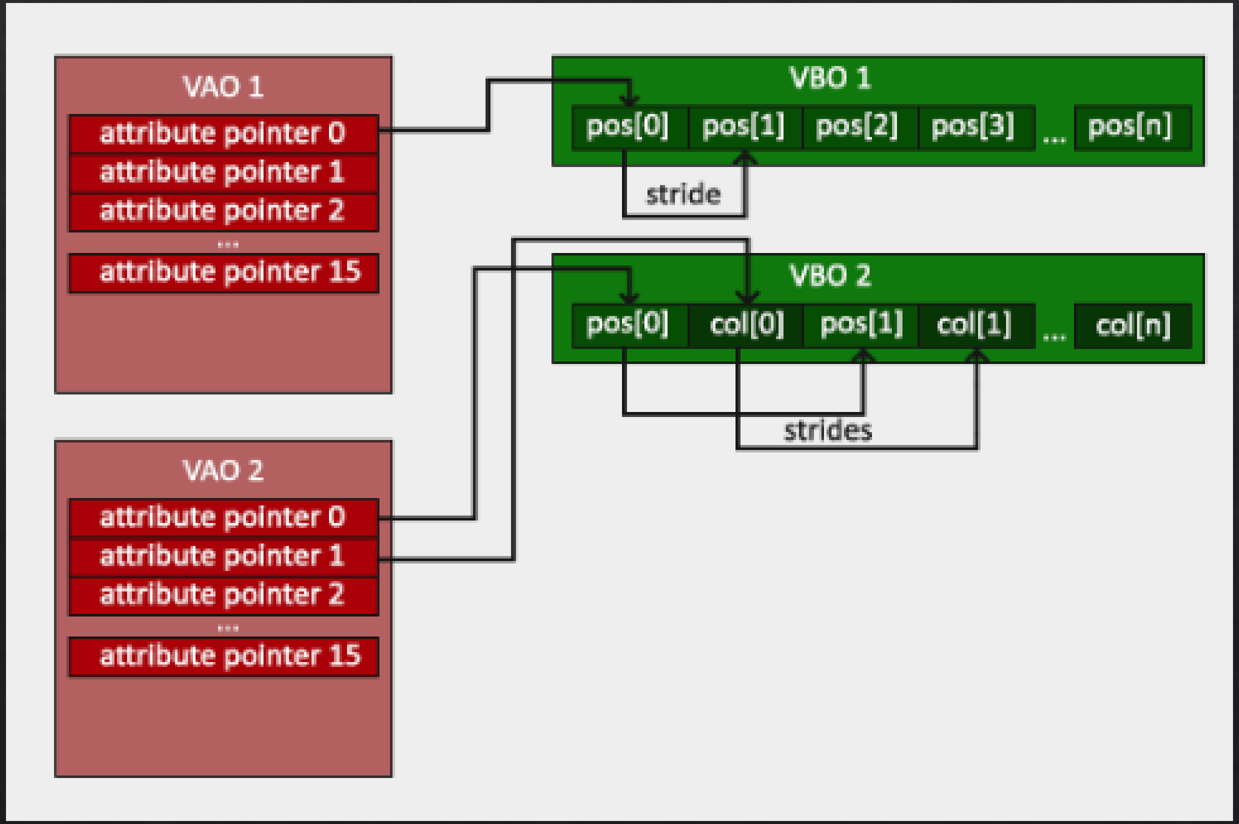
- To use them we create them, bind them to the current context, and then initialize the data like usual

```
unsigned int VAO;
glGenVertexArrays(1, &VAO);
// 1. bind Vertex Array Object
glBindVertexArray(VAO);
// 2. copy our vertices array in a buffer for OpenGL to use
glBindBuffer(GL_ARRAY_BUFFER, VBO);
glBufferData(GL_ARRAY_BUFFER, sizeof(vertices), vertices, GL_STATIC_DRAW);
// 3. then set our vertex attributes pointers
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(float), (void*)0);
glEnableVertexAttribArray(0);
```

- OpenGL automatically makes the connections

Tell OpenGL how to read the data

- Vertex array objects can be seen as containers linking the data (VBO) with how it is interpreted (attribute pointers)



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Set the Context for Rendering

- The hard part is done
- The shader program is complete
- The vertex array object has the data and how it should interpret it
- All that's needed is to set the OpenGL context to them

```
glUseProgram(shaderProgram);
glBindVertexArray(VAO);
```

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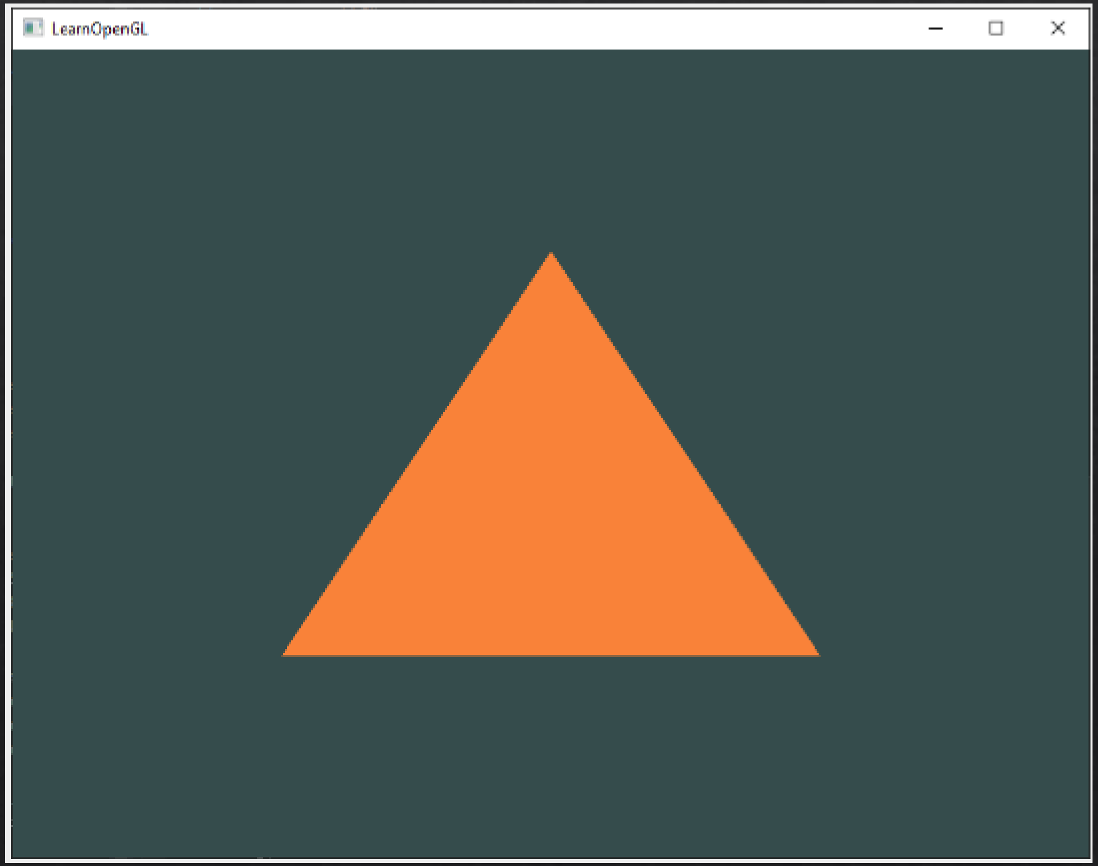
  6. **Render the triangle**

Render the Triangle

- Easy

```
glDrawArrays(GL_TRIANGLES, 0, 3);
```



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