The Shaders’ View of the Basic Computer Graphics Pipeline

- In general, you want to have a vertex and fragment shader as a minimum.
- A missing stage is OK. The output from one stage becomes the input of the next stage that is there.
- The last stage before the fragment shader feeds its output variables into the rasterizer. The interpolated values then go to the fragment shaders.

Fixed Function

Programmable

[Diagram of shader stages]
Shaders stages

```c
typedef enum VkPipelineStageFlagBits {
    VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT = 0x00000001,
    VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT = 0x00000002,
    VK_PIPELINE_STAGE_VERTEX_INPUT_BIT = 0x00000004,
    VK_PIPELINE_STAGE_VERTEX_SHADER_BIT = 0x00000008,
    VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT = 0x00000010,
    VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT = 0x00000020,
    VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT = 0x00000040,
    VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT = 0x00000080,
    VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT = 0x00000100,
    VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT = 0x00000200,
    VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT = 0x00000400,
    VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT = 0x00000800,
    VK_PIPELINE_STAGE_TRANSFER_BIT = 0x00001000,
    VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT = 0x00002000,
    VK_PIPELINE_STAGE_HOST_BIT = 0x00004000,
    VK_PIPELINE_STAGE_ALL_GRAPHICS_BIT = 0x00008000,
    VK_PIPELINE_STAGE_ALL_COMMANDS_BIT = 0x00010000,
} VkPipelineStageFlagBits;
```

**How Vulkan GLSL Differs from OpenGL GLSL**

Detecting that a GLSL Shader is being used with Vulkan/SPIR-V:

- In the compiler, there is an automatic
  `#define VULKAN 100`

**Vulkan Vertex and Instance indices:**

```c
    gl_VertexIndex
    gl_InstanceIndex
```

- Both are 0-based

**gl_FragColor:**

- In OpenGL, `gl_FragColor` broadcasts to all color attachments
- In Vulkan, it just broadcasts to color attachment location #0
- Best idea: don't use it at all – explicitly declare out variables to have specific location numbers
Shader combinations of separate texture data and samplers:
uniform sampler s;
uniform texture2D t;
vec4 rgba = texture( sampler2D( t, s ), vST );

Descriptor Sets:
layout( set=0, binding=0 ) . . . ;

Push Constants:
layout( push_constant ) . . . ;

Specialization Constants:
layout( constant_id = 3 )  const int N = 5;
• Only for scalars, but a vector's components can be constructed from specialization constants

Specialization Constants for Compute Shaders:
layout( local_size_x_id = 8, local_size_y_id = 16 );
• This sets gl_WorkGroupSize.x and gl_WorkGroupSize.y
• gl_WorkGroupSize.z is set as a constant

Vulkan: Shaders’ use of Layouts for Uniform Variables

All non-sampler uniform variables must be in block buffers
Vulkan Shader Compiling

- You half-precompile your shaders with an external compiler
- Your shaders get turned into an intermediate form known as SPIR-V, which stands for **Standard Portable Intermediate Representation**.
- SPIR-V gets turned into fully-compiled code at runtime, when the pipeline structure is finally created
- The SPIR-V spec has been public for a few years – new shader languages are surely being developed
- OpenGL and OpenCL have now adopted SPIR-V as well

![](image)

**Advantages:**

1. Software vendors don’t need to ship their shader source
2. Syntax errors appear during the SPIR-V step, not during runtime
3. Software can launch faster because half of the compilation has already taken place
4. This guarantees a common front-end syntax
5. This allows for other language front-ends

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SPIR-V: **Standard Portable Intermediate Representation for Vulkan**

```
```

Shaderfile extensions:
- .vert  Vertex
- .tesc  Tessellation Control
- .tese  Tessellation Evaluation
- .geom  Geometry
- .frag  Fragment
- .comp  Compute

(Can be overridden by the –S option)

- -V Compile for Vulkan
- -G Compile for OpenGL
- -I Directory(ies) to look in for #includes
- -S Specify stage rather than get it from shaderfile extension
- -c Print out the maximum sizes of various properties

Windows: glslangValidator.exe
Linux: glslangValidator
You Can Run the SPIR-V Compiler on Windows from a Bash Shell

1. Click on the Microsoft Start icon
2. Type the word `bash`
Running glslangValidator.exe

```
glslangValidator.exe -V sample-vert.vert -o sample-vert.spv
```

Compile for Vulkan ("-G" is compile for OpenGL)

Specify the output file

The input file. The compiler determines the shader type by the file extension:

- `.vert`  Vertex shader
- `.tccs`  Tessellation Control Shader
- `.tecs`  Tessellation Evaluation Shader
- `.geom`  Geometry shader
- `.frag`  Fragment shader
- `.comp`  Compute shader
How do you know if SPIR-V compiled successfully?

Same as C/C++ -- the compiler gives you no nasty messages.

Also, if you care, legal .spv files have a magic number of 0x07230203

So, if you do an `od -x` on the .spv file, the magic number looks like this:

```
0203 0723 . . .
```

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Reading a SPIR-V File into a Vulkan Shader Module

```cpp
#define SPIRV_MAGIC 0x07230203

VkResult Init12SpirvShader( std::string filename, VkShaderModule * pShaderModule )
{
    FILE *fp;
    (void) fopen_s( &fp, filename.c_str(), "rb");
    if( fp == NULL )
    {
        fprintf( FpDebug, "Cannot open shader file '%s'
", filename.c_str( ) );
        return VK_SHOULD_EXIT;
    }
    uint32_t magic;
    fread( &magic, 4, 1, fp );
    if( magic != SPIRV_MAGIC )
    {
        fprintf( FpDebug, "Magic number for spir-v file '%s' is 0x%08x -- should be 0x%08x"
, filename.c_str( ), magic, SPIRV_MAGIC );
        return VK_SHOULD_EXIT;
    }
    fseek( fp, 0L, SEEK_END );
    int size = ftell( fp );
    rewind( fp );
    unsigned char *code = new unsigned char [size];
    fread( code, size, 1, fp );
    fclose( fp );
}
```

---
Reading a SPIR-V File into a Shader Module

```cpp
VkShaderModule ShaderModuleVertex;

VkShaderModuleCreateInfo vsmci;
    vsmci.sType = VK_STRUCTURE_TYPE_SHADER_MODULE_CREATE_INFO;
    vsmci.pNext = nullptr;
    vsmci.flags = 0;
    vsmci.codeSize = size;
    vsmci.pCode = (uint32_t *)code;

VkResult result = vkCreateShaderModule( LogicalDevice, &vsmci, PALLOCATOR, OUT & ShaderModuleVertex );
fprintf( FpDebug, "Shader Module '%s' successfully loaded
", filename.c_str() );
delete [] code;
return result;
```
You can also take a look at SPIR-V Assembly

```
glslangValidator.exe -V -H sample-vert.vert -o sample-vert.spv
```

This prints out the SPIR-V “assembly” to standard output. Other than nerd interest, there is no graphics-programming reason to look at this. 😊

For example, if this is your Shader Source

```glsl
#version 400
#extension GL_ARB_separate_shader_objects : enable
#extension GL_ARB_shading_language_420pack : enable
layout( std140, set = 0, binding = 0 ) uniform matBuf
{
    mat4 uModelMatrix;
    mat4 uViewMatrix;
    mat4 uProjectionMatrix;
    mat3 uNormalMatrix;
} Matrices;

// non-opaque must be in a uniform block:
layout( std140, set = 1, binding = 0 ) uniform lightBuf
{
    vec4 uLightPos;
} Light;

layout( location = 0 ) in vec3 aVertex;
layout( location = 1 ) in vec3 aNormal;
layout( location = 2 ) in vec3 aColor;
layout( location = 3 ) in vec2 aTexCoord;

layout ( location = 0 ) out vec3 vNormal;
layout ( location = 1 ) out vec3 vColor;
layout ( location = 2 ) out vec2 vTexCoord;

void main( )
{
    mat4 PVM = Matrices.uProjectionMatrix * Matrices.uViewMatrix * Matrices.uModelMatrix;
    gl_Position = PVM * vec4( aVertex, 1. );
    vNormal = Matrices.uNormalMatrix * aNormal;
    vColor = aColor;
    vTexCoord = aTexCoord;
}
```
This is the SPIR-V Assembly, Part I

Capability Shader

ExtInstImport "GLSL.std.450"
MemoryModel Logical GLSL450
EntryPoint Vertex 4 "main" 34 37 48 53 56 57 61 63
Source GLSL 400
SourceExtension "GL_ARB_separate_shader_objects"
SourceExtension "GL_ARB_shading_language_420pack"
Name 4 "main"
Name 10 "PVM"
Name 13 "matBuf"
MemberName 13(matBuf) 0 "uModelMatrix"
MemberName 13(matBuf) 1 "uViewMatrix"
MemberName 13(matBuf) 2 "uProjectionMatrix"
MemberName 13(matBuf) 3 "uNormalMatrix"
Name 15 "Matrices"
Name 32 "gl_Vertex" 0 "gl_Position"
MemberName 32(gl_PerVertex) 0 "gl_Position" 0 "gl_PointSize"
MemberName 32(gl_PerVertex) 2 "gl_ClipDistance"
Name 34 ""
Name 37 "aVertex"
Name 48 "aNormal"
Name 53 "aColor"
Name 57 "vColor"
Name 61 "vTexCoord"
Name 63 "aTexCoord"
Name 69 "lightBuf"
MemberName 69(lightBuf) 0 "uLightPos"
Name 67 "Light"
MemberDecorate 13(matBuf) 0 ColMajor
MemberDecorate 13(matBuf) 0 Offset 0
MemberDecorate 13(matBuf) 0 MatrixStride 16
MemberDecorate 13(matBuf) 1 ColMajor
MemberDecorate 13(matBuf) 1 Offset 64
MemberDecorate 13(matBuf) 1 MatrixStride 16
MemberDecorate 13(matBuf) 2 ColMajor
MemberDecorate 13(matBuf) 2 Offset 128
MemberDecorate 13(matBuf) 2 MatrixStride 16
MemberDecorate 13(matBuf) 3 ColMajor
MemberDecorate 13(matBuf) 3 Offset 192
MemberDecorate 13(matBuf) 3 MatrixStride 16
Decorate 13(matBuf) Block
Decorate 15(Matrices) DescriptorSet 0

This is the SPIR-V Assembly, Part II

Decorate 15(Matrices) Binding 0
MemberDecorate 32(gl_PerVertex) 0 BuiltIn Position
MemberDecorate 32(gl_PerVertex) 1 BuiltIn PointSize
MemberDecorate 32(gl_PerVertex) 2 BuiltIn ClipDistance
Decorate 37(gl_PerVertex) Block
Decorate 37(gl_PerVertex) Location 0
Decorate 48(vNormal) Location 0
Decorate 53(aNormal) Location 0
Decorate 57(aColor) Location 0
Decorate 61(vTexCoord) Location 2
Decorate 63(aTexCoord) Location 3
MemberDecorate 65(lightBuf) 0 Offset 0
MemberDecorate 65(lightBuf) Block
MemberDecorate 65(lightBuf) 0 Offset 128
MemberDecorate 65(lightBuf) 0 Offset 192
MemberDecorate 65(lightBuf) 3 MatrixStride 16
Decorate 15(lightBuf) Block
Decorate 15(lightBuf) 0 Offset 0

1/3/2020
This is the SPIR-V Assembly, Part III

SPIR-V: Printing the Configuration
SPIR-V: More Information

SPIR-V Tools:
http://github.com/KhronosGroup/SPIRV-Tools

A Google-Wrapped Version of glslangValidator

The shaderc project from Google (https://github.com/google/shaderc) provides a glslangValidator wrapper program called glslc that has a much improved command-line interface. You use, basically, the same way:

\[ \text{glslc.exe} \quad -\text{target-env=vulkan} \quad \text{sample-vert.vert} \quad -o \quad \text{sample-vert.spv} \]

There are several really nice features. The two I really like are:

1. You can include files into your shader source

2. You can “#define” definitions on the command line like this:

\[ \text{glslc.exe} \quad -\text{target-env=vulkan} \quad -D\text{NUMPONTS}=4 \quad \text{sample-vert.vert} \quad -o \quad \text{sample-vert.spv} \]

glslc is included in your Sample .zip file