Descriptor Sets

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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?

```glsl
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;
```
What are Descriptor Sets?

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( each scene )
{
    Bind Descriptor Set #0
    for( each object )
    {
        Bind Descriptor Set #1
        for( each draw )
        {
            Bind Descriptor Set #2
            Do the drawing
        }
    }
}
```
Descriptor Sets

Our example will assume the following shader uniform variables:

```cpp
// non-opaque must be in a uniform block:
layout( std140, set = 0, binding = 0 ) uniform matBuf
{
    mat4 uModelMatrix;
    mat4 uViewMatrix;
    mat4 uProjectionMatrix;
    mat3 uNormalMatrix;
} Matrices;

layout( std140, set = 1, binding = 0 ) uniform lightBuf
{
    vec4 uLightPos;
} Light;

layout( std140, set = 2, binding = 0 ) uniform miscBuf
{
    float uTime;
    int   uMode;
} Misc;

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

**CPU:**

Uniform data created in a C++ data structure

- Knows the CPU data structure
- Knows where the data starts
- Knows the data’s size

**GPU:**

Uniform data in a “blob”*

- Knows where the data starts
- Knows the data’s size
- Doesn’t know the CPU or GPU data structure

**GPU:**

Uniform data used in the shader

- Knows the shader data structure
- Doesn’t know where each piece of data starts

```
struct matBuf {
    glm::mat4 uModelMatrix;
    glm::mat4 uViewMatrix;
    glm::mat4 uProjectionMatrix;
    glm::mat3 uNormalMatrix;
};

struct lightBuf {
    glm::vec4 uLightPos;
};

struct miscBuf {
    float uTime;
    int uMode;
};

layout( std140, set = 0, binding = 0 ) uniform matBuf {
    mat4 uModelMatrix;
    mat4 uViewMatrix;
    mat4 uProjectionMatrix;
    mat3 uNormalMatrix;
}

layout( std140, set = 1, binding = 0 ) uniform lightBuf {
    vec4 uLightPos;
}

layout( std140, set = 2, binding = 0 ) uniform miscBuf {
    float uTime;
    int uMode;
}

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

* “binary large object”

Oregon State University Computer Graphics
Step 1: Descriptor Set Pools

You don’t allocate Descriptor Sets on the fly – that is too slow. Instead, you allocate a “pool” of Descriptor Sets and then pull from that pool later.
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;
}
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.

```cpp
// Matrices
layout( std140, set = 0, binding = 0 ) uniform matBuf
{
    mat4 uModelMatrix;
    mat4 uViewMatrix;
    mat4 uProjectionMatrix;
    mat3 uNormalMatrix;
} Matrices;

// Light
layout( std140, set = 1, binding = 0 ) uniform lightBuf
{
    vec4 uLightPos;
} Light;

// Misc
layout( std140, set = 2, binding = 0 ) uniform miscBuf
{
    float uTime;
    int uMode;
} Misc;

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

### MatrixSet DS Layout Binding:
- set = 0
  - binding: 0
  - descriptorType: matBuf
  - descriptorCount: 4
  - pipeline stage(s): all

### LightSet DS Layout Binding:
- set = 1
  - binding: 0
  - descriptorType: lightBuf
  - descriptorCount: 1
  - pipeline stage(s): all

### MiscSet DS Layout Binding:
- set = 2
  - binding: 0
  - descriptorType: miscBuf
  - descriptorCount: 2
  - pipeline stage(s): all

### TexSamplerSet DS Layout Binding:
- set = 3
  - binding: 0
  - descriptorType: sampler2D
  - descriptorCount: 1
  - pipeline stage(s): all

https://www.britishmuseum.org
VkResult Init13DescriptorSetLayouts( )
{
    VkResult result;

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

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

    // DS #2:
    VkDescriptorSetLayoutBinding MiscSet[1];
    MiscSet[0].binding             = 0;
    MiscSet[0].descriptorType      = VK_DESCRIPTOR_TYPE_UNIFORM_BUFFER;
    MiscSet[0].descriptorCount     = 1;
    MiscSet[0].stageFlags          = VK_SHADER_STAGE_VERTEX_BIT | VK_SHADER_STAGE_FRAGMENT_BIT;
    MiscSet[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 );
Step 2: Define the Descriptor Set Layouts

MatrixSet DS Layout Binding:
- binding
- descriptorType
- descriptorCount
- pipeline stage(s)

set = 0

vdslc0 DS Layout Cl:
- bindingCount
- type
- number of that type
- pipeline stage(s)

LightSet DS Layout Binding:
- binding
- descriptorType
- descriptorCount
- pipeline stage(s)

set = 1

vdslc1 DS Layout Cl:
- bindingCount
- type
- number of that type
- pipeline stage(s)

MiscSet DS Layout Binding:
- binding
- descriptorType
- descriptorCount
- pipeline stage(s)

set = 2

vdslc2 DS Layout Cl:
- bindingCount
- type
- number of that type
- pipeline stage(s)

TexSamplerSet DS Layout Binding:
- binding
- descriptorType
- descriptorCount
- pipeline stage(s)

set = 3

vdslc3 DS Layout Cl:
- bindingCount
- type
- number of that type
- pipeline stage(s)

Array of Descriptor Set Layouts

Pipeline Layout
VkDescriptorSetLayoutCreateInfo *vdslc0 = &MatrixSet[0];

VkDescriptorSetLayoutCreateInfo *vdslc1 = &LightSet[0];

VkDescriptorSetLayoutCreateInfo *vdslc2 = &MiscSet[0];

VkDescriptorSetLayoutCreateInfo *vdslc3 = &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]);
Step 3: Include the Descriptor Set Layouts in a Graphics Pipeline Layout

```c
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

vkAllocateDescriptorSets()
Step 4: Allocating the Memory for Descriptor Sets

```c
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

<table>
<thead>
<tr>
<th>VkDescriptorBufferInfo vdbi0;</th>
</tr>
</thead>
<tbody>
<tr>
<td>vdbi0.buffer = MyMatrixUniformBuffer.buffer;</td>
</tr>
<tr>
<td>vdbi0.offset = 0;</td>
</tr>
<tr>
<td>vdbi0.range = sizeof(Matrices);</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>VkDescriptorBufferInfo vdbi1;</th>
</tr>
</thead>
<tbody>
<tr>
<td>vdbi1.buffer = MyLightUniformBuffer.buffer;</td>
</tr>
<tr>
<td>vdbi1.offset = 0;</td>
</tr>
<tr>
<td>vdbi1.range = sizeof(Light);</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>VkDescriptorBufferInfo vdbi2;</th>
</tr>
</thead>
<tbody>
<tr>
<td>vdbi2.buffer = MyMiscUniformBuffer.buffer;</td>
</tr>
<tr>
<td>vdbi2.offset = 0;</td>
</tr>
<tr>
<td>vdbi2.range = sizeof(Misc);</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>VkDescriptorImageInfo vdi0;</th>
</tr>
</thead>
<tbody>
<tr>
<td>vdi0.sampler = MyPuppyTexture.texSampler;</td>
</tr>
<tr>
<td>vdi0.imageView = MyPuppyTexture.texImageView;</td>
</tr>
<tr>
<td>vdi0.imageLayout = VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL;</td>
</tr>
</tbody>
</table>

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

```c
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 = &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 = &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.
Step 5: Tell the Descriptor Sets where their data is

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 = (VkDescriptorBufferInfo *)nullptr;
    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 = (VkDescriptorImageInfo *)nullptr;
    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);
Step 6: Include the Descriptor Set Layout when Creating a Graphics Pipeline

```cpp
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 );
```
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.
Sidebar: The Entire Collection of Descriptor Set Paths

- **VkDescriptorPoolCreateInfo**
  - `vkCreateDescriptorPool( )`
    - Create the pool of Descriptor Sets for future use

- **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

- **VkDescriptorSetLayoutBinding**
  - `VkDescriptorBufferInfo`  
  - `VkDescriptorImageInfo`
  - `VkDescriptorSetAllocateInfo`
  - `vkWriteDescriptorSet`
  - `vkCmdBindDescriptorSets( )`
  - `vkUpdateDescriptorSets( )`
    - Tell a particular Descriptor Set where its CPU data is
    - Re-write CPU data into a particular Descriptor Set
    - Make a particular Descriptor Set “current” for rendering
Sidebar: Why Do Descriptor Sets Need to Provide Layout Information to the Pipeline Data Structure?

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?

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