Vulkanised 2025

The 7th Vulkan Developer Conference
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So you want to write a Vulkan Renderer in 2025

Charles Giessen
LunarG, Inc.

Who am I?

- Started learning Vulkan in 2017
- Joined LunarG in 2019
  - Maintain the Vulkan-Loader, Api dump, VkCube, Vulkaninfo, Vulkan-Utility-Libraries, SDK development, & more
- Joined the Vulkan Community Discord in 2018
  - Moderator since ~2021

Charles Giessen
LunarG

GPU SOFTWARE SPECIALISTS

Disclaimers

- Strictly my opinions
- My experience is with Desktop Vulkan
  - Android is my blindspot
- Vulkan is MASSIVE
  - Cannot cover everything!
- Not covering rendering algorithms
  - Focusing on the Vulkan parts of rendering

Let’s get started!

How to design a Vulkan Renderer

1. Pick the API Version
2. Pick the extensions to use
3. ????
4. Profit!!!!

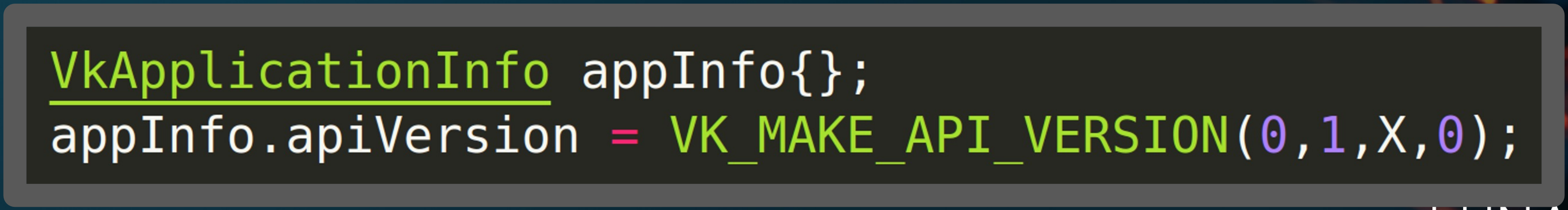
What version to target?

Which version to target?

- Whatever your hardware minimum is!
- Depends on target platform
    - Desktop (Linux & Windows) can reliably use 1.3
    - Android lags behind with 1.1
    - MacOS (MoltenVK) is 1.2 but supports most everything in 1.3
- 1.4 still too new to recommend

Three different version numbers

- Instance
  - From the Vulkan-Loader
  - vkEnumerateInstanceVersion (Added in 1.1)
- Physical Device
  - From the GPU Driver
  - VkPhysicalDeviceProperties::apiVersion
- Application
  - Defined by the application
  - VkApplicationInfo::apiVersion



```
VkApplicationInfo appInfo{};
appInfo.apiVersion = VK_MAKE_API_VERSION(0,1,X,0);
```

What extensions to use?

Two Types of Extensions

- Device
  - Vast majority
  - From vkEnumerateDeviceExtensions
  - Many have been promoted into Core Versions
- Instance
  - Small number
  - From vkEnumerateInstanceExtensions
  - VK_EXT_debug_utils
  - WSI: VK_KHR_<platform>_surface & VK_KHR_surface

300+ published extensions

- Every extension solves a problem
  - Some fix just one site
  - Other rewrite half the API
- Depends on many things
  - Hardware minimum
  - Target version
  - Supported platforms
  - Maintenance constraints
- Way too many to cover each individually

But which to choose!?

- Overwhelming to read about each one
- Many are aliases
  - To core functionality
  - To other extensions
- Many have dependencies on other extensions
- In addition, must enable feature bools
  - VkPhysicalDeviceFeatures2 pNext chain
  - Core features in VkPhysicalDeviceVulkan<Version#>Features
  - Extension features in VkPhysicalDeviceVulkan<Ext_name>Features<Ext_suffix>
- More specifics on checking & enabling extensions
  - https://github.com/KhronosGroup/Vulkan-Guide/blob/main/chapters/enabling_extensions.adoc

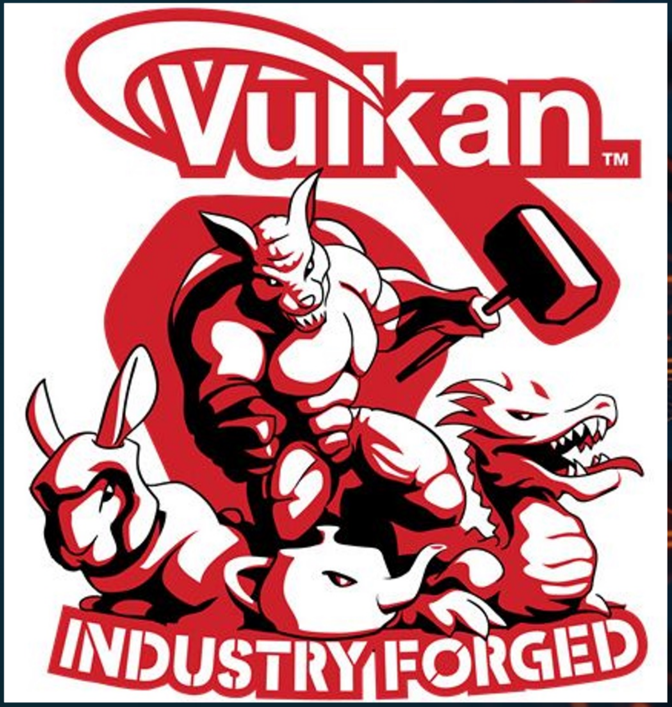
Vulkan-Profiles

- Profiles define explicit extension & features requirements
  - Expressed in JSON
- Example: VP_KHR_roadmap_2024
  - “This roadmap profile is intended to be supported by newer devices shipping in 2024 across mainstream smartphone, tablet, laptops, console and desktop devices.”
- Profiles-Library sets up VkDevice according to a given Profile
- Profiles are a great help in picking extensions & features
  - Just use what’s in a profile
  - Or *use* the profile directly!

Why not just use Vulkan 1.0?

Vulkan 1.0

- Single target, no guesswork
- Supported everywhere
- Just learning 1.0 is hard enough
    - New things means more to learn
- Huge departure from OpenGL
- New concepts introduced
    - Render Passes
    - Synchronization
    - Descriptor Sets
    - Pipelines
    - And more!



New paradigms, new problems

- Not all parts of Vulkan 1.0 are a success
  - Clunky interfaces
  - Complex interactions
  - Missing capabilities
- To be expected for an entirely new API!
- Picking a version and extensions is hard
- Yet using Vulkan 1.0 is even harder

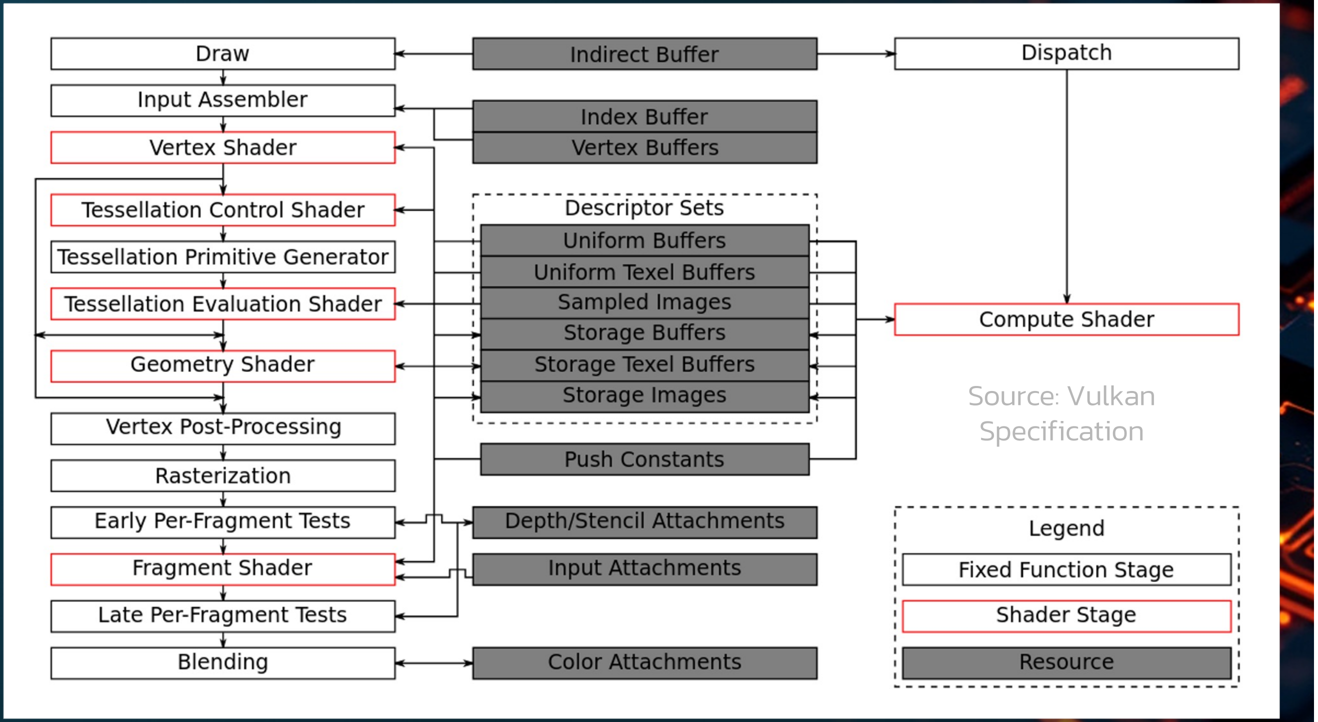
We aren’t stuck with Vulkan 1.0

- Good news is that this is 2025, not 2016
- Most of the glaring have been fixed
- Many more problems fixed in the following years
- The rest of the slides discuss these problems and their solutions

Immutable Pipelines

What even is a pipeline?

- Compiled binary of pipeline inputs
- Bake once
  - Costly
- Bind many times
  - Cheap
- Exchange time for space



Draw
Input Assembler
Vertex Shader
Tessellation Control Shader
Tessellation Primitive Generator
Tessellation Evaluation Shader
Geometry Shader
Vertex Post-Processing
Rasterization
Early Per-Fragment Tests
Fragment Shader
Late Per-Fragment Tests
Blending

Indirect Buffer
Index Buffer
Vertex Buffers
Descriptor Sets
Uniform Buffers
Uniform Texel Buffers
Sampled Images
Storage Buffers
Storage Texel Buffers
Storage Images
Push Constants
Depth/Stencil Attachments
Input Attachments
Color Attachments

Dispatch
Compute Shader

Legend
Fixed Function Stage
Shader Stage
Resource

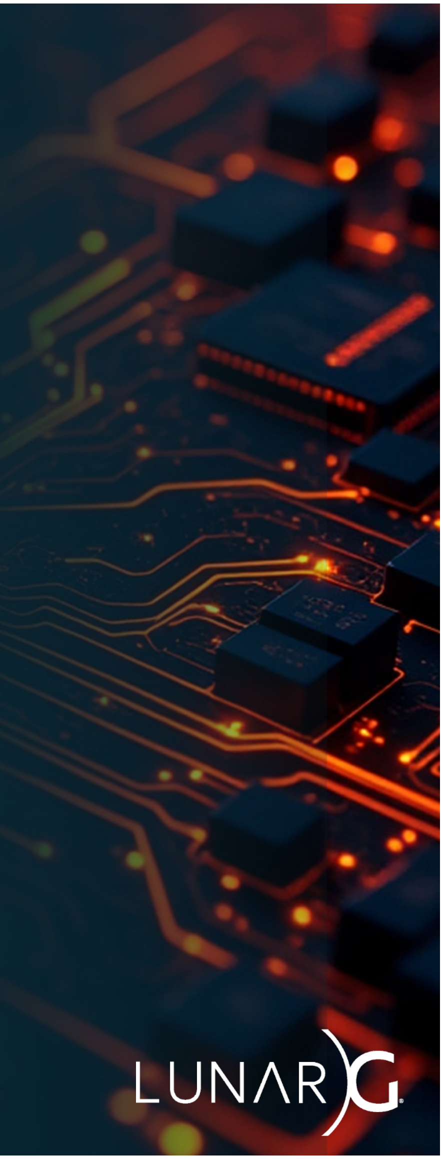
Source: Vulkan Specification

What’s the catch?

- Pipelines require everything to be known ahead of time
- Each combination of inputs requires a dedicated pipeline
    - Shader, topology, blend mode, vertex layout, cull mode, etc
- Causes a combinatorial explosion of variants
    - 10,000’s of pipelines for shipping titles
- Pipeline creating takes time
    - Creates stutters if done just-in-time

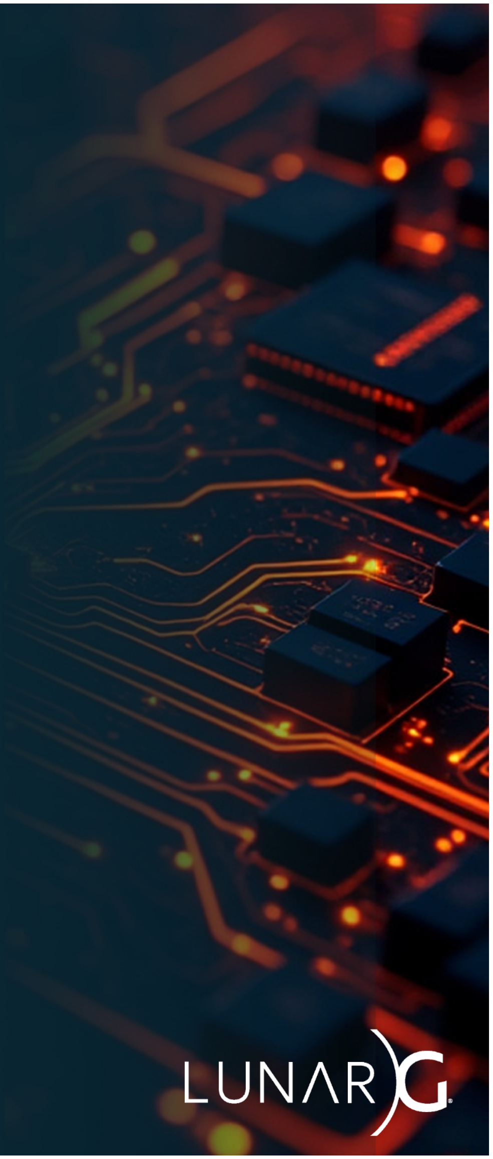
VkDynamicState

- Not everything has to be immutable
- Set desired state while recording command buffers
- Over 70 states can be dynamic
- Great reference for all of it:
  - https://github.com/KhronosGroup/Vulkan-Guide/blob/main/chapters/dynamic_state_map.adoc



Reducing compilation overhead

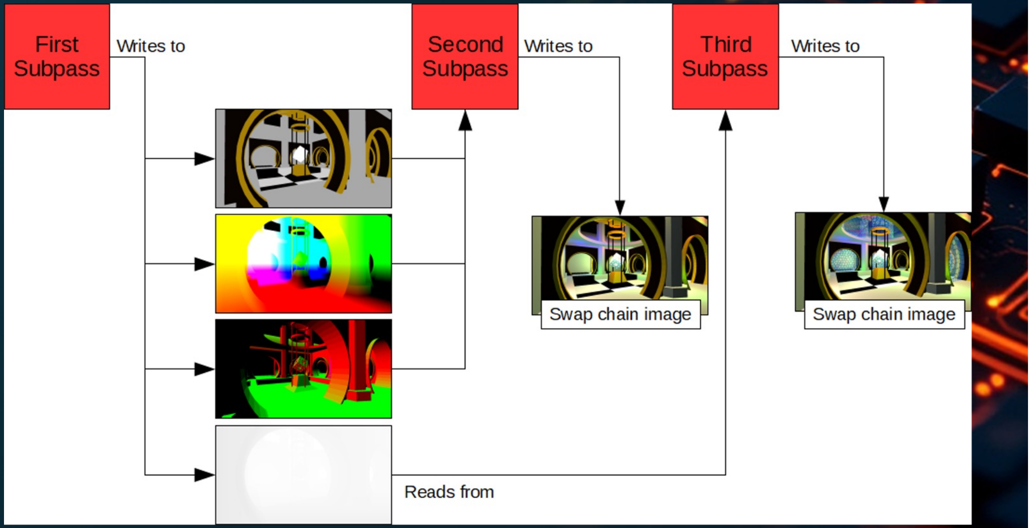
- VK_EXT_graphics_pipeline_libraries
  - Divide graphics pipeline into multiple parts
  - Link them into single binary right before binding
  - Diminishes cost of many variants
- VK_EXT_shader_object
  - Ditch pipelines entirely
  - Bind compiled shader stages
  - Currently only available on AMD & Nvidia
- Jury is still out on best way to do this



Render Passes

Render Passes and Sub Passes

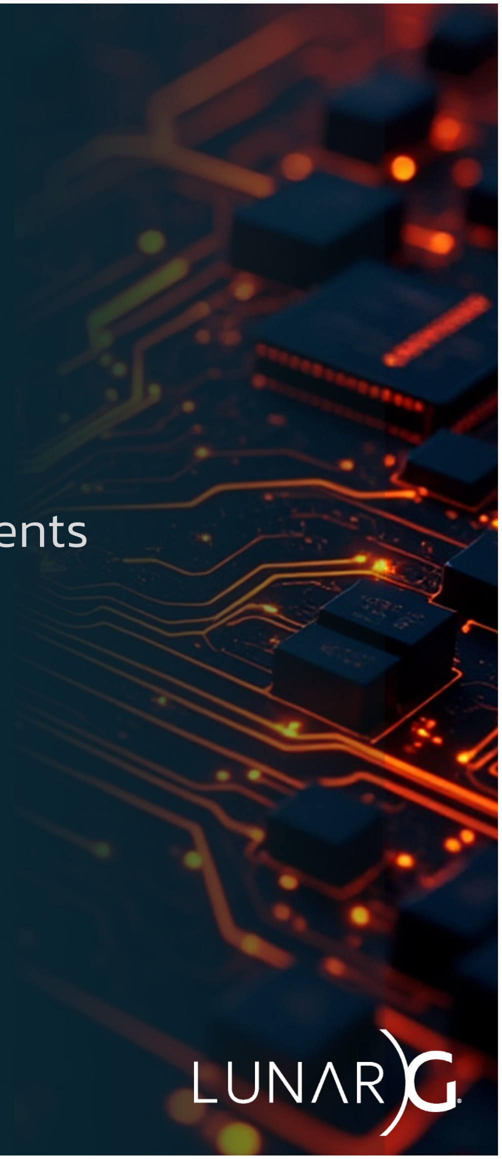
- All drawing commands happen inside a “renderpass”
- Acts as a pseudo render graph
- Allows tiling GPU’s to use memory efficiently
- Describes image attachments
- Defines the subpasses
- Declare dependencies between subpasses



Source: Sascha Willems
Vulkan input attachments and sub passes

Great in theory…

- Not so great to use in practice
- Single object with many responsibilities
  - Defines attachments
  - Defines memory barriers for attachments
  - Defines subpasses that read from and write to attachments
- Hard to architect into a renderer
  - Yet another input for pipelines
- Main benefit is for tiling based GPU’s
  - Commonly found in mobile
- Requires using VkFramebuffers
  - Only exists to combine images and renderpasses



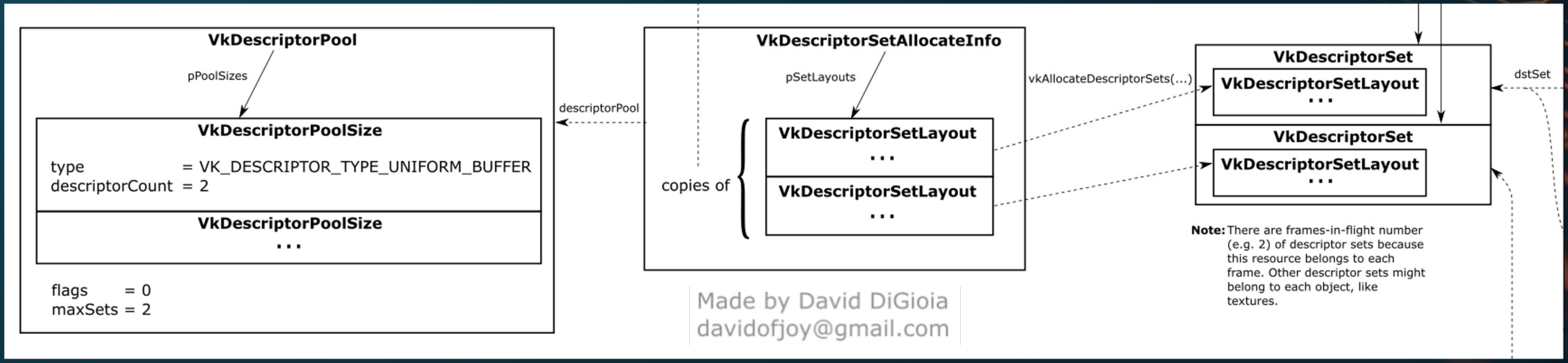
Introducing Dynamic Rendering

- 1.3’s dynamicRendering feature, VK_KHR_dynamic_rendering
- Replaces VkRenderpass
- Describe renderpasses inline with command buffer recording
- Greatly simplifies application architecture
  - Creating pipelines only needs attachment descriptions
- Tiling GPU’s aren’t left behind either
- 1.4 dynamicRenderingLocalRead, VK_KHR_dynamic_rendering_local_read
  - Enables efficient multi-pass rendering

Descriptor Sets

Descriptor Sets

- Organize shader inputs into “sets” by update frequency
- Update each set together
- Bind sets as needed
- Reasonable API for the gamut of existing hardware
- Small snippet of descriptor API:



Note: There are frames-in-flight number (e.g. 2) of descriptor sets because this resource belongs to each frame. Other descriptor sets might belong to each object, like textures.

Made by David DiGioia
davidofjoy@gmail.com

Descriptor Difficulties

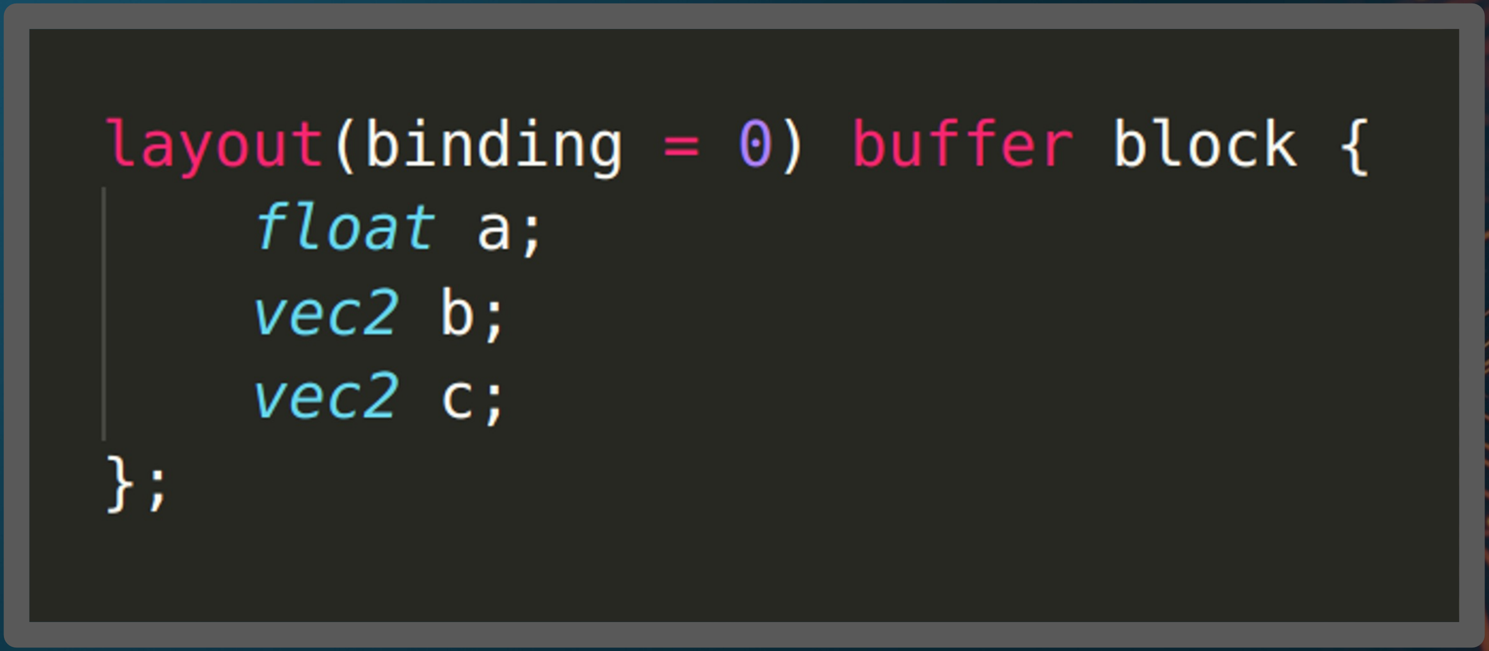
- Cannot update descriptors after binding in a command buffer
- All descriptors must be valid, even if not used
- Descriptor arrays must be sampled uniformly
  - Different invocations can’t use different indices
  - Can sample “dynamically uniform”, eg runtime based index
- Upper limit on descriptor counts
- Discourages GPU-Driven rendering architectures

Solution Space

- Descriptor Indexing
  - 1.3, optional in 1.2, or VK_EXT_descriptor_indexing
  - Update descriptors after binding
  - Update unused descriptors
  - Relax requirement that all descriptors must be valid, even if unused
  - Non-uniform array indexing
- Buffer Device Address
  - 1.3, optional in 1.2, or VK_KHR_buffer_device_address
  - Directly access buffers through addresses without a descriptor
- Descriptor Buffers – VK_EXT_descriptor_buffer
  - Manage descriptors directly
  - Similar to D3D12's descriptor model

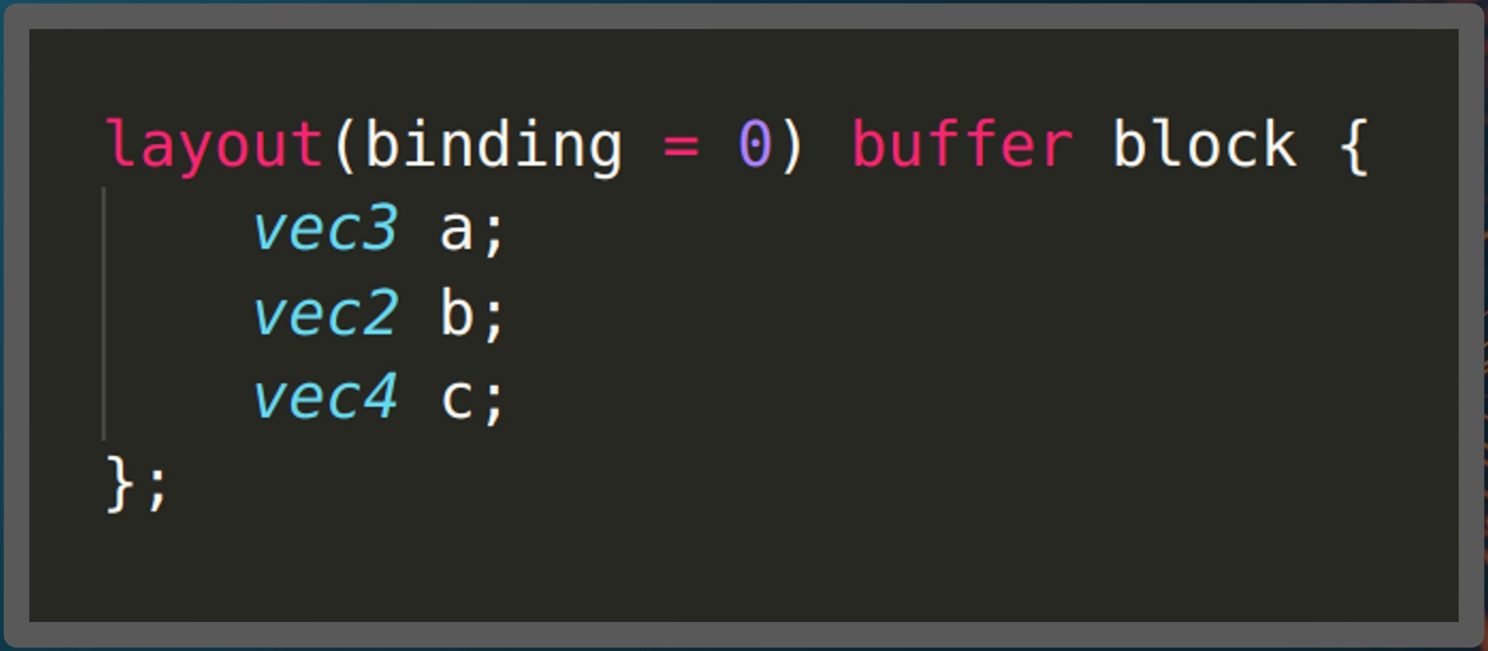
Shader Memory Layout

What is the equivalent C Buffer of this?



```
layout(binding = 0) buffer block {
    float a;
    vec2 b;
    vec2 c;
};
```

And of this?

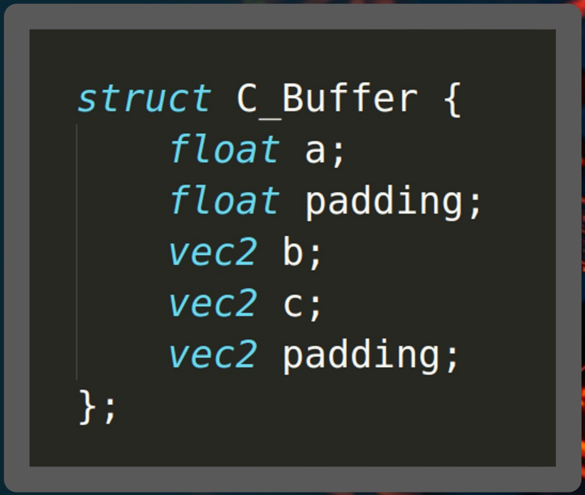


```
layout(binding = 0) buffer block {
    vec3 a;
    vec2 b;
    vec4 c;
};
```

Trick question!

- Didn’t specify which layout to use
    - “Extended Alignment” AKA std140
    - “Base Alignment” AKA std430
    - “Scalar Block Layout” AKA scalar
- Each defines offset, alignment and padding
    - For each type (float, int, vec2, vec3, vec4, etc)
- So which should you use?

std140 / std430



```
struct C_Buffer {
    float a;
    float padding;
    vec2 b;
    vec2 c;
    vec2 padding;
};
```

Scalar block layout!

- It uses C-like structure rules
- Matches expectations
- Enables easy sharing of data between host and device
  - No tedious padding and offsetting!
- Very commonly supported
- Great reference for all shader memory layouts
  - https://github.com/KhronosGroup/Vulkan-Guide/blob/main/chapters/shader_memory_layout.adoc

Synchronization

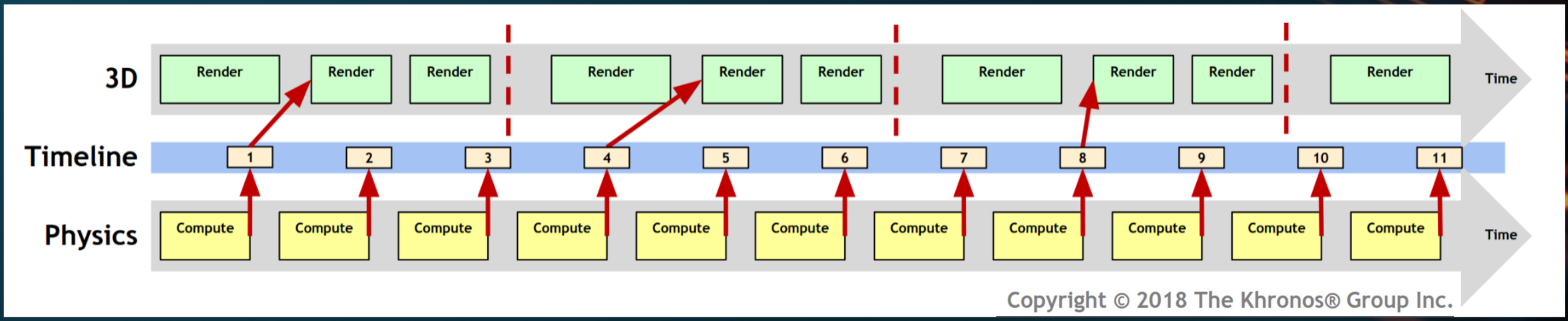
Synchronization

- By far the hardest part of Vulkan
- Many different kinds of sync
  - Fence, Binary Semaphore, Event, Barrier
- Good synchronization are critical to good performance

LUNARG.

Timeline Semaphores

- Streamlines Host and Device sync
- Replaces fences and (binary) semaphores
- Is a monotonically increasing uint64_t
- Have work wait for a value, increment to signal work is done
- Able to “Wait before signal”
- Does not currently work with swap chains



Synchronization 2

- Improve usability and simplify the synchronization interface
- Specifies pipeline stages and access flags together
- More efficient Events
- Perform image memory barriers without transitions
- Makes using synchronization just that much easier
- Exhaustive discussion of the changes here
  - https://github.com/KhronosGroup/Vulkan-Guide/blob/main/chapters/extensions/VK_KHR_synchronization2.adoc

Miscellaneous Features

Shader Draw Parameters

- Adds additional shader builtins
  - BaseInstance
  - BaseVertex
  - DrawIndex
- Useful for indexing into buffers

Indirect Rendering

- Generate draw commands on GPU
  - EX: Frustum culling
- But how many commands to use?
- DrawIndirectCount allows sourcing the count from GPU buffer

VK_EXT_device_generated_commands

- New extension for GPU driven techniques
- Does way more than sourcing drawing parameters from GPU
  - Bind Vertex & Index buffers
  - Push constants
  - Pipelines & Shader objects
  - Draw calls
  - Compute dispatches
  - Raytracing
  - Mesh shading

Conclusion

Conclusion

- Vulkan-Guide is awesome
- Vulkan 1.0 was just a starting point
- The new stuff is worth the time and effort
    - All added for good reasons

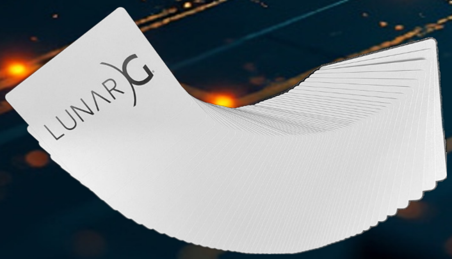
Thank you!

Actions

Download this Presentation

https://khr.io/1cr

Talk to us and get Swag!



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https://khr.io/1cq

Your Feedback Matters!

Survey Results

➔ Are shared with the Khronos Vulkan Working Group

➔ Are used to drive development priorities throughout 2025

Survey Closes
Wednesday, Feb. 19, 2025
(GMT—7)