Vulkan

Data Buffers

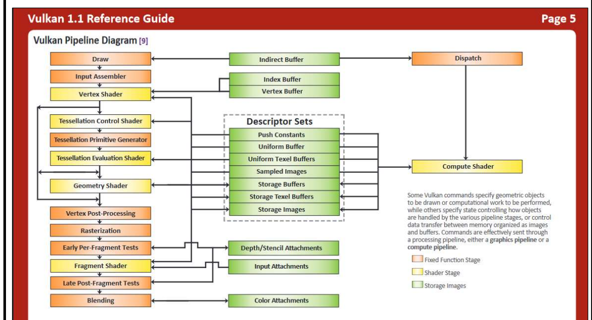
Oregon State University

Mike Bailey

mjb@cs.oregonstate.edu

From the Quick Reference Card

Even though Vulkan is up to 1.3, the most current Vulkan Reference card is version 1.1



https://www.khronos.org/files/vulkan11-reference-guide.pdf

Terminology Issues

A Vulkan **Data Buffer** is just a group of contiguous bytes in GPU memory. They have no inherent meaning. The data that is stored there is whatever you want it to be. (This is sometimes called a "Binary Large Object", or "BLOB".)

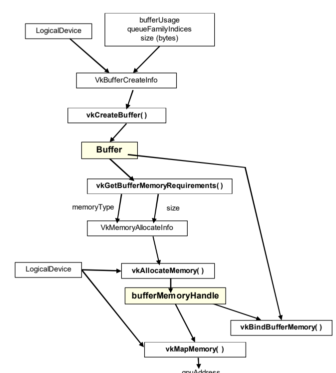
It is up to you to be sure that the writer and the reader of the Data Buffer are interpreting the bytes in the same way!

Vulkan calls these things "Buffers". But, Vulkan calls other things "Buffers", too, such as Texture Buffers and Command Buffers. So, I sometimes have taken to calling these things "Data Buffers" and have even gone so far as to extend some of Vulkan's own terminology:

```
typedef VkBuffer          VkDataBuffer;
```

This is probably a bad idea in the long run.

Creating and Filling Vulkan Data Buffers



Creating a Vulkan Data Buffer

```
VkBuffer  Buffer;             // or "VkDataBuffer   Buffer"

VkBufferCreateInfo  vbci;
        vbci.sType = VK_STRUCTURE_TYPE_BUFFER_CREATE_INFO;
        vbci.pNext = nullptr;
        vbci.flags = 0;
        vbci.size = << buffer size in bytes >>
        vbci.usage = <<or'ed bits of: >>
                VK_USAGE_TRANSFER_SRC_BIT
                VK_USAGE_TRANSFER_DST_BIT
                VK_USAGE_UNIFORM_TEXEL_BUFFER_BIT
                VK_USAGE_STORAGE_TEXEL_BUFFER_BIT
                VK_USAGE_UNIFORM_BUFFER_BIT
                VK_USAGE_STORAGE_BUFFER_BIT
                VK_USAGE_INDEX_BUFFER_BIT
                VK_USAGE_VERTEX_BUFFER_BIT
                VK_USAGE_INDIRECT_BUFFER_BIT
        vbci.sharingMode = << one of: >>
                VK_SHARING_MODE_EXCLUSIVE
                VK_SHARING_MODE_CONCURRENT
        vbci.queueFamilyIndexCount = 0;
        vbci.pQueueFamilyIndices = (const iont32_t) nullptr;

result = vkCreateBuffer ( LogicalDevice, IN &vbci, PALLOCATOR,  OUT &Buffer );
```

"or" these bits together to specify how this buffer will be used

Allocating Memory for a Vulkan Data Buffer, Binding a Buffer to Memory, and Writing to the Buffer

```
VkMemoryRequirements            vmr;
result = vkGetBufferMemoryRequirements( LogicalDevice, Buffer, OUT &vmr );


VkMemoryAllocateInfo            vmai;
        vmai.sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO;
        vmai.pNext = nullptr;
        vmai.flags = 0;
        vmai.allocationSize = vmr.size;
        vmai.memoryTypeIndex = FindMemoryThatIsHostVisible( );

. . .

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

result = vkBindBufferMemory( LogicalDevice, Buffer, IN vdm, 0 );            // 0 is the offset

. . .

result = vkMapMemory( LogicalDevice, IN vdm, 0, VK_WHOLE_SIZE, 0, &ptr );

        << do the memory copy >>

result = vkUnmapMemory( LogicalDevice, IN vdm );
```

Finding the Right Type of Memory


```
int
FindMemoryThatIsHostVisible( )
{
        VkPhysicalDeviceMemoryProperties        vpdmp;
        vkGetPhysicalDeviceMemoryProperties( PhysicalDevice, OUT &vpdmp );
        for( unsigned int i = 0; i < vpdmp.memoryTypeCount; i++ )
        {
                VkMemoryType vmt = vpdmp.memoryTypes[ i ];
                if( ( vmt.propertyFlags & VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT ) != 0 )
                {
                        return i;
                }
        }
        return  -1;
}
```


Finding the Right Type of Memory


```
int
FindMemoryThatIsDeviceLocal( )
{
        VkPhysicalDeviceMemoryProperties        vpdmp;
        vkGetPhysicalDeviceMemoryProperties( PhysicalDevice, OUT &vpdmp );
        for( unsigned int i = 0; i < vpdmp.memoryTypeCount; i++ )
        {
                VkMemoryType vmt = vpdmp.memoryTypes[ i ];
                if( ( vmt.propertyFlags & VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT ) != 0 )
                {
                        return i;
                }
        }
        return  -1;
}
```


Finding the Right Type of Memory


```
VkPhysicalDeviceMemoryProperties                        vpdmp;
vkGetPhysicalDeviceMemoryProperties( PhysicalDevice, OUT &vpdmp );
```

```
6 Memory Types:
Memory  0:
Memory  1:  DeviceLocal
Memory  2:  HostVisible HostCoherent
Memory  3:  HostVisible HostCoherent HostCached
Memory  4:  DeviceLocal HostVisible HostCoherent
Memory  5:  DeviceLocal

4 Memory Heaps:
Heap 0:  size = 0xdbb00000 DeviceLocal
Heap 1:  size = 0xfd504000
Heap 2:  size = 0x0d600000 DeviceLocal
Heap 3:  size = 0x02000000 DeviceLocal
```

These are the numbers for the Nvidia A6000 cards

Memory-Mapped Copying to GPU Memory, Example I


```
void *mappedDataAddr;

vkMapMemory( LogicalDevice, myBuffer.vdm, 0, VK_WHOLE_SIZE, 0, OUT (void *)&mappedDataAddr );

        memcpy( mappedDataAddr, &VertexData, sizeof(VertexData) );

vkUnmapMemory( LogicalDevice, myBuffer.vdm );
```


Memory-Mapped Copying to GPU Memory, Example II


```
struct vertex *vp;

vkMapMemory( LogicalDevice, IN myBuffer.vdm, 0, VK_WHOLE_SIZE, 0, OUT (void *)&vp );

for( int i = 0; i < numTrianglesInObjFile; i++ )          // number of triangles
{
        for( int j = 0; j < 3; j++ )                      // 3 vertices per triangle
        {
                vp->position = glm::vec3( . . . );
                vp->normal = glm::vec3( . . . );
                vp->color = glm::vec3( . . . );
                vp->texCoord = glm::vec2( . . . );
                vp++;
        }
}

vkUnmapMemory( LogicalDevice, myBuffer.vdm );
```


Sidebar: The Vulkan Memory Allocator (VMA)

The **Vulkan Memory Allocator** is a set of functions to simplify your view of allocating buffer memory. I am including its github link here and a little sample code in case you want to take a peek.

https://github.com/GPUOpen-LibrariesAndSDKs/VulkanMemoryAllocator

This repositoryalso includes a smattering of documentation.

See our class VMA noteset for more VMA details

Sidebar: The Vulkan Memory Allocator (VMA)

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```
#define VMA_IMPLEMENTATION
#include "vk_mem_alloc.h"
. . .
VkBufferCreateInfo              vbci;
. . .
VmaAllocationCreateInfo         vaci;
        vaci.physicalDevice = PhysicalDevice;
        vaci.device = LogicalDevice;
        vaci.usage = VMA_MEMORY_USAGE_GPU_ONLY;

VmaAllocator                    var;
vmaCreateAllocator( IN &vaci, OUT &var );
. . .
. .
VkBuffer                        Buffer;
VmaAllocation                   van;
vmaCreateBuffer( IN var, IN &vbci, IN &vaci, OUT &Buffer. OUT &van, nullptr );
```

```
void *mappedDataAddr;
vmaMapMemory( var, van, OUT &mappedDataAddr );

        memcpy( mappedDataAddr, &VertexData, sizeof(VertexData) );

vmaUnmapMemory( var, van );
```

See our class VMA noteset for more VMA details

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Something I've Found Useful

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I find it handy to encapsulate buffer information in a struct:

```
typedef struct MyBuffer
{
        VkDataBuffer        buffer;
        VkDeviceMemory      vdm;
        VkDeviceSize        size;       // in bytes
} MyBuffer;

. . .

// example:
MyBuffer                MyObjectUniformBuffer;
```

It's the usual object-oriented benefit – you can pass around just one data-item and everyone can access whatever information they need.

It also makes it impossible to accidentally associate the wrong VkDeviceMemory and/or VkDeviceSize with the wrong data buffer.

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Initializing a Data Buffer

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It's the usual object-oriented benefit – you can pass around just one data-item and everyone can access whatever information they need.

```
VkResult
Init05DataBuffer( VkDeviceSize size, VkBufferUsageFlags usage, OUT MyBuffer * pMyBuffer )
{
. . .
        vbci.size = pMyBuffer->size = size;
. . .
        result = vkCreateBuffer ( LogicalDevice, IN &vbci, PALLOCATOR,  OUT &pMyBuffer->buffer );
. . .
        pMyBuffer->vdm = vdm;
. . .
}
```

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Here are C/C++ structs used by the Sample Code to hold some uniform variables

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

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

The uNormal is set to:
glm::inverseTranspose(uView * uSceneOrient * uModel)

Here's the associated GLSL shader code to access those uniform variables:

```
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;
```

In the vertex shader, each object vertex gets transformed by:
uProjection* uView * uSceneOrient * uModel

In the vertex shader, each surface normal vector gets transformed by the **uNormal**

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Filling those Uniform Variables

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```
const float EYEDIST =   3.0f;
const double FOV    =   glm::radians(60.);      // field-of-view angle in radians

glm::vec3  eye(0.,0.,EYEDIST);
glm::vec3  look(0.,0.,0.);
glm::vec3  up(0.,1.,0.);

Scene.uProjection          = glm::perspective( FOV, (double)Width/(double)Height, 0.1, 1000. );
Scene.uProjection[1][1]  *= -1.;               // account for Vulkan's LH screen coordinate system
Scene.uView                = glm::lookAt( eye, look, up );
Scene.uSceneOrient         = glm::mat4( 1. );

Object.uModelOrient = glm::mat4( 1. );          // identity
Object.uNormal        = glm::inverseTranspose( Scene.uView * Scene.uSceneOrient * Object.uModel )
```

This code assumes that this line:

#define   GLM_FORCE_RADIANS

is listed before GLM is #included!

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The Parade of Buffer Data

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MyBuffer   MyObjectUniformBuffer;

The MyBuffer does not hold any actual data itself. It just information about what is in the data buffer

```
VkResult
Init05DataBuffer( VkDeviceSize size, VkBufferUsageFlags usage, OUT MyBuffer * pMyBuffer )
{
. . .
        vbci.size = pMyBuffer->size = size;
. . .
        result = vkCreateBuffer ( LogicalDevice, IN &vbci, PALLOCATOR,  OUT &pMyBuffer->buffer );
. . .
        pMyBuffer->vdm = vdm;
. . .
}
```

This C struct is holding the original data, written by the application.

Memory-mapped copy operation

The Data Buffer in GPU memory is holding the copied data. It is readable by the shaders

struct objectBuf   Object;

```
Object.uModelOrient = glm::mat4( 1. );          // identity
Object.uNormal        = glm::inverseTranspose( Scene.uView * Scene.uSceneOrient * Object.uModel )
```

uniform objectBuf   Object;

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

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Filling the Data Buffer

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```
typedef struct MyBuffer
{
        VkDataBuffer          buffer;
        VkDeviceMemory        vdm;
        VkDeviceSize          size;      // in bytes
} MyBuffer;

. . .

// example:
MyBuffer              MyObjectUniformBuffer;
```

```
Init05UniformBuffer( sizeof(Object),        OUT &MyObjectUniformBuffer );

Fill05DataBuffer( MyObjectUniformBuffer,     IN (void *) &Object );
```

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

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Creating and Filling the Data Buffer – the Details

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```
VkResult
Init05DataBuffer( VkDeviceSize size, VkBufferUsageFlags usage, OUT MyBuffer * pMyBuffer )
{
        VkResult result = VK_SUCCESS;
        VkBufferCreateInfo  vbci;
                vbci.sType = VK_STRUCTURE_TYPE_BUFFER_CREATE_INFO;
                vbci.pNext = nullptr;
                vbci.flags = 0;
                vbci.size = pMyBuffer->size = size;
                vbci.usage = usage;
                vbci.sharingMode = VK_SHARING_MODE_EXCLUSIVE;
                vbci.queueFamilyIndexCount = 0;
                vbci.pQueueFamilyIndices = (const uint32_t *)nullptr;
        result = vkCreateBuffer ( LogicalDevice, IN &vbci, PALLOCATOR,  OUT &pMyBuffer->buffer );

        VkMemoryRequirements            vmr;
        vkGetBufferMemoryRequirements( LogicalDevice, IN pMyBuffer->buffer, OUT &vmr );        // fills vmr

        VkMemoryAllocateInfo            vmai;
                vmai.sType = VK_STRUCTURE_TYPE_MEMORY_ALLOCATE_INFO;
                vmai.pNext = nullptr;
                vmai.allocationSize = vmr.size;
                vmai.memoryTypeIndex = FindMemoryThatIsHostVisible( );

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

        result = vkBindBufferMemory( LogicalDevice, pMyBuffer->buffer, IN vdm, OFFSET_ZERO );
        return result;
}
```

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Creating and Filling the Data Buffer – the Details

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```
VkResult
Fill05DataBuffer( IN MyBuffer myBuffer, IN void * data )
{
        // the size of the data had better match the size that was used to Init the buffer!

        void * pGpuMemory;
        vkMapMemory( LogicalDevice, IN myBuffer.vdm, 0, VK_WHOLE_SIZE, 0, OUT &pGpuMemory );
                                                        // 0 and 0 are offset and flags
        memcpy( pGpuMemory, data, (size_t)myBuffer.size );

        vkUnmapMemory( LogicalDevice, IN myBuffer.vdm );
        return VK_SUCCESS;
}
```

Remember – to Vulkan and GPU memory, these are just *bits*. It is up to *you* to handle their meaning correctly.

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