

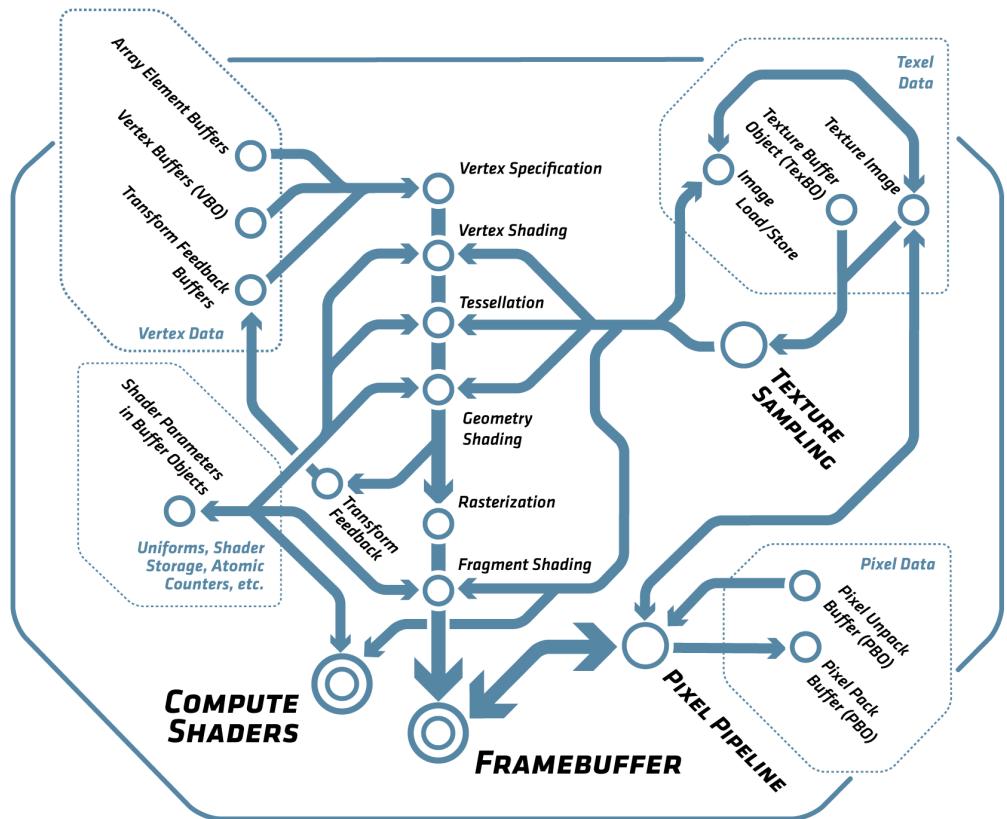


Vulkan, OpenGL, OpenGL ES

SIGGRAPH 2016

Agenda

	Khronos 3D Graphics BoF	Speakers
2:30	Vulkan and OpenGL Status Updates	Neil Trevett, NVIDIA Tobias Hector, Imagination Tech Tom Olson, ARM
3:00	ISV Experience: Porting Unreal Engine 4 to Vulkan	Rolando Caloca Olivares, Epic Games
3:30	ISV Experience: Porting DOOM to Vulkan	Axel Gneiting, id Software
4:00	Panel: Best practices for Programming to the Vulkan API	Chris Hebert, NVIDIA Tobias Hector, Imagination Tech Dan Archard, Qualcomm Rolando Caloca Olivares, Epic Games Axel Gneiting, id Software
5:00	Panel: Tools for the Vulkan Ecosystem	Bill Hollings, The Brenwill Workshop Kyle Spagnoli, NVIDIA Karl Schultz, LunarG Andrew Woloszyn, Google
6:00	Party Time!	



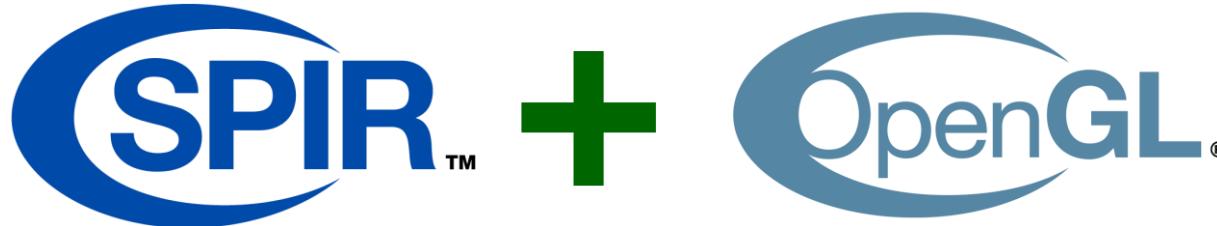
KHRONOS
GROUP™

OpenGL®

SIGGRAPH 2016
Neil Trevett
Khronos President

NEW ARB_gl_spirv OpenGL Extension

- Enables OpenGL driver to ingest compiled SPIR-V code
 - Specification released here at SIGGRAPH
 - Available today in developer release drivers from NVIDIA
- Accepts SPIR-V output from open source Glslang Khronos Reference compiler
 - <https://github.com/KhronosGroup/glslang>



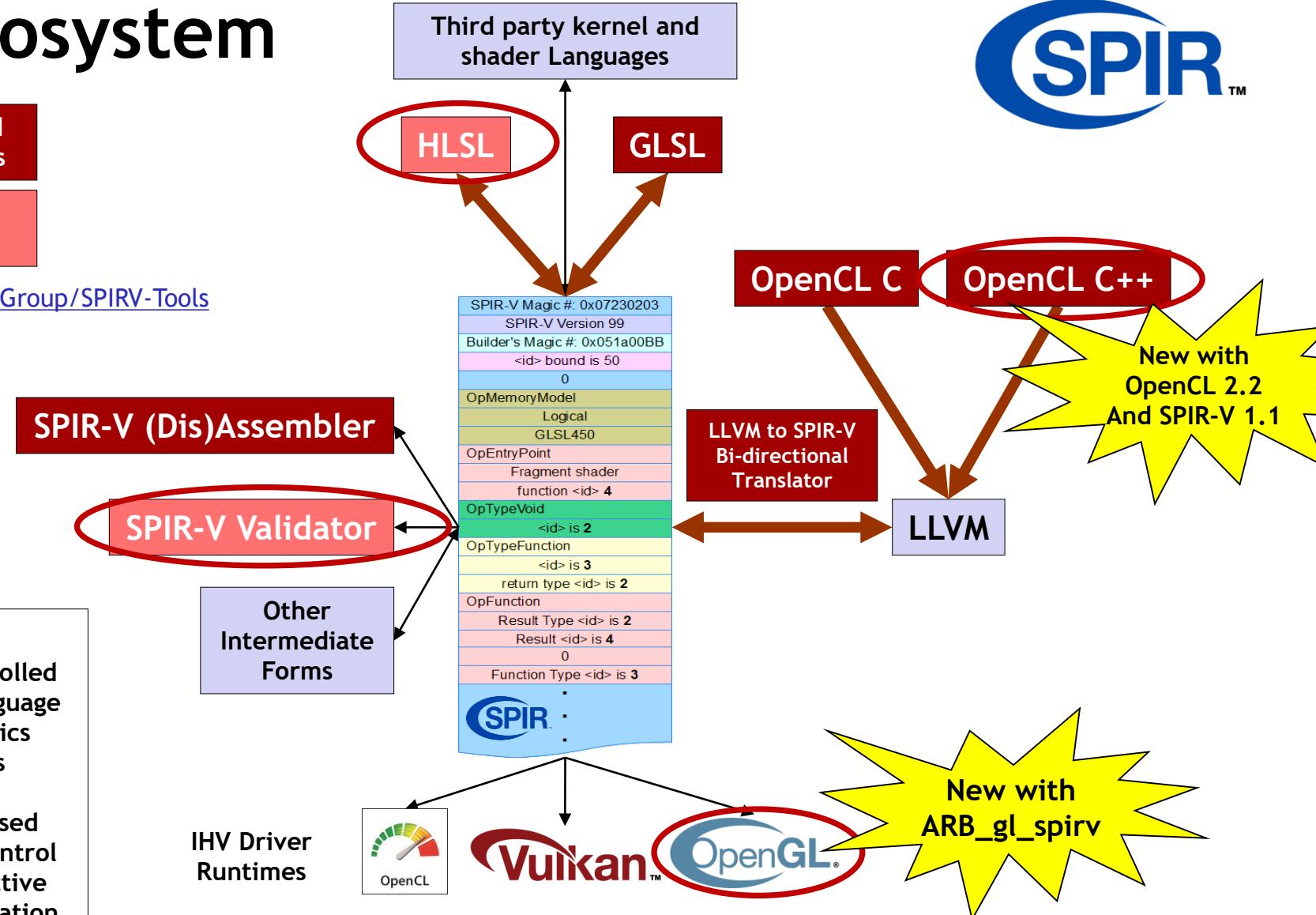
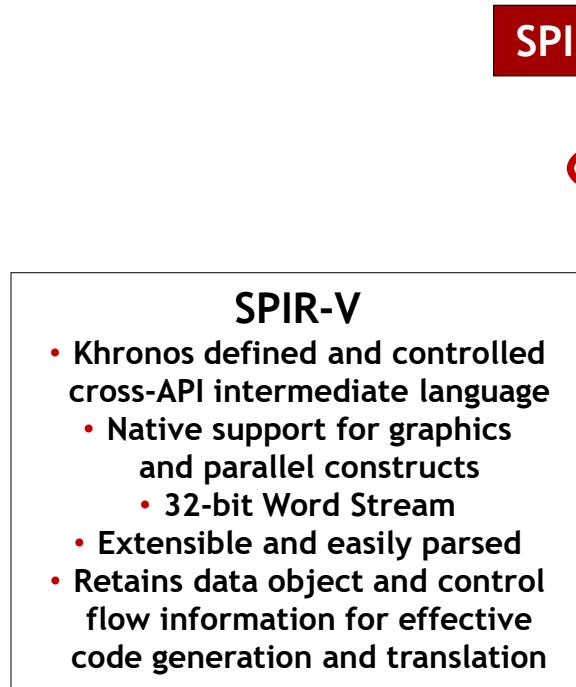
Enables OpenGL to participate in SPIR-V-based toolchain innovations

SPIR-V Ecosystem

Khronos has open sourced these tools and translators

Khronos plans to open source these tools soon

<https://github.com/KhronosGroup/SPIRV-Tools>

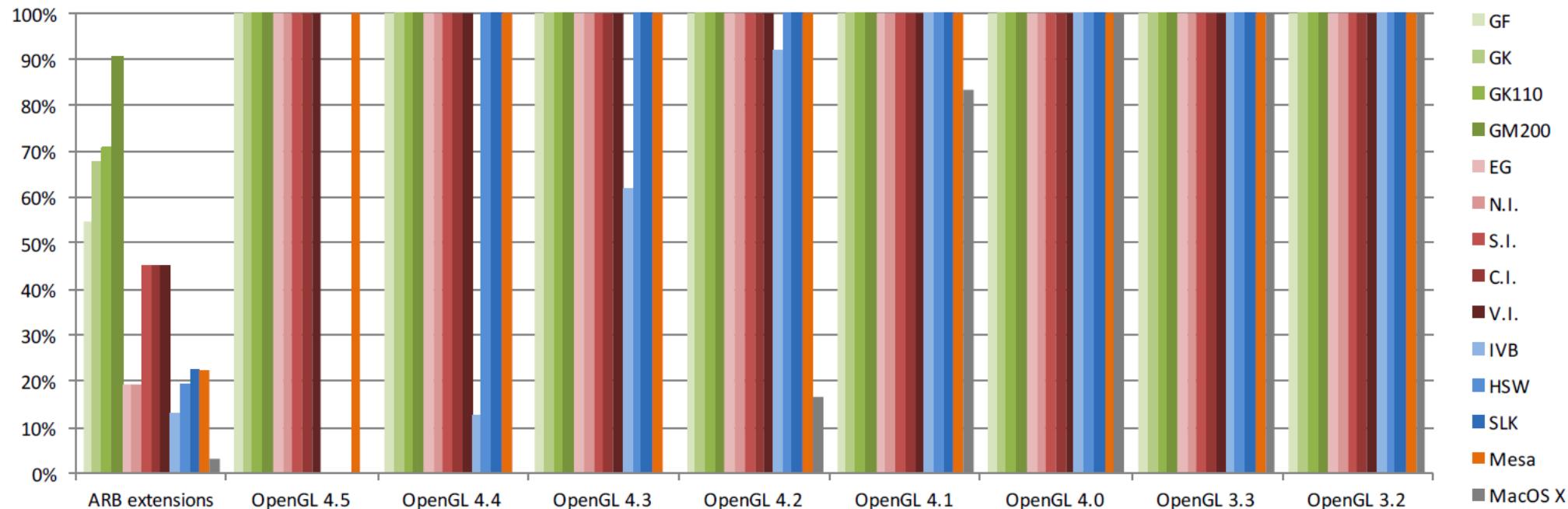


OpenGL Driver Support Update

- ARB extension support increased across the board
- Mesa 12.1 released yesterday reaches OpenGL 4.5!
- GLEW 2.0 released today!
 - Forward-compatible contexts, adds new extensions, OS Mesa and EGL support
 - <https://github.com/nigels-com/glew.git>

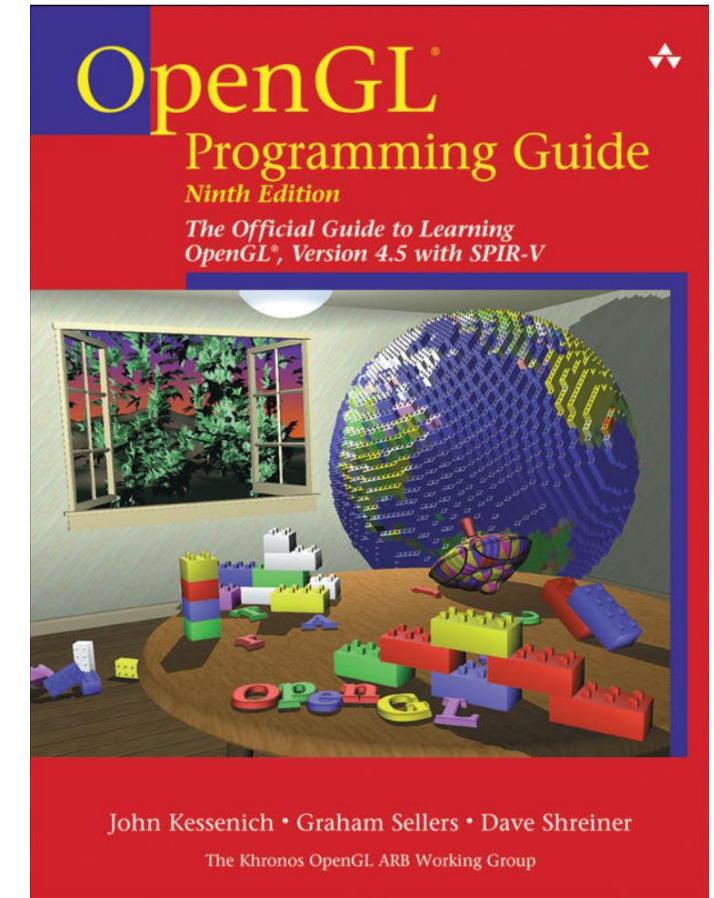
Khronos significantly improving OpenGL 4.5 conformance tests

- Release in April
- Working to release as many tests in open source as possible



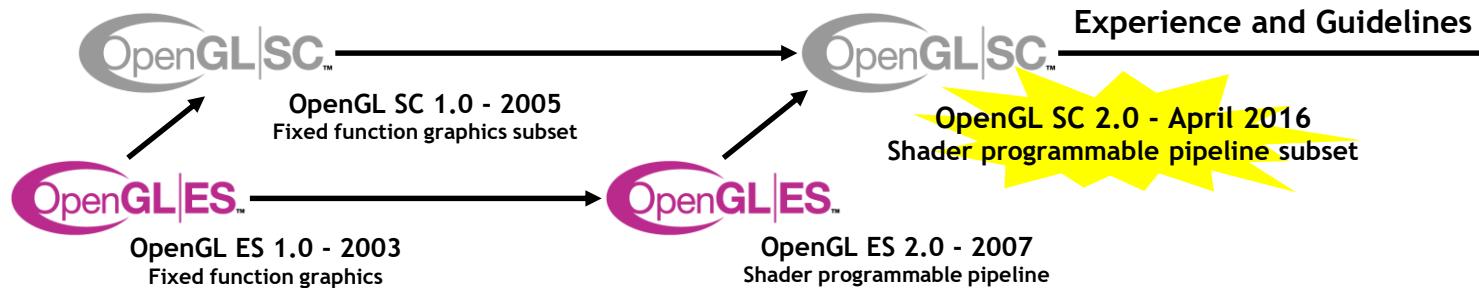
More OpenGL News

9th Edition of the OpenGL Programming Guide released - includes OpenGL 4.5 with SPIR-V support



Doom4 primary API is OpenGL

Safety Critical 3D



New Generation APIs for
safety certifiable vision,
graphics and compute
e.g. ISO 26262 and DO-178B/C

Vulkan™

Small driver size
Advanced functionality
Graphics and compute

Khronos Launches Safety Critical Advisory Panel - and Invites Industry Experts to Participate

Experienced practitioners in the field of safety critical system design are invited to apply for Advisory Panel membership simply by sending an email to khronos_scap_apply@khronos.org. Please include your contact information, a short history of your experience along with why you feel you could help us set the future direction of safety critical APIs.

[Read the press release](#)

Safety Critical Advisory Panel Announced Today!
Generating API design guidelines to enable system certifications
<https://www.khronos.org/openglsc/>



OpenGL ES Update

Tobias Hector | OpenGL ES Chair
Lead Software Design Engineer, Imagination

Introduction

- You might have noticed...
 - I'm not Tom!
 - Really, I'm not just Tom wearing a beard.
- I took the helm in May
 - Have been steering this ship ever since

Introduction

- You might have noticed...
 - I'm not Tom!
 - Really, I'm not just Tom wearing a beard.
- I took the helm in May
 - Have been steering this ship ever since
- Tom was an excellent chair for nearly 10 years
 - Comfortable
 - Sturdy
 - Easy to clean
 - And saw through 4 OpenGL ES releases!

OpenGL ES Status

- Little demand for a new OpenGL ES at present
 - So not announcing one this year
 - Keeping an eye on the market for changes
- High demand for making OpenGL ES more robust
 - Particularly with regards to WebGL
- Focus on fixes and enhancements
 - 3.2 API spec updated last month
 - More fixes on the way (including for 3.0 and 3.1 specifications, and ESSL)

ES 3.2 Conformance

- OpenGL ES 3.2 CTS Released!
 - Integration of ES tests from AOSP
 - Many ES 3.2 tests
- New OpenGL ES CTS Lead
 - Alexander Galazin (ARM)
 - Elected in May - doing a great job!
- Many companies now conformant
 - Nvidia
 - ARM
 - Verisilicon
 - Other submissions pending



K H R O N O S™
G R O U P

Vulkan Update SIGGRAPH 2016

Tom Olson, ARM | Vulkan Working Group chair

Status

- Vulkan 1.0 launched in February
 - Only two months late...
- A complete package
 - Specs (API, SPIR-V, Data Formats, extensions)
 - GLSL to SPIR-V compiler (glslang)
 - Standard loader and validation layers
 - Conformance test suite
 - Drivers and SDKs
- All Khronos resources in open source
 - Software under Apache 2.0
 - Specification license on the way
 - <https://github.com/KhronosGroup/>



Adoption and Availability - Hardware

- Conformant GPUs



- Desktop hardware

- AMD GCN (production)
- Intel Skylake and Broadwell (beta, production coming soon)
- NVIDIA Kepler, Maxwell, Pascal (production)

- Mobile hardware

- Samsung Galaxy S7
- NVIDIA Shield / Shield TV
- Google Nexus 5X, 6P, Player, Pixel C (Android N Developer Preview)
- Lots more on the way!

Adoption - Platforms

- Windows



- Linux



SteamOS



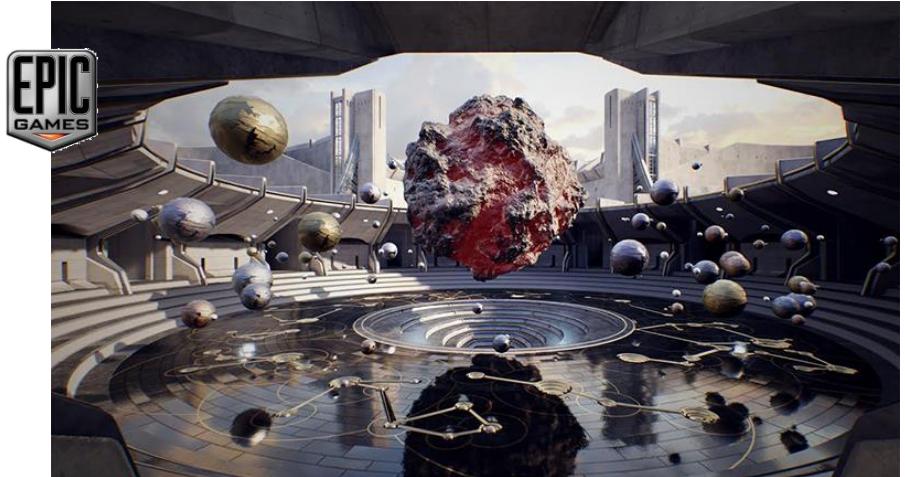
- iOS / MacOS



Adoption - Games and Engines



DotA 2 on Vulkan port of Source 2



'ProtoStar' demo on Vulkan port of Unreal Engine 4



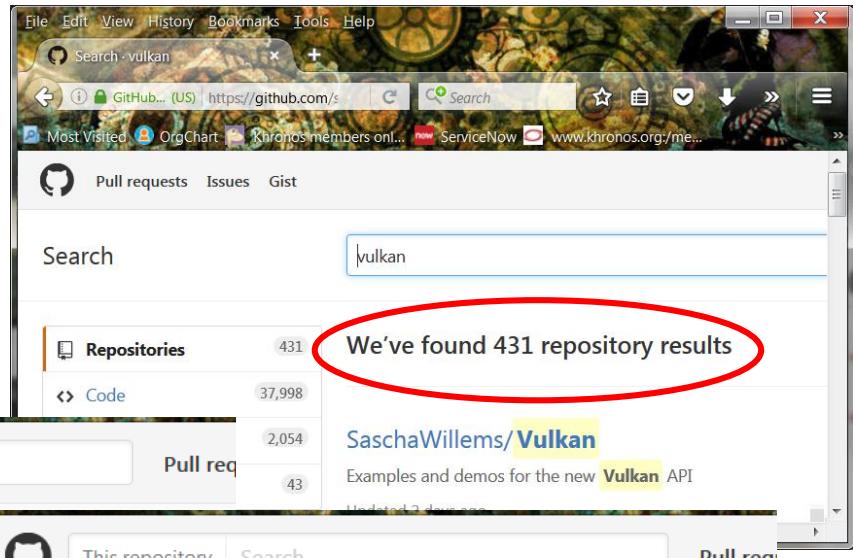
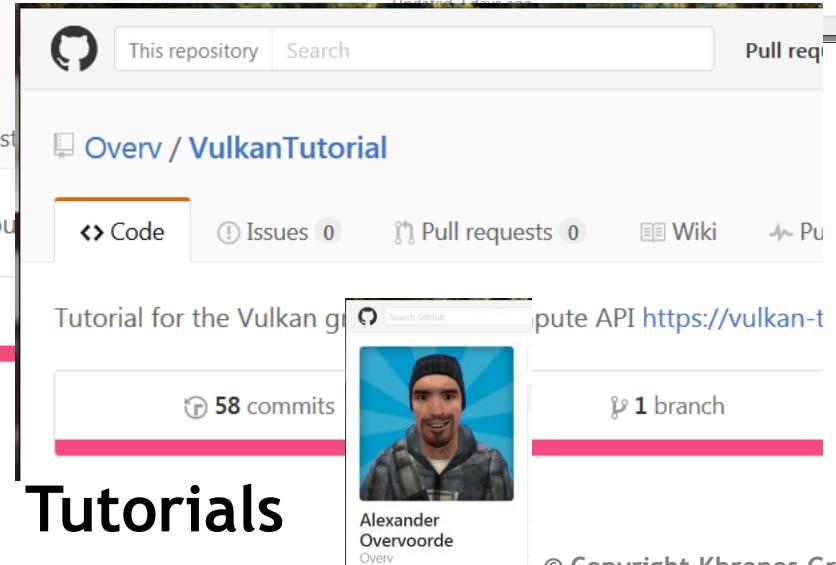
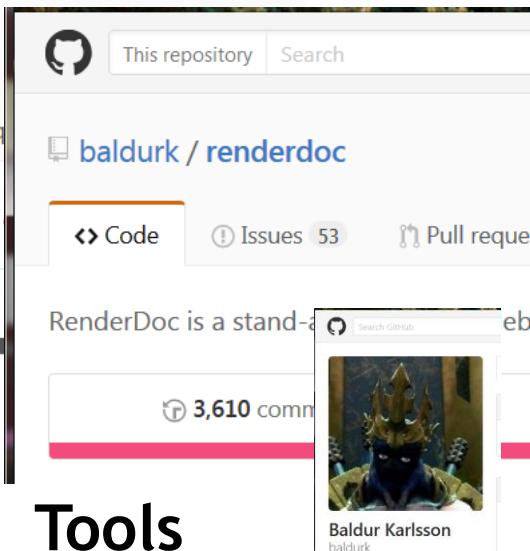
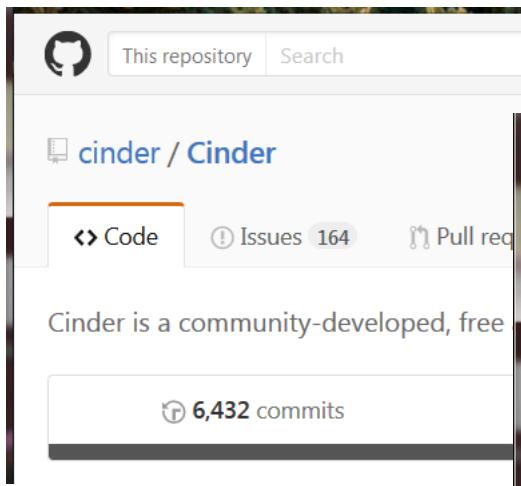
Talos Principle on Vulkan port of Serious Engine



DOOM on Vulkan port of id Tech 6

Community and Ecosystem

A huge amount of activity
on GitHub!

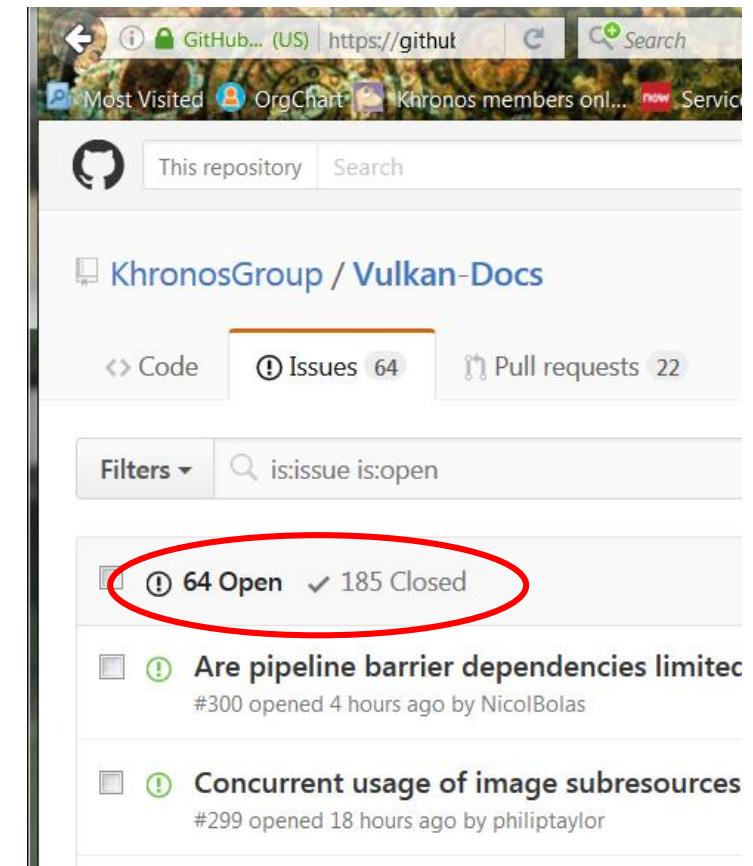


Community and Ecosystem: What's New

- Vulkan Conformance Test 1.0.1 nearing release
 - 107k total test cases (34% increase vs 1.0.0)
 - Substantial coverage improvement
 - Thanks Samsung, Intel, Google!
- SDK and Validation Layers progress
 - 8 SDK releases over last six months
 - All areas of spec have some coverage - growing every day
 - 1450+ commits; 222+ GitHub and 180+ LunarXchange issues resolved since launch
- Glslang compiler has partial HLSL support
 - See GitHub glslang issue #362 *Complete basic HLSL parser*
- New tools
 - SPIRV-Cross cross-compiler / reflection tool (Hans-Kristian Arntzen, ARM)
 - Vulkan-hpp (Markus Tavenrath / Andreas Süßenbach, NVIDIA)

What we're working on: Vulkan 1.0

- Vulkan 1.0 spec maintenance
 - Bug fixes
 - Clarifications
 - Reference page extraction
 - Extensions to fill gaps
- BTW: Putting specs on GitHub was a GREAT idea!
 - Fantastic input from community
 - Typo and error reports
 - Requests for clarification
 - Notes on undefined corner cases
- Spending 50% of meeting time on GitHub issues
 - Weekly spec update (most weeks)



What *else* we're working on: Vulkan Next

- Vulkan Next is in active development
 - Core spec in definition
 - Some features may come out as extensions
 - Schedule TBD
- Top priorities
 - Better multi-GPU support
 - VR support (e.g. efficient multi-view rendering, direct screen access)
 - Cross-API and cross-process sharing
 - Subgroup instructions (e.g. shader ballot)
 - Generalized renderpass / subpass dependencies
 - Rigorous memory model

We need your help!

- **Use Vulkan**
 - At least experimentally
 - ...and give us feedback
- **Contribute to the ecosystem**
 - All Khronos Vulkan code projects are Apache 2.0
 - We need examples, tutorials, demos, tools...
 - *Note - watch for RFQs forthcoming at www.khronos.org*
- **Help us promote the API**
 - Got a cool Vulkan-generated video? Let us host and promote it!
 - Send mail to 'marketing' at khronos.org

Porting UE4 to Vulkan

Lessons learned during Protostar demo
(and beyond!)

Rolando Caloca O.
Epic Games

Intro

- UE4 RHI Architecture in a hurry
- Protostar & Initial RHI
- Optimizations for Protostar
- How the RHI works
- Future plans & challenges

UE4 RHI Architecture in a hurry

- RHI = Render Hardware Interface
 - aka our cross-platform way to talk to each Gfx API



UE4 RHI Architecture in a hurry

- Original architecture
 - Game Thread enqueues rendering commands
 - Rendering Thread generates Vulkan Cmd Buffers



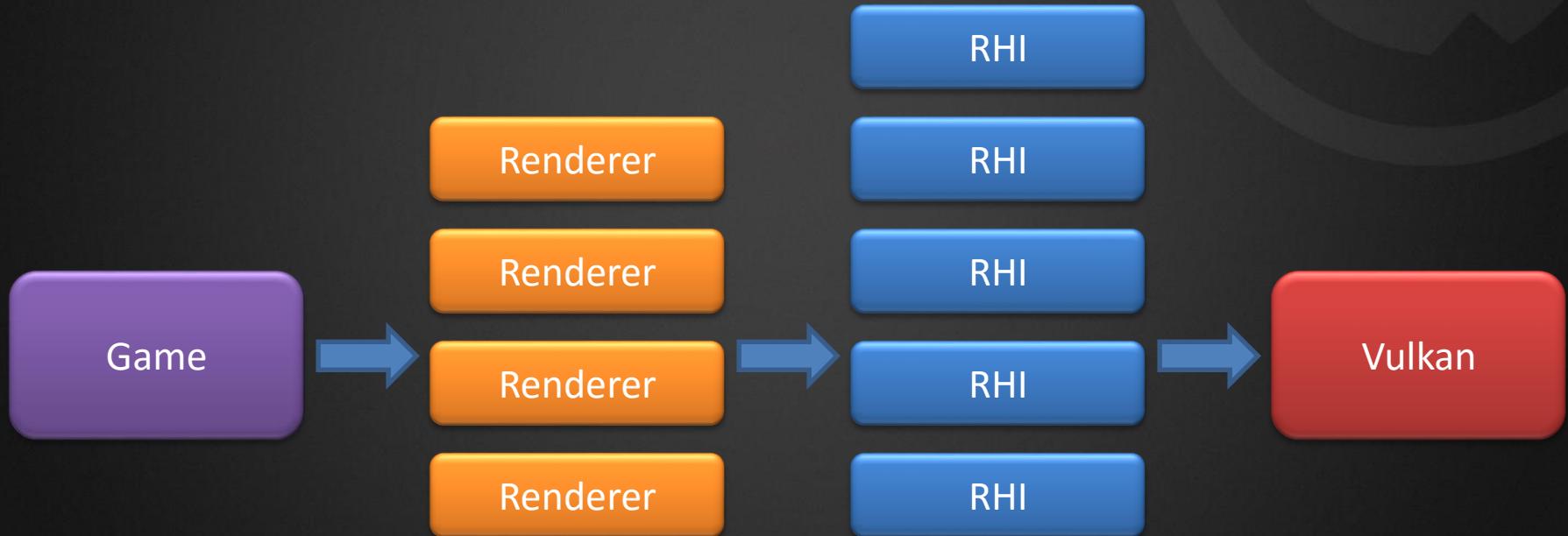
UE4 RHI Architecture in a hurry

- Improved architecture
 - Game Thread enqueues rendering commands
 - Rendering Thread generates RHI command list
 - RHI Thread translates into Vulkan Cmd Buffers



UE4 RHI Architecture in a hurry

- Finally, multithreaded: N Render threads with M RHI threads



UE4 RHI Architecture in a hurry

- Why use the RHI command list/thread and not directly generate Vulkan commands?
 - Easier to bring up new RHIs!
 - Allows us to decouple frontend/backend which makes multithreading easier
 - We got a CPU improvement ~5 - 10% due to cache locality (both instruction & data)

Vulkan

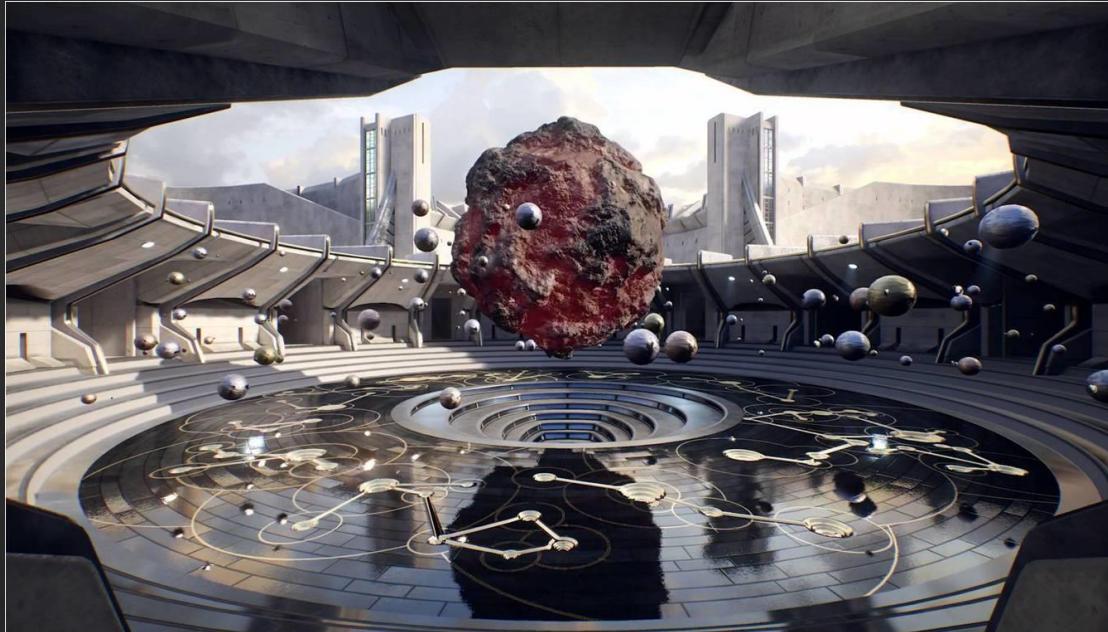
- Why?
 - Cross-platform, high-performance API
 - Predictability
 - eg Driver doesn't mysteriously take different time during the same draw calls on different runs
 - Control over memory allocations, aliasing
 - Control over GPU performance
 - Flushing caches, etc
 - Very similar to D3D12 and Metal



Protostar

- Collaboration between Epic, Samsung, Qualcomm and Confetti
- Tech Demo showcasing the Samsung S7 phone and the Vulkan API on mobile
 - Help push the industry adoption of Vulkan!

Protostar



Video!

Vulkan RHI 0.1

- One big pool for DescriptorSets
 - 32k entries
 - Would run out after a while, plus had some sync issues
- All updates to buffers/textures doing in-place map/unmap
 - Didn't work on some drivers as they don't allow linear textures on host visible memory
- Immediately after every unmap, submit CmdBuffer and wait
 - GPU stalling the CPU during load!

Vulkan RHI 0.1

- Crazy hitching during PSO creation
 - We'll talk about that more later...
- No RHI thread
 - Rendering Thread directly generating Vulkan commands
- Barely hitting 20 fps on CPU

Vulkan RHI 0.2

- Optimization time!
 - Profile CPU using hierarchical counter and address each bottleneck
 - eg DescriptorSet writes were generated every update, so cache them!
 - eg Split DescriptorSets into one for Vertex and one for Pixel
 - eg Remove tons of dynamic object allocations
 - Rinse & repeat!
- After a couple of weeks doing optimization work, got to 30 fps on both CPU & GPU

Vulkan RHI 0.2

- However lots of validation issues...

Vulkan RHI 0.2

- However lots of validation issues...



Vulkan RHI 0.2

- However lots of validation issues...
- Ship it!

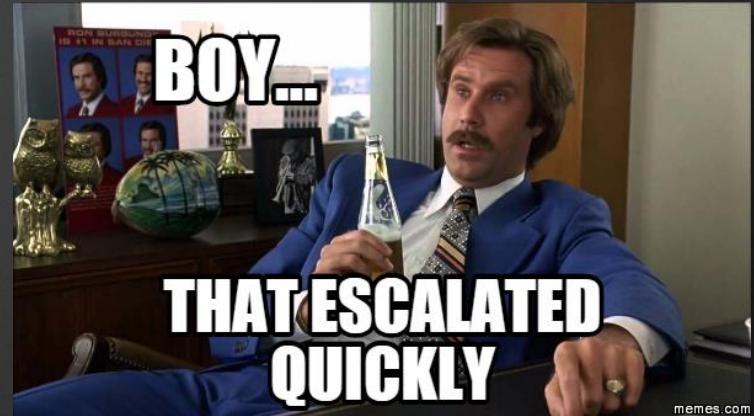


Vulkan RHI 1.0

- Demo out of the door!
- Now figure out what is needed to make this usable for full titles!
 - Just come up with a list...

Vulkan RHI 1.0

- Demo out of the door!
- Now figure out what is needed to make this usable for full titles!
 - Just come up with a list...



Vulkan RHI 1.0 Task List

- Cleanup
 - Remove all TODOs & hacks

Vulkan RHI 1.0 Task List

- Cleanup
 - Remove all TODOs & hacks



Vulkan RHI 1.0 Task List

- Robust & fault tolerant
- Support separate RHI thread
 - Then support parallel RHI threads!
- Pass all validation layer warnings!
 - Some perf warnings *might* be acceptable...
 - eg Pixel shader outputs to disabled attachment

Vulkan RHI 1.0 Task List

- Feature parity with D3D12 & Metal

Vulkan RHI Task list

- Run Kite!



Vulkan RHI Task list

- Run Paragon!
 - Same or better than D3D11!



And Beyond!

- Get the full Editor running...



Today's Vulkan RHI

- Today's state:
 - Separate RHI Thread translating commands
 - Mobile renderer working
 - Decent perf
 - Missing optimized Descriptor Set Layouts
 - Passing most validation
 - Mostly missing image layouts
 - Starting to get SM4/Deferred up & running

Today's Vulkan RHI

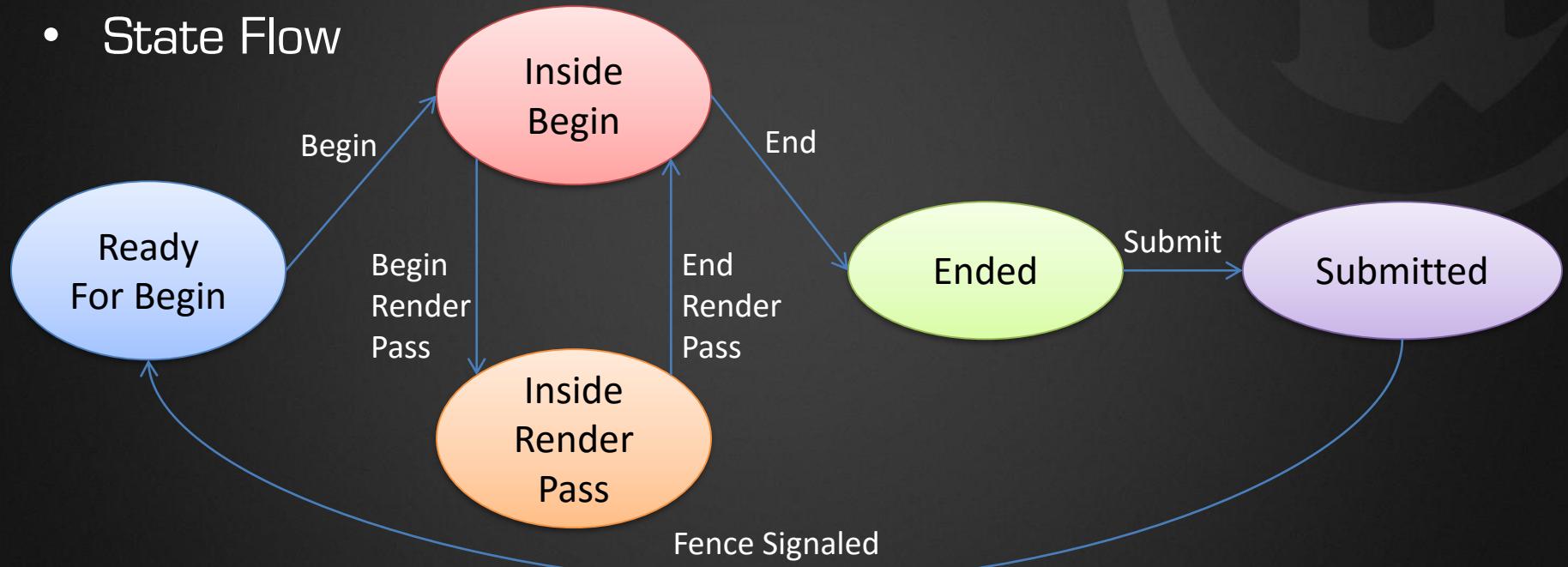
- Command Buffers
- Resource Management
- Back Buffer/Swapchains
- Rendering
- Render Passes
- Shaders
- PSOs
- Tools

Vulkan RHI: Command Buffers

- Every RHI thread/Context has a CmdBuffer Manager
- CmdBuffer Manager has a list of persistent CmdBuffers
 - Also has an Active and Upload CmdBuffer
 - Upload needed as you can't copy data in the middle of a RenderPass
- Every CmdBuffer:
 - Has a Fence and a Counter
 - Tracks how many times the Fence has been signaled (Periodically queried, then reset to unsignaled)
 - Knows its state (ReadyForBegin, Inside/OutsideRenderPass, Ended, Submitted)

Vulkan RHI: Command Buffers

- State Flow



Vulkan RHI: Resources

- Buffers, Images, Fences and Semaphores
- Allocating a Resource means acquiring one from its pool
 - Could be a reused one
 - Could be a brand new one
- Releasing a Resource means not used by the application
- Destroying a Resource means calling `vkDestroy*`()

Vulkan RHI: Resource Managers

- General Pattern for Managers:
 - Has a UsedList, PendingFreeList and FreeList
 - Alloc resource
 - Is there a matching one in the FreeList? If so return one from there and move to the UsedList, otherwise make a new one and put in UsedList
 - Release resource
 - Move from UsedList to PendingFreeList, and store Fence Count
 - Periodically (eg once per frame, every CmdBuffer submit)
 - Go through FreeList and anything not used for N frames, Destroy
 - Go through PendingFreeList, and if the Cmd Buffer's Fence counter > Released Fence counter, move to FreeList

Vulkan RHI: Other Managers/Utils

- Buffer SubAllocations
 - Manages sub-ranges so we don't constantly have to create VkBuffers
- Fence Manager
- TempFrameAllocator
 - Tape/linear buffer sub allocations, resets every frame (after Fence signaled)
- Deferred Deletion Queue
 - High level releases a ref count ptr of a texture or buffer, which gets added to this Queue
 - This checks Fences and directs it to its appropriate Resource Manager

Vulkan RHI: BackBuffer/Swapchain

- `RHI::GetBackBuffer()`
 - That would be ideal place for calling `vkAcquireNextImageKHR()`
 - But that's called both inside and outside `RHI::BeginViewport()` and potentially multiple times, both on Render and RHI threads
 - RHI Thread would have to sync back with Rendering Thread
 - One solution would be to have 2 BackBuffers:
 - One for Rendering Thread
 - One for RHI Thread
 - Makes sync with Queues & Presentation hard!

Vulkan RHI: BackBuffer/Swapchain

- Instead: Dummy BackBuffer texture
 - Rendering Thread creates new dummy texture if it doesn't have one
 - And Inserts a command for the RHI thread to call `vkAcquireNextImage()`
 - Now Renderer can sets the Dummy BB to nullptr when needed

Render Thread:

```
GetBackbuffer()  
if (!BB)  
    BB=new Dummy  
    InsertRHICmd()  
return BB
```

```
AdvanceBackBuffer()  
BB=nullptr
```

RHI Thread:

```
ExecCmd: vkAcquireNextImage()
```

```
Use Acquired Image Index
```

Vulkan RHI: Rendering (State)

- High-level Renderer:
 - SetBoundShaderState(VS, PS)
 - SetDepthStencilState(...)
 - Draw(A)
 - Draw(B)
 - SetRasterizerState(...)
 - Draw(C)

Vulkan RHI: Rendering (State)

- High-level Renderer:
 - SetBoundShaderState(VS, PS)
 - Reset BSS state for this thread, mark all state flags dirty
 - SetDepthStencilState(...)
 - Set DepthStencil state flags dirty
 - Draw(A)
 - PrepareDraw
 - Find PSO with all state flags in cache, or create if needed
 - State flags marked as no longer dirty
 - vkCmdDraw()

Vulkan RHI: Rendering (State)

- [...]
 - Draw(B)
 - PrepareDraw
 - NoOp (no dirty flags), use current PSO
 - vkCmdDraw()
 - SetRasterizerState(...)
 - Mark Rasterizer state flags as dirty
 - Draw(C)
 - PrepareDraw
 - Find PSO with all state flags in cache, or create if needed
 - State flags marked as no longer dirty
 - vkCmdDraw()

Vulkan RHI: Rendering (Resources)

- High-level Renderer:
 - SetBoundShaderState(VS, PS)
 - Draw(A)
 - Draw(B)
 - SetTexture()
 - Draw(C)

Vulkan RHI: Rendering (Resources)

- High-level Renderer:
 - SetBoundShaderState(VS, PS)
 - Mark dirty DescriptorSet Write list
 - Draw(A)
 - PrepareDraw()
 - If dirty Write list
 - » Get new DescriptorSets from Pool, update and bind
 - » Set Write list to not dirty
 - vkCmdDraw(...)
 - Draw(B)
 - PrepareDraw()
 - NoOp as no dirty write list
 - vkCmdDraw(...)

Vulkan RHI: Rendering (Resources)

- [...]
 - SetTexture()
 - Update Write list and set to dirty
 - Draw(C)
 - PrepareDraw()
 - If dirty Write list
 - » Get new DescriptorSets from Pool, update and bind
 - » Set Write list to not dirty
 - vkCmdDraw(...) and set not dirty Write list

Vulkan RHI: Render Passes

- UE4 has no concept of Render Passes
 - SetRenderTarget(...)
 - Draw(...)
 - CopyToResolveTarget(...)
 - SetRenderTarget(...)
 - Draw(...)
 - Dispatch() [Compute]
 - Draw(...)
 - SetRenderTarget(...)
 - Draw(...)

Vulkan RHI: Render Passes

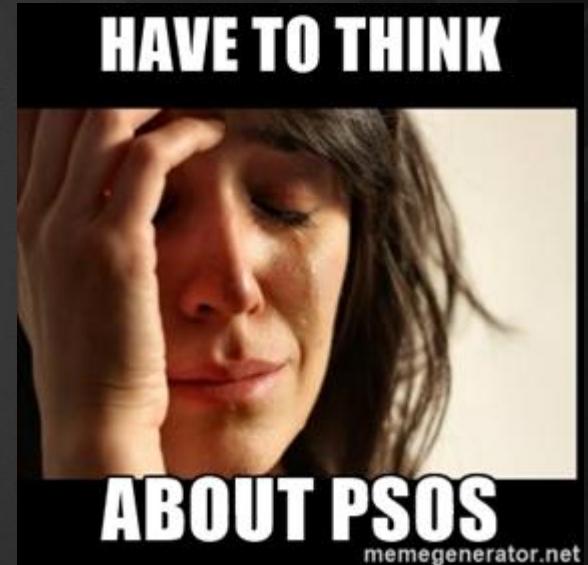
- No good way (yet) for tracking transitions
 - The Renderer can also be multithreaded!
 - Renderer can switch to compute workloads w/o knowledge of previous state
- Tied also to resource/layout transitions/barriers
 - Started exposing resource transitions in the RHI but not enough info
- Still active area of research
 - Might need to expose it at the higher level

Vulkan RHI: Shaders

- Shaders are written in hlsl (usf files)
- Use hlslcc to convert from hlsl>glsl
 - Then converted to SPIR-V using glslang lib from the VulkanSDK linked into the Engine
- Might have a direct SPIR-V backend for hlslcc
 - Will depend on extensions/features

Vulkan RHI: PSOs

- UE4 compiles shaders conservatively
 - Runtime matching of vertex/pixel shaders
 - Any combination can be done at runtime
 - eg Blueprint dynamically adds a point light
 - Might have N vertex shaders, M pixel shaders
 - Unfeasible to pre-compile all combinations!
 - Have to create at runtime, causing hitches



Vulkan RHI: Shader Pipelines

- We already had added support for Shader Pipelines
 - Declare Vertex+Pixel stages at compile time
 - But not all passes support it yet (only Depth and Velocity currently)
 - Used to remove unused interpolators between Pixel & Vertex shaders as some architectures benefit from it
 - Original plan was to migrate this into PSOs
 - But still need all the rest of the state specified to be useful!

Vulkan RHI: Protostar

- We needed something so the demo wouldn't hitch
 - First run-through experience not awesome due to so many PSOs being created
 - Couldn't use ShaderPipelines as many passes not yet converted
 - Solution: Pipeline Cache!

Vulkan RHI: PSO Cache

- Cache:
 - Add every new unique PSO to a runtime cache off a hash from the render states and shader microcode's CRC
 - Trigger a save command from console and serialize to disk
 - At load time if the file is there, pre-create the PSOs
 - Two levels: Local cache inside BoundShaderState, and global one
 - Is PSO key inside local BSS? Yes -> return local BSS copy
 - Is PSO key inside global BSS? Yes->copy to local BSS and return
 - Otherwise, create new PSO and add to both global and local caches
 - Virtually hitch-free in the final demo!

Vulkan RHI: PSO Cache

- Issues:
 - Shader code changes all the time
 - Out of sync whenever materials get tweaked
 - Doesn't catch all cases... gotta catch 'em all!
 - Some studios don't have the resources to have QA running through the full game
 - Cache can be YUGE
- Really need a better solution...

Vulkan RHI: PSO Plans

- Plan A: Started prototyping real PSO support
 - Still researching API and impact to codebase
- Plan B: Doing research for specifying a ‘general’ PSO with some common/default state
 - Use derived pipelines [*VK_PIPELINE_CREATE_DERIVATIVE_BIT*] to get faster compiles
 - We do know *some* PSOs that might be needed at load time
 - Just not all of them

Vulkan RHI: PSO Plans

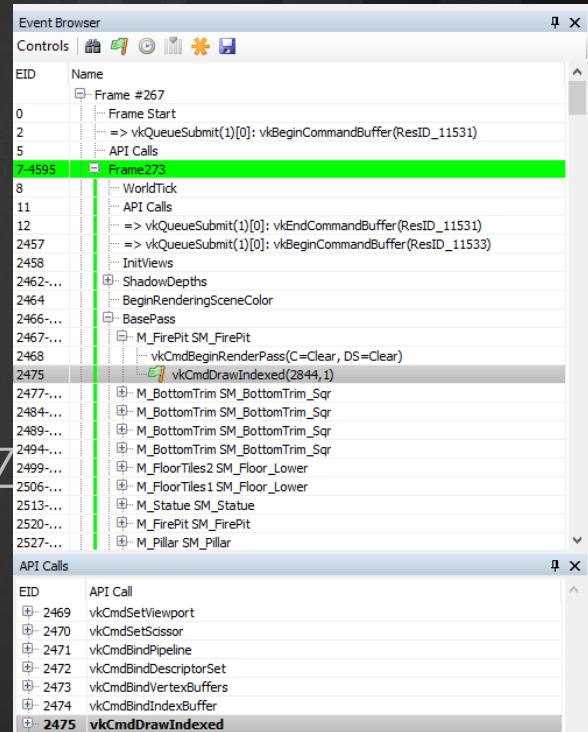
- Plan C: On the RenderThread, when creating a PSO we can start compiling an unoptimized version [*VK_PIPELINE_CREATE_DISABLE_OPTIMIZATION_BIT*] in another thread
 - Hopefully it compiles faster!
 - With enough latency between RenderThread and RHI Thread, might be enough time to hide the hitch!
 - Meanwhile on another thread compile the optimized version and swap once its done
- Plans orthogonal and final solution probably a mix of all

Vulkan RHI: Tools

- You're only as good as your tools ;)
- Use Vulkan's Validation Layers!
 - BOLO for yesterday's BoF on Vulkan Tools Loader and Validation session from Khronos

Vulkan RHI: Tools

- Use RenderDoc!
 - <https://renderdoc.org/builds>
 - Vital on UE4 for tracking/diagnosing issues
 - Not just for Vulkan! (D3D11, OpenGL)
 - Use Debug Markers and Object Names
 - http://www.saschawillems.de/?page_id=2017



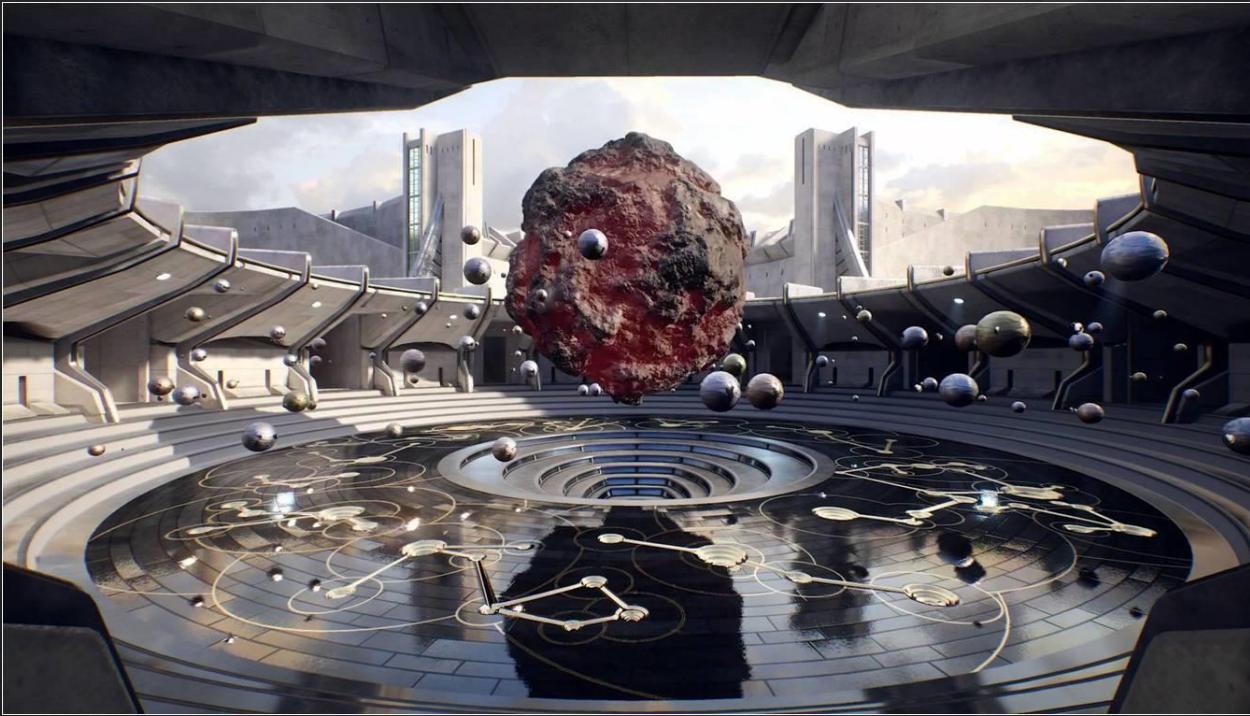
Vulkan RHI: Closing...

- But wait, there's more!
 - Plans on investigating:
 - Render Subpasses
 - Push Constants
 - Reworking Descriptor Set Layouts
- Drivers are greatly improved, but you'll still run into BSODs
 - Report bugs to IHVs with repro steps
 - At least get one card from each major vendor
 - Helps you determine if it's a driver issue or a bug in your code

Thanks!

Rendering,
Core Rendering,
Mobile Rendering
&
Platform Teams

Samsung,
Qualcomm &
Confetti



Q?
[@rcalocao](https://twitter.com/rcalocao)

Porting DOOM to Vulkan

SIGGRAPH 2016

Axel Gneiting

id Software



SIGGRAPH 2016



Agenda

- Demo & short idTech 6 overview
- Porting to Vulkan
 - Shaders, pipelines & states
 - Descriptor Sets
 - Multithreading
 - Image layouts & barriers
 - Memory & synchronization
 - Asynchronous compute
- Results & Future Work



DOOM



Video



SIGGRAPH 2016



idTech 6

- PC OpenGL & Vulkan, PS4, Xbox One
- DOOM and future id Software titles
- 60+ Hz on all Platforms
- Shader syntax similar to HLSL
 - Translated to PSSL/HLSL/GLSL at build time



CPU

- Parallel command buffer generation
 - Split up into several “contexts” per frame
 - Each contexts owns command buffer
 - For each context we run multiple jobs to fill CB
 - Last job in frame submits command buffers to GPU
- OpenGL runs sequential on one thread
 - Some scene preparation work is still in jobs



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GPU

- Clustered forward shading with some deferred
- Same shader for most of the geometry
 - Same set of textures too (virtual texturing)
 - Very few state changes
- Extensive post process
 - DoF, Temporal AA, SSDO, motion blur, etc.
- Lots of asynchronous compute
 - DXT encode, particles & post processing



Porting to Vulkan

- Started 2015 with an early version
 - Wrote most of the Vulkan backend code
 - Got first triangle rendering
- Picked it up in late March 2016 again
- Was mostly running at game launch
 - RenderDoc helps, even better now!
- Small issues delaying release ☹
 - Driver issues
 - Swap chain surprisingly hard to get right



Porting to Vulkan

- Validation layers were unreliable back then
- Lots of false errors
- Had to write some validation code ourselves
- Validation layers much better now
- Still good to have own validation for debugging



Shaders

- Already had GLSL translator
 - But OpenGL was binding by name
 - Vulkan uses binding IDs at pipeline creation
- Using AMD extensions if available
 - Variant for all shaders
 - AMD_shader_ballot & AMD_gcn_shader



Shaders

- Normalized clip space is upside down
 - Shader generator adds `gl_Position.y = -gl_Position.y` at end of every vertex program
 - Can we please have an extension that fixes this?
 - Platform differences are a waste of time
- Z range is good: [0,1] ☺



Pipelines & States

- Abstraction layer still old style API like
- Need to emulate stateful API & track states
- Hash table for pipelines, render passes & frame buffer states
 - Way smaller perf overhead than thought
- Dynamic state for scissor/viewport/stencil and depth bias
- Only ~350 total graphics pipelines for entire game



Pipelines & States

- Pipeline creation expensive
 - Lookup misses unacceptable at runtime
 - Some pipelines take 100+ ms to compile
- Solution
 - Play game and serialize states to disk
 - On startup launch jobs to compile pipelines
 - Fairly robust, missed pipelines would just cause stalls for player



Descriptor Sets

- No deletion of Vulkan objects while playing
 - Geometry statically loaded
 - Textures virtualized
- Got away with a descriptor hash table
- One big descriptor set for each combination
- Complete table flush if a Vulkan handle gets deleted
 - Level load & unload, etc.
- About 3-4k descriptor sets usually



Descriptor Sets

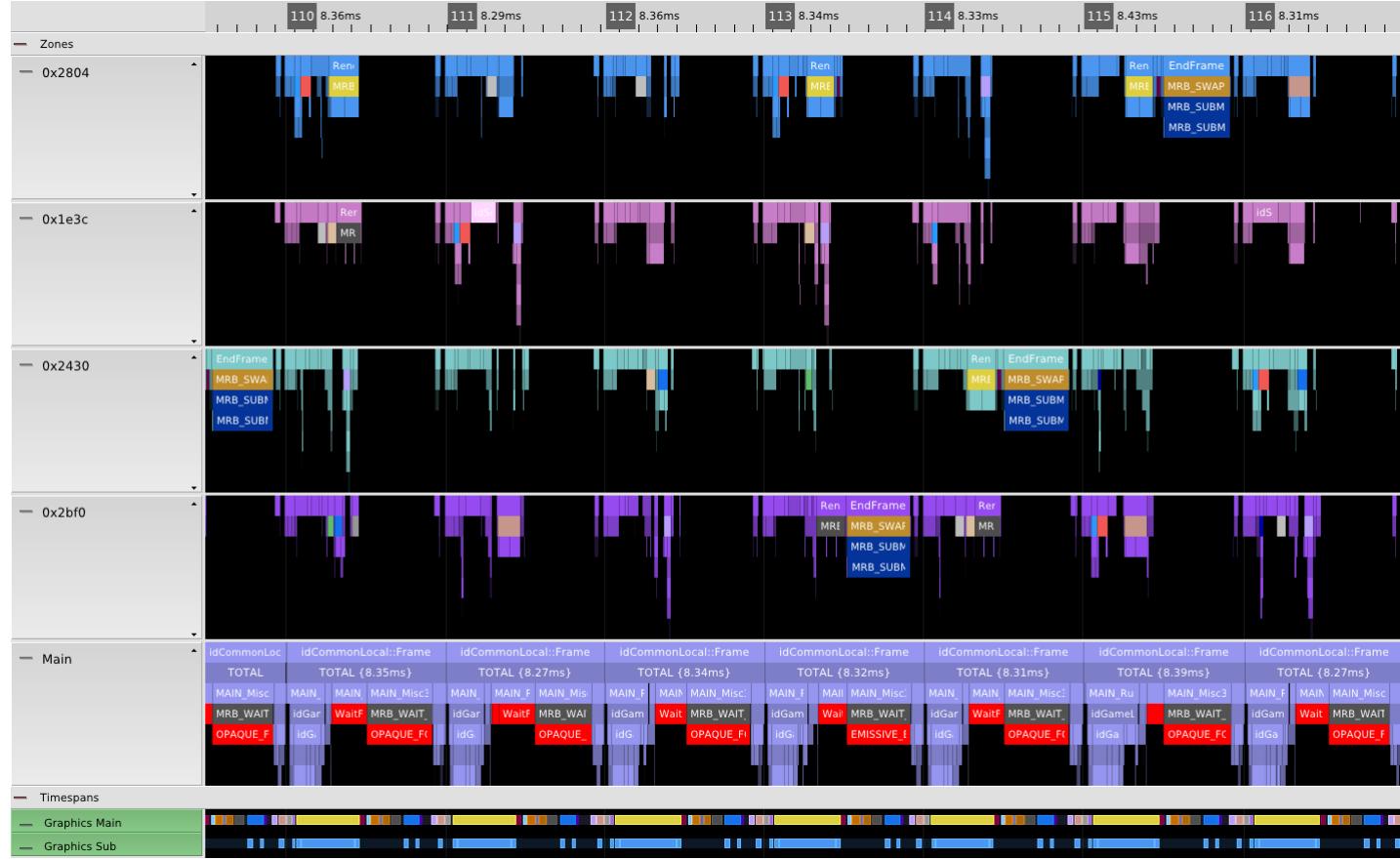
- Dynamic uniforms written to ring buffer
- Thread safe allocation from ring with atomics
 - 256 byte align allocations for simplicity
- Bound with UNIFORM_BUFFER_DYNAMIC
 - Offset set as vkCmdBindDescriptorSets parameter
- Also used UNIFORM_BUFFER_DYNAMIC for skinning data
 - Baked range problematic
 - Got away with 64kB range for everything
 - Alternative would have been way more descriptor sets



Multithreading

- Mostly straight forward port from consoles
- Image layouts problematic (more soon)
- Double buffered CBs per context
- Read/write locks for state hash tables
 - Never blocks if no state misses





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Image layouts & barriers

- Image layouts were a big headache
 - 25+ barriers per frame
 - Hundreds of layout changes
- Combining as many barriers as possible
- Knowing last image state difficult
 - We only specify the new state in code
- But parallelism makes complete automatic tracking impossible



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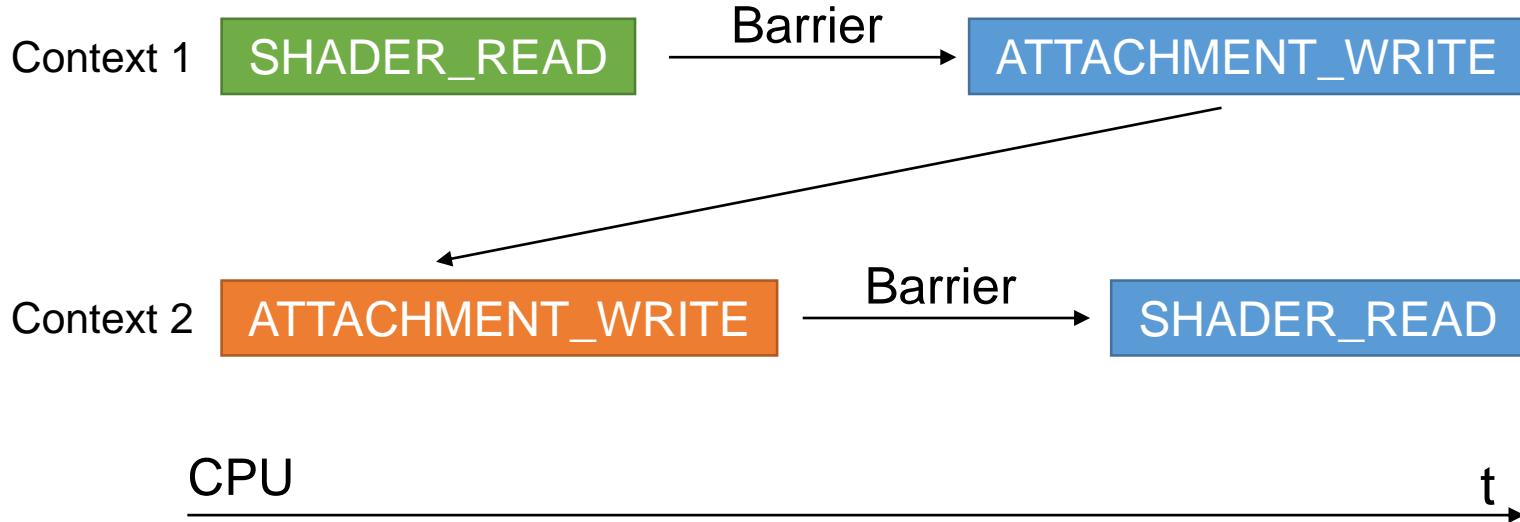


Image layouts & barriers

- Automatic tracking inside each context / CB
- Not many images used across CBs
- Start of frame: Set state for start of CB to fix up missing tracking
- End of frame:
 - Go over transitions & determine initial next frame state
 - Validate image transitions
- No vkCmdSetEvent/vkCmdWaitEvents right now



Image layouts & barriers



Memory

- Simple block allocator
 - Split into max 128 MB pieces
 - Try smaller allocation until allocation succeeds
 - Or falls back to system memory if allocations fail in VRAM
 - Resizable images allocated individually
- NVIDIA problematic under pressure (2GB)
 - Lots of fixes in driver by now
 - Use NV_dedicated_allocation if possible



Memory

- All uploads through common manager
- Double buffered host staging memory
- Each staging buffer associated with
 - Command buffer
 - Fence
- If buffer is full, write fence at end of CB and submit
- Wait on fence before reuse
- Flush host visible ranges before graphics submits



Synchronization

- Double buffering everywhere
 - Wait for command buffer fence on CPU
 - Minimizes latency
- GPUView is your friend!
 - Much more useful than with OpenGL/DX11
- Swap chains are tricky
 - Make sure acquire & present always matching
 - Acquire as late as possible (avoids stalls)



- Semaphore Wait
- Semaphore Signal
- Present
- Work (Submit)
- API Calls

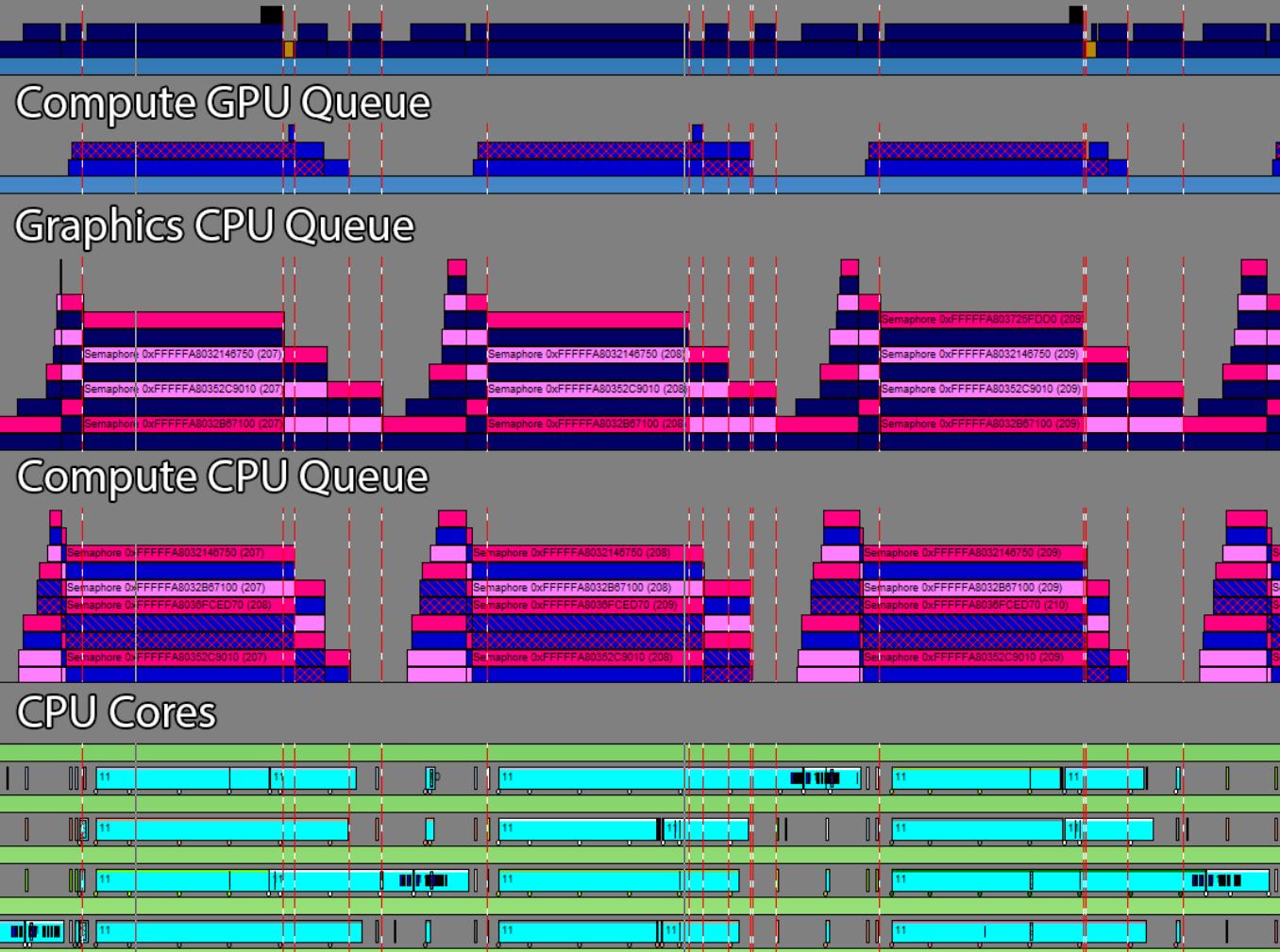
Graphics GPU Queue

Compute GPU Queue

Graphics CPU Queue

Compute CPU Queue

CPU Cores



Asynchronous Compute

- Useful for leveraging wasted GPU idle time
 - E.g. during shadow & depth pass
- GPU particles & post process
- Post process overlaps with beginning of next frame
 - Present from compute queue on AMD
 - NVIDIA still working on driver support
- Using SHARING_MODE_CONCURRENT for render targets
 - Careful, might be slower



Results

- Very pleased with performance gains
- 60%-70% in some scenes on AMD in GPU limit
 - Faster than OpenGL even without async/intrinsics
- NVIDIA GPU time about the same
- Render CPU limit is mostly gone
 - People reporting 60+ Hz in power saving mode
- Lots of potential



Future Work

- Prepare image barriers & layouts at beginning of frame
- Remove hashes and make high level code aware of states
- Know exactly what pipelines are used in game
- Better use of render passes (sub passes, layout transitions)



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Future Work

- Split barriers (`vkCmdSetEvent/vkCmdWaitEvents`)
- Command buffer reuse (e.g. deferred passes & post process)
- More asynchronous compute
- Asynchronous transfers



Thanks

- Jean Geffroy, Tiago Sousa, Billy Khan & the whole team at id Software
- Baldur Karlsson for RenderDoc
- AMD and NVIDIA for help on Vulkan port
- Make sure to play the game!



We are Hiring

- Various openings across Zenimax Studios !
- Please visit <https://jobs.zenimax.com>



Panel: Best Practices for Programming to the Vulkan API



Chris Hebert 

Developer of Technology Engineer
Optimizing Cuda, OpenGL, & Vulkan
for ISVs targeting Nvidia HW



Tobias Hector 

Software Design Engineer, PowerVR
API and Extension Development



Dan Archard 

Principal Engineer, ACG Team
Getting the most out of Vulkan
on Qualcomm HW



Axel Gneiting 

Senior Engine Programmer
Ported Doom to Vulkan



Rolando Caloca 

Sr. Rendering Engineer
Vulkan port of Unreal Engine 4

Memory Transfers and Pipeline Barriers



Chris Hebert
Developer of Technology
Engineer



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Moving Forward with Vulkan

Pipelining Memory Operations

Chris Hebert, Dev Tech Software Engineer, Professional Visualization



Agenda

- CPU -> GPU Transfers
- Pipeline Barriers

CPU->GPU Transfers

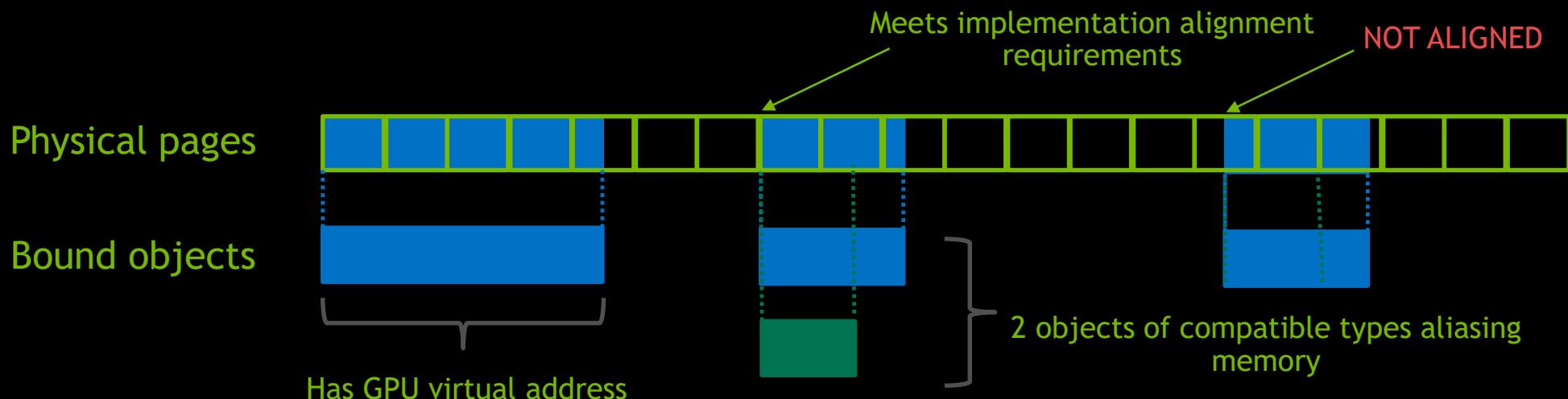
Low-level memory control

Console-like access to memory

Vulkan exposes several physical memory pools - device memory, host visible, etc.

Application binds buffer and image virtual memory to physical memory

Application is responsible for sub-allocation



Resource management

Allocation and Sub allocation

HEAP supporting A,B

HEAP supporting B



Allocate memory type from heap

Allocation Type A

Allocation Type B

...



Query resource about size, alignment & type requirements

Assign memory subregion to a resource (allows aliasing)

Image

...

...

Buffer

Create resource views on subranges of
a buffer or image (array slices...)



BufferView

BufferView

Resources

Give Vulkan something to work with

Vulkan exposes several heaps of different types

Vulkan heaps support different properties

- `VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT` → Fastest to access from GPU
- `VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT` → Slower but visible from CPU
- `VK_MEMORY_PROPERTY_HOST_COHERENT_BIT` → No need to flush/invalidate
- `VK_MEMORY_PROPERTY_HOST_CACHED_BIT` → Faster, may need to flush/invalidate
- `VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT` → Device only, but allocated at a later time

Resources

PCIe vs SoC(UMA)

HOST_VISIBLE OR DEVICE_LOCAL



Type 1 : DEVICE_LOCAL
Type 2 : HOST_VISIBLE | HOST_COHERENT
Type 3 : HOST_COHERENT | LAZILY_ALLOCATED

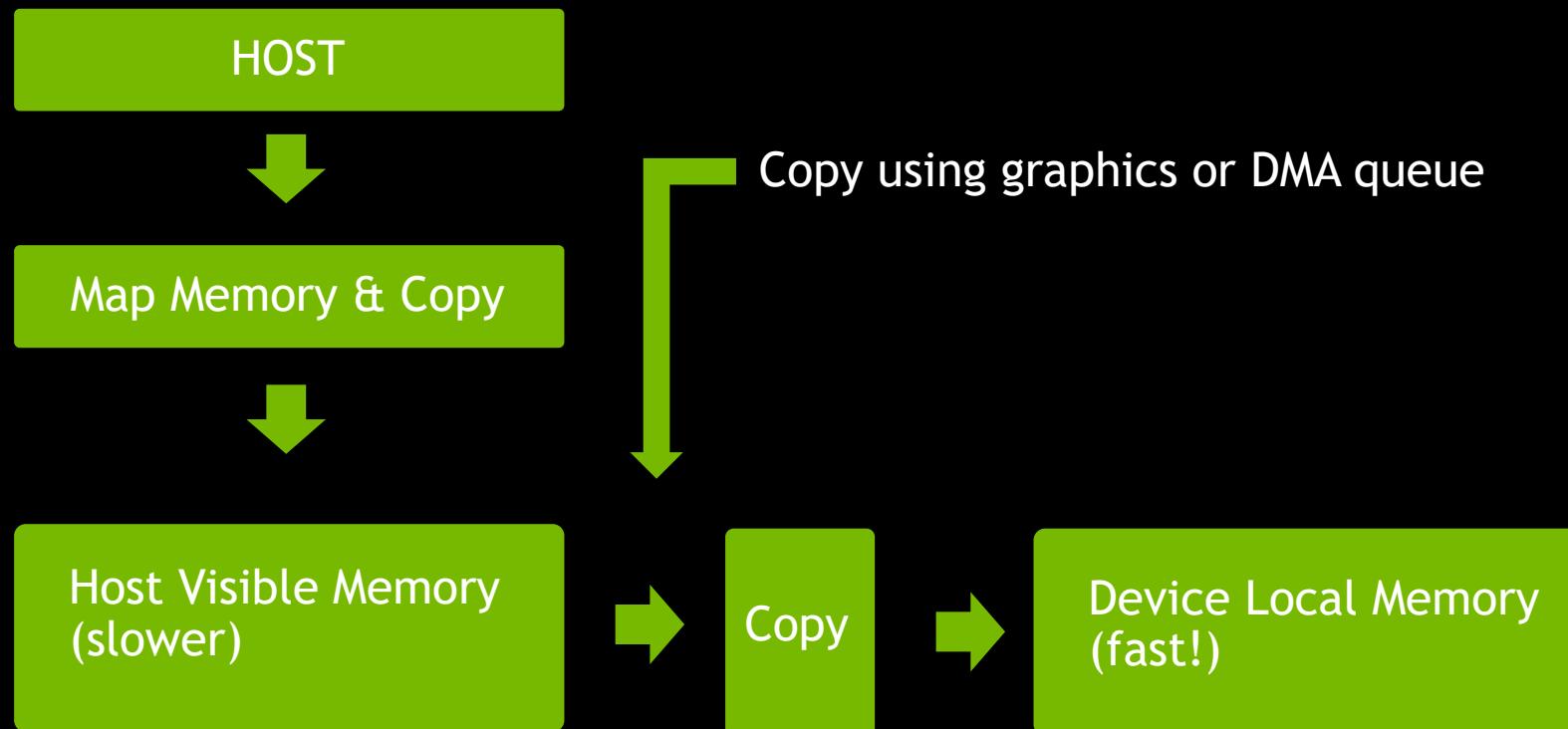
HOST_VISIBLE AND DEVICE_LOCAL



Type 1 : DEVICE_LOCAL
Type 2 : DEVICE_LOCAL | HOST_VISIBLE | HOST_COHERENT
Type 3 : DEVICE_LOCAL | HOST_VISIBLE | HOST_CACHED

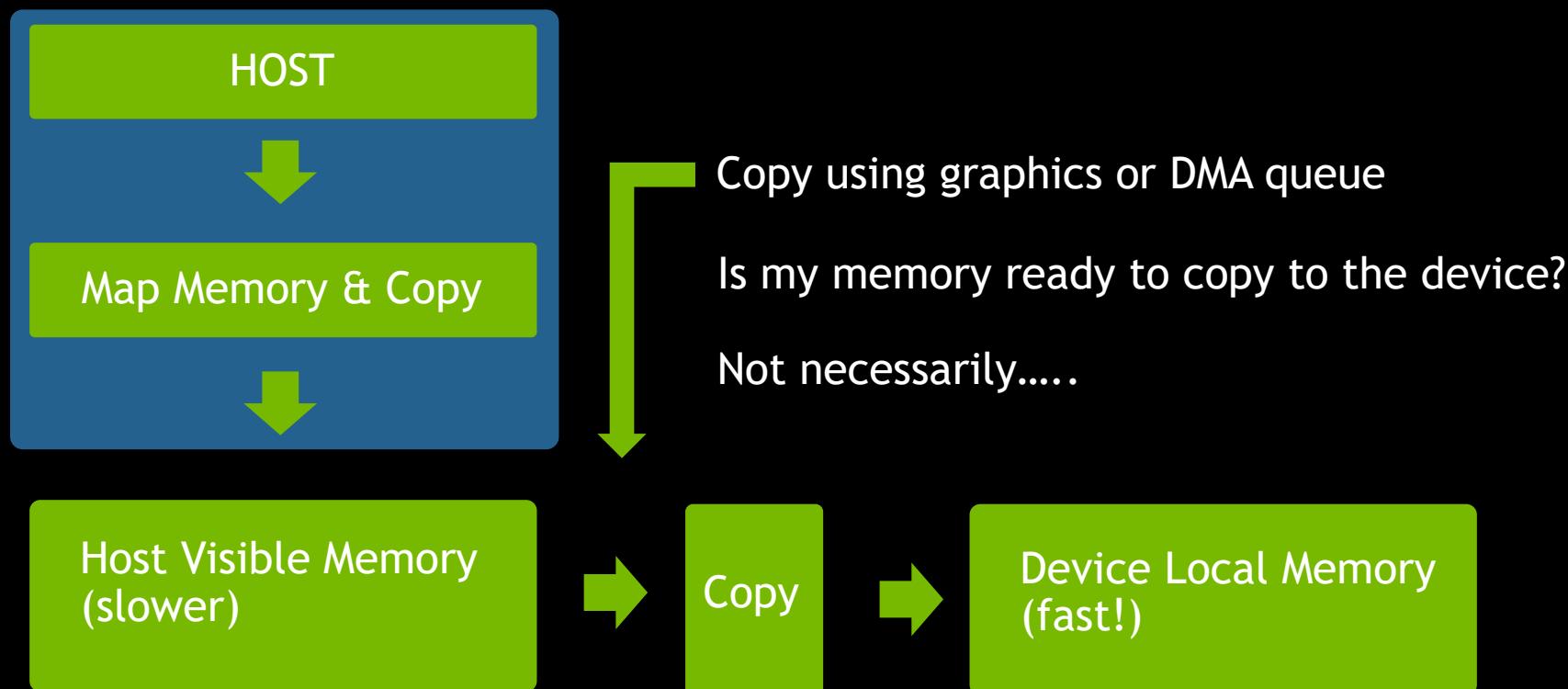
Staging memory

Using staging buffers



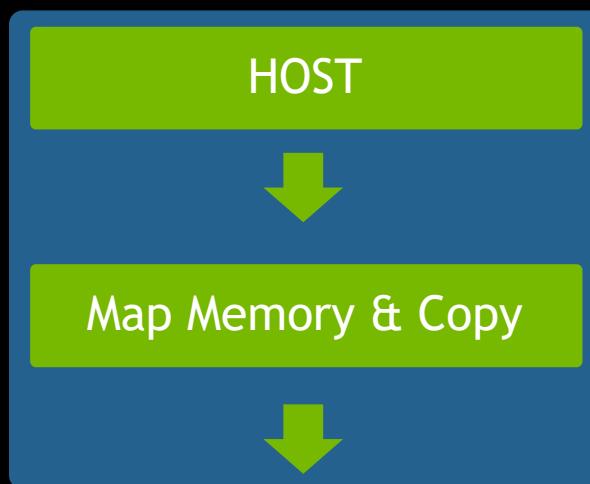
Staging memory

Using staging buffers



Staging memory

Using staging buffers

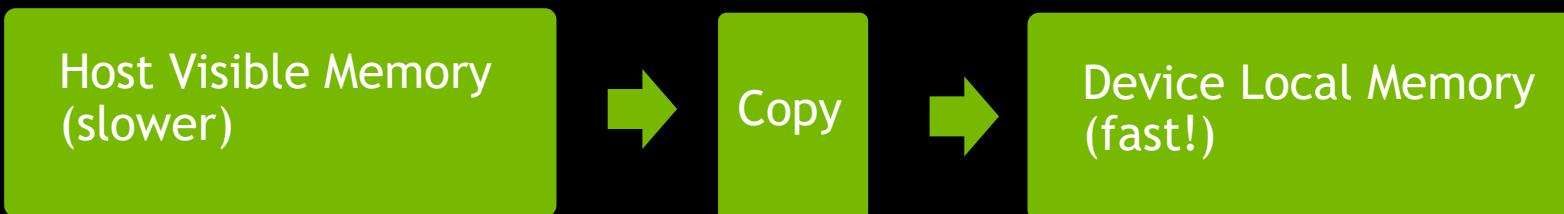


If `VK_MEMORY_PROPERTY_HOST_COHERENT_BIT` Is supported on the heap, then no need to flush.

Otherwise, blocking call to :

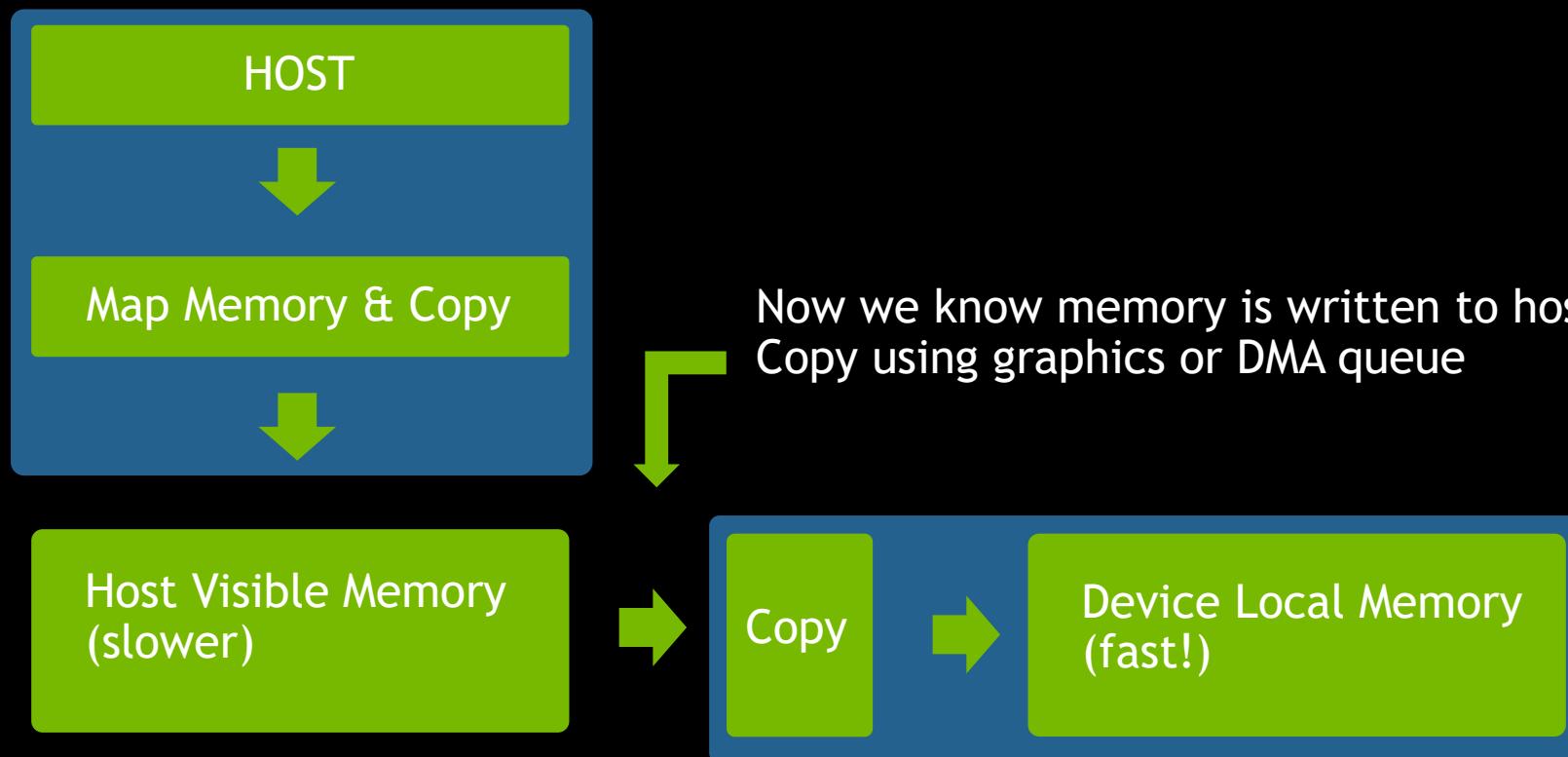
```
VkResult vkFlushMappedMemoryRanges(  
VkDevice device,  
uint32_t memoryRangeCount,  
const VkMappedMemoryRange* pMemoryRanges);
```

Will flush any memory still to be written.



Staging memory

Using staging buffers



Memory synchronisation

Using pipeline barriers

In any application, both reads from and writes to memory take place frequently.

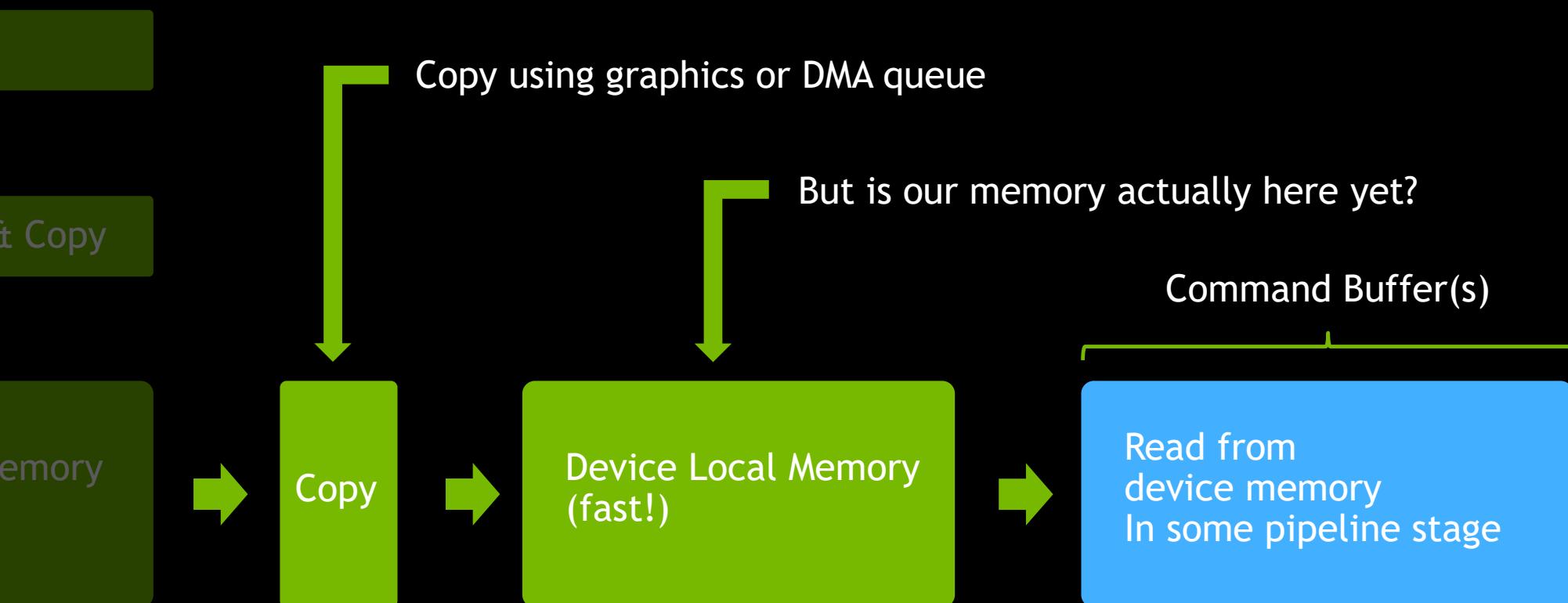
Potential for hazards even in single thread.

Examples (by no means exhaustive):

- Staging large uniform or vertex buffer updates
- Reading from texture rendered to in a previous pass
- Staging large buffer for compute work.

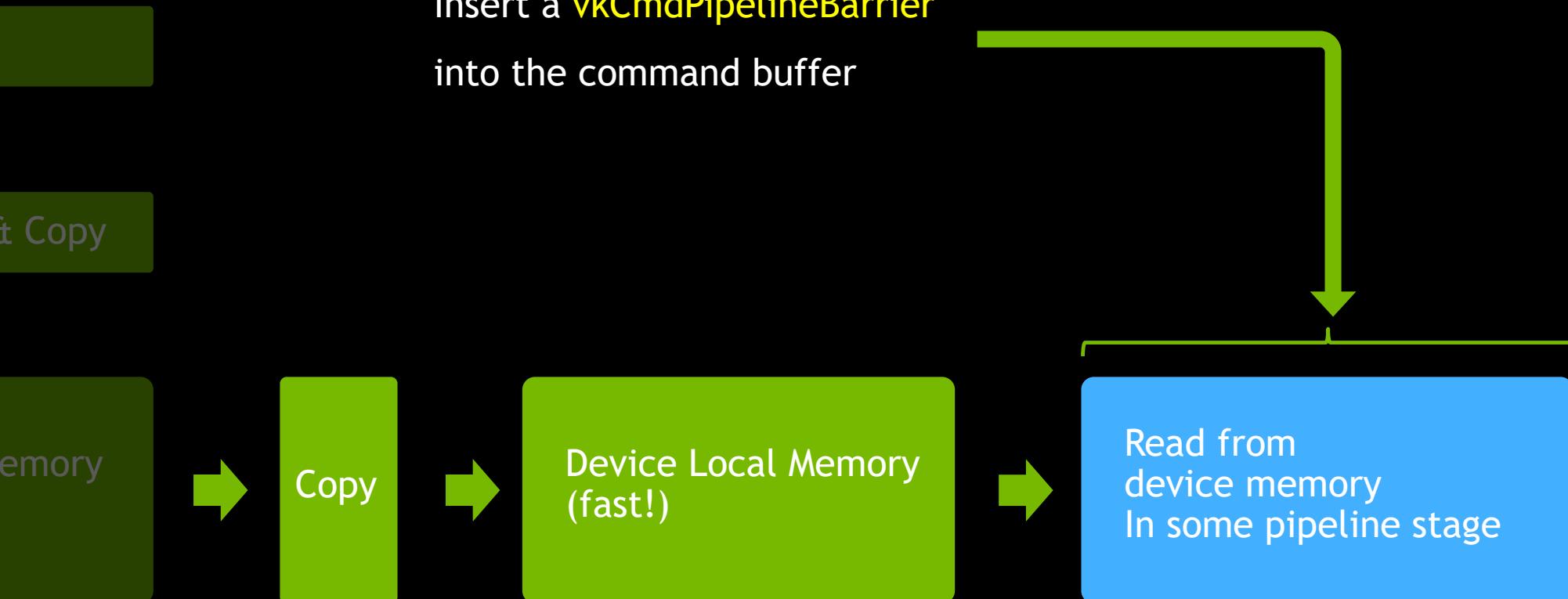
Staging memory

Using pipeline barriers



Staging memory

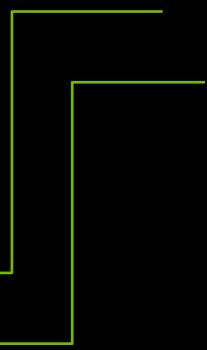
Using pipeline barriers



Staging memory

Using pipeline barriers

```
void vkCmdPipelineBarrier(  
    VkCommandBuffer commandBuffer,  
    VkPipelineStageFlags srcStageMask, ←  
    VkPipelineStageFlags dstStageMask, ←  
    VkDependencyFlags dependencyFlags,  
    uint32_t memoryBarrierCount, const VkMemoryBarrier* pMemoryBarriers,  
    uint32_t bufferMemoryBarrierCount, const VkBufferMemoryBarrier* pBufferMemoryBarriers,  
    uint32_t imageMemoryBarrierCount, const VkImageMemoryBarrier* pImageMemoryBarriers);
```



All of these must be complete....
... before any of these execute.
(e.g.
VK_PIPELINE_STAGE_VERTEX_INPUT_BIT
VK_PIPELINE_STAGE_VERTEX_SHADER_BIT
VK_PIPELINE_STAGE_TRANSFER_BIT)

Staging memory

Using pipeline barriers

Can take arrays of :

- | | | |
|-----------------------|---|--|
| VkMemoryBarrier | - | Global barrier for all memory types |
| VkBufferMemoryBarrier | - | Scoped to a range defined by the buffer |
| VkImageMemoryBarrier | - | Can also perform layout transitions (where applicable) |

```
typedef struct VkMemoryBarrier {  
    VkStructureType sType;  
    const void* pNext;  
    VkAccessFlags srcAccessMask; <--  
    VkAccessFlags dstAccessMask; <--  
} VkMemoryBarrier;
```

All of these must complete
with the srcStageMask of
the pipeline barrier

All of these must complete
with the dstStageMask of
the pipeline barrier

e.g.

VK_ACCESS_SHADER_READ_BIT
VK_ACCESS_SHADER_WRITE_BIT
VK_ACCESS_COLOR_ATTACHMENT_READ_BIT
VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT

Updating Buffers

vkCmdUpdateBuffer

Great for UBO's or small VBO's

No need to stage

Better for the performance path

Limited to 64k transfers

Still treated as transfer operation; use a memory barrier

Must take place outside of a render pass

```
void vkCmdUpdateBuffer(  
    VkCommandBuffer commandBuffer,  
    VkBuffer dstBuffer,  
    VkDeviceSize dstOffset,  
    VkDeviceSize dataSize,  
    const uint32_t* pData);
```

Optimal Transfers

A few tips.

Keep transfers to a minimum

- Batch if possible

Keep data on the GPU if possible

- Use compute for updates, pass parameters as push constants

Try to keep transfers off the performance path

- Transfer when you have time.

Use barriers as late as possible

- Don't hold up the queue unnecessarily

Ping Pong/Double Buffer

- Use one buffer while the other transfers

Conclusion

Takeaways

Vulkan memory is programmable

Sub allocate whenever feasible

Use the right heap for the right job

Stage memory to fastest heap where appropriate

Make sure caches are flushed when you need the memory

Make sure transfers are complete when you need the memory

Keep transfers to a minimum and off the performance path

Thank You

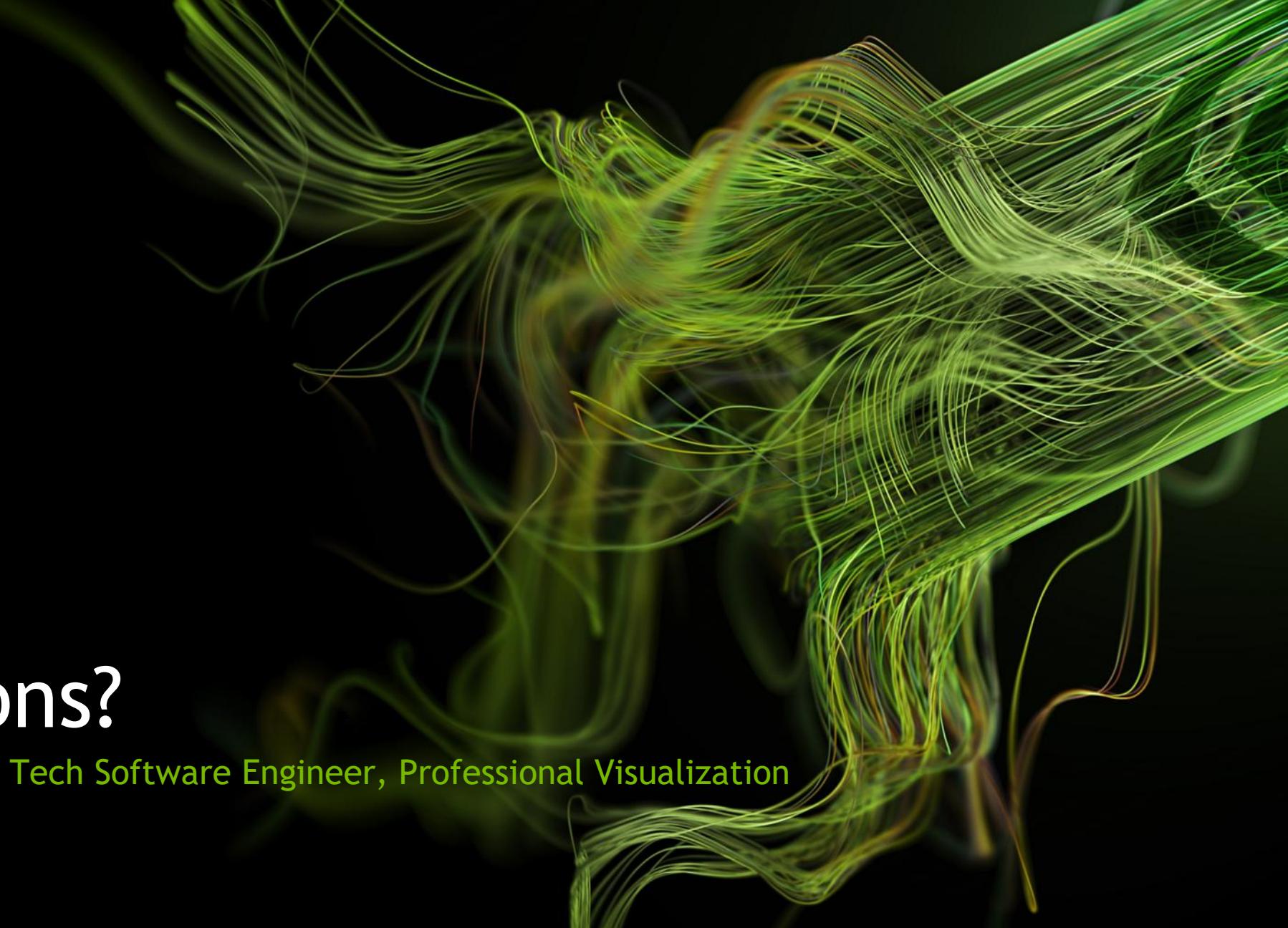
Enjoy Vulkan!!



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Questions?

Chris Hebert, Dev Tech Software Engineer, Professional Visualization



RenderPass Usage



Tobias Hector
Software Design Engineer



Imagination

Best Practices: Render Passes & Scheduling

Tobias Hector, Leading Software Design Engineer
27th July, 2016

What is a Render Pass?

- **Unique feature of Vulkan**
 - Allows multiple passes to be scheduled efficiently
 - Explicitly calls out how tile-based GPUs should operate
- **Benefits across all GPUs**
 - Scheduling benefits on all GPUs
 - Bandwidth and memory savings on tile based GPUs
- **Huge enabler for portability**
 - Best way to do e.g. Deferred Shading, for all vendors
 - No need for vendor-specific extensions (e.g. Pixel Local Storage)

Efficient scheduling

- **Scheduling work is involved**
 - See my previous presentation: <https://bit.ly/keepyourpufed>
 - Need to consider exactly when things need to happen
- **Scheduling effectively means having knowledge of the future**
 - Synchronization primitives describe the present and past
 - Requires **very** careful app management

Render pass dependencies

- **Render passes describe future work**
 - Dependencies between sub passes
 - No implicit order between sub passes
- **Drivers can compile these structures**
 - Can construct an optimised dependency graph
 - Future work can be scheduled extremely efficiently
 - Graham Sellers' talk: <http://bit.ly/renderpasses-amd>
- **Render pass instances use this graph**
 - Acts as a framework in which to execute draw commands

Additional benefits

As if that wasn't enough...

- **Tile-based GPUs get an extra boost**
 - Sub passes can be merged – keeping G-Buffer-like data completely on-chip
 - No bandwidth required!
 - Some direct renderers may avoid cache flushes
 - Savings on the order of GB/s
- **If you don't need to read/write from RAM...**
 - Then don't even allocate attachments in the first place
 - Can represent significant memory savings for high resolutions
 - E.g. One 1080p RGBA8 attachment is ~8MB

Best Practices

- **Put as much possible in as few render passes as possible**
 - Even passes that don't depend on each other!
 - E.g. Multiple shadow map generation passes
 - Most apps should need just 1 or 2!
- **Use subpass dependencies**
 - Instead of barriers or events
- **Use initialLayout/finalLayout**
 - Instead of explicit image transitions

Best Practices

- **Use Load and Store Ops!**
 - Use DONT_CARE liberally
 - Use CLEAR instead of vkCmdClearAttachment/vkCmdClearImage
- **Use MSAA resolve attachments**
 - Instead of vkCmdResolveImage
- **Use TRANSIENT_ATTACHMENT_BIT and LAZILY_ALLOCATED_MEMORY**
 - No need to allocate memory on some architectures!

Conclusion

- **Render passes are awesome**
 - We're going to continue to make them even more awesome
- **You should definitely use them**
 - They are not scary or difficult, I promise
 - (well, no more than Vulkan already is...)
- **If you have any questions, please ask me!**
 - Either during the panel or afterwards
 - I'm very friendly
 - Also on twitter: @TobskiHectov

Pipeline State Object Caching



Dan Archard
Principal Engineer



Pipeline State Object Caching

Dan Archard

Principal Engineer, ACG
QCT
July 11, 2016

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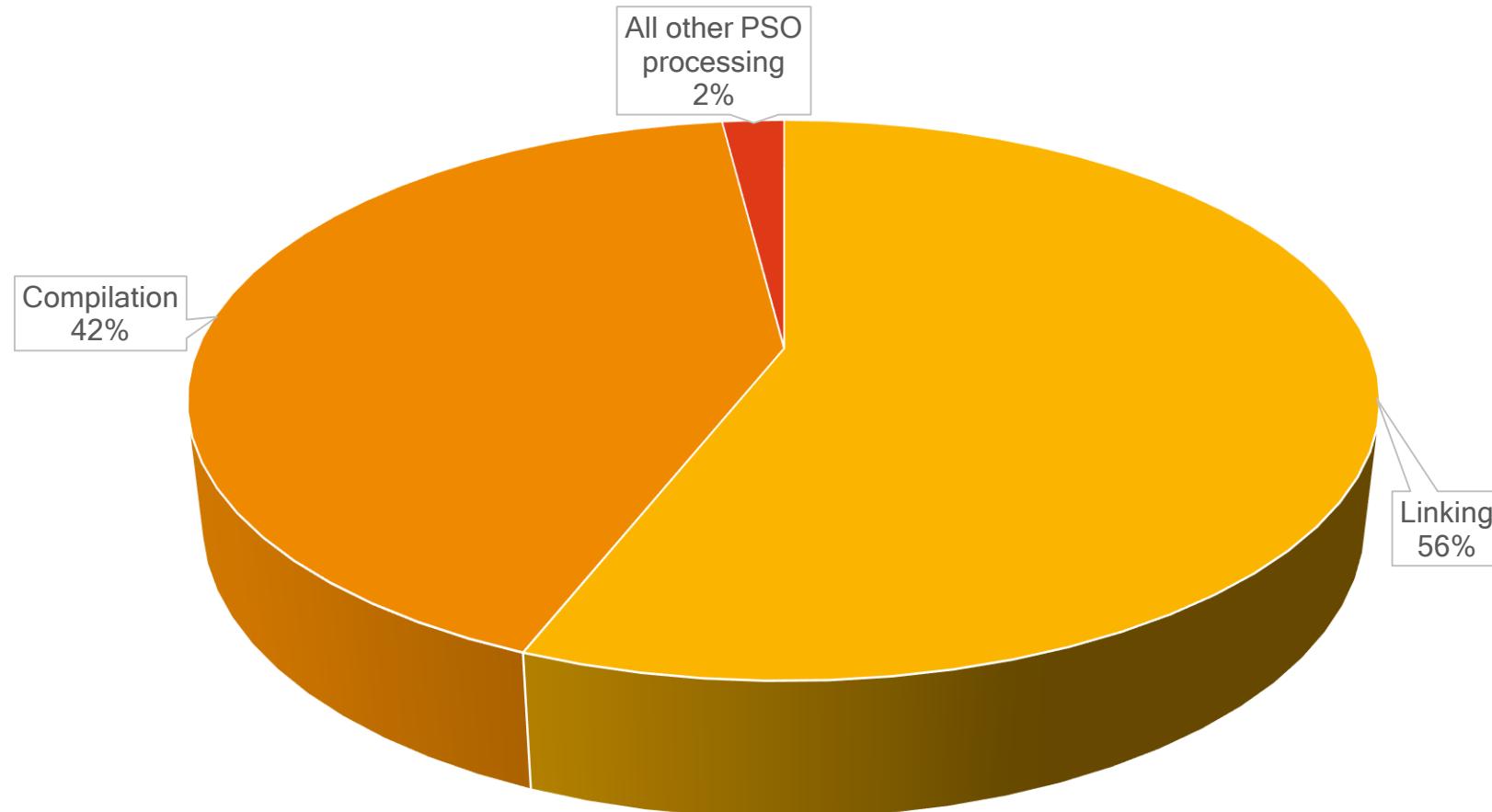


Why do we care?

- ... because it's one of the easiest optimizations you'll ever make!
- Perfect PSO creation isn't always viable
 - DX9/DX11 rendering interface, script driven rendering state etc.
 - PSOs created on the fly are the reality
- Creating pipelines can be SLOOOOOOOOWWWWWWW!
 - ... so it hitches like crazy
- There's a bunch of redundant work happening during PSO creation
 - GLES took care of this for you
- Use case from Epic Games Protostar

PSO create time break-down

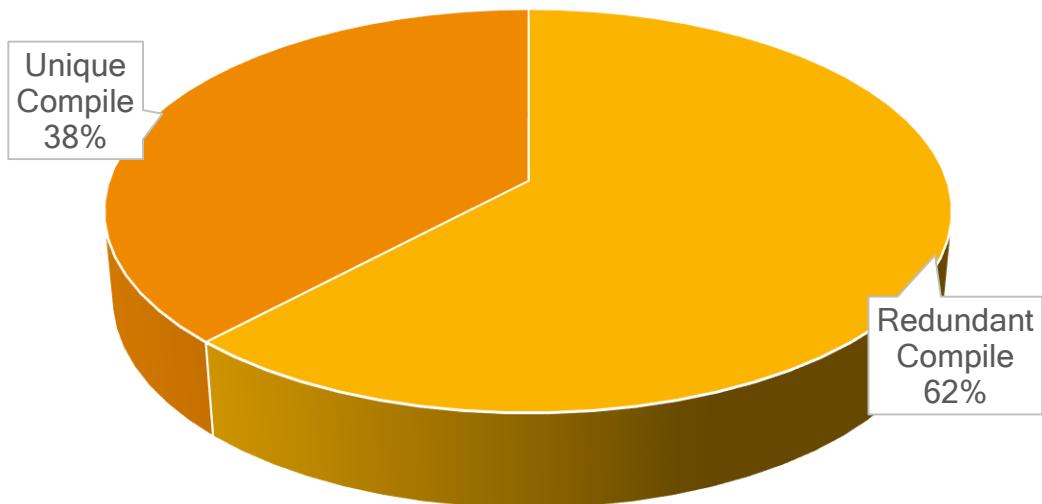
Epic Games Protostar*



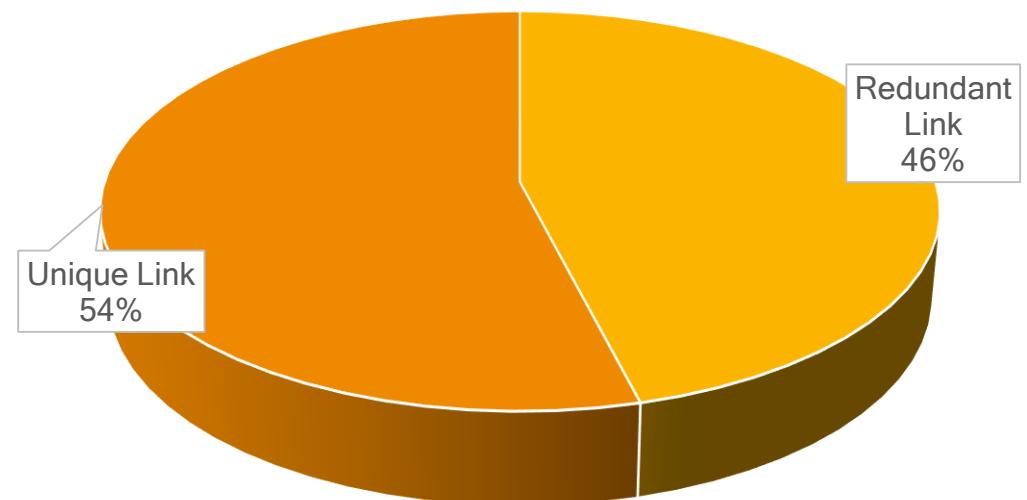
Redundancy

Epic Game Protostar*

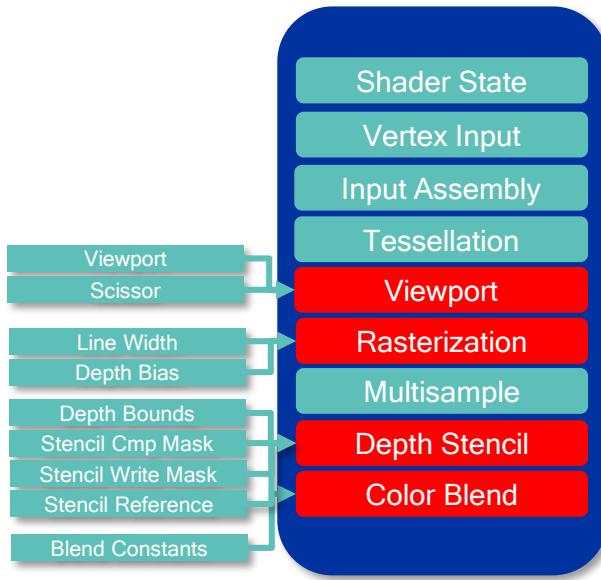
Compile



Link

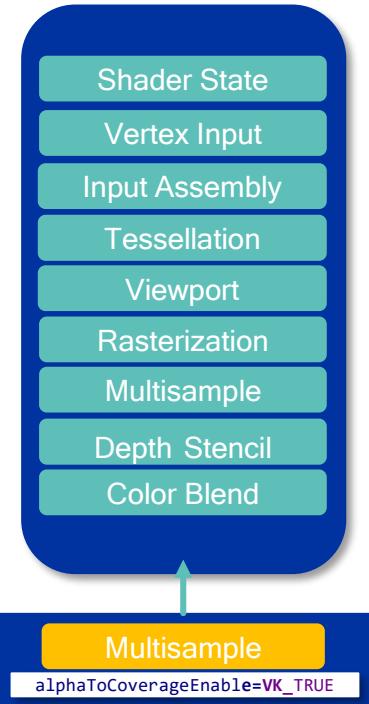


Possible solutions to speed up PSO creation



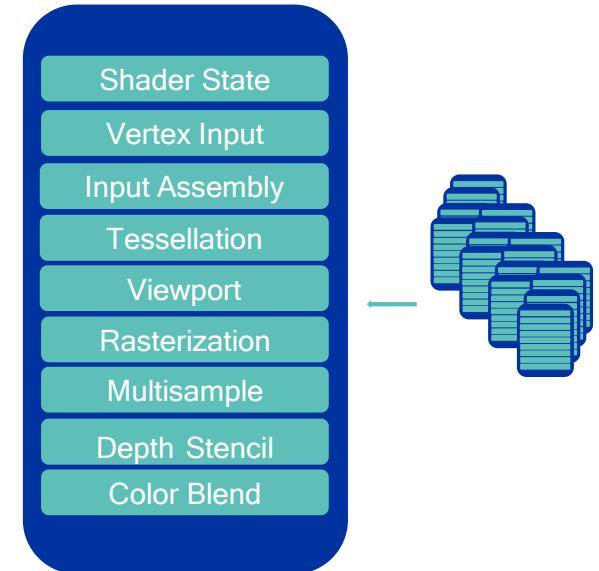
Dynamic Pipeline State

- Limited what state can change



Derived Pipelines

- Vendor specific
- Difficult to plug in to most engines



Pipeline State Cache

Pipeline cache

Creating a pipeline

```
VkGraphicsPipelineCreateInfo pipelineCreateInfo = {};
createInfo.sType = VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_CREATE_INFO;
// ...

VkPipeline pipeline;

VkResult vkCreateGraphicsPipelines(
    device,                      // VkDevice
    VK_NULL_HANDLE,              // VkPipelineCache
    1,                           // uint32_t
    &pipelineCreateInfo,          // const VkGraphicsPipelineCreateInfo*
    nullptr,                     // const VkAllocationCallbacks*
    pipeline);                  // VkPipeline*
```

device	device
VK_NULL_HANDLE,	pipelineCache
1,	createInfoCount
&pipelineCreateInfo,	pCreateInfos
nullptr,	pAllocator
pipeline);	pPipelines

Pipeline Cache

Creating a pipeline using a cache

```
static VkPipelineCache pipelineCache;

VkPipelineCacheCreateInfo pipelineCacheCreateInfo = {};
pipelineCacheCreateInfo.sType = VK_STRUCTURE_TYPE_PIPELINE_CACHE_CREATE_INFO;

VkResult result = vkCreatePipelineCache(
    device, // VkDevice
    &pipelineCacheCreateInfo, // const VkPipelineCacheCreateInfo*
    nullptr, // const VkAllocationCallbacks*
    &pipelineCache); // VkPipelineCache*
```

//

```
VkGraphicsPipelineCreateInfo createInfo = {};
createInfo.sType = VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_CREATE_INFO;
// ...

VkPipeline pipeline;

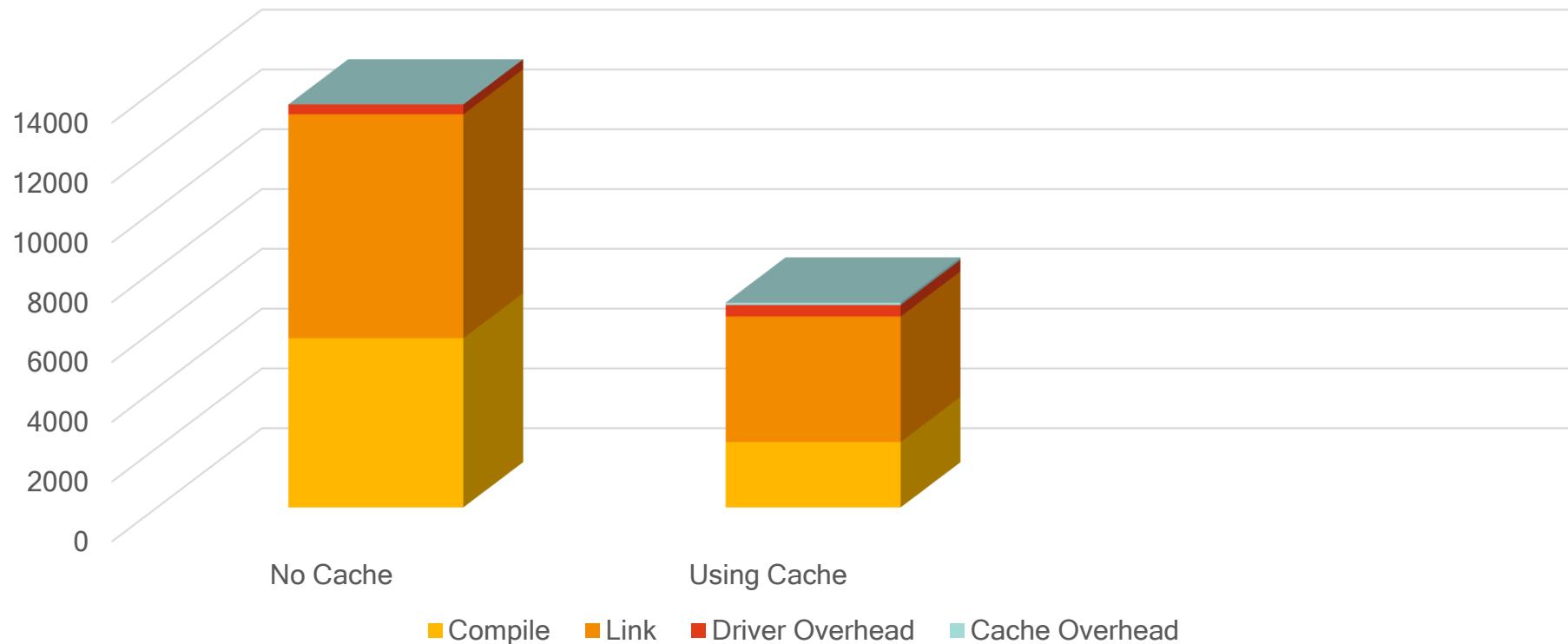
VkResult result = vkCreateGraphicsPipelines(
    device, // VkDevice
    &pipelineCache, // VkPipelineCache
    1, // uint32_t
    &createInfo, // const VkGraphicsPipelineCreateInfo*
    nullptr, // const VkAllocationCallbacks*
    pipeline); // VkPipeline*
```

<code>device,</code> <code>&pipelineCacheCreateInfo,</code> <code>nullptr,</code> <code>&pipelineCache);</code>	<code>// VkDevice</code> <code>// const VkPipelineCacheCreateInfo*</code> <code>// const VkAllocationCallbacks*</code> <code>// VkPipelineCache*</code>	<code>device,</code> <code>pCreateInfo,</code> <code>pAllocator,</code> <code>pPipelineCache);</code>
<code>//</code>		
<code>VkGraphicsPipelineCreateInfo createInfo = {};</code> <code>createInfo.sType = VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_CREATE_INFO;</code> <code>// ...</code>		
<code>VkPipeline pipeline;</code>		
<code>VkResult result = vkCreateGraphicsPipelines(</code> <code>device,</code> <code>&pipelineCache,</code> <code>1,</code> <code>&createInfo,</code> <code>nullptr,</code> <code>pipeline);</code>	<code>// VkDevice</code> <code>// VkPipelineCache</code> <code>// uint32_t</code> <code>// const VkGraphicsPipelineCreateInfo*</code> <code>// const VkAllocationCallbacks*</code> <code>// VkPipeline*</code>	<code>device</code> <code>pipelineCache</code> <code>createInfoCount</code> <code>pCreateInfos</code> <code>pAllocator</code> <code>pPipelines</code>

Pipeline Cache

Creating a pipeline using a cache

Total PSO Create Time - Epic Games Protostar*



Pipeline Cache

Loading from disk

- Pipeline cache can take initial data on create
- Save & Restore cache across runs:

```
VkPipelineCache pipelineCache;

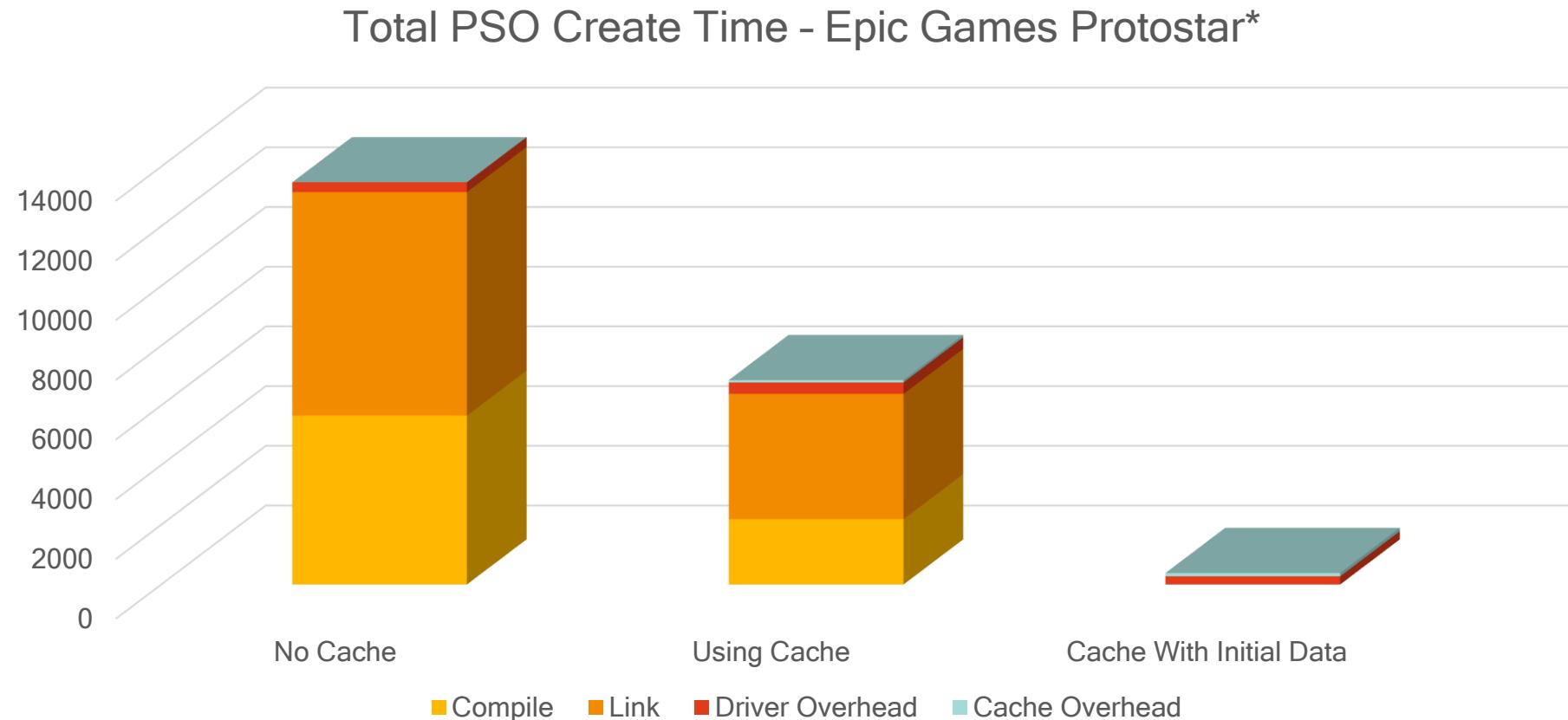
VkPipelineCacheCreateInfo createInfo = {};
createInfo.sType = VK_STRUCTURE_TYPE_PIPELINE_CACHE_CREATE_INFO;
createInfo.pInitialData = LoadPipelineCacheFromDisk(&createInfo.initialDataSize);

VkResult result = vkCreatePipelineCache(
    device,           // VkDevice
    &createInfo,      // const VkPipelineCacheCreateInfo*
    nullptr,          // const VkAllocationCallbacks*
    &pipelineCache); // VkPipelineCache*
```

device,	// VkDevice	device,
&createInfo,	// const VkPipelineCacheCreateInfo*	pCreateInfo,
nullptr,	// const VkAllocationCallbacks*	pAllocator,
&pipelineCache);	// VkPipelineCache*	pPipelineCache);

Pipeline Cache

Loading from disk



Thank you

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Panel: Tools for the Vulkan Ecosystem



Bill Hollings

Architect

MoltenVK: Vulkan on iOS/macOS

THE BRENWILL
WORKSHOP



Karl Schultz

Principal Engineer

LunarG SDK and Tools



Kyle Spagnoli

Engineer

Bringing Vulkan support to
NVIDIA® Nsight™



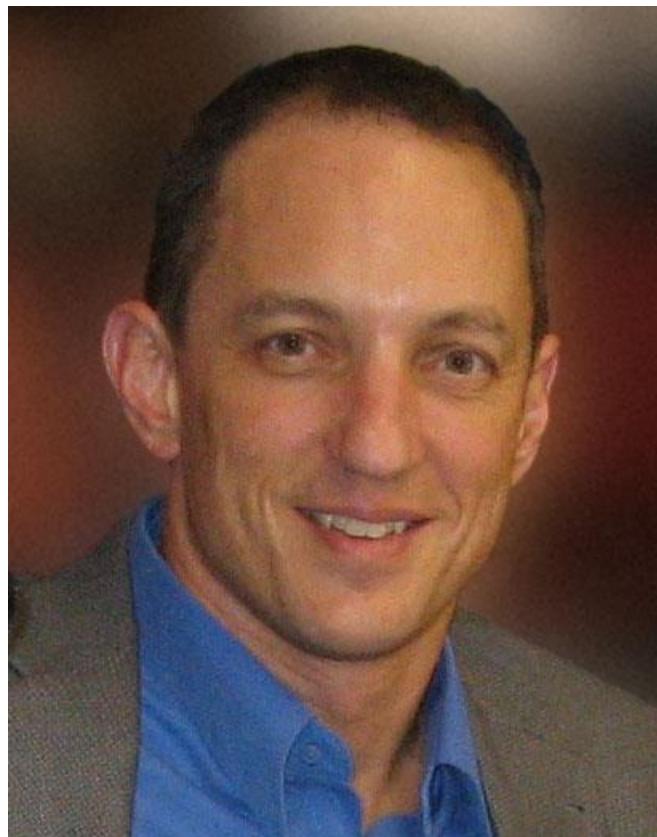
Andrew Woloszyn

Software Engineer

SPIR-V Tools



Vulkan on iOS/macOS



Bill Hollings
Architect

THE BRENWILL
WORKSHOP



Vulkan on iOS & macOS

**Bill Hollings, The Brenwill Workshop Ltd.
July 2016**

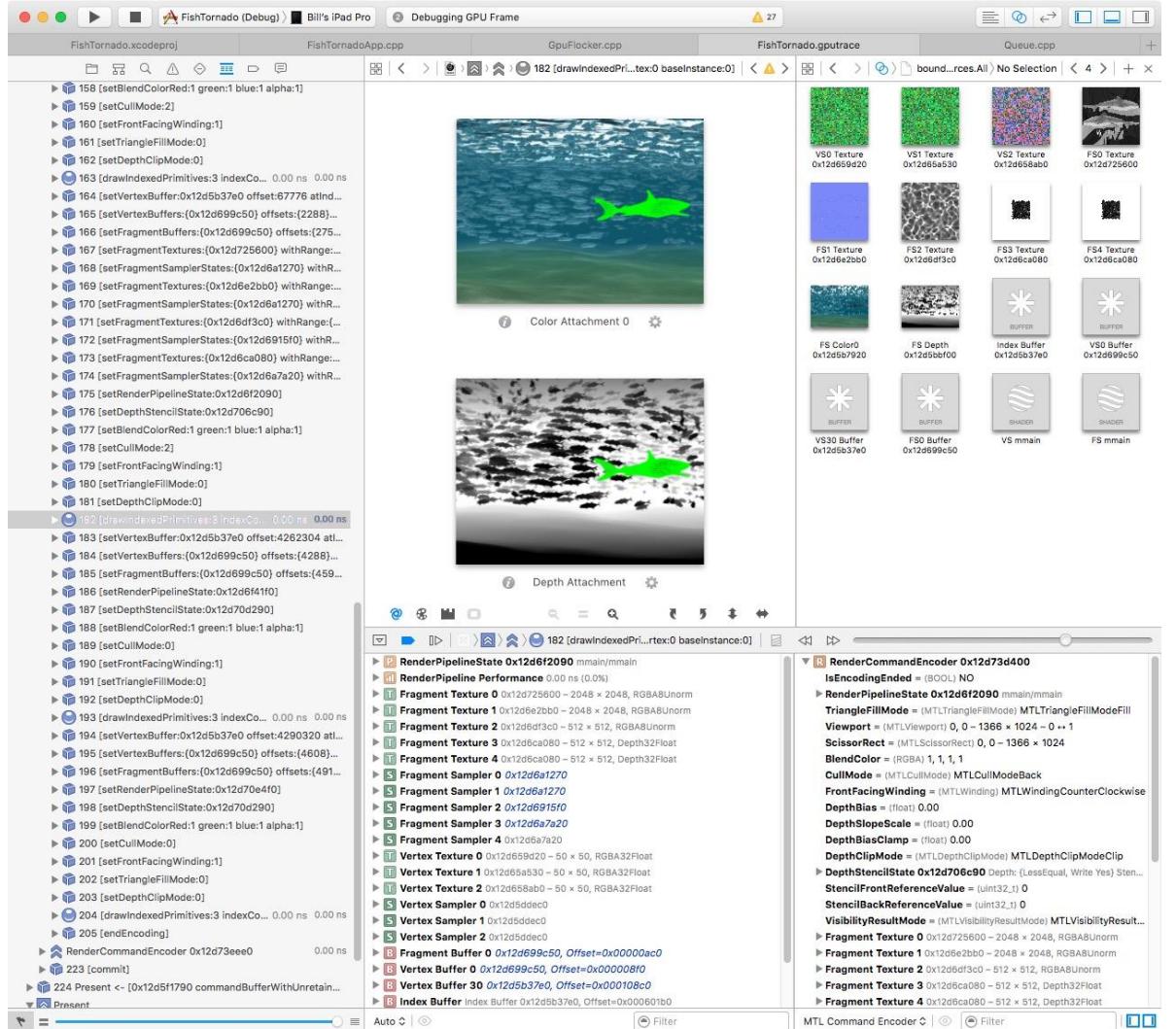
MoltenVK

- MoltenVK is an implementation of Vulkan on iOS & macOS
 - Built on Metal
- Vulkan & Metal are static-state, command-buffer APIs
 - Very little friction
 - MoltenVK minimal overhead
- MoltenVK feature set dependent on Metal
 - Metal's focus is on providing a convenient API
 - MoltenVK helps define x-platform compatibility



Xcode Profiling Tools - GPU Frame Capture

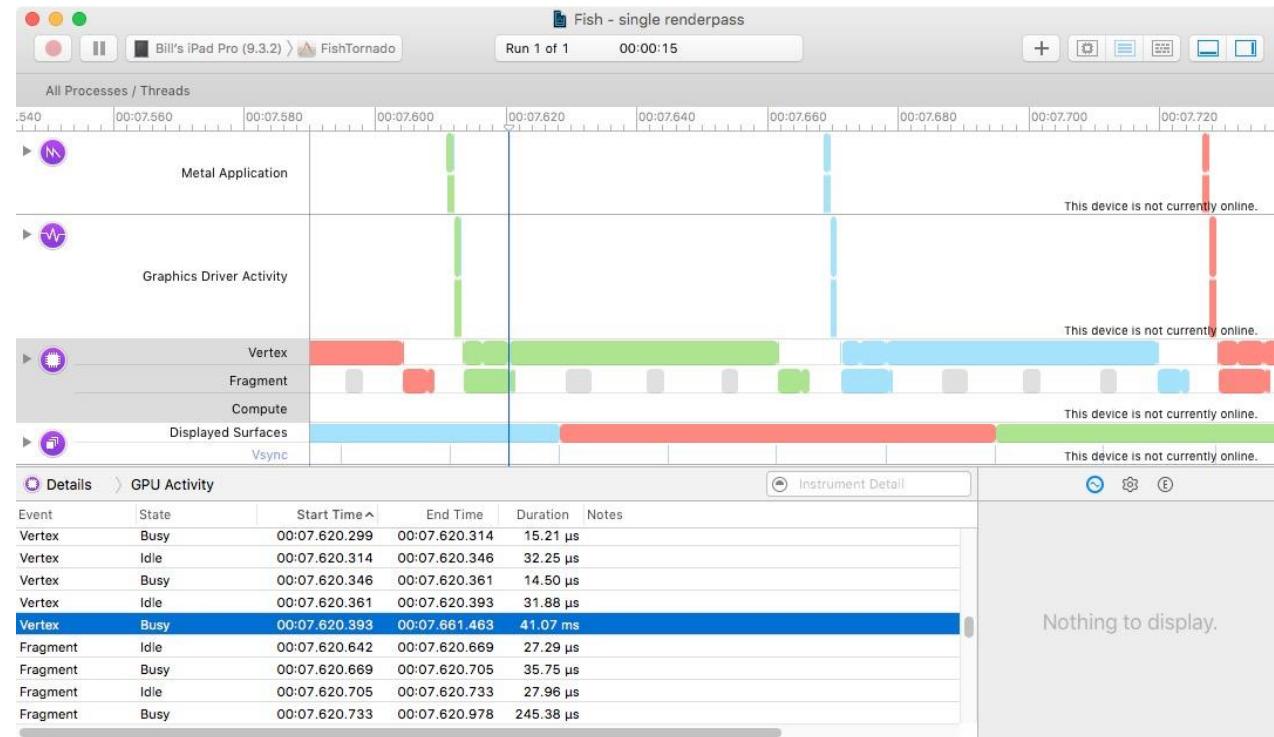
- Apple's strong focus on ecosystem developer tools
 - Apple committed to Metal
 - MoltenVK leverages this
- GPU Frame Capture
 - Vulkan command sequence
 - Capture rendering stages
 - Cmd buffs & renderpasses
 - Pipeline state & shaders
 - Resources & render state
 - Identifies inefficiencies
- Manual or programmatic
 - Trace setup activity



Xcode Profiling Tools - Metal System Trace

- **Metal System Trace**

- Detailed tracing of CPU & GPU activity per frame
- Separates per-frame loads
- Identifies utilization shortfalls:
 - blocking,
 - device starvation
 - sync issues



Xcode Profiling Tools - Other

- **GPU Driver**
 - CPU & GPU performance monitoring
- **Allocations and Leaks**
 - CPU memory allocation details
 - Identify memory leak details
- **These tools available to Vulkan developers**
 - Apple provides a sophisticated suite of tools for graphics developers using Apple's ecosystem.
 - MoltenVK makes all of these tools available to Vulkan developers.

Bringing Vulkan Support to NVIDIA® Nsight™



Kyle Spagnoli
Engineer



NVIDIA[®]

NSIGHT VSE + VULKAN

Kyle Spagnoli



Compile Debug Profile

Microsoft®
DirectX®



Getting Started...

JetPack



Trace



NVTX
NVIDIA Tools eXtension

IDE Integration



Standalone and CLI



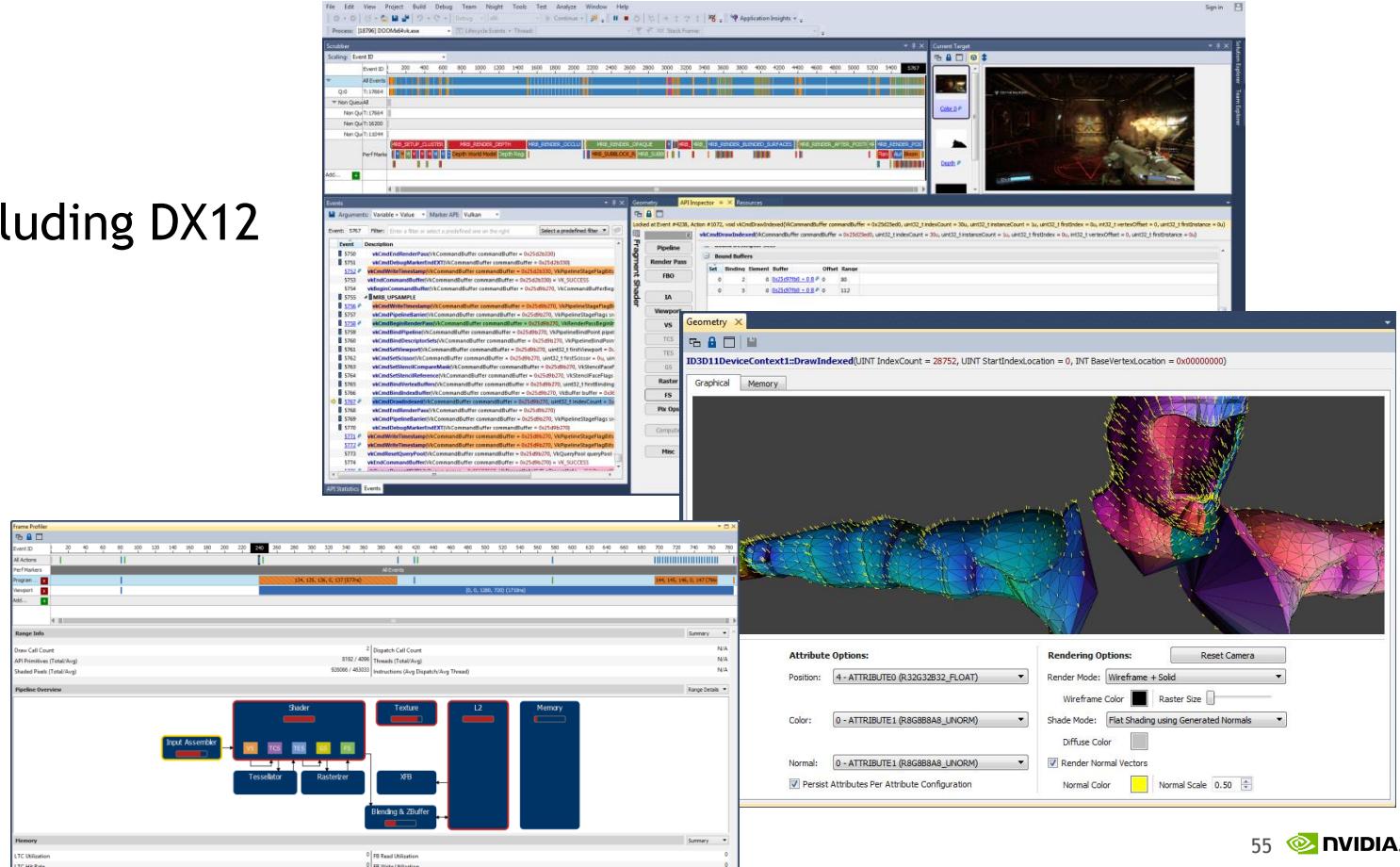
Hardware Support



NSIGHT VISUAL STUDIO EDITION 5.2

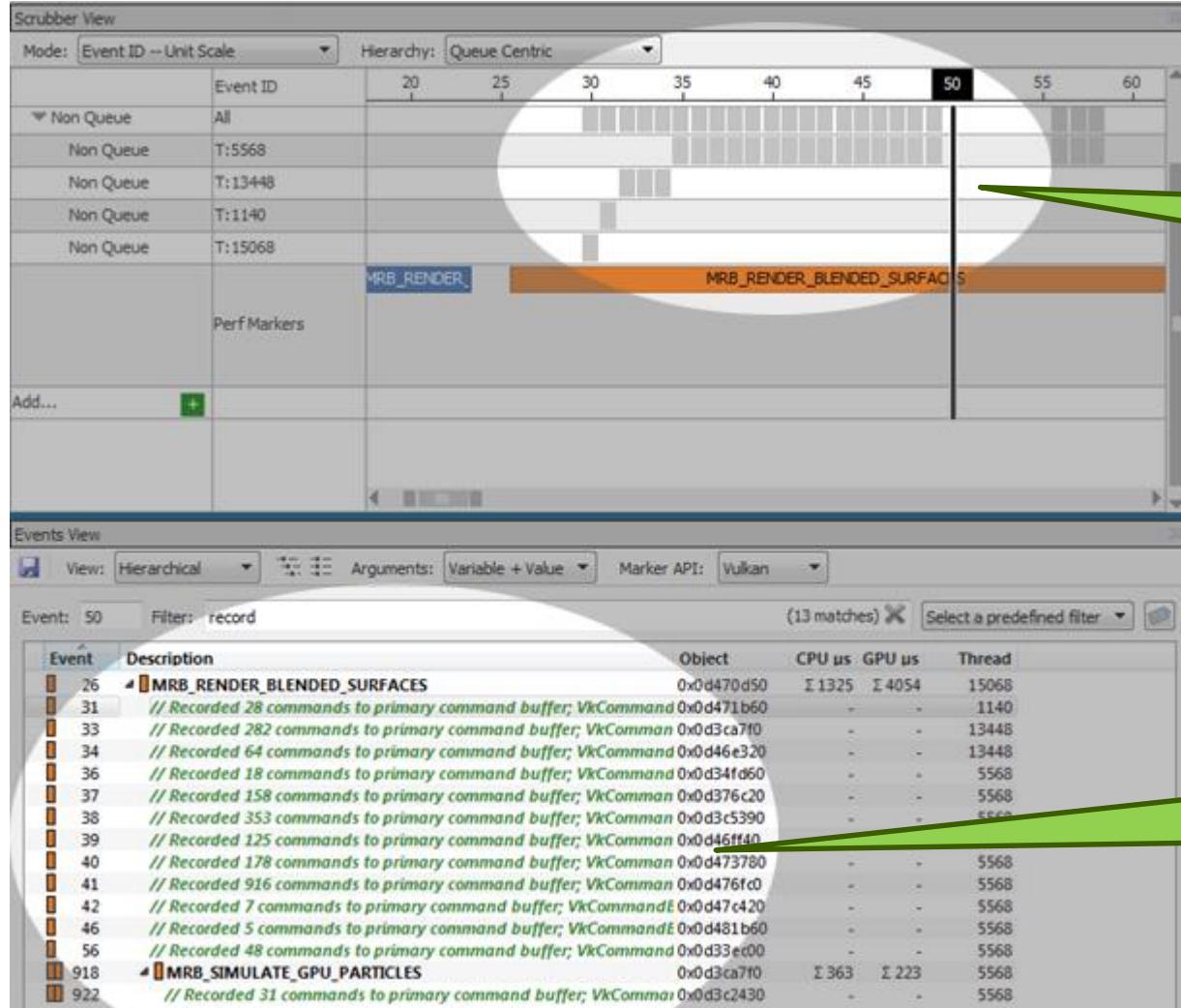
Vulkan, VR, and Advanced Graphics Profiling

- Vulkan API support
- New Range Profiler, including DX12
- New Geometry View
- Oculus VR SDK support
- CUDA 8.0 support



MULTI-THREAD / MULTI-QUEUE

Recording Command Buffers

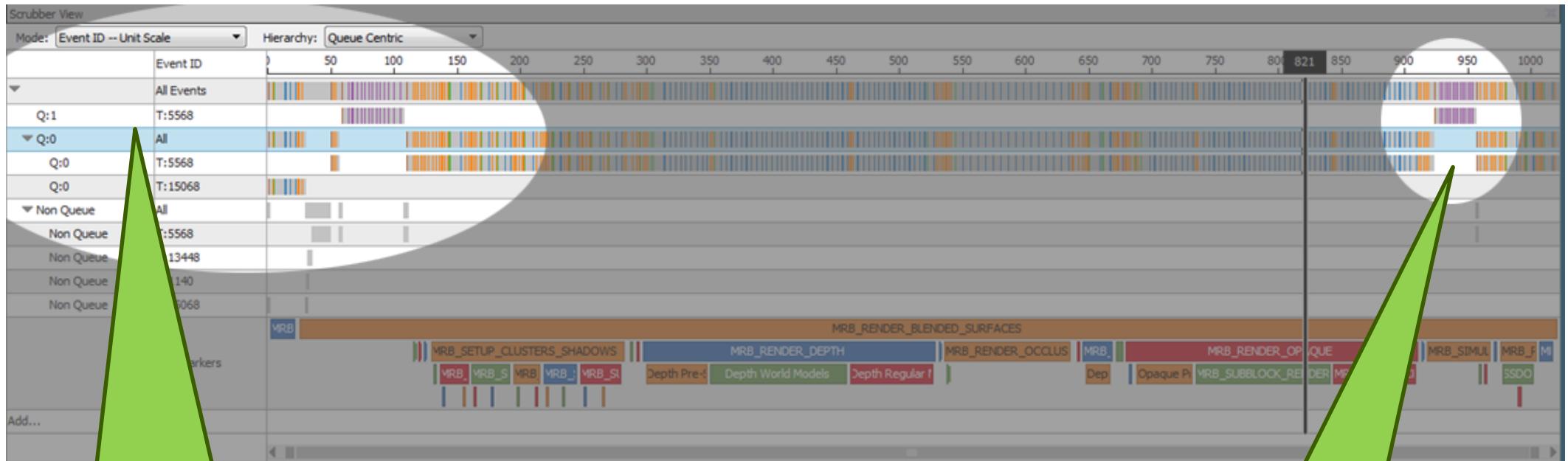


Scrubber shows all threads for command buffer construction

Events view shows entry for in-frame command buffer construction

MULTI-THREAD/MULTI-QUEUE

Executing Command Buffers



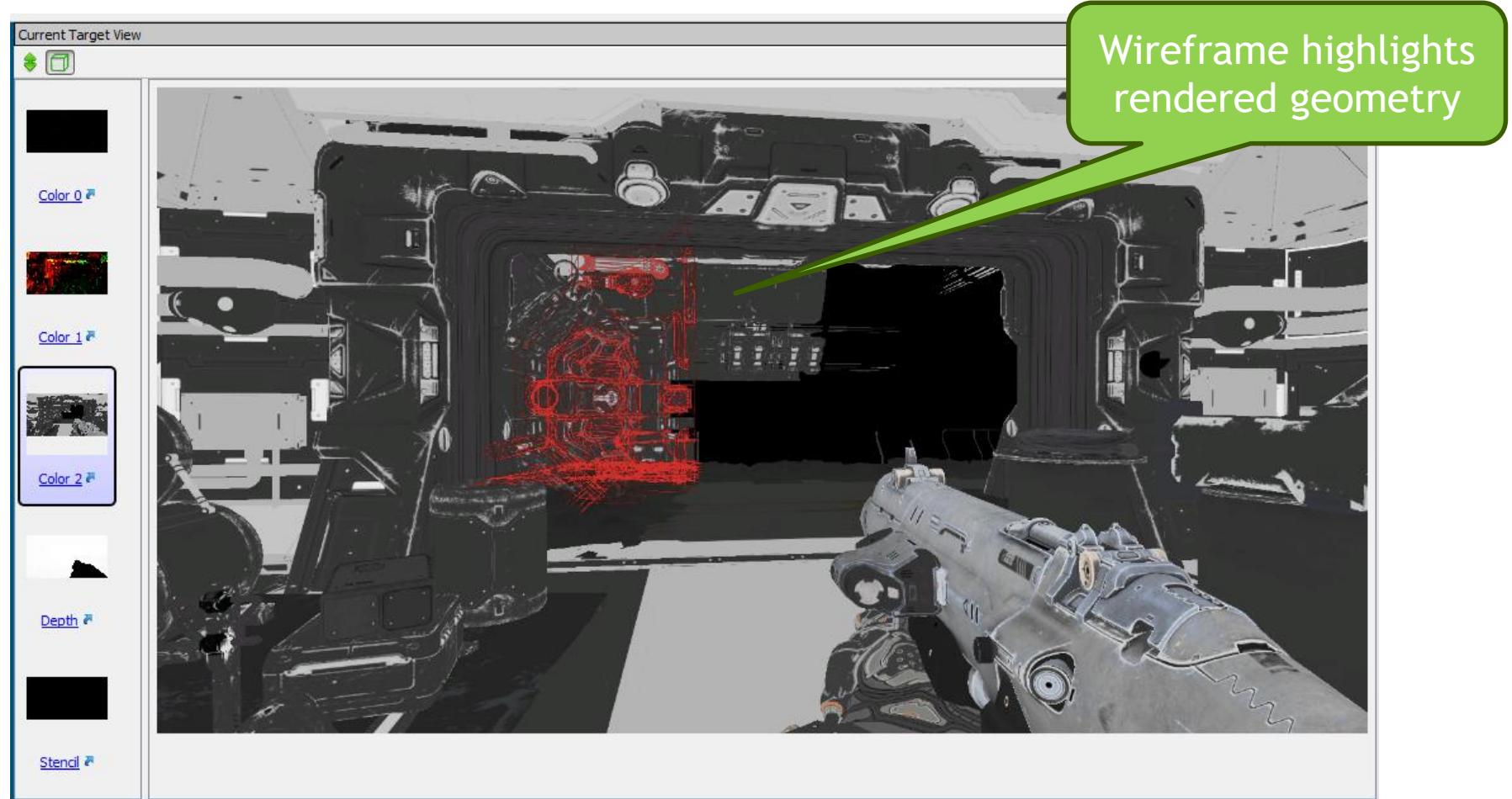
Scrubber highlights multiple queues. This application uses one for compute and one for graphics

Scrubber shows queue as it migrates from thread to thread

CURRENT RENDER TARGET DISPLAY

Dig Into Per Pass Rendering Results

View each render target for any draw call in flight



Wireframe highlights
rendered geometry

BARRIER INFORMATION

Managing Rendering Passes & Resource Transitions

Details for each pipeline barrier and what resources/stages are impacted

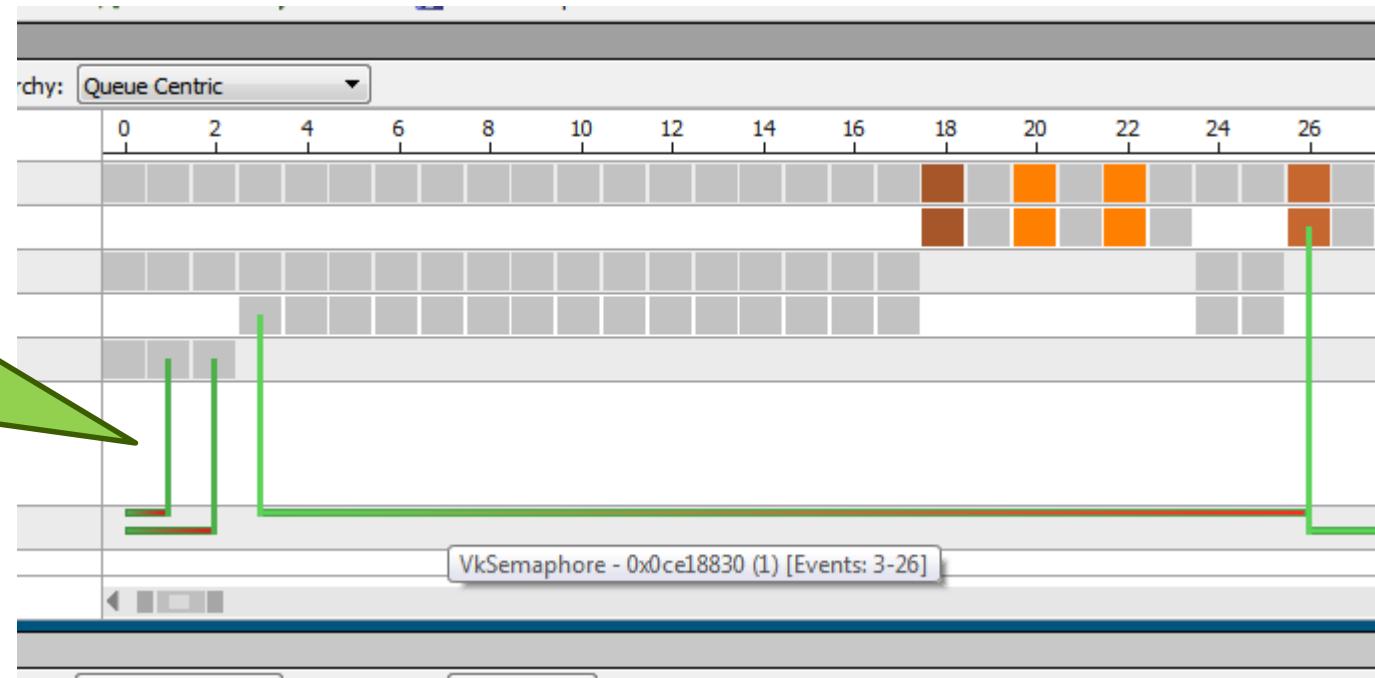
Events View	
Event	Description
137	MRB_SUBBLOCK_RENDERING
139	Pipeline Barrier
141	vkCmdPipelineBarrier
155	MRB_SUBBLOCK_RENDERING
157	Pipeline Barrier
162	MRB_SUBBLOCK_RENDERING
164	Pipeline Barrier
166	vkCmdPipelineBarrier

```
void vkCmdPipelineBarrier(
    VkCommandBuffer commandBuffer = 0x0d376c20,
    VkPipelineStageFlags srcStageMask = VkPipelineStageFlags(
        VK_PIPELINE_STAGE_LATE_FRAGMENT_TESTS_BIT | VK_PIPELINE_STAGE_COLOR_ATTACHMENT_OUTPUT_BIT),
    VkPipelineStageFlags dstStageMask = VkPipelineStageFlags(
        VK_PIPELINE_STAGE_FRAGMENT_SHADER_BIT),
    VkDependencyFlags dependencyFlags = VkDependencyFlags(
        0),
    uint32_t memoryBarrierCount = 1u,
    VkMemoryBarrier pMemoryBarriers = {{VkMemoryBarrier::sType = VK_STRUCTURE_TYPE_MEMORY_BARRIER,
    VkMemoryBarrier::pNext = nullptr,
    VkMemoryBarrier::srcAccessMask = VkAccessFlags(
        VK_ACCESS_COLOR_ATTACHMENT_WRITE_BIT | VK_ACCESS_DEPTH_STENCIL_ATTACHMENT_WRITE_BIT),
    VkMemoryBarrier::dstAccessMask = VkAccessFlags(
        VK_ACCESS_INPUT_ATTACHMENT_READ_BIT | VK_ACCESS_SHADER_READ_BIT)}},
    uint32_t bufferMemoryBarrierCount = 0u,
    VkBufferMemoryBarrier pBufferMemoryBarriers = nullptr,
    uint32_t imageMemoryBarrierCount = 0u,
    VkImageMemoryBarrier pImageMemoryBarriers = nullptr)
```

FENCES, SIGNALS & SEMAPHORES

Synchronization Primitives

Highlight synchronization points involving fences, events, and semaphores



API INSPECTOR

View API State

Geometry API Inspector Resources texture.cpp vulkandebbug.cpp

Pipeline

Fragment Shader

- Pipeline Shader Stage**
 - Create Flags: None Stage: FRAGMENT Module: 0x062b16e0 Name: main
- Shader Module**
 - Create Flags: None Code: [View SPIRv](#)
- Push Constants**
 - No push constants accessed used by this stage
- Bound Descriptor Sets**

Bind Point	Layout	Set	Descriptor Set	Dynamic Offsets
GRAPHICS	0x049756d0	0	0x03f2f300	-
- Bound Buffers**

Set	Binding	Element	Buffer	Offset	Range
0	4	0	0x045d02a0 + 0 B	0	256
- Bound Images & Samplers**

Set	Binding	Element	Sampler	Image View	Image Layout
0	1	0	0x04802c90	0x0463fad0	GENERAL
0	2	0	0x04802e10	0x0463f850	GENERAL
0	3	0	0x04802f90	0x0463f530	GENERAL
- Associated Image Views**

Image View: 0x0463fad0 Sampler: 0x04802c90

Set: 0 Binding: 1

Create Flags: None Aspect Mask: COLOR
 Image: 0x04571840
 View Type: 2D Base Mip Level: 0
 Format: R16G16B16A16_SFLOAT Level Count: 1
 Components: {R: R, G: G, B: B, A: A} Base Array Layer: 0
 Layer Count: 1

Geometry API Inspector Resources texture.cpp vulkandebbug.cpp

Pipeline

Pixel Operations

Depth/Stencil State

State Create Flags:	None	Stencil Write Mask [Front]:	0x00000000
Depth Test Enable:	TRUE	Stencil Reference [Front]:	0x00000000
Depth Write Enable:	TRUE	Stencil Fail Op. [Back]:	KEEP
Depth Compare Op.:	LESS_OR_EQUAL	Stencil Pass Op. [Back]:	KEEP
Depth Bounds Test Enable:	FALSE	Stencil Depth Fail Op. [Back]:	KEEP
Stencil Test Enable:	FALSE	Stencil Compare Op. [Back]:	ALWAYS
Stencil Fail Op. [Front]:	KEEP	Stencil Compare Mask [Back]:	0x00000000
Stencil Pass Op. [Front]:	KEEP	Stencil Write Mask [Back]:	0x00000000
Stencil Depth Fail Op. [Front]:	KEEP	Stencil Reference [Back]:	0x00000000
Stencil Compare Op. [Front]:	NEVER	Min Depth Bounds:	0.00
Stencil Compare Mask [Front]:	0x00000000	Max Depth Bounds:	0.00

Multisample State

State Create Flags:	None	Min. Sample Shading:	0.00	Alpha To One Enable:	FALSE
Rasterization Samples:	1	Sample Mask:	nullptr	Sample Shading Enable:	FALSE
Alpha To Coverage Enable:	FALSE				

Color Blend State

State Create Flags:	None	Logic Op.:	CLEAR
Logic Op. Enable:	FALSE	Blend Constants:	(0.00, 0.00, 0.00, 0.00)

Attachment Blend States

Index	Blend Enable	Src. Color Blend Factor	Dst. Color Blend Factor	Color Blend Op.	Src. Alpha Blend Factor	Dst. Alpha Blend Factor
0	FALSE	ZERO	ZERO	ADD	ZERO	ZERO

All memory at a glance

DEVICE MEMORY

Visualize Memory Usage & Layout

Listing of contained resources

The screenshot displays a memory visualization interface with three main sections:

- Memory Pools (83):** A table showing memory pool details. The first row (0x36436d90) is highlighted.
- Resources (494):** A table listing individual resources. The first few rows show various textures and their properties.
- Data:** A pane showing raw memory data starting at offset 3072. It includes columns for Address, Data (Hash), and several columns of raw hex data.

A large green speech bubble at the bottom left points to the "Resource Map" at the bottom of the interface, which shows a visual representation of memory layout.

Visual resource layout

Resource Map

Name	Size	Flags	Mapping
0x36436d90	512.00 MB	DEVICE_LOCAL	Unmapped
0x366b9310	384.00 MB	DEVICE_LOCAL	Unmapped
0x25ca7990	128.00 MB	DEVICE_LOCAL	Unmapped
0x366b97e0	128.00 MB	DEVICE_LOCAL	Unmapped
0x6794880	128.00 MB	DEVICE_LOCAL	Unmapped
0x4cddb540	128.00 MB	DEVICE_LOCAL	Unmapped
0x36435eb0	85.34 MB	DEVICE_LOCAL	Unmapped
0x364377a0	85.34 MB	DEVICE_LOCAL	Unmapped
0x047d8000	80.00 MB	HOST_VISIBLE HOST_COHERENT HOST_CACHED	0x0000000027750000
0x047d8770	80.00 MB	HOST_VISIBLE HOST_COHERENT HOST_CACHED	0x0000000002c75000
0x047d96d0	64.00 MB	HOST_VISIBLE HOST_COHERENT	0x0000000003175000
0xbb394b00	64.00 MB	DEVICE_LOCAL	Unmapped
0x364380d0	48.00 MB	DEVICE_LOCAL	Unmapped
0x364385a0	32.00 MB	DEVICE_LOCAL	Unmapped
0x36565360	22.50 MB	DEVICE_LOCAL	Unmapped
0x366b79b0	10.67 MB	DEVICE_LOCAL	Unmapped
0x36434cc0	8.00 MB	DEVICE_LOCAL	Unmapped
0x36438a70	6.25 MB	DEVICE_LOCAL	Unmapped
0x36475600	6.25 MB	DEVICE_LOCAL	Unmapped
0x36474fe0	6.25 MB	DEVICE_LOCAL	Unmapped
0x36474090	6.25 MB	DEVICE_LOCAL	Unmapped
0x36472030	6.25 MB	DEVICE_LOCAL	Unmapped
0x3647e3b0	6.25 MB	DEVICE_LOCAL	Unmapped
0x3647b470	6.25 MB	DEVICE_LOCAL	Unmapped

Offset	Type	Name	Size	Overlaps With
3072	Texture	0x4d0872f0	1024.00 B	
4096	Texture	0x4d085220	1024.00 B	
5120	Texture	0x4d0849b0	26.00 KB	
31744	Texture	0x4d0ef700	272.00 KB	
310272	Texture	0x4d0ecb00	688.00 KB	
1014784	Texture	0x4d0eeb00	688.00 KB	
1719296	Texture	0x4d0eead0	608.00 KB	
2341888	Texture	0x4d0ee9e0	544.00 KB	
2898944	Texture	0x4d0ee8f0	512.00 KB	
3423232	Texture	0x4cdfdd30	864.00 KB	
4307968	Texture	0x4cdfdc40	768.00 KB	
5094400	Texture	0x4cdfdb50	544.00 KB	
5651456	Texture	0x4cdfda60	720.00 KB	
6388736	Texture	0x4cdfd970	432.00 KB	
6831104	Texture	0x4cdfd880	352.00 KB	
7191552	Texture	0x4cdfd790	352.00 KB	
7552000	Texture	0x4cdfd6a0	352.00 KB	
7912448	Texture	0x4cdfd5b0	800.00 KB	
8731648	Texture	0x4cdfd4c0	800.00 KB	
9550848	Texture	0x4cdfd3d0	800.00 KB	
10370048	Texture	0x4cdfd2e0	800.00 KB	
11189248	Texture	0x4cdfd1f0	640.00 KB	
11844608	Texture	0x4cdfd100	416.00 KB	
12270592	Texture	0x4cdfd010	800.00 KB	
13089792	Texture	0x4cdfcf20	2.00 KB	
13091840	Texture	0x4cdfce30	2.00 KB	

Address	Data (Hash: 0xe43484de)
0x00000000000000c00	20202020202020ff ff20202020202020 20202020202020ff ff2020202020
0x00000000000000c20	fffffffffffffff fffffffffff 202020202020ff ff2020202020
0x00000000000000c40	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000c60	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000c80	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000ca0	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000cc0	20202020202020ff ff202020202020 20202020202020ff ff2020202020
0x00000000000000ce0	20202020202020ff ff202020202020 20202020202020ff ff2020202020
0x00000000000000d00	20202020202020ff ff202020202020 20202020202020ff ff2020202020
0x00000000000000d20	20202020202020ff ff202020202020 20202020202020ff ff2020202020
0x00000000000000d40	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000d60	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000d80	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000da0	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000dc0	20202020202020ff ff202020202020 20202020202020ff ff2020202020
0x00000000000000de0	20202020202020ff ff202020202020 20202020202020ff ff2020202020
0x00000000000000e00	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000e20	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000e40	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000e60	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000e80	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000ea0	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000ec0	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000ee0	0000000000000000 0000000000000000 0000000000000000 0000000000000000
0x00000000000000f00	0000000000000000 0000000000000000 0000000000000000 0000000000000000

Visual resource layout

SERIALIZATION

Generate Source Code For A Single Frame

```
12 //-----
13 // CreateResources004
14 //-----
15 void CreateResources004()
16 {
17     // Create VkBuffer_uidof_11098
18     {
19         static VkBufferCreateInfo VkBufferCreateInfo_temp_1414[1] = { VkBufferCreateInfo{
20             /* sType = */ VK_STRUCTURE_TYPE_BUFFER_CREATE_INFO,
21             /* pNext = */ nullptr,
22             /* flags = */ VKBufferCreateFlags(0),
23             /* size = */ 33312ull,
24             /* usage = */ VkBufferUsageFlags(VK_BUFFER_USAGE_TRANSFER_DST_BIT | VK_BUFFER_USAGE_VERTEX_BUFFER_BIT),
25             /* sharingMode = */ VK_SHARING_MODE_EXCLUSIVE,
26             /* queueFamilyIndexCount = */ 0u,
27             /* pQueueFamilyIndices = */ nullptr} };
28         NV_THROW_IF(vkCreateBuffer(VkDevice_uidof_3, VkBufferCreateInfo_temp_1414, nullptr, &vkBuffer_uidof_11098) != VK_SUCCESS, "NV_THROW_IF(vkCreateBuffer(VkDevice_uidof_3, VkBufferCreateInfo_temp_1414, nullptr, &vkBuffer_uidof_11098) != VK_SUCCESS, \"")
29     }
30
31     // Create VkBuffer_uidof_11099
32     {
33         static VkBufferCreateInfo VkBufferCreateInfo_temp_1415[1] = { VkBufferCreateInfo{
34             /* sType = */ VK_STRUCTURE_TYPE_BUFFER_CREATE_INFO,
35             /* pNext = */ nullptr,
36             /* flags = */ VKBufferCreateFlags(0),
37             /* size = */ 6448ull,
38             /* usage = */ VkBufferUsageFlags(VK_BUFFER_USAGE_TRANSFER_DST_BIT | VK_BUFFER_USAGE_INDEX_BUFFER_BIT),
39             /* sharingMode = */ VK_SHARING_MODE_EXCLUSIVE,
40             /* queueFamilyIndexCount = */ 0u,
41             /* pQueueFamilyIndices = */ nullptr} };
42         NV_THROW_IF(vkCreateBuffer(VkDevice_uidof_3, VkBufferCreateInfo_temp_1415, nullptr, &vkBuffer_uidof_11099) != VK_SUCCESS, "NV_THROW_IF(vkCreateBuffer(VkDevice_uidof_3, VkBufferCreateInfo_temp_1415, nullptr, &vkBuffer_uidof_11099) != VK_SUCCESS, \"")
43     }
44 }
```



C++ code compiles into...



ROADMAP & AVAILABILITY

Upcoming release

NSIGHT Visual Studio Edition 5.2 with Vulkan Support

- Available when you return from SIGGRAPH
- C++ Serialization is a beta feature



Additions to come:

- Performance Info & Range Profiler
- Android Support
- Linux Support
- Shader Editing
- Analysis & Hints
- Shader Reflection Information
- Sparse Texture
- Improved Barrier GUI
- Support Future Extensions

Thank you!

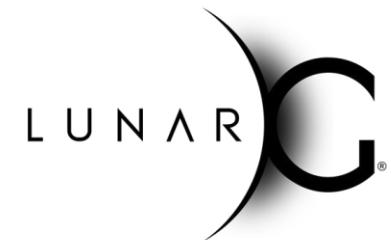
*Check out our demo during the Khronos
After Party for a hands on Vulkan demo
of Nsight + DOOM*

Test Drive Vulkan Support @ Booth #509

LunarG Vulkan SDK and Tools



Karl Schultz
Principal Engineer



LunarG SDK and Tools

Karl Schultz, LunarG, Inc.

SIGGRAPH – Vulkan Tools Roundtable

July 2016

Vulkan SDK

- Current release based on Vulkan spec/header 1.0.21
 - Released on July 21
- Cadence is approximately monthly right now
- Derived from public GitHub repos
- Value-add:
 - Components tested and verified
 - “One-stop shop”
 - Easy install

Vulkan SDK Tools

- We'll be talking about:
 - API Dump, Screenshot, vktrace/vkreplay, vktraceviewer, RenderDoc
- Other parts of the SDK, not discussed here:
 - Loader and Validation Layers
 - Covered in Tuesday BOF
 - Check out recordings if you missed it
 - “Vulkan Validation Layers Deep Dive” Webinar coming, probably September 27
 - Vulkan header files
 - Vulkan Spec docs
 - Samples / demos

API Dump

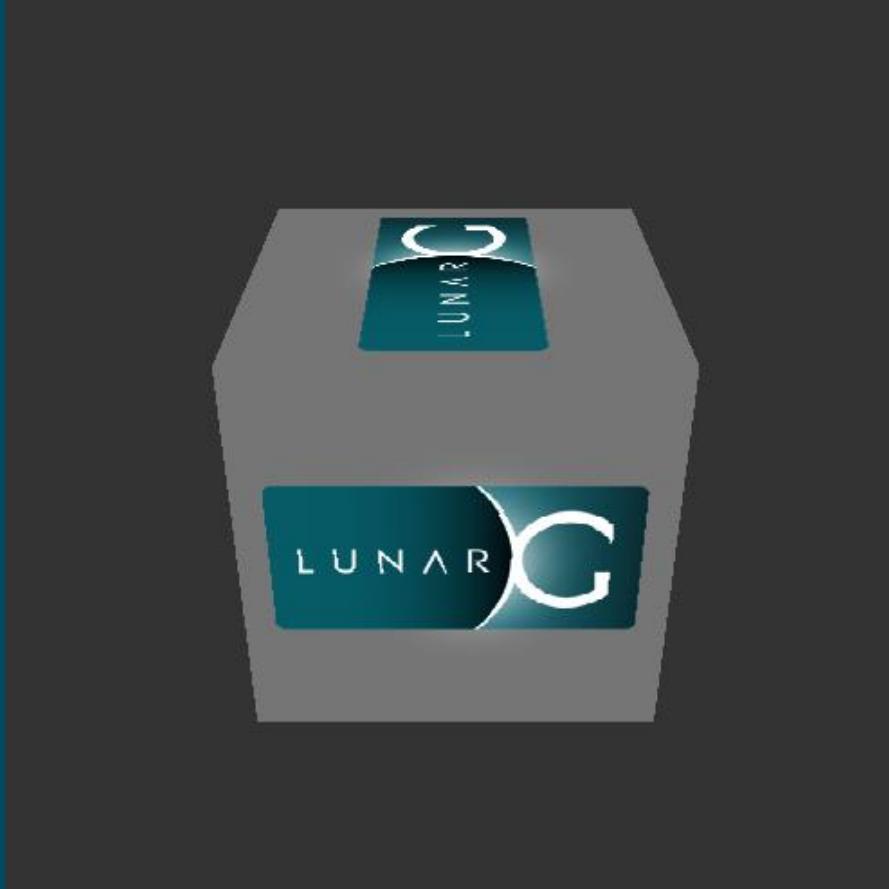
- Implemented as a Vulkan layer
- Writes API calls out as text output
- Good for seeing what led up to a problem

```
$ VK_INSTANCE_LAYERS=VK_LAYER_LUNARG_api_dump ./tri
t{0} vkCreateInstance(pCreateInfo = 0x7ffedd58e9c0, pAllocator = 0x0, *pInstance
= 0x2014710) = VK_SUCCESS
    pCreateInfo:
        sType = VK_STRUCTURE_TYPE_INSTANCE_CREATE_INFO
        pNext = 0x7ffedd58e9a0
        flags = 0x0
        pApplicationInfo = 0x7ffedd58eba0
        enabledLayerCount = 0x0
        ppEnabledLayerNames = 0x0
        enabledExtensionCount = 0x2
        ppEnabledExtensionNames = 0x7ffedd58f140
            pApplicationInfo:
                sType = VK_STRUCTURE_TYPE_APPLICATION_INFO
                pNext = 0x0
                pApplicationName = tri
                applicationVersion = 0
                pEngineName = tri
                engineVersion = 0
                apiVersion = 4194304
            pNext:

t{0} vkEnumeratePhysicalDevices(instance = 0x2014710, *pPhysicalDeviceCount =
0x1, pPhysicalDevices = 0x0) = VK_SUCCESS
t{0} vkEnumeratePhysicalDevices(instance = 0x2014710, *pPhysicalDeviceCount =
0x1, *pPhysicalDevices = 0x2216600) = VK_SUCCESS
```

Screenshot

```
$ export VK_INSTANCE_LAYERS=VK_LAYER_LUNARG_screenshot  
$ export _VK_SCREENSHOT=5  
$ ./cube  
$ ls *.ppm  
  
5.ppm
```



- Implemented as a Vulkan layer
- These commands capture the 5th frame and store it in 5.ppm
- Vktrace (next slide) can also take screenshots using this layer

vktrace vkreplay

```
$ vktrace -p cube -o cube_trace.vktrace
$ ls -l cube_trace.vktrace
-rw-rw-r-- 1 karl karl 32646746 Jul 22 14:46 cube_trace.vktrace

$ vkreplay -t cube_trace.vktrace -l 2
```

- **Vktrace sets environment to load vktrace layer and then launches app as a child process**
- **Vktrace layer serializes Vulkan API calls and records them into a file**
- **Vkreplay plays back the vktrace file**
- **Work in Progress:**
 - WSI mapping – allows recording on one window system and playback on another
 - OS mapping – handle OS-specific issues like structure packing
 - GPU mapping – handle differences in GPU capabilities and physical limits
 - Other issues and features – See VulkanTools GitHub

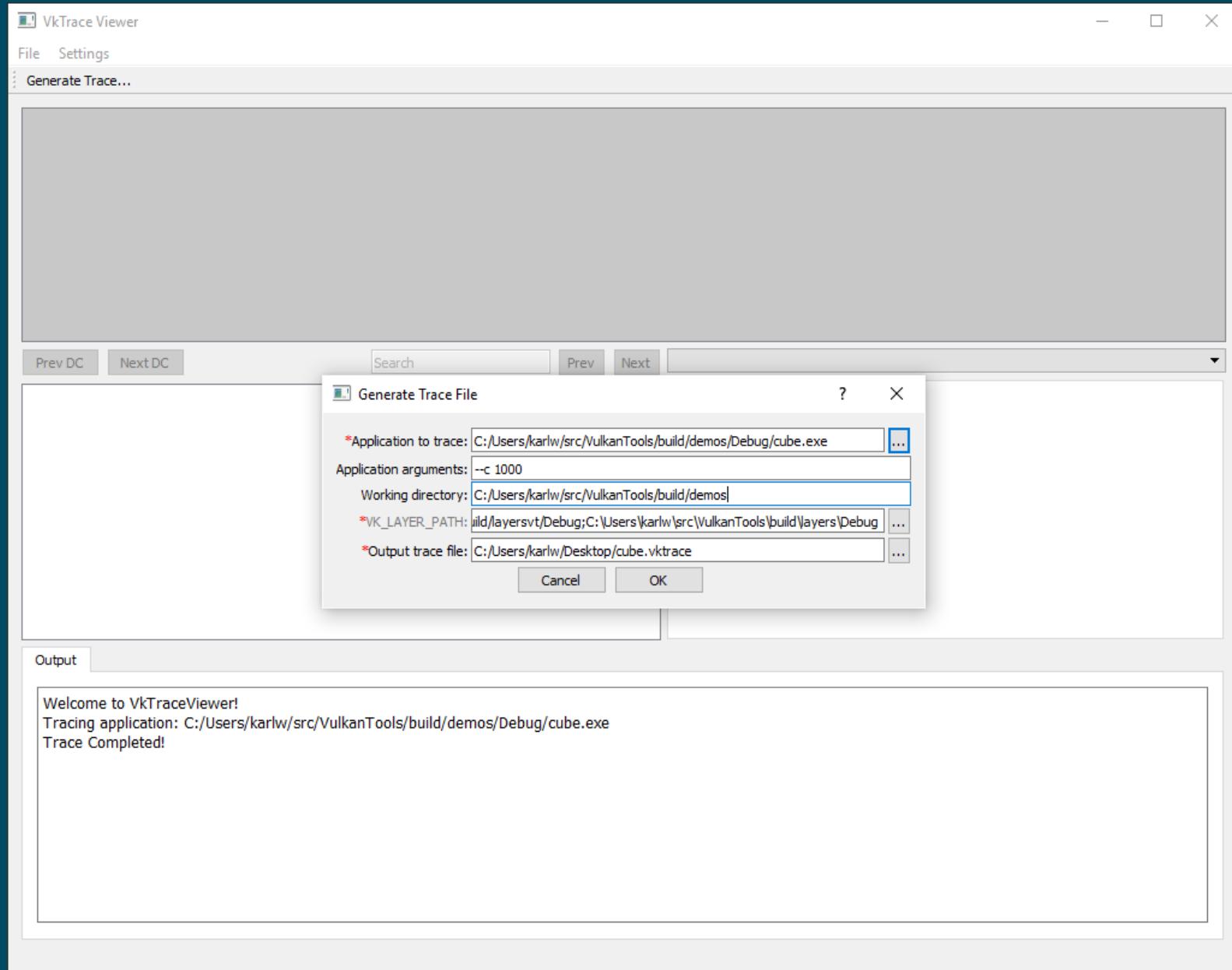
VkTrace Viewer – Interactive vktrace File Explorer

- Developer: Peter Lohrmann
- Pretty cool tool to look at vktrace files
- Coming in future LunarG SDK
- But code is in the LunarG VulkanTools repo
 - Windows version currently in better shape than the Linux version
 - Needs Qt to build
- Features
 - Load existing vktrace files
 - Start an app to generate a vktrace file
 - Replay a vktrace file
 - Single-step through a vktrace file
 - Examine vktrace packet detail
 - Run to a specific packet

VkTrace Viewer

Generate Trace

- Essentially the same as running vktrace from the command line
- Or open an existing vktrace file from the File menu

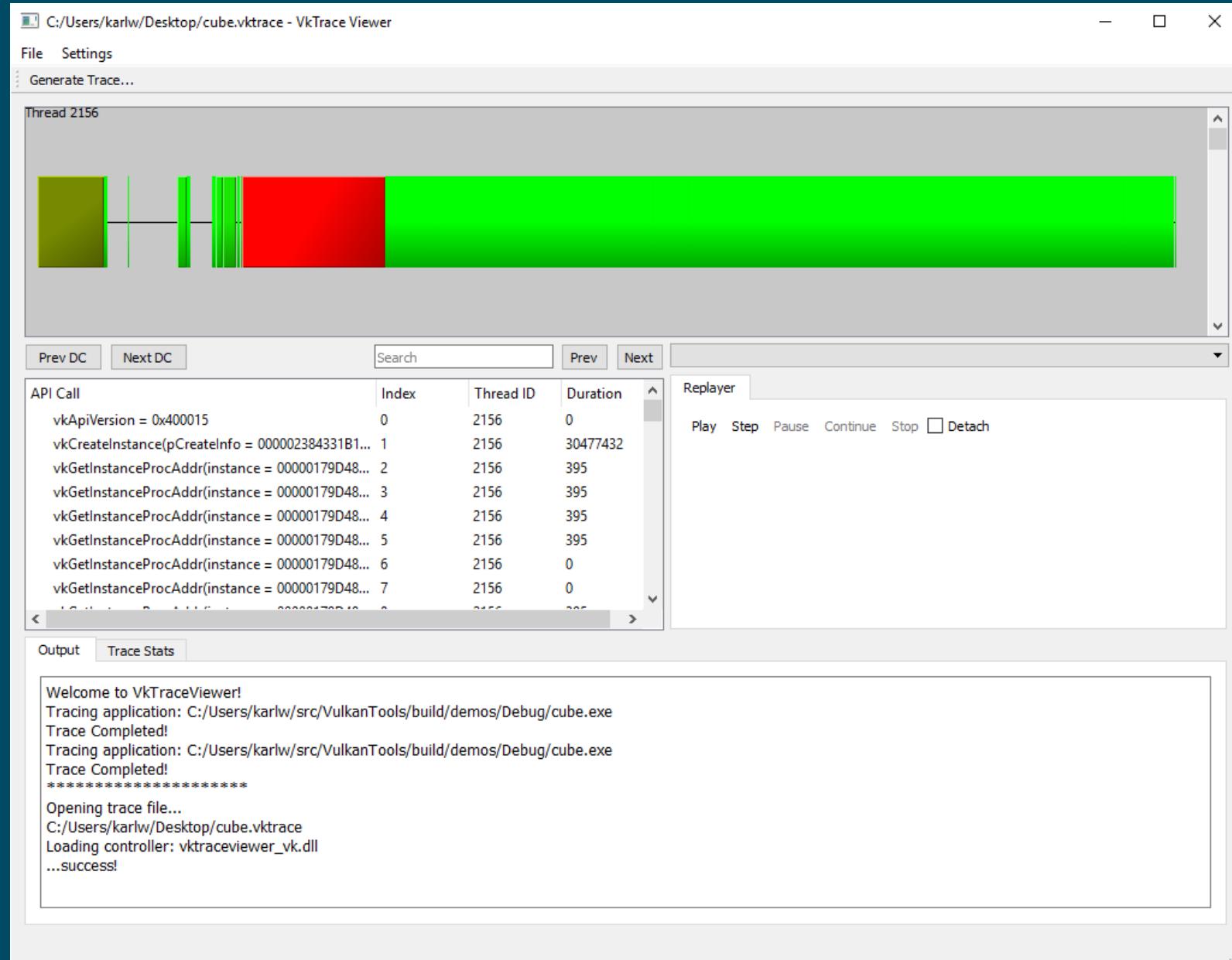


VkTrace Viewer

Examine Trace

Initial Screen

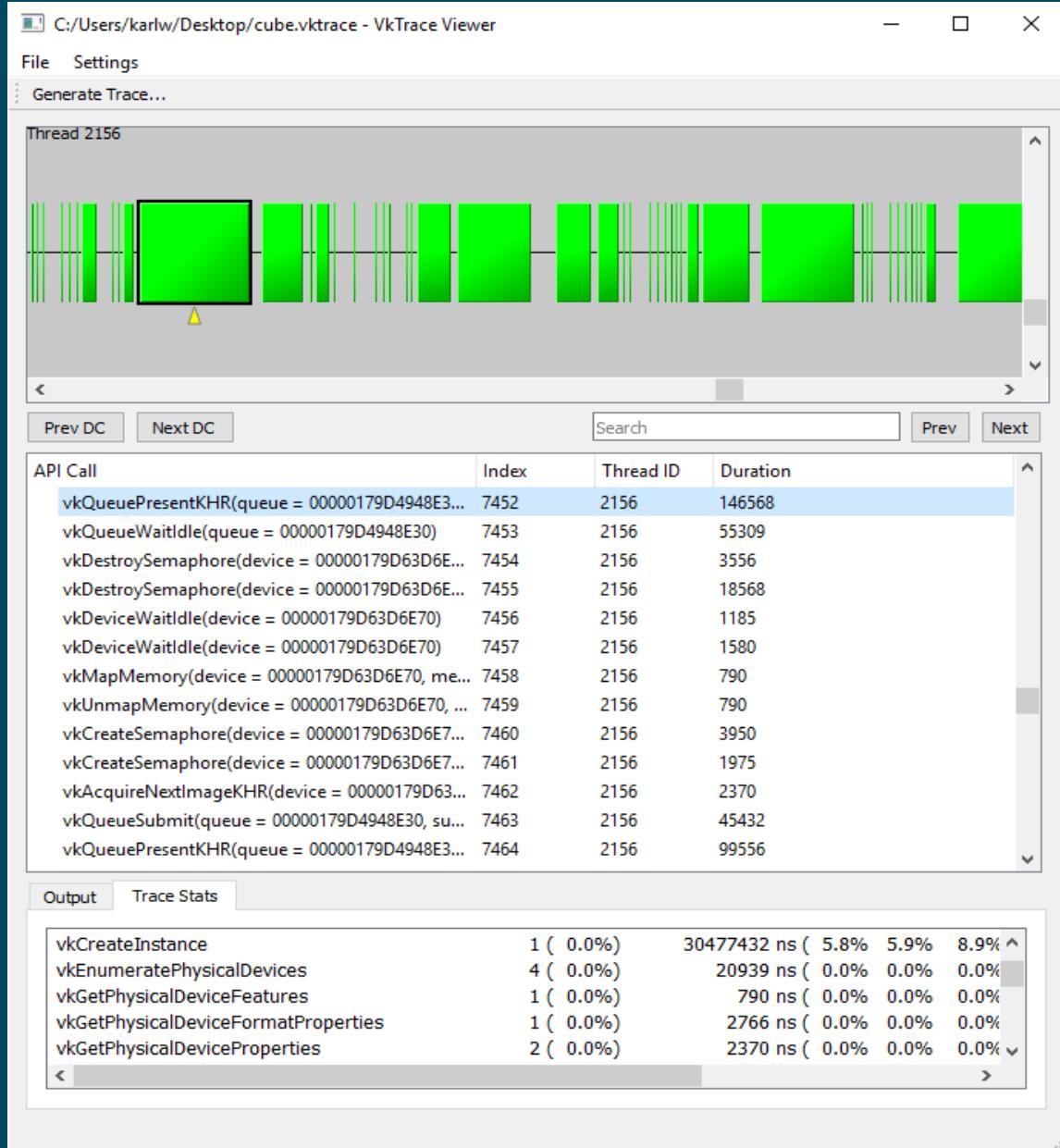
- Comes up right after you create the trace
- Packets are shown in the bar graph
- A red packet is taking a long time
- This one is the first Present
- Note API call list panel
- “Prev DC” and “Next DC” are for Draw Calls



VkTrace Viewer

Examine Trace One Frame

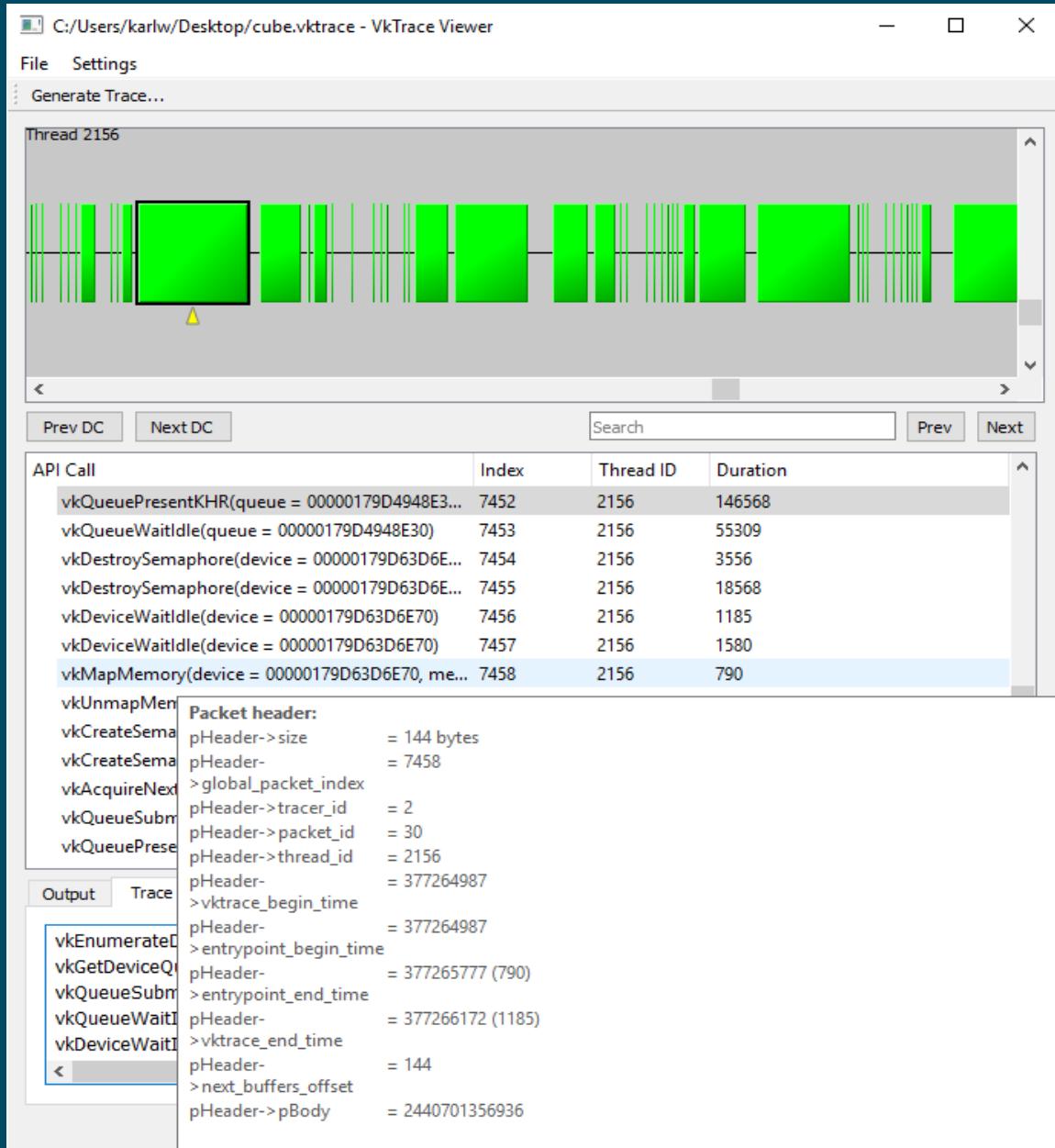
- Zoomed in graph to show about 3 frames
- API call window shows calls for 1 frame
- 12 API calls
- Present through QueueSubmit shown here
- Note Trace Stats panel



VkTrace Viewer

Examine Trace with Hover

- Hover over a call in the API Call frame
- Packet header info displays
- Also some parameter and structure data



VkTrace Viewer Replay / Step



C:/Users/karlw/Desktop/cube.vktrace - VkTrace Viewer

File Settings
Generate Trace...

Thread 9132

API Call Index Thread ID Duration

vkCreateSemaphore(device = 0000...	6909	9132	1975
vkAcquireNextImageKHR(device =...	6910	9132	1580
vkQueueSubmit(queue = 0000022...	6911	9132	14617
vkQueuePresentKHR(queue = 00...	6912	9132	86914
vkQueueWaitIdle(queue = 000002...	6913	9132	94814
vkDestroySemaphore(device = 00...	6914	9132	16987
vkDestroySemaphore(device = 00...	6915	9132	1580
vkDeviceWaitIdle(device = 000002...	6916	9132	790
vkDeviceWaitIdle(device = 000002...	6917	9132	1185

Replayer
Play Step Pause Continue Stop >

Welcome to VkTraceViewer!

Opening trace file...
C:/Users/karlw/Desktop/cube.vktrace
Loading controller: vktraceviewer_vk.dll
...success!
Replay Started
[\(6911\)](#): Replay Paused
(6911) Error: DOT not found, unable to generate state diagrams.

RenderDoc

- Developer: Baldur Karlsson
- Shipped in LunarG Windows SDK
- <https://github.com/baldurk/renderdoc>
- Popular for D3D11 and OpenGL
- Vulkan Support has been added
- No Linux GUI yet
- Cannot possibly do justice to it here – check out video tutorials on YouTube, etc

cube_2016.07.22_13.39.57_frame26758.rdc - RenderDoc v0.29

File Window Tools Help

Timeline - Frame #26758

- Colour Pass #1 (1 Targets)

Presentable Image 0 Reads ▲, Clears ▲ and Writes ▲

Event Browser

Controls | Mesh Output Texture Viewer Capture Executable cube (Vulkan)

EID Name

- Frame #26758
 - Frame Start
 - Colour Pass #1 (1 Targets)
 - => vkQueueSubmit(1)[0]: vkBeginCommand...
 - vkCmdBeginRenderPass(C=Clear, D=Clear)
 - vkCmdDraw(36, 1)
 - vkCmdEndRenderPass(C=Store, D=Don't C...
 - => vkQueueSubmit(1)[0]: vkEndCommandB...
 - vkQueuePresentKHR()

Tools

Capture Delay 0 Trigger Capture

Capture Frame # 2 Queue Capture

Captures collected:

 cube
Vulkan
22/07/2016 13:40:10

API Calls

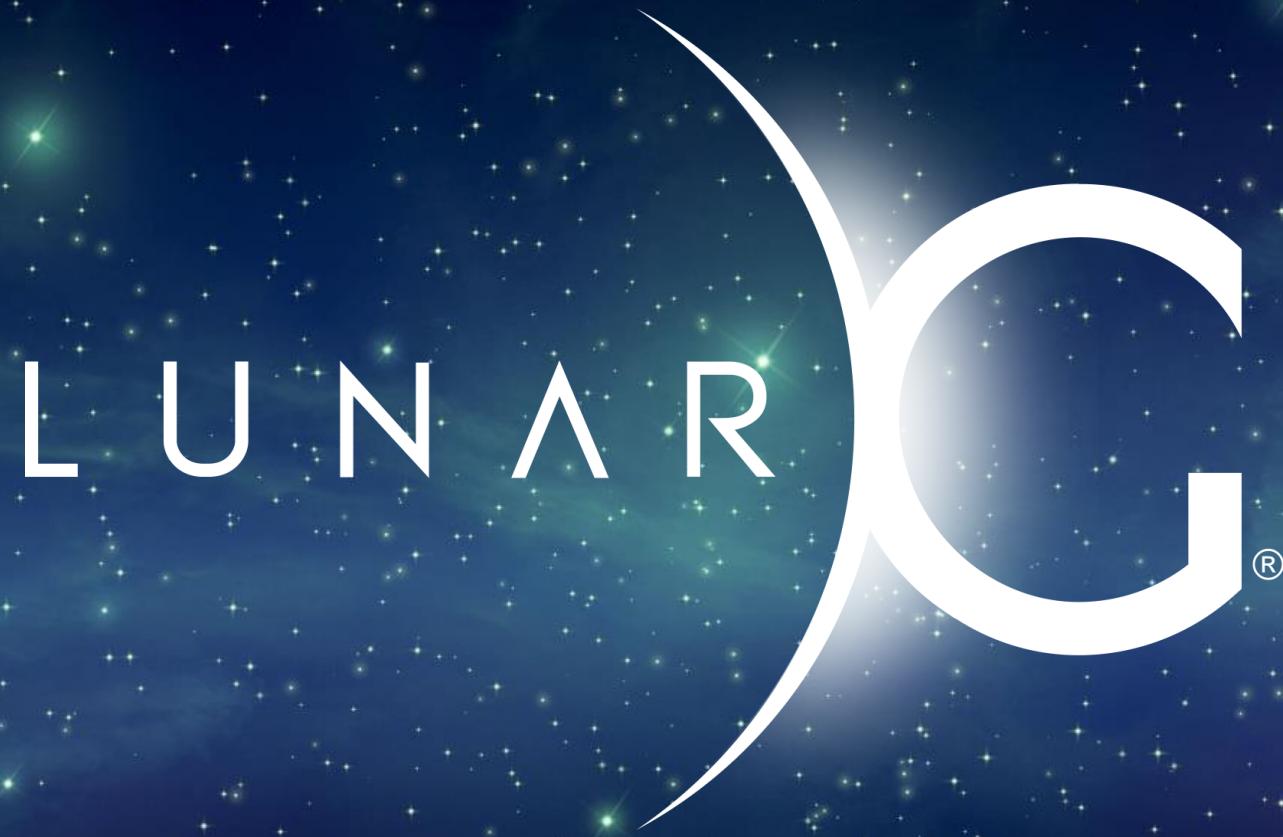
EID API Call

- 9 vkCmdBindPipeline
- 10 vkCmdBindDescriptorSet
 - cmdid: ID 170
 - layoutid: ID 164
 - bind: VK_PIPELINE_BIND_POINT_GRAPHICS
 - first: 0
 - numSets: 1
 - Debug Messages
 - DescriptorSet: ID 174
 - offsCount: 0
- 11 vkCmdSetViewport

Callstack

Open Save Delete

✓ cube_2016.07.22_13.39.57_frame26758.rdc loaded. No problems detected.



SPIR-V Tools



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SPIR-V Tooling

- SPIR-V is the binary intermediate language used for Compute Kernels in OpenCL and Shaders in Vulkan.
 - Easy to parse SSA form.
 - Retains high-level information.
 - Contains enough information to allow useful reflection of the binary.



Compilation

- **Glslang** <https://github.com/khronosgroup/glslang>
 - Reference Glsl -> SPIR-V compiler.
 - Compile a fragment shader: glslangValidator -V foo.frag -o output.spv
 - Output generated assembly: glslangValidator -H foo.frag
 - Can be used as a library for online compilation.
- **Shaderc** <https://github.com/google/shaderc>
 - Wrapper around the reference compiler (glslang)
 - Provides a gcc/clang-like command-line interface.
 - Adds support for both <> and “” includes.
 - Adds command-line preprocessor defines.
 - Adds -M dependency generation.
 - Adds a C and C++ library interface that has all of the functionality of the command-line tool.
 - Compile a fragment shader: glslc -fshader-stage=fragment foo.glsl -o a.spv

```
awoloszyn ~/Sandbox/shaderc/build/install/bin
└─▶ ccat foo.glsl
#version 450
#include "in_out.glsl"

void main() {
    out_color = in_color;
}
awoloszyn ~/Sandbox/shaderc/build/install/bin
└─▶ ccat in_out.glsl
#ifndef COLOR_LOCATION
layout(location = COLOR_LOCATION) in vec4 in_color;
#endif
layout(location = 0) out vec4 out_color;
awoloszyn ~/Sandbox/shaderc/build/install/bin
└─▶ ./glslc -o foo.spv -fshader-stage=fragment foo.glsl -DCOLOR_LOCATION=2
awoloszyn ~/Sandbox/shaderc/build/install/bin
└─▶ █
```

SPIRV-Tools

- A collection of command-line tools and libraries for handling SPIR-V.
- **spirv-dis**
 - Takes a SPIR-V module and produces a human-readable format similar to llvm.
- **spirv-as**
 - Takes the human-readable format and turns it back into a SPIR-V module.
- **spirv-val (Not Yet Complete)**
 - Validates that a given SPIR-V module follows all of the rules set out in the spec.
- **spirv-opt**
 - Optimization tool and framework for transforming SPIR-V.
 - Currently has a debug info stripping pass.
- Library interfaces to all of these.

```
awołoszyn ~/Sandbox/shaderc/build/install/bin
└─> ./spirv-dis foo.spv
; SPIR-V
; Version: 1.0
; Generator: Khronos Glslang Reference Front End; 1
; Bound: 13
; Schema: 0
        OpCapability Shader
%1 = OpExtInstImport "GLSL.std.450"
        OpMemoryModel Logical GLSL450
        OpEntryPoint Fragment %main "main" %out_color %in_color
        OpExecutionMode %main OriginUpperLeft
        OpSource GLSL 450
        OpSourceExtension "GL_GOOGLE_cpp_style_line_directive"
        OpSourceExtension "GL_GOOGLE_include_directive"
        OpName %main "main"
        OpName %out_color "out_color"
        OpName %in_color "in_color"
        OpDecorate %out_color Location 0
        OpDecorate %in_color Location 2
    %void = OpTypeVoid
    %3 = OpTypeFunction %void
    %float = OpTypeFloat 32
    %v4float = OpTypeVector %float 4
%_ptr_Output_v4float = OpTypePointer Output %v4float
    %out_color = OpVariable %_ptr_Output_v4float Output
%_ptr_Input_v4float = OpTypePointer Input %v4float
    %in_color = OpVariable %_ptr_Input_v4float Input
    %main = OpFunction %void None %3
        %5 = OpLabel
    %12 = OpLoad %v4float %in_color
        OpStore %out_color %12
        OpReturn
        OpFunctionEnd
```

```
awołoszyn ~/Sandbox/shaderc/build/install/bin
```



bin : zsh

SPIRV-Cross

- SPIR-V to higher level language conversion tool
 - SPIR-V to GLSL
 - SPIR-V to MSL
 - SPIR-V to C++
- Library interface to do the same
- Reflection api for determining shader resources

```
awoloszyn ~/Sandbox/spirv-cross/build
└─> ./spirv-cross foo.spv | ccat
#version 450

layout(location = 0) out vec4 out_color;
layout(location = 2) in vec4 in_color;

void main()
{
    out_color = in_color;
}
awoloszyn ~/Sandbox/spirv-cross/build
└─> █
```

What's needed for the future?

- **Linker**
 - Turn multiple SPIR-V modules into one larger module
 - Size improvements due to merged constants/globals/functions
- **Debug Info**
 - More complete debug information in generated SPIR-V
- **Simulation/Debugging tools**
 - Single-stepping SPIR-V, value examination, ...
- **Optimization Passes**
 - Architecture agnostic optimizations
 - Constant folding, Variable elimination, etc
 - Constant Specialization pass
- **More high-level language support**
 - Work is being done in glslang to support HLSL