Vulkan

Compute Shaders

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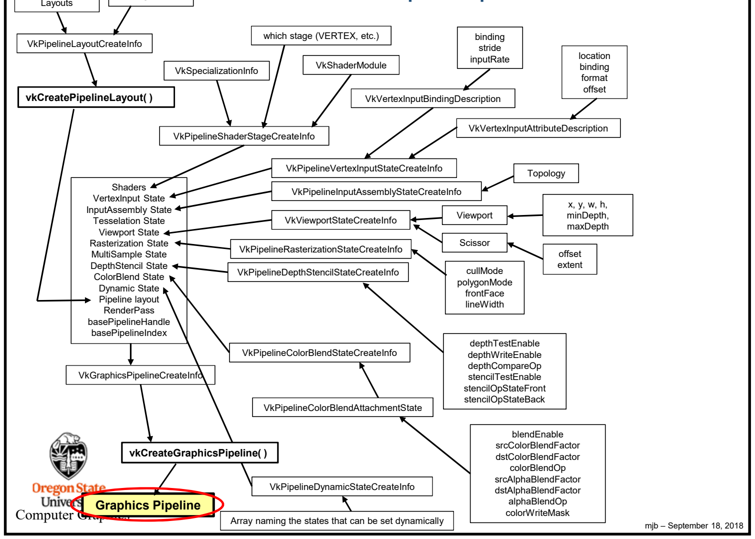
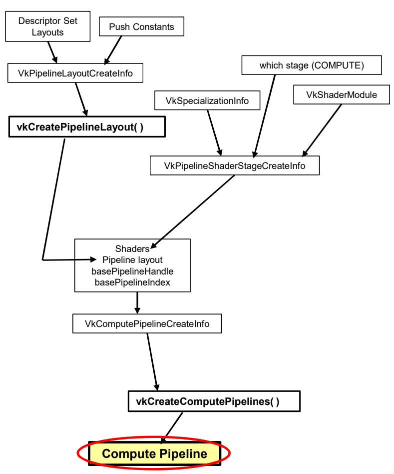
Remember the Graphics Pipeline?



Here is how you create a much-simpler Compute Pipeline



Start with Creating the Data Buffers

This is a Particle System application, so we need Positions, Velocities, and (possibly) Colors

1

```
layout( std140, set = 0, binding = 0 ) buffer Pos
{
    vec4 Positions[ ];      // array of structures
};
```

2

```
layout( std140, set = 0, binding = 1 ) buffer Vel
{
    vec4 Velocities[ ];     // array of structures
};
```

3

```
layout( std140, set = 0, binding = 2 ) buffer Col
{
    vec4 Colors[ ];         // array of structures
};
```

You can use the empty brackets, but only on the *last* element of the buffer. The actual dimension will be determined for you when OpenGL examines the size of this buffer's data store.

A Reminder about Data Buffers

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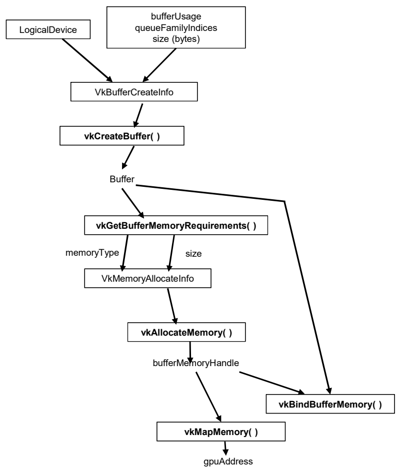

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Creating a Shader Storage Buffer

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```
VkBufferCreateInfo  vbci;
        vbci.sType = VK_STRUCTURE_TYPE_BUFFER_CREATE_INFO;
        vbci.pNext = nullptr;
        vbci.flags = 0;
        vbci.size = << buffer size in bytes >>
        vbci.usage = VK_USAGE_STORAGE_BUFFER_BIT;
        vbci.sharingMode = VK_SHARING_MODE_EXCLUSIVE;
        vbci.queueFamilyIndexCount = 0;
        vbci.pQueueFamilyIndices = (const iont32_t) nullptr;

VkBuffer  Buffer;

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

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

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```
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 );
```

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Fill the Data Buffer

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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;
}
```

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And, since we have Data Buffers, we will need Descriptor Sets to Create the Pipeline Layout

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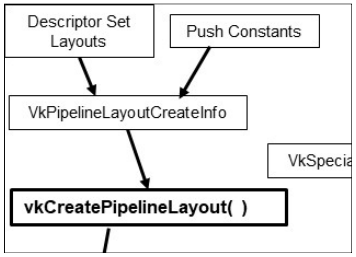

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Create the Compute Pipeline Layout

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```
VkDescriptorSetLayoutBinding          ComputeSet[1];
        ComputeSet[0].binding          = 0;
        ComputeSet[0].descriptorType     = VK_DESCRIPTOR_TYPE_STORAGE_BUFFER;
        ComputeSet[0].descriptorCount    = 3;
        ComputeSet[0].stageFlags         = VK_SHADER_STAGE_COMPUTE_BIT;
        ComputeSet[0].pImmutableSamplers = (VkSampler *)nullptr;

VkDescriptorSetLayoutCreateInfo            vdslc;
        vdslc0.sType = VK_STRUCTURE_TYPE_DESCRIPTOR_SET_LAYOUT_CREATE_INFO;
        vdslc0.pNext = nullptr;
        vdslc0.flags = 0;
        vdslc0.bindingCount = 1;
        vdslc0.pBindings = &ComputeSet[0];

result = vkCreateDescriptorSetLayout( LogicalDevice, &vdslc, PALLOCATOR, OUT &ComputeSetLayout );

VkPipelineLayoutCreateInfo                  vplci;
        vplci.sType = VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO;
        vplci.pNext = nullptr;
        vplci.flags = 0;
        vplci.setLayoutCount = 1;
        vplci.pSetLayouts = ComputeSetLayout;
        vplci.pushConstantRangeCount = 0;
        vplci.pPushConstantRanges = (VkPushConstantRange *)nullptr;

result = vkCreatePipelineLayout( LogicalDevice, IN &vplci, PALLOCATOR, OUT &ComputePipelineLayout );
```

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Create the Compute Pipeline

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```
VkPipelineShaderStageCreateInfo             vpssci;
        vpssci.sType = VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_CREATE_INFO;
        vpssci.pNext = nullptr;
        vpssci.flags = 0;
        vpssci.stage = VK_SHADER_STAGE_COMPUTE_BIT;
        vpssci.module = computeShader;
        vpssci.pName = "main";
        vpssci.pSpecializationInfo = (VkSpecializationInfo *)nullptr;


VkComputePipelineCreateInfo                 vcpci[1];
        vcpci[0].sType = VK_STRUCTURE_TYPE_COMPUTE_PIPELINE_CREATE_INFO;
        vcpci[0].pNext = nullptr;
        vcpci[0].flags = 0;
        vcpci[0].stage = vpssci;
        vcpci[0].layout = ComputePipelineLayout;
        vcpci[0].basePipelineHandle = VK_NULL_HANDLE;
        vcpci[0].basePipelineIndex = 0;

result = vkCreateComputePipelines( LogicalDevice, VK_NULL_HANDLE, 1, &vcpci[0], PALLOCATOR, &ComputePipeline );
```

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The Particle System Compute Shader -- Setup

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```
#version 430
#extension GL_ARB_compute_shader :  enable

layout( std140, set = 0, binding = 0 )  buffer  Pos
{
        vec4  Positions[  ];              // array of structures
};

layout( std140, set = 0, binding = 1 )  buffer  Vel
{
        vec4  Velocities[  ];             // array of structures
};

layout( std140, set = 0, binding = 2 )  buffer  Col
 {
        vec4  Colors[  ];          // array of structures
};

layout( local_size_x = 64,  local_size_y = 1, local_size_z = 1 )   in;
```

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The Particle System Compute Shader – The Physics

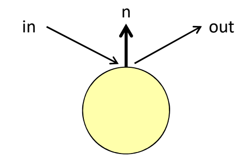

```
#define POINT          vec3
#define VELOCITY       vec3
#define VECTOR         vec3
#define SPHERE         vec4

const VECTOR G      = VECTOR( 0., -9.8, 0. );
const float    DT   = 0.1;

const SPHERE Sphere = vec4( -100., -800., 0.,  600. );          // x, y, z, r

      . . .

uint  gid = gl_GlobalInvocationID.x;              // the .y and .z are both 1 in this case

POIINT      p  = Positions[  gid  ].xyz;
VELOCITY  v  = Velocities[  gid  ].xyz;

POINT       pp = p + v*DT + .5*DT*DT*G;
VELOCITY  vp = v + G*DT;

Positions[  gid  ].xyz  = pp;
Velocities[  gid  ].xyz = vp;
```

$$p' = p + v \cdot t + \frac{1}{2} G \cdot t^2$$

$$v' = v + G \cdot t$$

The Particle System Compute Shader – How About Introducing a Bounce?


```
VELOCITY
Bounce( VELOCITY vin, VECTOR n )
{
      VELOCITY vout = reflect( vin, n );
      return vout;
}

VELOCITY
BounceSphere( POINT p, VELOCITY v, SPHERE s )
{
      VECTOR  n = normalize( p - s.xyz );
      return Bounce( v, n );
}

bool
IsInsideSphere( POINT p, SPHERE s )
{
      float r = length( p - s.xyz );
      return  (  r < s.w  );
}
```



The Particle System Compute Shader – How About Introducing a Bounce?


```
uint  gid = gl_GlobalInvocationID.x;              // the .y and .z are both 1 in this case

POINT       p  = Positions[  gid  ].xyz;
VELOCITY v  = Velocities[  gid  ].xyz;

POINT        pp = p + v*DT + .5*DT*DT*G;
VELOCITY  vp = v + G*DT;

if(  IsInsideSphere( pp, Sphere )  )
{
      vp = BounceSphere( p, v, S );
      pp = p + vp*DT + .5*DT*DT*G;
}

Positions[   gid  ].xyz = pp;
Velocities[  gid  ].xyz = vp;
```

$$p' = p + v \cdot t + \frac{1}{2} G \cdot t^2$$

$$v' = v + G \cdot t$$

Graphics Trick Alert: Making the bounce happen from the surface of the sphere is time-consuming. Instead, bounce from the previous position in space. If DT is small enough (and it is), nobody will ever know…

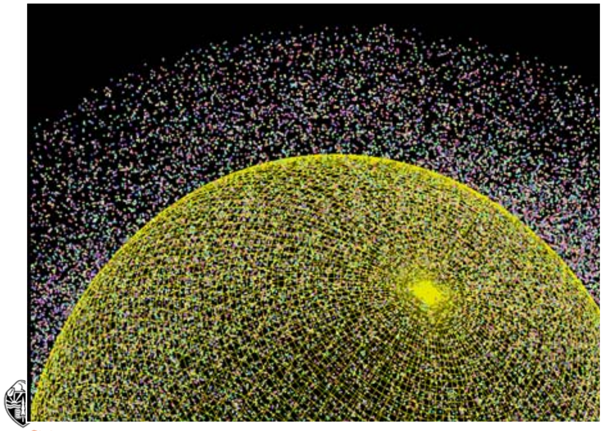
Dispatching the Compute Shader from the Command Buffer


```
const int NUM+PARTICLES      = 1000000;
const int NUM_WORK_ITEMS     = 64;
const int NUM_WORK_GROUPS = NUM_PARTICLES / NUM_WORK_ITEMS;

      . . .

vkCmdBindPipeline( CommandBuffer, VK_PIPELINE_BIND_POINT_COMPUTE, ComputePipeline );

vkCmdDispatch( CommandBuffer, NUM_WORK_GROUPS, 1,  1 );
```

Or,

```
vkCmdBindPipeline( CommandBuffer, VK_PIPELINE_BIND_POINT_COMPUTE, ComputePipeline );

vkCmdDispatchIndirect( CommandBuffer, Buffer, 0 );                // offset
```

The Bouncing Particle System Compute Shader – What Does It Look Like?



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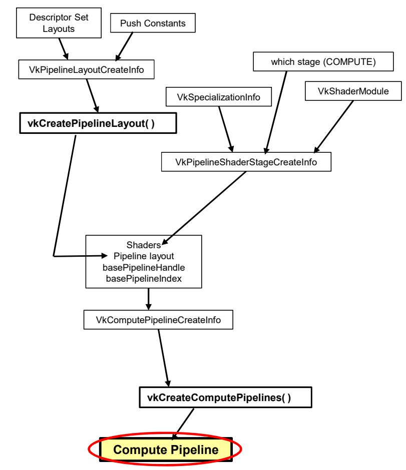
Remember the Compute Pipeline?



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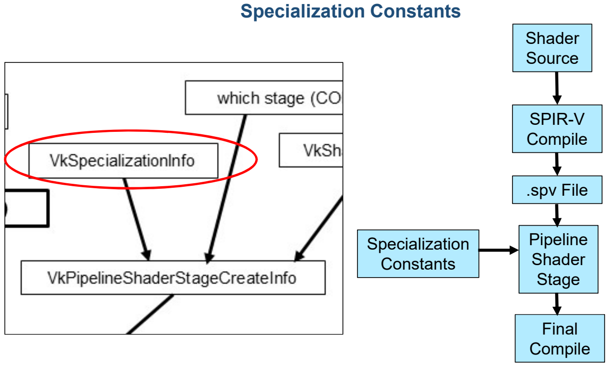
Specialization Constants



- A Specialization Constant is a way of injecting an integer or Boolean constant into an .spv-compiled version of a shader right before the final compilation.
- That final compilation happens when you call **vkCreateComputePipelines( )**
- Without Specialization Constants, you would have to commit to a final value before the SPIR-V compile was done, which could have been a long time ago

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Specialization Constants

In the compute shader

```
layout( constant_id = 0 )  const int numXworkItems = 32;

layout( local_size_x = numXworkItems,  local_size_y = 1, local_size_z = 1 )   in;
```

In the C/C++ program:

```
VkSpecializationMapEntry        vsme[1];        // one array element for each
                                                //      Specialization Constant
        vsme.constantID = 0;
        vsme.offset = 0;                // # bytes into the Specialization Constant
                                        //      array this one item is
        vsme.size = sizeof(int);        // size of just this Specialization Constant

int numXworkItems = 64;

VkSpecializationInfo        vsi;
        vsi.mapEntryCount = 1;
        vsi.pMapEntries = &vsme[0];
        vsi.dataSize = sizeof(int);             // size of all the Specialization Constants together
        vsi.pData = &numXworkItems;             // array of all the Specialization Constants
```

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Linking the Specialization Constants into the Compute Pipeline

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```
VkSpecializationMapEntry vsme[1];
        vsme.constantID = 0;
        vsme.offset = 0;
        vsme.size = sizeof(int);

int numXworkItems = 64;

VkSpecializationInfo        vsi;
        vsi.mapEntryCount = 1;
        vsi.pMapEntries = &vsme[0];
        vsi.dataSize = sizeof(int);
        vsi.pData = &numXworkItems;

VkPipelineShaderStageCreateInfo         vpssci;
            vpssci.sType = VK_STRUCTURE_TYPE_PIPELINE_SHADER_STAGE_CREATE_INFO;
            vpssci.pNext = nullptr;
            vpssci.flags = 0;
            vpssci.stage = VK_SHADER_STAGE_COMPUTE_BIT;
            vpssci.module = computeShader;
            vpssci.pName = "main";
            vpssci.pSpecializationInfo = &vsi;

VkComputePipelineCreateInfo             vcpci[1];
            vcpci[0].sType = VK_STRUCTURE_TYPE_COMPUTE_PIPELINE_CREATE_INFO;
            vcpci[0].pNext = nullptr;
            vcpci[0].flags = 0;
            vcpci[0].stage = vpssci;
            vcpci[0].layout = ComputePipelineLayout;
            vcpci[0].basePipelineHandle = VK_NULL_HANDLE;
            vcpci[0].basePipelineIndex = 0;

result = vkCreateComputePipelines( LogicalDevice, VK_NULL_HANDLE, 1, &vcpci[0], PALLOCATOR, &ComputePipeline );
```

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