Pipeline Barriers: 
A case of Gate-ing and Wait-ing

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From the Command Buffer Notes:
These are the Commands that can be entered into the Command Buffer, I

```c
vkCmdBeginQuery( commandBuffer, flags );
vkCmdBeginRenderPass( commandBuffer, const contents );
vkCmdBindDescriptorSets( commandBuffer, pDynamicOffsets );
vkCmdBindIndexBuffer( commandBuffer, indexType );
vkCmdBindPipeline( commandBuffer, pipeline );
vkCmdBindVertexBuffer( commandBuffer, firstBinding, bindingCount, const pOffsets );
vkCmdBlitImage( commandBuffer, filter );
vkCmdClearAttachments( commandBuffer, attachmentCount, const pRects );
vkCmdClearColorImage( commandBuffer, pRanges );
vkCmdClearDepthStencilImage( commandBuffer, pRanges );
vkCmdCopyBuffer( commandBuffer, pRegions );
vkCmdCopyBufferToImage( commandBuffer, pRanges );
vkCmdCopyImage( commandBuffer, pRegions );
vkCmdCopyImageToBuffer( commandBuffer, pRegions );
vkCmdCopyQueryPoolResults( commandBuffer, flags );
vkCmdDebugMarkerBeginEXT( commandBuffer, pMarkerInfo );
vkCmdDebugMarkerEndEXT( commandBuffer );
vkCmdDebugMarkerInsertEXT( commandBuffer, pMarkerInfo );
vkCmdDispatch( commandBuffer, groupCountX, groupCountY, groupCountZ );
vkCmdDispatchIndirect( commandBuffer, offset );
vkCmdDispatchIndirect( commandBuffer, offset );
vkCmdDraw( commandBuffer, vertexCount, instanceCount, firstVertex, firstInstance );
vkCmdDrawIndexed( commandBuffer, indexCount, instanceCount, firstIndex, int32_t vertexOffset, firstInstance );
vkCmdDrawIndexedIndirect( commandBuffer, stride );
vkCmdDrawIndexedIndirectCountAMD( commandBuffer, stride );
vkCmdDrawIndirect( commandBuffer, stride );
vkCmdDrawIndirectCountAMD( commandBuffer, stride );
vkCmdEndQuery( commandBuffer, query );
vkCmdEndRenderPass( commandBuffer );
vkCmdExecuteCommands( commandBuffer, commandBufferCount, const pCommandBuffers );
```
From the Command Buffer Notes:
These are the Commands that can be entered into the Command Buffer, II

```c
vkCmdFillBuffer( commandBuffer, dstBuffer, dstOffset, size, data );
vkCmdNextSubpass( commandBuffer, contents );
vkCmdPipelineBarrier( commandBuffer, srcStageMask, dstStageMask, dependencyFlags, memoryBarrierCount, VkMemoryBarrier* pMemoryBarriers, 
                        bufferMemoryBarrierCount, pBufferMemoryBarriers, imageMemoryBarrierCount, pImageMemoryBarriers );
vkCmdProcessCommandsNVX( commandBuffer, pProcessCommandsInfo );
vkCmdPushConstants( commandBuffer, layout, stageFlags, offset, size, pValues );
vkCmdPushDescriptorSetKHR( commandBuffer, pipelineBindPoint, layout, set, descriptorWriteCount, pDescriptorWrites );
vkCmdPushDescriptorSetWithTemplateKHR( commandBuffer, descriptorUpdateTemplate, layout, set, pData );
vkCmdReserveSpaceForCommandsNVX( commandBuffer, pReserveSpaceInfo );
vkCmdResetEvent( commandBuffer, event, stageMask );
vkCmdResetQueryPool( commandBuffer, queryPool, firstQuery, queryCount );
vkCmdResolveImage( commandBuffer, srcImage, srcImageLayout, dstImage, dstImageLayout, regionCount, pRegions );
vkCmdSetBlendConstants( commandBuffer, blendConstants[4] );
vkCmdSetDepthBias( commandBuffer, depthBiasConstantFactor, depthBiasClamp, depthBiasSlopeFactor );
vkCmdSetDepthBounds( commandBuffer, minDepthBounds, maxDepthBounds );
vkCmdSetDeviceMaskKHX( commandBuffer, deviceMask );
vkCmdSetDiscardRectangleEXT( commandBuffer, firstDiscardRectangle, discardRectangleCount, pDiscardRectangles );
vkCmdSetEvent( commandBuffer, event, stageMask );
vkCmdSetLineWidth( commandBuffer, lineWidth );
vkCmdSetScissor( commandBuffer, firstScissor, scissorCount, pScissors );
vkCmdSetStencilCompareMask( commandBuffer, faceMask, compareMask );
vkCmdSetStencilReference( commandBuffer, faceMask, reference );
vkCmdSetStencilWriteMask( commandBuffer, faceMask, writeMask );
vkCmdSetViewport( commandBuffer, firstViewport, viewportCount, pViewports );
vkCmdSetViewportWScalingNV( commandBuffer, firstViewport, viewportCount, pViewportWScalings );
vkCmdUpdateBuffer( commandBuffer, dstBuffer, dstOffset, dataSize, pData );
vkCmdWaitEvents( commandBuffer, eventCount, pEvents, srcStageMask, dstStageMask, memoryBarrierCount, pMemoryBarriers, 
                 bufferMemoryBarrierCount, pBufferMemoryBarriers, imageMemoryBarrierCount, pImageMemoryBarriers );
vkCmdWriteTimestamp( commandBuffer, pipelineStage, queryPool, query );
```
Potential Memory Race Conditions that Pipeline Barriers can Prevent

1. Write-then-Read (WtR) – the memory write in one operation starts overwriting the memory that another operation’s read needs to use

2. Read-then-Write (RtW) – the memory read in one operation hasn’t yet finished before another operation starts overwriting that memory

3. Write-then-Write (WtW) – two operations start overwriting the same memory and the end result is non-deterministic

Note: there is no problem with Read-then-Read (RtR) as no data has been changed
vkCmdPipelineBarrier( ) Function Call

A Pipeline Barrier is a way to establish a memory 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
);
The Scenario

src cars → TOP_OF_PIPE Street → VERTEX_INPUT Street → VERTEX_SHADER Street → Fragments Street → COLOR_ATTACHMENT_OUTPUT Street → TRANSFER_BIT Street → BOTTOM_OF_PIPE Street → dst cars
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 the first car in the src group enters that intersection

4. There are connections from those sensors to the traffic lights so that when the first car in the src group enters its intersection, the proper dst traffic light will be turned red

5. When the last car in the src group completely makes it through its intersection, the proper dst traffic light can be turned back to green

6. The Vulkan command pipeline ordering is this: (1) the src cars get released, (2) the pipeline barrier is invoked (which turns some lights red), (3) the dst cars get released (which end up being stopped by a red light somewhere)
### Pipeline Stage Masks – Where in the Pipeline is this Memory Data being Generated or Consumed?

<table>
<thead>
<tr>
<th>Stage Mask</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT</td>
<td>Top of the pipeline</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT</td>
<td>Draw indirect stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_VERTEX_INPUT_BIT</td>
<td>Vertex input stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_VERTEX_SHADER_BIT</td>
<td>Vertex shader stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT</td>
<td>Tessellation control shader stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT</td>
<td>Tessellation evaluation shader stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT</td>
<td>Geometry shader stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT</td>
<td>Fragment shader stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_EARLY_FRAGMENT_TESTS_BIT</td>
<td>Early fragment tests stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT</td>
<td>Late fragment tests stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT</td>
<td>Color attachment output stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT</td>
<td>Compute shader stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_TRANSFER_BIT</td>
<td>Transfer stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT</td>
<td>Bottom of the pipeline</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_HOST_BIT</td>
<td>Host stage</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_ALL_GRAPHICS_BIT</td>
<td>All graphics stages</td>
</tr>
<tr>
<td>VK_PIPELINE_STAGE_ALL_COMMANDS_BIT</td>
<td>All commands stages</td>
</tr>
</tbody>
</table>
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_COMPUTE_SHADER_BIT
VK_PIPELINE_STAGETRANSFER_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
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
### Pipeline Stages and what Access Operations can Happen There

<table>
<thead>
<tr>
<th>Pipeline Stage</th>
<th>VK Access Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT</td>
<td>VK_ACCESS_INDIRECT_COMMAND_READ_BIT</td>
</tr>
<tr>
<td>2 VK_PIPELINE_STAGE_DRAW_INDIRECT_BIT</td>
<td>VK_ACCESS_INDEX_READ_BIT</td>
</tr>
<tr>
<td>3 VK_PIPELINE_STAGE_VERTEX_INPUT_BIT</td>
<td>VK_ACCESS_VERTEX_ATTRIBUTE_READ_BIT</td>
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<tr>
<td>4 VK_PIPELINE_STAGE_VERTEX_SHADER_BIT</td>
<td>VK_ACCESS_UNIFORM_READ_BIT</td>
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<tr>
<td>5 VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT</td>
<td>VK_ACCESS_INPUT_ATTACHMENT_READ_BIT</td>
</tr>
<tr>
<td>6 VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT</td>
<td>VK_ACCESS_SHADER_READ_BIT</td>
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<tr>
<td>7 VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT</td>
<td>VK_ACCESS_COLOR_ATTACHMENT_READ_BIT</td>
</tr>
<tr>
<td>8 VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT</td>
<td>VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT</td>
</tr>
<tr>
<td>9 VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT</td>
<td>VK_ACCESS_TRANSFER_READ_BIT</td>
</tr>
<tr>
<td>10 VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT</td>
<td>VK_ACCESS_HOST_READ_BIT</td>
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<tr>
<td>11 VK_PIPELINE_STAGE_MEMORY_READ_BIT</td>
<td>VK_ACCESS_MEMORY_READ_BIT</td>
</tr>
<tr>
<td>12 VK_PIPELINE_STAGE_MEMORY_WRITE_BIT</td>
<td>VK_ACCESS_MEMORY_WRITE_BIT</td>
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</table>

- "●" indicates that the access operation is allowed in that stage.
- "●●" indicates that the access operation is not allowed in that stage.
## Access Operations and what Pipeline Stages they can be used In

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<tbody>
<tr>
<td>VK_ACCESS_INDIRECT_COMMAND_READ_BIT</td>
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<td>VK_ACCESS_INDEX_READ_BIT</td>
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<td>VK_ACCESS_VERTEX_ATTRIBUTE_READ_BIT</td>
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<td>VK_ACCESS_INPUT_ATTACHMENT_READ_BIT</td>
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<td>VK_ACCESS_SHADER_READ_BIT</td>
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<tr>
<td>VK_ACCESS_SHADER_WRITE_BIT</td>
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<td>VK_ACCESS_COLOR_ATTACHMENT_READ_BIT</td>
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<td>VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_READ_BIT</td>
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<tr>
<td>VK_ACCESS_HOST_READ_BIT</td>
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<td>VK_ACCESS_MEMORY_READ_BIT</td>
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<td>VK_ACCESS_MEMORY_WRITE_BIT</td>
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</tbody>
</table>
Example: Be sure we are done writing an output image before using it for something else

```
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
```

```
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_HOST_READ_BIT
VK_ACCESS_HOST_WRITE_BIT
VK_ACCESS_MEMORY_READ_BIT
VK_ACCESS_MEMORY_WRITE_BIT
```

Stages

Access types

src

dst

src

dst (no access setting needed)
The Scenario

src cars are generating the image

dst cars are doing something with that image
Example: Don’t read a buffer back to the host until a shader is done writing it

**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

**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

**src**

**dst (no access setting needed)**
The Scenario

src cars

TOP_OF_PIPE Street

VERTEX_INPUT Street

src cars

vertex shader Street

dst cars

BOTTOM_OF_PIPE Street

TRANSFER_BIT Street

COLOR_ATTACHMENT_OUTPUT Street

dst cars
VkImageLayout – How an Image gets Laid Out in Memory
depends on how it will be Used

Here, the use of vkCmdPipelineBarrier() is to simply change the layout of an image