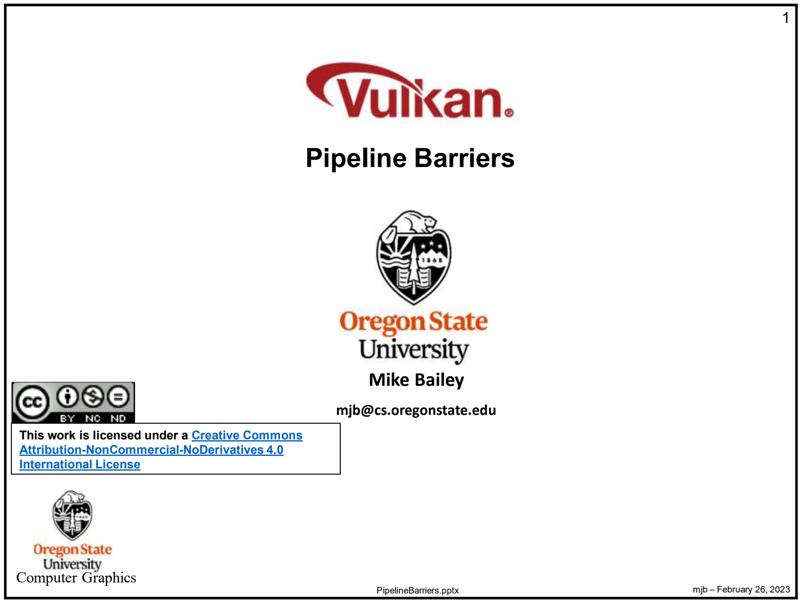

Vulkan.

Pipeline Barriers

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Mike Bailey
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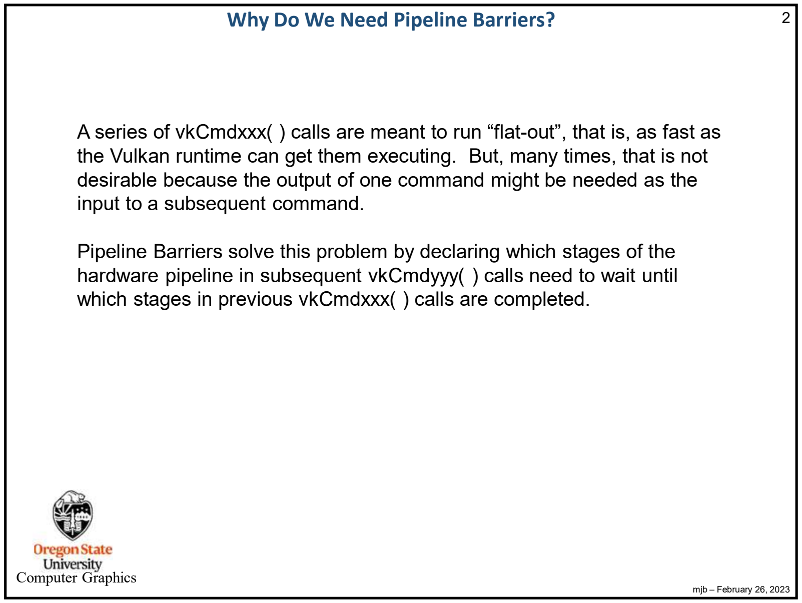
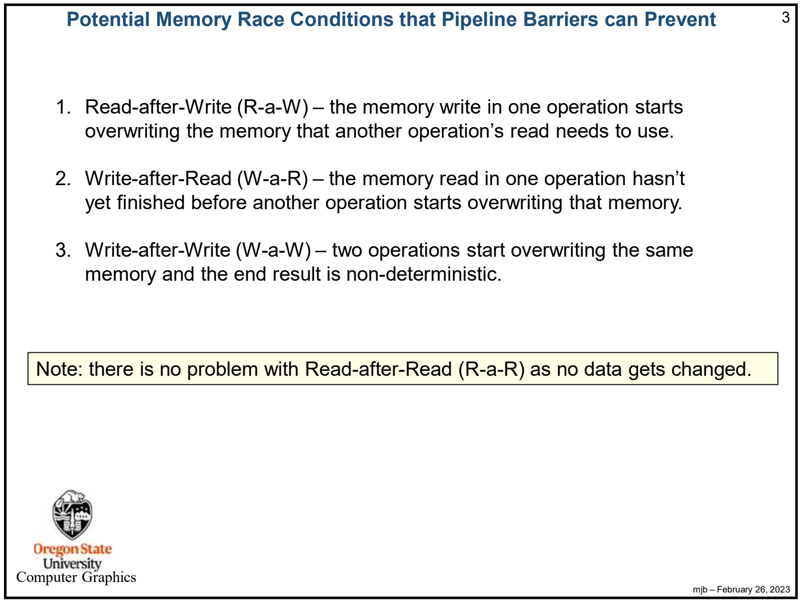


Why Do We Need Pipeline Barriers?

A series of vkCmdxxx( ) calls are meant to run “flat-out”, that is, as fast as the Vulkan runtime can get them executing. But, many times, that is not desirable because the output of one command might be needed as the input to a subsequent command.

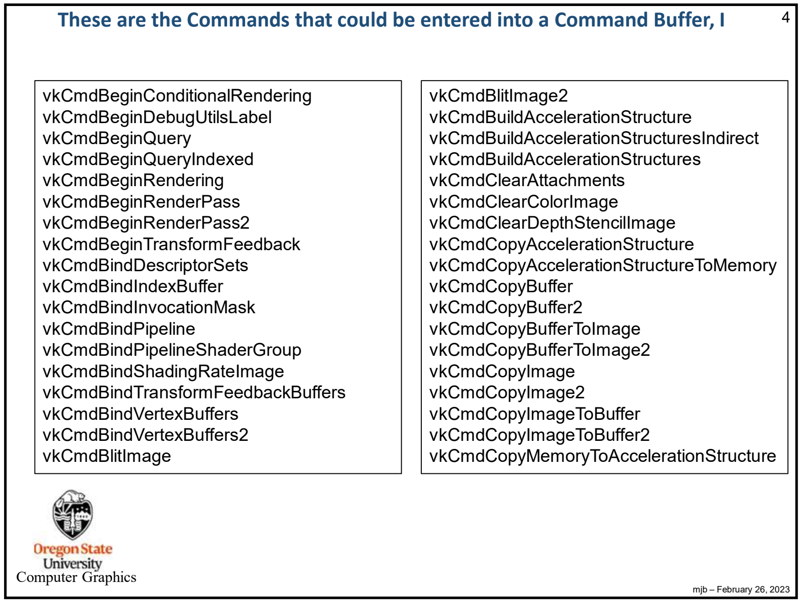
Pipeline Barriers solve this problem by declaring which stages of the hardware pipeline in subsequent vkCmdyyy( ) calls need to wait until which stages in previous vkCmdxxx( ) calls are completed.



Potential Memory Race Conditions that Pipeline Barriers can Prevent

1. Read-after-Write (R-a-W) – the memory write in one operation starts overwriting the memory that another operation’s read needs to use.
2. Write-after-Read (W-a-R) – the memory read in one operation hasn’t yet finished before another operation starts overwriting that memory.
3. Write-after-Write (W-a-W) – two operations start overwriting the same memory and the end result is non-deterministic.

Note: there is no problem with Read-after-Read (R-a-R) as no data gets changed.



These are the Commands that could be entered into a Command Buffer, I

vkCmdBeginConditionalRendering
vkCmdBeginDebugUtilsLabel
vkCmdBeginQuery
vkCmdBeginQueryIndexed
vkCmdBeginRendering
vkCmdBeginRenderPass
vkCmdBeginRenderPass2
vkCmdBeginTransformFeedback
vkCmdBindDescriptorSets
vkCmdBindIndexBuffer
vkCmdBindInvocationMask
vkCmdBindPipeline
vkCmdBindPipelineShaderGroup
vkCmdBindShadingRateImage
vkCmdBindTransformFeedbackBuffers
vkCmdBindVertexBuffers
vkCmdBindVertexBuffers2
vkCmdBlitImage

vkCmdBlitImage2
vkCmdBuildAccelerationStructure
vkCmdBuildAccelerationStructuresIndirect
vkCmdBuildAccelerationStructures
vkCmdClearAttachments
vkCmdClearColorImage
vkCmdClearDepthStencilImage
vkCmdCopyAccelerationStructure
vkCmdCopyAccelerationStructureToMemory
vkCmdCopyBuffer
vkCmdCopyBuffer2
vkCmdCopyBufferToImage
vkCmdCopyBufferToImage2
vkCmdCopyImage
vkCmdCopyImage2
vkCmdCopyImageToBuffer
vkCmdCopyImageToBuffer2
vkCmdCopyMemoryToAccelerationStructure

These are the Commands that could be entered into a Command Buffer, II

vkCmdCopyQueryPoolResults
vkCmdCuLaunchKernelX
vkCmdDebugMarkerBegin
vkCmdDebugMarkerEnd
vkCmdDebugMarkerInsert
vkCmdDispatch
vkCmdDispatchBase
vkCmdDispatchIndirect
vkCmdDraw
vkCmdDrawIndexed
vkCmdDrawIndexedIndirect
vkCmdDrawIndexedIndirectCount
vkCmdDrawIndirect
vkCmdDrawIndirectByteCount
vkCmdDrawIndirectCount
vkCmdDrawMeshTasksIndirectCount
vkCmdDrawMeshTasksIndirect
vkCmdDrawMeshTasks

vkCmdDrawMulti
vkCmdDrawMultiIndexed
vkCmdEndConditionalRendering
vkCmdEndDebugUtilsLabel
vkCmdEndQuery
vkCmdEndQueryIndexed
vkCmdEndRendering
vkCmdEndRenderPass
vkCmdEndRenderPass2
vkCmdEndTransformFeedback
vkCmdExecuteCommands
vkCmdExecuteGeneratedCommands
vkCmdFillBuffer
vkCmdInsertDebugUtilsLabel
vkCmdNextSubpass
vkCmdNextSubpass2
vkCmdPipelineBarrier
vkCmdPipelineBarrier2

These are the Commands that could be entered into a Command Buffer, III

vkCmdPreprocessGeneratedCommands
vkCmdPushConstants
vkCmdPushDescriptorSet
vkCmdPushDescriptorSetWithTemplate
vkCmdResetEvent
vkCmdResetEvent2
vkCmdResetQueryPool
vkCmdResolveImage
vkCmdResolveImage2
vkCmdSetBlendConstants
vkCmdSetCheckpoint
vkCmdSetCoarseSampleOrder
vkCmdSetCullMode
vkCmdSetDepthBias
vkCmdSetDepthBiasEnable
vkCmdSetDepthBounds
vkCmdSetDepthBoundsTestEnable
vkCmdSetDepthCompareOp

vkCmdSetDepthTestEnable
vkCmdSetDepthWriteEnable
vkCmdSetDeviceMask
vkCmdSetDiscardRectangle
vkCmdSetEvent
vkCmdSetEvent2
vkCmdSetExclusiveScissor
vkCmdSetFragmentShadingRateEnum
vkCmdSetFragmentShadingRate
vkCmdSetFrontFace
vkCmdSetLineStipple
vkCmdSetLineWidth
vkCmdSetLogicOp
vkCmdSetPatchControlPoints
vkCmdSetPrimitiveRestartEnable
vkCmdSetPrimitiveTopology
vkCmdSetRasterizerDiscardEnable
vkCmdSetRayTracingPipelineStackSize

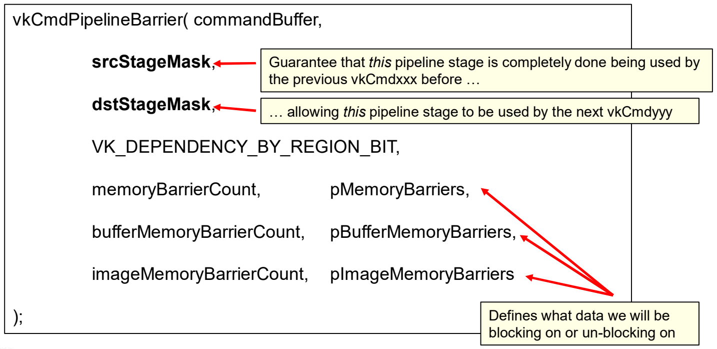
These are the Commands that could be entered into a Command Buffer, IV

vkCmdSetSampleLocations
vkCmdSetScissor
vkCmdSetScissorWithCount
vkCmdSetStencilCompareMask
vkCmdSetStencilOp
vkCmdSetStencilReference
vkCmdSetStencilTestEnable
vkCmdSetStencilWriteMask
vkCmdSetVertexInput
vkCmdSetViewport
vkCmdSetViewportShadingRatePalette
vkCmdSetViewportWithCount
vkCmdSetViewportWScaling

vkCmdSubpassShading
vkCmdTraceRaysIndirect2
vkCmdTraceRaysIndirect
vkCmdTraceRays
vkCmdUpdateBuffer
vkCmdWaitEvents
vkCmdWaitEvents2
vkCmdWriteAccelerationStructuresProperties
vkCmdWriteBufferMarker2
vkCmdWriteBufferMarker
vkCmdWriteTimestamp
vkCmdWriteTimestamp2

vkCmdPipelineBarrier( ) Function Call

A **Pipeline Barrier** is a way to establish a dependency between commands that were submitted before the barrier and commands that are submitted after the barrier



```
vkCmdPipelineBarrier( commandBuffer,

        srcStageMask,

        dstStageMask,

        VK_DEPENDENCY_BY_REGION_BIT,

        memoryBarrierCount,        pMemoryBarriers,

        bufferMemoryBarrierCount,  pBufferMemoryBarriers,

        imageMemoryBarrierCount,   pImageMemoryBarriers

);
```

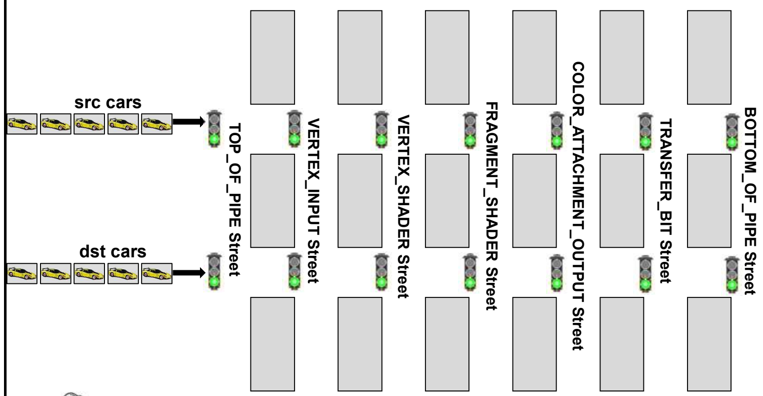
Guarantee that *this* pipeline stage is completely done being used by the previous vkCmdxxx before …

… allowing *this* pipeline stage to be used by the next vkCmdyyy

Defines what data we will be blocking on or un-blocking on

The hope is maximize the number of unblocked stages:
produce data *early* and consume date *late*

The Scenario



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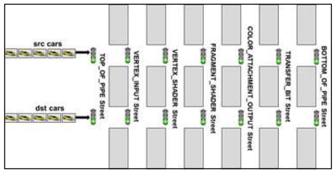
The Scenario

1. The cross-streets are named after pipeline stages
2. All traffic lights start out green
3. There are special sensors at all intersections that will know when ***any car in the src group*** is in that intersection
4. There are connections from those sensors to the traffic lights so that when ***any car in the src group*** is in the intersection, the proper ***dst*** traffic lights will be turned red
5. When the ***last car in the src group*** completely makes it through its intersection, the proper ***dst*** traffic lights are turned back to green
6. The Vulkan command pipeline ordering is this: (1) the **src** cars get released by the previous vkCmdxxx, (2) the pipeline barrier is invoked (which turns some lights red), (3) the dst cars get released by the next vkCmdyyy, (4) the **dst** cars stop at the red light, (5) the **src** cars clear the intersection, (6) the dst lights turn green, (6) the **dst** cars continue.



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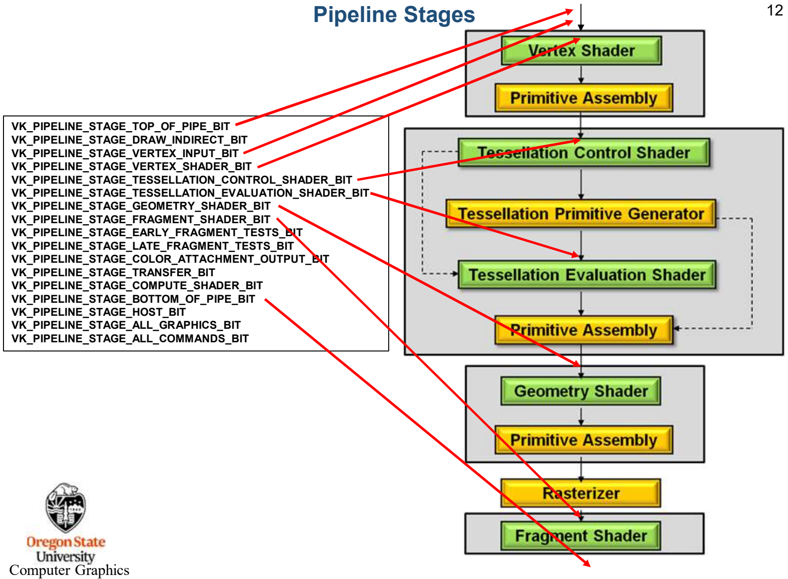
Pipeline Stage Masks – Where in the Pipeline is this Memory Data being Generated or Consumed?

VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT
VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT
VK_PIPELINE_STAGE_VERTEX_INPUT_BIT
VK_PIPELINE_STAGE_VERTEX_SHADER_BIT
VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT
VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT
VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT
VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT
VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT
VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT
VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT
VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT
VK_PIPELINE_STAGE_TRANSFER_BIT
VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT
VK_PIPELINE_STAGE_HOST_BIT
VK_PIPELINE_STAGE_ALL_GRAPHICS_BIT
VK_PIPELINE_STAGE_ALL_COMMANDS_BIT

Pipeline Stages



VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT
VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT
VK_PIPELINE_STAGE_VERTEX_INPUT_BIT
VK_PIPELINE_STAGE_VERTEX_SHADER_BIT
VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT
VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT
VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT
VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT
VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT
VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT
VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT
VK_PIPELINE_STAGE_TRANSFER_BIT
VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT
VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT
VK_PIPELINE_STAGE_HOST_BIT
VK_PIPELINE_STAGE_ALL_GRAPHICS_BIT
VK_PIPELINE_STAGE_ALL_COMMANDS_BIT

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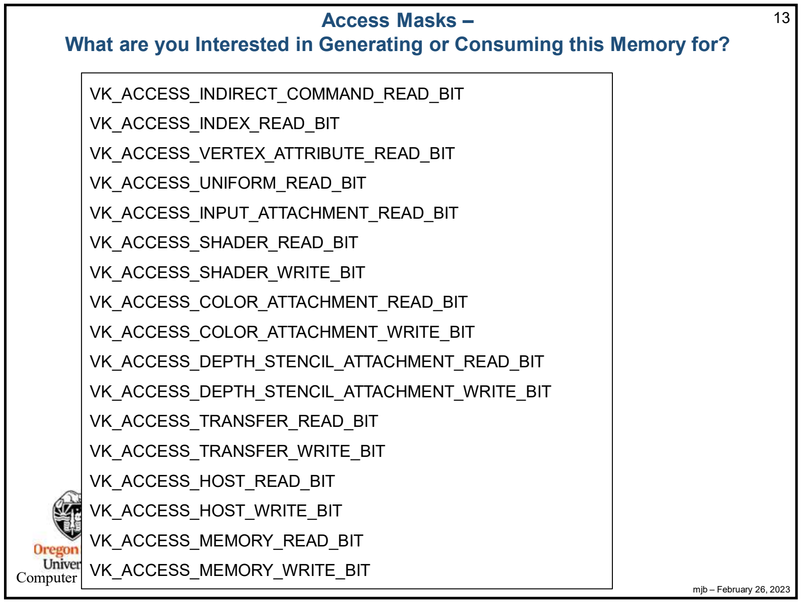

Access Masks – What are you Interested in Generating or Consuming this Memory for?

VK_ACCESS_INDIRECT_COMMAND_READ_BIT
VK_ACCESS_INDEX_READ_BIT
VK_ACCESS_VERTEX_ATTRIBUTE_READ_BIT
VK_ACCESS_UNIFORM_READ_BIT
VK_ACCESS_INPUT_ATTACHMENT_READ_BIT
VK_ACCESS_SHADER_READ_BIT
VK_ACCESS_SHADER_WRITE_BIT
VK_ACCESS_COLOR_ATTACHMENT_READ_BIT
VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT
VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT
VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT
VK_ACCESS_TRANSFER_READ_BIT
VK_ACCESS_TRANSFER_WRITE_BIT
VK_ACCESS_HOST_READ_BIT
VK_ACCESS_HOST_WRITE_BIT
VK_ACCESS_MEMORY_READ_BIT
VK_ACCESS_MEMORY_WRITE_BIT

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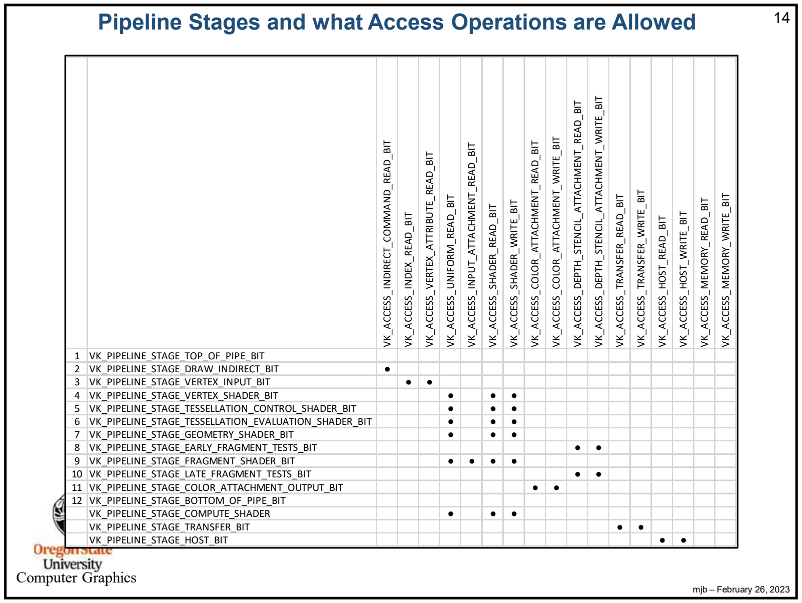

Pipeline Stages and what Access Operations are Allowed

		VK_ACCESS_INDIRECT_COMMAND_READ_BIT	VK_ACCESS_INDEX_READ_BIT	VK_ACCESS_VERTEX_ATTRIBUTE_READ_BIT	VK_ACCESS_UNIFORM_READ_BIT	VK_ACCESS_INPUT_ATTACHMENT_READ_BIT	VK_ACCESS_SHADER_READ_BIT	VK_ACCESS_SHADER_WRITE_BIT	VK_ACCESS_COLOR_ATTACHMENT_READ_BIT	VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT	VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT	VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT	VK_ACCESS_TRANSFER_READ_BIT	VK_ACCESS_TRANSFER_WRITE_BIT	VK_ACCESS_HOST_READ_BIT	VK_ACCESS_HOST_WRITE_BIT	VK_ACCESS_MEMORY_READ_BIT	VK_ACCESS_MEMORY_WRITE_BIT
1	VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT																	
2	VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT	●																
3	VK_PIPELINE_STAGE_VERTEX_INPUT_BIT		●	●														
4	VK_PIPELINE_STAGE_VERTEX_SHADER_BIT				●		●	●										
5	VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT				●		●	●										
6	VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT				●		●	●										
7	VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT				●		●	●										
8	VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT										●	●						
9	VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT				●	●	●	●										
10	VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT										●	●						
11	VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT								●	●								
12	VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT																	
	VK_PIPELINE_STAGE_COMPUTE_SHADER				●		●	●										
	VK_PIPELINE_STAGE_TRANSFER_BIT												●	●				
	VK_PIPELINE_STAGE_HOST_BIT														●	●		

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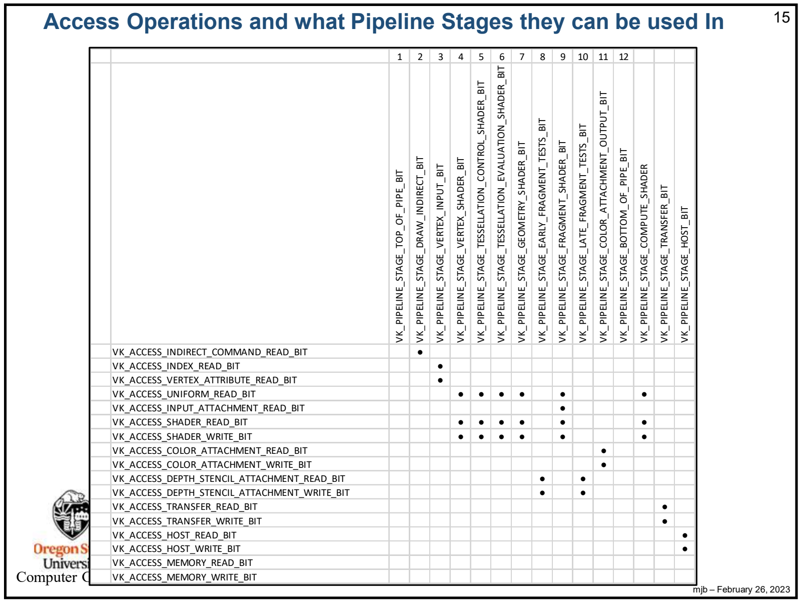

Access Operations and what Pipeline Stages they can be used In

	1	2	3	4	5	6	7	8	9	10	11	12			
	VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT	VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT	VK_PIPELINE_STAGE_VERTEX_INPUT_BIT	VK_PIPELINE_STAGE_VERTEX_SHADER_BIT	VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT	VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT	VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT	VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT	VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT	VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT	VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT	VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT	VK_PIPELINE_STAGE_COMPUTE_SHADER	VK_PIPELINE_STAGE_TRANSFER_BIT	VK_PIPELINE_STAGE_HOST_BIT
VK_ACCESS_INDIRECT_COMMAND_READ_BIT		●													
VK_ACCESS_INDEX_READ_BIT			●												
VK_ACCESS_VERTEX_ATTRIBUTE_READ_BIT			●												
VK_ACCESS_UNIFORM_READ_BIT				●	●	●	●		●				●		
VK_ACCESS_INPUT_ATTACHMENT_READ_BIT									●						
VK_ACCESS_SHADER_READ_BIT				●	●	●	●		●				●		
VK_ACCESS_SHADER_WRITE_BIT				●	●	●	●		●				●		
VK_ACCESS_COLOR_ATTACHMENT_READ_BIT											●				
VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT											●				
VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT								●		●					
VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT								●		●					
VK_ACCESS_TRANSFER_READ_BIT														●	
VK_ACCESS_TRANSFER_WRITE_BIT														●	
VK_ACCESS_HOST_READ_BIT															●
VK_ACCESS_HOST_WRITE_BIT															●
VK_ACCESS_MEMORY_READ_BIT															
VK_ACCESS_MEMORY_WRITE_BIT															

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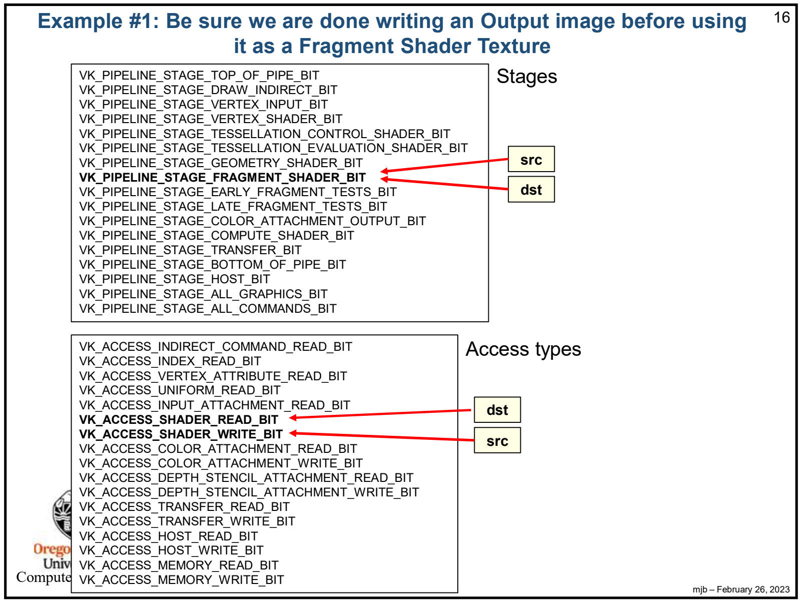

Example #1: Be sure we are done writing an Output image before using it as a Fragment Shader Texture

Stages

VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT
VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT
VK_PIPELINE_STAGE_VERTEX_INPUT_BIT
VK_PIPELINE_STAGE_VERTEX_SHADER_BIT
VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT
VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT
VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT
VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT
VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT
VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT
VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT
VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT
VK_PIPELINE_STAGE_TRANSFER_BIT
VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT
VK_PIPELINE_STAGE_HOST_BIT
VK_PIPELINE_STAGE_ALL_GRAPHICS_BIT
VK_PIPELINE_STAGE_ALL_COMMANDS_BIT

src

dst

Access types

VK_ACCESS_INDIRECT_COMMAND_READ_BIT
VK_ACCESS_INDEX_READ_BIT
VK_ACCESS_VERTEX_ATTRIBUTE_READ_BIT
VK_ACCESS_UNIFORM_READ_BIT
VK_ACCESS_INPUT_ATTACHMENT_READ_BIT
VK_ACCESS_SHADER_READ_BIT
VK_ACCESS_SHADER_WRITE_BIT
VK_ACCESS_COLOR_ATTACHMENT_READ_BIT
VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT
VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT
VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT
VK_ACCESS_TRANSFER_READ_BIT
VK_ACCESS_TRANSFER_WRITE_BIT
VK_ACCESS_HOST_READ_BIT
VK_ACCESS_HOST_WRITE_BIT
VK_ACCESS_MEMORY_READ_BIT
VK_ACCESS_MEMORY_WRITE_BIT

dst

src

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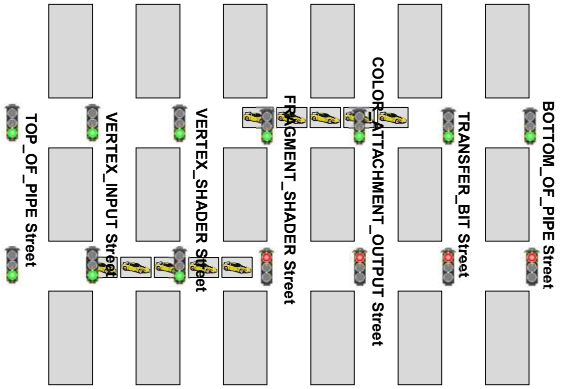
Example #1: The Scenario

src cars are generating the image

dst cars are waiting to use that image as a texture



Example #2: Setting a Pipeline Barrier so the Drawing Waits for the Compute Shader to Finish

```
VkBufferMemoryBarrier                    vbmb;
        vbmb.sType = VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER;
        vbmb.pNext = nullptr;
        vbmb.srcAccessFlags = VK_ACCESS_SHADER_WRITE_BIT;
        vbmb.dstAccessFlags = VK_ACCESS_SHADER_READ_BIT;
        vbmb.srcQueueFamilyIndex = 0;
        vbmb.dstQueueFamilyIndex = 0;
        vbmb.buffer =
        vbmb.offset = 0;
        vbmb.size = NUM_PARTICLES * sizeof( glm::vec4 );

const uint32 bufferMemoryBarrierCount = 1;

vkCmdPipelineBarrier
(
        commandBuffer,
        VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT,
        VK_PIPELINE_STAGE_VERTEX_SHADER_BIT,
        VK_DEPENDENCY_BY_REGION_BIT,
        0,  nullptr,   bufferMemoryBarrierCount, IN &vbmb,  0,nullptr
);
```

Example #2: Setting a Pipeline Barrier so the Compute Shader Waits for the Drawing to Finish

```
VkBufferMemoryBarrier                    vbmb;
        vbmb.sType = VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER;
        vbmb.pNext = nullptr;
        vbmb.srcAccessFlags = VK_ACCESS_SHADER_WRITE_BIT;
        vbmb.dstAccessFlags = VK_ACCESS_SHADER_READ_BIT;
        vbmb.srcQueueFamilyIndex = 0;
        vbmb.dstQueueFamilyIndex = 0;
        vbmb.buffer =
        vbmb.offset = 0;
        vbmb.size = NUM_PARTICLES * sizeof( glm::vec4 );

const uint32 bufferMemoryBarrierCount = 1;

vkCmdPipelineBarrier
(
        commandBuffer,
        VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT,
        VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT,
        VK_DEPENDENCY_BY_REGION_BIT,
        0,  nullptr,   bufferMemoryBarrierCount, IN &vbmb,    0,     nullptr
);
```