GPU SUBMISSION STRATEGIES

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WHOAMI

I work as a DevTech at AMD!

My role can be summarized as:

I help game developers make the most out of our hardware

Fun fact:

I always have a Justin Bieber poster in my office!

GPU WORK SUBMISSION

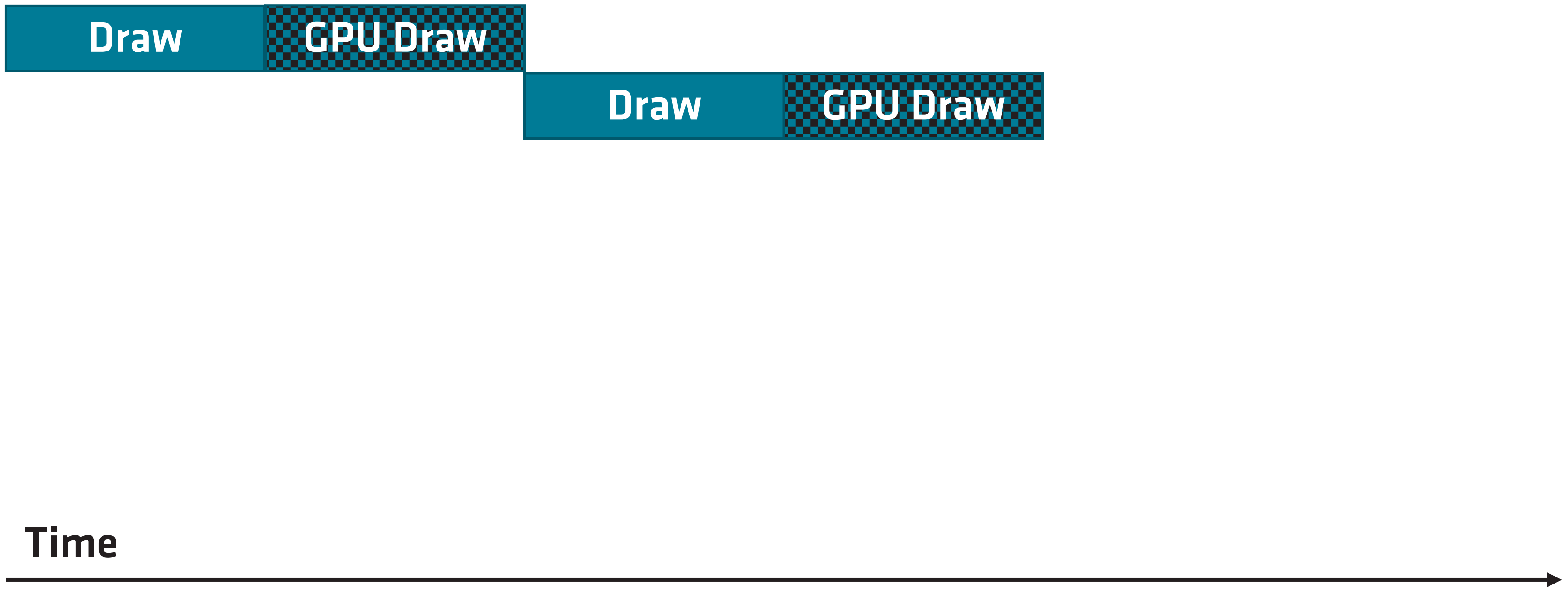
Some background

FROM A HIGH-LEVEL VIEW

- Draw…
- Draw…
- Draw…

Draw → Draw

NAÏVE APPROACH



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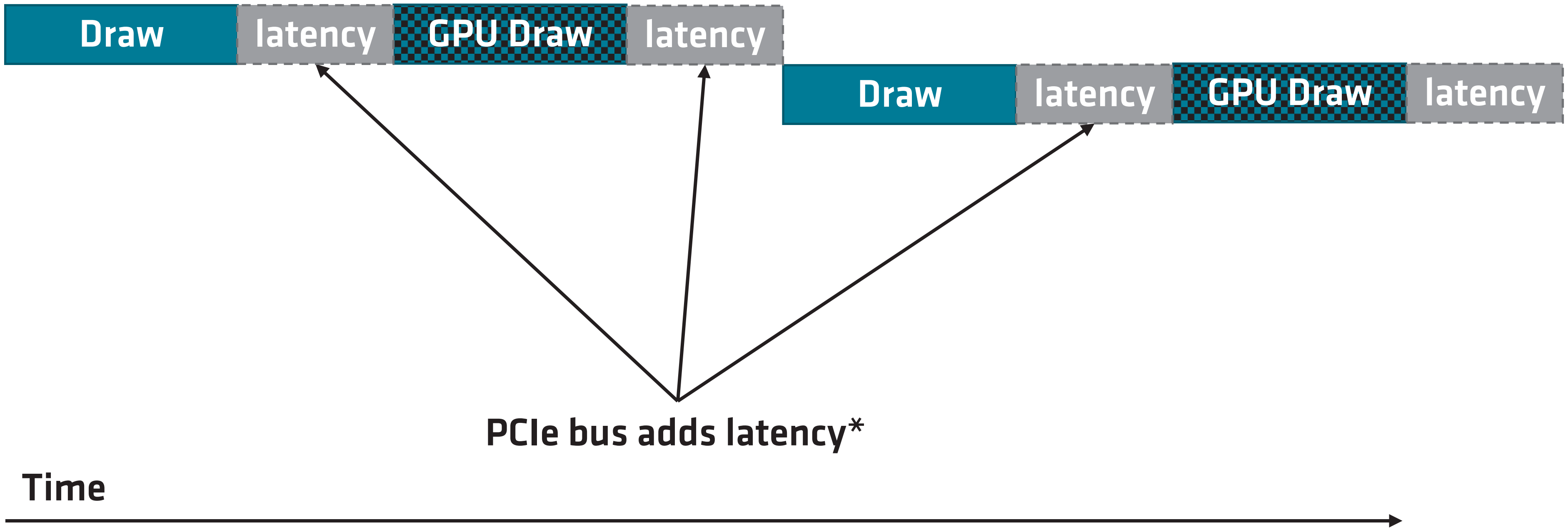


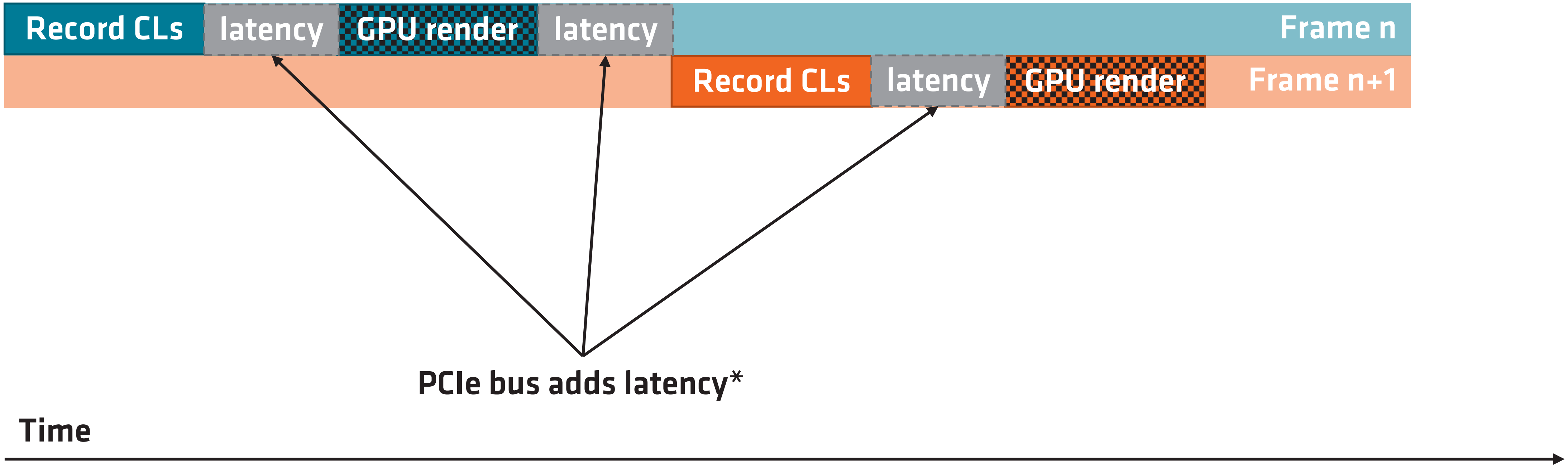
** Also the driver stack, we'll talk about that a bit later*

HOW WORK IS SUBMITTED TO THE GPU

- Command list:
  - Draw…
  - Draw…
  - Draw…

[Public]

IF DRAWING WAS SYNCHRONOUS



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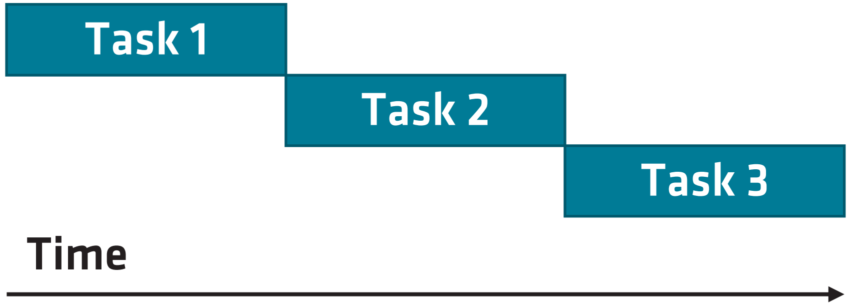
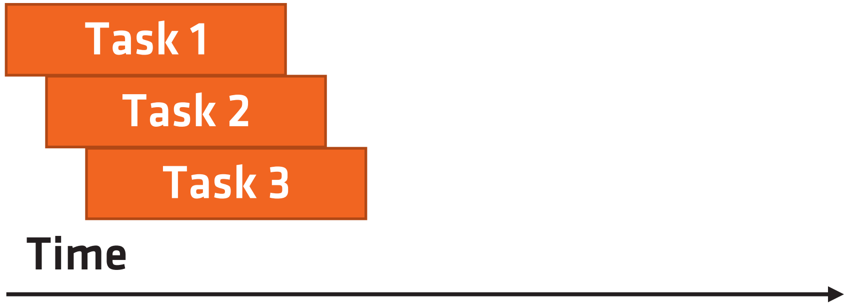
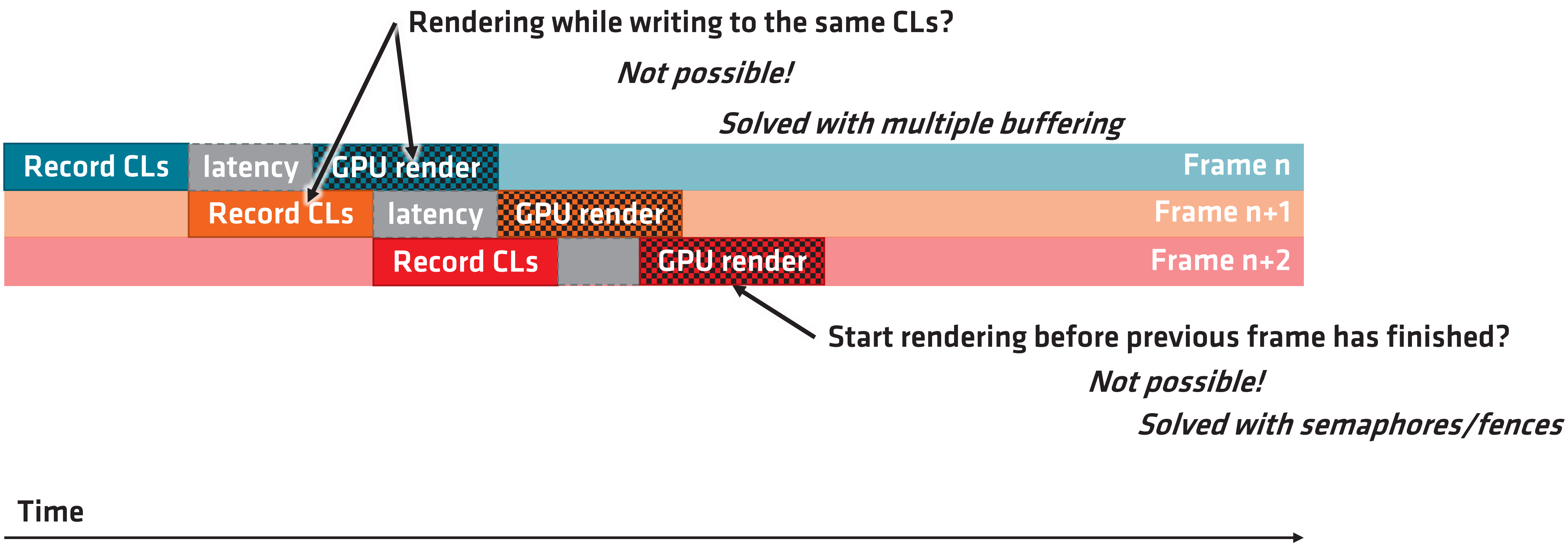
SYNCHRONOUS VS ASYNCHRONOUS





WITH AN ASYNC APPROACH



WHAT ABOUT MULTIPLE SUBMISSIONS?

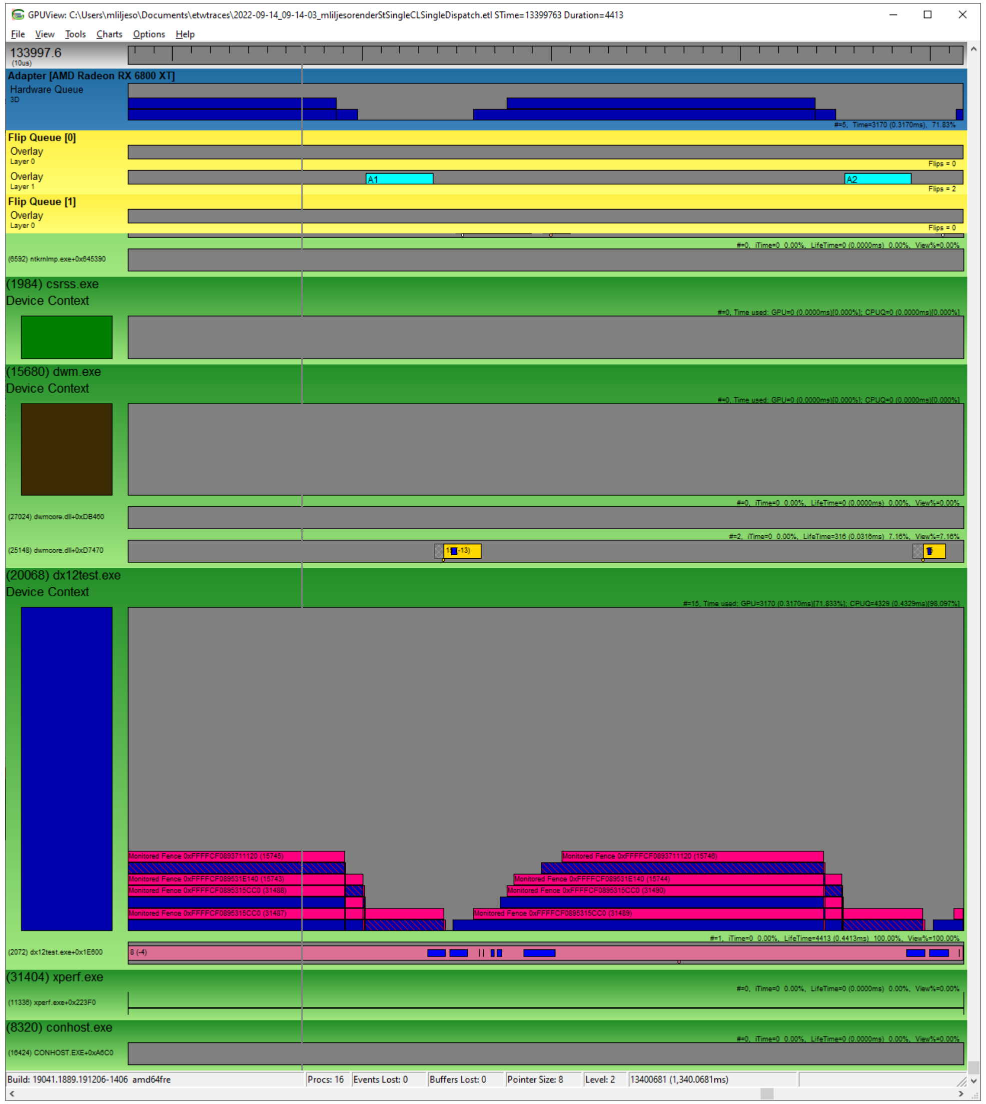
In most games we are not doing a single submit per frame though

- Let’s look at different submission patterns
- How they will be executed on the HW
- We will use a real-world example
- And some suitable tools

TODAY'S TOOLS

GPUView

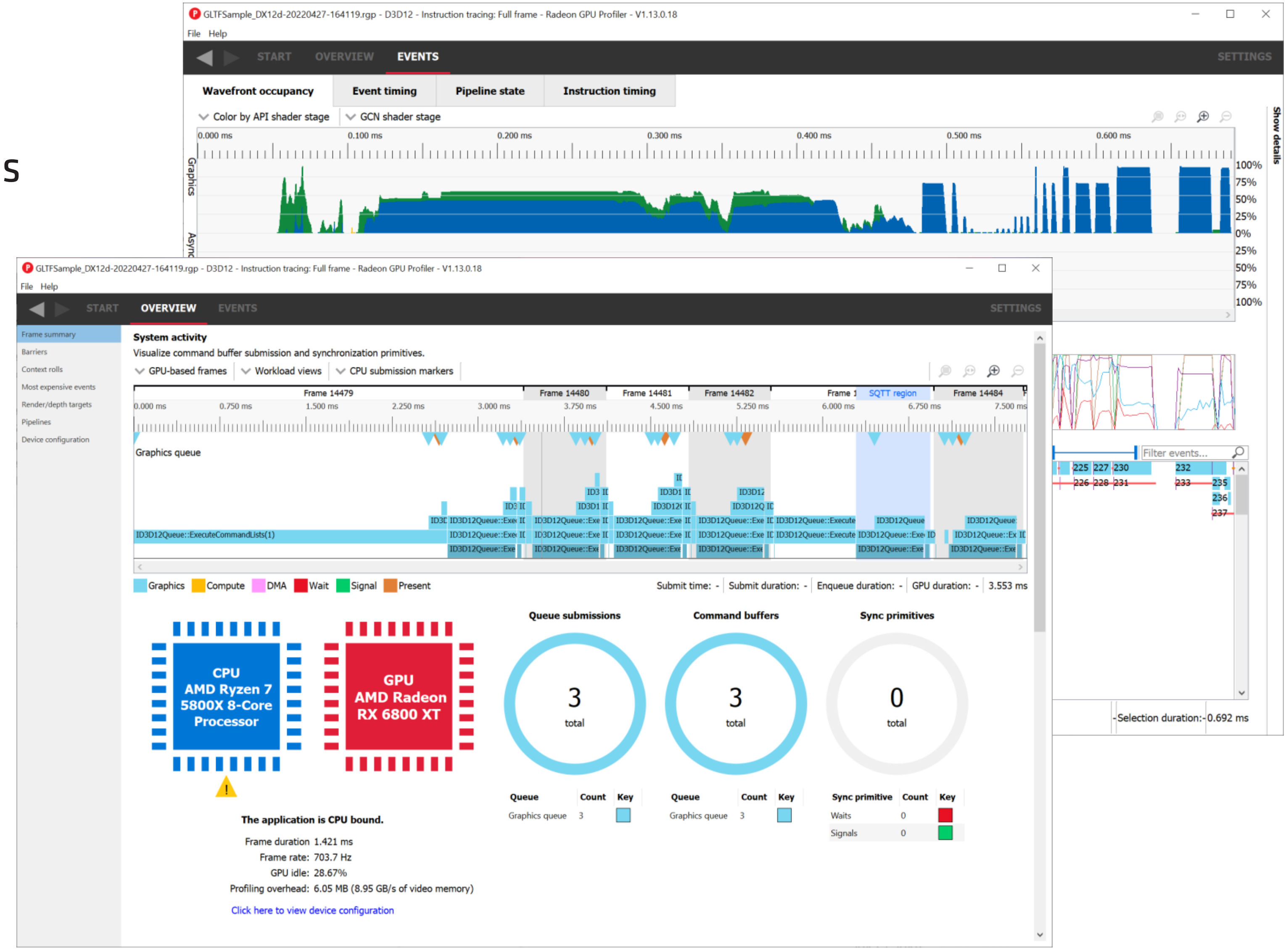
- Tool developed by Microsoft
- Holistic CPU and GPU overview
- Can be used to answer questions like:
  - Are we CPU bound or GPU bound?
  - Or both, during different parts of the frame?
  - Are stutters due to memory allocations in-between frames or something else?



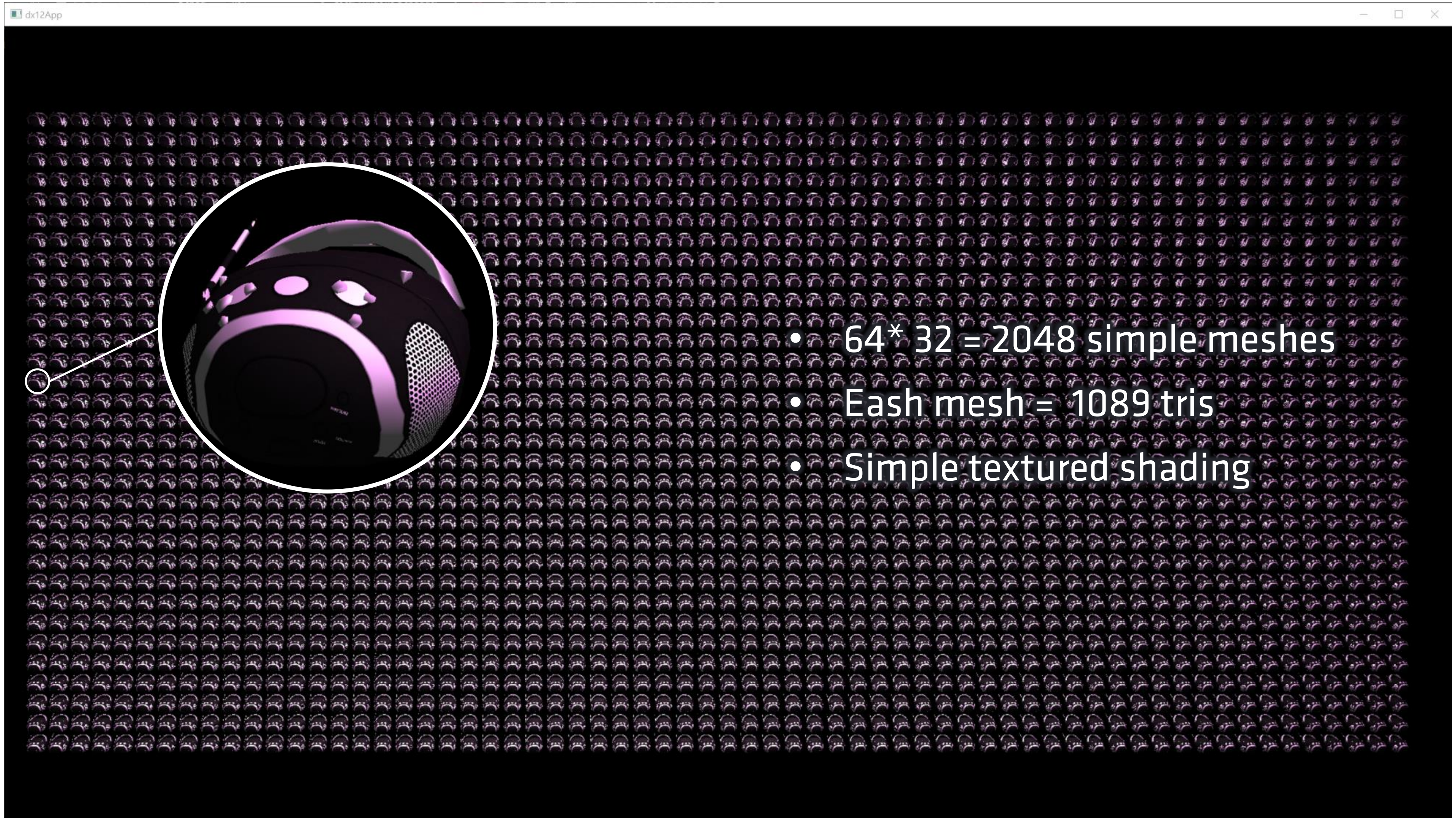
TODAY'S TOOLS

Radeon™ GPU Profiler (RGP)

- A profiling tool for AMD graphic cards
- In depth analysis of a GPU frame
- Graphics and async compute usage
- Event timing
- Barriers
- Instruction timing
- …



THE EXAMPLE APPLICATION



CONTENT WARNING

This application is designed to show limits

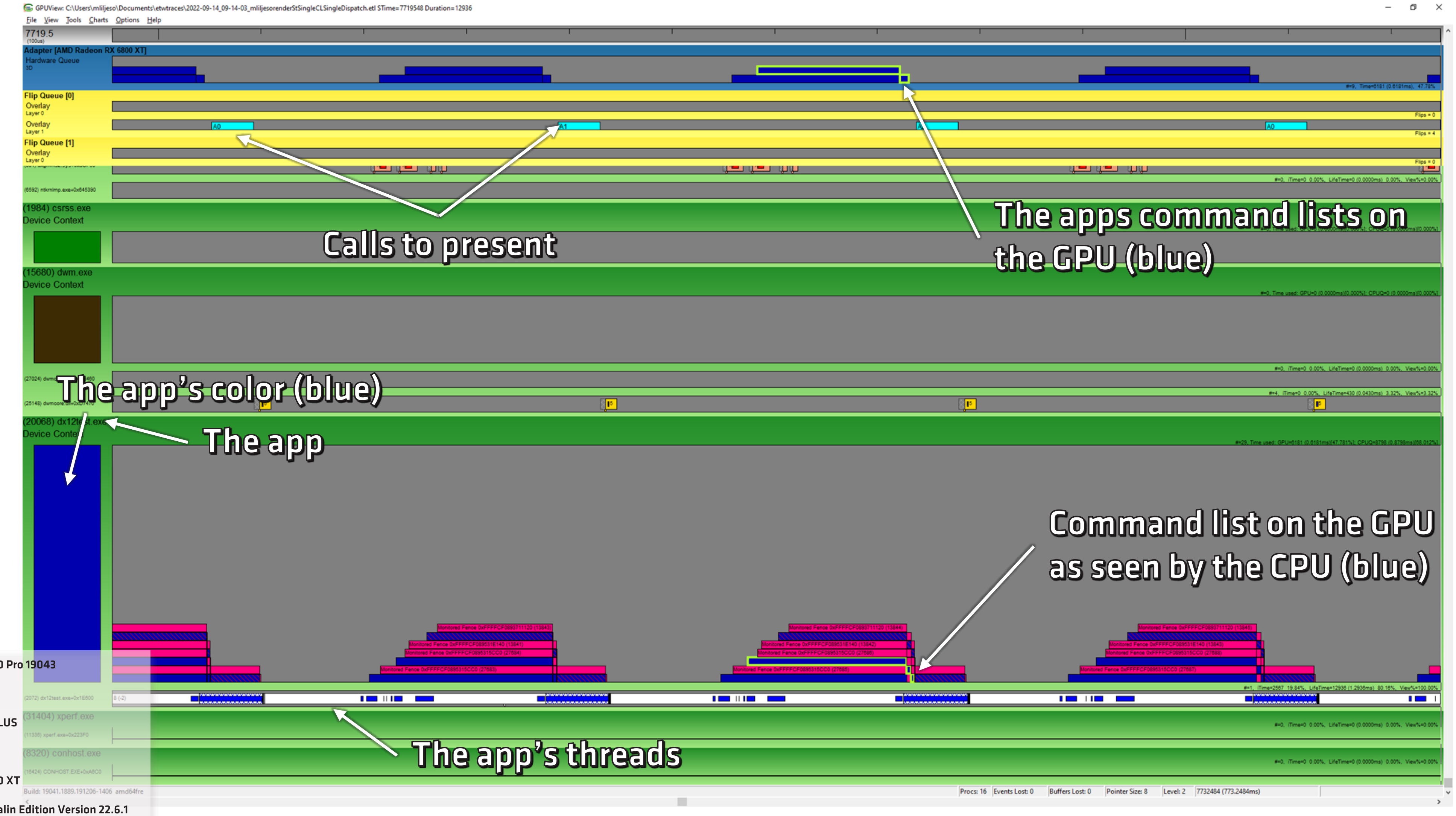
It’s not an example of good renderer design

THE BASE CASE

1 Command list for everything in the whole frame

- Barrier: framebuffer from **present** to **render target**
- Clear render target (back buffer) and depth buffer
- Draw 2048 boomboxes
- Barrier: framebuffer from **render target** to **present**

THE BASE CASE



OS	Microsoft Windows 10 Pro 19043
Processor	AMD Ryzen 7 5800X
Motherboard	TUF GAMING X570-PLUS
RAM	32,0 GB DDR4
GPU	AMD Radeon RX 6800 XT
Driver	AMD Software Adrenalin Edition Version 22.6.1

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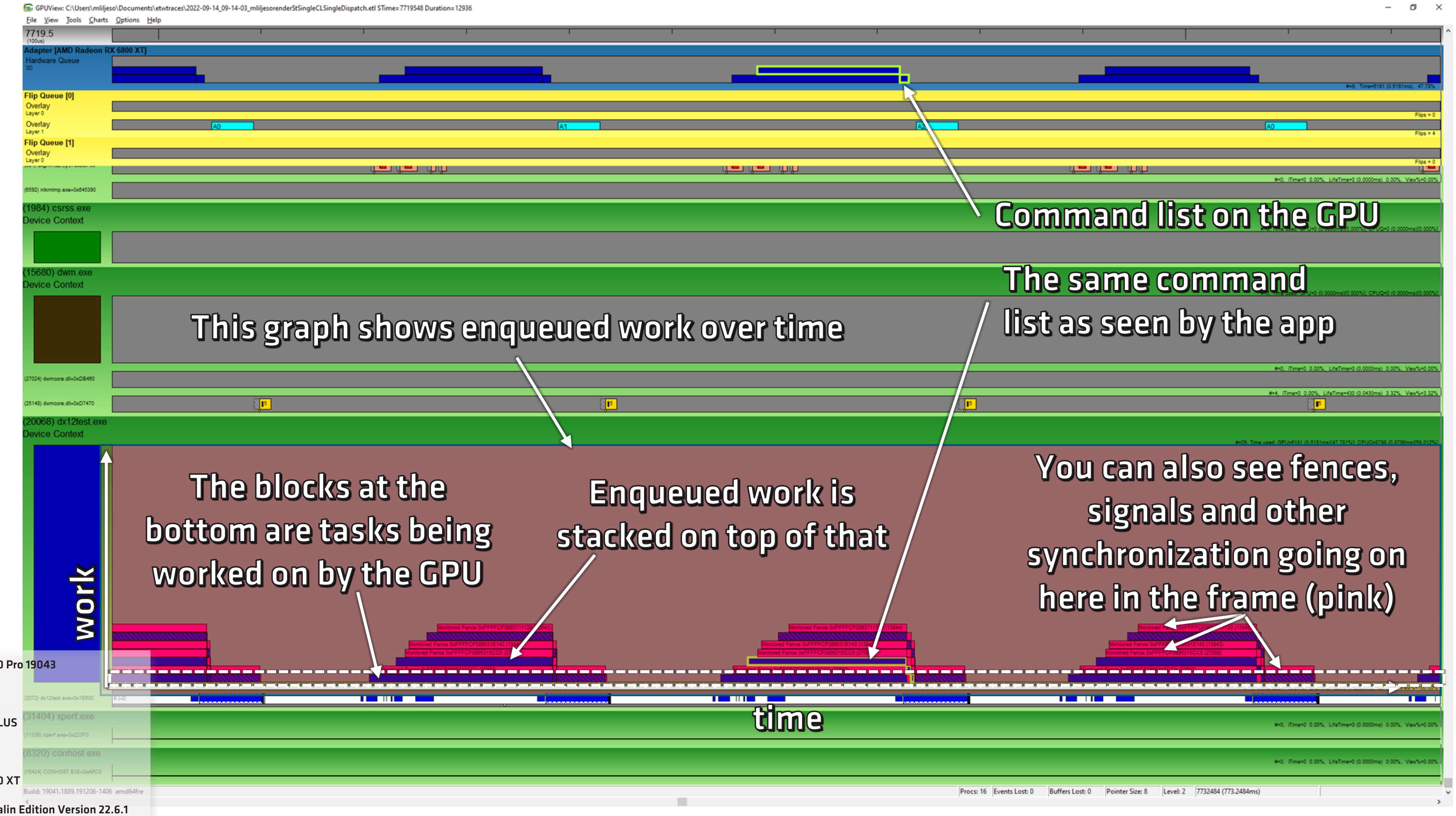

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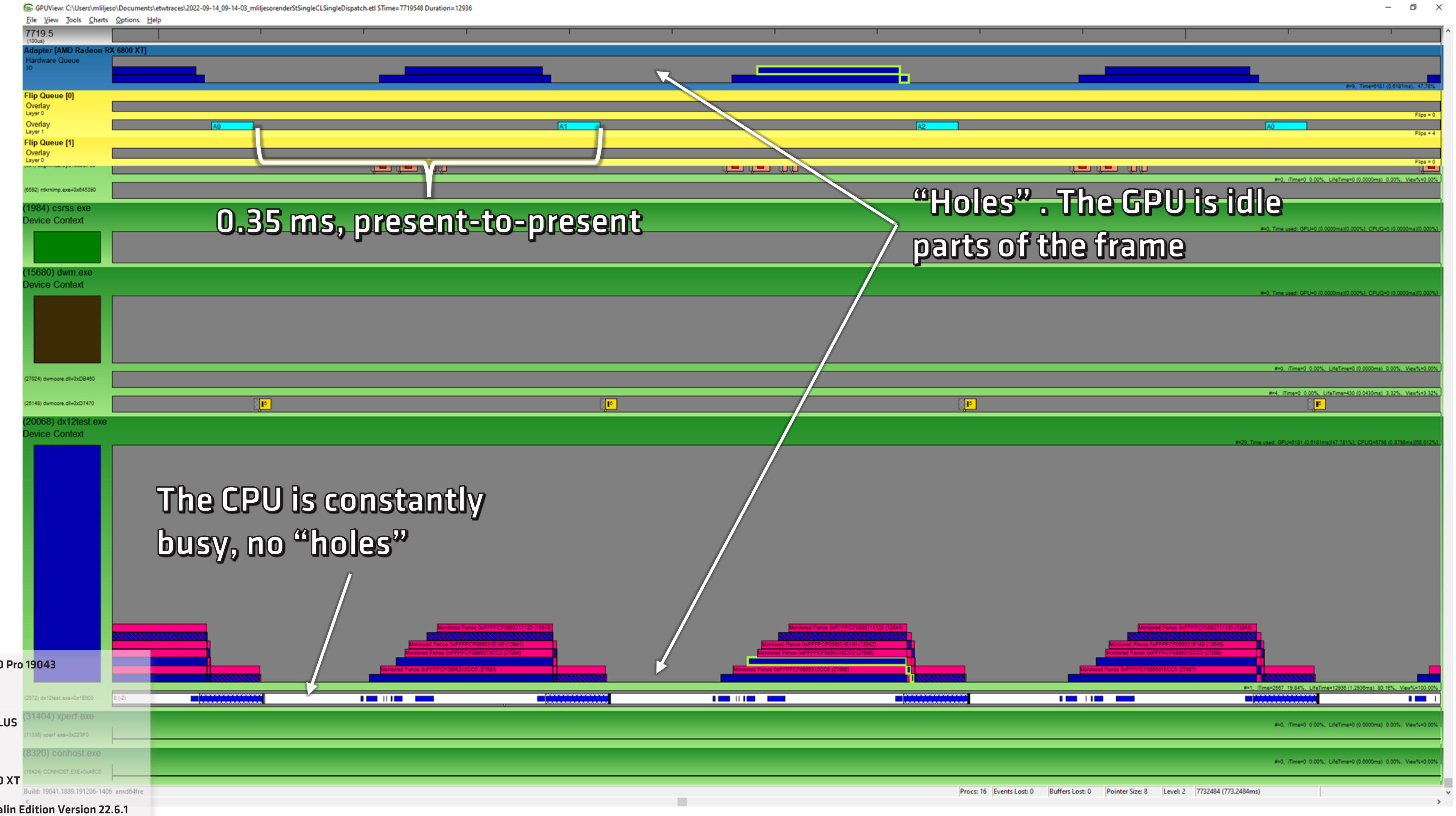

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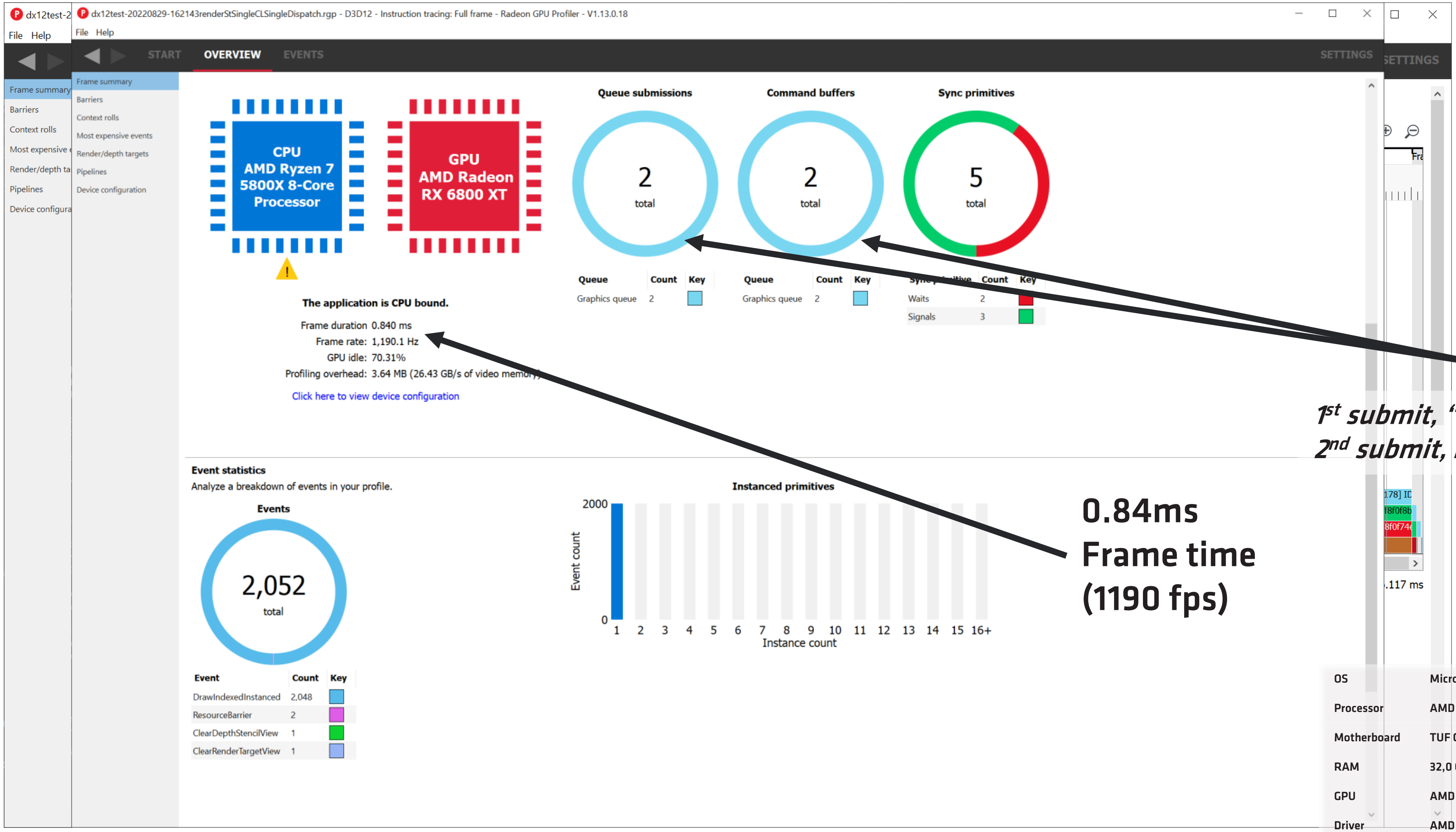

2 ?!

1st submit, "our" submit
2nd submit, inserted by driver

0.84ms Frame time (1190 fps)

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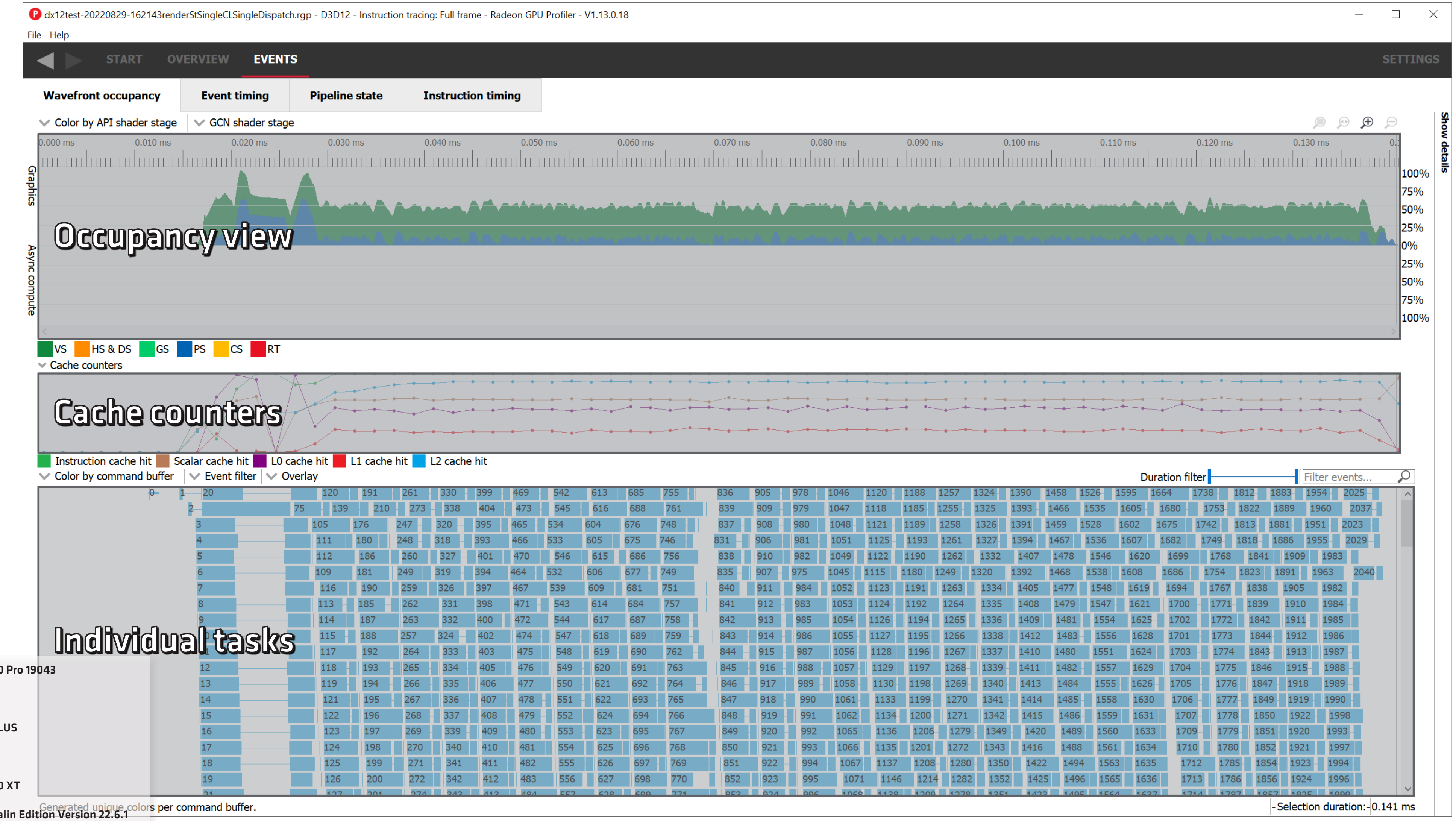

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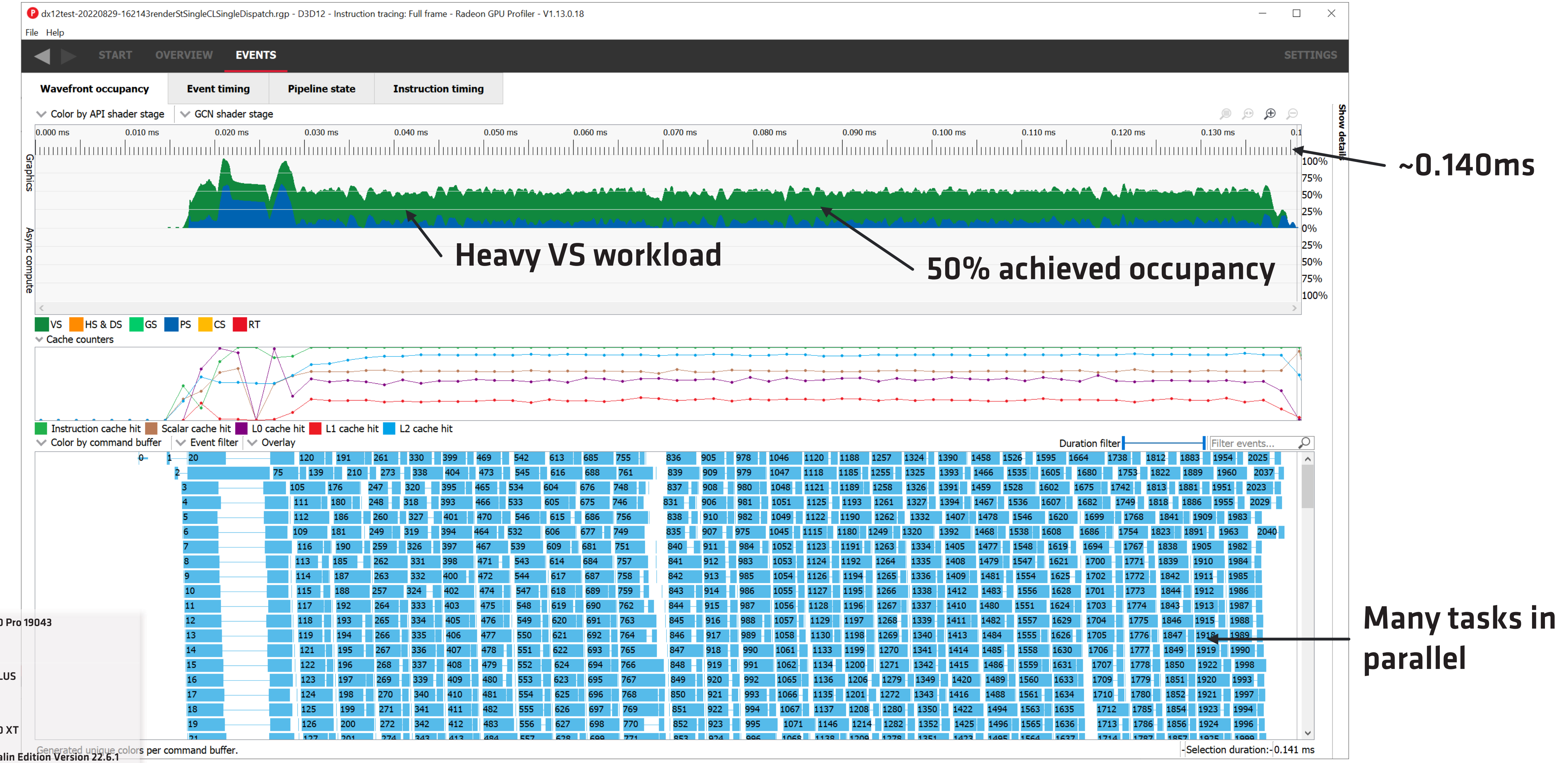

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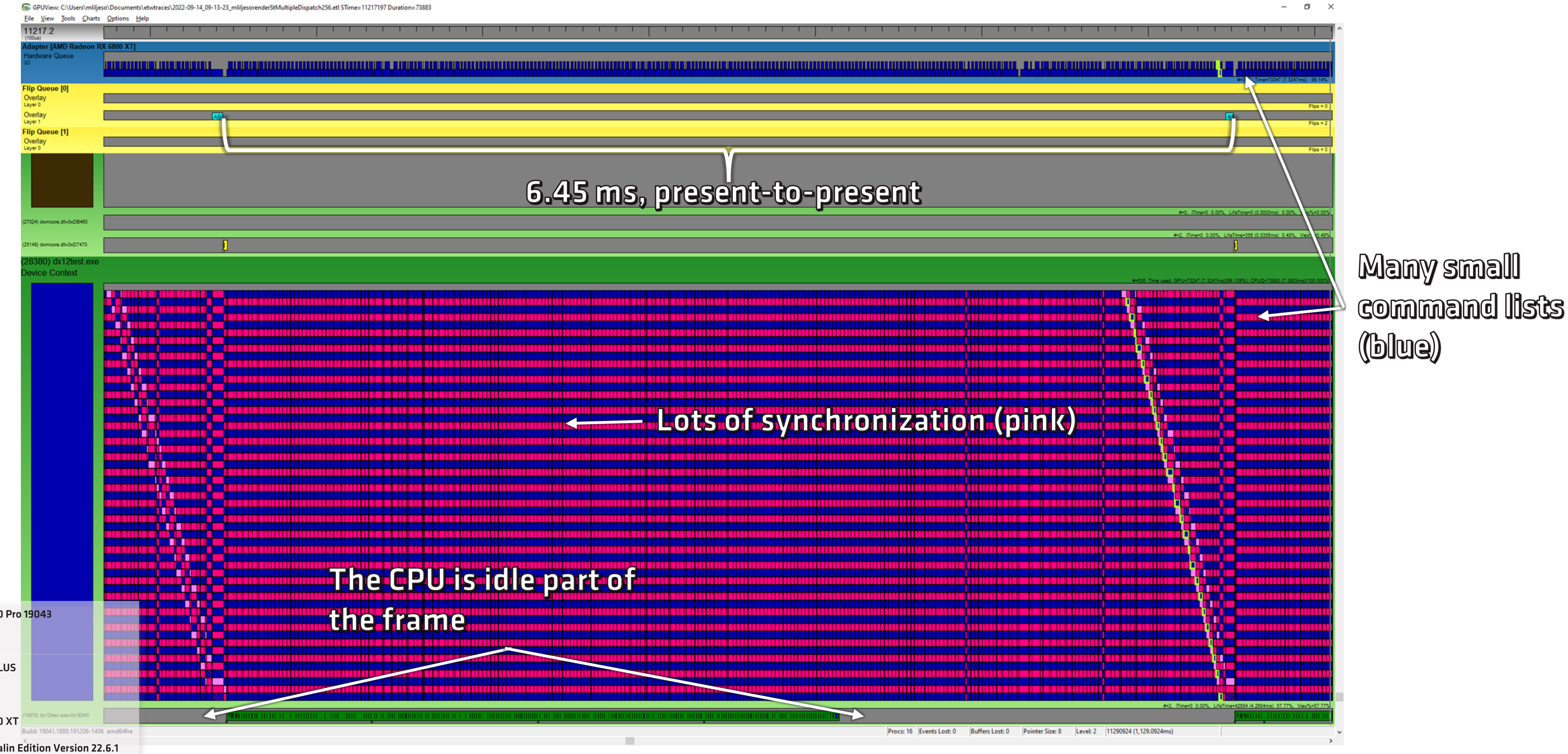
WITH SMALL BATCHES

Command lists with a few draws

1:	Barrier: framebuffer from present to render target Clear render target (back buffer) and depth buffer
2 – 257:	Draw 2048 boomboxes in batches of 8. (8 meshes per CL)
258:	Barrier: framebuffer from render target to present

All CLs submitted one-by-one

WITH SMALL BATCHES



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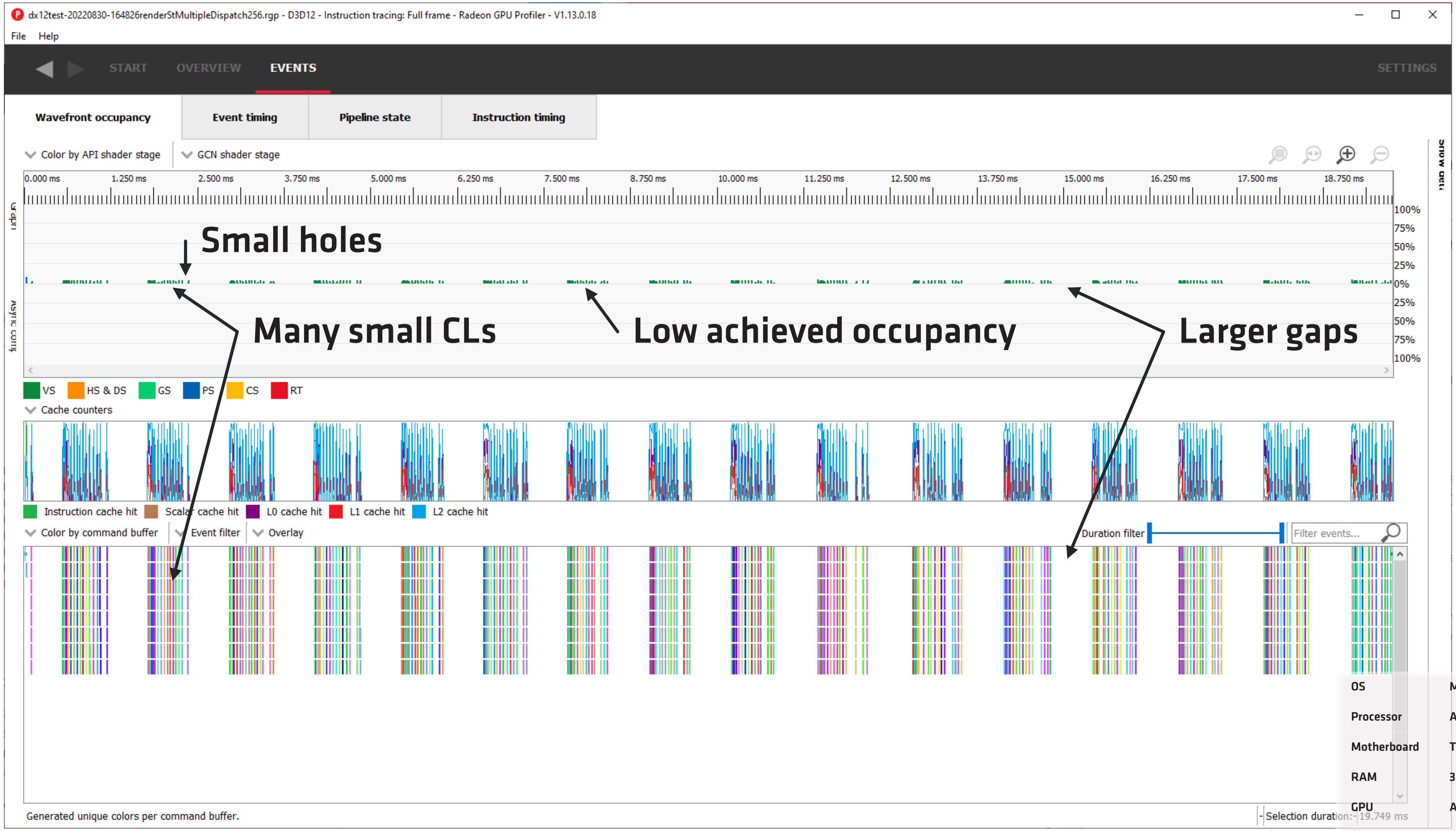

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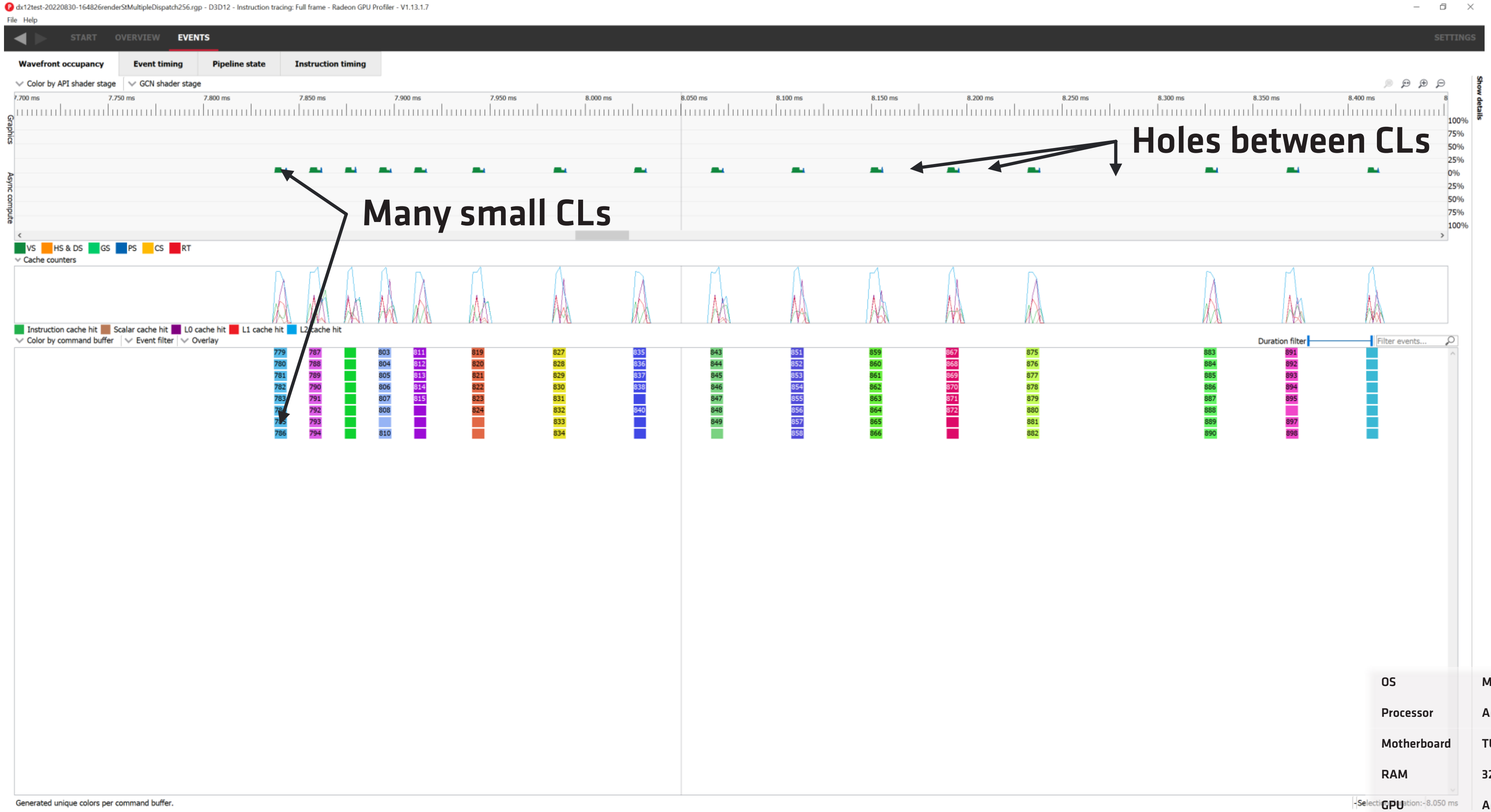

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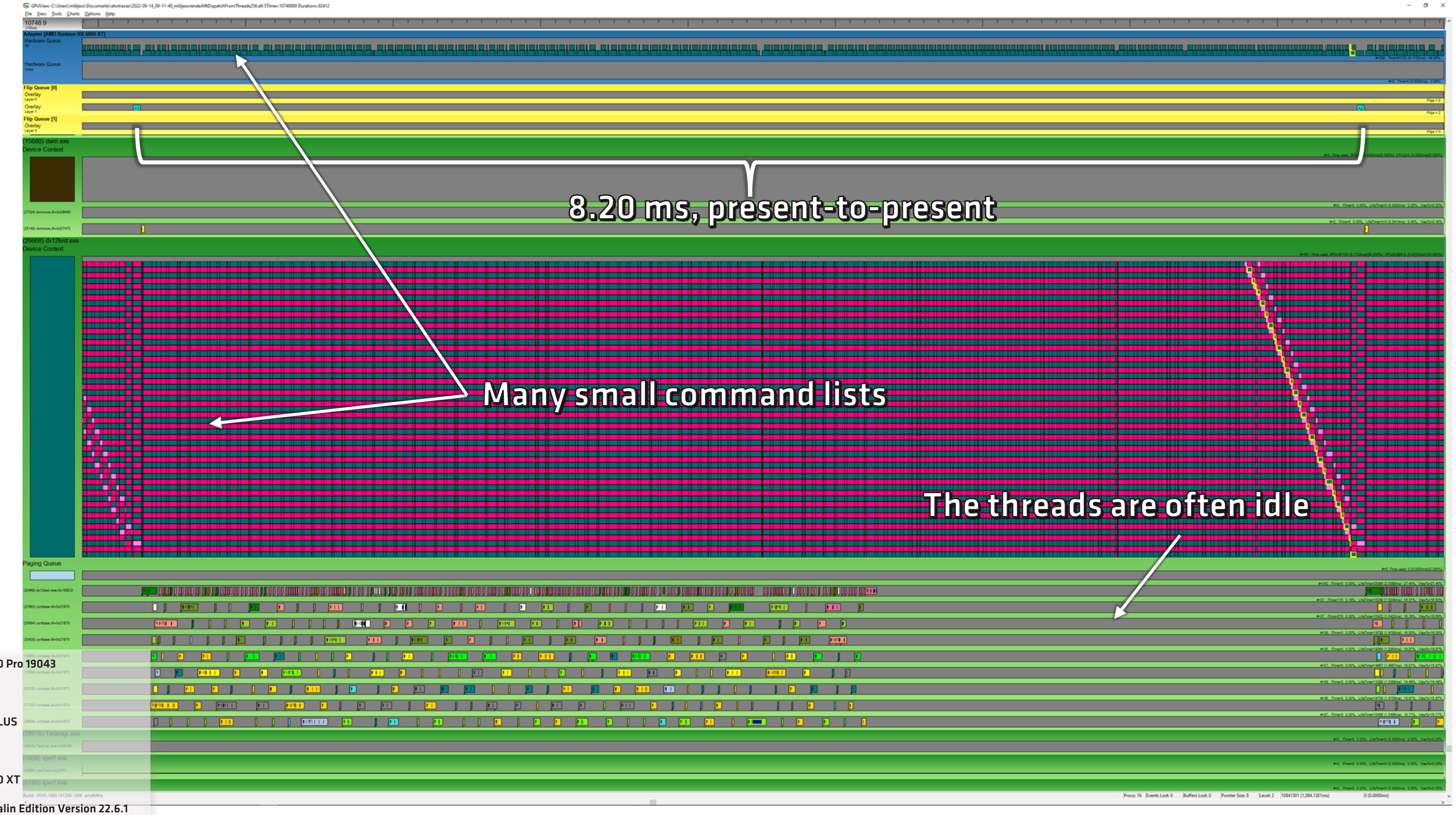
WITH MULTI THREADING

Command lists with a few draws

1:	Barrier: framebuffer from present to render target Clear render target (back buffer) and depth buffer
2 – 257:	Draw 2048 boomboxes in batches of 8. (8 meshes per CL) As 256 tasks from a thread pool
258:	Barrier: framebuffer from render target to present

All CLs submitted one-by-one from their respective thread

WITH MULTI THREADING



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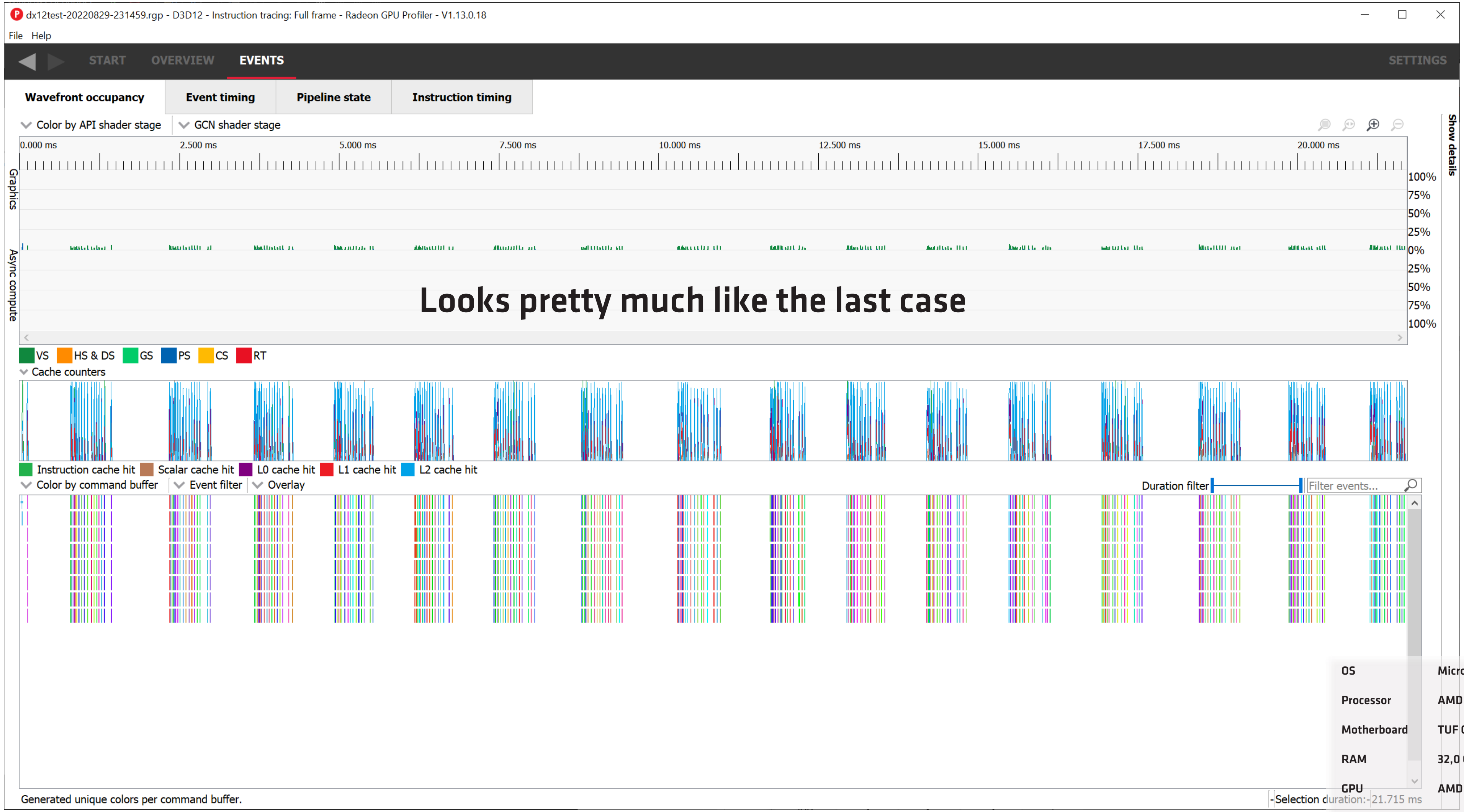

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THAT DOESN'T LOOK TOO GOOD

SO WHY DO WE SEE WHAT WE SEE?

- Why does performance tank so badly with many submits?
- Why doesn't multithreading help?

Let's look at the driver stack!

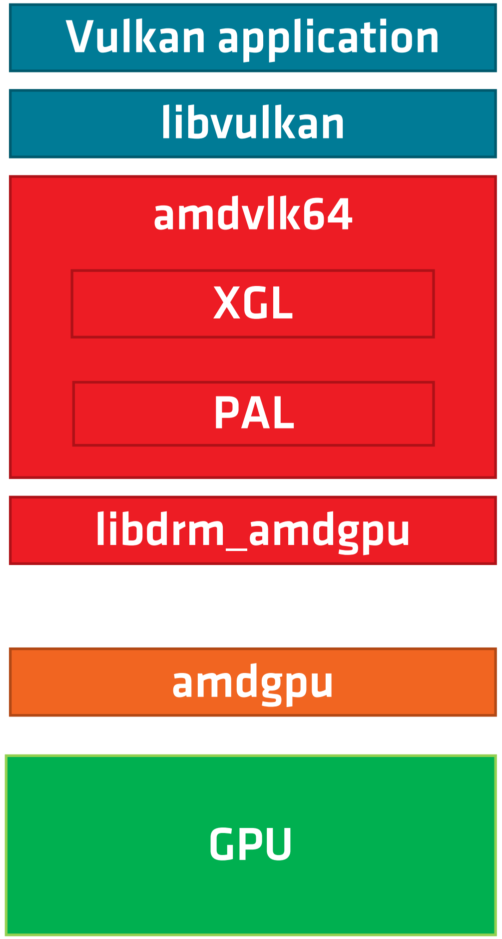
- In this case, let's use our open-source vulkan driver as an example
- Since it's open source, we can freely discuss its details
- The source code is available online here: https://github.com/GPUOpen-Drivers/AMDVLK

THE DRIVER STACK

- This is what our Open Source driver look like
  - The application is on top and calls the vulkan runtime, libvulkan
  - The runtime talks to the upmost part of the driver, amdvlk64
  - The red upper part, amdvlk64 talks to libdrm_amdgpu which communicates with the lower orange part amdgpu
  - amdgpu talks to the graphics card

Drm in this case stands for Direct Rendering Manager

- Basically an API for modern GPU drivers in linux



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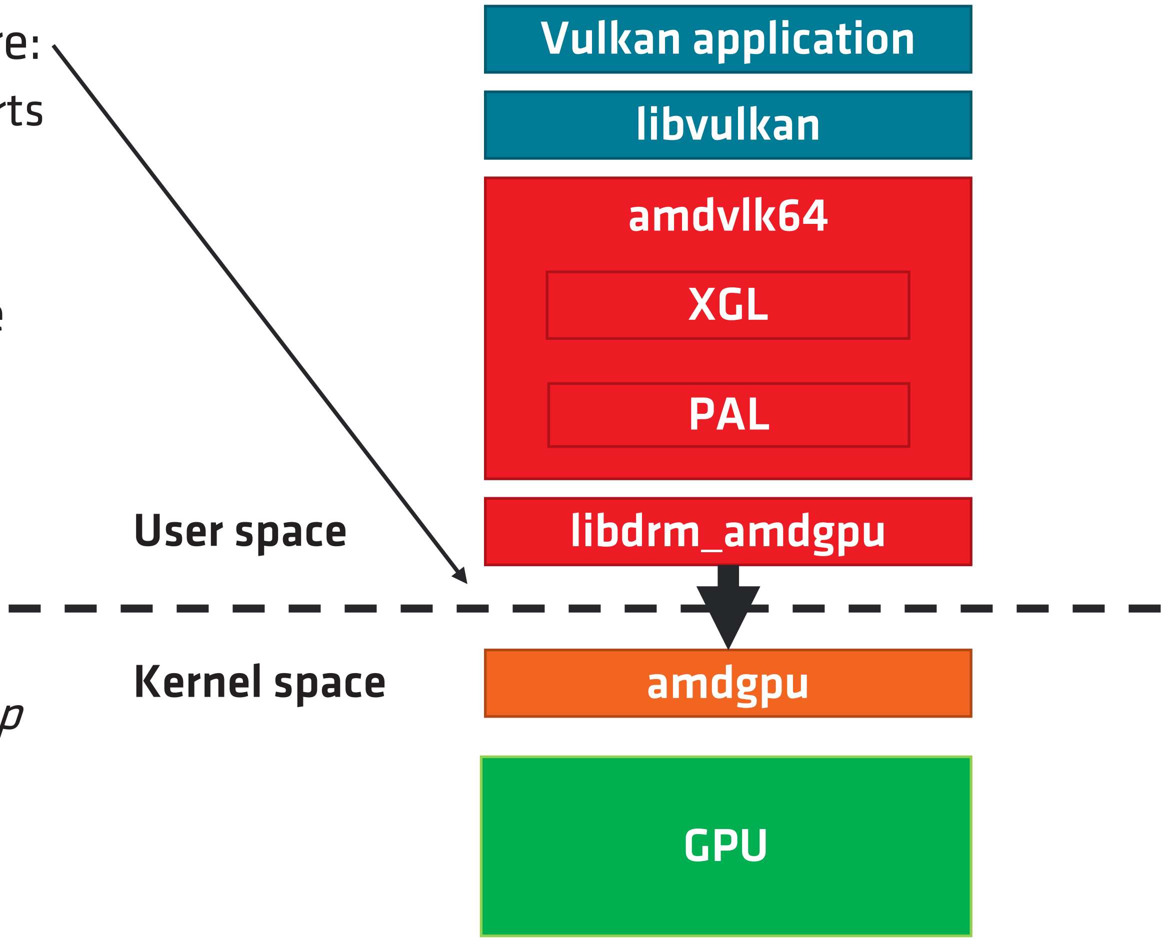
THE DRIVER STACK

- The interesting part of this picture is this line here:
  - It divides the driver into user and kernel space parts
- To protect the system and the user, only the operating system kernel can access the hardware
  - The CPU can therefore execute in **user space** and **kernel space**
  - Switching between the two takes time

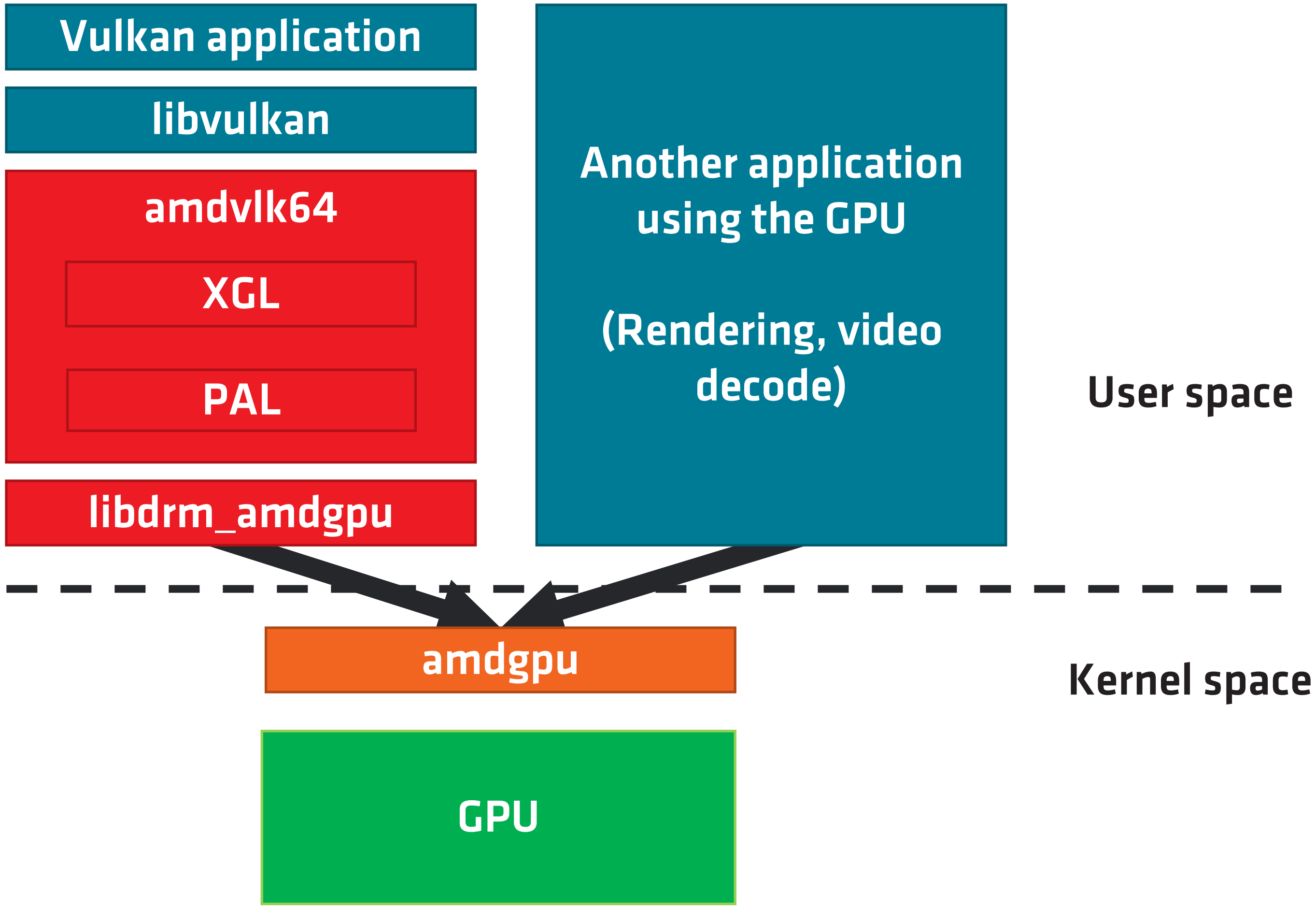
Important note:

Not all calls to the user mode part of the driver end up causing a mode switch to kernel mode



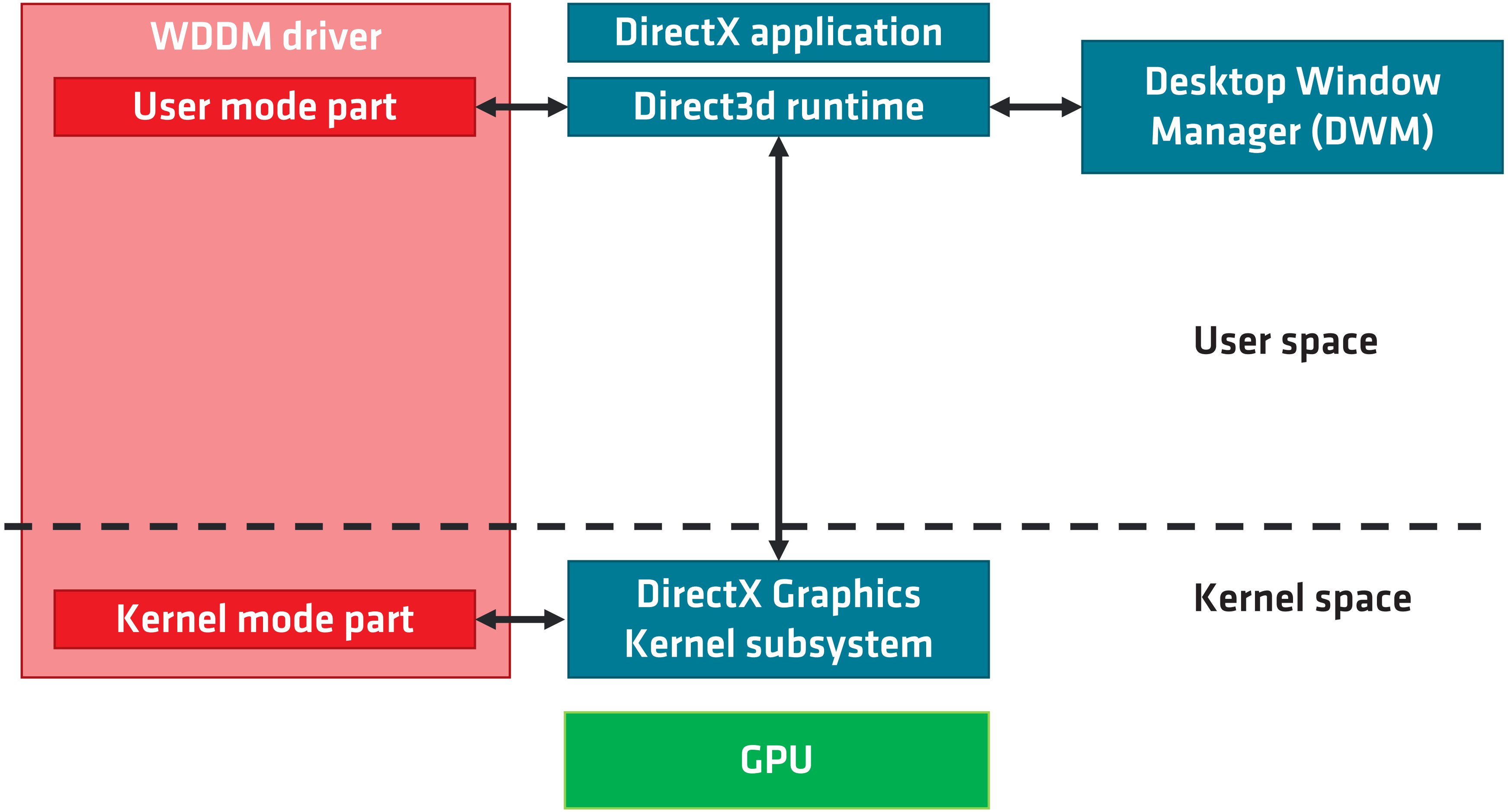
THE DRIVER STACK

- The driver also needs to support multiple applications using the graphics card
- The kernel mode part therefore supports scheduling GPU work for multiple applications

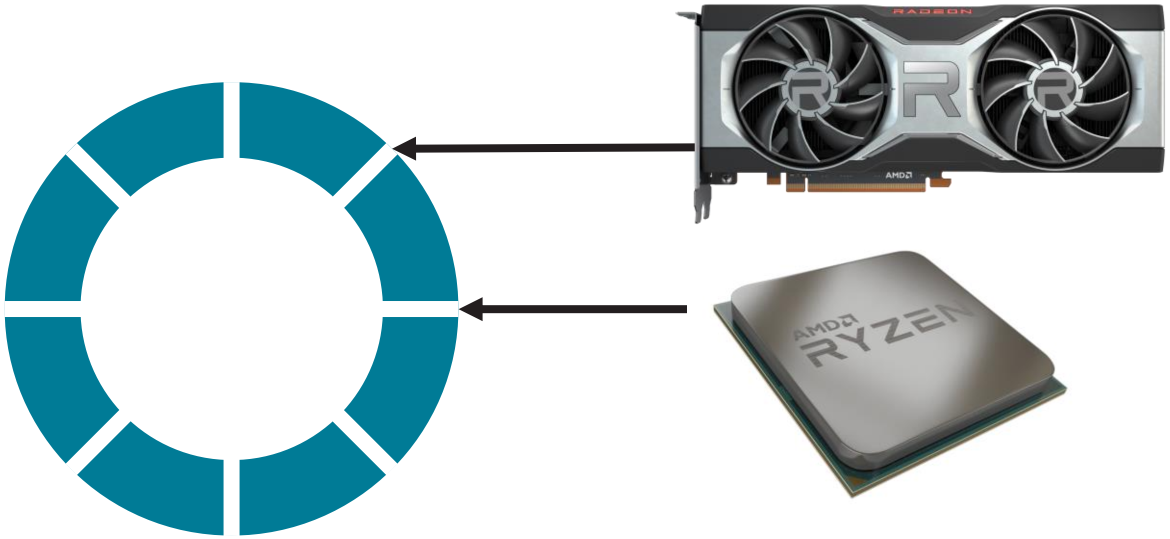


THE DRIVER STACK, ON WINDOWS

- There's a similar setup on windows
- The driver is split up in user mode and kernel mode parts
  - The model is called: *Windows Display Driver Model*
- There is a compositor that handles multiple applications rendering at the same time
  - It is called: *Desktop Window Manager*

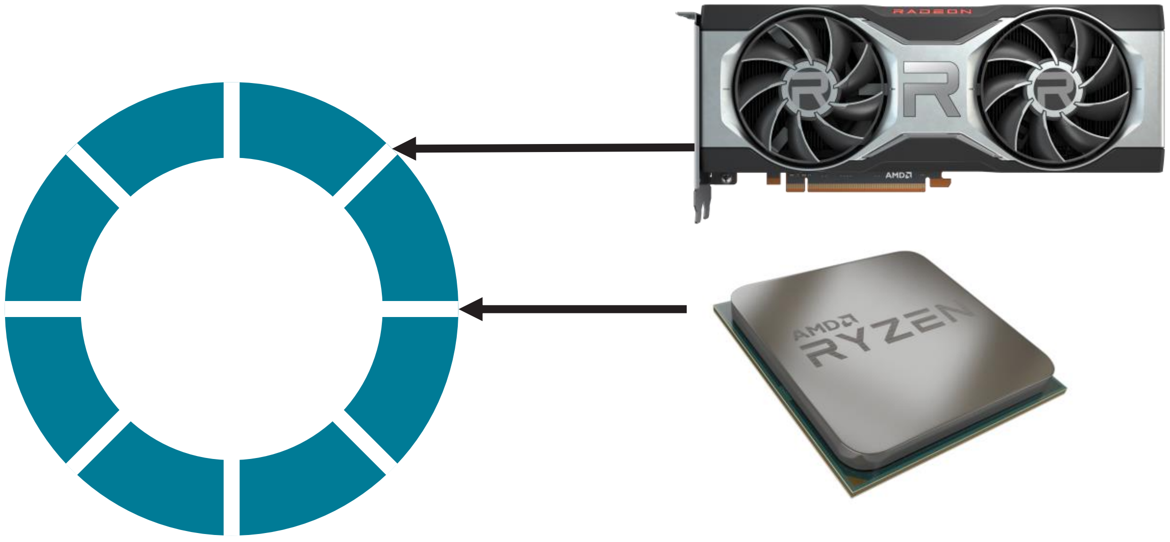


CPU → GPU COMMUNICATION



- The CPU communicates with the GPU over a *ring buffer*
- The ring buffer has two pointers:
  - The CPU writes data and moves the *write pointer* forward
  - The GPU reads data and moves the *read pointer* forward

CPU → GPU COMMUNICATION



- The CPU communicates with the GPU over a *ring buffer*
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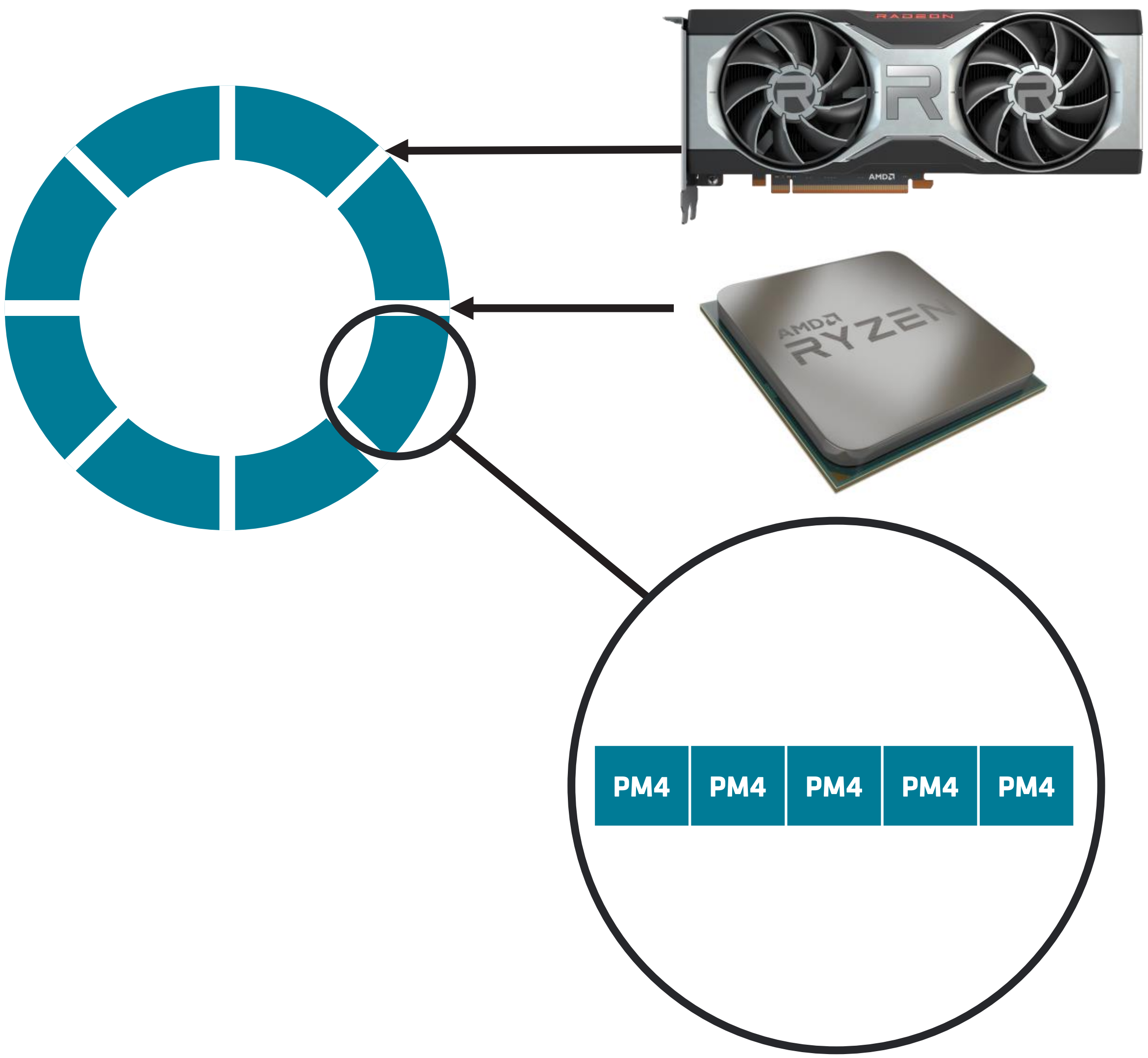
CPU ➔ GPU COMMUNICATION



- The ring buffer contains *PM4 packets* which contain:
  - State settings
  - Draws
  - And other things telling the GPU what to do
- PM4 packets travel over the PCIe bus
  - The *Command Processor* on the GPU receives these packets and configures the GPU accordingly

WHAT CAN WE DO WITH THIS KNOWLEDGE?

- We learnt that the driver and runtime is a few layers thick
- Some calls will end up in the kernel
  - Causing a mode switch
  - Not cheap
  - We should try to limit the amount of mode switches

- We also saw how packets with instructions are sent to the GPU
  - By writing to the ring buffer and moving pointers forward
  - That communication over the PCIe bus is not free either
  - We also mentioned the latency issues previously 😁

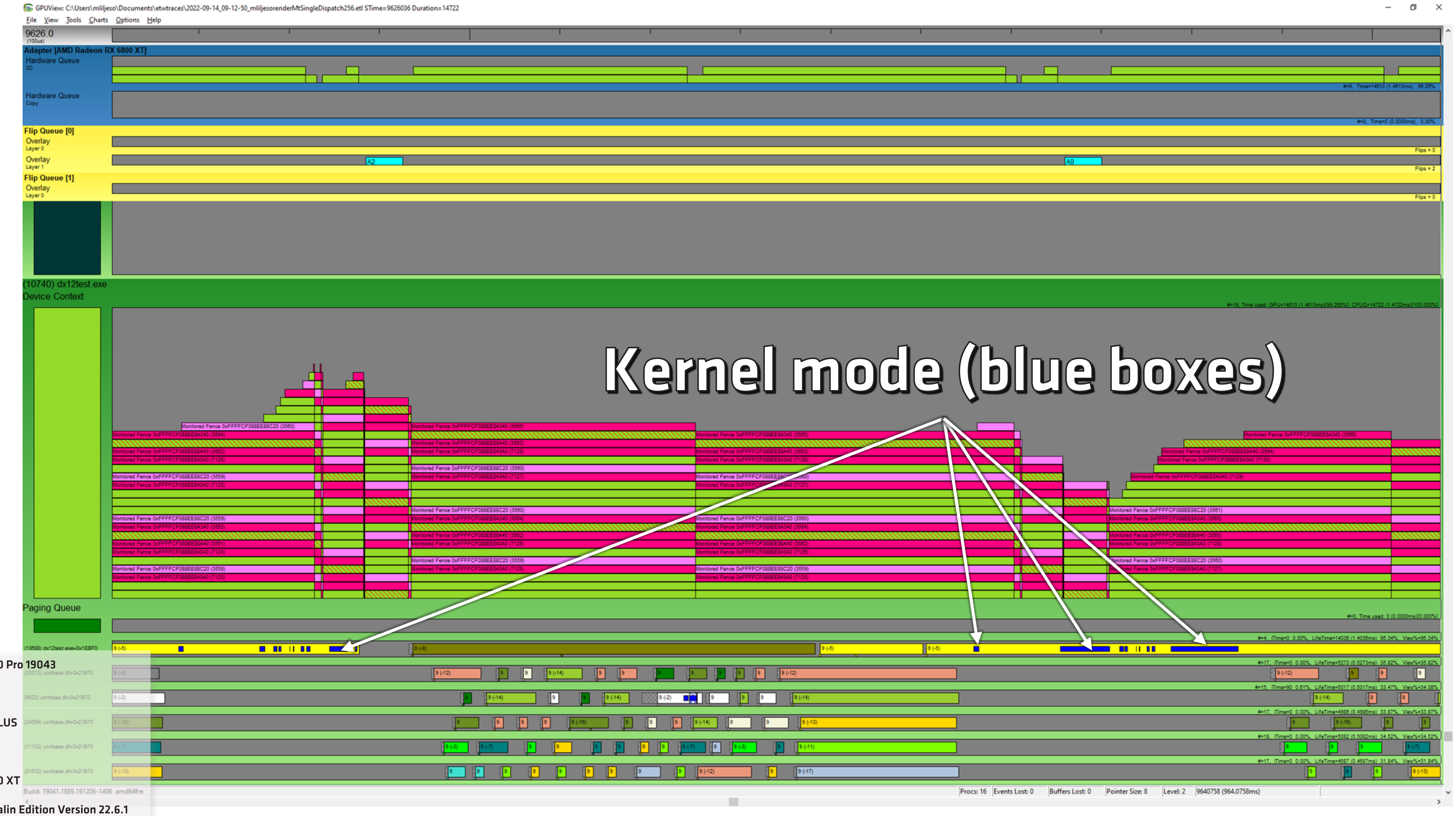
WITH MULTI THREADING, BUT WITH A SINGLE SUBMIT

Command lists with a few draws

1:	Barrier: framebuffer from present to render target Clear render target (back buffer) and depth buffer
2 – 257:	Draw 2048 boomboxes in batches of 8. (8 meshes per CL) As 256 tasks from a thread pool
258:	Barrier: framebuffer from render target to present

All CLs submitted in one go from the main thread

WITH MULTI THREADING, BUT WITH A SINGLE SUBMIT



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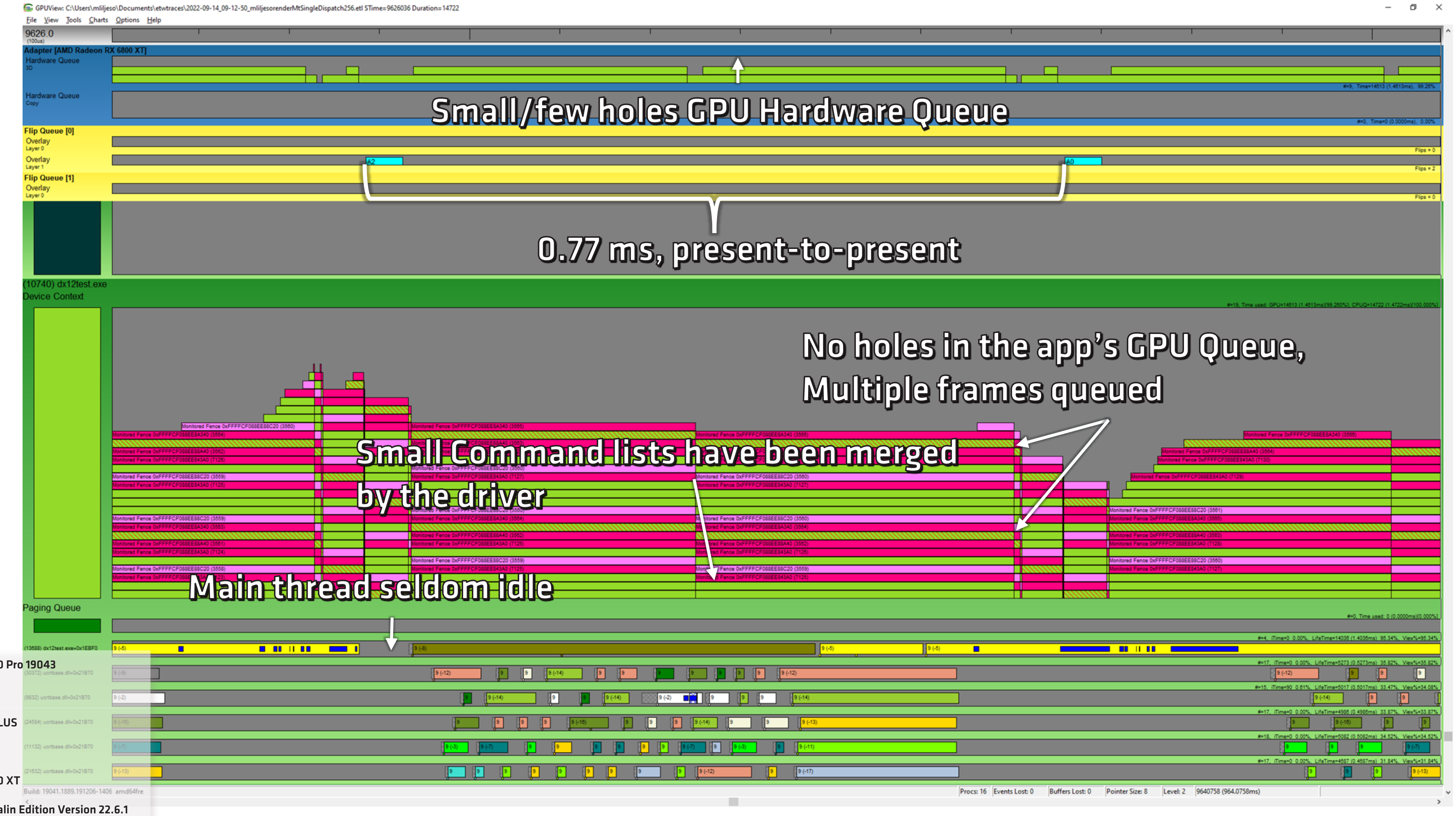

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WITH MULTI THREADING, BUT WITH A SINGLE SUBMIT

Clustered, as seen in GPUView

Low "height"

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BETTER, BUT STILL HORRENDOUS

WITH SANE MULTI THREADING

Command lists with a few draws

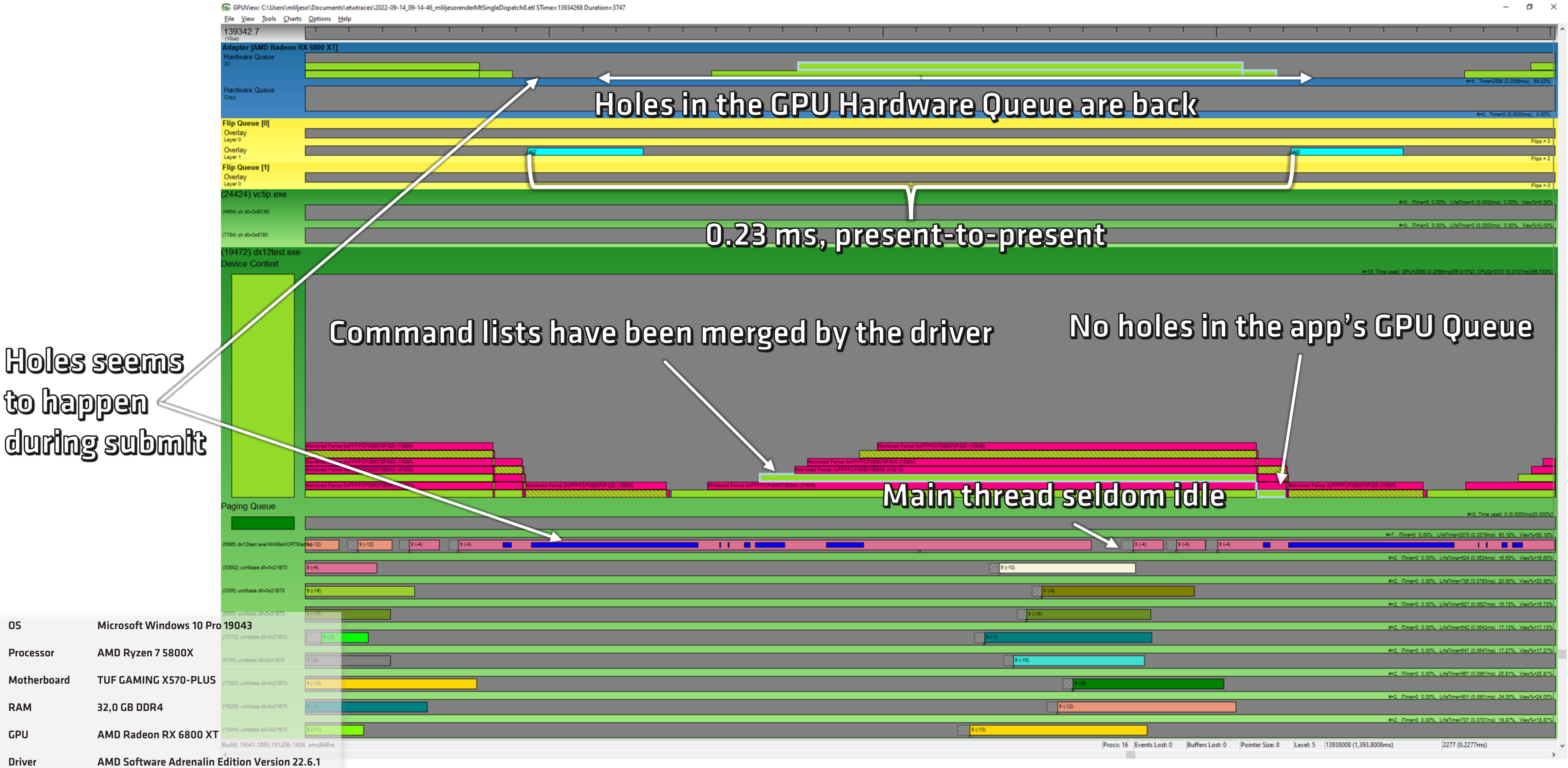
1: Barrier: framebuffer from present to render target
Clear render target (back buffer) and depth buffer

2 – 10: Draw 2048 boomboxes in batches of 256. (256 meshes per CL)
As 8 tasks from a thread pool

11: Barrier: framebuffer from render target to present

All CLs submitted in one go from the main thread

WITH SANE MULTI THREADING



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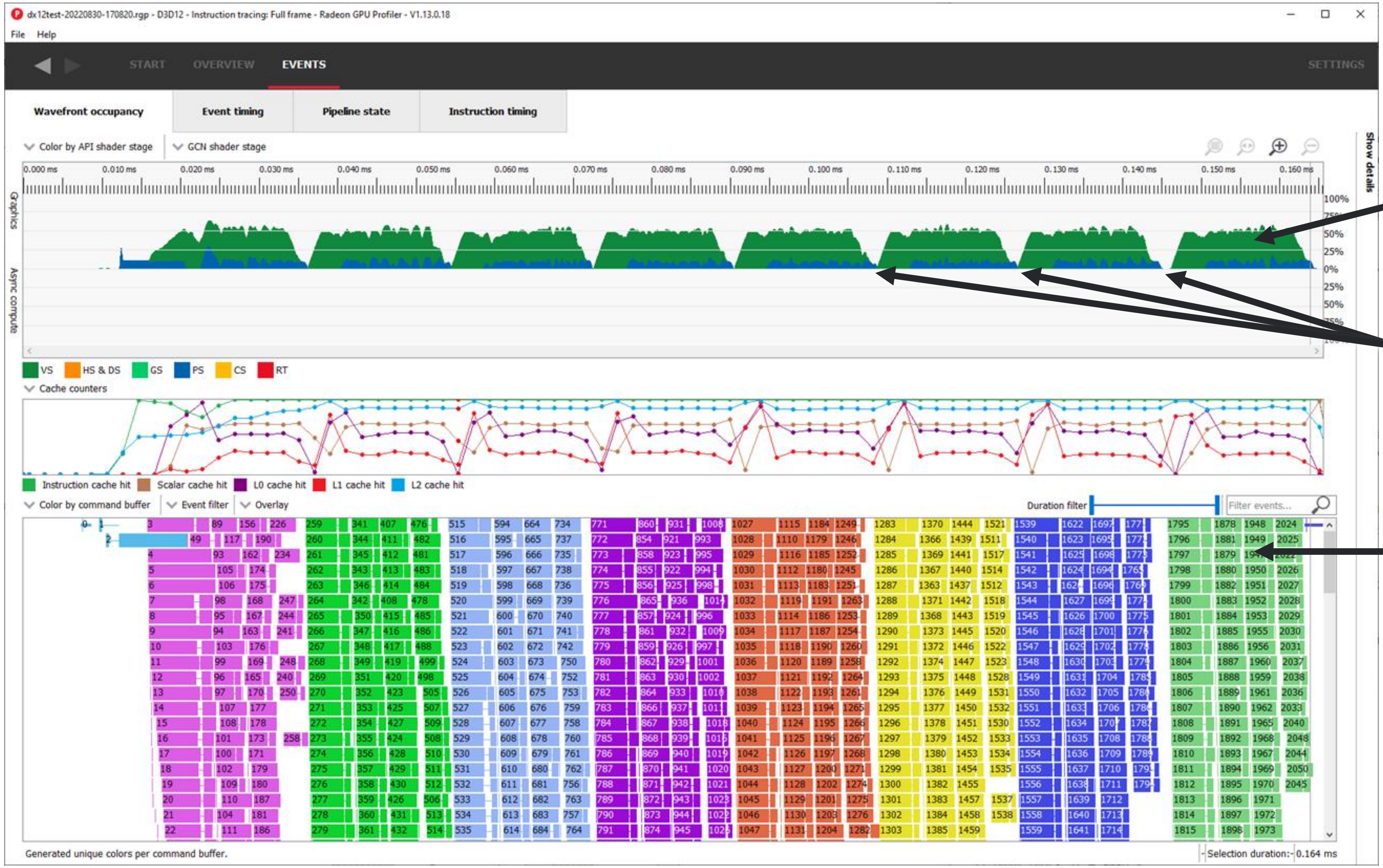

Occupancy up again

Still visible dips in the occupancy view

Parallelism again

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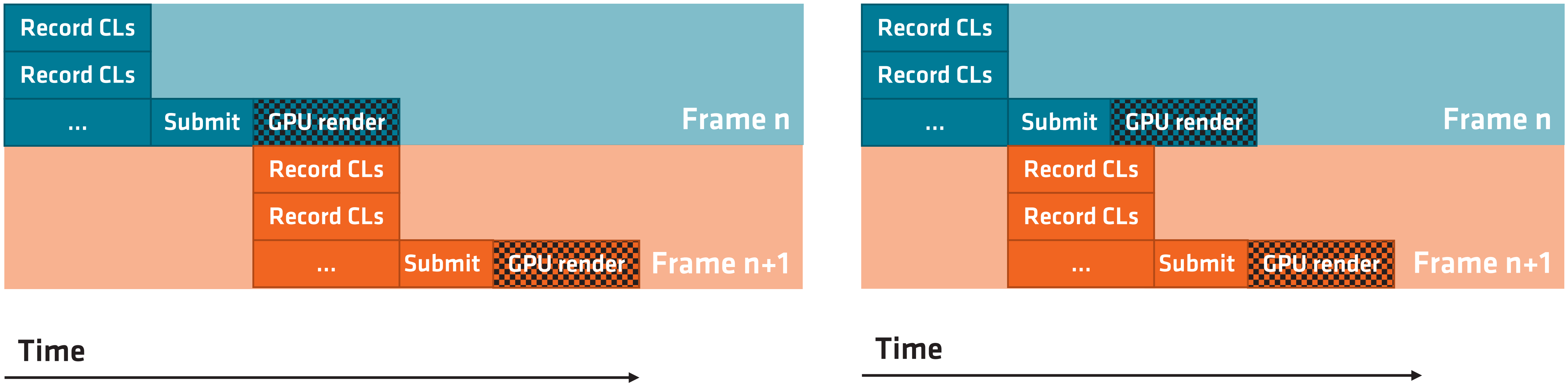
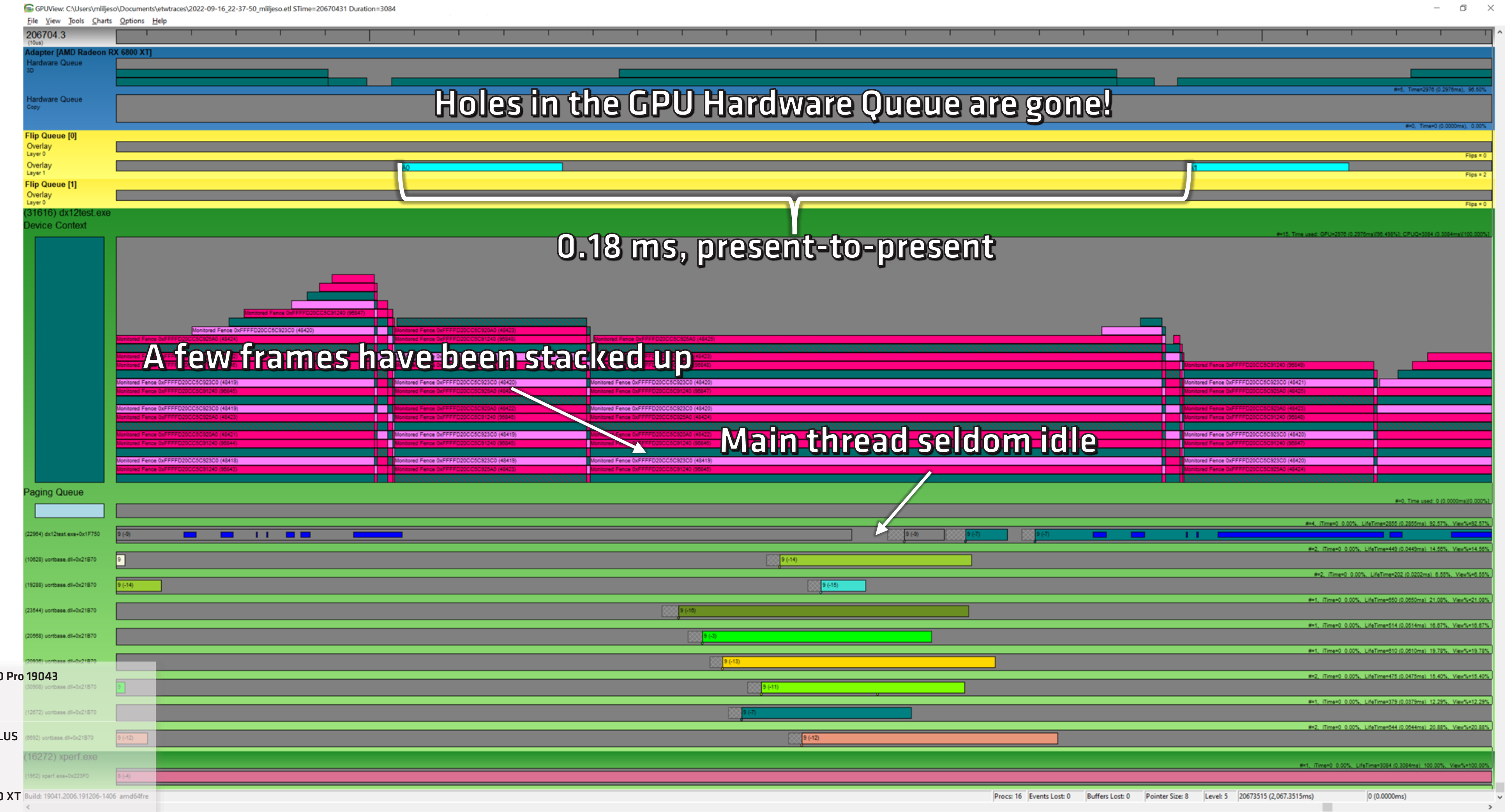
WITH SUBMIT IN PARALLEL WITH CL RECORDING

What we've been doing so far

With async submit



WITH SUBMIT IN PARALLEL WITH CL RECORDING



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SOME CONCLUSIONS

- Submission strategy can affect performance
- Submit size matters: Avoid small CLs
  - That will keep the GPU busy
- Batch CLs up for submission
  - Not one-by-one
- Take advantage of multithreaded command list recording
  - When you see a benefit from it
- Kick off next frame CL recording early

- If unsure of good API usage, take a look at our performance guides on GPUOpen!
  - https://gpuopen.com/performance/
  - https://gpuopen.com/ryzen-performance/

THANKS

- Lou Kramer
- Gareth Thomas
- Dominik Baumeister
- Matthäus Chajdas

QUESTIONS?

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