1

GLSL for Vulkan

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VulkanGLSL.pptx

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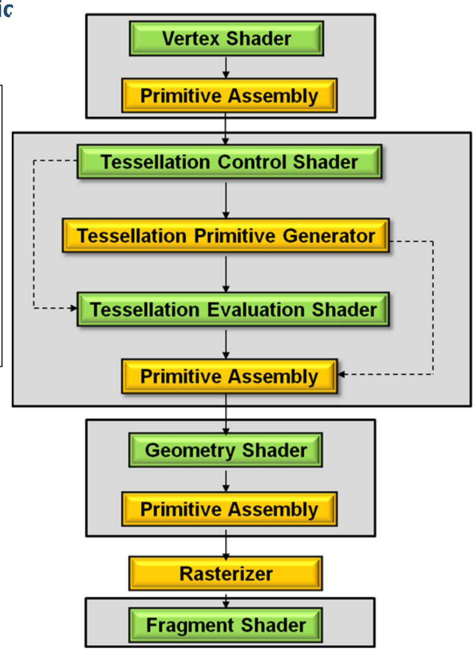
1

2

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

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2

3

Vulkan Shader Stages

Shader stages

```
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;
```

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3

4

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:

gl_VertexIndex
gl_InstanceIndex

OpenGL uses:

gl_VertexID
gl_InstanceID

- 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

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How Vulkan GLSL Differs from OpenGL GLSL

5

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

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Vulkan: Shaders' use of Layouts for Uniform Variables

6

```
// non-sampler variables must be in a uniform block:
layout( std140, set = 0, binding = 0 ) uniform matBuf
{
        mat4 uModelMatrix;
        mat4 uViewMatrix;
        mat4 uProjectionMatrix;
        mat3 uNormalMatrix;
} Matrices;

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

layout( set = 2, binding = 0 ) uniform sampler2D uTexUnit;
```

All non-sampler uniform variables must be in block buffers

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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

GLSL Source → **External GLSL Compiler** → SPIR-V → **Compiler in driver** → Vendor-specific code

Develop Time (External GLSL Compiler) | Run Time (Compiler in driver)

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

glslangValidator shaderFile -V [-H] [-I<dir>] [-S <stage>] -o shaderBinaryFile.spv

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

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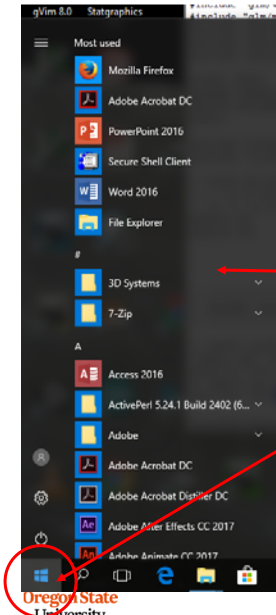
You Can Run the SPIR-V Compiler on Windows from a Bash Shell

9



This is only available within 64-bit Windows 10.

2. Type the word *bash*

1. Click on the Microsoft Start icon

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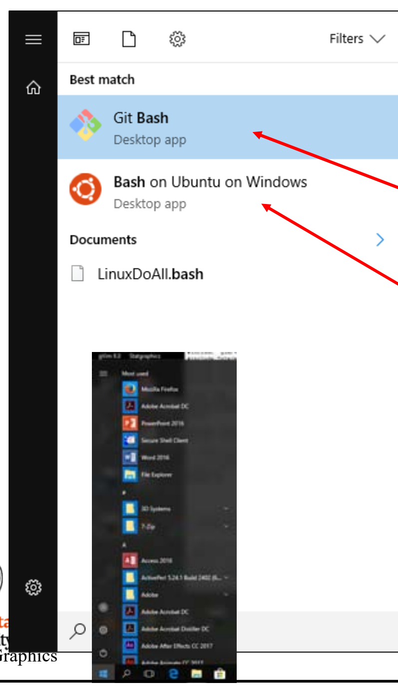
9

You Can Run the SPIR-V Compiler on Windows from a Bash Shell

10



This is only available within 64-bit Windows 10.

Pick one:

- Can get to your personal folders
- Does not have make

- Can get to your personal folders
- Does have make

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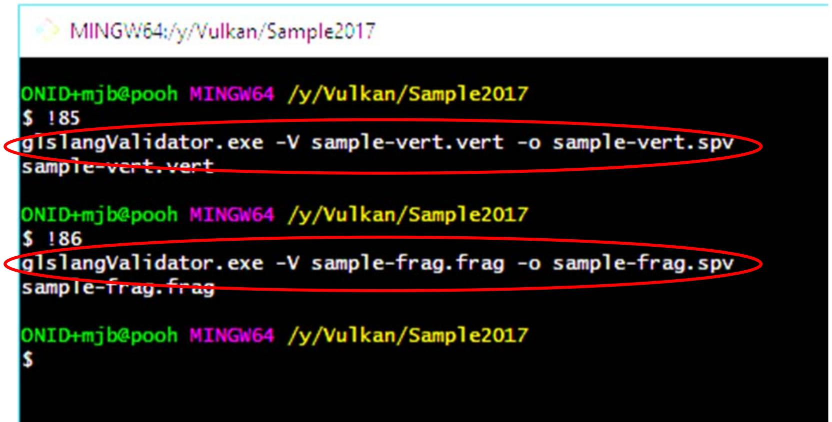
10

Running glslangValidator.exe

11



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Running glslangValidator.exe

12

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

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

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

Specify the output file

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12

How do you know if SPIR-V compiled successfully?

13

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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13

Reading a SPIR-V File into a Vulkan Shader Module

14

```
#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'\n", 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\n",
						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 );
```

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14

Reading a SPIR-V File into a Shader Module

15

```
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\n", filename.c_str() );
     delete [ ] code;
     return result;
}
```

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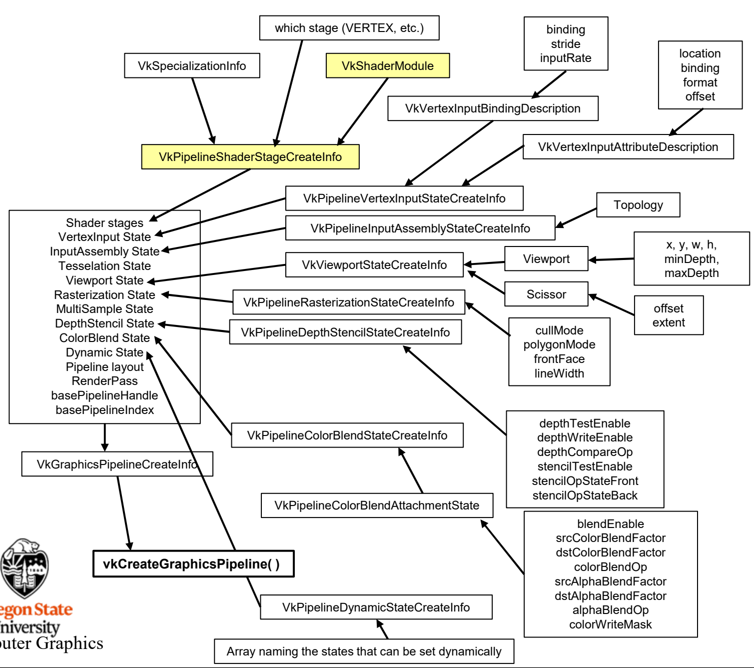
15

Vulkan: Creating a Pipeline

16



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16

You can also take a look at SPIR-V Assembly

17

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. ☺

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17

For example, if this is your Shader Source

18

```
#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;
}
```

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18

This is the SPIR-V Assembly, Part I

19

```
#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;
}
```

```
        Capability Shader
1:      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_PerVertex"
        MemberName 32(gl_PerVertex) 0  "gl_Position"
        MemberName 32(gl_PerVertex) 1  "gl_PointSize"
        MemberName 32(gl_PerVertex) 2  "gl_ClipDistance"
        Name 34  ""
        Name 37  "aVertex"
        Name 48  "vNormal"
        Name 53  "aNormal"
        Name 56  "vColor"
        Name 57  "aColor"
        Name 61  "vTexCoord"
        Name 63  "aTexCoord"
        Name 65  "lightBuf"
        MemberName 65(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
```

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19

This is the SPIR-V Assembly, Part II

20


```
#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;
}
```


```
                        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 32(gl_PerVertex) Block
                        Decorate 37(aVertex) Location 0
                        Decorate 48(vNormal) Location 0
                        Decorate 53(aNormal) Location 1
                        Decorate 56(vColor) Location 1
                        Decorate 57(aColor) Location 2
                        Decorate 61(vTexCoord) Location 2
                        Decorate 63(aTexCoord) Location 3
                        MemberDecorate 65(lightBuf) 0 Offset 0
                        Decorate 65(lightBuf) Block
                        Decorate 67(Light) DescriptorSet 1
                        Decorate 67(Light) Binding 0
               2:       TypeVoid
               3:       TypeFunction 2
               6:       TypeFloat 32
               7:       TypeVector 6(float) 4
               8:       TypeMatrix 7(fvec4) 4
               9:       TypePointer Function 8
              11:       TypeVector 6(float) 3
              12:       TypeMatrix 11(fvec3) 3
     13(matBuf):        TypeStruct 8 8 8 12
              14:       TypePointer Uniform 13(matBuf)
   15(Matrices):    14(ptr) Variable Uniform
              16:       TypeInt 32 1
              17:    16(int) Constant 2
              18:       TypePointer Uniform 8
              21:    16(int) Constant 1
              25:    16(int) Constant 0
              29:       TypeInt 32 0
              30:    29(int) Constant 1
              31:       TypeArray 6(float) 30
32(gl_PerVertex):       TypeStruct 7(fvec4) 6(float) 31
              33:       TypePointer Output 32(gl_PerVertex)
              34:    33(ptr) Variable Output
              36:       TypePointer Input 11(fvec3)
    37(aVertex):    36(ptr) Variable Input
              39:  6(float) Constant 1065353216
              45:       TypePointer Output 7(fvec4)
              47:       TypePointer Output 11(fvec3)
    48(vNormal):    47(ptr) Variable Output
              49:    16(int) Constant 3
```

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20

This is the SPIR-V Assembly, Part III


```
#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;
}
```

```
         50:            TypePointer Uniform 12
 53(aNormal):      36(ptr) Variable Input
  56(vColor):      47(ptr) Variable Output
  57(aColor):      36(ptr) Variable Input
         59:            TypeVector 6(float) 2
         60:            TypePointer Output 59(fvec2)
61(vTexCoord):     60(ptr) Variable Output
         62:            TypePointer Input 59(fvec2)
63(aTexCoord):     62(ptr) Variable Input
 65(lightBuf):              TypeStruct 7(fvec4)
         66:            TypePointer Uniform 65(lightBuf)
   67(Light):      66(ptr) Variable Uniform
    4(main):           2 Function None 3
          5:           Label
    10(PVM):      9(ptr) Variable Function
         19:      18(ptr) AccessChain 15(Matrices) 17
         20:           8 Load 19
         22:      18(ptr) AccessChain 15(Matrices) 21
         23:           8 Load 22
         24:           8 MatrixTimesMatrix 20 23
         26:      18(ptr) AccessChain 15(Matrices) 25
         27:           8 Load 26
         28:           8 MatrixTimesMatrix 24 27
                       Store 10(PVM) 28
         35:           8 Load 10(PVM)
         38:    11(fvec3) Load 37(aVertex)
         40:    6(float) CompositeExtract 38 0
         41:    6(float) CompositeExtract 38 1
         42:    6(float) CompositeExtract 38 2
         43:    7(fvec4) CompositeConstruct 40 41 42 39
         44:    7(fvec4) MatrixTimesVector 35 43
         46:      45(ptr) AccessChain 34 25
                       Store 46 44
         51:      50(ptr) AccessChain 15(Matrices) 49
         52:          12 Load 51
         54:    11(fvec3) Load 53(aNormal)
         55:    11(fvec3) MatrixTimesVector 52 54
                       Store 48(vNormal) 55
         58:    11(fvec3) Load 57(aColor)
                       Store 56(vColor) 58
         64:    59(fvec2) Load 63(aTexCoord)
                       Store 61(vTexCoord) 64
                       Return
                       FunctionEnd
```

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SPIR-V: Printing the Configuration

glslangValidator –c

```
MaxLights 32
MaxClipPlanes 6
MaxTextureUnits 32
MaxTextureCoords 32
MaxVertexAttribs 64
MaxVertexUniformComponents 4096
MaxVaryingFloats 64
MaxVertexTextureImageUnits 32
MaxCombinedTextureImageUnits 80
MaxTextureImageUnits 32
MaxFragmentUniformComponents 4096
MaxDrawBuffers 32
MaxVertexUniformVectors 128
MaxVaryingVectors 8
MaxFragmentUniformVectors 16
MaxVertexOutputVectors 16
MaxFragmentInputVectors 15
MinProgramTexelOffset -8
MaxProgramTexelOffset 7
MaxClipDistances 8
MaxComputeWorkGroupCountX 65535
MaxComputeWorkGroupCountY 65535
MaxComputeWorkGroupCountZ 65535
MaxComputeWorkGroupSizeX 1024
MaxComputeWorkGroupSizeY 1024
MaxComputeWorkGroupSizeZ 64
MaxComputeUniformComponents 1024
MaxComputeTextureImageUnits 16
MaxComputeImageUniforms 8
MaxComputeAtomicCounters 8
MaxComputeAtomicCounterBuffers 1
MaxVaryingComponents 60
MaxVertexOutputComponents 64
MaxGeometryInputComponents 64
MaxGeometryOutputComponents 128
MaxFragmentInputComponents 128
MaxImageUnits 8
MaxCombinedImageUnitsAndFragmentOutputs 8
MaxCombinedShaderOutputResources 8
MaxImageSamples 0
MaxVertexImageUniforms 0
MaxTessControlImageUniforms 0
MaxTessEvaluationImageUniforms 0
MaxGeometryImageUniforms 0
MaxFragmentImageUniforms 81
```

```
MaxCombinedImageUniforms 8
MaxGeometryTextureImageUnits 16
MaxGeometryOutputVertices 256
MaxGeometryTotalOutputComponents 1024
MaxGeometryUniformComponents 1024
MaxGeometryVaryingComponents 64
MaxTessControlInputComponents 128
MaxTessControlOutputComponents 128
MaxTessControlTextureImageUnits 16
MaxTessControlUniformComponents 1024
MaxTessControlTotalOutputComponents 4096
MaxTessEvaluationInputComponents 128
MaxTessEvaluationOutputComponents 128
MaxTessEvaluationTextureImageUnits 16
MaxTessEvaluationUniformComponents 1024
MaxTessPatchComponents 120
MaxPatchVertices 32
MaxTessGenLevel 64
MaxViewports 16
MaxVertexAtomicCounters 0
MaxTessControlAtomicCounters 0
MaxTessEvaluationAtomicCounters 0
MaxGeometryAtomicCounters 0
MaxFragmentAtomicCounters 8
MaxCombinedAtomicCounters 8
MaxAtomicCounterBindings 1
MaxVertexAtomicCounterBuffers 0
MaxTessControlAtomicCounterBuffers 0
MaxTessEvaluationAtomicCounterBuffers 0
MaxGeometryAtomicCounterBuffers 0
MaxFragmentAtomicCounterBuffers 1
MaxCombinedAtomicCounterBuffers 1
MaxAtomicCounterBufferSize 16384
MaxTransformFeedbackBuffers 4
MaxTransformFeedbackInterleavedComponents 64
MaxCullDistances 8
MaxCombinedClipAndCullDistances 8
MaxSamples 4
nonInductiveForLoops 1
whileLoops 1
doWhileLoops 1
generalUniformIndexing 1
generalAttributeMatrixVectorIndexing 1
generalVaryingIndexing 1
generalSamplerIndexing 1
generalVariableIndexing 1
generalConstantMatrixVectorIndexing 1
```

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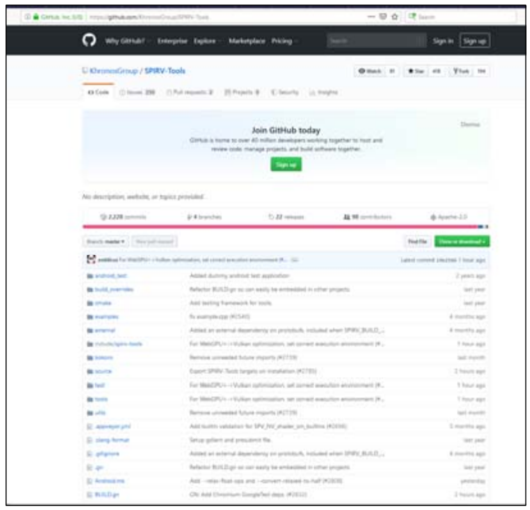
SPIR-V: More Information

23

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



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23

A Google-Wrapped Version of glslangValidator

24

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:

glslc.exe –target-env=vulkan sample-vert.vert -o 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:
   glslc.exe --target-env=vulkan -DNUMPONTS=4 sample-vert.vert -o sample-vert.spv

glslc is included in your Sample .zip file

Oregon State
University
Computer Graphics

mjb – December 17, 2020

24