Vulkan.

Multipass Rendering

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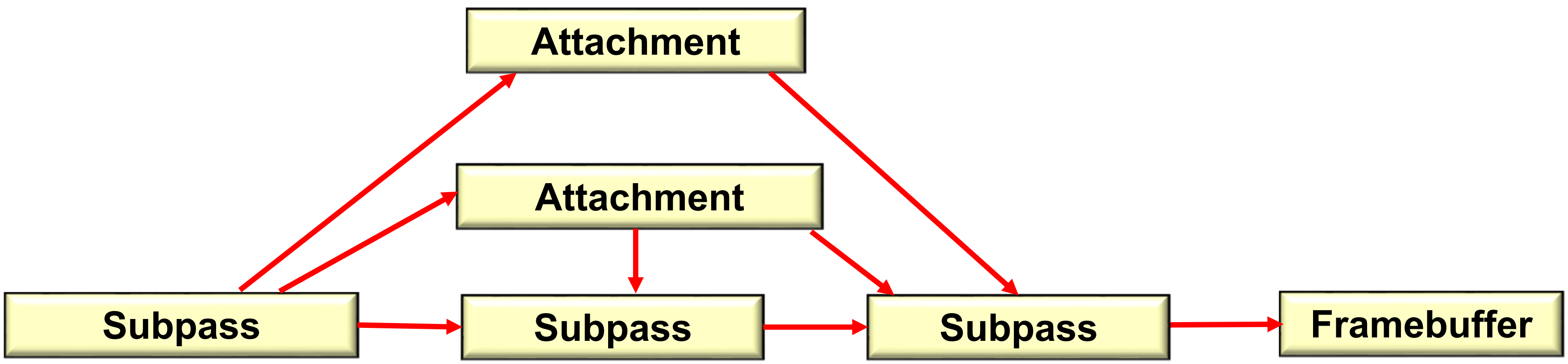
Multipass Rendering uses Attachments -- What is a Vulkan *Attachment* Anyway?

"[An attachment is] an image associated with a renderpass that can be used as the input or output of one or more of its subpasses."

-- Vulkan Programming Guide

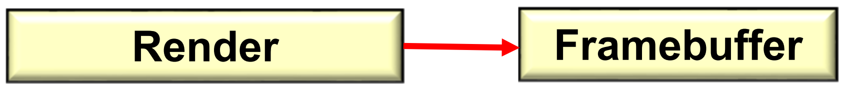
An attachment can be written to, read from, or both.

For example:



Back in Our Single-pass Days

So far, we've only performed single-pass rendering, within a single Vulkan RenderPass.



Here comes a quick reminder of how we did that.

Afterwards, we will extend that.

Back in Our Single-pass Days, I


```
VkAttachmentDescription                    vad [2 ];
        vad[0].flags = 0;
        vad[0].format = VK_FORMAT_B8G8R8A8_SRGB;
        vad[0].samples = VK_SAMPLE_COUNT_1_BIT;
        vad[0].loadOp = VK_ATTACHMENT_LOAD_OP_CLEAR;
        vad[0].storeOp = VK_ATTACHMENT_STORE_OP_STORE;
        vad[0].stencilLoadOp = VK_ATTACHMENT_LOAD_OP_DONT_CARE;
        vad[0].stencilStoreOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
        vad[0].initialLayout = VK_IMAGE_LAYOUT_UNDEFINED;
        vad[0].finalLayout = VK_IMAGE_LAYOUT_PRESENT_SRC_KHR;

        vad[1].flags = 0;
        vad[1].format = VK_FORMAT_D32_SFLOAT_S8_UINT;
        vad[1].samples = VK_SAMPLE_COUNT_1_BIT;
        vad[1].loadOp = VK_ATTACHMENT_LOAD_OP_CLEAR;
        vad[1].storeOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
        vad[1].stencilLoadOp = VK_ATTACHMENT_LOAD_OP_DONT_CARE;
        vad[1].stencilStoreOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
        vad[1].initialLayout = VK_IMAGE_LAYOUT_UNDEFINED;
        vad[1].finalLayout = VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL;


    VkAttachmentReference                  colorReference;
        colorReference.attachment = 0;
        colorReference.layout = VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL;


    VkAttachmentReference                  depthReference;
        depthReference.attachment = 1;
        depthReference.layout = VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL;
```

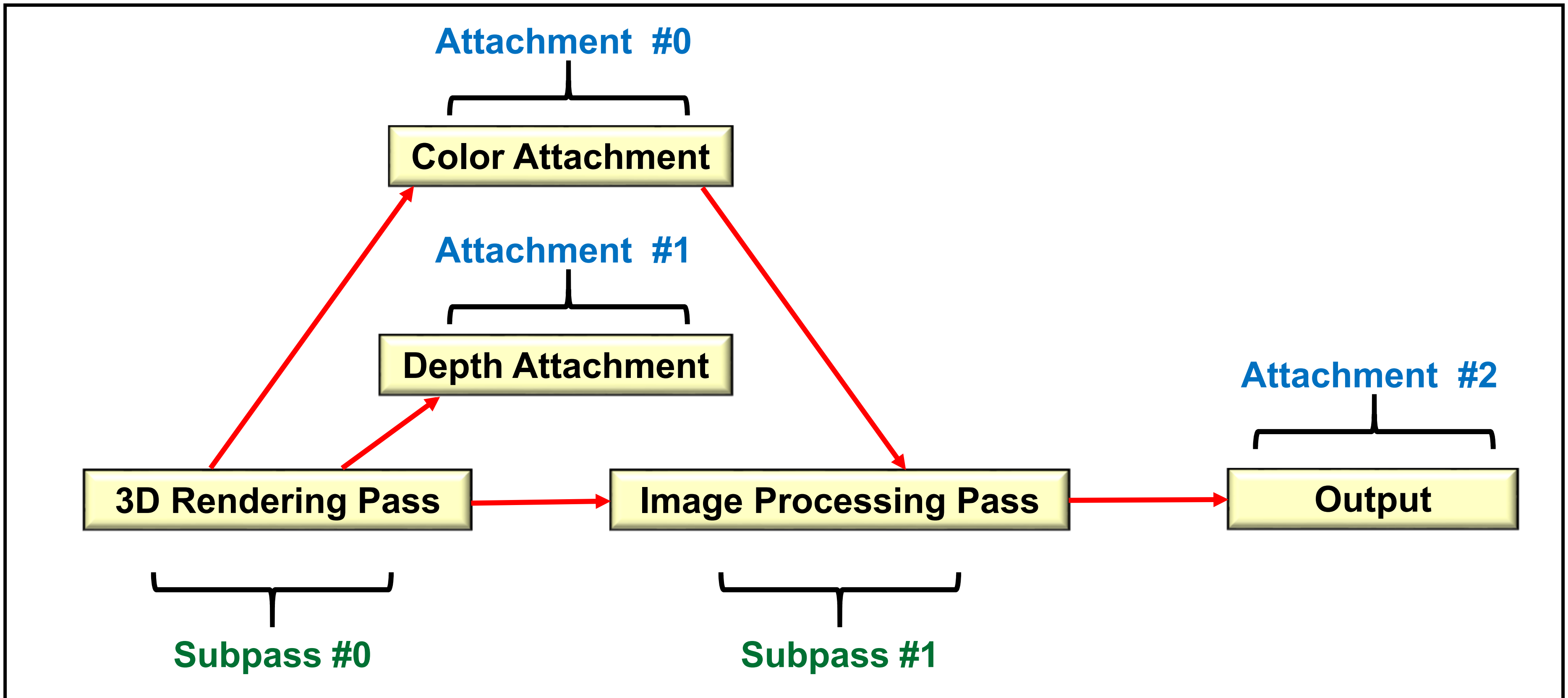
Back in Our Single-pass Days, II


```
VkSubpassDescription                    vsd;
        vsd.flags = 0;
        vsd.pipelineBindPoint = VK_PIPELINE_BIND_POINT_GRAPHICS;
        vsd.inputAttachmentCount = 0;
        vsd.pInputAttachments = (VkAttachmentReference *)nullptr;
        vsd.colorAttachmentCount = 1;
        vsd.pColorAttachments = &colorReference;
        vsd.pResolveAttachments = (VkAttachmentReference *)nullptr;
        vsd.pDepthStencilAttachment = &depthReference;
        vsd.preserveAttachmentCount = 0;
        vsd.pPreserveAttachments = (uint32_t *)nullptr;


VkRenderPassCreateInfo                  vrpci;
        vrpci.sType = VK_STRUCTURE_TYPE_RENDER_PASS_CREATE_INFO;
        vrpci.pNext = nullptr;
        vrpci.flags = 0;
        vrpci.attachmentCount = 2;          // color and depth/stencil
        vrpci.pAttachments = vad;
        vrpci.subpassCount = 1;
        vrpci.pSubpasses = &vsd;
        vrpci.dependencyCount = 0;
        vrpci.pDependencies = (VkSubpassDependency *)nullptr;


result = vkCreateRenderPass( LogicalDevice, IN &vrpci, PALLOCATOR, OUT &RenderPass );
```

Multipass Rendering

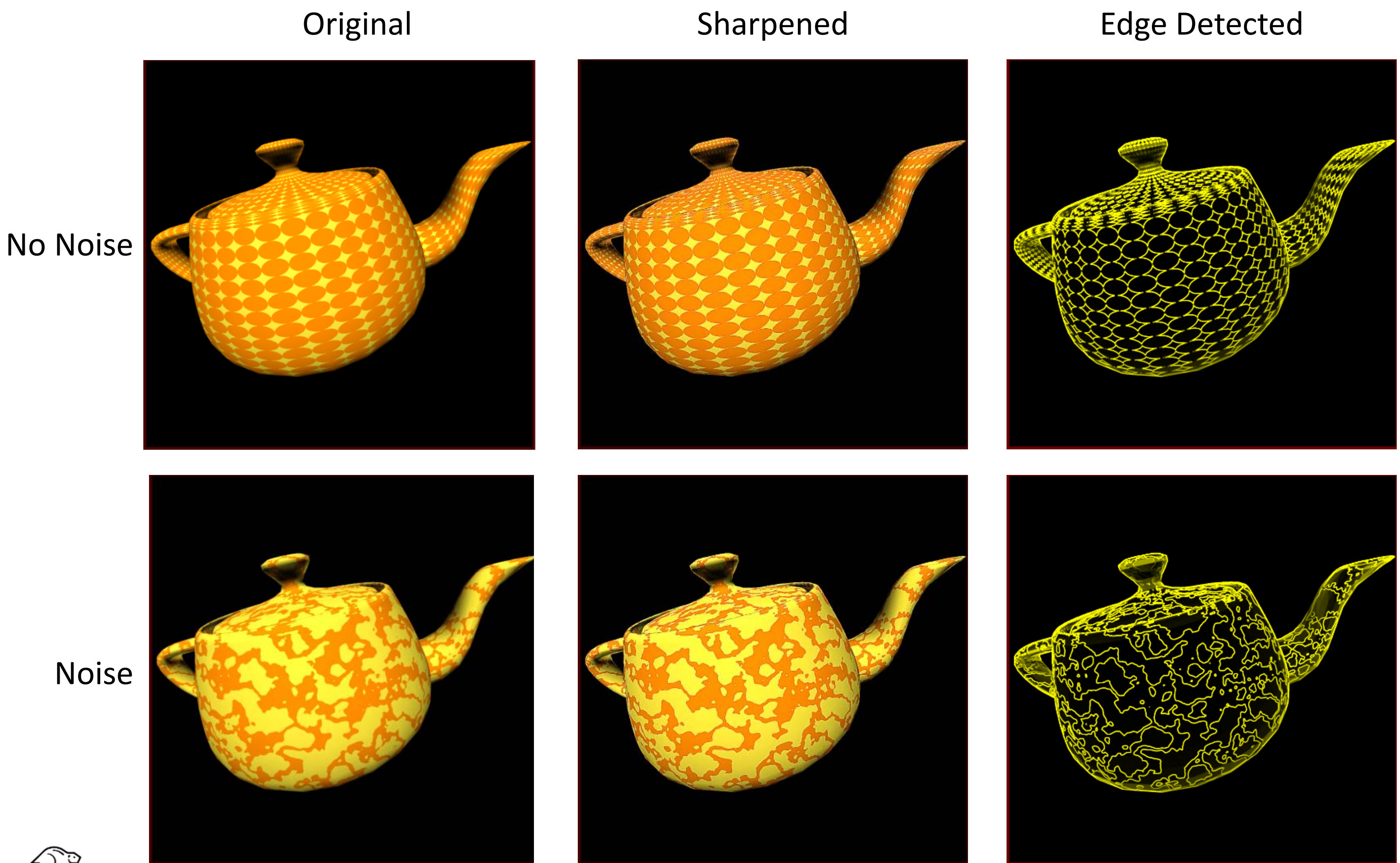
So far, we've only performed single-pass rendering, but within a single Vulkan RenderPass, we can also have several subpasses, each of which is feeding information to the next subpass or subpasses.

In this case, we will look at following up a 3D rendering with some image processing on the outcome.



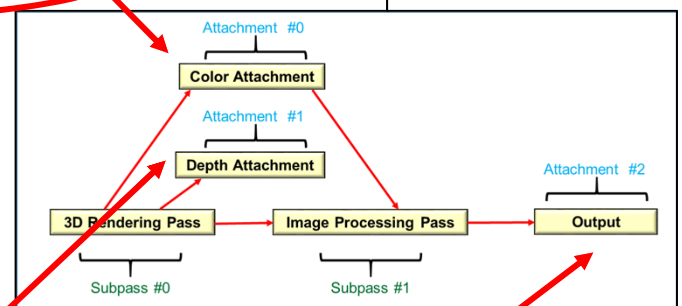
Notice how close this resembles a Directed Acyclic Graph (DAG) data structure: nodes connected by arrows that point in one direction

Multipass Algorithm to Render and then Image Process



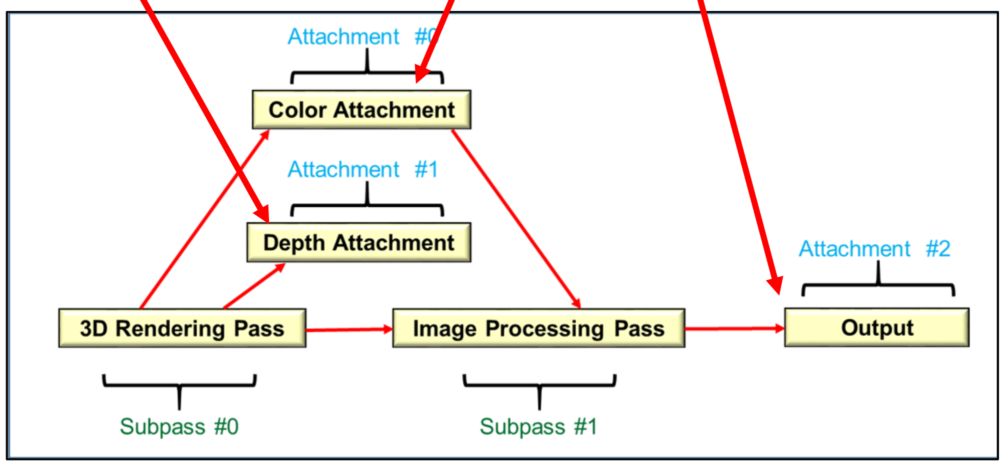
Multipass, I

```
VkAttachmentDescription                    vad [ 3 ];
        vad[0].flags = 0;
        vad[0].format = VK_FORMAT_B8G8R8A8_SRGB;
        vad[0].samples = VK_SAMPLE_COUNT_1_BIT;
        vad[0].loadOp = VK_ATTACHMENT_LOAD_OP_CLEAR;
        vad[0].storeOp = VK_ATTACHMENT_STORE_OP_STORE;
        vad[0].stencilLoadOp = VK_ATTACHMENT_LOAD_OP_DONT_CARE;
        vad[0].stencilStoreOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
        vad[0].initialLayout = VK_IMAGE_LAYOUT_UNDEFINED;
        vad[0].finalLayout = VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL;

        vad[1].flags = 0;
        vad[1].format = VK_FORMAT_D32_SFLOAT_S8_UINT;
        vad[1].samples = VK_SAMPLE_COUNT_1_BIT;
        vad[1].loadOp = VK_ATTACHMENT_LOAD_OP_CLEAR;
        vad[1].storeOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
        vad[1].stencilLoadOp = VK_ATTACHMENT_LOAD_OP_DONT_CARE;
        vad[1].stencilStoreOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
        vad[1].initialLayout = VK_IMAGE_LAYOUT_UNDEFINED;
        vad[1].finalLayout = VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL;

        vad[2].flags = 0;
        vad[2].format = VK_FORMAT_B8G8R8A8_SRGB;
        vad[2].samples = VK_SAMPLE_COUNT_1_BIT;
        vad[2].loadOp = VK_ATTACHMENT_LOAD_OP_DONT_CARE;
        vad[2].storeOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
        vad[2].stencilLoadOp = VK_ATTACHMENT_LOAD_OP_DONT_CARE;
        vad[2].stencilStoreOp = VK_ATTACHMENT_STORE_OP_DONT_CARE;
        vad[2].initialLayout = VK_IMAGE_LAYOUT_UNDEFINED;
        vad[2].finalLayout = VK_IMAGE_LAYOUT_PRESENT_SRC_KHR;
```



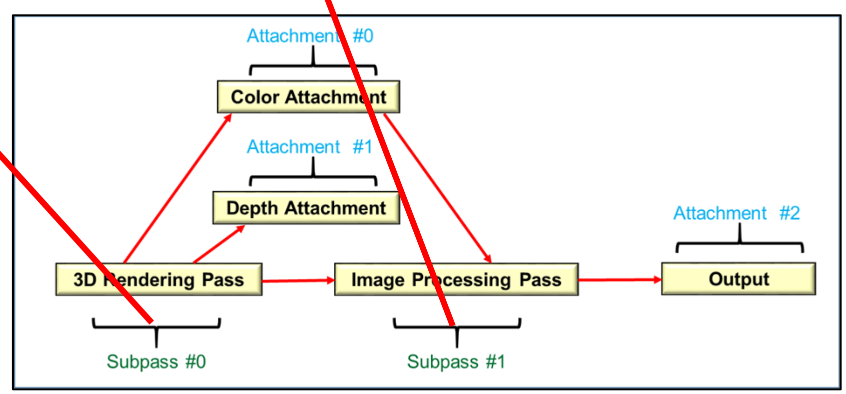
Multipass, II

```
VkAttachmentReference                    colorReference;
          colorReference.attachment = 0;
          colorReference.layout = VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL;

VkAttachmentReference                    depthReference;
          depthReference.attachment = 1;
          depthReference.layout = VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL;

VkAttachmentReference                    outputReference;
          outputReference.attachment = 2;
          outputReference.layout = VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL;
```



Multipass, III

```
VkSubpassDescription                    vsd[2];
        vsd[0].flags = 0;
        vsd[0].pipelineBindPoint = VK_PIPELINE_BIND_POINT_GRAPHICS;
        vsd[0].inputAttachmentCount = 0;
        vsd[0].pInputAttachments = (VkAttachmentReference *)nullptr;
        vsd[0].colorAttachmentCount = 1;
        vsd[0].pColorAttachments = colorReference;
        vsd[0].pResolveAttachments = (VkAttachmentReference *)nullptr;
        vsd[0].pDepthStencilAttachment = &depthReference;
        vsd[0].preserveAttachmentCount = 0;
        vsd[0].pPreserveAttachments = (uint32_t *) nullptr;

        vsd[1].flags = 0;
        vsd[1].pipelineBindPoint = VK_PIPELINE_BIND_POINT_GRAPHICS;
        vsd[1].inputAttachmentCount = 1;
        vsd[1].pInputAttachments = colorReference;
        vsd[1].colorAttachmentCount = 1;
        vsd[1].pColorAttachments = &outputReference;
        vsd[1].pResolveAttachments = (VkAttachmentReference *)nullptr;
        vsd[1].pDepthStencilAttachment = (VkAttachmentReference *) nullptr;
        vsd[1].preserveAttachmentCount = 0;
        vsd[1].pPreserveAttachments = (uint32_t *) nullptr;
```



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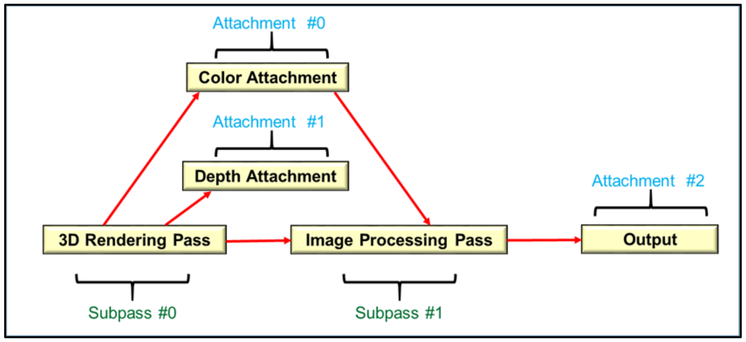
Multipass, IV

```
VkSubpassDependency                    vsdp[1];
        vsdp[0].srcSubpass  = 0;                        // 3D rendering
        vsdp[0].dstSubpass = 1;                         // image processing
        vsdp[0].srcStageMask   = VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT;
        vsdp[0].dstStageMask   = VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT;
        vsdp[0].srcAccessMask = VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT;
        vsdp[0].dstAccessMask = VK_ACCESS_SHADER_READ_BIT;
        vsdp[0].dependencyFlags = VK_DEPENDENCY_BY_REGION_BIT;


VkRenderPassCreateInfo                  vrpci;
        vrpci.sType = VK_STRUCTURE_TYPE_RENDER_PASS_CREATE_INFO;
        vrpci.pNext = nullptr;
        vrpci.flags = 0;
        vrpci.attachmentCount = 3;   // color, depth/stencil, output
        vrpci.pAttachments = vad;
        vrpci.subpassCount = 2;
        vrpci.pSubpasses = vsd;
        vrpci.dependencyCount = 1;
        vrpci.pDependencies = vsdp;


result = vkCreateRenderPass( LogicalDevice, IN &vrpci, PALLOCATOR, OUT &RenderPass );
```



Placing a Pipeline Barrier so an Image is not used before it is Ready


```
VkImageMemoryBarrier                vimb;
        vimb.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
        vimb.pNext = nullptr;
        vimb.oldLayout   = VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL;
        vimb.newLayout = VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL;
        vimb.srcQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
        vimb.dstQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
        vimb.image = textureImage;
        vimb.srcAccessMask = VK_ACCESS_COLOR_ATTACHMENT_OUTPUT_BIT;
        vimb.dstAccessMask = VK_ACCESS_SHADER_READ_BIT;
        vimb.subresourceRange = visr;

vkCmdPipelineBarrier(TextureCommandBuffer,
        VK_PIPELINE_STAGE_TRANSFER_BIT, VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT, 0,
        0, (VkMemoryBarrier *)nullptr,
        0, (VkBufferMemoryBarrier *)nullptr,
        1, IN &vimb);
```

Multipass, V


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

// first subpass is automatically started here

vkCmdBindPipeline( CommandBuffers[nextImageIndex], VK_PIPELINE_BIND_POINT_GRAPHICS,
                GraphicsPipeline );

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

vkCmdBindVertexBuffers( CommandBuffers[nextImageIndex], 0, 1, vBuffers, offsets );

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

. . .

vkCmdNextSubpass(CommandBuffers[nextImageIndex], VK_SUBPASS_CONTENTS_INLINE );

// second subpass is started here – doesn't need any new drawing vkCmd's

. . .

vkCmdEndRenderPass( CommandBuffers[nextImageIndex] );
```