



Vertex Buffers



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Oregon State
University
Computer Graphics

What is a Vertex Buffer?

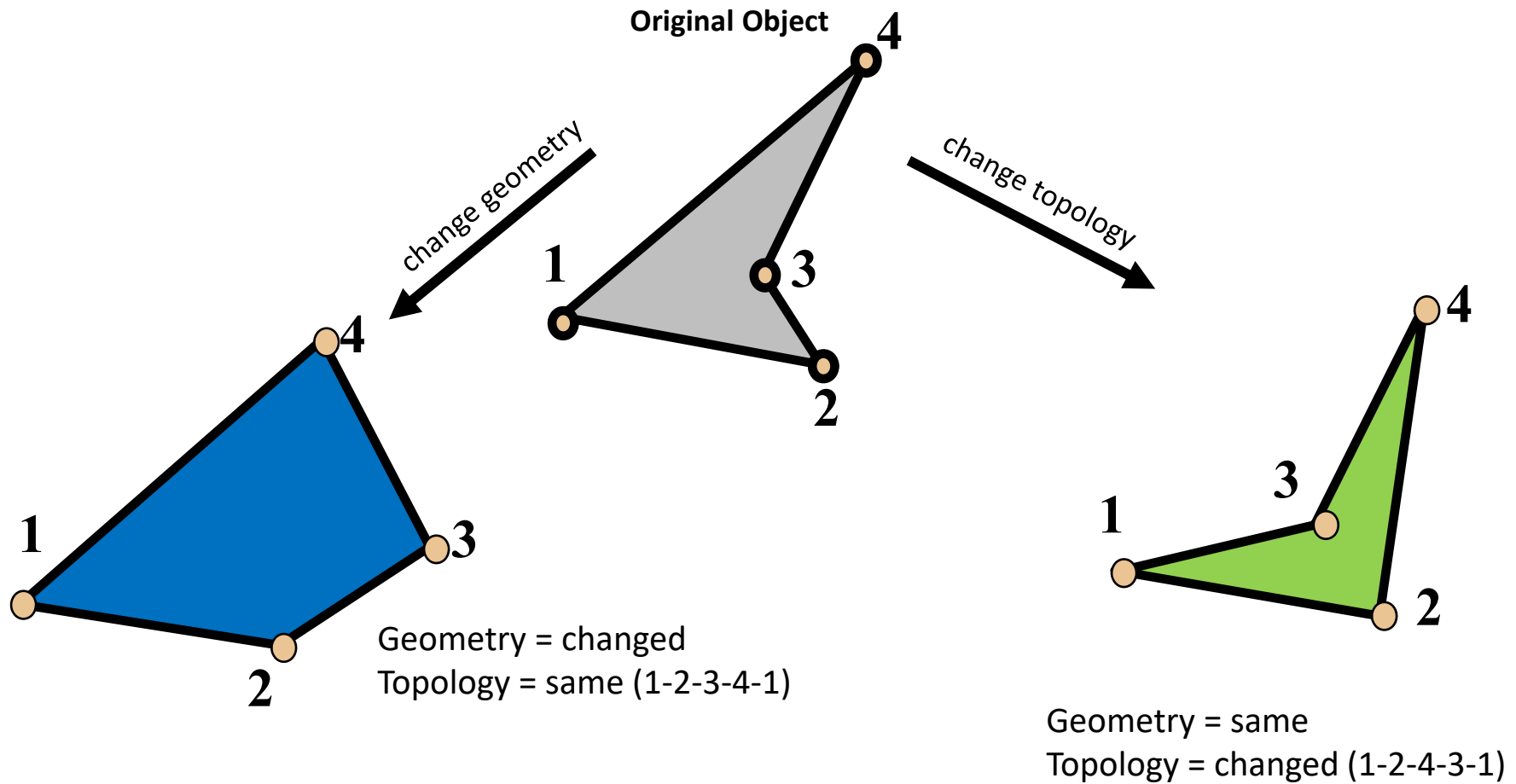
Vertex Buffers are how you draw things in Vulkan. They are very much like Vertex Buffer Objects in OpenGL, but more detail is exposed to you (a lot more...).

But, the good news is that Vertex Buffers are really just ordinary Data Buffers, so some of the functions will look familiar to you.

First, a quick review of computer graphics geometry . . .



Geometry vs. Topology



Geometry:

Where things are (e.g., coordinates)

Topology:

How things are connected

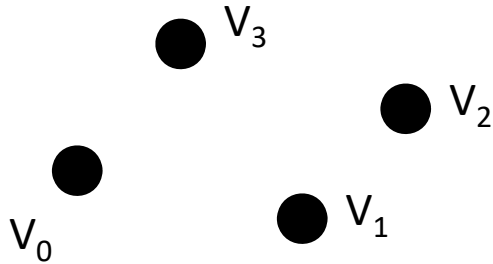
Vulkan Topologies

```
typedef enum VkPrimitiveTopology
{
    VK_PRIMITIVE_TOPOLOGY_POINT_LIST = 0,
    VK_PRIMITIVE_TOPOLOGY_LINE_LIST = 1,
    VK_PRIMITIVE_TOPOLOGY_LINE_STRIP = 2,
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST = 3,
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP = 4,
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN = 5,
    VK_PRIMITIVE_TOPOLOGY_LINE_LIST_WITH_ADJACENCY = 6,
    VK_PRIMITIVE_TOPOLOGY_LINE_STRIP_WITH_ADJACENCY = 7,
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST_WITH_ADJACENCY = 8,
    VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP_WITH_ADJACENCY = 9,
    VK_PRIMITIVE_TOPOLOGY_PATCH_LIST = 10,
} VkPrimitiveTopology;
```

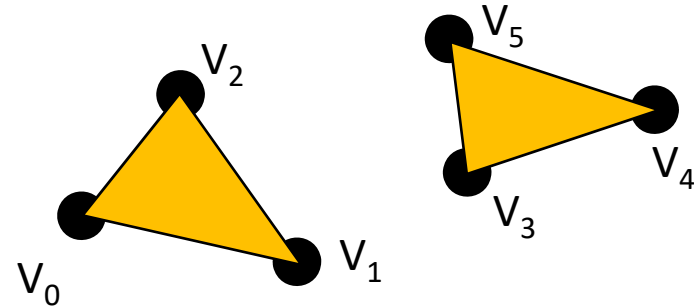


Vulkan Topologies – Some OpenGL Topologies are Missing

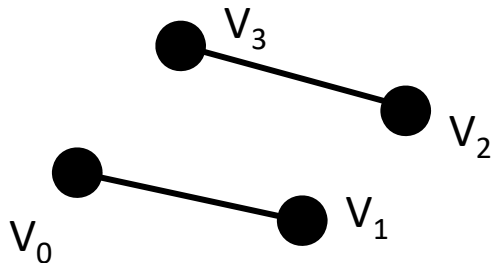
VK_PRIMITIVE_TOPOLOGY_POINT_LIST



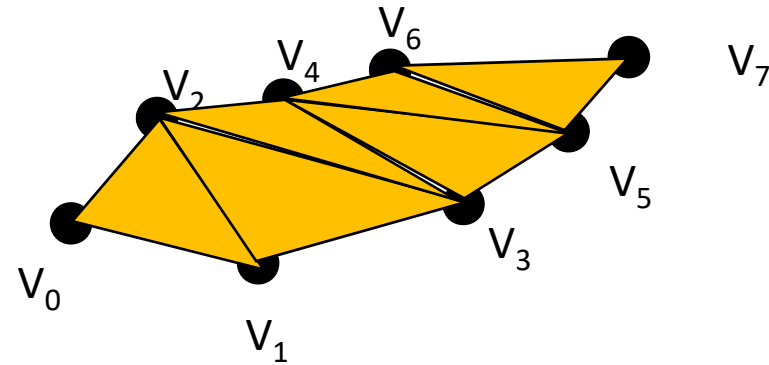
VK_PRIMITIVE_TOPOLOGY_TRIANGLE_LIST



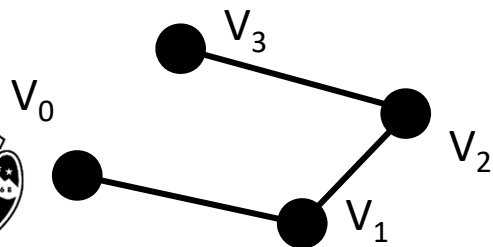
VK_PRIMITIVE_TOPOLOGY_LINE_LIST



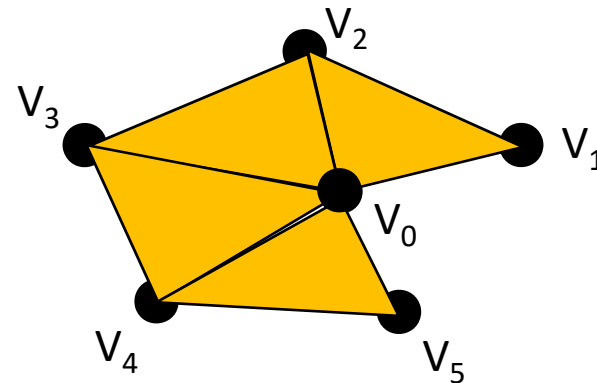
VK_PRIMITIVE_TOPOLOGY_TRIANGLE_STRIP



VK_PRIMITIVE_TOPOLOGY_LINE_STRIP



VK_PRIMITIVE_TOPOLOGY_TRIANGLE_FAN



OpenGL Topologies – Polygon Requirements

Polygons must be:

- **Convex** and
- **Planar**



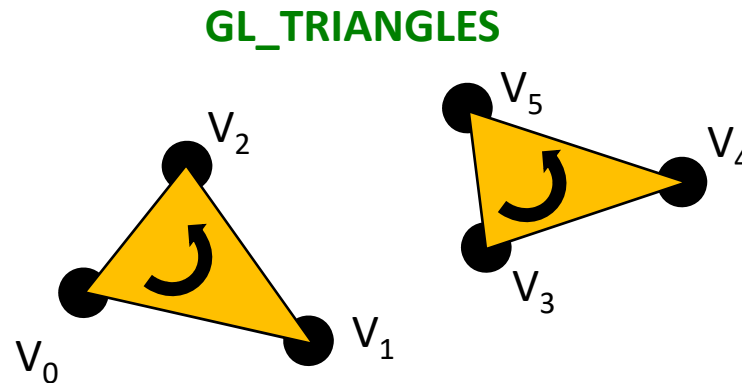
Vulkan Topologies – Requirements and Orientation

Polygons must be:

- **Convex** and
- **Planar**

Polygons are traditionally:

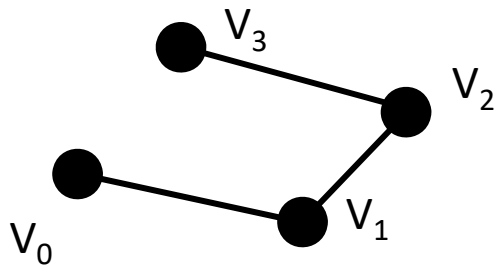
- **CCW** when viewed from outside the solid object



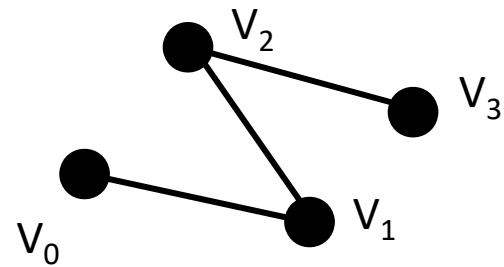
It's not absolutely necessary, but there are possible optimizations if you are **consistent**

OpenGL Topologies – Vertex Order Matters

VK_LINE_STRIP



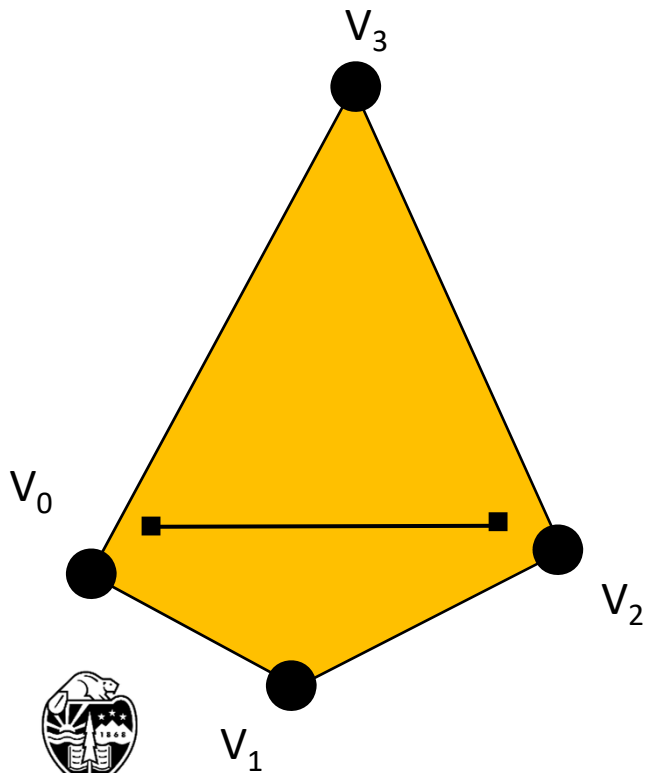
VK_LINE_STRIP



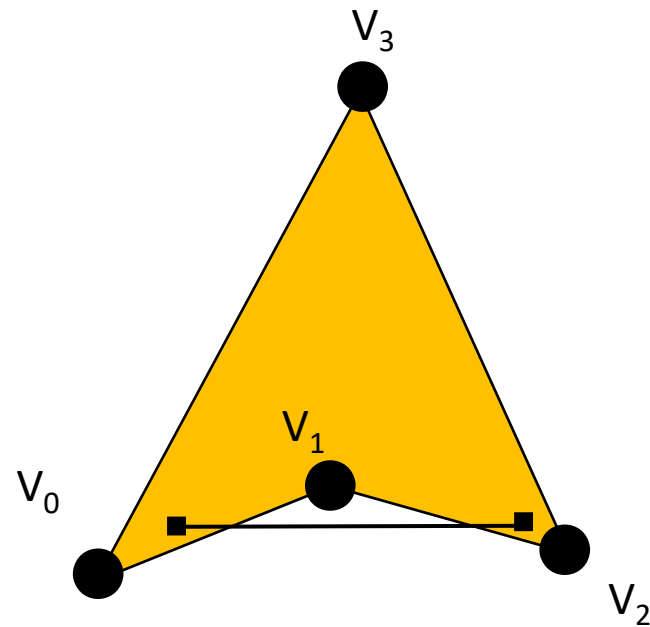
What does “Convex Polygon” Mean?

We can go all mathematical here, but let's go visual instead. In a convex polygon, a line between **any** two points inside the polygon never leaves the inside of the polygon.

Convex



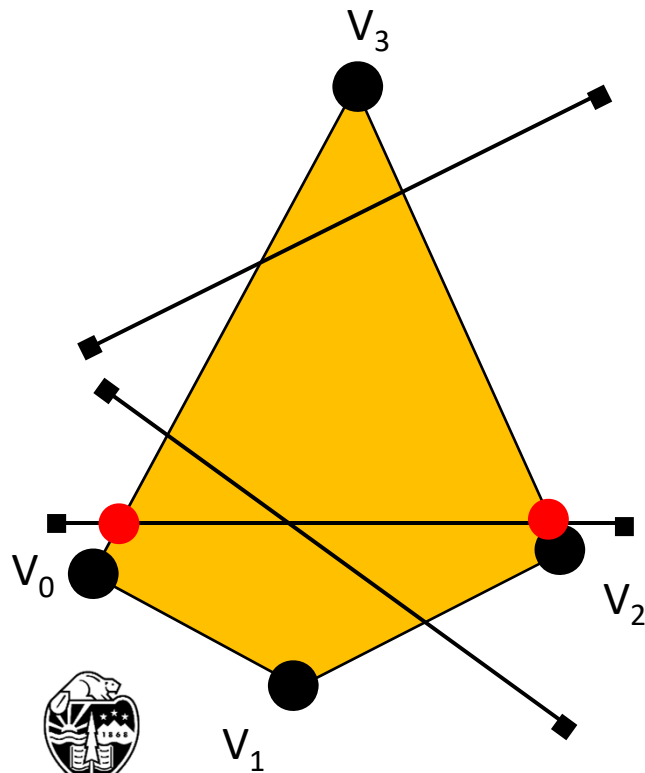
Not Convex



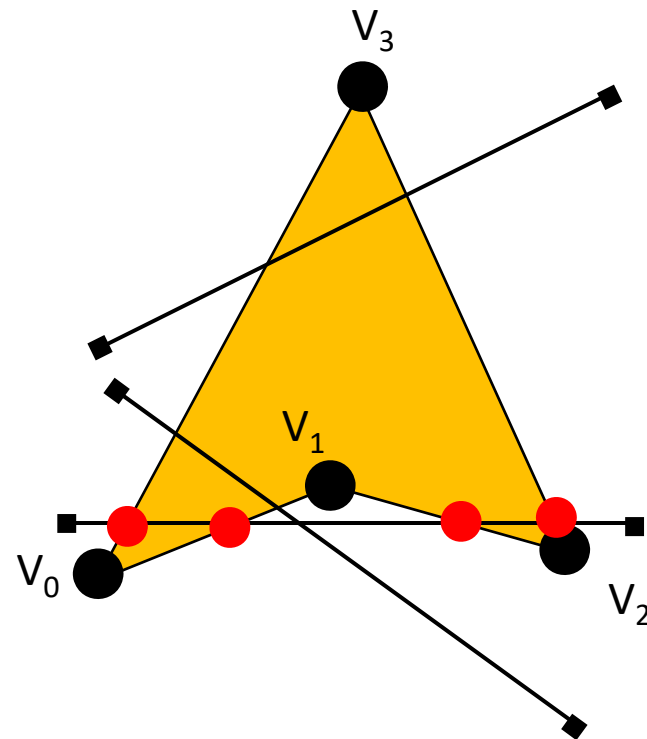
Why is there a Requirement for Polygons to be Convex?

Graphics polygon-filling hardware can be highly optimized if you know that, no matter what direction you fill the polygon in, there will be two and only two intersections between the scanline and the polygon's edges

Convex



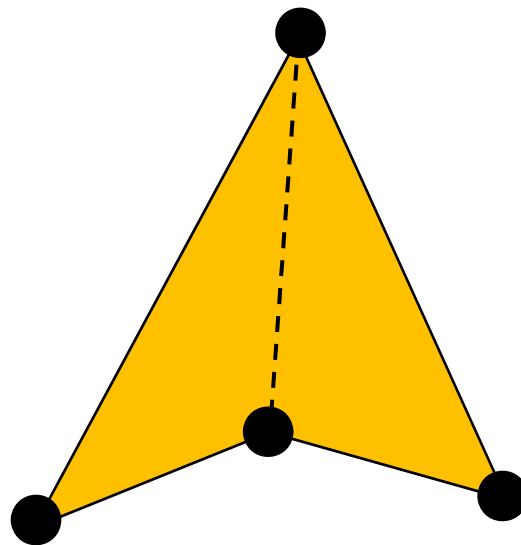
Not Convex



What if you need to display Polygons that are not Convex?

There is an open source library to break a non-convex polygon into convex polygons. It is called *Polypartition*, and is found here:

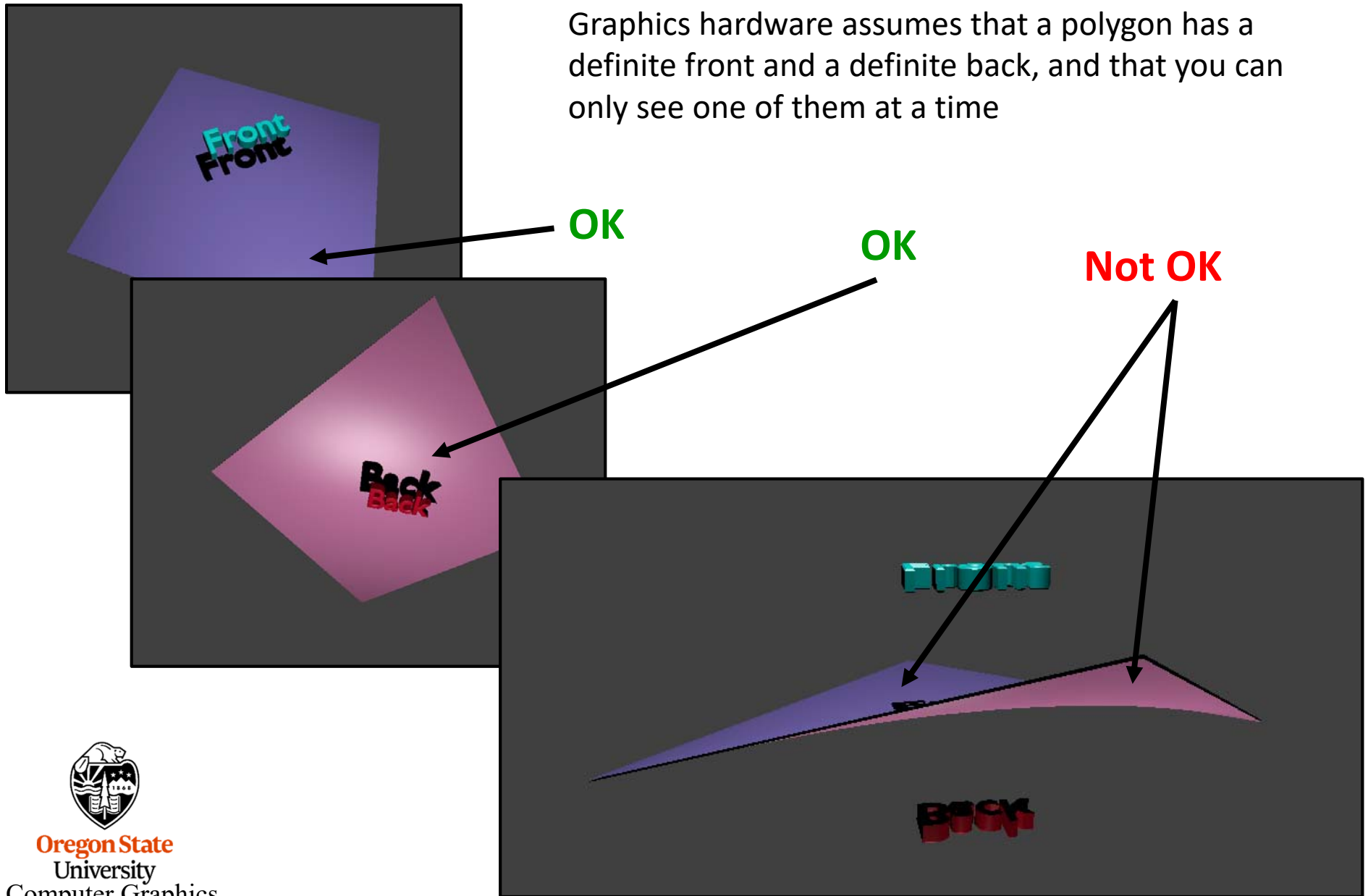
<https://github.com/ivanfratric/polypartition>



If you ever need to do this, contact me. I have working code ...

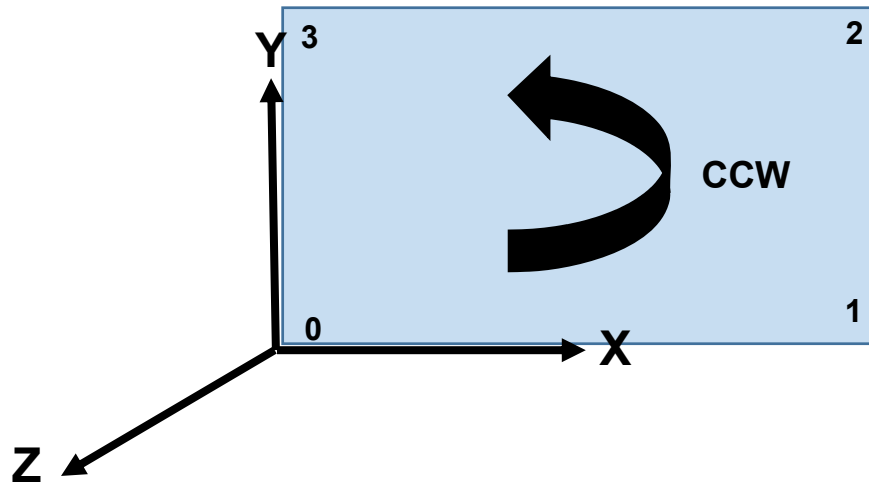
Why is there a Requirement for Polygons to be Planar?

Graphics hardware assumes that a polygon has a definite front and a definite back, and that you can only see one of them at a time

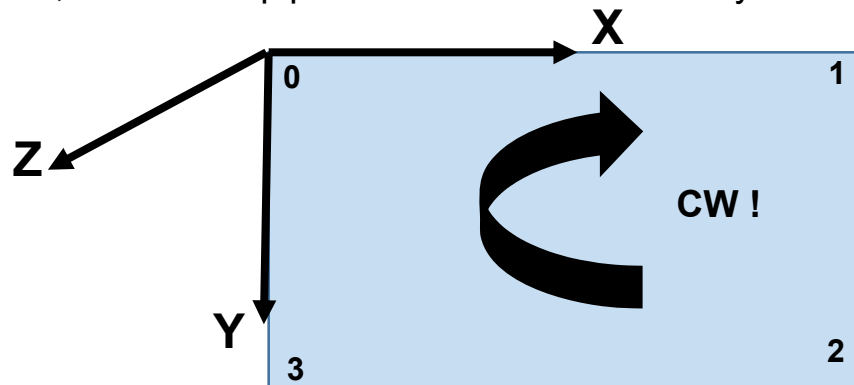


Vertex Orientation Issues

Thanks to OpenGL, we are all used to drawing in a right-handed coordinate system.



Internally, however, the Vulkan pipeline uses a left-handed system:

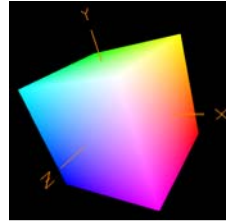
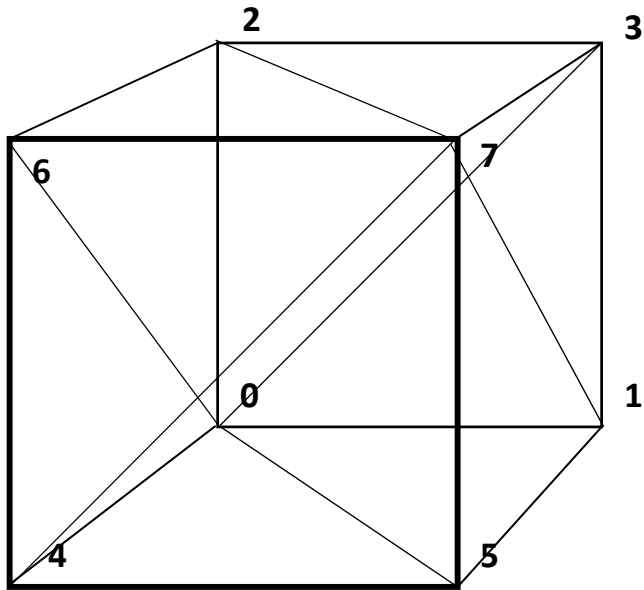


The best way to handle this is to continue to draw in a RH coordinate system and then fix it up in the projection matrix, like this:

```
ProjectionMatrix[1][1] *= -1.;
```

This is like saying “Y’ = -Y”.

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 },
};
```



Triangles in an Array of Structures

From the file SampleVertexData.cpp:

```

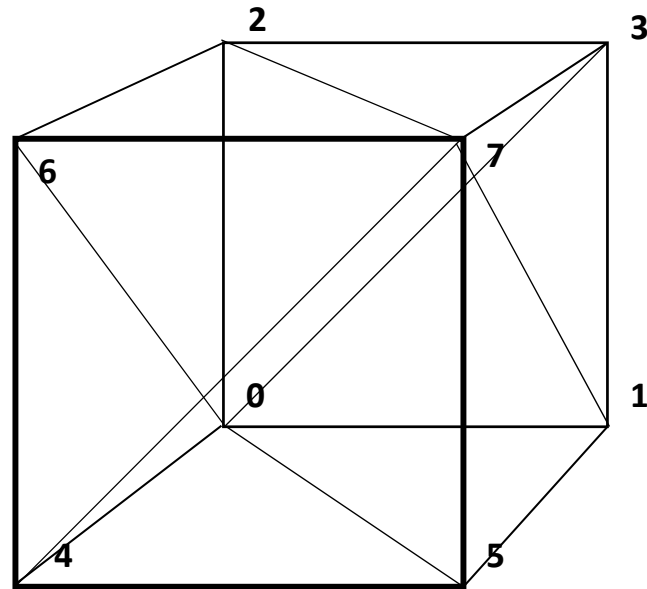
struct vertex
{
    glm::vec3    position;
    glm::vec3    normal;
    glm::vec3    color;
    glm::vec2    texCoord;
};

struct vertex VertexData[ ] =
{
    // triangle 0-2-3:
    // vertex #0:
    {
        { -1., -1., -1. },
        { 0., 0., -1. },
        { 0., 0., 0. },
        { 1., 0. }
    },

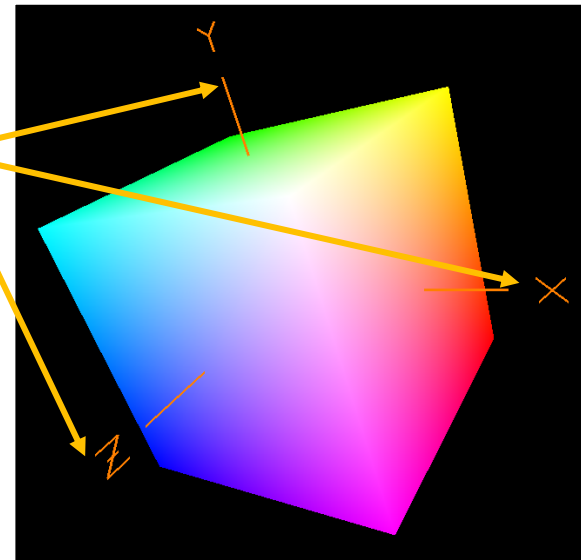
    // vertex #2:
    {
        { -1., 1., -1. },
        { 0., 0., -1. },
        { 0., 1., 0. },
        { 1., 1. }
    },

    // vertex #3:
    {
        { 1., 1., -1. },
        { 0., 0., -1. },
        { 1., 1., 0. },
        { 0., 1. }
    },
};

```

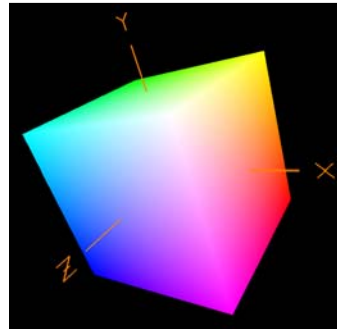
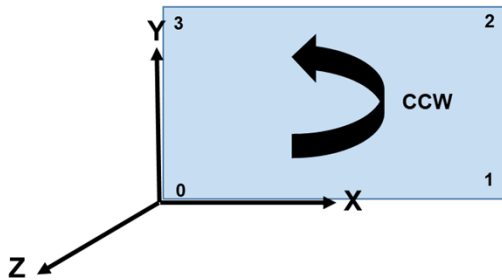


Modeled in
right-handed
coordinates



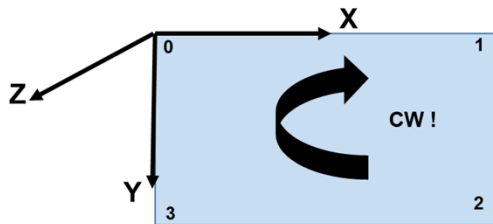
Vertex Orientation Issues

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This object was modeled such that triangles that face the viewer will look like their vertices are oriented CCW (this is detected by looking at vertex orientation at the start of the rasterization).

Because this 3D object is closed, Vulkan can save rendering time by not even bothering with triangles whose vertices look like they are oriented CW. This is called **backface culling**.



Vulkan's change in coordinate systems can mess up the backface culling.

So I recommend, at least at first, that you do no culling.

```
VkPipelineRasterizationStateCreateInfo
```

```
vprsci;
```

```
...
```

```
vprsci.cullMode = VK_CULL_MODE_NONE
```

```
vprsci.frontFace = VK_FRONT_FACE_COUNTER_CLOCKWISE;
```




```
MyBuffer      MyVertexDataBuffer;

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

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



What Init05DataBuffer Does

```
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 );

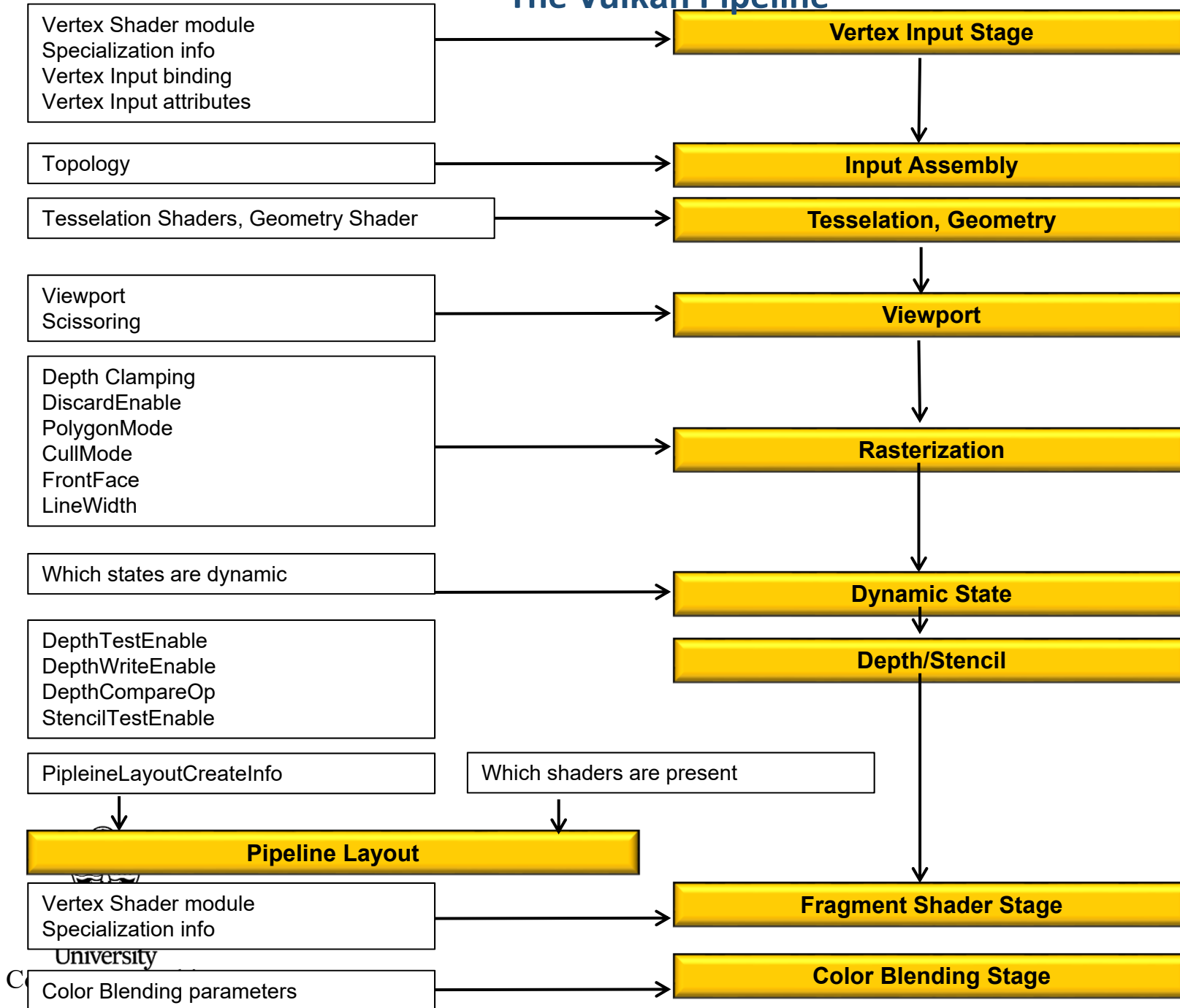
    VkMemoryRequirements          vmr;
    vkGetBufferMemoryRequirements( LogicalDevice, IN pMyBuffer->buffer, OUT &vmr );      // fills vmr

    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;
}
```

The Vulkan Pipeline



Telling the Pipeline about its Input

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

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

vvibd

```
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;
```



Telling the Pipeline about its Input

```

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

```

vviad has 4 elements
because we have 4 per-
vertex pipeline inputs

Telling the Pipeline about its Input

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;;
```



Telling the Pipeline about its Input

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 );
```

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, buffers, 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 );
```

Better to do this than to
hard-code a number

