Drawing

Oregon State University
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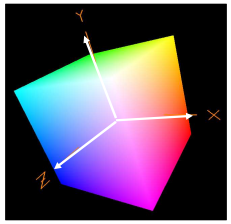

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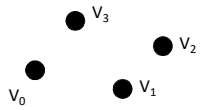
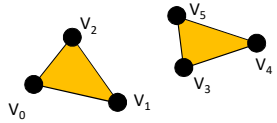
Vulkan Topologies

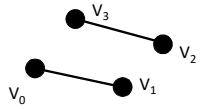
VK_PRIMITIVE_TOPOLOGY_POINT_LIST



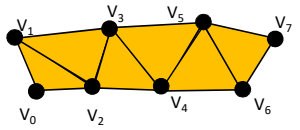
VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST



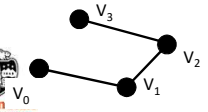
VK_PRIMITIVE_TOPOLOGY_LINE_LIST



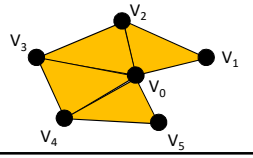
VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP



VK_PRIMITIVE_TOPOLOGY_LINE_STRIP



VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN



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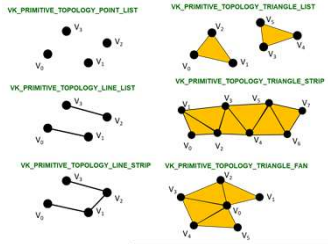
Vulkan Topologies



The same as OpenGL topologies, with a few left out.

```
typedef enum VkPrimitiveTopology
{
    VK_PRIMITIVE_TOPOLOGY_POINT_LIST
    VK_PRIMITIVE_TOPOLOGY_LINE_LIST
    VK_PRIMITIVE_TOPOLOGY_LINE_STRIP
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN
    VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY
    VK_PRIMITIVE_TOPOLOGY_LINE_STRIP_WITH_ADJACENCY
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY
    VK_PRIMITIVE_TOPOLOGY_PATCH_LIST
} VkPrimitiveTopology;
```

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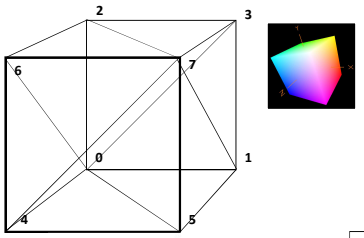
A Colored Cube Example




```
static GLfloat CubeColors[ ][3] =
{
        { 0., 0., 0. },
        { 1., 0., 0. },
        { 0., 1., 0. },
        { 1., 1., 0. },
        { 0., 0., 1. },
        { 1., 0., 1. },
        { 0., 1., 1. },
        { 1., 1., 1. },
};
```

```
static GLfloat CubeVertices[ ][3] =
{
        { -1., -1., -1. },
        {  1., -1., -1. },
        { -1.,  1., -1. },
        {  1.,  1., -1. },
        { -1., -1.,  1. },
        {  1., -1.,  1. },
        { -1.,  1.,  1. },
        {  1.,  1.,  1. }
};
```

```
static GLuint CubeTriangleIndices[ ][3] =
{
        { 0, 2, 3 },
        { 0, 3, 1 },
        { 4, 5, 7 },
        { 4, 7, 6 },
        { 1, 3, 7 },
        { 1, 7, 5 },
        { 0, 4, 6 },
        { 0, 6, 2 },
        { 2, 6, 7 },
        { 2, 7, 3 },
        { 0, 1, 5 },
        { 0, 5, 4 }
};
```

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This data is contained in the file ***SampleVertexData.cpp***

Triangles Represented as an Array of Structures

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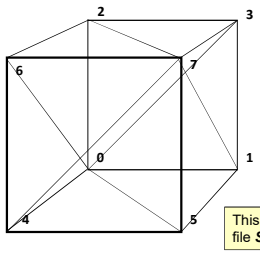
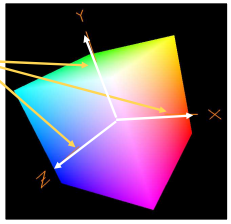
```
struct vertex
{
	glm::vec3	position;
	glm::vec3	normal;
	glm::vec3	color;
	glm::vec2	texCoord;
};

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. }
	},
```



This data is contained in the file ***SampleVertexData.cpp***

Modeled in right-handed coordinates



Non-indexed Buffer Drawing

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From the file **SampleVertexData.cpp**:

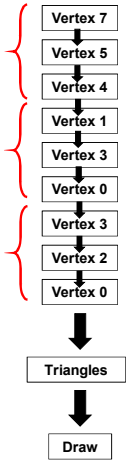
```
struct vertex
{
	glm::vec3	position;
	glm::vec3	normal;
	glm::vec3	color;
	glm::vec2	texCoord;
};

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. }
	},
```

Stream of Vertices



Initializing and Filling the Vertex Buffer

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```
struct vertex  VertexData[ ] =
{
	. . .
};

MyBuffer	MyVertexDataBuffer;

	. . .

Init05MyVertexDataBuffer(  sizeof(VertexData), OUT &MyVertexDataBuffer );	// create
Fill05DataBuffer( MyVertexDataBuffer,		(void *) VertexData );		// fill

	. . .

VkResult
Init05MyVertexDataBuffer( IN VkDeviceSize size, OUT MyBuffer * pMyBuffer )
{
	VkResult result;
	result = Init05DataBuffer( size, VK_BUFFER_USAGE_VERTEX_BUFFER_BIT, pMyBuffer );
	return result;
}


VkResult
Fill05DataBuffer( IN MyBuffer myBuffer, IN void * data )
{
	. . .
}
```


A Preview of What *Init05DataBuffer* Does

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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, 0 );		// 0 is the offset
	return result;
}
```

Telling the Pipeline about its Input

9

We will come to the Pipeline later, but for now, know that a Vulkan pipeline is essentially a very large data structure that holds (what OpenGL would call) the **state**, including how to parse its input.

C/C++:

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

GLSL Shader:

```
layout( location = 0 ) in vec3 aVertex;
layout( location = 1 ) in vec3 aNormal;
layout( location = 2 ) in vec3 aColor;
layout( location = 3 ) in vec2 aTexCoord;
```

```
VkVertexInputBindingDescription     vvibd[1];     // one of these per buffer data buffer
        vvibd[0].binding = 0;                     // which binding # this is
        vvibd[0].stride = sizeof( struct vertex );    // bytes between successive structs
        vvibd[0].inputRate = VK_VERTEX_INPUT_RATE_VERTEX;     // read one value per vertex
```

Always use the C/C++ **sizeof( )** construct rather than hardcoding the byte count!

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Telling the Pipeline about its Input

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

```
layout( location = 0 ) in vec3 aVertex;
layout( location = 1 ) in vec3 aNormal;
layout( location = 2 ) in vec3 aColor;
layout( location = 3 ) in vec2 aTexCoord;
```

```
VkVertexInputAttributeDescription     vviad[4];     // array per vertex input attribute
        // 4 = vertex, normal, color, texture coord
        vviad[0].location = 0;                // location in the layout decoration
        vviad[0].binding = 0;                 // which binding description this is part of
        vviad[0].format = VK_FORMAT_VEC3;     // x, y, z
        vviad[0].offset = offsetof( struct vertex, position );        // 0

        vviad[1].location = 1;
        vviad[1].binding = 0;
        vviad[1].format = VK_FORMAT_VEC3;     // nx, ny, nz
        vviad[1].offset = offsetof( struct vertex, normal );          // 12

        vviad[2].location = 2;
        vviad[2].binding = 0;
        vviad[2].format = VK_FORMAT_VEC3;     // r, g, b
        vviad[2].offset = offsetof( struct vertex, color );           // 24

        vviad[3].location = 3;
        vviad[3].binding = 0;
        vviad[3].format = VK_FORMAT_VEC2;     // s, t
        vviad[3].offset = offsetof( struct vertex, texCoord );        // 36
```

Always use the C/C++ construct ***offsetof***, rather than hardcoding the byte offset!

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Telling the Pipeline Data Structure about its Input

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We will come to the Pipeline Data Structure later, but for now, know that a Vulkan Pipeline is essentially a very large data structure that holds (what OpenGL would call) the state, including how to parse its vertex input.

```
VkPipelineVertexInputStateCreateInfo     vpvisci;     // used to describe the input vertex attributes
        vpvisci.sType = VK_STRUCTURE_TYPE_PIPELINE_VERTEX_INPUT_STATE_CREATE_INFO;
        vpvisci.pNext = nullptr;
        vpvisci.flags = 0;
        vpvisci.vertexBindingDescriptionCount = 1;
        vpvisci.pVertexBindingDescriptions = vvibd;
        vpvisci.vertexAttributeDescriptionCount = 4;
        vpvisci.pVertexAttributeDescriptions = vviad;

VkPipelineInputAssemblyStateCreateInfo     vpiasci;
        vpiasci.sType = VK_STRUCTURE_TYPE_PIPELINE_INPUT_ASSEMBLY_STATE_CREATE_INFO;
        vpiasci.pNext = nullptr;
        vpiasci.flags = 0;
        vpiasci.topology = VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST;
```

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Telling the Pipeline Data Structure about its Input

12

We will come to the Pipeline Data Structure later, but for now, know that a Vulkan Pipeline is essentially a very large data structure that holds (what OpenGL would call) the state, including how to parse its vertex input.

```
VkGraphicsPipelineCreateInfo     vgpci;
        vgpci.sType = VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_CREATE_INFO;
        vgpci.pNext = nullptr;
        vgpci.flags = 0;
        vgpci.stageCount = 2;                 // number of shader stages in this pipeline
        vgpci.pStages = vpssci;
        vgpci.pVertexInputState = &vpvisci;
        vgpci.pInputAssemblyState = &vpiasci;
        vgpci.pTessellationState = (VkPipelineTessellationStateCreateInfo *)nullptr;     // &vptsci
        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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Telling the Command Buffer what Vertices to Draw

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We will come to Command Buffers later, but for now, know that you will specify the vertex buffer that you want drawn.

```
VkBuffer        buffers[1]   = { MyVertexDataBuffer.buffer };
VkDeviceSize offsets[1]   = { 0 };

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

const uint32_t  firstInstance = 0;
const uint32_t  firstVertex = 0;
const uint32_t  instanceCount = 1;
const uint32_t  vertexCount = sizeof( VertexData ) / sizeof( VertexData[0] );

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

Always use the C/C++ construct ***sizeof***, rather than hardcoding a byte count!

Drawing with an Index Buffer

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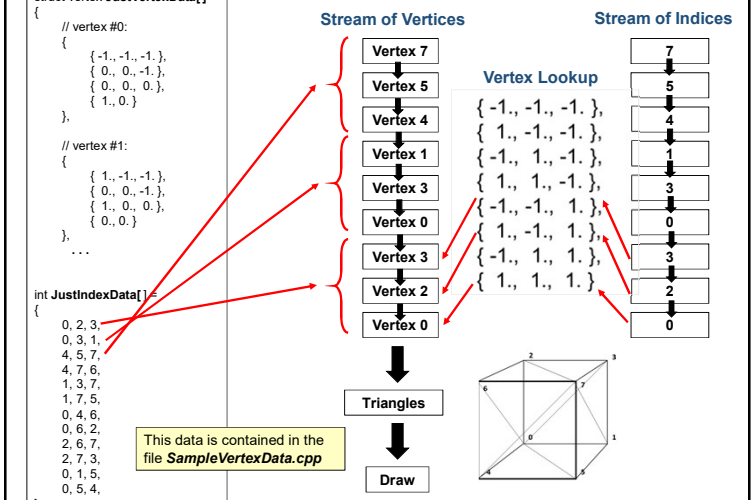
```
struct vertex JustVertexData[ ] =
{
        // vertex #0:
        {
                { -1., -1., -1. },
                {  0.,  0., -1. },
                {  0.,  0.,  0. },
                {  1.,  0. }
        },

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

int JustIndexData[ ] =
{
        0, 2, 3,
        0, 3, 1,
        4, 5, 7,
        4, 7, 6,
        1, 3, 7,
        1, 7, 5,
        0, 4, 6,
        0, 6, 2,
        2, 6, 7,
        2, 7, 3,
        0, 1, 5,
        0, 5, 4,
};
```



This data is contained in the file ***SampleVertexData.cpp***

Drawing with an Index Buffer

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```
vkCmdBindVertexBuffers( commandBuffer, firstBinding, bindingCount, vertexDataBuffers, vertexOffsets );

vkCmdBindIndexBuffer( commandBuffer, indexDataBuffer, indexOffset, indexType );
```

```
typedef enum VkIndexType
{
    VK_INDEX_TYPE_UINT16 = 0,       // 0 –          65,535
    VK_INDEX_TYPE_UINT32 = 1,       // 0 – 4,294,967,295
} VkIndexType;
```

```
vkCmdDrawIndexed( commandBuffer, indexCount, instanceCount, firstIndex,  vertexOffset, firstInstance);
```


Drawing with an Index Buffer

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```
VkResult
Init05MyIndexDataBuffer(IN VkDeviceSize size, OUT MyBuffer * pMyBuffer)
{
        VkResult result = Init05DataBuffer(size, VK_BUFFER_USAGE_INDEX_BUFFER_BIT, pMyBuffer);
                                                        // fills pMyBuffer
        return result;
}
```

```
Init05MyVertexDataBuffer(  sizeof(JustVertexData), IN &MyJustVertexDataBuffer );
Fill05DataBuffer( MyJustVertexDataBuffer,          (void *) JustVertexData );

Init05MyIndexDataBuffer(  sizeof(JustIndexData),   IN &MyJustIndexDataBuffer );
Fill05DataBuffer( MyJustIndexDataBuffer,           (void *) JustIndexData );
```

Drawing with an Index Buffer

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```
VkBuffer vBuffers[1] = { MyJustVertexDataBuffer.buffer };
VkBuffer iBuffer     = { MyJustIndexDataBuffer.buffer  };

vkCmdBindVertexBuffers( CommandBuffers[nextImageIndex], 0, 1, vBuffers, offsets );
                                    // 0, 1 = firstBinding, bindingCount
vkCmdBindIndexBuffer( CommandBuffers[nextImageIndex], iBuffer, 0, VK_INDEX_TYPE_UINT32 );

const uint32_t vertexCount = sizeof( JustVertexData ) / sizeof( JustVertexData[0] );
const uint32_t indexCount  = sizeof( JustIndexData )  / sizeof( JustIndexData[0] );
const uint32_t instanceCount = 1;
const uint32_t firstVertex = 0;
const uint32_t firstIndex = 0;
const uint32_t firstInstance = 0;
const uint32_t vertexOffset  = 0;

vkCmdDrawIndexed( CommandBuffers[nextImageIndex], indexCount, instanceCount, firstIndex,
                  vertexOffset, firstInstance );
```

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Indirect Drawing (not to be confused with *Indexed*)

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```
typedef struct
VkDrawIndirectCommand
{
    uint32_t    vertexCount;
    uint32_t    instanceCount;
    uint32_t    firstVertex;
    uint32_t    firstInstance;
} VkDrawIndirectCommand;
```

In Vulkan, "Indirect" means that you store the arguments in GPU memory and then give the vkCmdXxx call a pointer to those arguments

vkCmdDrawIndirect(CommandBuffers[nextImageIndex], buffer, offset, drawCount, stride);

Compare this with:

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

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Indexed Indirect Drawing (i.e., both Indexed and Indirect)

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```
typedef struct
VkDrawIndexedIndirectCommand
{
    uint32_t    indexCount;
    uint32_t    instanceCount;
    uint32_t    firstIndex;
    int32_t     vertexOffset;
    uint32_t    firstInstance;
} VkDrawIndexedIndirectCommand;
```

In Vulkan, "Indirect" means that you store the arguments in GPU memory and then give the vkCmdXxx call a pointer to those arguments

vkCmdDrawIndexedIndirect(commandBuffer, buffer, offset, drawCount, stride);

Compare this with:

vkCmdDrawIndexed(commandBuffer, indexCount, instanceCount, firstIndex, vertexOffset, firstInstance);

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Sometimes the Same Vertex Needs Multiple Attributes

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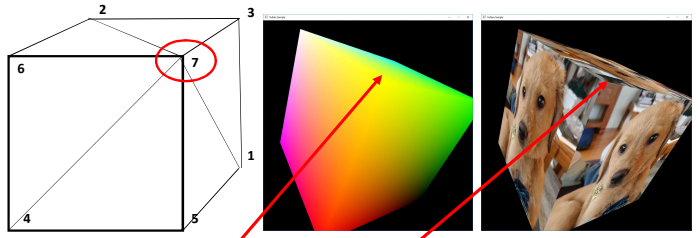

Sometimes a vertex that is common to multiple faces has the same attributes, no matter what face it is in. Sometimes it doesn't.

A color-interpolated cube like this actually has both. Vertex #7 above has the same color, regardless of what face it is in. However, Vertex #7 has 3 different normal vectors, depending on which face you are defining. Same with its texture coordinates.

Thus, when using indexed buffer drawing, you need to create a new vertex struct if *any* of {position, normal, color, texCoords} changes from what was previously-stored at those coordinates.

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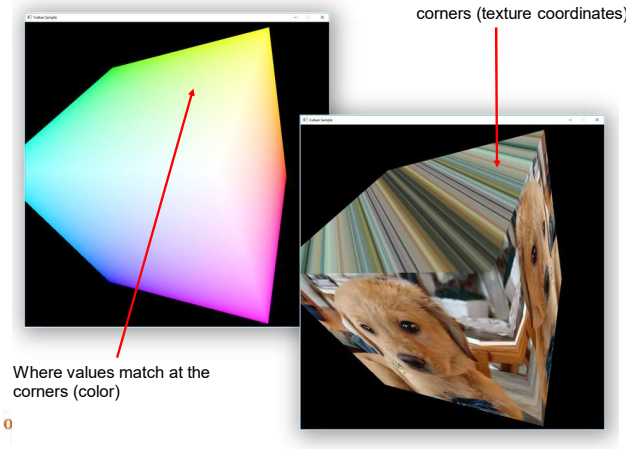
Sometimes the Same Point Needs Multiple Attributes

21



The OBJ File Format – a triple-indexed way of Drawing

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```
v 1.710541 1.283360 -0.040860
v 1.714593 1.273043 -0.041268
v 1.706114 1.279109 -0.040795
v 1.719083 1.277235 -0.041195
v 1.722786 1.267216 -0.041939
v 1.727196 1.271285 -0.041795
v 1.730680 1.261384 -0.042630
v 1.723121 1.280378 -0.037323
v 1.714513 1.286599 -0.037101
v 1.706156 1.293797 -0.037073
v 1.702207 1.290297 -0.040704
v 1.697843 1.285852 -0.040489
v 1.709169 1.295845 -0.029862
v 1.717523 1.288344 -0.029807

. . .

vn  0.1725  0.2557 -0.9512
vn -0.1979 -0.1899 -0.9616
vn -0.2050 -0.2127 -0.9554
vn  0.1664  0.3020 -0.9387
vn -0.2040 -0.1718 -0.9638
vn  0.1645  0.3203 -0.9329
vn -0.2055 -0.1698 -0.9638
vn  0.4419  0.6436 -0.6249
vn  0.4573  0.5682 -0.6841
vn  0.5160  0.5538 -0.6535
vn  0.1791  0.2082 -0.9616
vn -0.2167 -0.2250 -0.9499
vn  0.6624  0.6871 -0.2987
```

```
vt 0.816406 0.955536
vt 0.822754 0.959168
vt 0.815918 0.959442
vt 0.823242 0.955292
vt 0.829102 0.958862
vt 0.829590 0.955109
vt 0.835449 0.958618
vt 0.824219 0.951263
vt 0.817383 0.951538
vt 0.810059 0.951385
vt 0.809570 0.955383
vt 0.809082 0.959320
vt 0.811035 0.946381

. . .

f 73/73/75 65/65/67 66/66/68
f 66/66/68 74/74/76 73/73/75
f 74/74/76 66/66/68 67/67/69
f 67/67/69 75/75/77 74/74/76
f 75/75/77 67/67/69 69/69/71
f 69/69/71 76/76/78 75/75/77
f 71/71/73 72/72/74 77/77/79
f 72/72/74 78/78/80 77/77/79
f 78/78/80 72/72/74 73/73/75
f 73/73/75 79/79/81 78/78/80
f 79/79/81 73/73/75 74/74/76
f 74/74/76 80/80/82 79/79/81
f 80/80/82 74/74/76 75/75/77
f 75/75/77 81/81/83 80/80/82
```

V / T / N

Note: The OBJ file format uses ***1-based*** indexing for faces!

Drawing an OBJ Object

23

```
MyBuffer  MyObjBuffer;                  // global

. . .

MyObjBuffer = VkOsuLoadObjFile( "filename.obj" );      // initializes and fills the buffer with
                                                       // triangles defined in GPU memory with an array of struct vertex
```

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

```
VkPipelineInputAssemblyStateCreateInfo      vpiasci;
    vpiasci.sType = VK_STRUCTURE_TYPE_PIPELINE_INPUT_ASSEMBLY_STATE_CREATE_INFO;
    vpiasci.pNext = nullptr;
    vpiasci.flags = 0;
    vpiasci.topology = VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST;
```

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

```
VkBuffer        objBuffer[1] = { MyObjBuffer.buffer };
VkDeviceSize offsets[1]    = { 0 };
vkCmdBindVertexBuffers( CommandBuffers[nextImageIndex], 0, 1, objBuffer, offsets );

const uint32_t  firstInstance = 0;
const uint32_t  firstVertex = 0;
const uint32_t  instanceCount = 1;
const uint32_t  vertexCount = MyObjBuffer.size / sizeof( struct vertex );

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