Vulkan®

Shaders and SPIR-V

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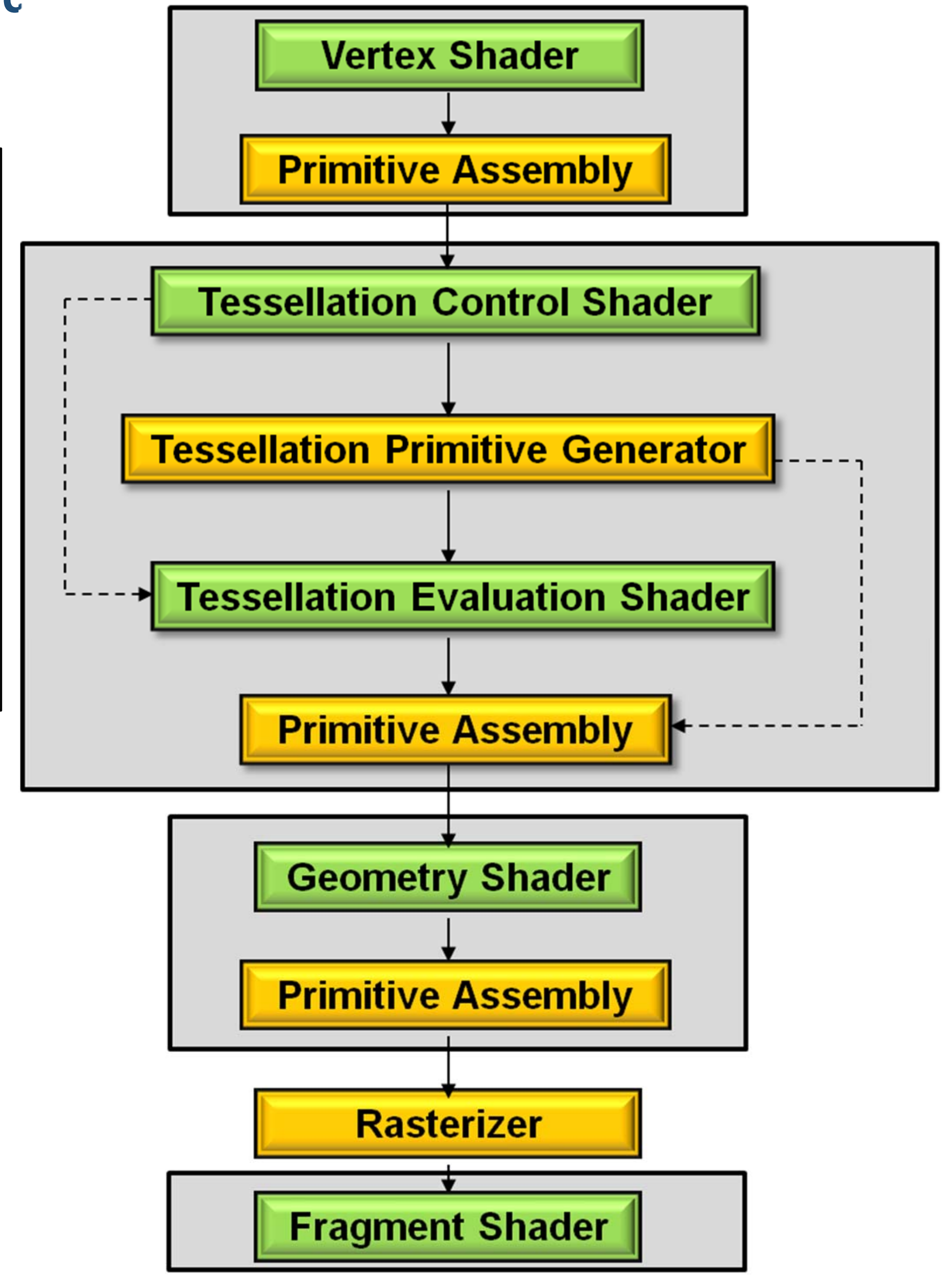
The Shaders' View of the Basic Computer Graphics Pipeline

• 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**

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;
```

Vulkan: GLSL Differences from OpenGL

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

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

Vertex and Instance indices:

gl_VertexIndex
gl_InstanceIndex

These are
gl_VertexID
gl_InstanceID
In OpenGL. The Vulkan names make more sense.

- Both are 0-based

gl_FragColor:

- In OpenGL, it broadcasts to all color attachments
- In Vulkan, it just broadcasts to color attachment location #0
- Best idea: don't use it – explicitly declare out variables to have specific location numbers

Vulkan: GLSL Differences from OpenGL

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;
```

- Can only use basic operators, declarations, and constructors
- Only for scalars, but a vector can be constructed from specialization constants

Specialization Constants for Compute Shaders:

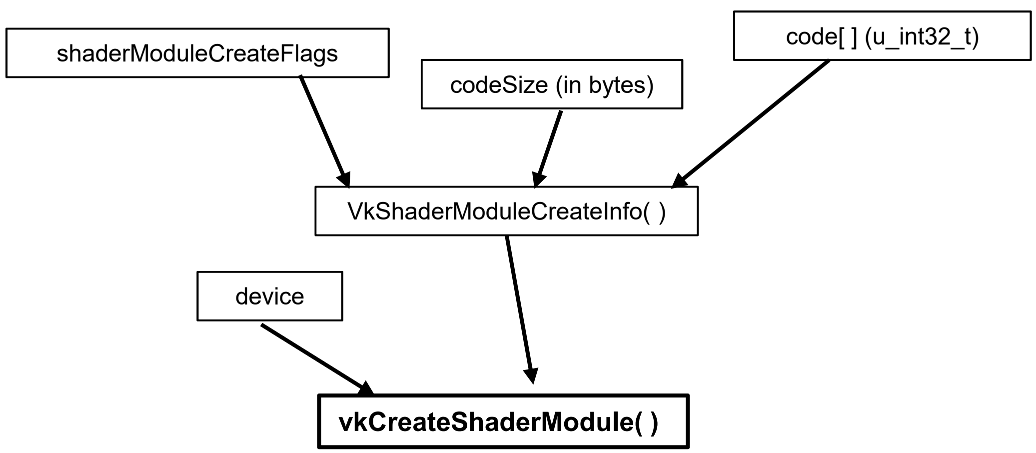
```
layout( local_size_x_id = 8, local_size_y_id = 16 );
```

- gl_WorkGroupSize.z is still as it was

Vulkan: Shaders’ use of Layouts for Uniform Variables

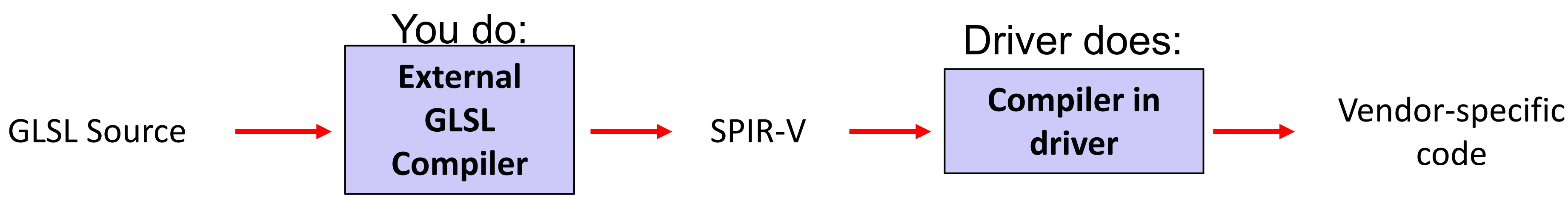
```
layout( std140, set = 0, binding = 0 ) uniform matBuf
{
        mat4 uModelMatrix;
        mat4 uViewMatrix;
        mat4 uProjectionMatrix;
        mat3 uNormalMatrix;
} Matrices;

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

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

All opaque (non-sampler) uniform variables must be in block buffers



Vulkan Shader Compiling

- You pre-compile your shaders with an external compiler
- Your shaders get turned into an intermediate form known as SPIR-V
- SPIR-V gets turned into fully-compiled code at runtime
- SPIR-V spec has been public for a couple of years –new shader languages are surely being developed
- OpenGL and OpenCL will be moving to 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

SPIR-V, from the Khronos Group

The first open standard intermediate language for parallel compute and graphics:

- SPIR (**Standard Portable Intermediate Representation**) was initially developed for use by OpenCL and SPIR versions 1.2 and 2.0 were based on LLVM. SPIR has now evolved into a true cross-API standard that is fully defined by Khronos with native support for shader and kernel features – called SPIR-V.
- SPIR-V is the first open standard, cross-API intermediate language for natively representing parallel compute and graphics and is incorporated as part of the core specification of both OpenCL 2.1 and OpenCL 2.2 and the new Vulkan graphics and compute API.
- SPIR-V exposes the machine model for OpenCL 1.2, 2.0, 2.1, 2.2 and Vulkan - including full flow control, and graphics and parallel constructs not supported in LLVM. SPIR-V also supports OpenCL C and OpenCL C++ kernel languages as well as the GLSL shader language for Vulkan.
- SPIR-V 1.1, launched in parallel with OpenCL 2.2, now supports all the kernel language features of OpenCL C++ in OpenCL 2.2, including initializer and finalizer function execution modes to support constructors and destructors. SPIR-V 1.1 also enhances the expressiveness of kernel programs by supporting named barriers, subgroup execution, and program scope pipes.
- SPIR-V is catalyzing a revolution in the language compiler ecosystem - it can split the compiler chain across multiple vendors' products, enabling high-level language front-ends to emit programs in a standardized intermediate form to be ingested by Vulkan or OpenCL drivers. For hardware vendors, ingesting SPIR-V eliminate the need to build a high-level language source compiler into device drivers, significantly reducing driver complexity, and will enable a broad range of language and framework front-ends to run on diverse hardware architectures.
- For developers, using SPIR-V means that kernel source code no longer has to be directly exposed, kernel load times can be accelerated and developers can choose the use of a common language front-end, improving kernel reliability and portability across multiple hardware implementations.

KHRONOS GROUP
CONNECTING SOFTWARE TO SILICON

SPIR™

https://www.khronos.org/spir

SPIR-V:
Standard Portable Intermediate Representation for Vulkan

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

Shaderfile extensions:

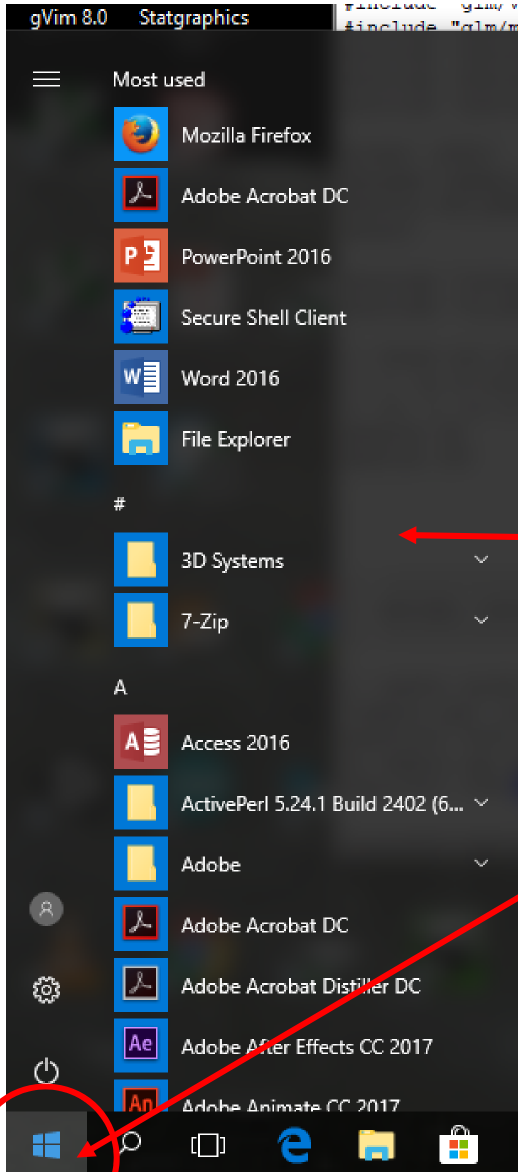
.vert	Vertex
.tesc	Tessellation Control
.tese	Tessellation Evaluation
.geom	Geometry
.frag	Fragment
.comp	Compute

(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: setenv LD_LIBRARY_PATH /usr/local/common/gcc-6.3.0/lib64/

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



2. Type word *bash*

1. Click on the Microsoft Start icon

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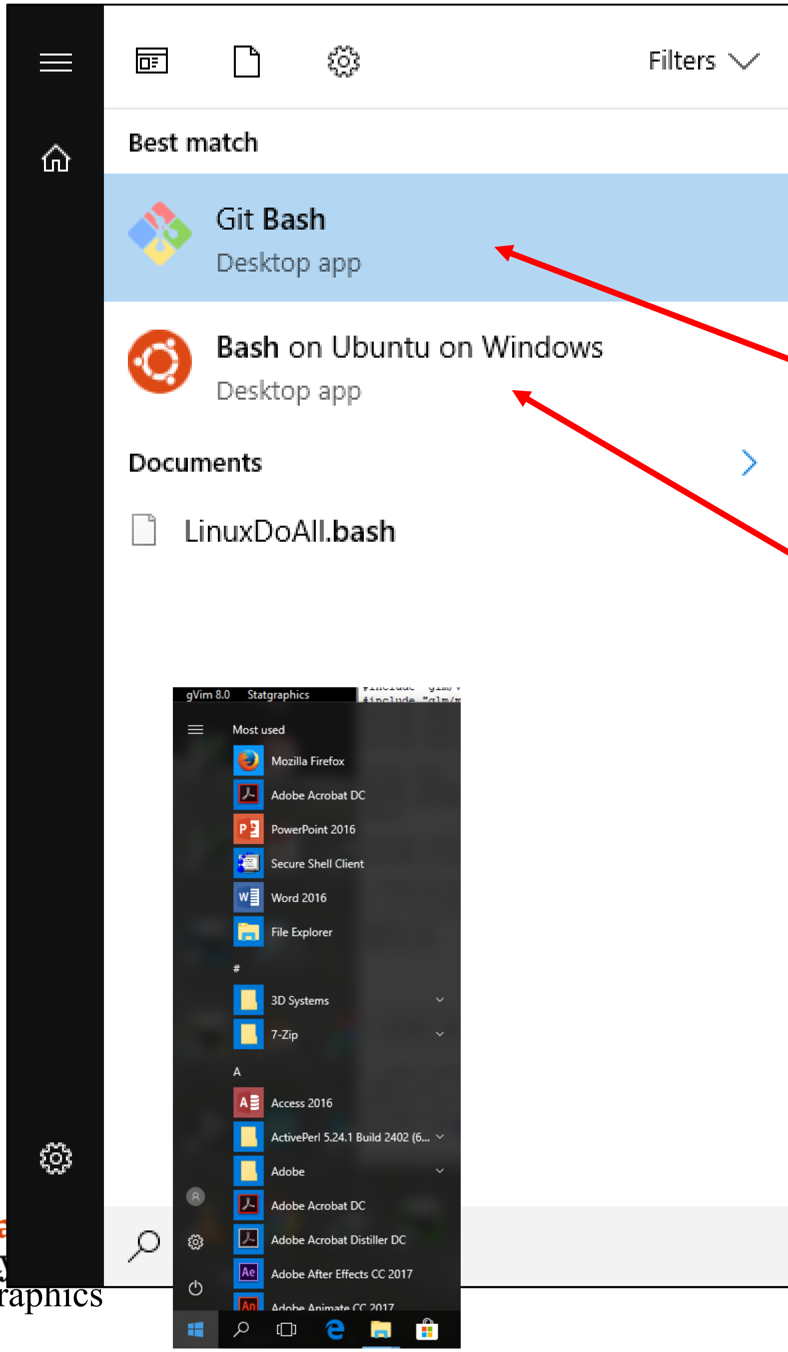
You Can Run the SPIR-V Compiler on Windows from a Bash Shell



Pick one:

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

- Cannot get to your personal folders
- Does have make

Running glslangValidator.exe

MINGW64:/y/Vulkan/Sample2017

```
ONID+mjb@pooh MINGW64 /y/Vulkan/Sample2017
$ !85
glslangValidator.exe -V sample-vert.vert -o sample-vert.spv
sample-vert.vert

ONID+mjb@pooh MINGW64 /y/Vulkan/Sample2017
$ !86
glslangValidator.exe -V sample-frag.frag -o sample-frag.spv
sample-frag.frag

ONID+mjb@pooh MINGW64 /y/Vulkan/Sample2017
$
```

You can also run SPIR-V from a Linux Shell


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

$  glslangValidator.exe  -V  sample-frag.frag  -o  sample-frag.spv
```

You can also run SPIR-V from a Linux Shell

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

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 . . .

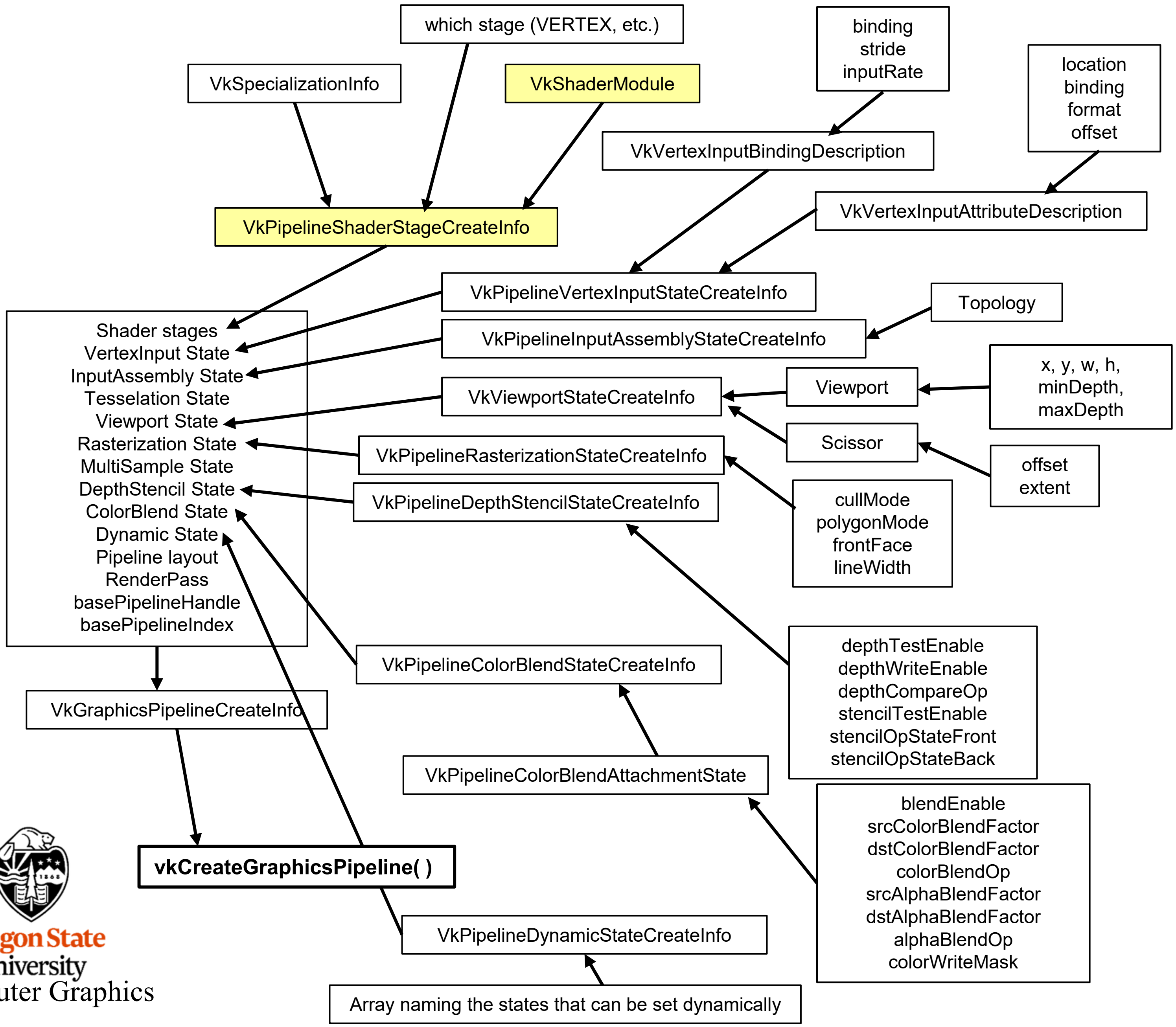
Reading a SPIR-V File into a Vulkan Shader Module

```
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 );
```

Reading a SPIR-V File into a Shader Module

```
	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, IN &vsmci, PALLOCATOR, pShaderModule );
	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


```
#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
```

This is the SPIR-V Assembly, Part II


```
#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


```
#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
```

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
```

SPIR-V: More Information

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

Installing bash on Windows

1.Open **Settings**.
2.Click on **Update & security**.
3.Click on **For Developers**.
4.Under "Use developer features", select the **Developer mode** option to setup the environment to install Bash.
5.On the message box, click **Yes** to turn on developer mode.
6.After the necessary components install, you'll need to restart your computer.
7.Once your computer reboots, open **Control Panel**.
8.Click on **Programs**.
9.Click on **Turn Windows features on or off**.
10.Check the **Windows Subsystem for Linux (beta)** option.
11.Click **OK**.
12.Once the components installed on your computer, click the **Restart now** button to complete the task.

After your computer restarts, you will notice that Bash will not appear in the "Recently added" list of apps, this is because Bash isn't actually installed yet. Now that you have setup the necessary components, use the following steps to complete the installation of Bash.

1.Open Start, do a search for **bash.exe**, and press **Enter**.
2.On the command prompt, type **y** and press **Enter** to download and install Bash from the Windows Store.
3.Then you'll need to create a default UNIX user account. This account doesn't have to be the same as your Windows account. Enter the username in the required field and press **Enter** (you can't use the username "admin").
4.Close the "bash.exe" command prompt

Now that you completed the installation and setup, you can open the Bash tool from the Start menu like you would with any other app.

https://www.windowscentral.com/how-install-bash-shell-command-line-windows-10