Descriptor Sets

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In OpenGL

OpenGL puts all uniform data in the same "set", but with different binding numbers, so you can get at each one.

Each uniform variable gets updated one-at-a-time.

Wouldn't it be nice if we could update a collection of related uniform variables all at once, without having to update the uniform variables that are not related to this collection?

```
layout( std140, binding = 0 )  uniform mat4        uModelMatrix;
layout( std140, binding = 1 ) uniform mat4         uViewMatrix;
layout( std140, binding = 2 ) uniform mat4         uProjectionMatrix;
layout( std140, binding = 3 ) uniform mat3         uNormalMatrix;
layout( std140, binding = 4 ) uniform vec4          uLightPos;
layout( std140, binding = 5 ) uniform float         uTime;
layout( std140, binding = 6 ) uniform  int          uMode;
layout(             binding = 7 ) uniform sampler2D uSampler;
```

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std140 has to do with the alignment of the different data types. It is the simplest, and so we use it in class to give everyone the highest probability that their system will be compatible with the alignment.

What are Descriptor Sets?

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Descriptor Sets are an intermediate data structure that tells shaders how to connect information held in GPU memory to groups of related uniform variables and texture sampler declarations in shaders. There are three advantages in doing things this way:

- Related uniform variables can be updated as a group, gaining efficiency.
- Descriptor Sets are activated when the Command Buffer is filled. Different values for the uniform buffer variables can be toggled by just swapping out the Descriptor Set that points to GPU memory, rather than re-writing the GPU memory.
- Values for the shaders' uniform buffer variables can be compartmentalized into what quantities change often and what change seldom (scene-level, model-level, draw-level), so that uniform variables need to be re-written no more often than is necessary.

```
for( sporadically )
{
        Bind Descriptor Set #0
        for( the entire scene )
        {
                Bind Descriptor Set #1
                for( each object in the scene )
                {
                        Bind Descriptor Set #2
                        Do the drawing
                }
        }
}
```

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Descriptor Sets

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Our example will assume the following shader uniform variables:

```
// non-opaque must be in a uniform block:
layout( std140, set = 0, binding = 0 ) uniform sporadicBuf
{
        int             uMode;
        int             uUseLighting;
        int             uNumInstances;
} Sporadic;

layout( std140, set = 1, binding = 0 ) uniform sceneBuf
{
        mat4            uProjection;
        mat4            uView;
        mat4            uSceneOrient;
        vec4            uLightPos;
        vec4            uLightColor;
        vec4            uLightKaKdKs;
        float           uTime;
} Scene;

layout( std140, set = 2, binding = 0 ) uniform objectBuf
{
        mat4            uModel;
        mat4            uNormal;
        vec4            uColor;
        float           uShininess;
} Object;

layout( set = 3, binding = 0 ) uniform sampler2D uSampler;
```

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Descriptor Sets

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CPU: Uniform data created in a C++ data structure

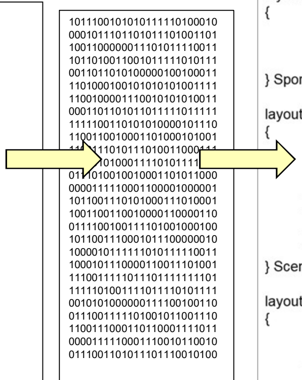
GPU: Uniform data in a "blob"*

GPU: Uniform data used in the shader

```
struct sporadicBuf
{
        int             uMode;
        int             uUseLighting;
        int             uNumInstances;
} Sporadic;

struct sceneBuf
{
        glm::mat4       uProjection;
        glm::mat4       uView;
        glm::mat4       uSceneOrient;
        glm::vec4       uLightPos;
        glm::vec4       uLightColor;
        glm::vec4       uLightKaKdKs;
        float           uTime;
} Scene;

struct objectBuf
{
        glm::mat4       uModel;
        glm::mat4       uNormal;
        glm::vec4       uColor;
        float           uShininess;
} Object;
```



```
// non-opaque must be in a uniform block:
layout( std140, set = 0, binding = 0 ) uniform sporadicBuf
{
        int             uMode;
        int             uUseLighting;
        int             uNumInstances;
} Sporadic;

layout( std140, set = 1, binding = 0 ) uniform sceneBuf
{
        mat4            uProjection;
        mat4            uView;
        mat4            uSceneOrient;
        vec4            uLightPos;
        vec4            uLightColor;
        vec4            uLightKaKdKs;
        float           uTime;
} Scene;

layout( std140, set = 2, binding = 0 ) uniform objectBuf
{
        mat4            uModel;
        mat4            uNormal;
        vec4            uColor;
        float           uShininess;
} Object;

layout( set = 3, binding = 0 ) uniform sampler2D uSampler;
```

* "binary large object"

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Step 1: Descriptor Set Pools

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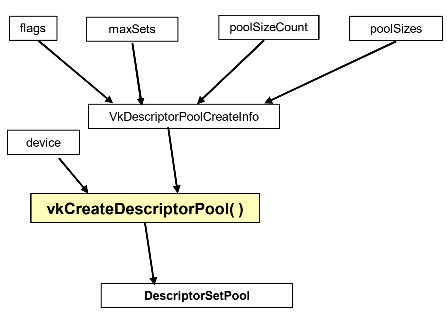
You don't allocate Descriptor Sets on the fly – that is too slow.
Instead, you allocate a "pool" of Descriptor Sets during initialization and then pull from that pool later.



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```
VkResult
Init13DescriptorSetPool( )
{
	VkResult result;

	VkDescriptorPoolSize		vdps[4];
		vdps[0].type = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
		vdps[0].descriptorCount = 1;
		vdps[1].type = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
		vdps[1].descriptorCount = 1;
		vdps[2].type = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
		vdps[2].descriptorCount = 1;
		vdps[3].type = VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER;
		vdps[3].descriptorCount = 1;

#ifdef CHOICES
VK_DESCRIPTOR_TYPE_SAMPLER
VK_DESCRIPTOR_TYPE_SAMPLED_IMAGE
VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER
VK_DESCRIPTOR_TYPE_STORAGE_IMAGE
VK_DESCRIPTOR_TYPE_UNIFORM_TEXEL_BUFFER
VK_DESCRIPTOR_TYPE_STORAGE_TEXEL_BUFFER
VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER
VK_DESCRIPTOR_TYPE_STORAGE_BUFFER
VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER_DYNAMIC
VK_DESCRIPTOR_TYPE_STORAGE_BUFFER_DYNAMIC
VK_DESCRIPTOR_TYPE_INPUT_ATTACHMENT
#endif

	VkDescriptorPoolCreateInfo		vdpci;
		vdpci.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_POOL_CREATE_INFO;
		vdpci.pNext = nullptr;
		vdpci.flags = 0;
		vdpci.maxSets = 4;
		vdpci.poolSizeCount = 4;
		vdpci.pPoolSizes = &vdps[0];

	result = vkCreateDescriptorPool( LogicalDevice, IN &vdpci, PALLOCATOR, OUT &DescriptorPool );
	return result;
}
```


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Step 2: Define the Descriptor Set Layouts

I think of Descriptor Set Layouts as a kind of "Rosetta Stone" that allows the Graphics Pipeline data structure to allocate room for the uniform variables and to access them.

https://www.britishmuseum.org

```
// non-opaque must be in a uniform block:
layout( std140, set = 0, binding = 0 ) uniform sporadicBuf
{
	int		uMode;
	int		uUseLighting;
	int		uNumInstances;
} Sporadic;

layout( std140, set = 1, binding = 0 ) uniform sceneBuf
{
	mat4		uProjection;
	mat4		uView;
	mat4		uSceneOrient;
	vec4		uLightPos;
	vec4		uLightColor;
	vec4		uLightKaKdKs;
	float		uTime;
} Scene;

layout( std140, set = 2, binding = 0 ) uniform objectBuf
{
	mat4		uModel;
	mat4		uNormal;
	vec4		uColor;
	float		uShininess;
} Object;

layout( set = 3, binding = 0 ) uniform sampler2D uSampler;
```

SporadicSet DS Layout Binding:	SceneSet DS Layout Binding:	ObjectSet DS Layout Binding:	TexSamplerSet DS Layout Binding:
binding descriptorType descriptorCount pipeline stage(s)	binding descriptorType descriptorCount pipeline stage(s)	binding descriptorType descriptorCount pipeline stage(s)	binding descriptorType descriptorCount pipeline stage(s)
set = 0	set = 1	set = 2	set = 3

```
VkResult
Init13DescriptorSetLayouts( )
{
	VkResult result;

	//DS #0:
	VkDescriptorSetLayoutBinding	SporadicSet[1];
		SporadicSet[0].binding		= 0;
		SporadicSet[0].descriptorType	= VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
		SporadicSet[0].descriptorCount	= 1;
		SporadicSet[0].stageFlags	= VK_SHADER_STAGE_VERTEX_BIT | VK_SHADER_STAGE_FRAGMENT_BIT;
		SporadicSet[0].pImmutableSamplers = (VkSampler *)nullptr;

	// DS #1:
	VkDescriptorSetLayoutBinding	SceneSet[1];
		SceneSet[0].binding		= 0;
		SceneSet[0].descriptorType	= VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
		SceneSet[0].descriptorCount	= 1;
		SceneSet[0].stageFlags		= VK_SHADER_STAGE_VERTEX_BIT | VK_SHADER_STAGE_FRAGMENT_BIT;
		SceneSet[0].pImmutableSamplers = (VkSampler *)nullptr;

	//DS #2:
	VkDescriptorSetLayoutBinding	ObjectSet[1];
		ObjectSet[0].binding		= 0;
		ObjectSet[0].descriptorType	= VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
		ObjectSet[0].descriptorCount	= 1;
		ObjectSet[0].stageFlags		= VK_SHADER_STAGE_VERTEX_BIT | VK_SHADER_STAGE_FRAGMENT_BIT;
		ObjectSet[0].pImmutableSamplers = (VkSampler *)nullptr;

	// DS #3:
	VkDescriptorSetLayoutBinding	TexSamplerSet[1];
		TexSamplerSet[0].binding		= 0;
		TexSamplerSet[0].descriptorType	= VK_DESCRIPTOR_TYPE_COMBINED_IMAGE_SAMPLER;
		TexSamplerSet[0].descriptorCount	= 1;
		TexSamplerSet[0].stageFlags		= VK_SHADER_STAGE_FRAGMENT_BIT;
		TexSamplerSet[0].pImmutableSamplers = (VkSampler *)nullptr;
```

```
uniform sampler2D   uSampler;
vec4 rgba = texture( uSampler, vST );
```

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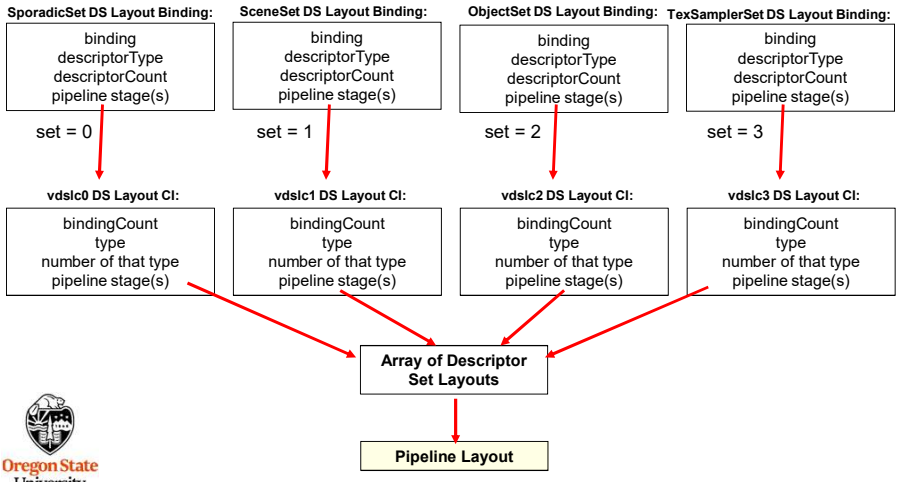
Step 2: Define the Descriptor Set Layouts

```
// globals:
VkDescriptorPool		DescriptorPool;
VkDescriptorSetLayout	DescriptorSetLayouts[4];
VkDescriptorSet		DescriptorSets[4];
```



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```
	VkDescriptorSetLayoutCreateInfo		vdslc0;
		vdslc0.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO;
		vdslc0.pNext = nullptr;
		vdslc0.flags = 0;
		vdslc0.bindingCount = 1;
		vdslc0.pBindings = &SporadicSet[0];

	VkDescriptorSetLayoutCreateInfo		vdslc1;
		vdslc1.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO;
		vdslc1.pNext = nullptr;
		vdslc1.flags = 0;
		vdslc1.bindingCount = 1;
		vdslc1.pBindings = &SceneSet[0];

	VkDescriptorSetLayoutCreateInfo		vdslc2;
		vdslc2.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO;
		vdslc2.pNext = nullptr;
		vdslc2.flags = 0;
		vdslc2.bindingCount = 1;
		vdslc2.pBindings = &ObjectSet[0];

	VkDescriptorSetLayoutCreateInfo		vdslc3;
		vdslc3.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO;
		vdslc3.pNext = nullptr;
		vdslc3.flags = 0;
		vdslc3.bindingCount = 1;
		vdslc3.pBindings = &TexSamplerSet[0];

	result = vkCreateDescriptorSetLayout( LogicalDevice, IN &vdslc0, PALLOCATOR, OUT &DescriptorSetLayouts[0] );
	result = vkCreateDescriptorSetLayout( LogicalDevice, IN &vdslc1, PALLOCATOR, OUT &DescriptorSetLayouts[1] );
	result = vkCreateDescriptorSetLayout( LogicalDevice, IN &vdslc2, PALLOCATOR, OUT &DescriptorSetLayouts[2] );
	result = vkCreateDescriptorSetLayout( LogicalDevice, IN &vdslc3, PALLOCATOR, OUT &DescriptorSetLayouts[3] );

	return result;
}
```


Step 3: Include the Descriptor Set Layouts in a Graphics Pipeline Layout

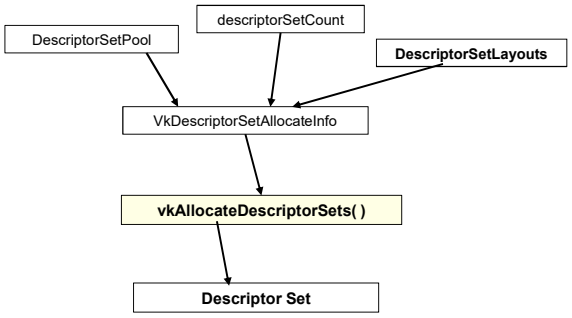

```
VkResult
Init14GraphicsPipelineLayout( )
{
	VkResult result;

	VkPipelineLayoutCreateInfo		vplci;
		vplci.sType = VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO;
		vplci.pNext = nullptr;
		vplci.flags = 0;
		vplci.setLayoutCount = 4;
		vplci.pSetLayouts = &DescriptorSetLayouts[0];
		vplci.pushConstantRangeCount = 0;
		vplci.pPushConstantRanges = (VkPushConstantRange *)nullptr;

	result = vkCreatePipelineLayout( LogicalDevice, IN &vplci, PALLOCATOR, OUT &GraphicsPipelineLayout );

	return result;
}
```

Step 4: Allocating the Memory for Descriptor Sets



Step 4: Allocating the Memory for Descriptor Sets


```
VkResult
Init13DescriptorSets( )
{
	VkResult result;

	VkDescriptorSetAllocateInfo		vdsai;
		vdsai.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_ALLOCATE_INFO;
		vdsai.pNext = nullptr;
		vdsai.descriptorPool = DescriptorPool;
		vdsai.descriptorSetCount = 4;
		vdsai.pSetLayouts = DescriptorSetLayouts;

	result = vkAllocateDescriptorSets( LogicalDevice, IN &vdsai, OUT &DescriptorSets[0] );
```

Step 5: Tell the Descriptor Sets where their CPU Data is


```
VkDescriptorBufferInfo          vdbi0;
    vdbi0.buffer = MySporadicUniformBuffer.buffer;
    vdbi0.offset = 0;
    vdbi0.range = sizeof(Sporadic);

VkDescriptorBufferInfo          vdbi1;
    vdbi1.buffer = MySceneUniformBuffer.buffer;
    vdbi1.offset = 0;
    vdbi1.range = sizeof(Scene);

VkDescriptorBufferInfo          vdbi2;
    vdbi2.buffer = MyObjectUniformBuffer.buffer;
    vdbi2.offset = 0;
    vdbi2.range = sizeof(Object);

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

This struct identifies what buffer it owns and how big it is

This struct identifies what buffer it owns and how big it is

This struct identifies what buffer it owns and how big it is

This struct identifies what texture sampler and image view it owns

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Step 5: Tell the Descriptor Sets where their CPU Data is


```
VkWriteDescriptorSet            vwds0;
        // ds 0:
        vwds0.sType = VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET;
        vwds0.pNext = nullptr;
        vwds0.dstSet = DescriptorSets[0];
        vwds0.dstBinding = 0;
        vwds0.dstArrayElement = 0;
        vwds0.descriptorCount = 1;
        vwds0.descriptorType = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
        vwds0.pBufferInfo = IN &vdbi0;
        vwds0.pImageInfo = (VkDescriptorImageInfo *)nullptr;
        vwds0.pTexelBufferView = (VkBufferView *)nullptr;

        // ds 1:
    VkWriteDescriptorSet            vwds1;
        vwds1.sType = VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET;
        vwds1.pNext = nullptr;
        vwds1.dstSet = DescriptorSets[1];
        vwds1.dstBinding = 0;
        vwds1.dstArrayElement = 0;
        vwds1.descriptorCount = 1;
        vwds1.descriptorType = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
        vwds1.pBufferInfo = IN &vdbi1;
        vwds1.pImageInfo = (VkDescriptorImageInfo *)nullptr;
        vwds1.pTexelBufferView = (VkBufferView *)nullptr;
```

This struct links a Descriptor Set to the buffer it is pointing to

This struct links a Descriptor Set to the buffer it is pointing to

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Step 5: Tell the Descriptor Sets where their data is

This struct links a Descriptor Set to the buffer it is pointing to

This struct links a Descriptor Set to the image it is pointing to

```
VkWriteDescriptorSet            vwds2;
        // ds 2:
        vwds2.sType = VK_STRUCTURE_TYPE_WRITE_DESCRIPTOR_SET;
        vwds2.pNext = nullptr;
        vwds2.dstSet = DescriptorSets[2];
        vwds2.dstBinding = 0;
        vwds2.dstArrayElement = 0;
        vwds2.descriptorCount = 1;
        vwds2.descriptorType = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
        vwds2.pBufferInfo = IN &vdbi2;
        vwds2.pImageInfo = (VkDescriptorImageInfo *)nullptr;
        vwds2.pTexelBufferView = (VkBufferView *)nullptr;

        // ds 3:
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 = IN &vdii0;
        vwds3.pTexelBufferView = (VkBufferView *)nullptr;

uint32_t copyCount = 0;

// this could have been done with one call and an array of VkWriteDescriptorSets:

vkUpdateDescriptorSets( LogicalDevice, 1, IN &vwds0, IN copyCount, (VkCopyDescriptorSet *)nullptr );
vkUpdateDescriptorSets( LogicalDevice, 1, IN &vwds1, IN copyCount, (VkCopyDescriptorSet *)nullptr );
vkUpdateDescriptorSets( LogicalDevice, 1, IN &vwds2, IN copyCount, (VkCopyDescriptorSet *)nullptr );
vkUpdateDescriptorSets( LogicalDevice, 1, IN &vwds3, IN copyCount, (VkCopyDescriptorSet *)nullptr );
```

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Step 6: Include the Descriptor Set Layout when Creating a Graphics Pipeline


```
VkGraphicsPipelineCreateInfo            vgpci;
        vgpci.sType = VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_CREATE_INFO;
        vgpci.pNext = nullptr;
        vgpci.flags = 0;
#ifdef CHOICES
VK_PIPELINE_CREATE_DISABLE_OPTIMIZATION_BIT
VK_PIPELINE_CREATE_ALLOW_DERIVATIVES_BIT
VK_PIPELINE_CREATE_DERIVATIVE_BIT
#endif
        vgpci.stageCount = 2;                   // number of stages in this pipeline
        vgpci.pStages = vpssci;
        vgpci.pVertexInputState = &vpvisci;
        vgpci.pInputAssemblyState = &vpiasci;
        vgpci.pTessellationState = (VkPipelineTessellationStateCreateInfo *)nullptr;
        vgpci.pViewportState = &vpvsci;
        vgpci.pRasterizationState = &vprsci;
        vgpci.pMultisampleState = &vpmsci;
        vgpci.pDepthStencilState = &vpdssci;
        vgpci.pColorBlendState = &vpcbsci;
        vgpci.pDynamicState = &vpdsci;
        vgpci.layout = IN GraphicsPipelineLayout;
        vgpci.renderPass = IN RenderPass;
        vgpci.subpass = 0;                      // subpass number
        vgpci.basePipelineHandle = (VkPipeline) VK_NULL_HANDLE;
        vgpci.basePipelineIndex = 0;

    result = vkCreateGraphicsPipelines( LogicalDevice, VK_NULL_HANDLE, 1, IN &vgpci,
                                        PALLOCATOR, OUT &GraphicsPipeline );
```

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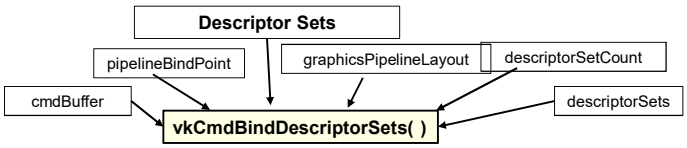
Step 7: Bind Descriptor Sets into the Command Buffer when Drawing




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

So, the Pipeline Layout contains the ***structure*** of the Descriptor Sets.
Any collection of Descriptor Sets that match that structure can be bound into that pipeline.

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Sidebar: The Entire Descriptor Set Journey

VkDescriptorPoolCreateInfo
vkCreateDescriptorPool( )
— Create the pool of Descriptor Sets for future use

VkDescriptorSetLayoutBinding
VkDescriptorSetLayoutCreateInfo
vkCreateDescriptorSetLayout( )
vkCreatePipelineLayout( )
— Describe a particular Descriptor Set layout and use it in a specific Pipeline layout

VkDescriptorSetAllocateInfo
vkAllocateDescriptorSets( )
— Allocate memory for particular Descriptor Sets

VkDescriptorBufferInfo
VkDescriptorImageInfo
VkWriteDescriptorSet
— Tell a particular Descriptor Set where its CPU data is

vkUpdateDescriptorSets( )
— Re-write CPU data into a particular Descriptor Set

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vkCmdBindDescriptorSets( )
— Make a particular Descriptor Set "current" for rendering

Sidebar: Why Do Descriptor Sets Need to Provide Layout Information to the Pipeline Data Structure?

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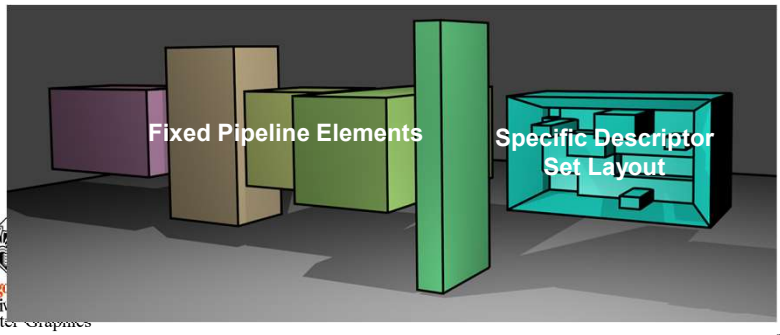
The pieces of the Pipeline Data Structure are fixed in size – with the exception of the Descriptor Sets and the Push Constants. Each of these two can be any size, depending on what you allocate for them. So, the Pipeline Data Structure needs to know how these two are configured before it can set its own total layout.

Think of the DS layout as being a particular-sized hole in the Pipeline Data Structure. Any data you have that matches this hole's shape and size can be plugged in there.

The Pipeline Data Structure



Sidebar: Why Do Descriptor Sets Need to Provide Layout Information to the Pipeline Data Structure?

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Any set of data that matches the Descriptor Set Layout can be plugged in there.