Porting your engine to Vulkan™ or DX12

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AGENDA

Introduction

Porting

- Memory management
- API of your renderer
- Pipelines, descriptors, command buffers
- Objects lifetime
- Multithreading on CPU
- Using multiple GPU queues
- Barriers
- Frame graph
- Additional considerations

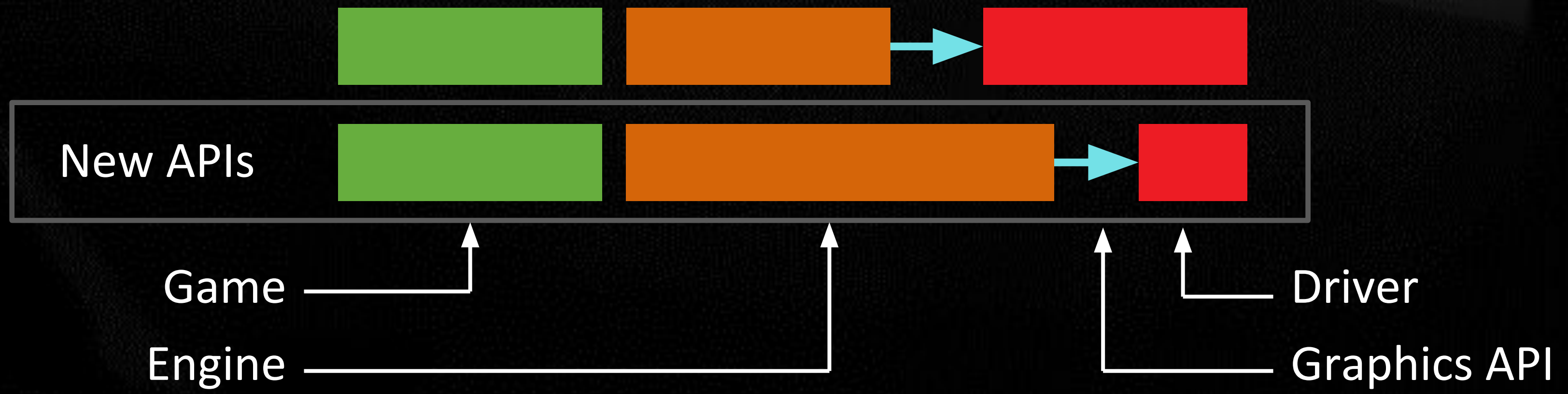
Conclusion

Introduction

Why port to Vulkan™ or DX12?

ADVANTAGES

- New generation graphics APIs are lower level, more explicit.
- Simple port won't necessarily give you performance uplift.
- It opens up possibilities to optimize better and use new GPU features.



ADVANTAGES

- multithreading on CPU
- using multiple GPU queues
- explicit multi-GPU
- better optimization for specific platforms
- less CPU overhead
- opportunity to improve engine architecture

Porting

How to port your engine?

RESPONSIBILITIES

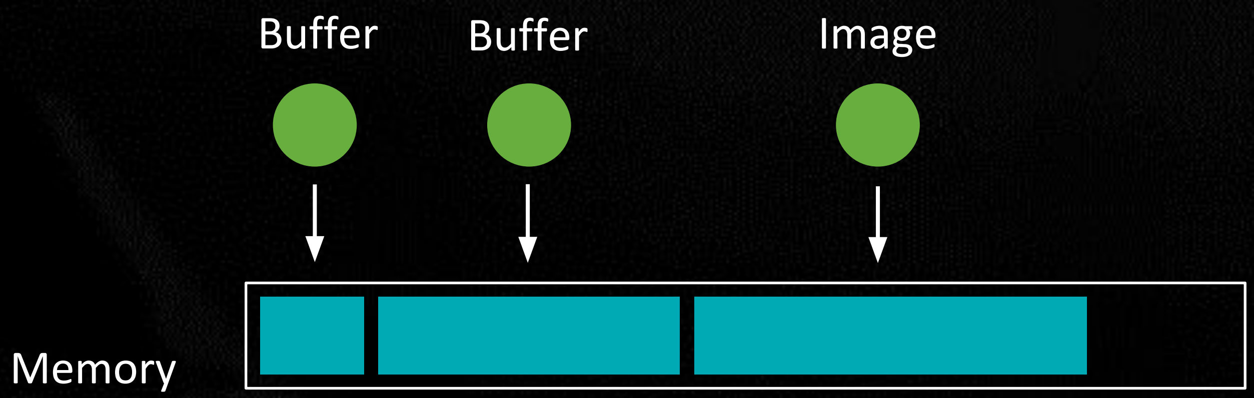
In the new APIs it is now your responsibility to do:

- memory allocation and management
- objects lifetime management
- command buffer recording and submission
- synchronization
- memory barriers for resources

MEMORY MANAGEMENT

THE CHALLENGE

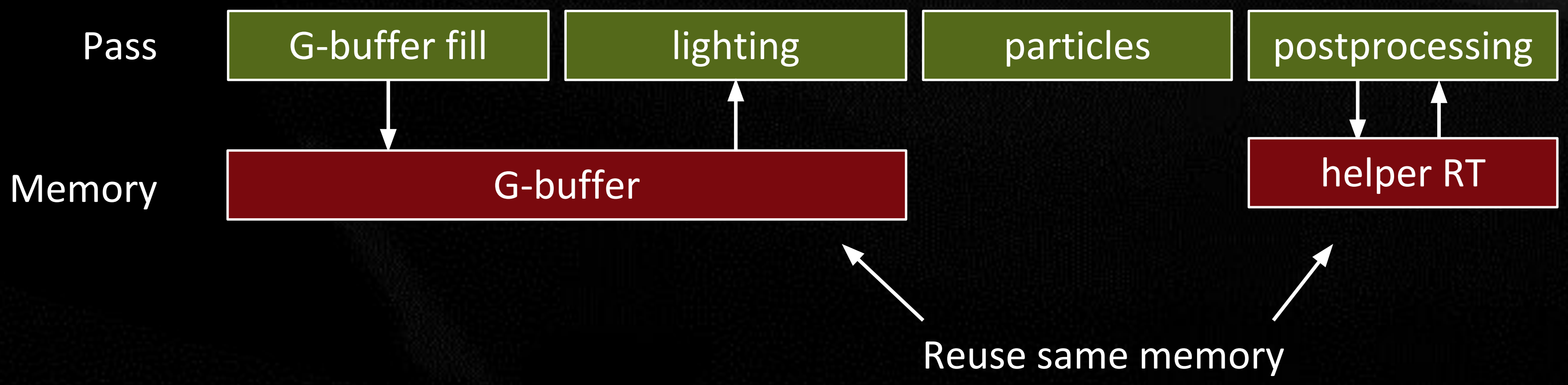
- Previous generation APIs (OpenGL™, DirectX® 11) manage memory automatically.
- New APIs (Vulkan™, DirectX® 12) are lower level, require explicit memory management.
  - Choose right memory type for your resource.
  - Allocate large blocks of memory.
  - Assign parts of them to your resources.
  - Respect alignment and other requirements.



MEMORY MANAGEMENT

ADVANTAGES

- manage memory better
- optimize better for specific platforms (e.g. discrete, integrated)
- save memory by aliasing:



MEMORY MANAGEMENT

RECOMMENDATIONS

Depending on usage pattern of your resource:

1. Frequent GPU read & write (render target, depth-stencil, UAV)
   - Always use video memory: D3D12_HEAP_TYPE_DEFAULT / VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT.
   - Allocate first.

2. Frequent GPU read, CPU write seldom or just initialized once (immutable)
   - Allocate in video memory: D3D12_HEAP_TYPE_DEFAULT / VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT.
   - Create staging copy in system memory D3D12_HEAP_TYPE_UPLOAD / VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT, transfer from there.
   - Place in system memory as fallback.

MEMORY MANAGEMENT
RECOMMENDATIONS

Depending on usage pattern of your resource:

3. Frequent CPU write, GPU read (dynamic)
   – Vulkan™, AMD GPU: use DEVICE_LOCAL + HOST_VISIBLE memory to directly write on CPU and read on GPU.
   – Otherwise, have one copy in system memory, one in video memory and make a transfer – see 2.

4. Frequent GPU write, CPU read (readback)
   – Use cached system memory: D3D12_HEAP_TYPE_READBACK / HOST_VISIBLE + HOST_CACHED.

MEMORY MANAGEMENT

SUB-ALLOCATION

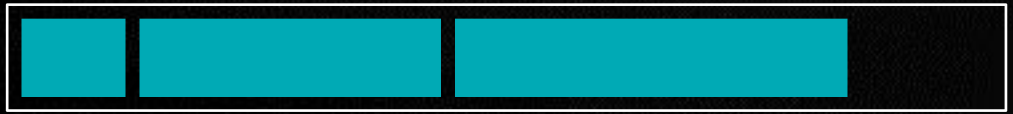
Possible solutions:

- Bad: Separate allocation for each resource (CreateCommittedResource).
  - slow, large overhead ☹
  - Vulkan™: limited maximum number of allocations, e.g. 4096

MEMORY MANAGEMENT

SUB-ALLOCATION

- Good: Allocate large (e.g. 256 MiB) blocks when needed, sub-allocate parts of them for your resources (CreatePlacedResource).
  - requires writing custom allocator → Vulkan™: you can use free library: Vulkan Memory Allocator https://github.com/GPUOpen-LibrariesAndSDKs/VulkanMemoryAllocator
  - making new allocations in runtime can cause hitching → do it on separate background thread



- Excellent: Allocate all needed memory and create all resources while loading game/level.

MEMORY MANAGEMENT

OVER-COMMITMENT

If you allocate too much video memory:

- new allocations may fail
- existing allocations can be migrated to system memory → performance degradation

MEMORY MANAGEMENT

OVER-COMMITMENT

Possible solutions:

- Bad: Allocate as much memory as you need, handle allocation errors, rely on system migration policy.
- Better: DX12: Manually control heap residency:
  ID3D12Device::Evict, MakeResident, SetResidencyPriority…
- Excellent: Explicitly control and limit memory usage:
  - Vulkan™: Query for VkMemoryHeap::size, leave some margin free (e.g. use maximum 80% of GPU memory).
  - DX12: Query for available budget DXGI_QUERY_VIDEO_MEMORY_INFO, adjust to it.

RENDERER API

- Many renderers have DX11-style or even DX9/OGL-style API.
- Using Vulkan™/DX12 under same interface is not a good idea.
- Better to redesign engine and then port.

```
• SetRenderState(D3DRS_CULLMODE, ...)
• SetRenderState(D3DRS_ZENABLE, ...)
• SetPixelShader(ps1)
• SetTexture(0, tex1)
• DrawIndexed()
```

☹

PIPELINES

THE CHALLENGE

- Pipeline / Pipeline State Object (PSO) encapsulates most of the configuration of graphics pipeline.
  vertex format, shaders, depth-stencil state, blend state, …

- Pipeline object is immutable. Different combination of settings requires new object.

PIPELINES

RECOMMENDATIONS

Possible solutions:

- Bad: Leave old interface with separate states.
  Flush on draw call: hash the state, lookup existing pipeline or create a new one.
  - bad: wait for it → hitching
  - better: create it on background thread

- SetRenderState(D3DRS_CULLMODE, ...)
- SetRenderState(D3DRS_ZENABLE, ...)
- SetPixelShader(ps1)
- SetTexture(0, tex1)
- DrawIndexed()

- Excellent: Create necessary pipelines on game loading.
  - explosion of possible combinations → limit their number, create only those really needed
  - creation takes long time (shader compilation happens there) → parallelize

DESCRIPTORS

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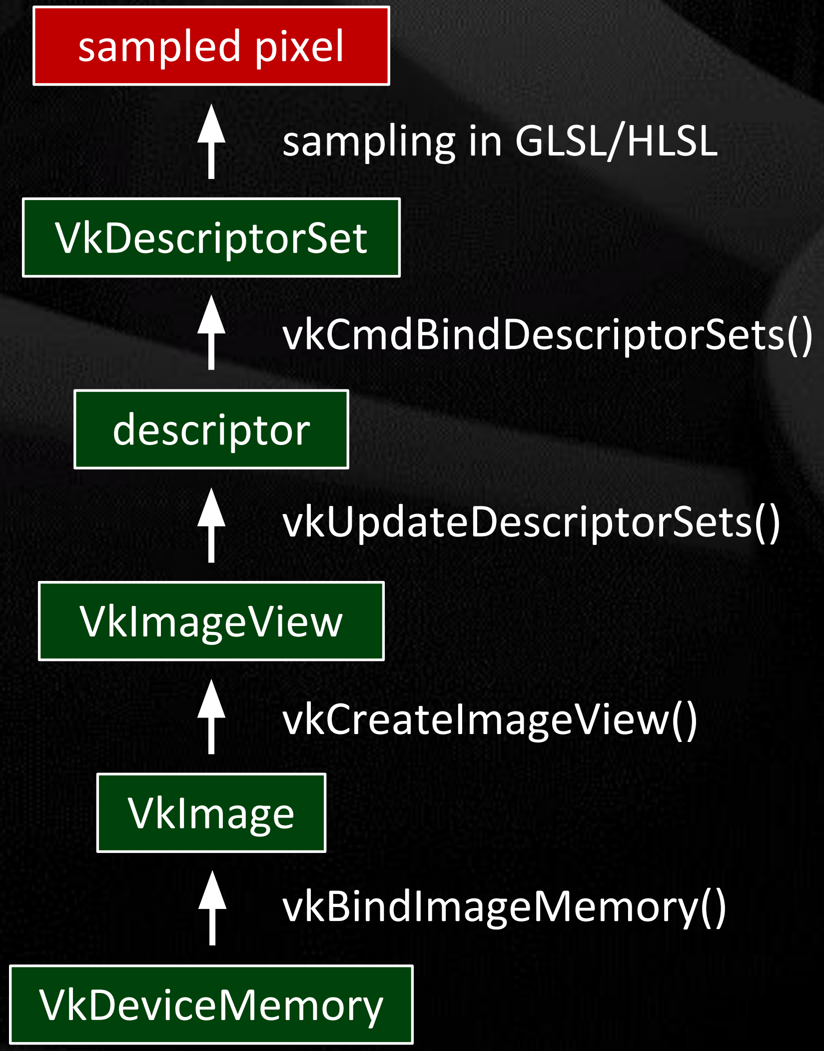
- New resource binding model – many levels of indirection.
- You need to predefine layout of descriptors as VkDescriptorSetLayout / ID3D12RootSignature.
- You need to initialize descriptors.



- Keep your descriptor set layout / root signature as small as possible.
- Group resources by rate of change – per frame, pass, material, object etc.
- Strive to keep the most frequently changing parameters first (DX12) / last (Vulkan).

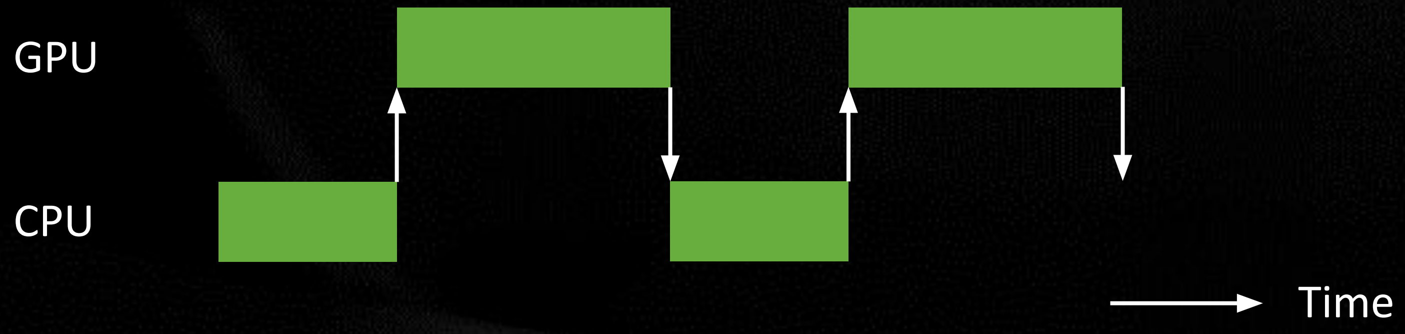
COMMAND BUFFERS

Command Buffer / Command List keeps sequence of graphics commands.

- fill it – post commands to it
- submit it for execution on the GPU

Possible solutions:

- Bad: Use single command buffer. Submit it and then immediately wait for it to finish.
  CPU and GPU get serialized ☹



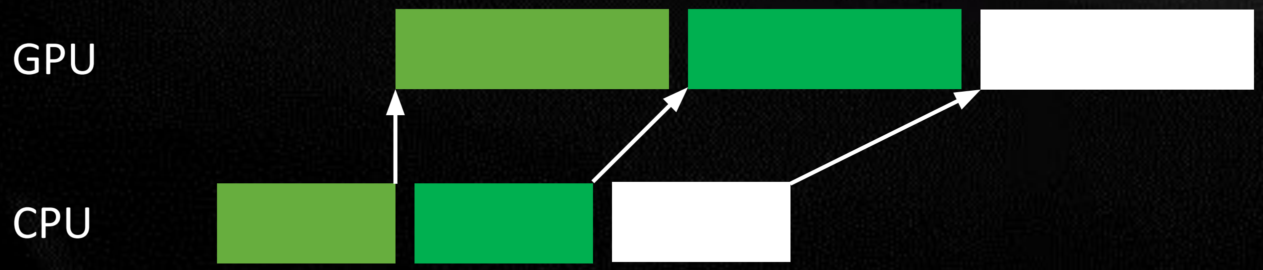
COMMAND BUFFERS

- Good: Double/triple-buffer your command buffers.

  Fill next one on CPU while previous is still being executed on GPU → pipelining

COMMAND BUFFERS

- Better: Split frame into multiple command buffers.
  - more regular feeding of GPU
  - commands submitted earlier → lower latency



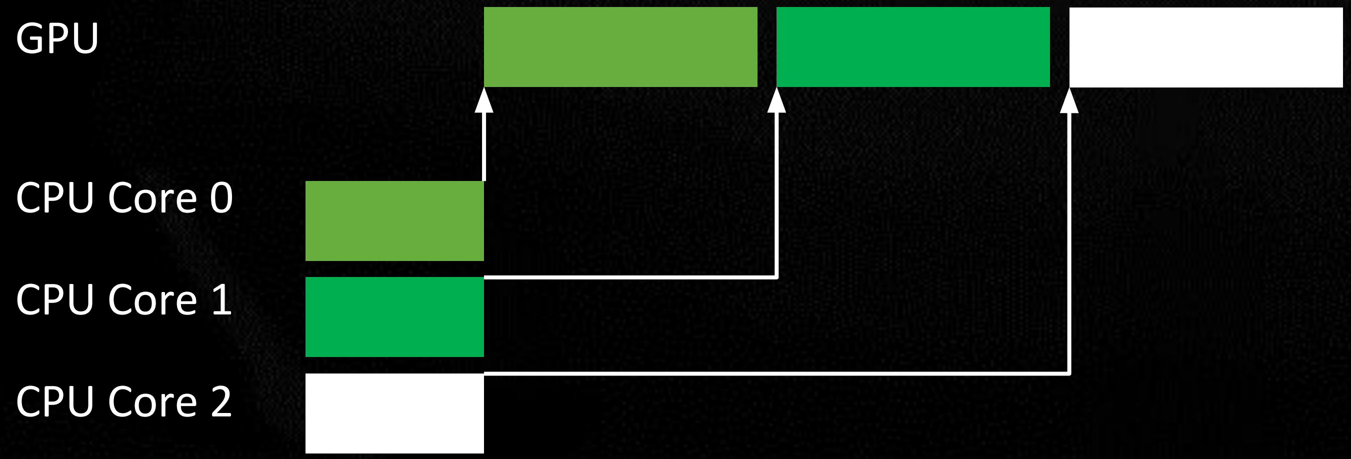
COMMAND BUFFERS

There is an overhead associated with each command buffer/submit/synchronization.

- Limit number of command buffers.
  - Aim for 15-30 per frame.
- Batch multiple command buffers into one submit call. Limit number of submits.
  - Aim for 5 per queue per frame.
- Control granularity of your command buffers.
  - Submit large chunks of work.

COMMAND BUFFERS

- Excellent: Record part of your frame once, submit it every frame.
- Excellent: Record multiple command buffers in parallel, on multiple threads.

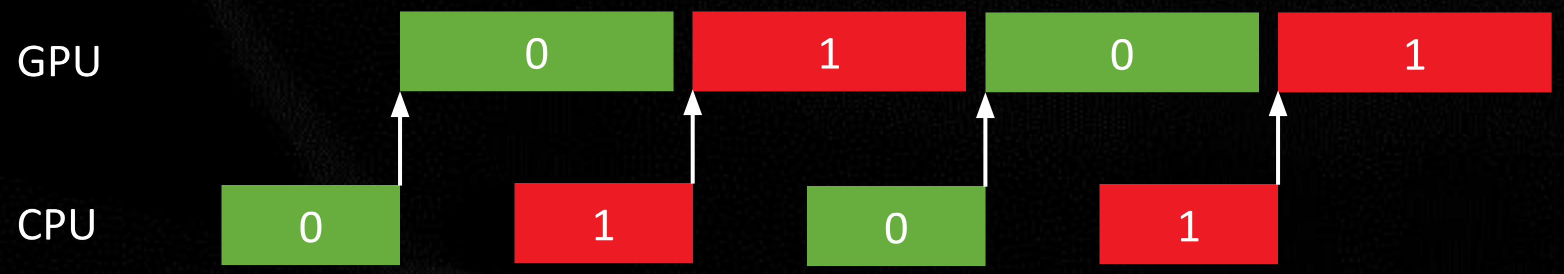


OBJECT LIFE-TIME

Most objects and data are not reference-counted or versioned by the API for usage on GPU.

- You need to make sure they remain alive and unchanged as long as they are used by the GPU.
- Includes: descriptors, contents of memory e.g. constant buffers.

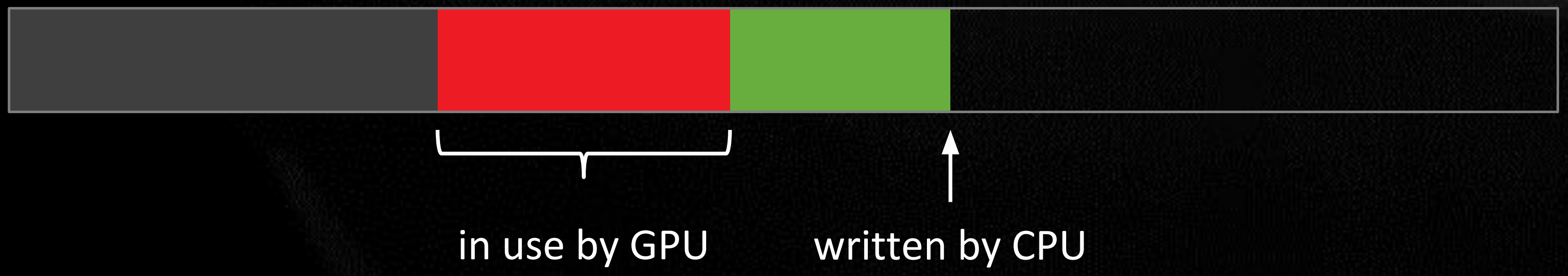
- Double/triple-buffer them together with command buffers.



OBJECT LIFE-TIME

Writing to mapped data behaves like you always used D3D11_MAP_WRITE_NO_OVERWRITE.

- Make a ring-buffer for your dynamic data.



MULTITHREADING (CPU)

Possible solutions:

- Bad: single-threaded game: `while(playing) { Update(); Render(); }`
- Better: Main thread with gameplay logic, scripting etc. + separate render thread + some background threads, e.g. AI, resource loading.

MULTITHREADING (CPU)

AMD

- Excellent: Task system
  - Pool of persistent threads, one per hardware thread, waiting for tasks.
  - Each frame consists of many tasks with dependencies between them.
  - Generic, scalable architecture ☺

MULTITHREADING (GPU)

Make use of multiple GPU queues to parallelize rendering.

- Graphics
- Async compute
- Transfer

MULTITHREADING (GPU)

Async compute

- General computations e.g. particles.
- Convert fullscreen passes to compute shaders.
- Execute parts of the frame in async compute.
  - preferably in parallel with geometry-intensive graphics work
  - finish frame by doing postprocessing and Present in async compute

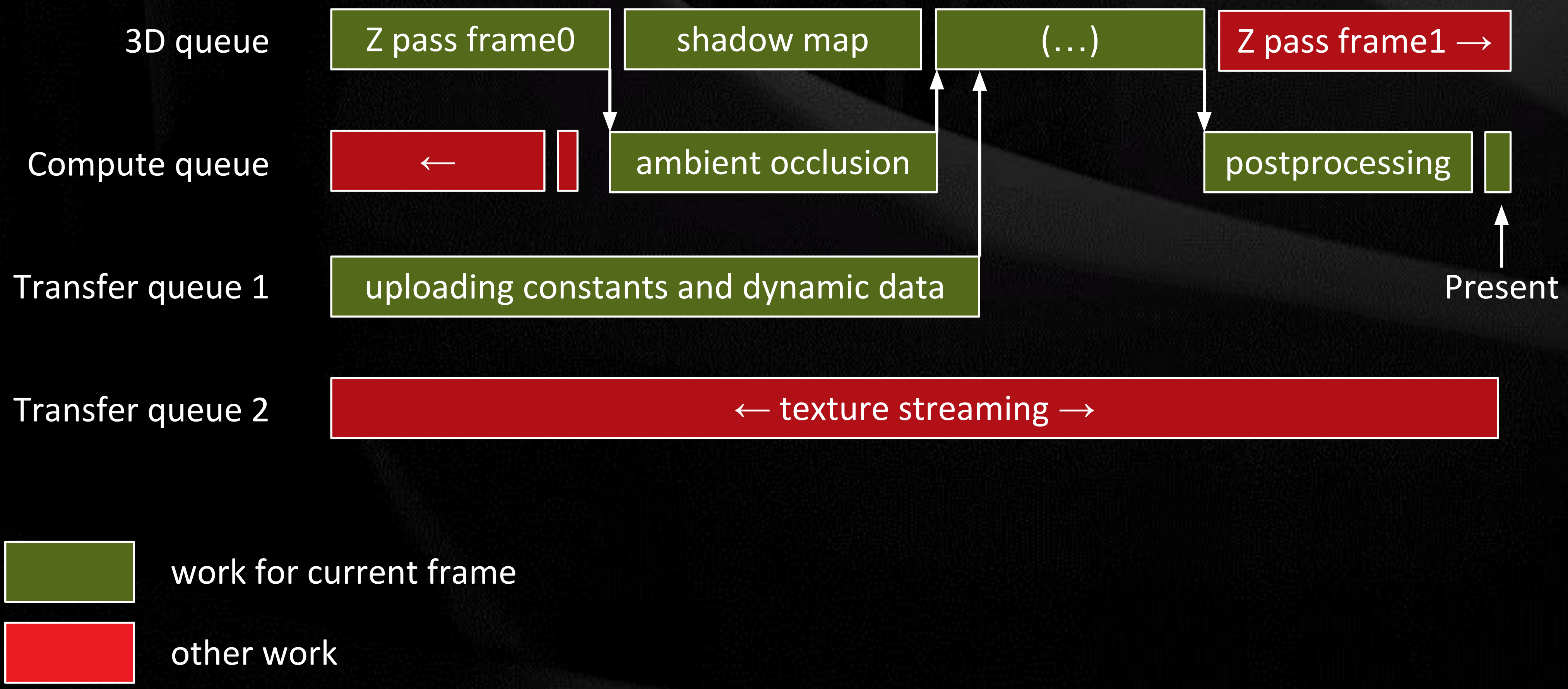
MULTITHREADING (GPU)

Transfer

- Uploading/downloading data to/from GPU memory through PCIe®
- Background transfers: texture streaming, defragmentation of GPU memory
- Copies inside video memory:
  - long time before the result is needed → use transfer queue
  - result is needed immediately on graphics queue → use graphics queue

MULTITHREADING (GPU)

EXAMPLE

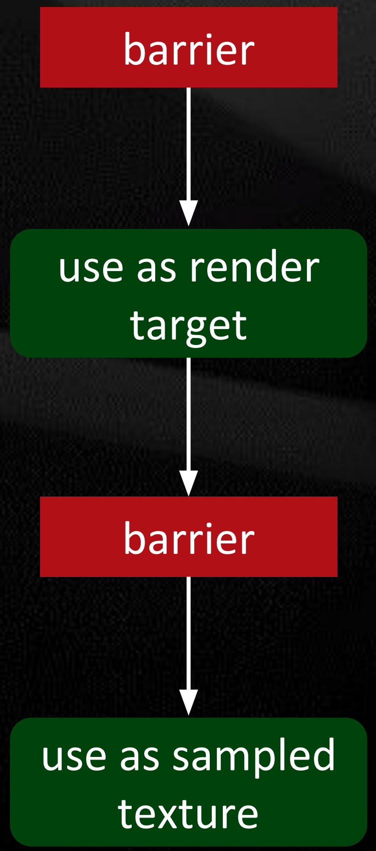


BARRIERS

A barrier synchronizes access to specific resource.

Possible solutions:

- Hard: Barriers hardcoded, placed manually.
  can reach good performance, but difficult and error-prone ☹
- Bad: Define “base state”. Always go back to this state after use.
  not very efficient ☹
- Better: Remember last state. Transition to new state before use.
  works, but still can do better ☹



BARRIERS

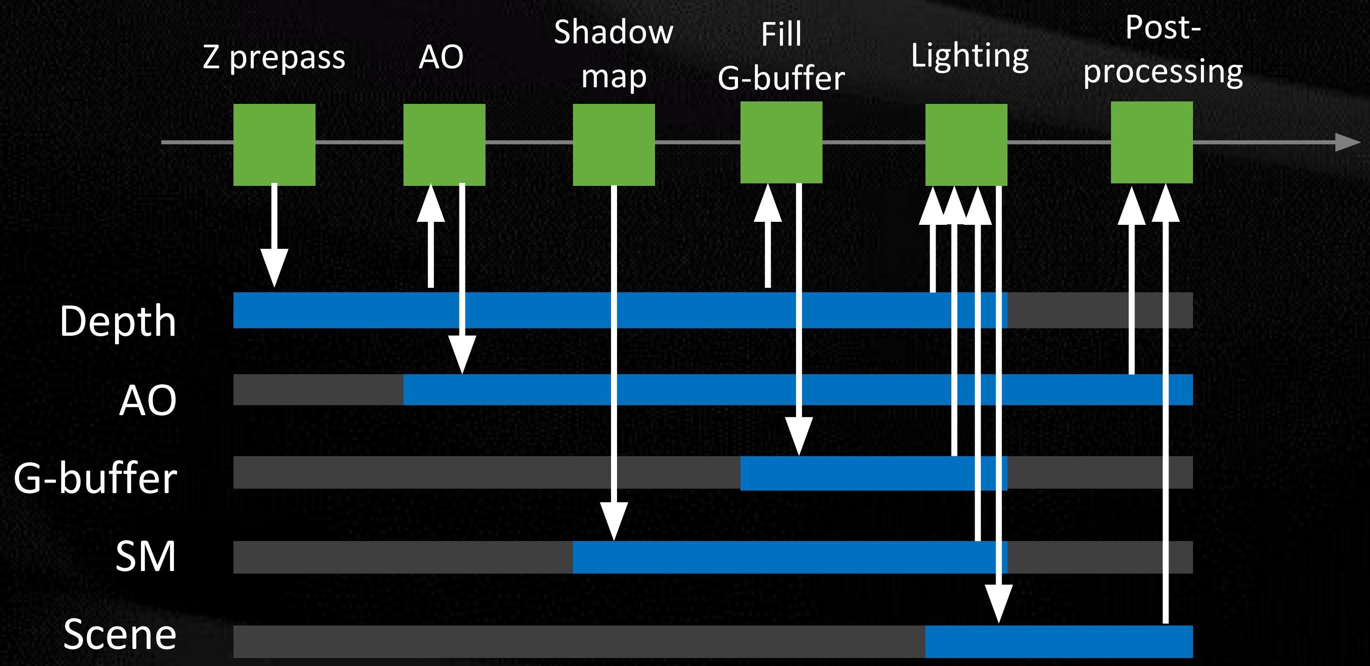
- Excellent: Have look-ahead of whole render frame. Find best place to issue barriers.

  place barriers as early as possible before result is needed – may hide their latency ☺

- Most of your resources don't need layout transitions in runtime. Only limited number does.
- Bad result: waiting for idle between all draw calls. Good result: everything pipelined.
- Batch barriers together into one call wherever possible.

FRAME GRAPH

- General, high-level solution.
- Describes structure of a render frame.
- Nodes are render passes – sequences of commands to be executed every frame.
- Each pass can read and write resources – e.g. intermediate render targets.

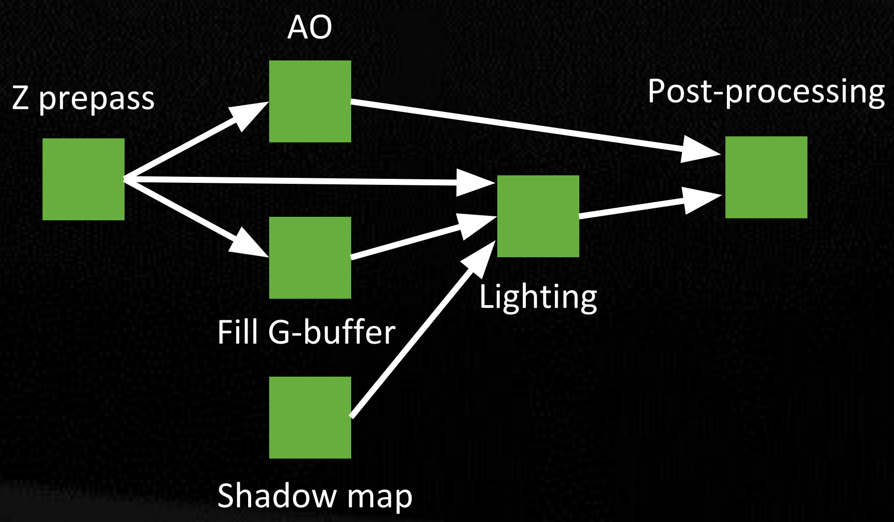


FRAME GRAPH

ADVANTAGES

With frame graph you can easier/automatically handle:

- render passes
  - determine order of render passes
  - group them into command buffers, Vulkan™ render passes and subpasses
  - parallelize on CPU – record command buffers on multiple threads
  - parallelize on GPU – assign passes to hardware queues



FRAME GRAPH
ADVANTAGES

With frame graph you can easier/automatically handle:

- resources
  - determine what barriers are needed
  - find the most optimal place to issue barriers
  - alias memory, if lifetime of resources don't overlap

ADDITIONAL CONSIDERATIONS

1/3

- Update Vulkan™ SDK regularly
- Update graphics driver regularly
  and tell your players to do the same
- Use Validation Layers
  - they don’t check everything
  - there may be false positives (when using extensions, bugs in validation layers)
  - but still consider each message, fix it or add to your ignore list
- Please do report bugs. Vulkan™ ecosystem needs your help!

ADDITIONAL CONSIDERATIONS

2/3

- Make your game easy to debug
  - Support enable/disable switches for as many features as possible
  - Use debug markers to annotate rendering commands and give names to resources

    Vulkan™: VK_EXT_debug_marker, DX12: PIXBeginEvent
  - Integrate system for debugging driver crashes and TDR

    VK_AMD_buffer_marker, …

- Use debugging and profiling tools, e.g.:

  RenderDoc, Microsoft PIX, Radeon GPU Profiler (RGP), etc…

ADDITIONAL CONSIDERATIONS
3/3

- First stability, then correctness, then performance.

- Use good software engineering practices.
  – Test early, test often, test on various GPUs.
  – Track regressions.

Conclusion

CONCLUSION

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- New graphics APIs (Vulkan™, Direct3D 12) are lower level, more explicit.

- Porting your engine to a new API:
  - requires some additional work
  - can result in better performance

- There are recommended good practices, software libraries, and tools that can help you with that.

LIBEARIES

- Anvil – cross-platform framework for Vulkan™
  https://github.com/GPUOpen-LibrariesAndSDKs/Anvil
- V-EZ – cross-platform wrapper that simplifies Vulkan™ API
  https://github.com/GPUOpen-LibrariesAndSDKs/V-EZ

- Vulkan Memory Allocator
  https://github.com/GPUOpen-LibrariesAndSDKs/VulkanMemoryAllocator
- simple_vulkan_synchronization – simplified interface for Vulkan™ synchronization
  https://github.com/Tobski/simple_vulkan_synchronization
- volk – meta loader for Vulkan™ API
  https://github.com/zeux/volk
- D3D12 Residency Starter Library
  https://github.com/Microsoft/DirectX-Graphics-Samples/tree/master/Libraries/D3DX12Residency

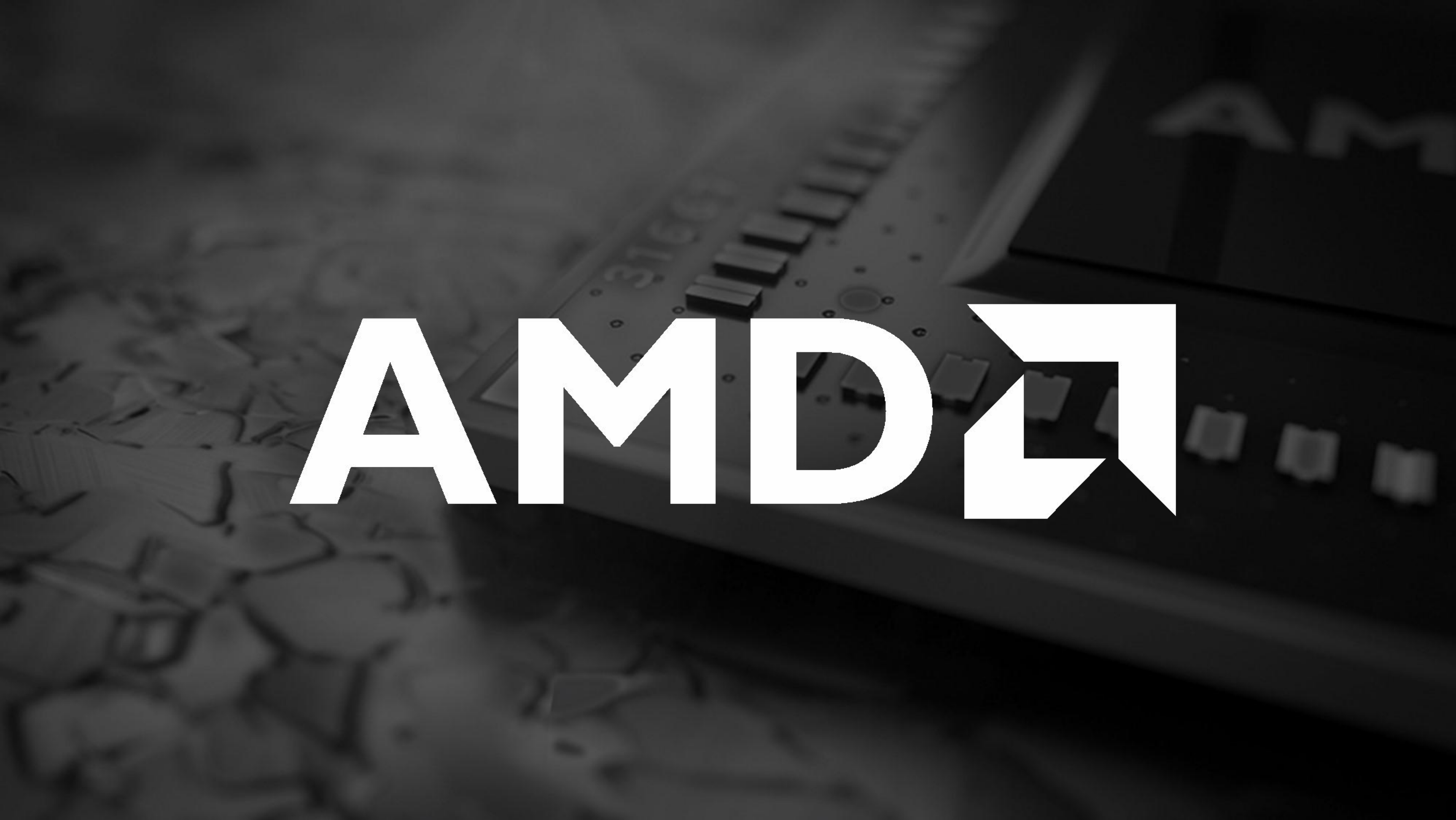
FURTHER READING

AMD

- Rodrigues, Tiago (Ubisoft Montreal). *Moving to DirectX® 12: Lessons Learned.* GDC 2017.
- Sawicki, Adam (AMD). *Memory management in Vulkan™ and DX12.* GDC 2018.

Thank you

Questions?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