Vulkan

Shaders and SPIR-V

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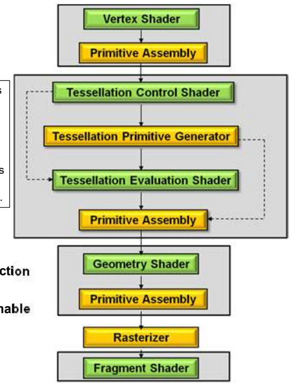
The Shaders' View of the Basic Computer Graphics Pipeline

- You need 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

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;
```


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 130
  or whatever the current version number is.
  Typically you use this like:

```
#ifdef VULKAN
    . . .
#endif
```

Vulkan Vertex and Instance indices:	OpenGL uses:
gl_VertexIndex	gl_VertexID
gl_InstanceIndex	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:
  layout (location = 0) out vec4 fFragColor;

How Vulkan GLSL Differs from OpenGL GLSL

Shader combinations of separate texture data and samplers as an option:

```
uniform sampler s;
uniform texture2D t;
vec4 rgba = texture( sampler2D( t, s ), vST );
```

Note: our sample code doesn't use this.

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

For example, Specialization Constants can be used with 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

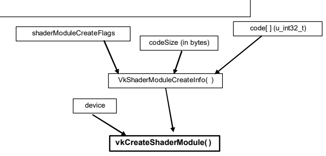
Vulkan: Shaders' use of Layouts for Uniform Variables

```
layout( std140, set = 0, binding = 0 ) uniform sceneMatBuf
{
    mat4 uProjectionMatrix;
    mat4 uViewMatrix;
    mat4 uSceneMatrix;
} SceneMatrices;

layout( std140, set = 1, binding = 0 ) uniform objectMatBuf
{
    mat4 uModelMatrix;
    mat4 uNormalMatrix;
} ObjectMatrices;

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

All non-sampler uniform variables *must* be in block buffers



Vulkan Shader Compiling

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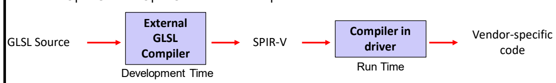
- You half-precompile your shaders with an external compiler
- Your shaders get turned into an intermediate form known as SPIR-V, which stands for **Standard Portable Intermediate Representation.**
- SPIR-V gets turned into fully-compiled code at runtime, when the pipeline structure is finally created
- 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



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

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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

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You can run the glslangValidator program from the Windows Command Prompt, but I have found it easier to run the SPIR-V compiler from Windows-Bash.

To install the bash shell on your own Windows machine, go to this URL:

https://www.msn.com/en-us/news/technology/how-to-install-and-run-bash-on-windows-11/ar-AA10EoPk

Or, follow these instructions:

1. Head to the **Start menu** search bar, type in 'terminal,' and launch the Windows Terminal as administrator. (On some systems, this is called the **Command Prompt**.)
2. Type in the following command in the administrator: **wsl --install**
3. Restart your PC once the installation is complete.

As soon as your PC boots up, the installation will begin again. Your PC will start downloading and installing the Ubuntu software. You'll soon get asked to set up a username and password. This can be the same as your system's username and password, but doesn't have to be. The installation will automatically start off from where you left it.

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

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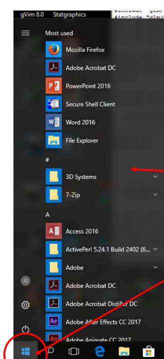

2. Type the word *bash*

1. Click on the Microsoft Start icon

BTW, within bash, if you want to list your files without that sometimes-hard-to-read filename coloring, do this:

ls -l --color=none

(ell-ess minus-ell minus-minus-color=none)

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Running glslangValidator.exe in bash

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As long as I am on bash, I like using the *make* utility. To do that, put these shader compile lines in a file called *Makefile*:

```
ALLSHADERS:      sample-vert.vert   sample-frag.frag
                 glslangValidator.exe -V sample-vert.vert   -o sample-vert.spv
                 glslangValidator.exe -V sample-frag.frag   -o sample-frag.spv
```

Then type *make ALLSHADERS*:

```
mjb@PC:/mnt/c/MJB/Vulkan/Sample2019-COLOREDCUBE$ make ALLSHADERS
glslangValidator.exe -V sample-vert.vert   -o sample-vert.spv
sample-vert.vert
glslangValidator.exe -V sample-frag.frag   -o sample-frag.spv
sample-frag.frag
mjb@PC:/mnt/c/MJB/Vulkan/Sample2019-COLOREDCUBE$
```

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Running glslangValidator.exe

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

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

Specify the SPIR-V 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**

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How do you know if SPIR-V compiled successfully?

Same as C/C++ -- the compiler gives you no nasty messages, it just prints the name of the source file you just compiled.

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

So, if you use the Linux command **od -x** on the .spv file, like this:

od -x sample-vert.spv

the magic number shows up like this:

```
0000000 0203 0723 0000 0001 000a 0008 007e 0000
0000020 0000 0000 0011 0002 0001 0000 000b 0006
. . .
```

"od" stands for "octal dump", even though it can format the raw bits as most anything: octal, hexadecimal, bytes, characters, etc. "-x" means to format in hexadecimal.

Reading a SPIR-V File into a Vulkan Shader Module


```
#ifndef _WIN32
        typedef int errno_t;
        int     fopen_s( FILE**, const char *, const char * );
#endif

#define SPIRV_MAGIC          0x07230203
. . .

VkResult
Init12SpirvShader( std::string filename, VkShaderModule * pShaderModule )
{
     FILE *fp;
#ifdef WIN32
        errno_t err = fopen_s( &fp, filename.c_str( ), "rb" );
        if( err != 0 )
#else
        fp = fopen( filename.c_str( ), "rb" );
        if( fp == NULL )
#endif
     {
          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 );
     . . .
```

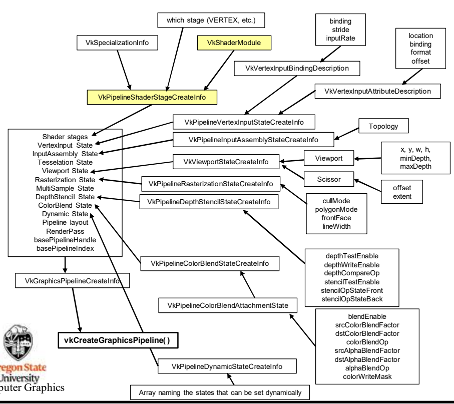

Reading a SPIR-V File into a Shader Module


```
. . .
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;
}
```


Vulkan: Creating a Pipeline



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


```
#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

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```
#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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This is the SPIR-V Assembly, Part II

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```
#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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This is the SPIR-V Assembly, Part III

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```
#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

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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

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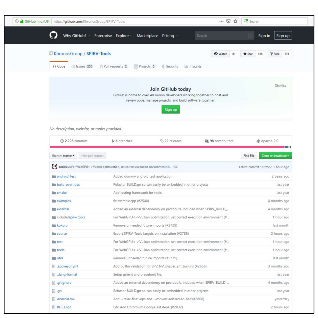
SPIR-V Tools:
http://github.com/KhronosGroup/SPIRV-Tools



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A Google-Wrapped Version of glslangValidator

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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

This causes a:
#define NUMPOINTS 4
to magically be inserted into the top of your source code.

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