Queues and Command Buffers

Vulkan: Overall Block Diagram

Application

Instance

Instance

Physical Device

Physical Device

Physical Device

Logical Device

Logical Device

Logical Device

Logical Device

Queue

Queue

Queue

Queue

Queue

Queue

Queue

Queue

Queue

Queue

Command Buffer

Command Buffer

Command Buffer

Command Buffer
Vulkan Queues and Command Buffers

- Graphics commands are recorded in command buffers, e.g., `vkCmdDoSomething(cmdBuffer, ...);`
- You can have as many simultaneous Command Buffers as you want
- Each command buffer can be filled from a different thread, but doesn't have to be
- 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 already has them
- 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

```c
uint32_t count;
vkGetPhysicalDeviceQueueFamilyProperties(IN PhysicalDevice, &count, OUT (VkQueueFamilyProperties *)nullptr);
VkQueueFamilyProperties *vqfp = new VkQueueFamilyProperties[count];
vkGetPhysicalDeviceQueueFamilyProperties(IN PhysicalDevice, &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");
}
```

For the Nvidia A6000 cards:

<table>
<thead>
<tr>
<th>Queue Family</th>
<th>Queue Count</th>
<th>Flags</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>16</td>
<td>Graphics Compute Transfer</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Transfer</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>Compute Transfer</td>
</tr>
</tbody>
</table>

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

```c
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

```c
float queuePriorities[] = {
    1. // one entry per queueCount
};

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;
vdci.sType = VK_STRUCTURE_TYPE_DEVICE_CREATE_INFO;
vdci.pNext = nullptr;
vdci.flags = 0;
vdci.queueCreateInfoCount = 1; // # of device queues wanted
vdci.pQueueCreateInfos = &vdqci[0]; // array of VkDeviceQueueCreateInfo's
vdci.enabledLayerCount = sizeof(myDeviceLayers) / sizeof(char *);
vdcipi.ppEnabledLayerNames = myDeviceLayers;
vdcipi.enabledExtensionCount = sizeof(myDeviceExtensions) / sizeof(char *);
vdcipi.ppEnabledExtensionNames = myDeviceExtensions;
vdcipi.pEnabledFeatures = IN &PhysicalDeviceFeatures;     // already created
result = vkCreateLogicalDevice( PhysicalDevice, IN &vdci, PALLOCATOR, OUT &LogicalDevice );

VkQueue Queue;
uint32_t queueFamilyIndex = FindQueueFamilyThatDoesGraphics();
uint32_t queueIndex = 0;
result = vkGetDeviceQueue ( LogicalDevice, queueFamilyIndex, queueIndex, OUT &Queue );
```

Creating the Command Pool as part of the Logical Device

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

```c
vkResult
Init06CommandBuffers() {
    VkResult result;

    // allocate 2 command buffers for the double-buffered rendering:
    {
        VkCommandBufferAllocateInfo
            vcbai = VkCommandBufferAllocateInfo();
        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 = VkCommandBufferAllocateInfo();
        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

```c
VkSemaphoreCreateInfo
vsci = VkSemaphoreCreateInfo();
    vsci.sType = VK_STRUCTURE_TYPE_SEMAPHORE_CREATE_INFO;
    vsci.pNext = nullptr;
    vsci.flags = 0;
VkSemaphore
    imageReadySemaphore = VkSemaphore();
    result = vkCreateSemaphore( LogicalDevice, IN &vsci, PALLOCATOR, OUT &imageReadySemaphore );

uint32_t
    nextImageIndex = 0;
VkAcquireNextImageKHR
    logicalDevice, IN SwapChain, IN vkACQ_MAX,
    IN imageReadySemaphore, IN VK_NULL_HANDLE, OUT &nextImageIndex );

VkCommandBufferBeginInfo
vcbbi = VkCommandBufferBeginInfo();
    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

- `vkCreateCommandBufferBeginInfo`
- `vkAllocateCommandBuffer()`

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

- `vkCmdBeginConditionalRendering`
- `vkCmdBeginDebugUtilsLabel`
- `vkCmdBeginRenderPass`
- `vkCmdBeginQueryIndexed`
- `vkCmdBeginQuery`
- `vkCmdBeginRendering`
- `vkCmdBeginRenderPass2`
- `vkCmdBeginTransformFeedback`
- `vkCmdBindDescriptorSets`
- `vkCmdBindIndexBuffer`
- `vkCmdBindInvocationMask`
- `vkCmdBindPipeline`
- `vkCmdBindPipelineShaderGroup`
- `vkCmdBindShadingRateImage`
- `vkCmdBindTransformFeedbackBuffers`
- `vkCmdBindVertexBuffer`
- `vkCmdBindVertexBuffer2`
- `vkCmdBlitImage`
- `vkCmdBlitImage2`
- `vkCmdBuildAccelerationStructure`
- `vkCmdBuildAccelerationStructureIndirect`
- `vkCmdBuildAccelerationStructures`
- `vkCmdClearAttachments`
- `vkCmdClearColorImage`
- `vkCmdClearDepthStencilImage`
- `vkCmdCopyAccelerationStructure`
- `vkCmdCopyAccelerationStructureToMemory`
- `vkCmdCopyBuffer`
- `vkCmdCopyBufferToImage`
- `vkCmdCopyBufferToImage2`
- `vkCmdCopyImage`
- `vkCmdCopyImage2`
- `vkCmdCopyMemoryToAccelerationStructure`
These are the Commands that could be entered into a Command Buffer, II

- `vkCmdCopyQueryPoolResults`
- `vkCmdCuLaunchKernelX`
- `vkCmdDebugMarkerBegin`
- `vkCmdDebugMarkerEnd`
- `vkCmdDraw`
- `vkCmdDrawIndexed`
- `vkCmdDrawIndexedIndirect`
- `vkCmdDrawIndexedIndirectCount`
- `vkCmdDrawIndirect`
- `vkCmdDrawIndirectByteCount`
- `vkCmdDrawIndirectCount`
- `vkCmdDrawMeshTasksIndirectCount`
- `vkCmdDrawMeshTasksIndirect`
- `vkCmdDrawMeshTasks`

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`
- `vkCmdSetFrontFace`
- `vkCmdSetLineStipple`
- `vkCmdSetLineWidth`
- `vkCmdSetLogicOp`
- `vkCmdSetPatchControlPoints`
- `vkCmdSetPrimitiveRestartEnable`
- `vkCmdSetPrimitiveTopology`
- `vkCmdSetRasterizerDiscardEnable`
- `vkCmdSetRayTracingPipelineStackSize`
These are the Commands that could be entered into a Command Buffer, IV

<table>
<thead>
<tr>
<th>Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>vkCmdSetSampleLocations</td>
</tr>
<tr>
<td>vkCmdSetScissor</td>
</tr>
<tr>
<td>vkCmdSetScissorWithCount</td>
</tr>
<tr>
<td>vkCmdSetStencilCompareMask</td>
</tr>
<tr>
<td>vkCmdSetStencilOp</td>
</tr>
<tr>
<td>vkCmdSetStencilReference</td>
</tr>
<tr>
<td>vkCmdSetStencilTestEnable</td>
</tr>
<tr>
<td>vkCmdSetStencilWriteMask</td>
</tr>
<tr>
<td>vkCmdSetVertexInput</td>
</tr>
<tr>
<td>vkCmdSetViewport</td>
</tr>
<tr>
<td>vkCmdSetViewportShadingRatePalette</td>
</tr>
<tr>
<td>vkCmdSetViewportWithCount</td>
</tr>
<tr>
<td>vkCmdSetViewportWScaling</td>
</tr>
<tr>
<td>vkCmdSubpassShading</td>
</tr>
<tr>
<td>vkCmdTraceRaysIndirect</td>
</tr>
<tr>
<td>vkCmdTraceRaysIndirect2</td>
</tr>
<tr>
<td>vkCmdTraceRays</td>
</tr>
<tr>
<td>vkCmdUpdateBuffer</td>
</tr>
<tr>
<td>vkCmdWaitEvents</td>
</tr>
<tr>
<td>vkCmdWaitEvents2</td>
</tr>
<tr>
<td>vkCmdWriteAccelerationStructuresProperties</td>
</tr>
<tr>
<td>vkCmdWriteBufferMarker2</td>
</tr>
<tr>
<td>vkCmdWriteBufferMarker</td>
</tr>
<tr>
<td>vkCmdWriteTimestamp</td>
</tr>
<tr>
<td>vkCmdWriteTimestamp2</td>
</tr>
</tbody>
</table>

How the `RenderScene()` Function Works

```c
VkResult
RenderScene()
{
    VkResult result;
    VkSemaphoreCreateInfo vsci;
    vsci.sType = VK_STRUCTURE_TYPE_SEMAPHORE_CREATE_INFO;
    vsci.pNext = nullptr;
    vsci.flags = 0;
    VkSemaphore imageReadySemaphore;
    result = vkCreateSemaphore(LogicalDevice, &vsci, PALLOCATOR, OUT &imageReadySemaphore);
    uint32_t nextImageIndex;
    vkAcquireNextImageKHR(LogicalDevice, SwapChain, UINT64_MAX, VK_NULL_HANDLE, 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.inheritanceInfo = (VkCommandBufferInheritanceInfo *)nullptr;
    result = vkBeginCommandBuffer(CommandBuffers[nextImageIndex], &vcbbi);
}```
**Computer Graphics**

```cpp
VkClearColorValue vccv;
vccv.float32[0] = 0.0;
vccv.float32[1] = 0.0;
vccv.float32[2] = 0.0;
vccv.float32[3] = 1.0;

VkClearDepthStencilValue vcdsv;
vcdsv.depth = 1.f;
vcdsv.stencil = 0;

VkClearValue vcv[2];
vcv[0].color = vccv;
vcv[1].depthStencil = vcdsv;

VkOffset2D o2d = { 0, 0 };
VkExtent2D e2d = { Width, Height };
VkRect2D r2d = { o2d, e2d };

VkRenderPassBeginInfo vrpbi;
vrpbi.sType = VK_STRUCTURE_TYPE_RENDER_PASS_BEGIN_INFO;
vrpbi.pNext = nullptr;
vrpbi.renderPass = RenderPass;
vrpbi.framebuffer = Framebuffers[nextImageIndex];
vrpbi.renderArea = r2d;
vrpbi.clearValueCount = 2;
vrpbi.pClearValues = vcv;               // used for VK_ATTACHMENT_LOAD_OP_CLEAR

vkCmdBeginRenderPass(CommandBuffers[nextImageIndex], IN &vrpbi, IN VK_SUBPASS_CONTENTS_INLINE);

VkViewport viewport = {
  0.,                     // x
  0.,                     // y
  (float)Width,
  (float)Height,
  0.,                     // minDepth
  1.                      // maxDepth
};

vkCmdSetViewport(CommandBuffers[nextImageIndex], 0, 1, IN &viewport);         // 0=firstViewport, 1=viewportCount

VkRect2D scissor = {
  0,
  0,
  Width,
  Height
};

vkCmdSetScissor(CommandBuffers[nextImageIndex], 0, 1, IN &scissor);

vkCmdBindDescriptorSets(CommandBuffers[nextImageIndex], VK_PIPELINE_BIND_POINT_GRAPHICS,
                         GraphicsPipelineLayout, 0, 4, DescriptorSets, 0, (uint32_t *)nullptr);

vkCmdBindPushConstants(CommandBuffers[nextImageIndex], PipelineLayout, VK_SHADER_STAGE_ALL, offset, size, void *values);

VkBuffer buffers[1] = { MyVertexDataBuffer.buffer };
VkDeviceSize offsets[1] = { 0 };

vkCmdBindVertexBuffers(CommandBuffers[nextImageIndex], 0, 1, buffers, offsets);               // 0, 1 = firstBinding, bindingCount

const uint32_t vertexCount = sizeof(VertexData) / sizeof(VertexData[0]);
const uint32_t instanceCount = 1;
const uint32_t firstVertex = 0;
const uint32_t firstInstance = 0;

vkCmdDraw(CommandBuffers[nextImageIndex], vertexCount, instanceCount, firstVertex, firstInstance);

vkCmdEndRenderPass(CommandBuffers[nextImageIndex]);

vkEndCommandBuffer(CommandBuffers[nextImageIndex]);
```
Submitting a Command Buffer to a Queue for Execution

```c
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

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

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

VkPipelineStageFlags waitAtBottom = VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT;
VkQueue presentQueue;
  result = vkGetDeviceQueue(LogicalDevice, FindQueueFamilyThatDoesGraphics(), 0, &presentQueue);

VkSubmitInfo vsi;
  vsi.sType = VK_STRUCTURE_TYPE_SUBMIT_INFO;
  vsi.pNext = nullptr;
  vsi.commandBufferCount = 1;
  vsi.pCommandBuffers = CommandBuffers[nextImageIndex];
  vsi.signalSemaphoreCount = 0;
  vsi.pSignalSemaphores = SemaphoreRenderFinished;

result = vkQueueSubmit(presentQueue, 1, &vsi, renderFence);
result = vkWaitForFences(LogicalDevice, 1, &renderFence, VK_TRUE, UINT64_MAX);
vkDestroyFence(LogicalDevice, renderFence, PALLOCATOR);

VkPresentInfoKHR vpi;
  vpi.sType = VK_STRUCTURE_TYPE_PRESENT_INFO_KHR;
  vpi.pNext = nullptr;
  vpi.swapchainCount = 1;
  vpi.pSwapchains = &SwapChain;
  vpi.pImageIndices = &nextImageIndex;
  vpi.pResults = nullptr;

result = vkQueuePresentKHR(presentQueue, &vpi);
```
What Happens After a Queue has Been Submitted?

As the Vulkan 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.