Vulkan

Textures

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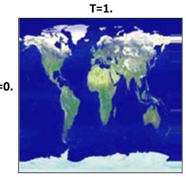
The Basic Idea

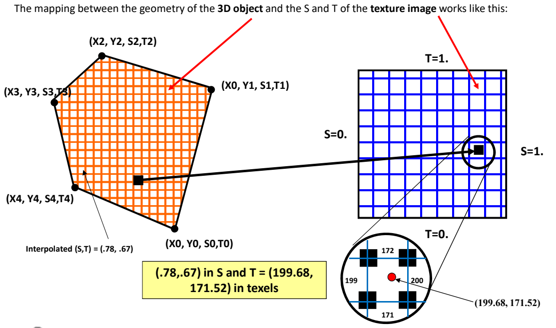
Texture mapping is a computer graphics operation in which a separate image, referred to as the **texture**, is stretched onto a piece of 3D geometry and follows it however it is transformed. This image is also known as a ***texture map***. This can be most any image. At one time, some graphics hardware required the image's pixel dimensions to be a ***power of two***. This restriction has been lifted on most (all?) graphics cards, but just to be safe… The X and Y dimensions did not need to be the *same* power of two, just a power of two. So, a 128x512 image would have been OK; a 129x511 image might not have.

Also, to prevent confusion, the texture pixels are not called ***pixels***. A pixel is a dot in the final screen image. A dot in the texture image is called a ***texture element***, or ***texel***. Similarly, to avoid terminology confusion, a texture's width and height dimensions are not called *X* and *Y*. They are called **S** and **T**. A texture map is not generally indexed by its actual resolution coordinates. Instead, it is indexed by a coordinate system that is resolution-independent. The left side is always **S=0.**, the right side is **S=1.**, the bottom is **T=0.**, and the top is **T=1.** Thus, you do not need to be aware of the texture's resolution when you are specifying coordinates that point into it. Think of S and T as a measure of what fraction of the way you are into the texture.



The Basic Idea

The mapping between the geometry of the **3D object** and the S and T of the **texture image** works like this:



You specify an (s,t) pair at each vertex, along with the vertex coordinate. At the same time that the rasterizer is interpolating the coordinates, colors, etc. inside the polygon, it is also interpolating the (s,t) coordinates. Then, when it goes to draw each pixel, it uses that pixel's interpolated (s,t) to lookup a color in the texture image.

In OpenGL terms: assigning an (s,t) to each vertex

Enable texture mapping:

```
glEnable( GL_TEXTURE_2D );
```

Draw your polygons, specifying **s** and **t** at each vertex:

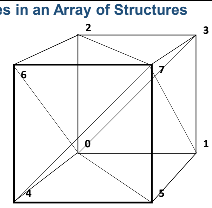
```
glBegin( GL_POLYGON );
        glTexCoord2f( s0, t0 );
        glNormal3f( nx0, ny0, nz0 );
        glVertex3f( x0, y0, z0 );

        glTexCoord2f( s1, t1 );
        glNormal3f( nx1, ny1, nz1 );
        glVertex3f( x1, y1, z1 );

        . . .
glEnd( );
```

Disable texture mapping:

```
glDisable( GL_TEXTURE_2D );
```

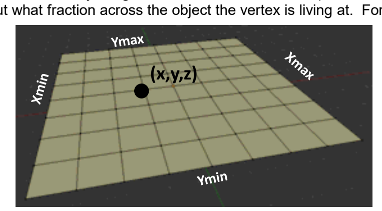

Triangles in an Array of Structures

```
struct vertex
{
        glm::vec3       position;
        glm::vec3       normal;
        glm::vec3       color;
        glm::vec2       texCoord;
};

struct vertex VertexData[  ] =
{
        // triangle 0-2-3:
        // vertex #0:
        {
                { -1., -1., -1. },
                {  0.,  0., -1. },
                {  0.,  0.,  0. },
                {  1., 0. }
        },

        // vertex #2:
        {
                { -1.,  1., -1. },
                {  0.,  0., -1. },
                {  0.,  1.,  0. },
                {  1., 1. }
        },

        // vertex #3:
        {
                {  1.,  1., -1. },
                {  0.,  0., -1. },
                {  1.,  1.,  0. },
                {  0., 1. }
        },
```



Using a Texture: How do you know what (s,t) to assign to each vertex?

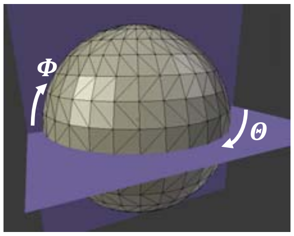
The easiest way to figure out what s and t are at a particular vertex is to figure out what fraction across the object the vertex is living at. For a plane,



$$s = \frac{x - Xmin}{Xmax - Xmin} \qquad t = \frac{y - Ymin}{Ymax - Ymin}$$

Using a Texture: How do you know what (s,t) to assign to each vertex?

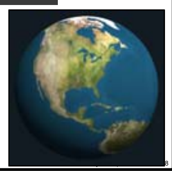
Or, for a sphere,



$$s = \frac{\Theta - (-\pi)}{2\pi} \qquad t = \frac{\Phi - (-\frac{\pi}{2})}{\pi}$$

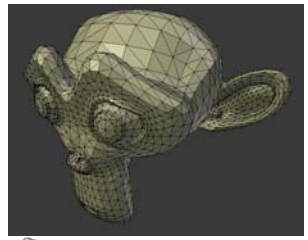
From the Sphere code:

s = (lng + M_PI) / (2.*M_PI);
t = (lat + M_PI/2.) / M_PI;



Using a Texture: How do you know what (s,t) to assign to each vertex?

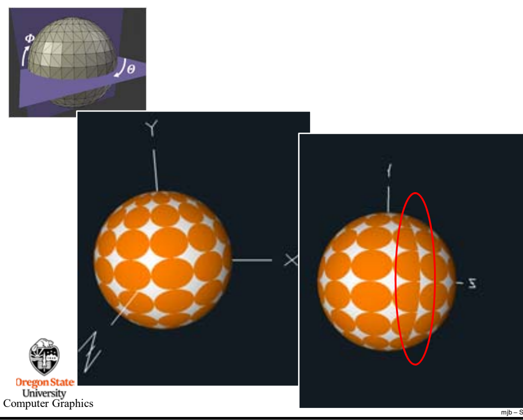
Uh-oh. Now what? Here's where it gets tougher…,



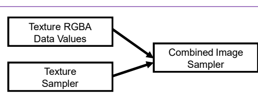
$s = ?$ $\qquad t = ?$

You really are at the mercy of whoever did the modeling…

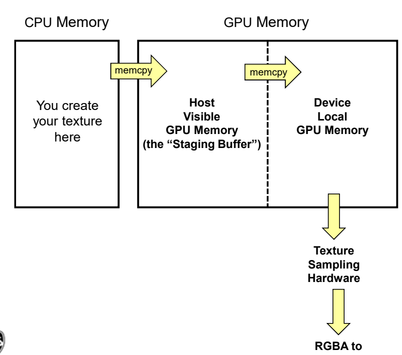
Be careful where *s* abruptly transitions from 1. back to 0.




```
VkDescriptorSetLayoutBinding          TexSamplerSet[1];
        TexSamplerSet[0].binding              = 0;
        TexSamplerSet[0].descriptorType     = VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER;
                                // uniform sampler2D uSampler
                                // vec4 rgba = texture( uSampler, vST );
        TexSamplerSet[0].descriptorCount    = 1;
        TexSamplerSet[0].stageFlags           = VK_SHADER_STAGE_FRAGMENT_BIT;
        TexSamplerSet[0].pImmutableSamplers = (VkSampler *)nullptr;

    . . .

VkDescriptorImageInfo                    vdii0;
        vdii0.sampler      = MyPuppyTexture.texSampler;
        vdii0.imageView = MyPuppyTexture.texImageView;
        vdii0.imageLayout = VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL;

    . . .

VkWriteDescriptorSet                     vwds3;
        vwds3.sType = VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET;
        vwds3.pNext = nullptr;
        vwds3.dstSet = DescriptorSets[3];
        vwds3.dstBinding = 0;
        vwds3.dstArrayElement = 0;
        vwds3.descriptorCount = 1;
        vwds3.descriptorType = VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER;
        vwds3.pBufferInfo = (VkDescriptorBufferInfo *)nullptr;
        vwds3.pImageInfo = &vdii0;
        vwds3.pTexelBufferView = (VkBufferView *)nullptr;
```



Memory Types



Memory Types

NVIDIA Discrete Graphics:

11 Memory Types:
Memory 0:
Memory 1:
Memory 2:
Memory 3:
Memory 4:
Memory 5:
Memory 6:
Memory 7: DeviceLocal
Memory 8: DeviceLocal
Memory 9: HostVisible HostCoherent
Memory 10: HostVisible HostCoherent HostCached

Intel Integrated Graphics:

3 Memory Types:
Memory 0: DeviceLocal
Memory 1: DeviceLocal HostVisible HostCoherent
Memory 2: DeviceLocal HostVisible HostCoherent HostCached

Texture Sampling Parameters

OpenGL

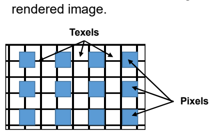
```
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT );
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT );
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR );
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR );
```

Vulkan

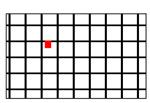
```
VkSamplerCreateInfo                vsci;
        vsci.magFilter = VK_FILTER_LINEAR;
        vsci.minFilter = VK_FILTER_LINEAR;
        vsci.mipmapMode = VK_SAMPLER_MIPMAP_MODE_LINEAR;
        vsci.addressModeU = VK_SAMPLER_ADDRESS_MODE_REPEAT;
        vsci.addressModeV = VK_SAMPLER_ADDRESS_MODE_REPEAT;
        vsci.addressModeW = VK_SAMPLER_ADDRESS_MODE_REPEAT;

          . . .

result = vkCreateSampler( LogicalDevice, IN &vsci, PALLOCATOR, pTextureSampler );
```


Textures' Undersampling Artifacts

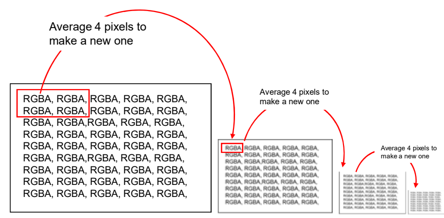
As an object gets farther away and covers a smaller and smaller part of the screen, the **texels : pixels ratio** used in the coverage becomes larger and larger. This means that there are pieces of the texture leftover in between the pixels that are being drawn into, so that some of the texture image is not being taken into account in the final image. This means that the texture is being undersampled and could end up producing artifacts in the rendered image.



Consider a texture that consists of one red texel and all the rest white. It is easy to imagine an object rendered with that texture as ending up all *white*, with the red texel having never been included in the final image. The solution is to create lower-resolutions of the same texture so that the red texel gets included somehow in all resolution-level textures.



Texture Mip*-mapping



- Total texture storage is ~ 2x what it was without mip-mapping
- Graphics hardware determines which level to use based on the texels : pixels ratio.
- In addition to just picking one mip-map level, the rendering system can sample from two of them, one less that the T:P ratio and one more, and then blend the two RGBAs returned. This is known as **VK_SAMPLER_MIPMAP_MODE_LINEAR**.

* Latin: *multim in parvo*, "many things in a small place"


```
VkResult
Init07TextureSampler( MyTexture * pMyTexture )
{
    VkResult result;

    VkSamplerCreateInfo                vsci;
        vsci.sType = VK_STRUCTURE_TYPE_SAMPLER_CREATE_INFO;
        vsci.pNext = nullptr;
        vsci.flags = 0;
        vsci.magFilter = VK_FILTER_LINEAR;
        vsci.minFilter = VK_FILTER_LINEAR;
        vsci.mipmapMode = VK_SAMPLER_MIPMAP_MODE_LINEAR;
        vsci.addressModeU = VK_SAMPLER_ADDRESS_MODE_REPEAT;
        vsci.addressModeV = VK_SAMPLER_ADDRESS_MODE_REPEAT;
        vsci.addressModeW = VK_SAMPLER_ADDRESS_MODE_REPEAT;
#ifdef CHOICES
VK_SAMPLER_ADDRESS_MODE_REPEAT
VK_SAMPLER_ADDRESS_MODE_MIRRORED_REPEAT
VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_EDGE
VK_SAMPLER_ADDRESS_MODE_CLAMP_TO_BORDER
VK_SAMPLER_ADDRESS_MODE_MIRROR_CLAMP_TO_EDGE
#endif
        vsci.mipLodBias = 0.;
        vsci.anisotropyEnable = VK_FALSE;
        vsci.maxAnisotropy = 1.;
        vsci.compareEnable = VK_FALSE;
        vsci.compareOp = VK_COMPARE_OP_NEVER;
#ifdef CHOICES
VK_COMPARE_OP_NEVER
VK_COMPARE_OP_LESS
VK_COMPARE_OP_EQUAL
VK_COMPARE_OP_LESS_OR_EQUAL
VK_COMPARE_OP_GREATER
VK_COMPARE_OP_NOT_EQUAL
VK_COMPARE_OP_GREATER_OR_EQUAL
VK_COMPARE_OP_ALWAYS
#endif
        vsci.minLod = 0.;
        vsci.maxLod = 0.;
        vsci.borderColor = VK_BORDER_COLOR_FLOAT_OPAQUE_BLACK;
#ifdef CHOICES
VK_BORDER_COLOR_FLOAT_TRANSPARENT_BLACK
VK_BORDER_COLOR_INT_TRANSPARENT_BLACK
VK_BORDER_COLOR_FLOAT_OPAQUE_BLACK
VK_BORDER_COLOR_INT_OPAQUE_BLACK
VK_BORDER_COLOR_FLOAT_OPAQUE_WHITE
VK_BORDER_COLOR_INT_OPAQUE_WHITE
#endif
        vsci.unnormalizedCoordinates = VK_FALSE;    // VK_TRUE means we are use raw texels as the index
                                                    // VK_FALSE means we are using the usual 0. - 1.

    result = vkCreateSampler( LogicalDevice, IN &vsci, PALLOCATOR, OUT &pMyTexture->texSampler );
```

enable comparison against a reference value during lookups


```
VkResult
Init07TextureBuffer( INOUT MyTexture * pMyTexture)
{
    VkResult result;

    uint32_t texWidth = pMyTexture->width;;
    uint32_t texHeight = pMyTexture->height;
    unsigned char *texture = pMyTexture->pixels;
    VkDeviceSize textureSize = texWidth * texHeight * 4;        // rgba, 1 byte each

    VkImage  stagingImage;
    VkImage  textureImage;

    // *******************************************************************************
    // this first {...} is to create the staging image:
    // *******************************************************************************
    {
        VkImageCreateInfo                vici;
            vici.sType = VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO;
            vici.pNext = nullptr;
            vici.flags = 0;
            vici.imageType = VK_IMAGE_TYPE_2D;
            vici.format = VK_FORMAT_R8G8B8A8_UNORM;
            vici.extent.width = texWidth;
            vici.extent.height = texHeight;
            vici.extent.depth = 1;
            vici.mipLevels = 1;
            vici.arrayLayers = 1;
            vici.samples = VK_SAMPLE_COUNT_1_BIT;
            vici.tiling = VK_IMAGE_TILING_LINEAR;
#ifdef CHOICES
VK_IMAGE_TILING_OPTIMAL
VK_IMAGE_TILING_LINEAR
#endif
            vici.usage = VK_IMAGE_USAGE_TRANSFER_SRC_BIT;
#ifdef CHOICES
VK_IMAGE_USAGE_TRANSFER_SRC_BIT
VK_IMAGE_USAGE_TRANSFER_DST_BIT
VK_IMAGE_USAGE_SAMPLED_BIT
VK_IMAGE_USAGE_STORAGE_BIT
VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT
VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT
VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT
VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT
#endif
            vici.sharingMode = VK_SHARING_MODE_EXCLUSIVE;
```

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```
#ifdef CHOICES
VK_IMAGE_LAYOUT_UNDEFINED
VK_IMAGE_LAYOUT_PREINITIALIZED
#endif
            vici.queueFamilyIndexCount = 0;
            vici.pQueueFamilyIndices = (const uint32_t *)nullptr;

      result = vkCreateImage(LogicalDevice, IN &vici, PALLOCATOR, OUT &stagingImage); // allocated, but not filled

      VkMemoryRequirements               vmr;
      vkGetImageMemoryRequirements( LogicalDevice, IN stagingImage, OUT &vmr);

      if (Verbose)
      {
            fprintf(FpDebug, "Image vmr.size = %lld\n", vmr.size);
            fprintf(FpDebug, "Image vmr.alignment = %lld\n", vmr.alignment);
            fprintf(FpDebug, "Image vmr.memoryTypeBits = 0x%08x\n", vmr.memoryTypeBits);
            fflush(FpDebug);
      }

      VkMemoryAllocateInfo               vmai;
            vmai.sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO;
            vmai.pNext = nullptr;
            vmai.allocationSize = vmr.size;
            vmai.memoryTypeIndex = FindMemoryThatIsHostVisible();   // because we want to mmap it

      VkDeviceMemory                     vdm;
      result = vkAllocateMemory( LogicalDevice, IN &vmai, PALLOCATOR, OUT &vdm);
      pMyTexture->vdm = vdm;

      result = vkBindImageMemory( LogicalDevice, IN stagingImage, IN vdm, 0);  // 0 = offset

      // we have now created the staging image -- fill it with the pixel data:

      VkImageSubresource                 vis;
            vis.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
            vis.mipLevel = 0;
            vis.arrayLayer = 0;

      VkSubresourceLayout                vsl;
      vkGetImageSubresourceLayout( LogicalDevice, stagingImage, IN &vis, OUT &vsl);

      if (Verbose)
      {
            fprintf(FpDebug, "Subresource Layout:\n");
            fprintf(FpDebug, "\toffset = %lld\n", vsl.offset);
            fprintf(FpDebug, "\tsize = %lld\n", vsl.size);
            fprintf(FpDebug, "\trowPitch = %lld\n", vsl.rowPitch);
            fprintf(FpDebug, "\tarrayPitch = %lld\n", vsl.arrayPitch);
            fprintf(FpDebug, "\tdepthPitch = %lld\n", vsl.depthPitch);
            fflush(FpDebug);
      |
```


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```
      void * gpuMemory;
      vkMapMemory( LogicalDevice, vdm, 0, VK_WHOLE_SIZE, 0, OUT &gpuMemory);
                        // 0 and 0 = offset and memory map flags

      if (vsl.rowPitch == 4 * texWidth)
      {
            memcpy(gpuMemory, (void *)texture, (size_t)textureSize);
      }
      else
      {
            unsigned char *gpuBytes = (unsigned char *)gpuMemory;
            for (unsigned int y = 0; y < texHeight; y++)
            {
                  memcpy(&gpuBytes[y * vsl.rowPitch], &texture[4 * y * texWidth], (size_t)(4*texWidth) );
            }
      }

      vkUnmapMemory( LogicalDevice, vdm);

}
// *****************************************************************************
```


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```
// *****************************************************************************
// this second {...} is to create the actual texture image:
// *****************************************************************************
{
      VkImageCreateInfo                  vici;
            vici.sType = VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO;
            vici.pNext = nullptr;
            vici.flags = 0;
            vici.imageType = VK_IMAGE_TYPE_2D;
            vici.format = VK_FORMAT_R8G8B8A8_UNORM;
            vici.extent.width  = texWidth;
            vici.extent.height = texHeight;
            vici.extent.depth = 1;
            vici.mipLevels = 1;
            vici.arrayLayers = 1;
            vici.samples = VK_SAMPLE_COUNT_1_BIT;
            vici.tiling = VK_IMAGE_TILING_OPTIMAL;
            vici.usage = VK_IMAGE_USAGE_TRANSFER_DST_BIT | VK_IMAGE_USAGE_SAMPLED_BIT;
                        // because we are transferring into it and will eventual sample from it
            vici.sharingMode = VK_SHARING_MODE_EXCLUSIVE;
            vici.initialLayout = VK_IMAGE_LAYOUT_PREINITIALIZED;
            vici.queueFamilyIndexCount = 0;
            vici.pQueueFamilyIndices = (const uint32_t *)nullptr;

      result = vkCreateImage(LogicalDevice, IN &vici, PALLOCATOR, OUT &textureImage); // allocated, but not filled

      VkMemoryRequirements               vmr;
      vkGetImageMemoryRequirements( LogicalDevice, IN textureImage, OUT &vmr);

      if( Verbose )
      {
            fprintf( FpDebug, "Texture vmr.size = %lld\n", vmr.size );
            fprintf( FpDebug, "Texture vmr.alignment = %lld\n", vmr.alignment );
            fprintf( FpDebug, "Texture vmr.memoryTypeBits = 0x%08x\n", vmr.memoryTypeBits );
            fflush( FpDebug );
      }
     VkMemoryAllocateInfo                vmai;
            vmai.sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO;
            vmai.pNext = nullptr;
            vmai.allocationSize = vmr.size;
            vmai.memoryTypeIndex = FindMemoryThatIsDeviceLocal( );  // because we want to sample from it

      VkDeviceMemory                     vdm;
      result = vkAllocateMemory( LogicalDevice, IN &vmai, PALLOCATOR, OUT &vdm);

      result = vkBindImageMemory( LogicalDevice, IN textureImage, IN vdm, 0 );        // 0 = offset
}
// *****************************************************************************
```


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```
// copy pixels from the staging image to the texture:

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( TextureCommandBuffer, IN &vcbbi);

// *****************************************************************************
// transition the staging buffer layout:
// *****************************************************************************
{
      VkImageSubresourceRange            visr;
            visr.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
            visr.baseMipLevel = 0;
            visr.levelCount = 1;
            visr.baseArrayLayer = 0;
            visr.layerCount = 1;

      VkImageMemoryBarrier               vimb;
            vimb.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
            vimb.pNext = nullptr;
            vimb.oldLayout = VK_IMAGE_LAYOUT_PREINITIALIZED;
            vimb.newLayout = VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL;
            vimb.srcQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
            vimb.dstQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
            vimb.image = stagingImage;
            vimb.srcAccessMask = 0;
            vimb.dstAccessMask = 0T;
            vimb.subresourceRange = visr;

      vkCmdPipelineBarrier( TextureCommandBuffer,
                  VK_PIPELINE_STAGE_TOP_OF_PIPE_BIT, VK_PIPELINE_STAGE_FRAG<EMT_SHADER_BIT, 0,
                  0, (VkMemoryBarrier *)nullptr,
                  0, (VkBufferMemoryBarrier *)nullptr,
                  1, IN &vimb );
}
// *****************************************************************************
```


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```
// *****************************************************************************
// transition the texture buffer layout:
// *****************************************************************************
{
      VkImageSubresourceRange            visr;
            visr.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
            visr.baseMipLevel = 0;
            visr.levelCount = 1;
            visr.baseArrayLayer = 0;
            visr.layerCount = 1;

      VkImageMemoryBarrier               vimb;
            vimb.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
            vimb.pNext = nullptr;
            vimb.oldLayout = VK_IMAGE_LAYOUT_PREINITIALIZED;
            vimb.newLayout = VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL;
            vimb.srcQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
            vimb.dstQueueFamilyIndex = VK_QUEUE_FAMILY_IGNORED;
            vimb.image = textureImage;
            vimb.srcAccessMask = 0;
            vimb.dstAccessMask = 0;
            vimb.subresourceRange = visr;

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

      // now do the final image transfer:

      VkImageSubresourceLayers           visl;
            visl.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
            visl.baseArrayLayer = 0;
            visl.mipLevel = 0;
            visl.layerCount = 1;

      VkOffset3D                         vo3;
            vo3.x = 0;
            vo3.y = 0;
            vo3.z = 0;

      VkExtent3D                         ve3;
            ve3.width = texWidth;
            ve3.height = texHeight;
            ve3.depth = 1;
```


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```
      VkImageCopy                        vic;
            vic.srcSubresource = visl;
            vic.srcOffset = vo3;
            vic.dstSubresource = visl;
            vic.dstOffset = vo3;
            vic.extent = ve3;

      vkCmdCopyImage(TextureCommandBuffer,
            stagingImage, VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL,
            textureImage, VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL, 1, IN &vic);
}
// *****************************************************************************
```

```
// ******************************************************************************
// transition the texture buffer layout a second time:
// ******************************************************************************
	{
		VkImageSubresourceRange			visr;
			visr.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
			visr.baseMipLevel = 0;
			visr.levelCount = 1;
			visr.baseArrayLayer = 0;
			visr.layerCount = 1;

		VkImageMemoryBarrier			vimb;
			vimb.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
			vimb.pNext = nullptr;
			vimb.oldLayout = VK_IMAGE_LAYOUT_TRANSFER_DST_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 = 0;
			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);
	}
	// ******************************************************************************

	result = vkEndCommandBuffer( TextureCommandBuffer );

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

	result = vkQueueSubmit( Queue, 1, IN &vsi, VK_NULL_HANDLE );
	result = vkQueueWaitIdle( Queue );
```



```
	// create an image view for the texture image:

	VkImageSubresourceRange			visr;
		visr.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;
		visr.baseMipLevel = 0;
		visr.levelCount = 1;
		visr.baseArrayLayer = 0;
		visr.layerCount = 1;

	VkImageViewCreateInfo			vivci;
		vivci.sType = VK_STRUCTURE_TYPE_IMAGE_VIEW_CREATE_INFO;
		vivci.pNext = nullptr;
		vivci.flags = 0;
		vivci.image = textureImage;
		vivci.viewType = VK_IMAGE_VIEW_TYPE_2D;
		vivci.format = VK_FORMAT_R8G8B8A8_UNORM;
		vivci.components.r = VK_COMPONENT_SWIZZLE_R;
		vivci.components.g = VK_COMPONENT_SWIZZLE_G;
		vivci.components.b = VK_COMPONENT_SWIZZLE_B;
		vivci.components.a = VK_COMPONENT_SWIZZLE_A;
		vivci.subresourceRange = visr;

	result = vkCreateImageView( LogicalDevice, IN &vivci, PALLOCATOR, OUT &pMyTexture->texImageView);

	return result;
}
```

Note that, at this point, the CPU buffer and the GPU Staging Buffer are no longer needed, and can be destroyed.

Reading in a Texture from a BMP File


```
typedef struct MyTexture
{
	uint32_t			width;
	uint32_t			height;
	VkImage			texImage;
	VkImageView		texImageView;
	VkSampler		texSampler;
	VkDeviceMemory		vdm;
} MyTexture;

•••

MyTexture		MyPuppyTexture;
```

```
result = Init06TextureBufferAndFillFromBmpFile ( "puppy.bmp", &MyTexturePuppy);
Init06TextureSampler( &MyPuppyTexture.texSampler );
```

This function can be found in the **sample.cpp** file. The BMP file needs to be created by something that writes uncompressed 24-bit color BMP files, or was converted to the uncompressed BMP format by a tool such as ImageMagick's *convert*, Adobe *Photoshop*, or GNU's *GIMP*.

Anisotropic Texture Filtering

https://en.wikipedia.org/wiki/Anisotropic_filtering