Web 进化论 – 2024年度大会

Vulkan synchronization for WebGPU

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May 28th, 2024

WebGPU

- Successor to WebGL
- API for accessing the GPU ... on the web!

Differences to WebGL

- No global state
- Command buffers
- Pipelines
- Bind groups
- Render/compute passes
- Compute shaders

WebGPU

vs

WebGL™

Differences to Vulkan

- Some features/extensions not available (yet)
  - VRS
  - Raytracing
  - Bindless
  - Geometry shaders
  - Etc.
- No explicit memory management
- No explicit synchronization

WebGPU

VS

Vulkan®

No explicit synchronization?

- So the browser is responsible
  - Rather, the WebGPU implementation in your browser
- In Chromium, that’s Dawn
  - https://dawn.googlesource.com/dawn
- Implements WebGPU on top of Vulkan
  - (Also DirectX 12, Metal and GLES)

Synchronization in Dawn

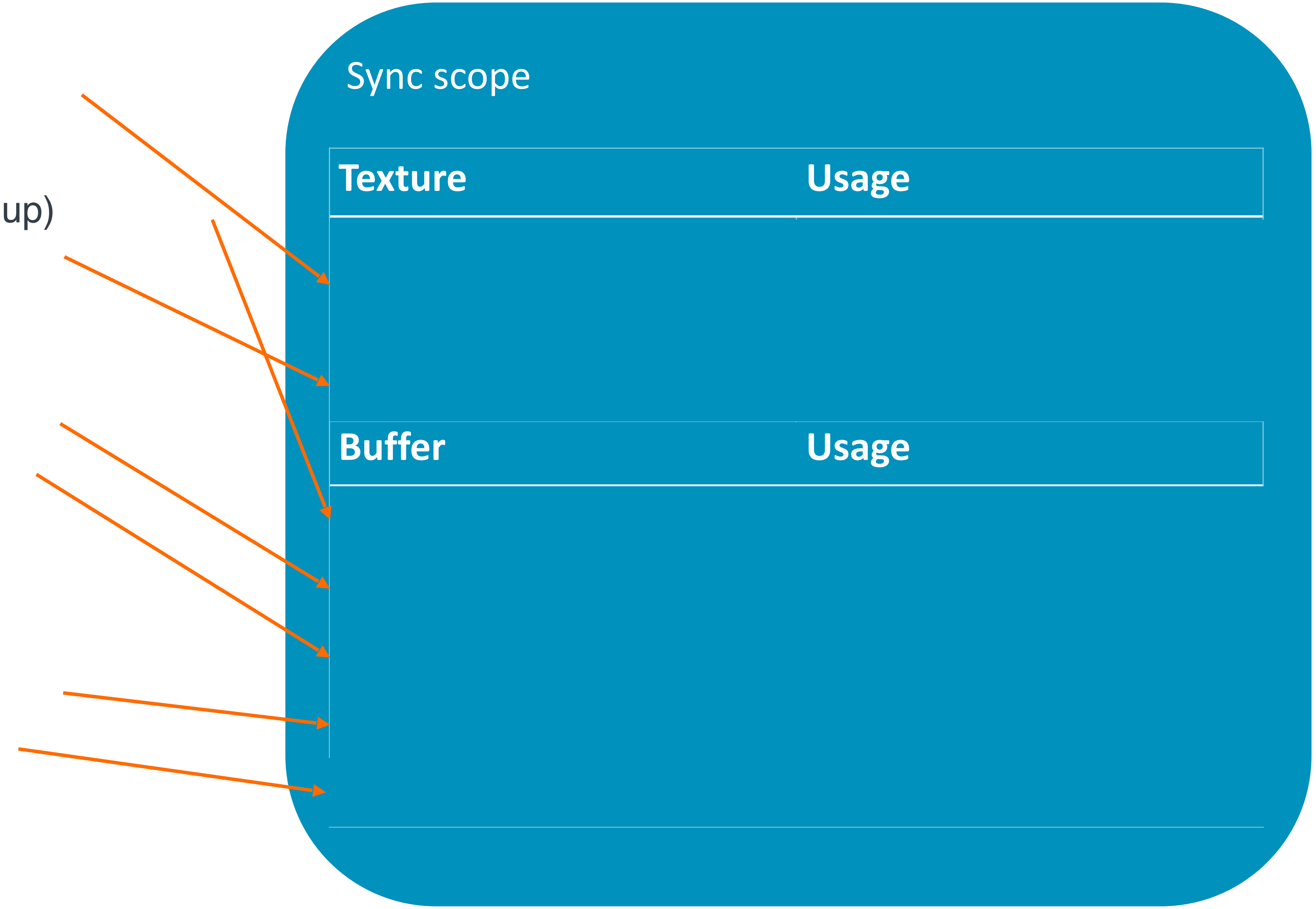
- User submits:
  - GPUCommandBuffer
  - Without synchronization
- We need:
  - VkCommandBuffer
  - With pipeline barriers

When recording GPUCommandEncoder

```
pass = cmd.beginRenderPass(mainPass)
pass.setPipeline(meshPipeline)
pass.setBindGroup(cameraMatricesBindGroup)
pass.setBindGroup(textureBindGroup)

// Draw table
pass.setVertexBuffer(tableVertices)
pass.setBindGroup(tableBindGroup)
pass.draw(123)

// Draw chair
pass.setVertexBuffer(chairVertices)
pass.setBindGroup(chairBindGroup)
pass.draw(234)
```



Sync scope

Texture	Usage

Buffer	Usage

When submitting GPUCommandBuffer

```
void CommandBuffer::BeginRenderPass
 (syncScope) {
        for (auto t : syncScope.textures) {
            t.texture->RecordPipelineBarrier(
                t.usage);
        }

        for (auto b : syncScope.buffers) {
            b.buffer->RecordPipelineBarrier(
                b.usage);
        }

    vkCmdBeginRenderPass(...);
}
```

Sync scope

Texture	**Usage**
Framebuffer	ColorAttachment
DepthBuffer	DepthAttachment
BurntWoodTexture	TextureBinding
Buffer	**Usage**
CameraMatrices	UniformBuffer
TableVertices	VertexBuffer
TableUniforms	UniformBuffer
ChairVertices	VertexBuffer
ChairUniforms	UniformBuffer

Recording a barrier

```
void Texture::RecordPipelineBarrier(
    TextureUsage usage)
{
    VkImageMemoryBarrier barrier = {};
    [...]
    barrier.accessMask = GetAccessMask(usage);
    barrier.imageLayout = GetImageLayout(usage);

    VkPipelineStageFlags stages =
        GetPipelineStage(usage);

    vkCmdPipelineBarrier(...);
}
```

Example

ColorAttachment

VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT

VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL

VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_B

Recording a barrier

```
[...]
barrier.srcAccessMask = GetAccessMask(mLastUsage);
barrier.oldImageLayout = GetImageLayout(mLastUsage);

VkPipelineStageFlags srcStage = GetPipelineStage(mLastUsage);

mLastUsage = usage;

[...]
```

Recording a barrier

- GetPipelineStage(usage)
  - The most common way to do Vulkan synchronization?
- Used in:
  - Dawn
  - Other open source WebGPU implementation
  - Vulkan applications
  - Commercial game engines
- Let’s hope there are no issues with it...

The issue with GetPipelineStage(usage)

```
void Texture::RecordPipelineBarrier(
    TextureUsage usage)
{
    VkImageMemoryBarrier barrier = {};
    [...]
    barrier.accessMask = GetAccessMask(usage);
    barrier.imageLayout = GetImageLayout(usage);

    VkPipelineStageFlags stage =
        GetPipelineStage(usage);

    vkCmdPipelineBarrier(...);
}
```

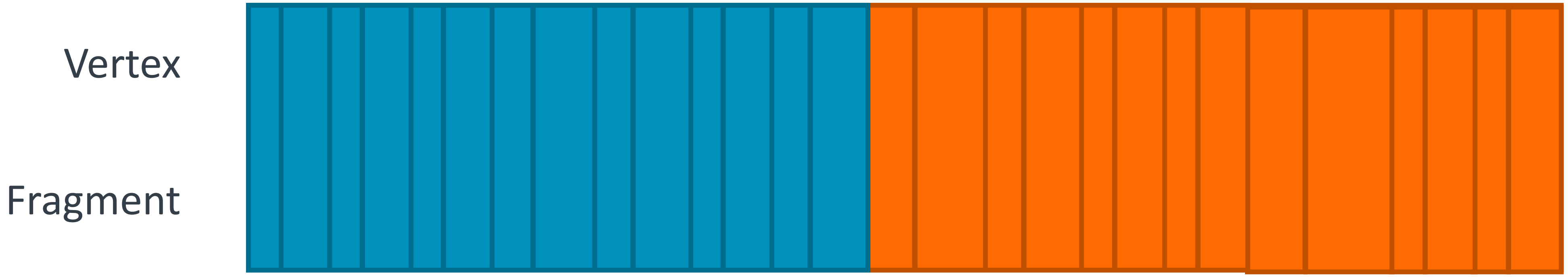
Example

TextureBinding

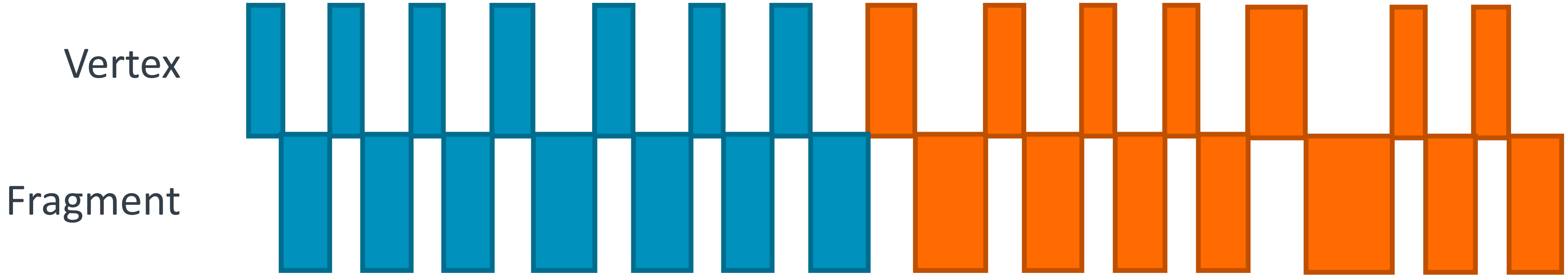
```
VK_ACCESS_SHADER_READ_BIT
VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL

VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT |
VK_PIPELINE_STAGE_VERTEX_SHADER_BIT |
VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT |
VK_PIPELINE_STAGE_GEOMETRY_SHADER_BIT |
VK_PIPELINE_STAGE_TESSELLATION_CONTROL_SHADER_BIT |
VK_PIPELINE_STAGE_TESSELLATION_EVALUATION_SHADER_BIT |
VK_PIPELINE_STAGE_TASK_SHADER_BIT_EXT |
VK_PIPELINE_STAGE_MESH_SHADER_BIT_EXT |
VK_PIPELINE_STAGE_RAY_TRACING_SHADER_BIT_KHR
```

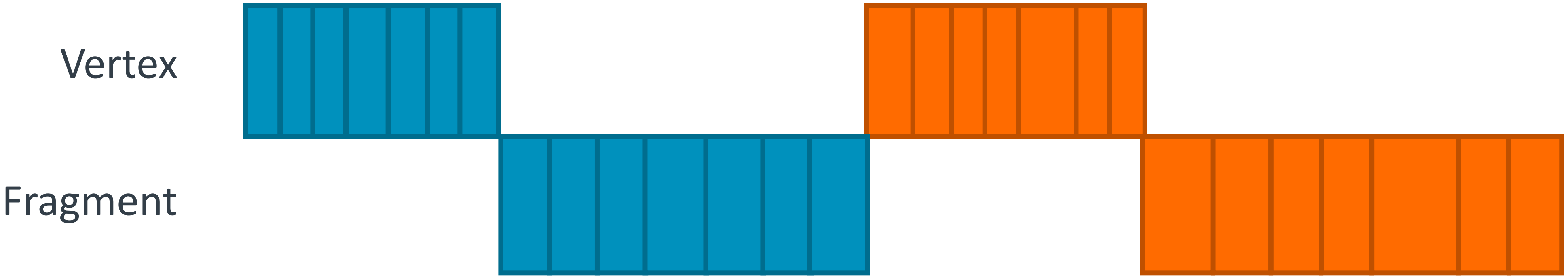
A simple frame



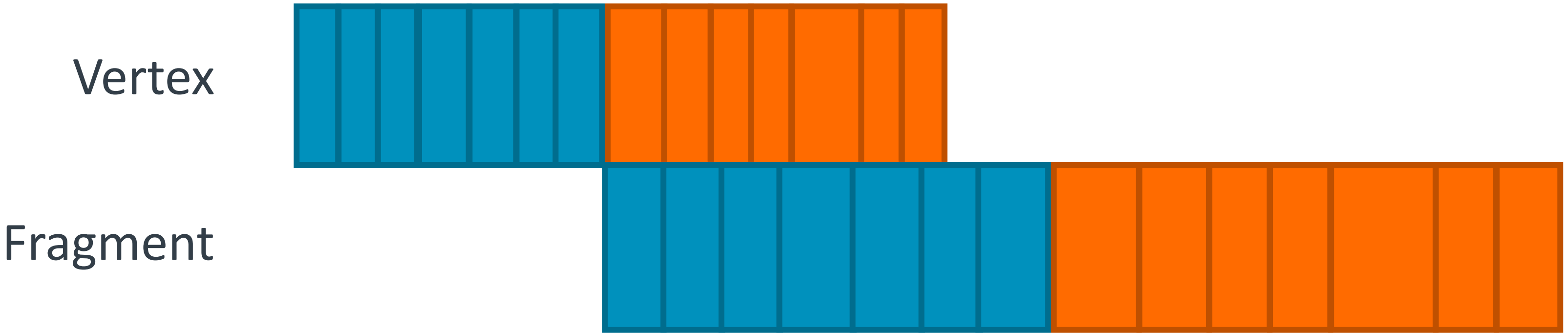
... on a tiled GPU



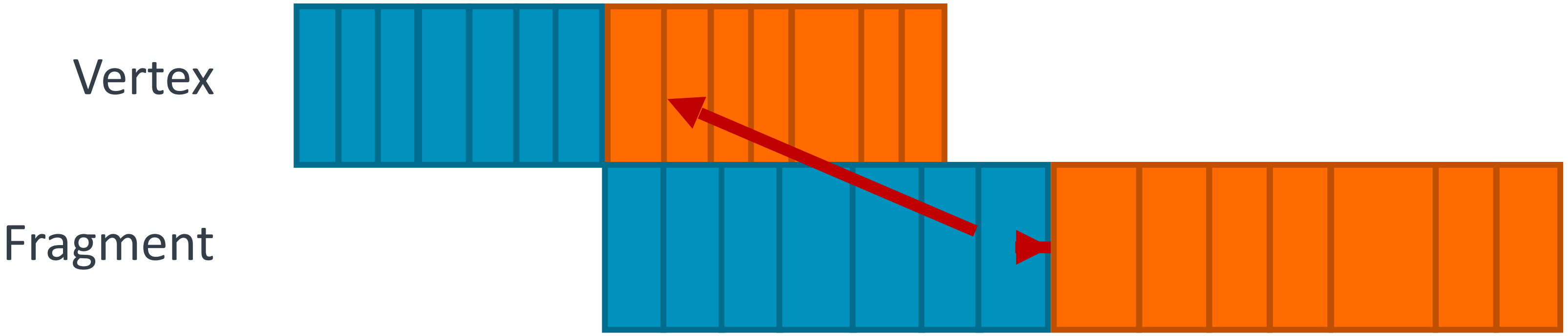
… on a tiled GPU

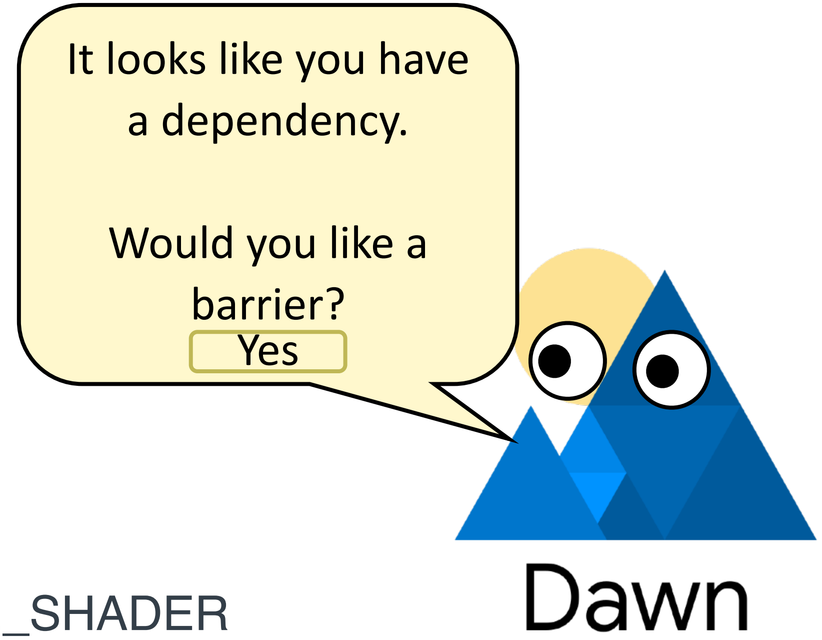


… on a tiled GPU



Hold it!



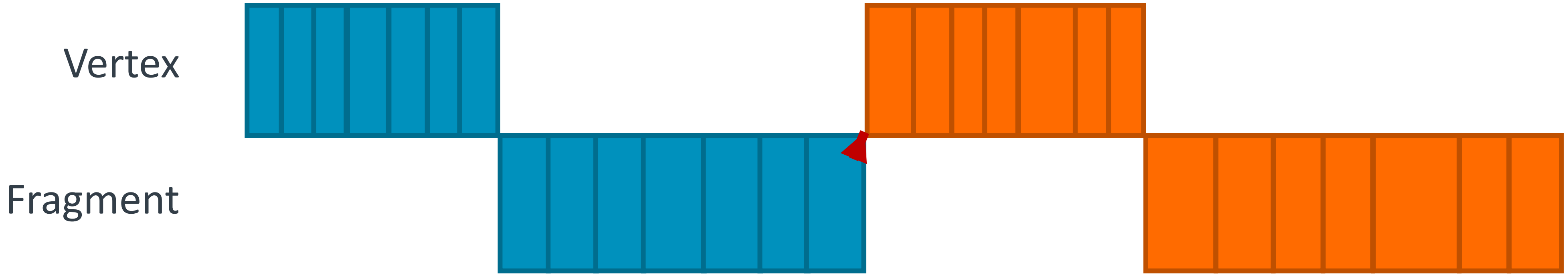

It looks like you have a dependency.

Would you like a barrier?
Yes
Dawn

srcStages = LATE_FRAGMENT_TESTS

dstStages = FRAGMENT_SHADER I VERTEX_SHADER I COMPUTE_SHADER

Hold it!



srcStages = LATE_FRAGMENT_TESTS

dstStages = FRAGMENT_SHADER I VERTEX_SHADER I COMPUTE_SHADER

The problem

- GetPipelineStage(usage)
  - Can’t tell if TextureBinding is Vertex, Fragment or Compute
- GetPipelineStage(usage, shaderStages)
  - Trivial to determine

Tracking shader stages

Sync scope

Texture	Usage
Framebuffer	ColorAttachment
DepthBuffer	DepthAttachment
BurntWoodTexture	TextureBinding
Buffer	**Usage**
CameraMatrices	UniformBuffer
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TableUniforms	UniformBuffer
ChairVertices	VertexBuffer
ChairUniforms	UniformBuffer

Tracking shader stages

Sync scope

Texture	Usage	Shader stages
Framebuffer	ColorAttachment	None
DepthBuffer	DepthAttachment	None
BurntWoodTexture	TextureBinding	Fragment
Buffer	**Usage**	**Shader stages**
CameraMatrices	UniformBuffer	Vertex
TableVertices	VertexBuffer	None
TableUniforms	UniformBuffer	Vertex
ChairVertices	VertexBuffer	None
ChairUniforms	UniformBuffer	Vertex

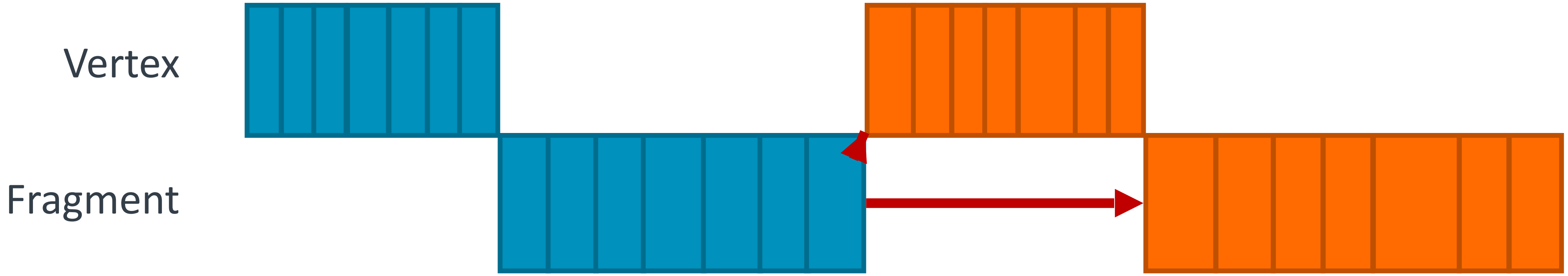
How to find the shader stages?

- Explicit tagging? Shader analysis?
- User already told us
- BindGroupLayoutEntry.visibility
  - Mask of all shader stages the resource is used in.

Recording a barrier

- From
  - GetPipelineStage(usage)
- To
  - GetPipelineStage(usage, shaderStages)

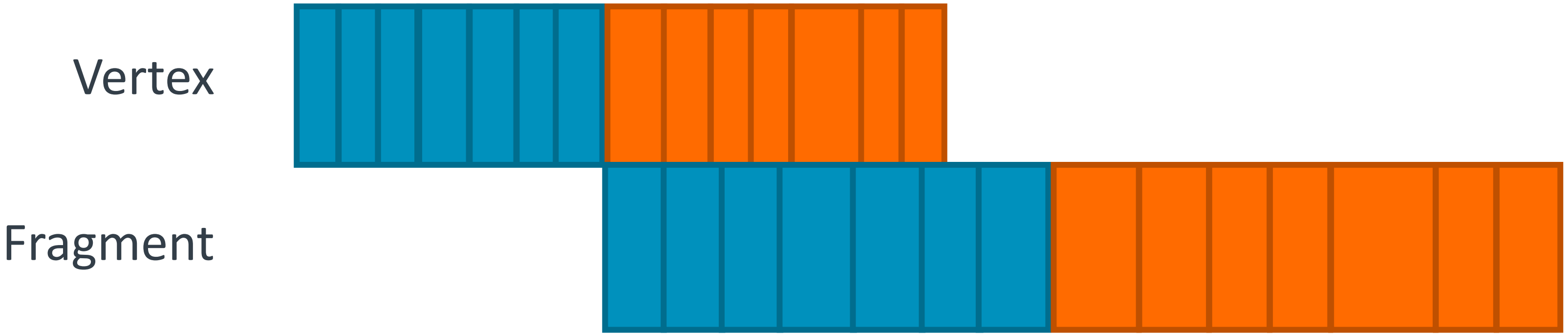
Results



srcStages = LATE_FRAGMENT_TESTS

dstStages = FRAGMENT_SHADER I VERTEX_SHADER I COMPUTE_SHADER

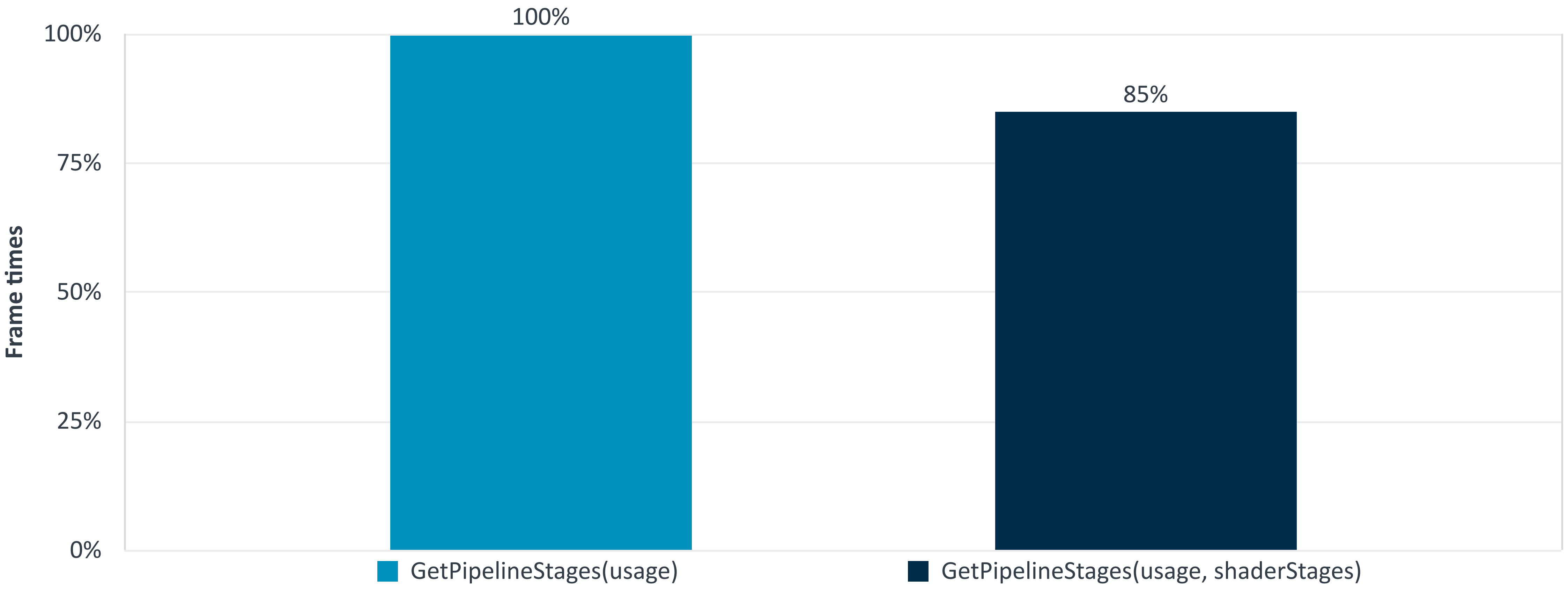
Results



srcStages = LATE_FRAGMENT_TESTS
dstStages = FRAGMENT_SHADER

Results

- Measured on an Immortalis-G715 device



When submitting GPUCommandBuffer

Flashback

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void CommandBuffer::BeginRenderPass
 (syncScope) {
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Barrier merging

- One vkCmdPipelineBarrier per resource is a lot...
- vkCmdPipelineBarrier can contain many memory barriers
- Let’s merge them into one!

Barrier merging example

- First barrier: TRANSFER → VERTEX
- Second barrier: FRAGMENT → FRAGMENT
- Merged barrier: TRANSFER | FRAGMENT → VERTEX | FRAGMENT

Better barrier merging

- Two vkCmdPipelineBarrier's
  - One for everything with VERTEX in its dstStageMask
  - One for everything else
- (Or synchronization2)

Conclusions

- If you’re doing:
  - GetPipelineStage(usage)
- Consider:
  - GetPipelineStage(usage, shaderStages)
- And save 15%

Resources

- Synchronization validation layers
  - See talk: Using Vulkan Synchronization Validation Effectively
- Vulkan Samples
  - Pipeline barriers sample
- Full details on the Dawn commit
  - https://dawn-review.googlesource.com/c/dawn/+/151340

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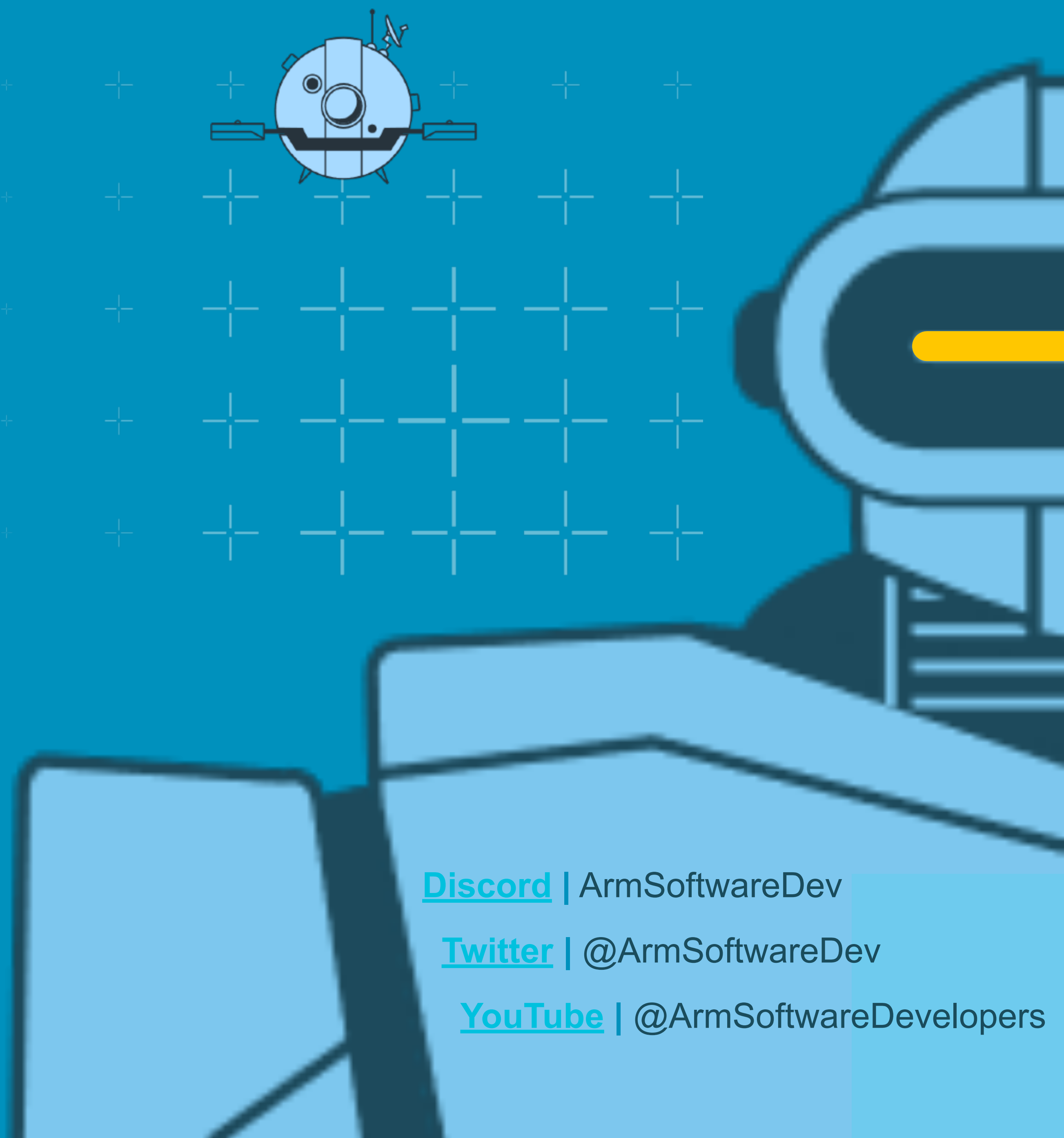

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