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

Command Buffer

Command Buffer

Command Buffer

Command Buffer
Vulkan: a More Typical (and Simplified) Block Diagram

Application

Instance

Physical Device

Logical Device

Queue

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
- Command Buffers record our 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

```c
uint32_t count;
vkGetPhysicalDeviceQueueFamilyProperties( IN PhysicalDevice, &count, OUT (VkQueueFamilyProperties *) nullptr );

VkQueueFamilyProperties *vqfp = new VkQueueFamilyProperties[ count ];
vkGetPhysicalDeviceFamilyProperties( 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");
}
```

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

```c
int FindQueueFamilyThatDoesGraphics() {
    uint32_t count = -1;
    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++ )
    {
        if( ( vqfp[i].queueFlags & VK_QUEUE_GRAPHICS_BIT ) != 0 )
            return i;
    }
    return -1;
}
```

“These are not the Queue Families you’re looking for.”
Creating a Logical Device Queue Needs to Know Queue Family Information

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

VkDeviceQueueCreateInfo vdqci[1];
    vdqci.sType = VK_STRUCTURE_TYPE_QUEUE_CREATE_INFO;
    vdqci.pNext = nullptr;
    vdqci.flags = 0;
    vdqci.queueFamilyIndex = FindQueueFamilyThatDoesGraphics( );
    vdqci.queueCount = 1;
    vdqci.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 *);
    vdci.ppEnabledLayerNames = myDeviceLayers;
    vdci.enabledExtensionCount = sizeof(myDeviceExtensions) / sizeof(char *);
    vdci.ppEnabledExtensionNames = myDeviceExtensions;
    vdci.pEnabledFeatures = 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 vcpci;
    vcpci.sType = VK_STRUCTURE_TYPE_COMMAND_POOL_CREATE_INFO;
    vcpci.pNext = nullptr;
    vcpci.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

```
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

- `vkAllocateCommandBuffer()`
  - `VkCommandBufferAllocateInfo`
  - `vkCreateCommandBufferPool()`
    - `VkCommandBufferPoolCreateInfo`
  - `VkCommandBufferBeginInfo`
  - `vkBeginCommandBuffer()`
These are the Commands that could 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, pRegions );
vkCmdCopyImage( commandBuffer, pRegions );
vkCmdCopyQueryPoolResults( commandBuffer, flags );
vkCmdDebugMarkerBeginEXT( commandBuffer, pMarkerInfo );
vkCmdDebugMarkerEndEXT( commandBuffer );
vkCmdDebugMarkerInsertEXT( commandBuffer, pMarkerInfo );
vvkCmdDispatch( 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

```c
vkCmdFillBuffer( commandBuffer, dstBuffer, dstOffset, size, data );
vkCmdNextSubpass( commandBuffer, contents );
vkCmdPipelineBarrier( commandBuffer, srcStageMask, dstStageMask, dependencyFlags, memoryBarrierCount, 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, pBufferMemoryBarrierCount, pBufferMemoryBarriers, imageMemoryBarrierCount, pImageMemoryBarriers );
vkCmdWriteTimestamp( commandBuffer, pipelineStage, queryPool, query );
```
```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, IN &vsci, PALLOCATOR, OUT &imageReadySemaphore);

    uint32_t nextImageIndex;
    vkAcquireNextImageKHR(LogicalDevice, IN SwapChain, IN UINT64_MAX, IN VK_NULL_HANDLE,
                           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);
```
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 };

VkClearPassBeginInfo 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], &vrpbi, VK_SUBPASS_CONTENTS_INLINE);
VkViewport viewport =
{
    0.,                         // x
    0.,                         // y
    (float)Width,              // Width
    (float)Height,             // 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 );

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

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

VkDeviceSize offsets[1] = { 0 };

vkCmdBindVertexBuffer( 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;
```
The Entire Submission / Wait / Display Process

- Create fence
  - VkFenceCreateInfo
    - vfci.sType = VK_STRUCTURE_TYPE_FENCE_CREATE_INFO;
    - vfci.pNext = nullptr;
    - vfci.flags = 0;
  - VkFence renderFence;
  - vkCreateFence( LogicalDevice, &vfci, PALLOCATOR, OUT &renderFence );
  - result = VK_SUCCESS;
- Get the queue
  - VkPipelineStageFlags waitAtBottom = VK_PIPELINE_STAGE_BOTTOM_OF_PIPE_BIT;
  - VkQueue presentQueue;
  - vkGetDeviceQueue( LogicalDevice, FindQueueFamilyThatDoesGraphics( ), 0, OUT &presentQueue );
  - // 0 = queueIndex
- Fill in the queue information
  - VkSubmitInfo
    - 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 );
  - result = vkWaitForFences( LogicalDevice, 1, IN &renderFence, VK_TRUE, UINT64_MAX );
- Submit the queue
- Wait for the fence
  - VkPresentInfoKHR
    - 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 );

The Entire Submission / Wait / Display Process

Create fence

Get the queue

Fill in the queue information

Submit the queue

Wait for the fence