DX12 & Vulkan
Dawn of a New Generation of Graphics APIs

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Agenda

Why do we need new APIs?

What‘s new?

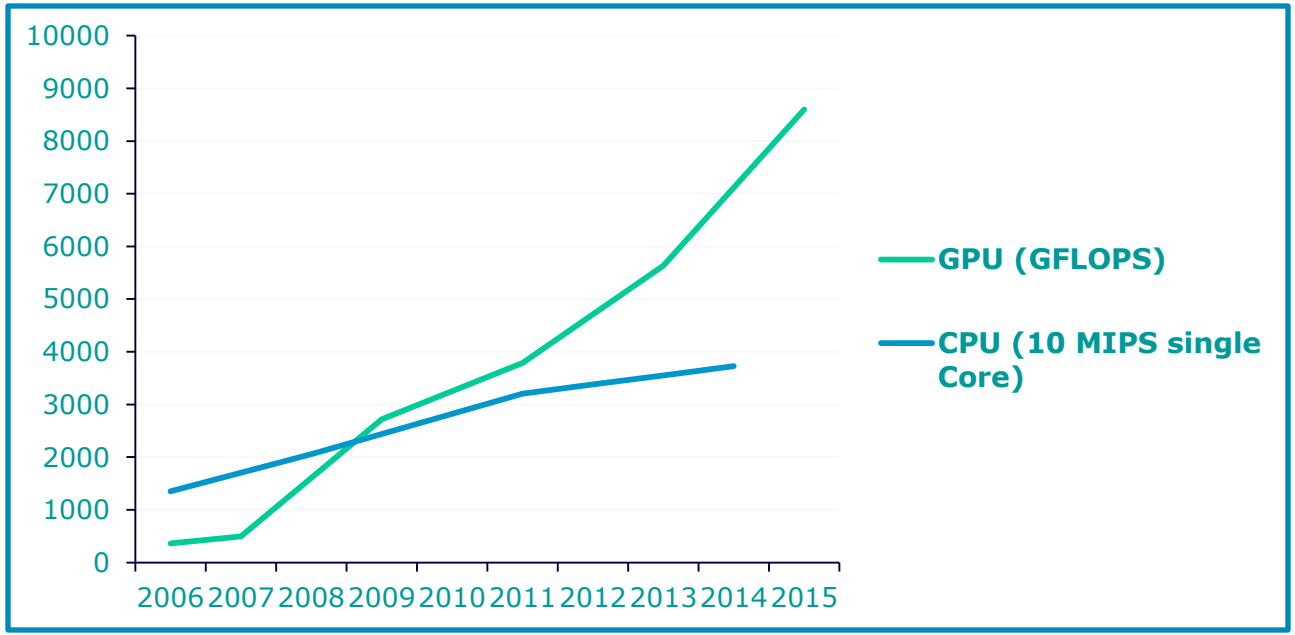
- Parallelism
- Explicit Memory Management
- PSOs and Descriptor Sets

Best Practices

Evolution of 3D Graphics APIs

- Software rasterization
- 1996 Glide: Bilinear filtering + Transparency
- 1998 DirectX 6: IHV independent + Multitexturing
- 1999 DirectX 7: Hardware Texturing&Lighting + Cube Maps
- 2000 DirectX 8: Programmable shaders + Tessellation
- 2002 DirectX 9: More complex shaders
- 2006 DirectX 10: Unified shader Model
- 2009 DirectX 11: Compute

GPU performance increasing faster than single core CPU performance



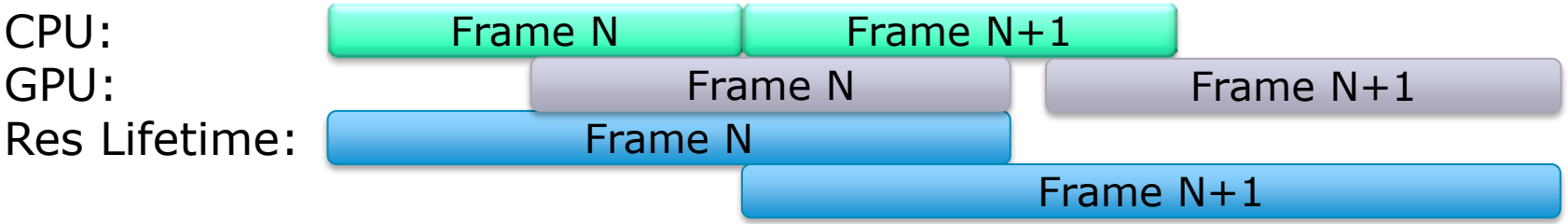
How to get GPU bound

- Optimize API usage (e.g. state caching & sorting)
- Batch, Batch, Batch!!!
  - ~10k draw calls max

- Allow multi-threaded command buffer recording
- Reduce workload of runtime/driver
  - Reduce runtime validation
  - Move work to init/load time (e.g. Pipeline setup)
  - More explicit control over the hardware
  - Reduce convenience functions

New APIs

Convenience function: Resource renaming



Examples:

- Backbuffer
- Dynamic vertex buffer
- Dynamic constant buffer
- Descriptor sets
- Command buffer

Track usage by End-Of-Frame-Fence

- Fences are expensive
- Use less than 10 fences per frame

Best practice for constant buffers:

- Use system memory (DX12: UPLOAD)
- Keep it mapped

2013: AMD Mantle

„Mantle is not for everyone“

Adopted by several developers & titles

- Developers are willing do the additional work
- Significant performance improvements in games
- Good ISVs don‘t need runtime validation

Only available on AMD GCN hardware

Needed standardization

2013: AMD Mantle

„Mantle is not a low level API “

- It‘s a „just the right level API“
- Support different HW configurations
  - Discreet GPU vs. Integrated
  - Shaders & command buffer are HW specific
- Support different HW generations
  - Think about future hardware
- On PC, your title is never alone

Next Generation API features

DirectX12 & Vulkan share the Mantle philosophy:

- Minimize overhead
- Minimize runtime validation
- Allow multithreaded command buffer recording
- Provide low level memory management
- Support multiple asynchronous queues
- Provide explicit access to multiple devices

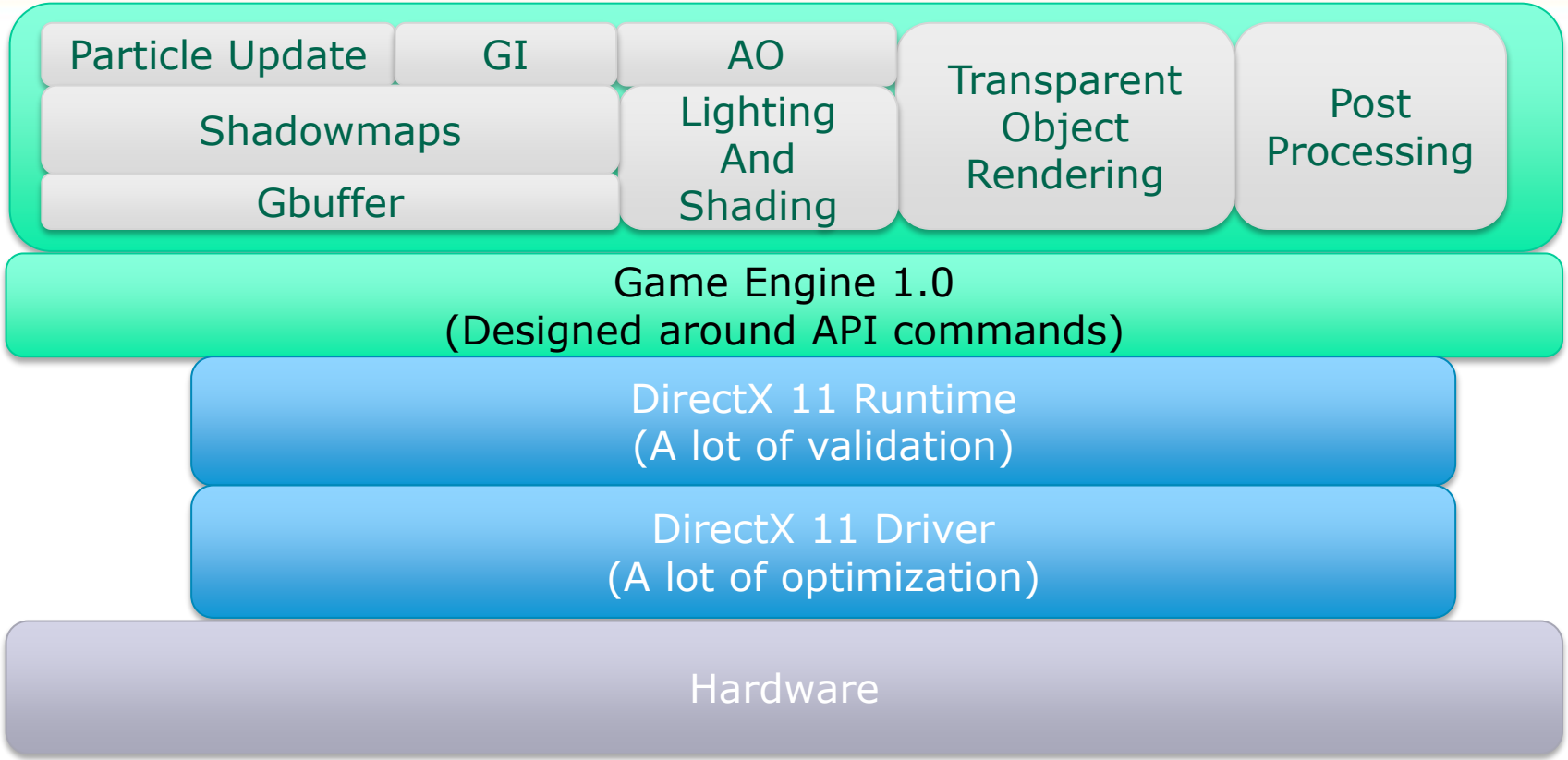
The big question: „How much performance will I gain from porting my code to new APIs?“

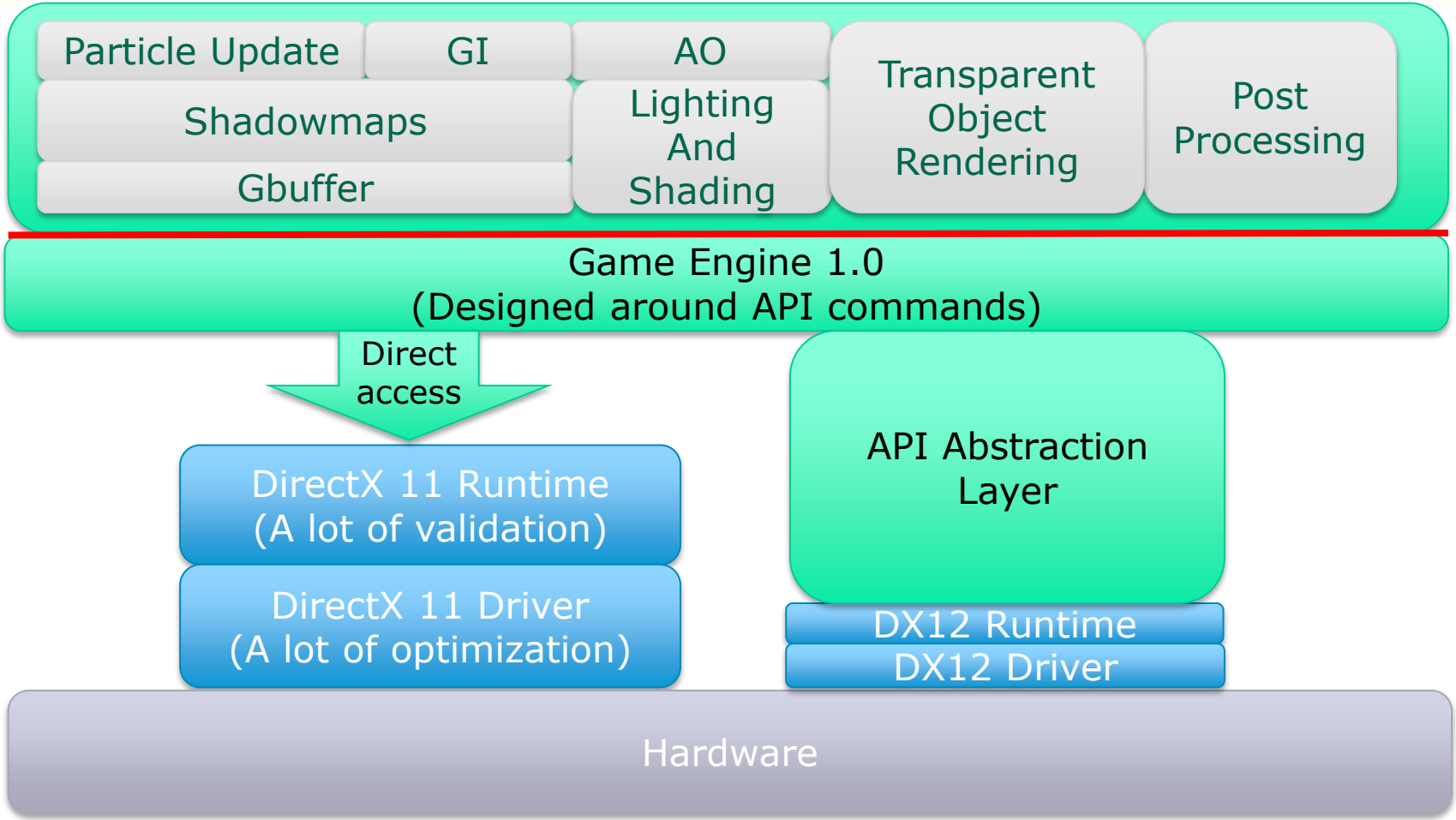
No magic involved!

Depends on the current bottlenecks

Depends a lot on engine design

- **Need to utilize new possibilities**
- It might „just work“ (esp. if heavily CPU limited)
- Might need redesign of engine (and asset pipeline)


Particle Update
GI
AO
Shadowmaps
Gbuffer
Lighting And Shading
Transparent Object Rendering
Post Processing
Game Engine 1.0
(Designed around API commands)
DirectX 11 Runtime
(A lot of validation)
DirectX 11 Driver
(A lot of optimization)
Hardware


Particle Update
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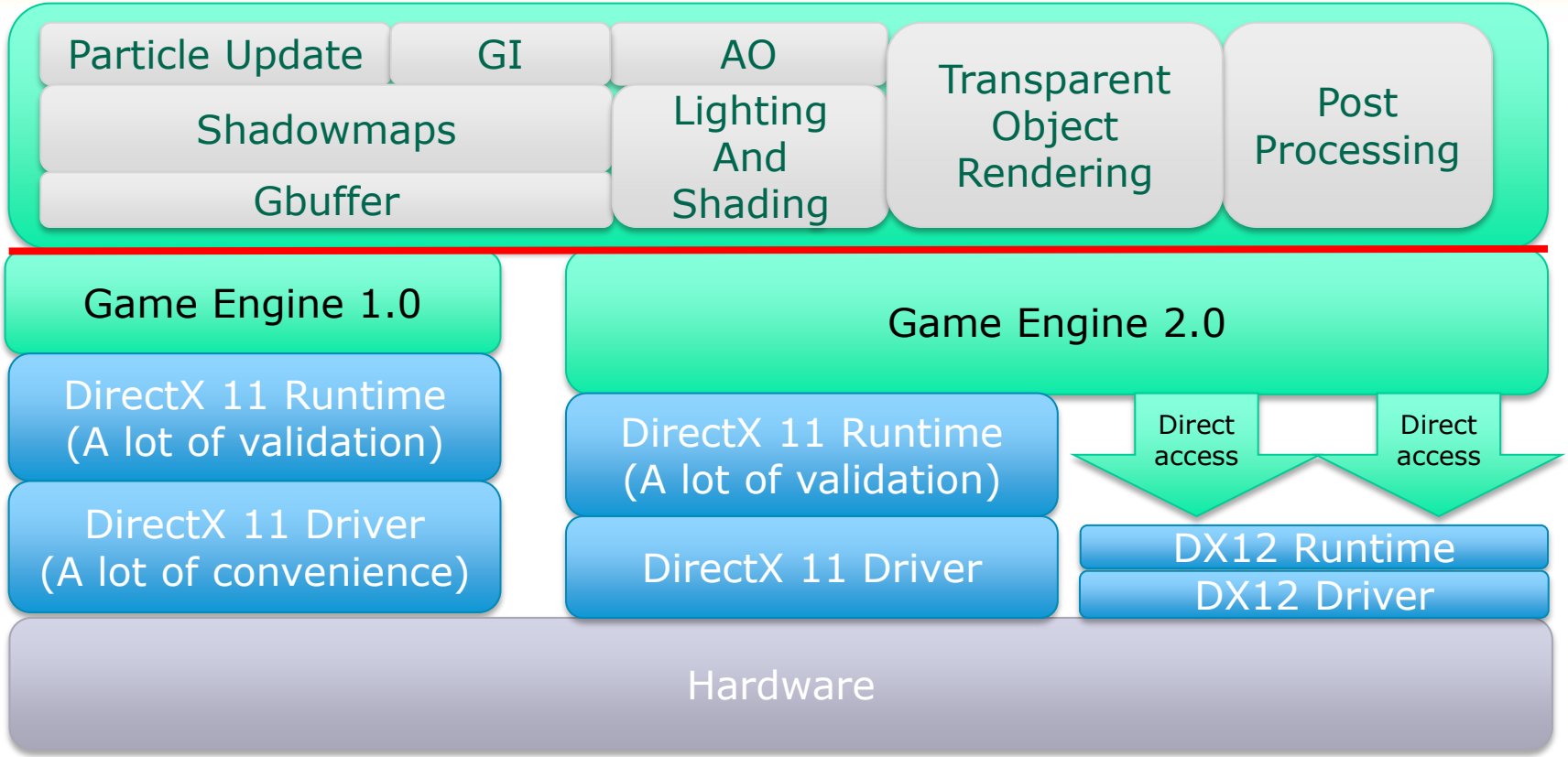
(Designed around API commands)
Direct access
DirectX 11 Runtime
(A lot of validation)
DirectX 11 Driver
(A lot of optimization)
API Abstraction Layer
DX12 Runtime
DX12 Driver
Hardware


Particle Update
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Shadowmaps
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Post Processing
Game Engine 1.0
DirectX 11 Runtime (A lot of validation)
DirectX 11 Driver (A lot of convenience)
Game Engine 2.0
DirectX 11 Runtime (A lot of validation)
DirectX 11 Driver
Direct access
Direct access
DX12 Runtime
DX12 Driver
Hardware

Think Parallel!

Keep the GPU busy

CPU side multithreading

- Multi threaded command buffer building
  - Submission to queue is not thread safe
  - Split frame into macro render jobs
- Offload shader compilation from main thread
- Batch command buffer submission
- Don‘t stall during submit/present

GPU side multithreading

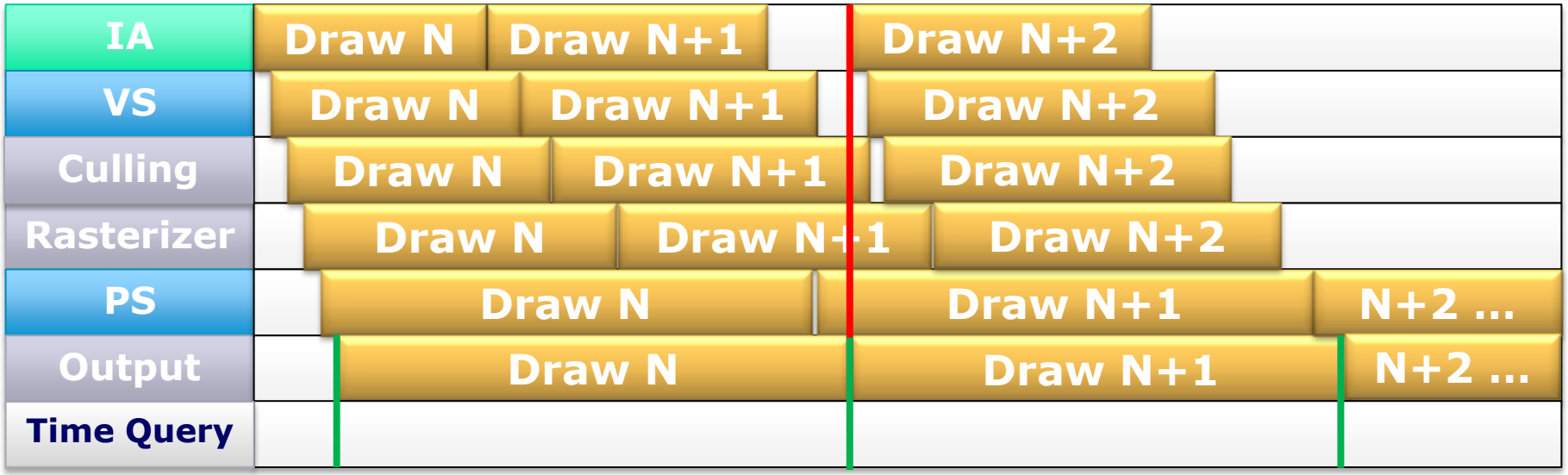
	Radeon Fury X	Radeon Fury
Compute Units	64	56
Core	1050 Mhz	1000 Mhz
Memory size	4 GB	4 GB
Memory BW	512 GB/s	512 GB/s
ALU	8.6 TFlops	7.17 TFlops

64 CU
x 4 SIMD per CU
x 10 Wavefronts per SIMD
x 64 Threads per Wavefront

Up to 163840 threads

Batch, Batch, Batch!!!

GPU: Single graphics queue



Multiple commands can execute in parallel

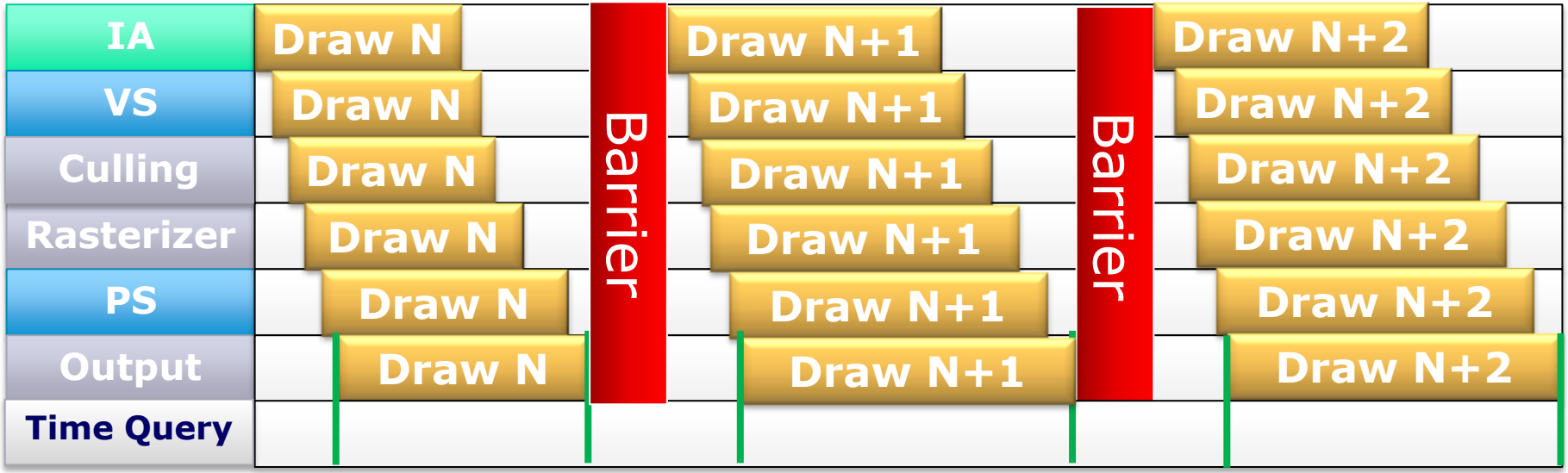
- Pipeline (usually) must maintain pixel order
- Load balancing is the main problem

Explicit Barriers & Transitions

- Indicate RaW/WaW Hazards
- Switch resource state between RO/RW/WO
  - Decompress DepthStencil/RTs
- May cause a stall or cache flush
  - **Batch them!**
  - Split Barriers may help in the future
- Always execute them on the last queue that wrote the resource

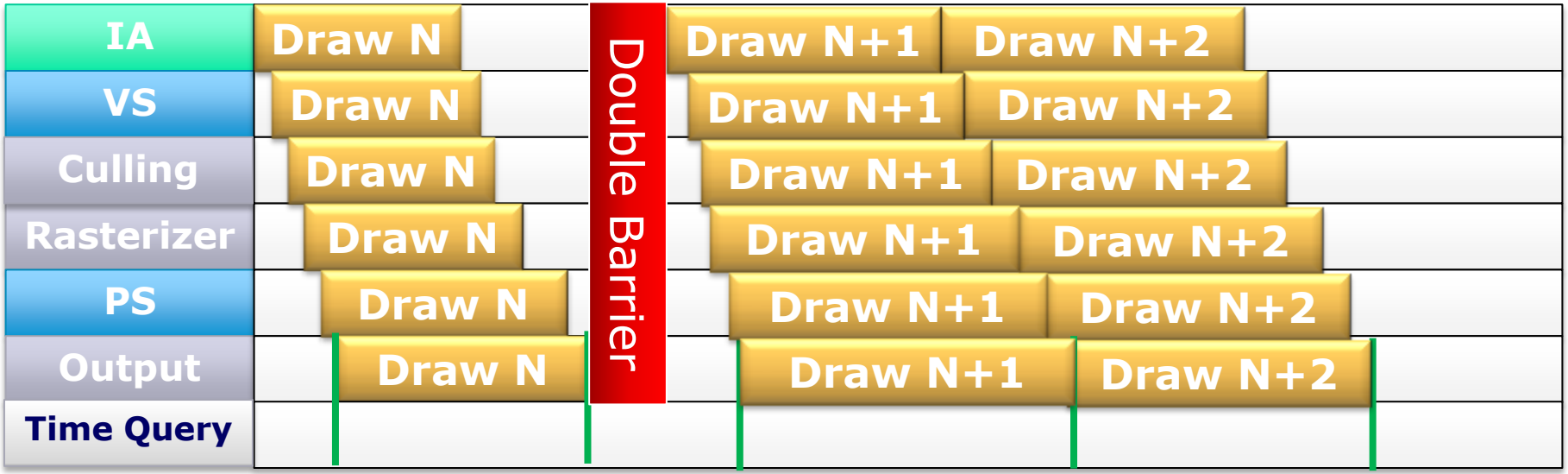
Most common cause for bugs!

GPU: Barriers



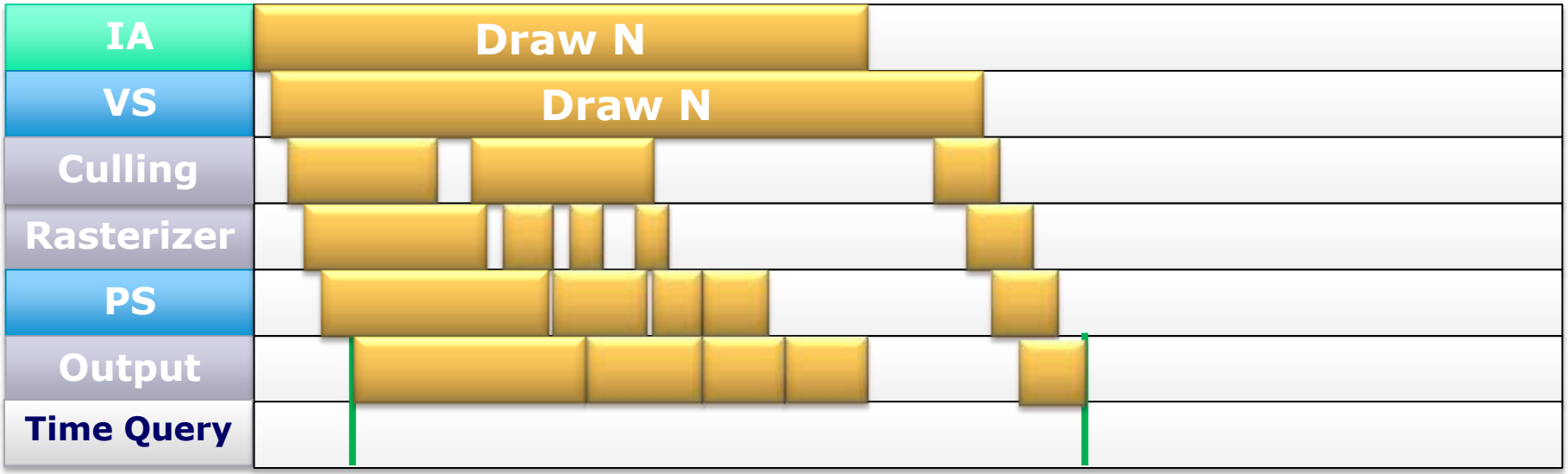
- Hard to detect Barriers in DX11
- Explicit in DX12

GPU: Barriers



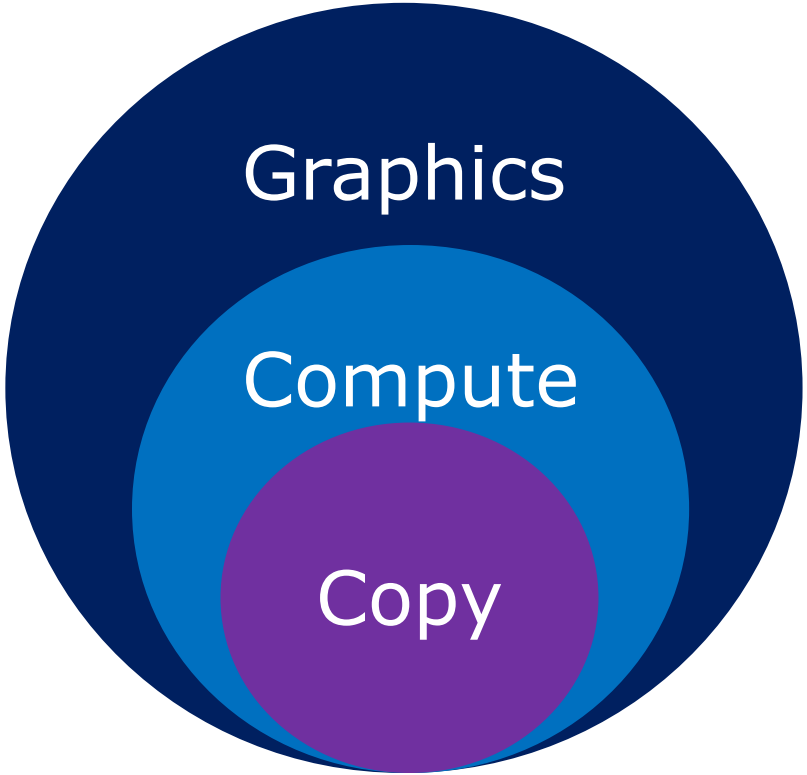
- Batch them!
- [DX12] In the future split barriers may help

GPU underutilization



Culling can cause bubbles of inactivity.
Fetch latency is a common cause for underutilization

Multiple Queues



- Let driver know about independent workloads
- Each queue type a superset
- Multiple queues per type
- Specify type at record time
- Parallel execution
  - Sync using fences
  - Shared GPU resources

Asynchronous Compute

Bus dominated	Shader throughput	Geometry dominated
Shadow mapping ROP heavy workloads G buffer operations DMA operations - Texture upload - Heap defrag	Deferred lighting Postprocessing effects Most compute tasks - Texture compression - Physics - Simulations	Rendering highly detailed models

Multiple queues allow to specify tasks to execute in parallel
Schedule different bottlenecks together to improve efficiency

Explicit MGPU

DirectX 11 only supports one device

- CF/SLI support essentially a driver hack
- Increases latency

Explicit MGPU allows

- Split Frame Rendering
- Master/Slave configurations
- Split frame rendering
- 3D/VR rendering using 2 dGPUs

Take Control!

Explicit Memory Managagement

Explicit Memory Management

- Control over heaps and residency
- Abstraction for different architectures
- VMM still exists
  - Use Evict/MakeResident to page out unused resources
  - Avoid oversubscribing resident memory!

	DEFAULT	UPLOAD	READBACK
Memory Pool	Local (dGPU) System(iGPU)	System	System
CPU Properties	No CPU access	Write Combine	Write Back
Usage	Frequent GPU Read/Write Max GPU Bandwidth	CPU Write Once, GPU Read Once Max CPU Write Bandwidth	GPU Write Once, CPU Read Max CPU Read Bandwidth

Explicit Memory Management

Rendertargets & UAVs

- Create in DEFAULT

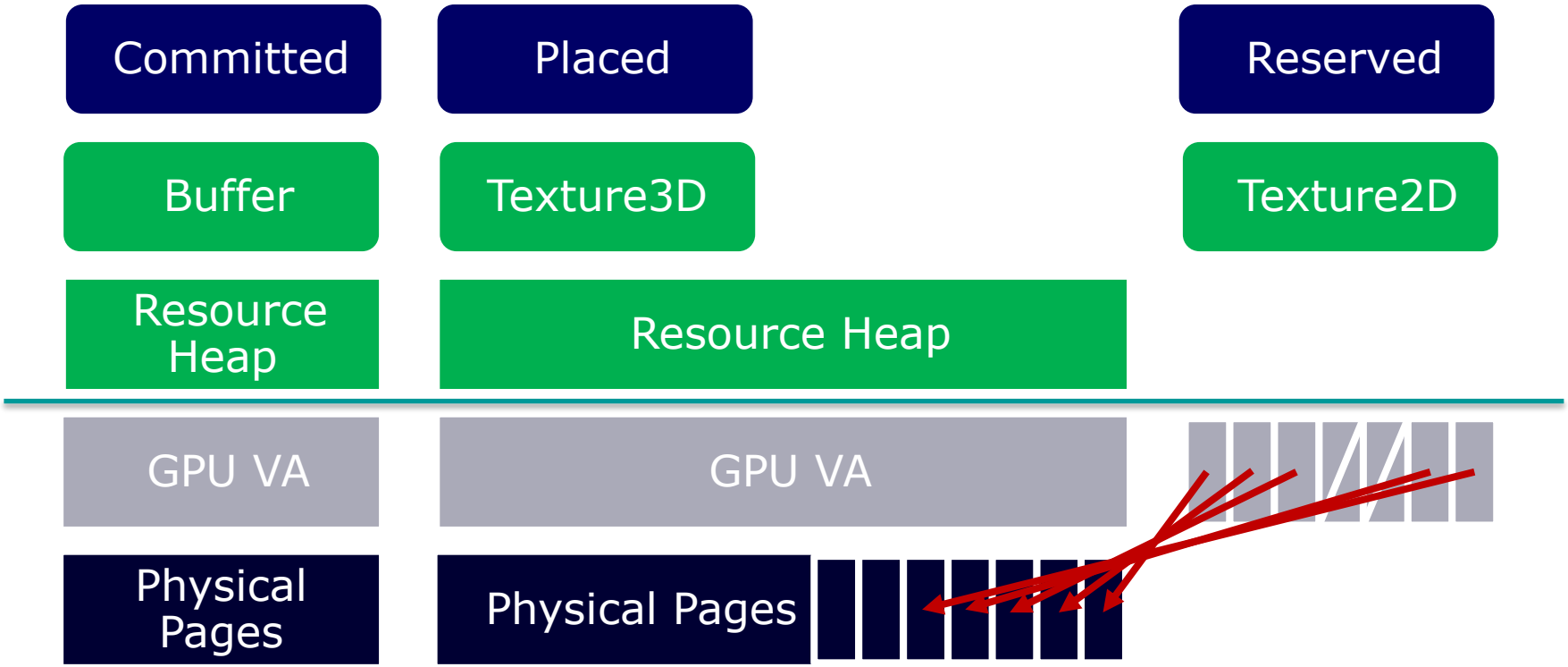
Textures

- Write to UPLOAD
- Use copy queue to copy to DEFAULT
  - Copy swizzles: required on iGPU!

Buffers (CB/VB/IB)

- Placement dependent on usage:
  - Write once/Read once => UPLOAD
  - Write once/Read many => Copy to DEFAULT

Direct3D 12 Resource Creation APIs



Explicit Memory Management

Don‘t over-allocate committed memory

- Share L1 with windows and other processes
  - Don‘t allocate more than 80%
- Reduce memory footprint
  - Use placed resources to reduce overhead
  - Use reserved resources as PRT

Allocate most important resources first

Group resources used together in same heap

- Use MakeResident/Evict

Avoid Redundancy!

Organize your pipelines

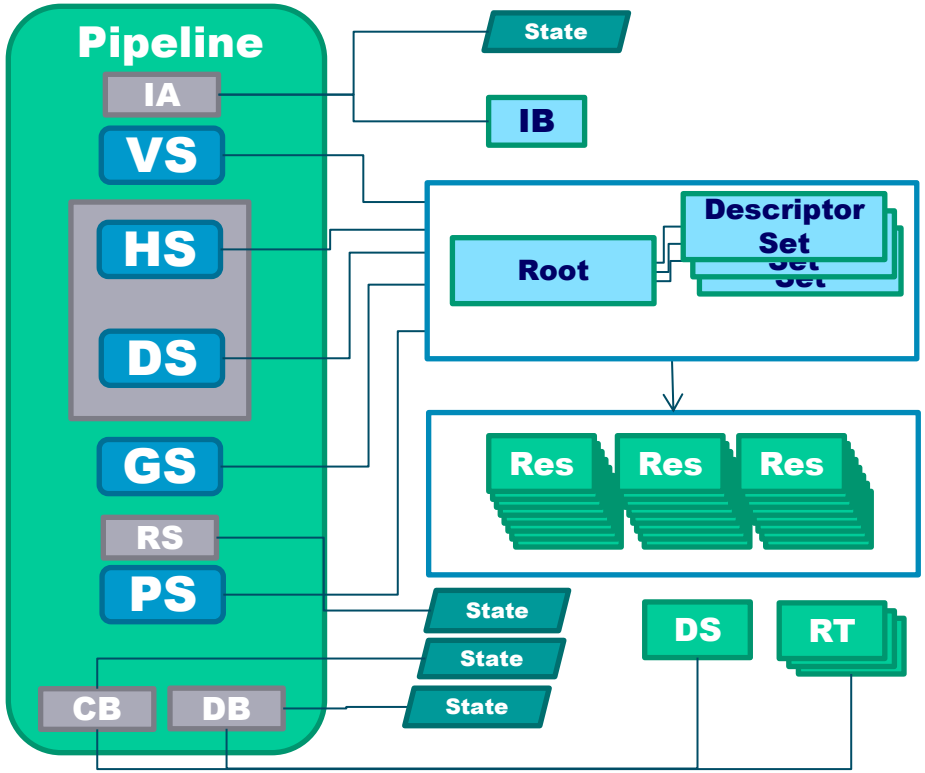
PipelineStateObjects

Full pipeline optimization
- Simplifies optimization

Additional information at startup
- Shaders
- Raster states
- Static constants

Build a pipeline cache
- No pre-warming

Most engines not designed for monolithic pipelines



Descriptor Sets

Old APIs:

- Single resource binding
- A lot of work for the driver to track, validate and manage resource bindings
  - Data management scripting language style

New APIs:

- Group resources in descriptor sets
- Pipelines contain „pointers“
  - Data management C/C++ style

Resource Binding

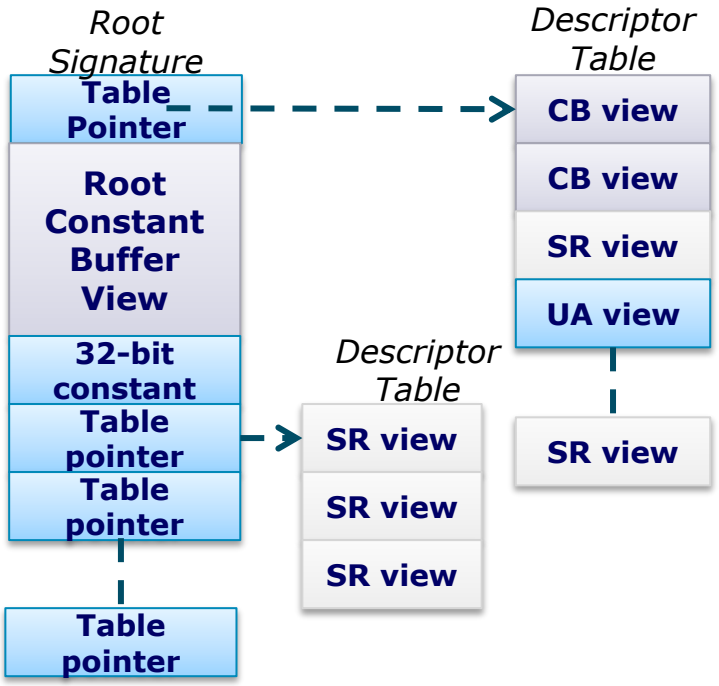


Table driven

Shared across all shader stages

Two-level table

- Root Signature describes a top-level layout
  - Pointers to descriptor tables
  - Direct pointers to constant buffers
  - Inline constants

Changing which table is pointed to is cheap

- It's just writing a pointer
- no synchronisation cost

Changing contents of table is harder

- Can't change table in flight on the hardware
- No automatic renaming

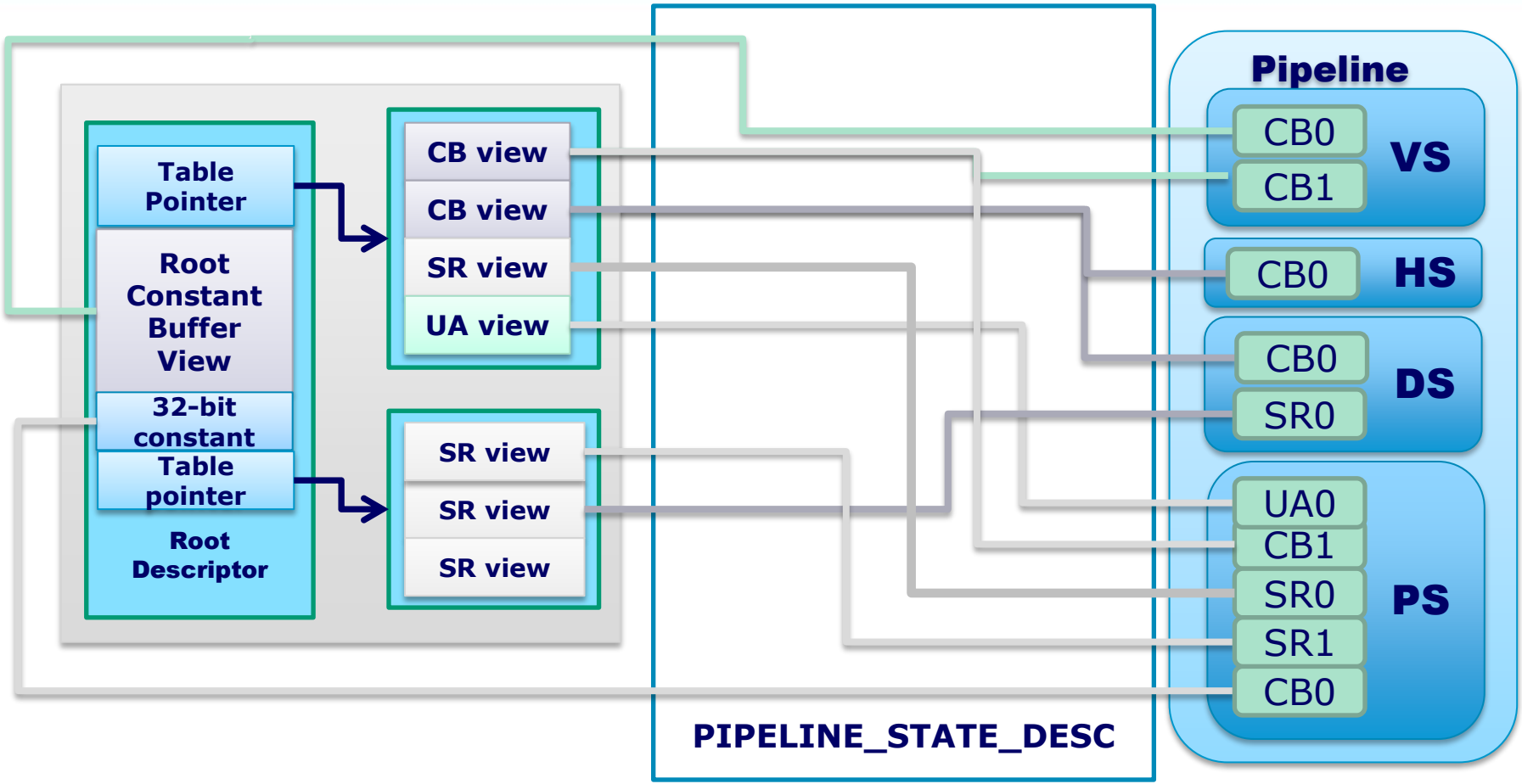


Table Pointer
Root Constant Buffer View
32-bit constant
Table pointer
Root Descriptor
CB view
CB view
SR view
UA view
SR view
SR view
SR view
PIPELINE_STATE_DESC
Pipeline
CB0
CB1
VS
CB0
HS
CB0
SR0
DS
UA0
CB1
SR0
SR1
CB0
PS

PSO: Best Practices

Use Shader and Pipeline cache
- Avoid duplication

Sort draw calls by PSO used
- Sort by Tessellation/GS enabled/disabled

Keep Root Descriptor small
- Group DescriptorSets by update pattern

Sort Root entries by frequency of update
- Most frequently changed entries first

Top 5 Performance Advice

#5. Avoid allocation/release at runtime

#4. Don‘t oversubscribe!
Manage your Memory efficiently

#3. Batch, Batch, Batch!
Group Barriers, group command buffer submissions

#2. Think Parallel!
On CPU as well as GPU

#1. Old optimization recommendations still apply

Thank you!

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