Vulkan.

Push Constants

Oregon State University
Mike Bailey
mjb@cs.oregonstate.edu

Push Constants

In an effort to expand flexibility and retain efficiency, Vulkan provides something called **Push Constants**. Like the name implies, these let you "push" constant values out to the shaders. These are typically used for small, frequently-updated data values. This is good, since Vulkan, at times, makes it cumbersome to send changes to the graphics.

By "small", Vulkan specifies that these must be at least 128 bytes in size, although they can be larger. For example, the maximum size is 256 bytes on the NVIDIA 1080ti. (You can query this limit by looking at the **maxPushConstantSize** parameter in the **VkPhysicalDeviceLimits** structure.) Unlike uniform buffers and vertex buffers, these are not backed by memory. They are actually part of the Vulkan pipeline.

Push Constants

On the shader side, if, for example, you are sending a 4x4 matrix, the use of push constants in the shader looks like this:

```
layout( push_constant ) uniform matrix
{
        mat4 modelMatrix;
} Matrix;
```

On the application side, push constants are pushed at the shaders by binding them to the Vulkan Command Buffer:

```
vkCmdPushConstants( CommandBuffer, PipelineLayout, stageFlags,
                    offset, size, pValues );
```

where:
stageFlags are or'ed bits of VK_PIPELINE_STAGE_VERTEX_SHADER_BIT, VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT, etc.

size is in bytes

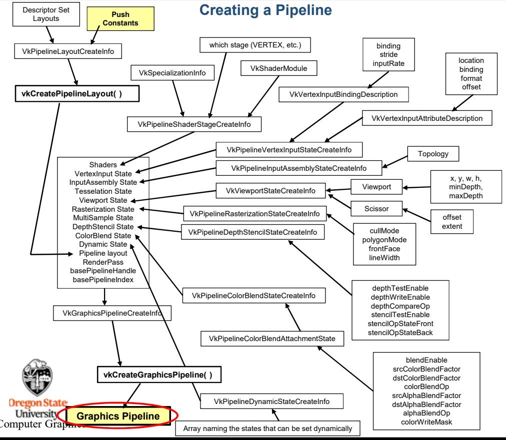
pValues is a void * pointer to the data, which in this 4x4 matrix example, would be of type **glm::mat4**.

Setting up the Push Constants for the Pipeline Structure

Prior to that, however, the pipeline layout needs to be told about the Push Constants:

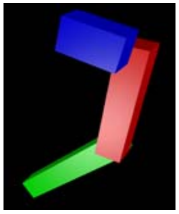
```
VkPushConstantRange                     vpcr[1];
      vpcr[0].stageFlags =
                 VK_PIPELINE_STAGE_VERTEX_SHADER_BIT
               | VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT;
      vpcr[0].offset = 0;
      vpcr[0].size = sizeof( glm::mat4 );

VkPipelineLayoutCreateInfo              vplci;
      vplci.sType = VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO;
      vplci.pNext = nullptr;
      vplci.flags = 0;
      vplci.setLayoutCount = 4;
      vplci.pSetLayouts = DescriptorSetLayouts;
      vplci.pushConstantRangeCount = 1;
      vplci.pPushConstantRanges = vpcr;

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

Creating a Pipeline



An Robotic Example using Push Constants

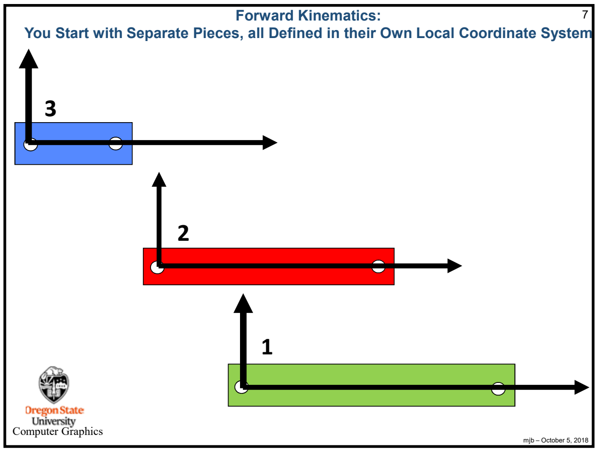
A robotic animation (i.e., a hierarchical transformation system)



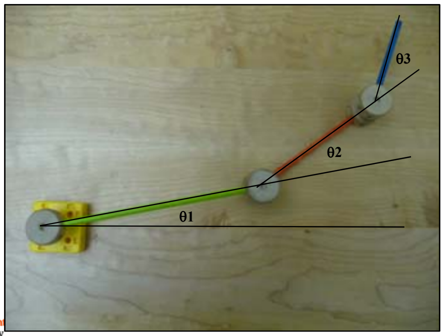
Where each arm is represented by:

```
struct arm
{
        glm::mat4    armMatrix;
        glm::vec3    armColor;
        float           armScale;     // scale factor in x
};

struct armArm1;
struct armArm2;
struct armArm3;
```

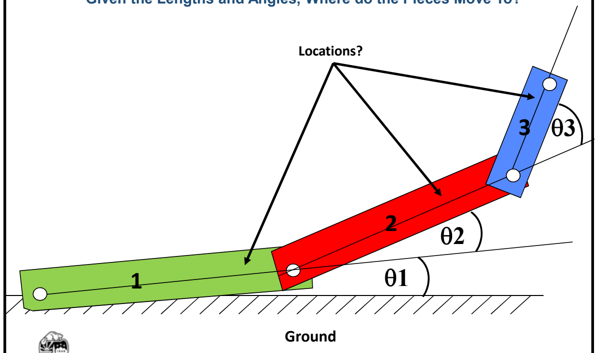
Forward Kinematics: You Start with Separate Pieces, all Defined in their Own Local Coordinate System



Forward Kinematics: Hook the Pieces Together, Change Parameters, and Things Move (All Young Children Understand This)



Forward Kinematics: Given the Lengths and Angles, Where do the Pieces Move To?



Positioning Part #1 With Respect to Ground

1. Rotate by Θ1
2. Translate by $T_{1/G}$

Write it

$$\left[M_{1/G}\right]=\left[T_{1/G}\right]*\left[R_{\theta 1}\right]$$

Say it

Why Do We Say it Right-to-Left?

Write it

$$[M_{1/G}] = [T_{1/G}] * [R_{\theta 1}]$$

Say it

We adopt the convention that the coordinates are multiplied on the right side of the matrix:

$$\begin{Bmatrix} x' \\ y' \\ z' \\ 1 \end{Bmatrix} = \begin{bmatrix} A & B & C & D \\ E & F & G & H \\ I & J & K & L \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix}$$

$$\begin{Bmatrix} x' \\ y' \\ z' \\ 1 \end{Bmatrix} = \left[M_{1/G}\right] \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix} = \left[T_{1/G}\right] * \left[R_{\theta 1}\right] * \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix}$$

So the right-most transformation in the sequence multiplies the (x,y,z,1) *first* and the left-most transformation multiples it *last*

Positioning Part #2 With Respect to Ground

1. Rotate by Θ2
2. Translate the length of part 1
3. Rotate by Θ 1
4. Translate by $T_{1/G}$

Write it

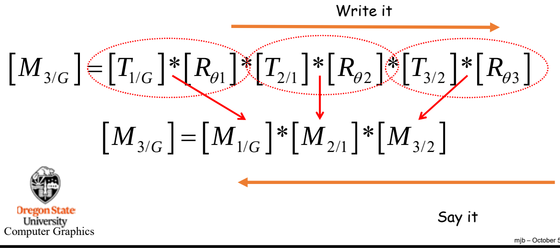
$$\left[M_{2/G}\right]=\left[T_{1/G}\right]*\left[R_{\theta 1}\right]*\left[T_{2/1}\right]*\left[R_{\theta 2}\right]$$

$$\left[M_{2/G}\right]=\left[M_{1/G}\right]*\left[M_{2/1}\right]$$

Say it

Positioning Part #3 With Respect to Ground

1. Rotate by Θ3
2. Translate the length of part 2
3. Rotate by Θ2
4. Translate the length of part 1
5. Rotate by Θ1
6. Translate by $T_{1/G}$



Write it

$$[M_{3/G}] = [T_{1/G}]*[R_{\theta1}]*[T_{2/1}]*[R_{\theta2}]*[T_{3/2}]*[R_{\theta3}]$$

$$[M_{3/G}] = [M_{1/G}]*[M_{2/1}]*[M_{3/2}]$$

Say it

In the *Reset* Function

```
struct arm              Arm1;
struct arm              Arm2;
struct arm              Arm3;

. . .

       Arm1.armMatrix = glm::mat4( );
       Arm1.armColor  = glm::vec3( 0.f, 1.f, 0.f );
       Arm1.armScale  = 6.f;

       Arm2.armMatrix = glm::mat4( );
       Arm2.armColor  = glm::vec3( 1.f, 0.f, 0.f );
       Arm2.armScale  = 4.f;

       Arm3.armMatrix = glm::mat4( );
       Arm3.armColor  = glm::vec3( 0.f, 0.f, 1.f );
       Arm3.armScale  = 2.f;
```

The constructor **glm::mat4( )** produces an identity matrix. The actual transformation matrices will be set in *UpdateScene( ).*

Setup the Push Constant for the Pipeline Structure

```
VkPushConstantRange                    vpcr[1];
             vpcr[0].stageFlags =
                          VK_PIPELINE_STAGE_VERTEX_SHADER_BIT
                        | VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT;
             vpcr[0].offset = 0;
             vpcr[0].size = sizeof( struct arm );

VkPipelineLayoutCreateInfo                    vplci;
             vplci.sType =
                       VK_STRUCTURE_TYPE_PIPELINE_LAYOUT_CREATE_INFO;
             vplci.pNext = nullptr;
             vplci.flags = 0;
             vplci.setLayoutCount = 4;
             vplci.pSetLayouts = DescriptorSetLayouts;
             vplci.pushConstantRangeCount = 1;
             vplci.pPushConstantRanges = vpcr;

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

In the *UpdateScene* Functiom

```
float rot1 = (float)Time;
float rot2 = 2.f * rot1;
float rot3 = 2.f * rot2;

glm::vec3 zaxis  =  glm::vec3(0., 0., 1.);

glm::mat4 m1g = glm::mat4();
m1g = glm::translate(m1g, glm::vec3(0., 0., 0.));
m1g = glm::rotate(m1g, rot1, zaxis);

glm::mat4 m21 = glm::mat4();
m21 = glm::translate(m21, glm::vec3(2.*Arm1.armScale, 0., 0.));
m21 = glm::rotate(m21, rot2, zaxis);
m21 = glm::translate(m21, glm::vec3(0., 0., 2.));

glm::mat4 m32 = glm::mat4();
m32 = glm::translate(m32, glm::vec3(2.*Arm2.armScale, 0., 0.));
m32 = glm::rotate(m32, rot3, zaxis);
m32 = glm::translate(m32, glm::vec3(0., 0., 2.));

Arm1.armMatrix = m1g;                   // m1g
Arm2.armMatrix = m1g * m21;             // m2g
Arm3.armMatrix = m1g * m21 * m32;       // m3g
```

In the *RenderScene* Function Without Pipeline Barriers

```
VkBuffer buffers[1]   =  { MyVertexDataBuffer.buffer };
vkCmdBindVertexBuffers( CommandBuffers[nextImageIndex], 0, 1, buffers, offsets );
```

1

```
vkCmdPushConstants( CommandBuffers[nextImageIndex], GraphicsPipelineLayout,
                VK_SHADER_STAGE_ALL, 0, sizeof(struct arm),  (void *)&Arm1 );
vkCmdDraw( CommandBuffers[nextImageIndex], vertexCount, instanceCount, firstVertex, firstInstance );
```

2

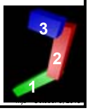
```
vkCmdPushConstants( CommandBuffers[nextImageIndex], GraphicsPipelineLayout,
                VK_SHADER_STAGE_ALL, 0, sizeof(struct arm),  (void *)&Arm2 );
vkCmdDraw( CommandBuffers[nextImageIndex], vertexCount, instanceCount, firstVertex, firstInstance );
```

3

```
vkCmdPushConstants( CommandBuffers[nextImageIndex], GraphicsPipelineLayout,
                VK_SHADER_STAGE_ALL, 0, sizeof(struct arm),  (void *)&Arm3 );
vkCmdDraw( CommandBuffers[nextImageIndex], vertexCount, instanceCount, firstVertex, firstInstance );
```

But, the problem is that
1. The vkCmdDraws must not start until the vkCmdPushConstants are done, and
2. The vkCmdPushConstants must not start until the vkCmdDraws are done

This is the type of problem that Pipeline Barriers were meant to solve



Setting Up Global Memory Pipeline Barriers

```
VkMemoryBarrier vmb;
        vmb.sType = VK_STRUCTURE_TYPE_MEMORY_BARRIER;
        vmb.pNext = nullptr;
        vmb.srcAccessMask =
        vmb.dstAccessMask =
```

```
vkCmdPipelineBarrier( commandBuffer,
        srcStageMask,
        dstStageMask,
        VK_DEPENDENCY_BY_REGION_BIT,
        1,      IN &vmb,
        0,      nullptr,
        0,      nullptr );
```

Setting Up Buffer Memory Pipeline Barriers

```
VkBufferMemoryBarrier vbmb;
        vbmb.sType = VK_STRUCTURE_TYPE_BUFFER_MEMORY_BARRIER;
        vbmb.pNext = nullptr;
        vbmb.srcAccessMask =
        vbmb.dstAccessMask =
        vbmb.srcQueueFamilyIndex =
        vbmb.dstQueueFamilyIndex =
        vbmb.buffer =
        vbmb.offset =
        vbmb.size =
```

```
vkCmdPipelineBarrier( commandBuffer,
        srcStageMask,
        dstStageMask,
        VK_DEPENDENCY_BY_REGION_BIT,
        0,      NULL,
        1,      IN &vbmb,
        0,      nullptr );
```

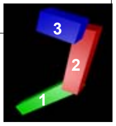
Setting Up Image Memory Pipeline Barriers

```
VkImageMemoryBarrier vimb;
        vimb.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
        vimb.pNext = nullptr;
        vimb.srcAccessMask =
        vimb.dstAccessMask =
        vimb.oldLayout =
        vimb.newLayout =
        vimb.srcQueueFamilyIndex =
        vimb.dstQueueFamilyIndex =
        vimb.image =
        vimb.subResourceRange =
```

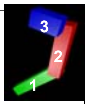
```
vkCmdPipelineBarrier( commandBuffer,
        srcStageMask,
        dstStageMask,
        VK_DEPENDENCY_BY_REGION_BIT,
        0,      NULL,
        0,      NULL,
        1,      IN &vimb );
```

In the *RenderScene* Function

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


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


vkCmdPushConstants( CommandBuffers[nextImageIndex], GraphicsPipelineLayout,
                VK_SHADER_STAGE_ALL, 0, sizeof(struct arm),  (void *)&Arm1  );


vkCmdPipelineBarrier(CommandBuffers[nextImageIndex], srcStageMask, dstStageMask,
VK_DEPENDENCY_BY_REGION_BIT, 1, IN vmb, 0,        nullptr, 0,    nullptr );


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


vkCmdPipelineBarrier(CommandBuffers[nextImageIndex], srcStageMask, dstStageMask,
VK_DEPENDENCY_BY_REGION_BIT, 1, IN vmb, 0,        nullptr, 0,    nullptr );
```



In the *RenderScene* Function



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

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

1

```
vkCmdPushConstants( CommandBuffers[nextImageIndex], GraphicsPipelineLayout,
                VK_SHADER_STAGE_ALL, 0, sizeof(struct arm),  (void *)&Arm1  );
vkCmdPipelineBarrier(CommandBuffers[nextImageIndex], srcStageMask, dstStageMask,
VK_DEPENDENCY_BY_REGION_BIT, 1, IN vmb, 0,        nullptr, 0,    nullptr );

vkCmdDraw( CommandBuffers[nextImageIndex], vertexCount, instanceCount, firstVertex, firstInstance );
vkCmdPipelineBarrier(CommandBuffers[nextImageIndex], srcStageMask, dstStageMask,
VK_DEPENDENCY_BY_REGION_BIT, 1, IN vmb, 0,        nullptr, 0,    nullptr );
```

2

```
vkCmdPushConstants( CommandBuffers[nextImageIndex], GraphicsPipelineLayout,
                VK_SHADER_STAGE_ALL, 0, sizeof(struct arm),  (void *)&Arm2  );
vkCmdPipelineBarrier(CommandBuffers[nextImageIndex], srcStageMask, dstStageMask,
VK_DEPENDENCY_BY_REGION_BIT, 1, IN vmb, 0,        nullptr, 0,    nullptr );

vkCmdDraw( CommandBuffers[nextImageIndex], vertexCount, instanceCount, firstVertex, firstInstance );
vkCmdPipelineBarrier(CommandBuffers[nextImageIndex], srcStageMask, dstStageMask,
VK_DEPENDENCY_BY_REGION_BIT, 1, IN vmb, 0,        nullptr, 0,    nullptr );
```

3

```
vkCmdPushConstants( CommandBuffers[nextImageIndex], GraphicsPipelineLayout,
                VK_SHADER_STAGE_ALL, 0, sizeof(struct arm),  (void *)&Arm3  );
vkCmdPipelineBarrier(CommandBuffers[nextImageIndex], srcStageMask, dstStageMask,
VK_DEPENDENCY_BY_REGION_BIT, 1, IN vmb, 0,        nullptr, 0,    nullptr );
vkCmdDraw( CommandBuffers[nextImageIndex], vertexCount, instanceCount, firstVertex, firstInstance );
```

In the Vertex Shader

```
layout( push_constant ) uniform arm
{
        mat4  armMatrix;
        vec3  armColor;
        float  armScale;          // scale factor in x
} RobotArm;

layout( location = 0 ) in vec3 aVertex;

        . . .

vec3 bVertex = aVertex;                          // arm coordinate system is [-1., 1.] in X
bVertex.x +=  1.;                                // now is [0., 2.]
bVertex.x  /=  2.;                               // now is [0., 1.]
bVertex.x *=  (RobotArm.armScale );              // now is [0., RobotArm.armScale]
bVertex = vec3(  RobotArm.armMatrix * vec4( bVertex, 1. )  );

        . . .

gl_Position = PVM * vec4( bVertex, 1. );         // Projection * Viewing * Modeling matrices
```