1

Drawing

Oregon State University
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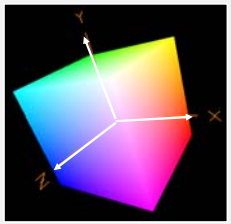

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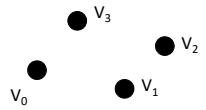
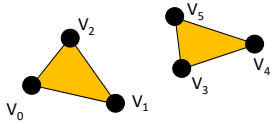
Vulkan Topologies

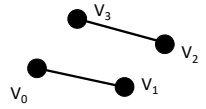
VK_PRIMITIVE_TOPOLOGY_POINT_LIST



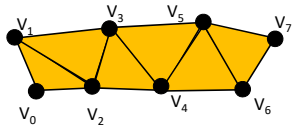
VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST



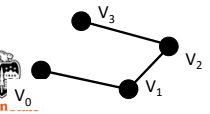
VK_PRIMITIVE_TOPOLOGY_LINE_LIST



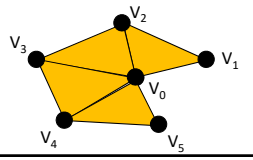
VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP



VK_PRIMITIVE_TOPOLOGY_LINE_STRIP



VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN



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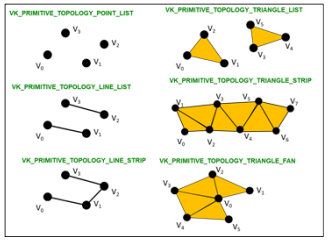
Vulkan Topologies




```
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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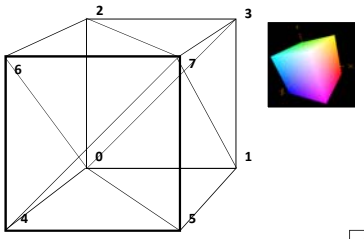
A Colored Cube Example




```
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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Triangles Represented as an Array of Structures

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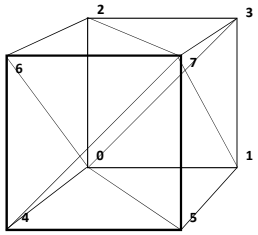
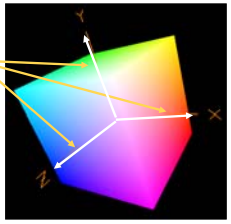
From the file **SampleVertexData.cpp**:

```
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. }
	},
```



Modeled in right-handed coordinates

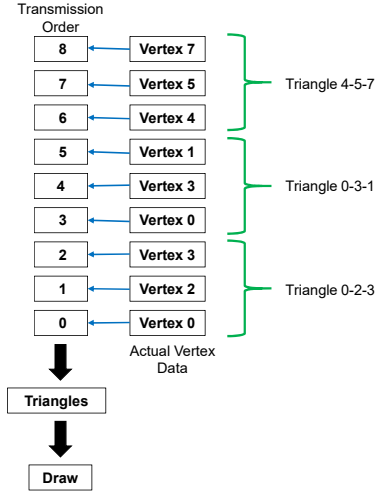


Non-indexed Buffer Drawing

6

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. }
	},
```



Filling the Vertex Buffer

7

```
MyBuffer	MyVertexDataBuffer;


Init05MyVertexDataBuffer(  sizeof(VertexData), &MyVertexDataBuffer );
Fill05DataBuffer( MyVertexDataBuffer,		(void *) VertexData );


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


A Reminder 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;
```

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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
```


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Telling the Pipeline about its Input

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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.

```
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 about its Input

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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.

```
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 pGraphicsPipeline );
```


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Telling the Command Buffer what Vertices to Draw

13

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;

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

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

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

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Drawing with an Indexed Buffer

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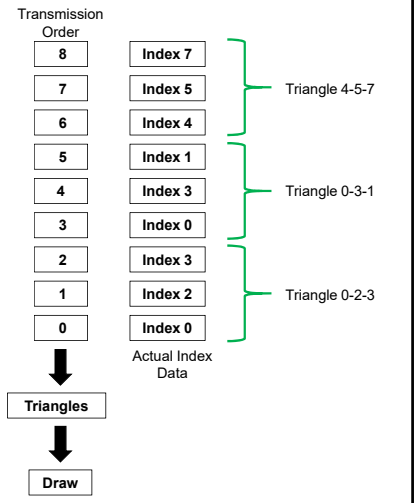
```
struct vertex JustVertexData[ ] =
{
        // vertex #0:
        {
                { -1., -1., -1. },
                {  0.,  0., -1. },
                {  0.,  0.,  0. },
                {  1., 0. }
        },

        // 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,
};
```



Drawing with an Indexed 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);
```

Remember that integer-indexed buffers are just BLOBs too.

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Drawing with an Indexed 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), &MyJustVertexDataBuffer );
Fill05DataBuffer( MyJustVertexDataBuffer,              (void *) JustVertexData );

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

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Drawing with an Indexed 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;

#ifdef VERTEX_BUFFER
      vkCmdDraw( CommandBuffers[nextImageIndex], vertexCount, instanceCount, firstVertex,
firstInstance );
#endif

#ifdef INDEX_BUFFER
vkCmdDrawIndexed( CommandBuffers[nextImageIndex], indexCount, instanceCount, firstIndex,
vertexOffset, firstInstance );
#endif
```

Note that there is no vertex-count! It is up to you to not exceed the number of vertices with your index numbers!

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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;
```

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)

19

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

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

Compare this with:

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

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Sometimes the Same Point Needs Multiple Attributes

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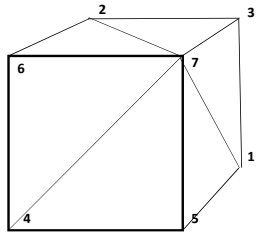

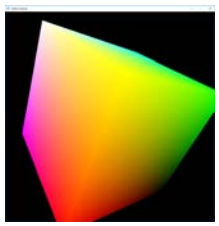

Sometimes a point that is common to multiple faces has the same attributes, no matter what face it is in. Sometimes it doesn't.

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

Thus, when using index-ed 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

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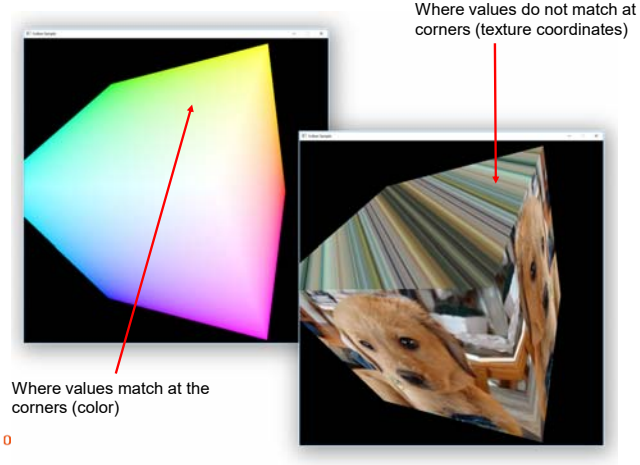

0

Computer Graphics

mjb – September 17, 2018

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!

mjb – September 17, 2018