Vulkan: Queues and Command Buffers

Graphics commands are recorded in command buffers, e.g.,
\texttt{vkCmdDoSomething(cmdBuffer, ...);}

- You can have as many simultaneous Command Buffers as you want
- Each command buffer can be filled from a different thread
- Command Buffers record commands, but no work takes place until a Command Buffer is submitted to a Queue
- We don't create Queues – the Logical Device has them already
- Each Queue belongs to a Queue Family
- We don't create Queue Families - the Physical Device already has them
Querying what Queue Families are Available

```cpp
uint32_t count;
vkGetPhysicalDeviceQueueFamilyProperties(IN PhysicalDevice, OUT &count, OUT (VkQueueFamilyProperties *)nullptr);
VkQueueFamilyProperties *vqfp = new VkQueueFamilyProperties[count];
vkGetPhysicalDeviceQueueFamilyProperties(PhysicalDevice, IN &count, OUT vqfp);
for(unsigned int i = 0; i < count; i++)
{
    fprintf(FpDebug, "\t%d: Queue Family Count = %2d  ;   ", i, vqfp[i].queueCount);
    if((vqfp[i].queueFlags & VK_QUEUE_GRAPHICS_BIT) != 0)
        fprintf(FpDebug, " Graphics");
    if((vqfp[i].queueFlags & VK_QUEUE_COMPUTE_BIT  ) != 0)
        fprintf(FpDebug, " Compute ");
    if((vqfp[i].queueFlags & VK_QUEUE_TRANSFER_BIT) != 0)
        fprintf(FpDebug, " Transfer");
    fprintf(FpDebug, "\n");
}
```

```
Found 3 Queue Families:
0: Queue Family Count = 16  ;   Graphics Compute Transfer
1: Queue Family Count =  1  ;    Transfer
2: Queue Family Count =  8  ;    Compute
```

Similarly, we Can Write a Function that Finds the Proper Queue Family

```cpp
int FindQueueFamilyThatDoesGraphics()
{
    uint32_t count = -1;
vkGetPhysicalDeviceQueueFamilyProperties(IN PhysicalDevice, OUT &count, OUT (VkQueueFamilyProperties *)nullptr);
VkQueueFamilyProperties *vqfp = new VkQueueFamilyProperties[count];
vkGetPhysicalDeviceQueueFamilyProperties(IN PhysicalDevice, IN &count, OUT vqfp);
for(unsigned int i = 0; i < count; i++)
{
    if((vqfp[i].queueFlags & VK_QUEUE_GRAPHICS_BIT) != 0)
        return i;
}
return -1;
}
```

Creating a Logical Device Needs to Know Queue Family Information

```cpp
float queuePriorities[queueCount] = {1.0f};
VkDeviceQueueCreateInfo vdqci[1];
vdqci[0].sType = VK_STRUCTURE_TYPE_QUEUE_CREATE_INFO;
vdqci[0].pNext = nullptr;
vdqci[0].flags = 0;
vdqci[0].queueFamilyIndex = FindQueueFamilyThatDoesGraphics();
vdqci[0].queueCount = 1;
vdqci[0].queuePriorities = (float *)queuePriorities;
VkDeviceCreateInfo vdci;
vdc.i.sType = VK_STRUCTURE_TYPE_DEVICE_CREATE_INFO;
vdc.i.pNext = nullptr;
vdc.i.flags = 0; vdci.queueCreateInfoCount = 1; // # of device queues wanted
vdci.pQueueCreateInfos = IN &vdqci[0]; // array of VkDeviceQueueCreateInfo's
vdci.enabledLayerCount = sizeof(myDeviceLayers) / sizeof(char *);
vdc.i.ppEnabledLayerNames = myDeviceLayers;
vdc.enabledExtensionCount = sizeof(myDeviceExtensions) / sizeof(char *);
vdc.i.ppEnabledExtensionNames = myDeviceExtensions;
vdc.i.pEnabledFeatures = IN &PhysicalDeviceFeatures; // already created
result = vkCreateLogicalDevice(PhysicalDevice, IN &vdci, PALLOCATOR, OUT &LogicalDevice);
```

Creating the Command Pool as part of the Logical Device

```cpp
VkResult Init06CommandPool()
{
    VkResult result;
    VkCommandPoolCreateInfo vcpci;
v pci.sType = VK_STRUCTURE_TYPE_COMMAND_POOL_CREATE_INFO;
v pci.pNext = nullptr;
v pci.flags = VK_COMMAND_POOL_CREATE_RESET_COMMAND_BUFFER_BIT | VK_COMMAND_POOL_CREATE_TRANSIENT_BIT; #ifdef CHOICES
    VK_COMMAND_POOL_CREATE_TRANSIENT_BIT
    VK_COMMAND_POOL_CREATE_RESET_COMMAND_BUFFER_BIT
    #endif
    vcpci.queueFamilyIndex = FindQueueFamilyThatDoesGraphics();
    result = vkCreateCommandPool(LogicalDevice, IN &vcpci, PALLOCATOR, OUT &CommandPool);
    return result;
}
```
Creating the Command Buffers

```cpp
VkResult
Init06CommandBuffers( ) {
    VkResult result;
    // allocate 2 command buffers for the double-buffered rendering:
    {
        VkCommandBufferAllocateInfo
            vcbai;
        vcbai.sType = VK_STRUCTURE_TYPE_COMMAND_BUFFER_ALLOCATE_INFO;
        vcbai.pNext = nullptr;
        vcbai.commandPool = CommandPool;
        vcbai.level = VK_COMMAND_BUFFER_LEVEL_PRIMARY;
        vcbai.commandBufferCount = 2; // 2, because of double-buffering
        result = vkAllocateCommandBuffers( LogicalDevice, IN &vcbai, OUT &CommandBuffers[0] );
    }
    // allocate 1 command buffer for the transferring pixels from a staging buffer to a texture buffer:
    {
        VkCommandBufferAllocateInfo
            vcbai;
        vcbai.sType = VK_STRUCTURE_TYPE_COMMAND_BUFFER_ALLOCATE_INFO;
        vcbai.pNext = nullptr;
        vcbai.commandPool = CommandPool;
        vcbai.level = VK_COMMAND_BUFFER_LEVEL_PRIMARY;
        vcbai.commandBufferCount = 1;
        result = vkAllocateCommandBuffers( LogicalDevice, IN &vcbai, OUT &TextureCommandBuffer );
    }
    return result;
}
```

Beginning a Command Buffer – One per Image

```cpp
VkSemaphoreCreateInfo
    vsci;
    vsci.sType = VK_STRUCTURE_TYPE_SEMAPHORE_CREATE_INFO;
    vsci.pNext = nullptr;
    vsci.flags = 0;
    VkSemaphore
        imageReadySemaphore;
    result = vkCreateSemaphore( LogicalDevice, IN &vsci, PALLOCATOR, OUT &imageReadySemaphore );
    uint32_t
        nextImageIndex;
    vkAcquireNextImageKHR( LogicalDevice, IN SwapChain, IN UINT64_MAX, IN imageReadySemaphore, IN VK_NULL_HANDLE, OUT &nextImageIndex );
    VkCommandBufferBeginInfo
        vcbbi;
        vcbbi.sType = VK_STRUCTURE_TYPE_COMMAND_BUFFER_BEGIN_INFO;
        vcbbi.pNext = nullptr;
        vcbbi.flags = VK_COMMAND_BUFFER_USAGE_ONE_TIME_SUBMIT_BIT;
        vcbbi.pInheritanceInfo = (VkCommandBufferInheritanceInfo *)nullptr;
    result = vkBeginCommandBuffer( CommandBuffers[ nextImageIndex ], IN &vcbbi );
    . . .
    vkEndCommandBuffer( CommandBuffers[ nextImageIndex ] );
```

Beginning a Command Buffer

```cpp
vkBeginCommandBuffer( )
vkAllocateCommandBuffer( )
vkCreateCommandBufferPool( )
vkCmdBeginQuery( commandBuffer, flags );
vkCmdBeginRenderPass( commandBuffer, const contents );
vkCmdBindDescriptorSets( commandBuffer, pDynamicOffsets );
vkCmdBindIndexBuffer( commandBuffer, indexType );
vkCmdBindPipeline( commandBuffer, pipeline );
vkCmdBindVertexBuffers( commandBuffer, firstBinding, bindingCount, const pOffsets );
vkCmdBlitImage( commandBuffer, filter );
vkCmdClearAttachments( commandBuffer, attachmentCount, const pRects );
vkCmdClearColorImage( commandBuffer, pRanges );
vkCmdClearDepthStencilImage( commandBuffer, pRanges );
vkCmdCopyBuffer( commandBuffer, pRegions );
vkCmdCopyBufferToImage( commandBuffer, pRegions );
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 );
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 );
```

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

```cpp
//vkCmdBeginQuery( commandBuffer, flags );
//vkCmdBeginRenderPass( commandBuffer, const contents );
//vkCmdBindDescriptorSets( commandBuffer, pDynamicOffsets );
//vkCmdBindIndexBuffer( commandBuffer, indexType );
//vkCmdBindPipeline( commandBuffer, pipeline );
//vkCmdBindVertexBuffers( commandBuffer, firstBinding, bindingCount, const pOffsets );
//vkCmdBlitImage( commandBuffer, filter );
//vkCmdClearAttachments( commandBuffer, attachmentCount, const pRects );
//vkCmdClearColorImage( commandBuffer, pRanges );
//vkCmdClearDepthStencilImage( commandBuffer, pRanges );
//vkCmdCopyBuffer( commandBuffer, pRegions );
//vkCmdCopyBufferToImage( commandBuffer, pRegions );
//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 );
//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 );
```

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

```cpp
//vkCmdBeginQuery( commandBuffer, flags );
//vkCmdBeginRenderPass( commandBuffer, const contents );
//vkCmdBindDescriptorSets( commandBuffer, pDynamicOffsets );
//vkCmdBindIndexBuffer( commandBuffer, indexType );
//vkCmdBindPipeline( commandBuffer, pipeline );
//vkCmdBindVertexBuffers( commandBuffer, firstBinding, bindingCount, const pOffsets );
//vkCmdBlitImage( commandBuffer, filter );
//vkCmdClearAttachments( commandBuffer, attachmentCount, const pRects );
//vkCmdClearColorImage( commandBuffer, pRanges );
//vkCmdClearDepthStencilImage( commandBuffer, pRanges );
//vkCmdCopyBuffer( commandBuffer, pRegions );
//vkCmdCopyBufferToImage( commandBuffer, pRegions );
//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 );
//vkCmdDraw( commandBuffer, vertexCount, instanceCount, firstVertex, firstInstance );
//vkCmdDrawIndexed( commandBuffer, indexCount, instanceCount, firstIndex, int32_t vertexOffset, firstInstance );
//vkCmdDrawIndexedIndirect( commandBuffer, stride );
//vkCmdDrawIndirect( commandBuffer, stride );
//vkCmdDrawIndirectCountAMD( commandBuffer, stride );
//vkCmdEndQuery( commandBuffer, query );
//vkCmdEndRenderPass( commandBuffer );
//vkCmdExecuteCommands( commandBuffer, commandBufferCount, const pCommandBuffers );
```
These are the Commands that could be entered into the Command Buffer, II

```cpp
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 );
vkCmdSetDeviceMaskKHX( commandBuffer, deviceMask );
vkCmdSetDiscardRectangleEXT( commandBuffer, firstDiscardRectangle, discardRectangleCount, pDiscardRectangles );
vkCmdSetEvent( commandBuffer, event, stageMask );
vkCmdSetLineWidth( commandBuffer, lineWidth );
vkCmdSetScissor( commandBuffer, scissor = {{0, 0}, {Width, Height}} );
vkCmdSetStencilReference( commandBuffer, faceMask, reference );
vkCmdSetStencilWriteMask( commandBuffer, faceMask, writeMask );
vkCmdSetViewport( commandBuffer, firstViewport, viewportCount, pViewports );
vkCmdSetViewportWScalingNV( commandBuffer, firstViewport, viewportCount, pViewportWScalings );
vkAcquireNextImageKHR( LogicalDevice, IN SwapChain, IN UINT64_MAX, IN VK_NULL_HANDLE, OUT &nextImageIndex );
vkCmdWriteTimestamp( commandBuffer, pipelineStage, queryPool, query );
vkCmdBindPipeline( commandBuffer, pipelineBindPoint, pipelineLayout );
vkCmdBindDescriptorSets( commandBuffer, pipelineBindPoint, layout, set, descriptorWriteCount, pDescriptorWrites );
vkCmdBindVertexBuffers( commandBuffer, firstBinding, bindingCount, buffers, offsets );
vkCmdBeginRenderPass( commandBuffer, renderPassBeginInfo );
vkCmdDraw( commandBuffer, vertexCount, instanceCount, firstVertex, firstInstance );
vkCmdEndRenderPass( commandBuffer );
vkEndCommandBuffer( commandBuffer );
```
Submitting a Command Buffer to a Queue for Execution

```cpp
VkSubmitInfo vsi;
    vsi.sType = VK_STRUCTURE_TYPE_SUBMIT_INFO;
    vsi.pNext = nullptr;
    vsi.commandBufferCount = 1;
    vsi.pCommandBuffers = &CommandBuffer;
    vsi.waitSemaphoreCount = 1;
    vsi.pWaitSemaphores = imageReadySemaphore;
    vsi.signalSemaphoreCount = 0;
    vsi.pSignalSemaphores = (VkSemaphore *)nullptr;
    vsi.pWaitDstStageMask = (VkPipelineStageFlags *)nullptr;
```

Submitting a Command Buffer to a Queue for Execution

The Entire Submission / Wait / Display Process

```cpp
VkFenceCreateInfo vfci;
    vfci.sType = VK_STRUCTURE_TYPE_FENCE_CREATE_INFO;
    vfci.pNext = nullptr;
    vfci.flags = 0;

VkFence renderFence;
    vkCreateFence(LogicalDevice, IN &vfci, PALLOCATOR, OUT &renderFence);
    result = VK_SUCCESS;

VkPipelineStageFlags waitAtBottom = VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT;

VkQueue presentQueue;
    vkGetDeviceQueue(LogicalDevice, FindQueueFamilyThatDoesGraphics(), 0, OUT &presentQueue);

VkSubmitInfo vsi;
    vsi.sType = VK_STRUCTURE_TYPE_SUBMIT_INFO;
    vsi.pNext = nullptr;
    vsi.waitSemaphoreCount = 1;
    vsi.pWaitSemaphores = &imageReadySemaphore;
    vsi.pWaitDstStageMask = &waitAtBottom;
    vsi.commandBufferCount = 1;
    vsi.pCommandBuffers = &CommandBuffers[nextImageIndex];
    vsi.signalSemaphoreCount = 0;
    vsi.pSignalSemaphores = &SemaphoreRenderFinished;

result = vkQueueSubmit(presentQueue, 1, IN &vsi, IN renderFence);  // submitCount
result = vkWaitForFences(LogicalDevice, 1, IN &renderFence, VK_TRUE, UINT64_MAX);  // waitAll, timeout

vkDestroyFence(LogicalDevice, renderFence, PALLOCATOR);

VkPresentInfoKHR vpi;
    vpi.sType = VK_STRUCTURE_TYPE_PRESENT_INFO_KHR;
    vpi.pNext = nullptr;
    vpi.waitSemaphoreCount = 0;
    vpi.pWaitSemaphores = (VkSemaphore *)nullptr;
    vpi.swapchainCount = 1;
    vpi.pSwapchains = &SwapChain;
    vpi.pImageIndices = &nextImageIndex;
    vpi.pResults = (VkResult *)nullptr;

result = vkQueuePresentKHR(presentQueue, IN &vpi);
```

What Happens After a Queue has Been Submitted?

As the Vulkan 1.1 Specification says:

"Command buffer submissions to a single queue respect submission order and other implicit ordering guarantees, but otherwise may overlap or execute out of order. Other types of batches and queue submissions against a single queue (e.g. sparse memory binding) have no implicit ordering constraints with any other queue submission or batch. Additional explicit ordering constraints between queue submissions and individual batches can be expressed with semaphores and fences."

In other words, the Vulkan driver on your system will execute the commands in a single buffer in the order in which they were put there.

But, between different command buffers submitted to different queues, the driver is allowed to execute commands between buffers in-order or out-of-order or overlapped-order, depending on what it thinks it can get away with.

The message here is, I think, always consider using some sort of Vulkan synchronization when one command depends on a previous command reaching a certain state first.