Porting to Vulkan

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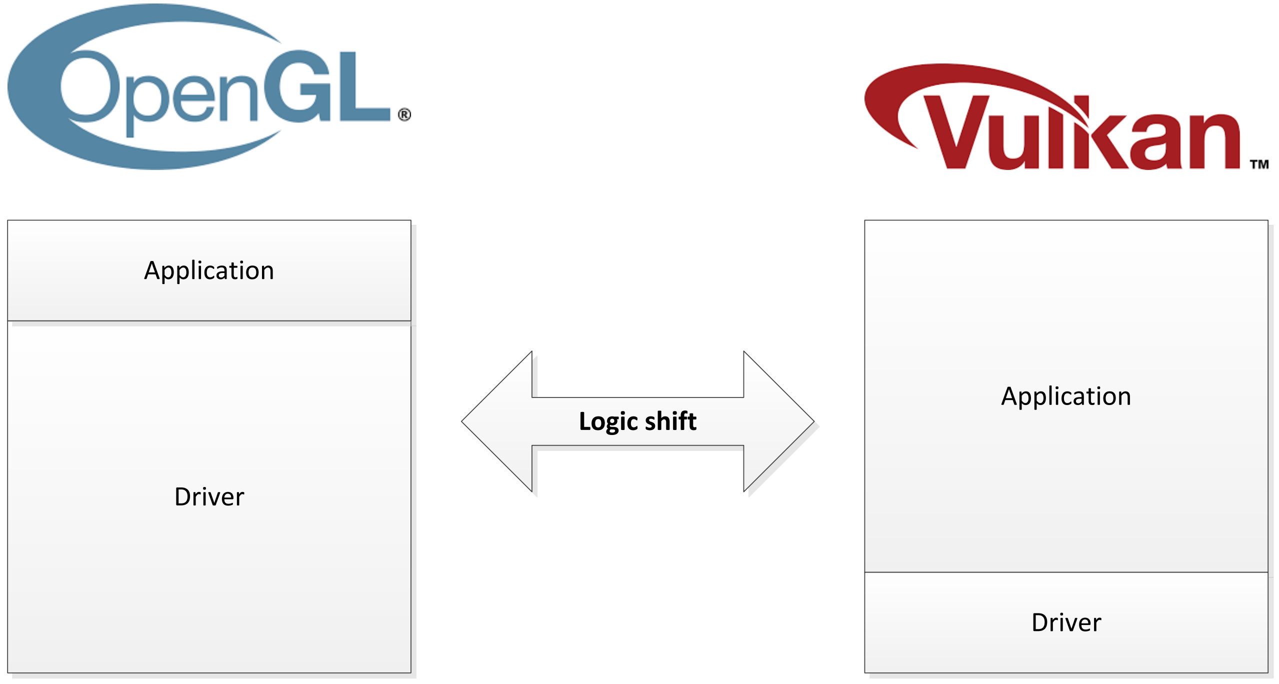
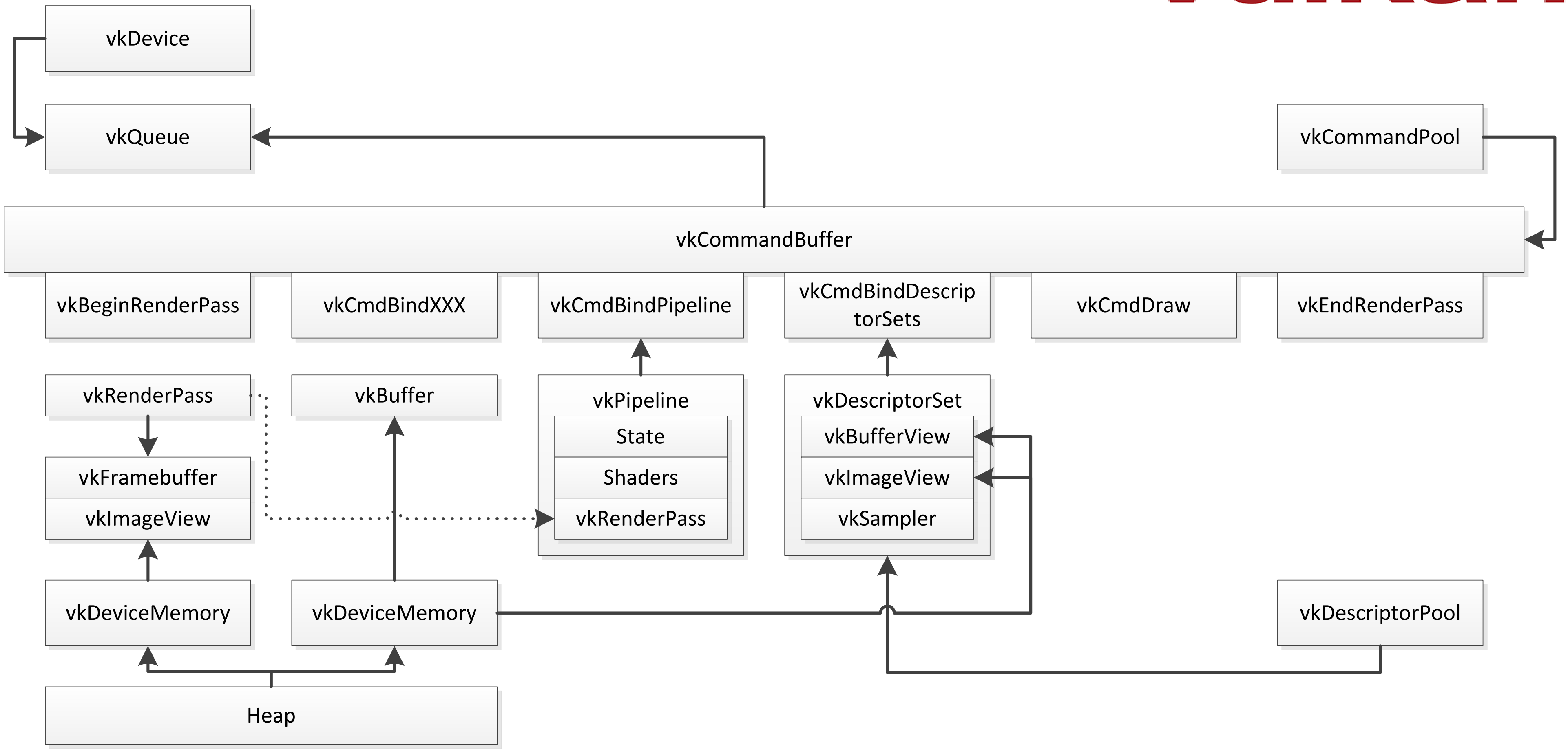
Agenda

- **API flashback**
- **Engine design**
  - Command buffers
  - Pipelines
  - Render passes
  - Memory management

API Flashback



API Flashback



Porting from OpenGL to Vulkan?

- **Most graphics engines today are designed around the principles of implicit driver behaviour**
  - A direct port to Vulkan won’t necessarily give you a lot of benefits

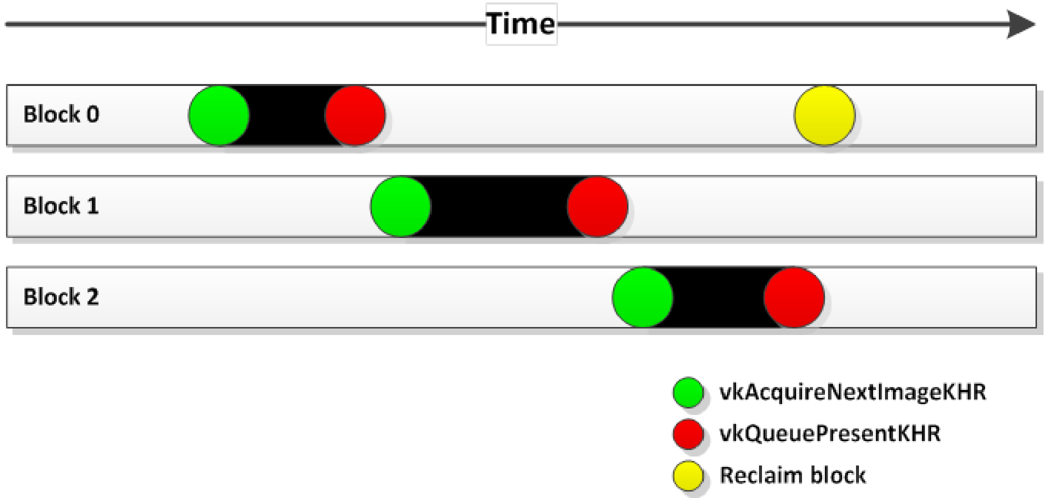
- **Approach it differently**
  - Re-design for Vulkan, and then port that to OpenGL

Allocating Memory

- **Memory is first allocated and then bound to Vulkan objects**
    - Different Vulkan objects may have different memory requirements
    - Allows for aliasing memory across different Vulkan objects
- **Driver does no ref counting of any objects in Vulkan**
    - Cannot free memory until you are sure it is never going to be used again
    - Also applies to API handles!
- **Most of the memory allocated during run-time is transient**
    - Allocate, write and use in the same frame
    - Block based memory allocator

Block Based Memory Allocator

- Relaxes memory reference counting
- Only entire blocks are freed/recycled
- Sub-allocations take refcount on block

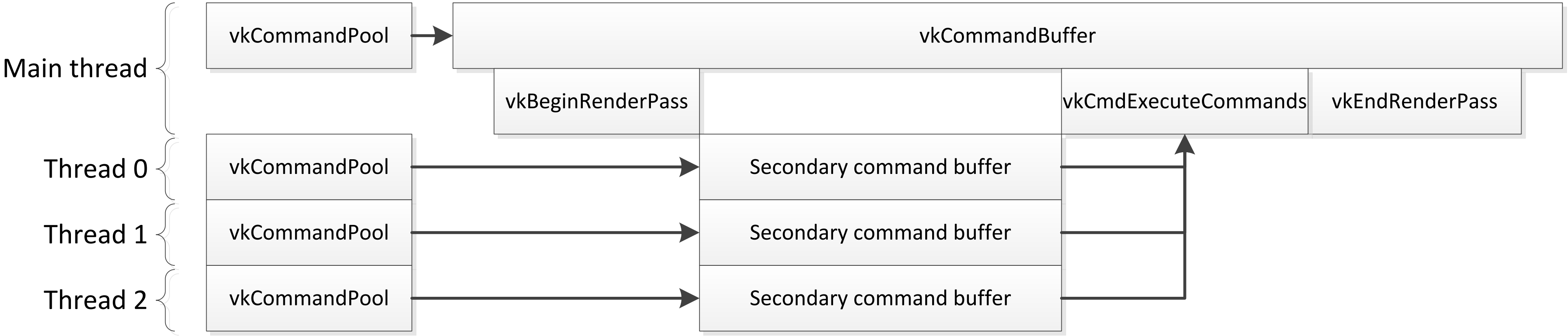


Command Buffers

- **Request command buffers on the fly**
  - Allocated using ONE_TIME_SUBMIT_BIT
  - Recycled

- **Separate command pools per**
  - Thread
  - Frame
  - Primary/secondary

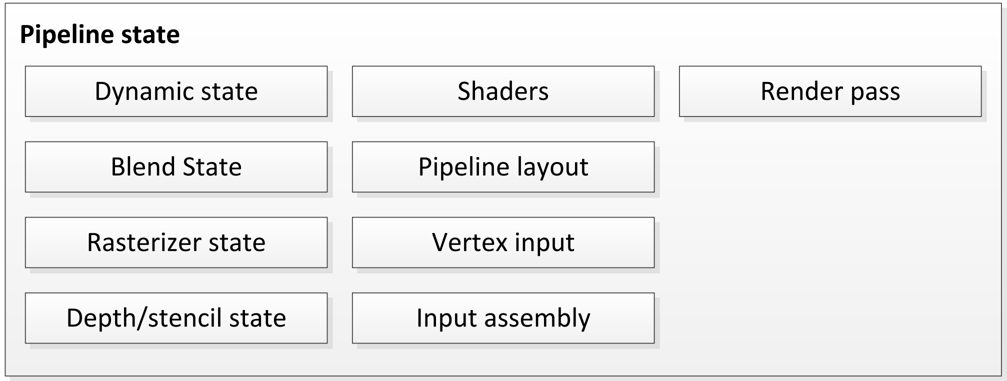
Secondary Command Buffers



Shaders

- **Standardize on SPIR-V binary shaders**
- **Extensively use the Khronos SPIRV-Cross library**
  - Cross compiling back to GLSL
  - Provides shader reflection for
    - Vertex attributes
    - Subpass attachments
    - Pipeline layouts
    - Push constants

Pipelines



Pipeline state

Dynamic state

Blend State

Rasterizer state

Depth/stencil state

Shaders

Pipeline layout

Vertex input

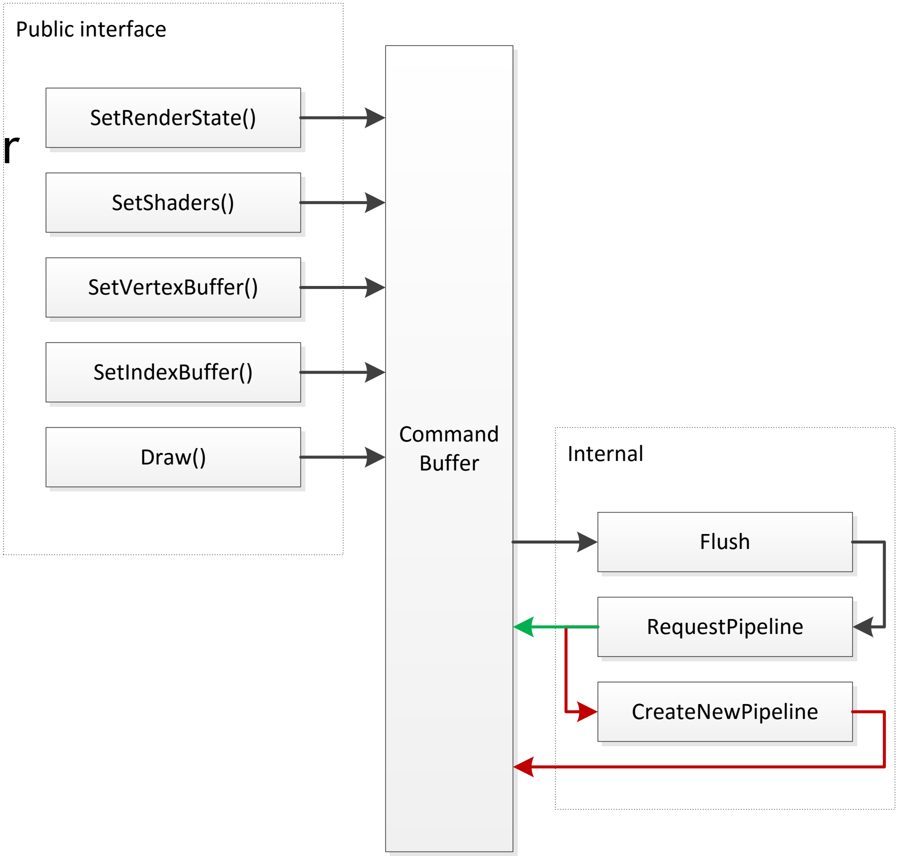
Input assembly

Render pass

Pipelines

- Not trivial to create all required pipeline state objects upfront

- Our approach:
  - Keep track of all pipeline state per command buffer
  - Flush pipeline creation when required
    - In our case this is implemented as an async operation



Pipelines

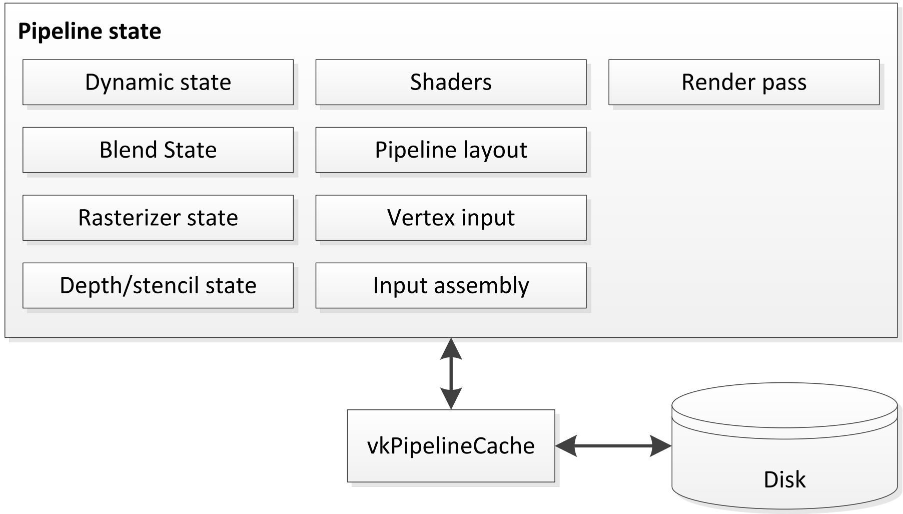
- **In an ideal world…**
  - All pipeline combinations should be created upfront

- **…but this requires detailed knowledge of every potential shader/state combination that you might have in your scene**
  - As an example, one of our fragment shaders have ~9000 combinations
  - Every one of these shaders can use different render state
  - We also have to make sure the pipelines are bound to compatible render passes
  - **An explosion of combinations!**

Pipeline cache

- **Vulkan has built-in support for pipeline caching**
  - Store to disk and re-use on next run

- **Can also speed up pipeline creation during run-time**
  - If the pipeline state is already in the cache it can be re-used

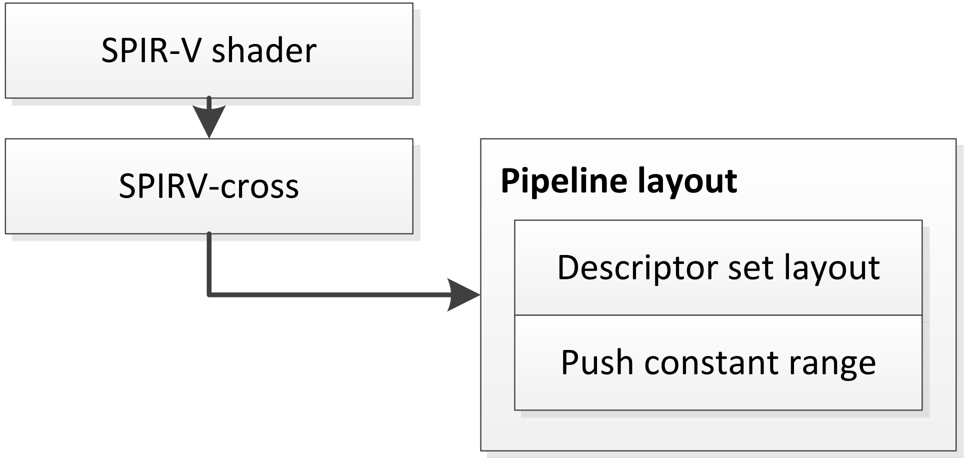


Pipeline layout

- **Defines what kind of resources are in each binding slot in your shaders**
  - Textures, samplers, buffers, push constants, etc
- **Can be shared among different pipeline objects**

Pipeline layout

- Use SPIRV-Cross to automatically get binding information from SPIR-V shaders



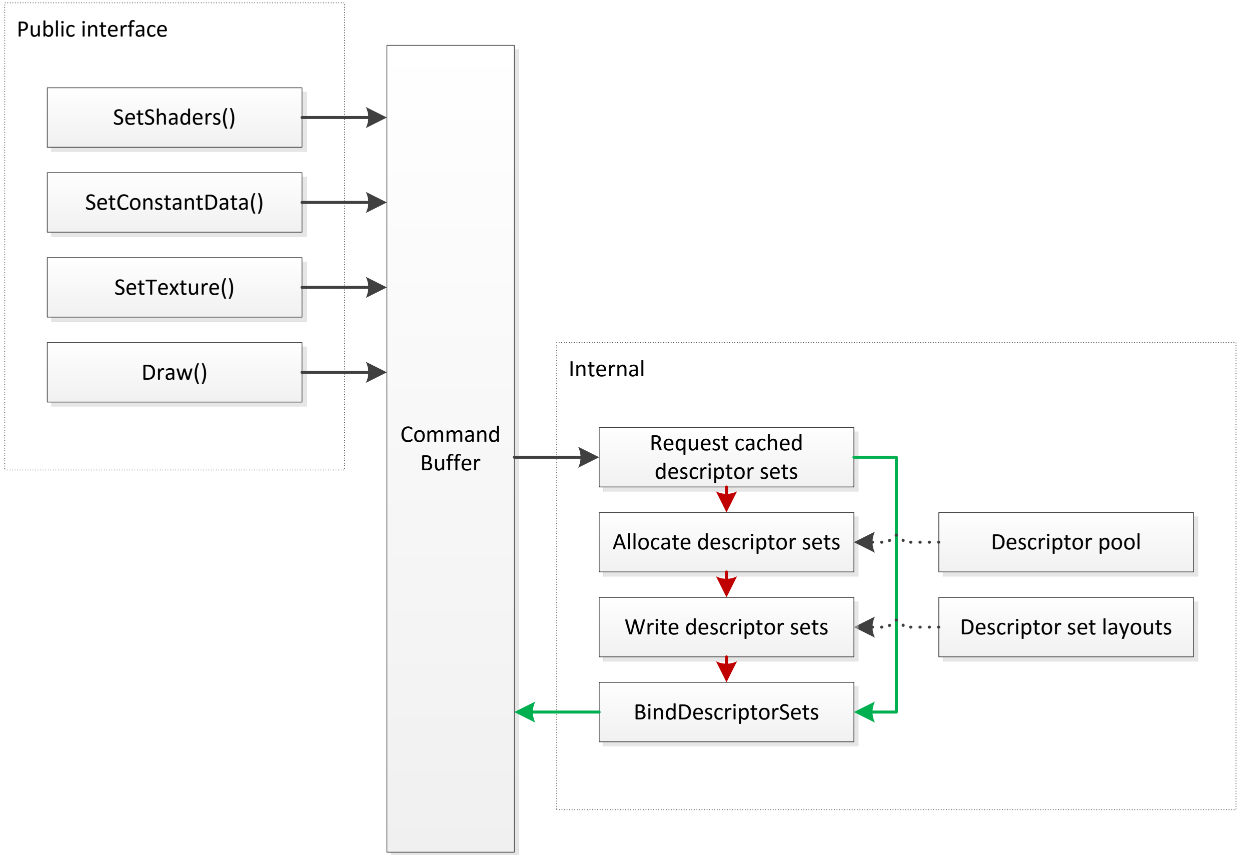
Descriptor Sets

- **Textures, uniform buffers, etc. are bound to shaders in descriptor sets**
  - Hierarchical invalidation
  - Order descriptor sets by update frequency

- **Ideally all descriptors are pre-baked during level load**
  - Keep track of low level descriptor sets per material
  - But, this is not trivial

Descriptor Sets

- **Our solution:**
  - Keep track of bindings and update descriptor sets when necessary
  - Keep cache of descriptor sets used with immutable Vulkan objects

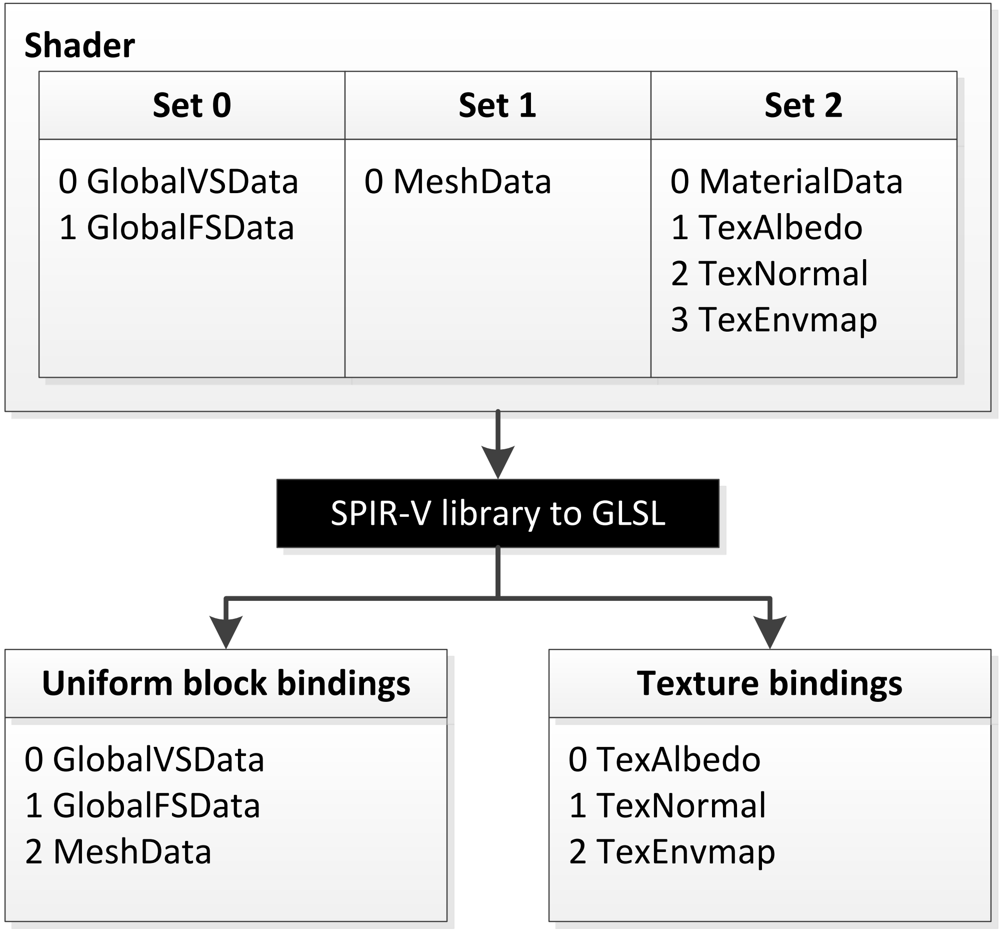


Descriptor Set emulation

- **We also need to support this in OpenGL**

- **Our solution:**
  - Emulate descriptor sets in our OpenGL backend
  - SPIRV-Cross collapses and serializes bindings

Descriptor Set emulation



Shader

Set 0	Set 1	Set 2
0 GlobalVSData 1 GlobalFSData	0 MeshData	0 MaterialData 1 TexAlbedo 2 TexNormal 3 TexEnvmap

SPIR-V library to GLSL

Uniform block bindings
0 GlobalVSData 1 GlobalFSData 2 MeshData

Texture bindings
0 TexAlbedo 1 TexNormal 2 TexEnvmap

Push Constants

- Push constants replace non-opaque uniforms
  - Think of them as small, fast-access uniform buffer memory
- Update in Vulkan with vkCmdPushConstants
- Directly mapped to registers on Mali GPUs

Push Constant Emulation

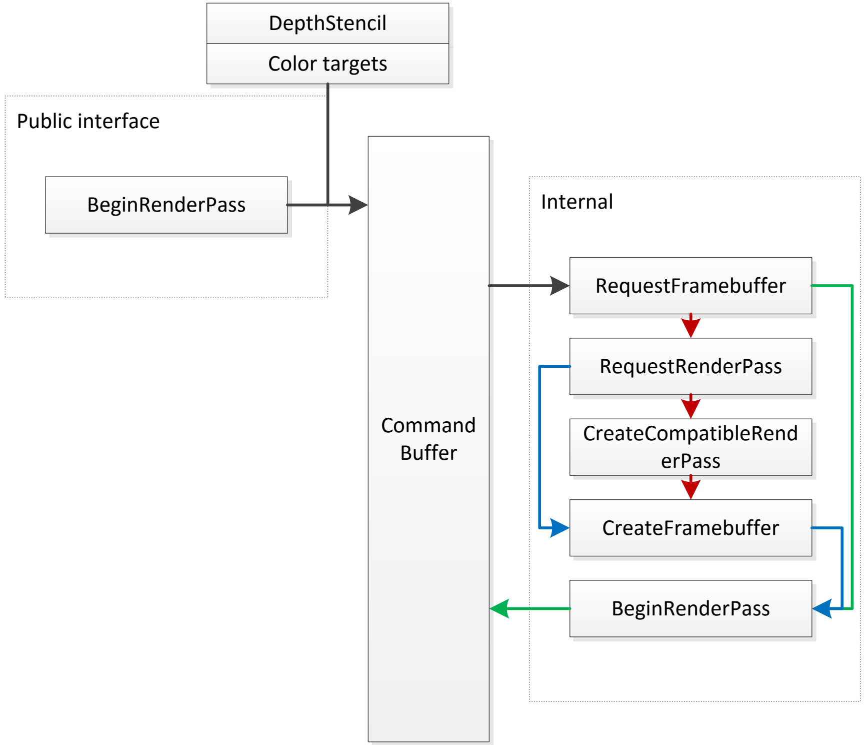
- **But again, we need to support OpenGL as well**

- **Our solution:**
  - Use SPIRV-Cross to turn push constants into regular non-opaque uniforms
  - Logic in our OpenGL/Vulkan backends redirect the push constant data appropriately

Render pass

- **Used to denote beginning and end of rendering to a framebuffer**

- **Can be re-used but must be compatible**
  - Attachments: Framebuffer format, image layout, MSAA?
  - Subpasses
  - Attachment load/store



Subpass Inputs

- Vulkan supports subpasses within render passes
- Standardized GL_EXT_shader_pixel_local_storage!
- Also useful for desktop GPUs

Subpass Input Emulation

- **Supporting subpasses in GL is not trivial, and probably not feasible on a lot of implementations**

- **Our solution:**
  - Use SPIRV-Cross to rewrite subpass inputs to Pixel Local Storage variables or texture lookups
  - This will only support a subset of the Vulkan subpass features, but good enough for our current use

Synchronization

- **Submitted work is completed out of order by the GPU**
- **Dependencies must be tracked by the application and handled explicitly**
  - Using output from a previous render pass
  - Using output from a compute shader
  - Etc
- **Synchronization primitives in Vulkan**
  - Pipeline barriers and events
  - Fences
  - Semaphores

Render passes and pipeline barriers

- Most of the time the application knows upfront how the output of a renderpass is going to be used afterwards
- Internally we have a couple of usage flags that we assign to a render pass
  - On EndRenderPass we implicitly trigger a pipeline barrier

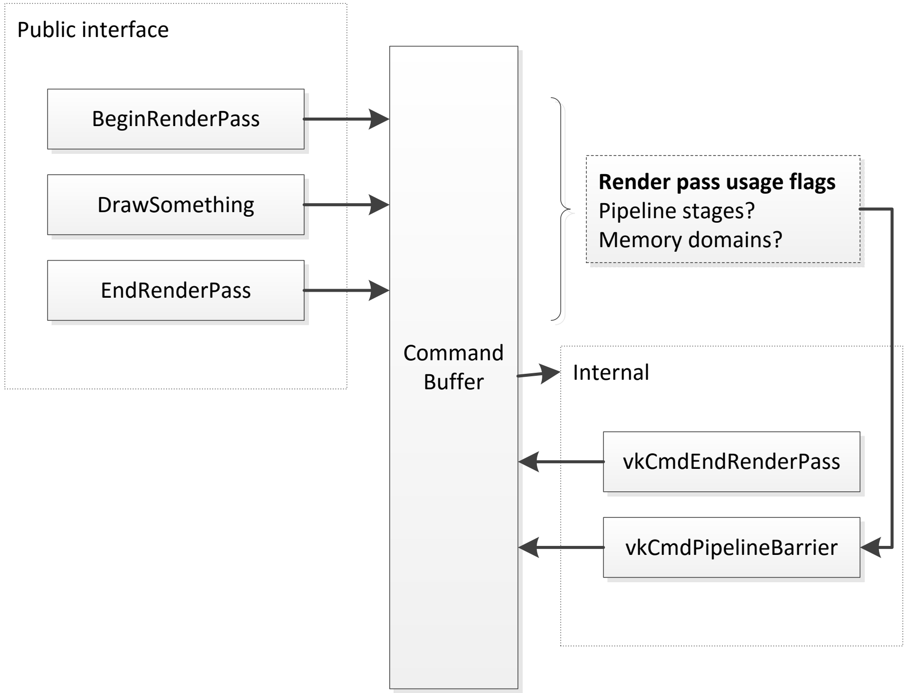


Image Layout Transitions

- **Must match how the image is used at any time**
- **Pedantic or relaxed**
  - Some implementations will require careful tracking of previous and new layout to achieve optimal performance
  - For Mali we can be quite relaxed with this – most of the time we can keep the image layout as VK_IMAGE_LAYOUT_GENERAL

Summary

- Don’t allocate or release during runtime
- Batching still applies
- Multi-thread your code!
- Use push-constants as much as possible
- Multi-pass is fantastic on mobile GPUs