LET’S TALK ABOUT (GPU) CRASHES

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AGENDA

• Introduction
• GPU crashes
  • What is TDR?
  • What can cause TDR?
  • Why does it happen so often?
  • Effects
  • Why is it so difficult?
• Debugging
  • What can we do?
  • Breadcrumb markers
• Conclusions – general advice
INTRODUCTION

What is a crash?
CRASH

Program terminates abnormally

Thesis:

“Crashes are good” *

Crashes are one of the security measures employed by the OS. Instead of a silent corruption, it lets you know you made a mistake.

* As long as they are easy to debug!
// Record geometry pass

color.values[0].color.float32[0] = 0.3f;
color.values[0].color.float32[1] = 0.5f;
color.values[0].color.float32[2] = 0.2f;
color.values[0].color.float32[3] = 1.0f;
color.values[1].depthStencil.depth = 1.0f;

VkRenderPassBeginInfo
renderPassBeginInfo.renderPass = g_Hlrender;
renderPassBeginInfo.framebuffer = g_FrameBuffer;
renderPassBeginInfo.renderPassExt = g_RenderPass;
renderPassBeginInfo.renderArea.offset = g_Offset;
renderPassBeginInfo.renderArea.extent = g_Extent;
renderPassBeginInfo.clearValueCount = 1;
renderPassBeginInfo.clearValues = clearValues;

vkCmdBindPipeline
(hCommandBuffer, VK_PIPELINE_STAGE_GRAPHICS_BIT, g_HlPipeline);

mat4 view = mat4.LookAt((vec3(0.0f, 0.0f, 0.0f)), (vec3(0.0f, 0.0f, 0.0f)), (vec3(0.0f, -1.0f, 0.0f)));
GPU CRASHES

What do I mean by that?
GPU CRASH

• We talk about graphics APIs here – mostly DirectX® 12 | Vulkan®

• Timeout Detection and Recovery (TDR)  2s
WHAT ARE POSSIBLE CAUSES?

- 🐞 Application bug – incorrect usage of the API ← most likely!
- 🐞 Driver bug
- External factors: driver update, hardware failure, ...
WHAT ARE POSSIBLE CAUSES?

- Infinite loop in a shader

- Memory page fault
  - Using a resource after `Release()` or `Evict()`
  - Indexing out of bounds
  - Incorrect address calculation

- Invalid/missing resource binding – null, wrong type, ...

- Corrupted data e.g., acceleration structure

- Other...
WHY HAPPENS SO OFTEN?

Old APIs (OGL, DX9, DX11):
- Driver is validating everything, each function returns error code
- GPU crash was likely a driver bug

New APIs (DX12, Vulkan):
- Driver is not validating, many functions return void
- Driver is simpler and faster 😊
- GPU crash is likely an application bug 😞
WHY HAPPENS SO OFTEN?

New APIs (DX12, Vulkan):

- Driver is not validating, many functions return `void`
  - Allocating functions like `CreateCommittedResource` return `HRESULT`  
  - GPU commands like `DrawIndexedInstanced` return `void`
  - `Debug|validation` layers provide validation during development

- GPU crash is likely an application bug 😞
  - Driver bugs happen but shouldn't be your first thought
WHY HAPPENS SO OFTEN?

Application bug – incorrect usage of the API

Happens more often as we use raw memory addresses, dynamic indexing, bindless, indirect, ray tracing...

DX11:
ID3D11Buffer*

DX12:
D3D12_GPU_VIRTUAL_ADDRESS

Future:
void* ?? 😅
“UNDEFINED BEHAVIOR”

Works fine  Visual corruption  Crash

What works on one GPU model may not work the same way on a different one
EFFECTS

• GPU and driver restarted

• Application observes an error code returned from API function
  • E.g., IDXGISwapChain4::Present() returns DXGI_ERROR_DEVICE_HUNG
  • E.g., vkQueueSubmit returns VK_ERROR_DEVICE_LOST

• Full machine hang or BSOD less frequent
Your device ran into a problem and needs to restart.
We're just collecting some error info, and then we'll restart for you.

100% complete

For more information about the issue and possible fixes, visit
https://support.microsoft.com/
and search for the issue code.
EFFECTS

Note that:

`IDXGISwapChain4::Present()` returns `DXGI_ERROR_DEVICE_HUNG`

- Doesn’t imply our app crashing (in theory)
  - We can continue or at least save some dump/log

- Doesn’t tell which pass or draw call is the culprit
  - Reported for the entire render frame
WHY IS IT SO DIFFICULT?

• “GPU Crash” can mean different things - timeout, page fault, ...

• GPUs are complex
  • Asynchronous – execute work submitted by the CPU
  • Pipelined – multiple commands in flight at various stages of the pipeline
  • Parallel – many threads, vertices, pixels processed at once

• Even if one hardware block fails, others may continue – no global STOP with break into a debugger

(Not an excuse for the lack of good debugging tools)
DEBUGGING

The solutions...
WHAT CAN WE DO?

• Capture with PIX or RenderDoc? No... They need a successfully rendered frame
  • Can still help with finding some issues

• Debug|validation layers
  • Validate correct API usage
  • Moderate performance overhead 🐢
  • Cannot validate what is not known on the CPU: GPU-generated data, descriptors, memory contents...

• GPU-Based Validation (GBV) | GPU-Assisted Validation
  • Extra validation on the GPU, shader instrumentation – descriptors etc...
  • Very high performance overhead 🐢 🐢 🐢
1. Startup: Create a buffer in the readback CPU memory, persistently mapped
   • VirtualAlloc + OpenExistingHeapFromAddress + CreatePlacedResource
   • VK_AMD_device_coherent_memory -
     VK_MEMORY_PROPERTY_DEVICE_COHERENT_BIT_AMD / DEVICE_UNCACHED_BIT_AMD

2. Rendering: Write numbers between passes or draw calls
   • ID3D12GraphicsCommandList2::WriteBufferImmediate
   • VK_AMD_buffer_marker - vkCmdWriteBufferMarkerAMD

3. After crash: Inspect the buffer pointer, see which breadcrumbs were successfully written last
BREADCRUMB MARKERS

Not that simple...

- Multiple draw calls in flight simultaneously

- The IN-OUT semantics:
  - `D3D12_WRITEBUFFERIMMEDIATE_MODE_MARKER_IN/OUT`
  - `VkPipelineStageFlagBits pipelineStage`

- Still may not be reliable
  - No one said that after a crash the subsequent commands don’t get executed
WHAT CAN WE DO?
contd.

- Breadcrumb markers

- **Device Removed Extended Data (DRED)** – new part of D3D12 doing such markers automatically

- Vendor-specific tools

- Last resort: disable individual effects and passes, see if the bug goes away
  - Ultra → High → Medium → Low
  - Disable ray tracing
  - Lower GPU memory usage: Texture quality = Low
  - Modify/simplify shaders
CONCLUSIONS – GENERAL ADVICE

Prevention is better than cure. Better to diagnose and treat earlier than later.

- Stability > Correctness > Performance
- Make the game repeatable – benchmark mode, saves, camera teleportation, reduce randomness
- Frequent testing on a range of GPUs (and update your drivers!)
- Use debug layer; make it free from any errors (the broken window theory)
- Ensure short iteration times – fast loading, command-line parameters, saves
- Make it easy to debug – toggles for various effects/passes/optimizations, intermediate texture preview
- Track regressions – if something used to work and stopped working, revert the culprit change

Ask for change! Better tools, better APIs, less crashes, better debugging experience. Talk to your ISV and IHV contacts.
THANK YOU!

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