A Vulkan Video Encoder from Mesa to GStreamer

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Vulkanised 2024

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Implementing a Vulkan Video encoder from Mesa to GStreamer

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Agenda

1. Vulkan Video
2. Mesa - driver
3. GStreamer - application
4. Demos

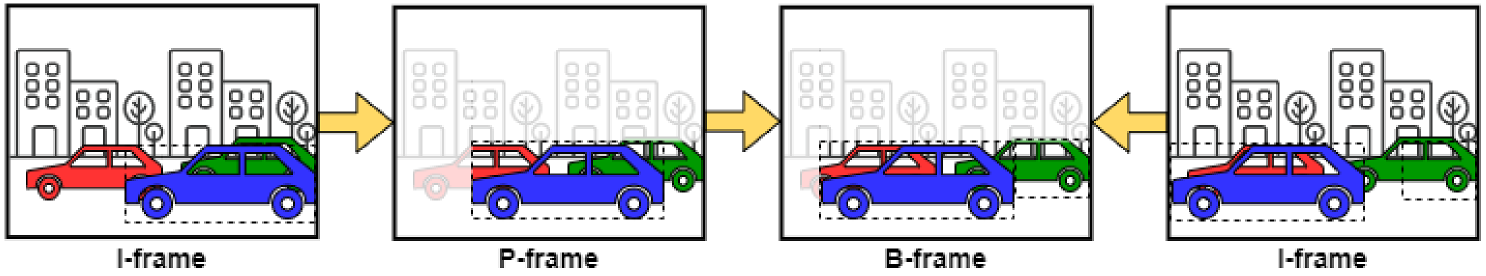
Vulkan Video

- Stateless codecs using GPU hardware acceleration
- Supported codecs: H.264, H.265, AV1
- Closer integration with Graphics and Displays.
- Cross-platform and vendor-neutral low-level HW state(-less) video codecs API
  - Each driver can operate differently depending on its capabilities with a common API.

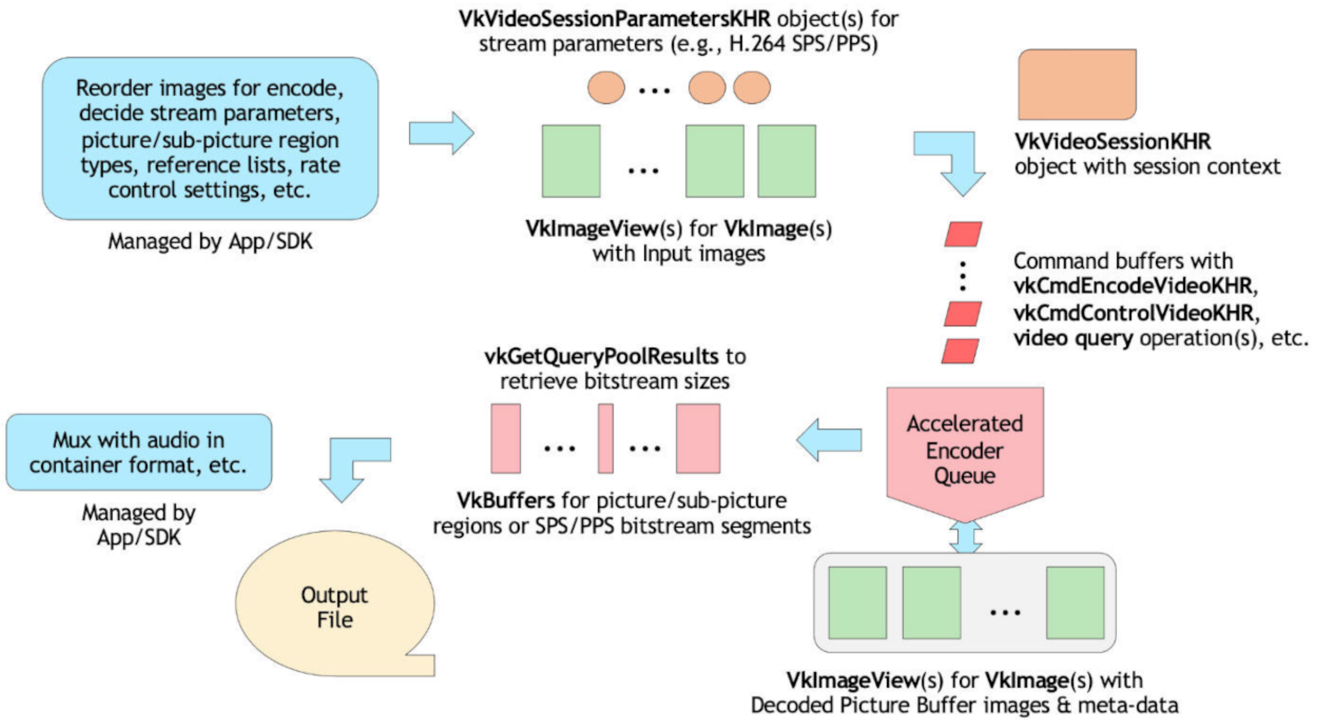
Vulkan Video Timeline

- **March 2018**: TSG was created and driven by IHVs such as AMD/Intel/Nvidia and open source operators
- **April 2021**: **Provisional extensions released** including the Video Decode and Encode extensions
- **January 2023**: Video Extensions for Accelerated H.264 and H.265 Decode **released**
- **December 2023**: Khronos **finalized** Vulkan Video Extensions for Accelerated H.264 and H.265 Encode

Encoding basics



Vulkan Video Encoding



VkVideoSessionParametersKHR object(s) for stream parameters (e.g., H.264 SPS/PPS)
Reorder images for encode, decide stream parameters, picture/sub-picture region types, reference lists, rate control settings, etc.
Managed by App/SDK
VkImageView(s) for **VkImage**(s) with Input images
VkVideoSessionKHR object with session context
Command buffers with **vkCmdEncodeVideoKHR**, **vkCmdControlVideoKHR**, **video query** operation(s), etc.
vkGetQueryPoolResults to retrieve bitstream sizes
Mux with audio in container format, etc.
Managed by App/SDK
Accelerated Encoder Queue
VkBuffers for picture/sub-picture regions or SPS/PPS bitstream segments
Output File
VkImageView(s) for **VkImage**(s) with Decoded Picture Buffer images & meta-data

The status of
Vulkan Video Encoder Support
in Mesa project

Contents

What is Mesa?

- **https://mesa3d.org/**
- Began as an open source implementation of the OpenGL.
- Now actively implementing Vulkan specification on various GPUs.
  - Intel, AMD, Qualcomm Adreno(R/E), Raspberry PI, etc..
  - **https://gitlab.freedesktop.org/mesa/mesa**
- Contributors: Igalia, Intel, Google, Collabora, Mesa community.

History of Vulkan Video development in Mesa

- Dave Airlie started in 2022 on AMD and Intel GPU(RADV and ANV)
  - **Dave's blog post**
  - With **Lynne** on FFmpeg.
  - Igalia joined on GStreamer later.
- Hyunjun joined in 2023, started working on Intel GPU(ANV)
- So Dave fully dedicated to AMD GPU(RADV).

The status of Vulkan Video development in Mesa

- Implemented and landed decoder first for h264 and h265.
  - **ANV H264 MR #20782**
  - **ANV H265 MR #22202**
  - **RADV H264/265 MR #20388**
- Now MR for h264/5 encoding are almost ready.
  - **RADV MR**
  - **ANV Branch**

Drivers supporting Vulkan Video in Mesa

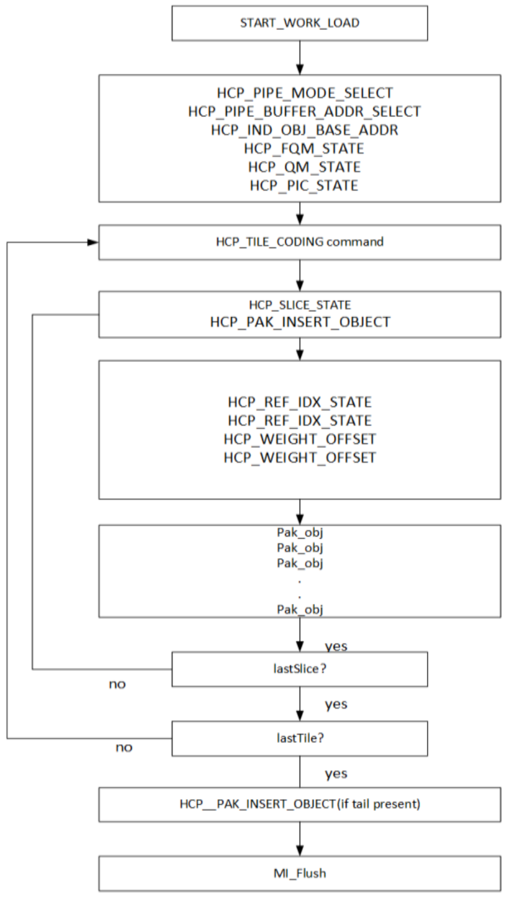
GPU	H264 dec	H265 dec	H264 enc	H265 enc
Intel(ANV)	O	O	WIP	WIP
AMD (RADV)	O	O	Ready	Ready

Working on Intel GPUs (1)

- Dived into Intel Vulkan driver(ANV) in 2023.
  - Started working on H265 decoding first.
- Tons of documents and source code of Intel VAAPI drivers.
  - Exhausted to learn lots of Video commands.
  - But better than nothing :)

Working on Intel GPUs (2)

- H265 Encoding Sequnce



Working on Intel GPUs (3)

- Complete each command very carefully.
  - Otherwise you got a GPU hang or even whole system down.
- When you get a GPU hang and don't see any clue.
  - Dumping whole video commands encoding a frame(by VAAPI Driver) into a file.
  - Compare to commands that you created

Working on Intel GPUs (4)

- Thanks to the existing infrastrutures of ANV
  - Easy to handle memories and images.
- Thanks to ANV maintainers.
  - They actively reviewed relevant merge requests.

Co-working with Applications

- GStreamer, VK CTS, FFMpeg...
- Each uses different parameters and makes it find bugs easily.
  - Different resolution, profile, SPS, PPS parameters.

Challenges

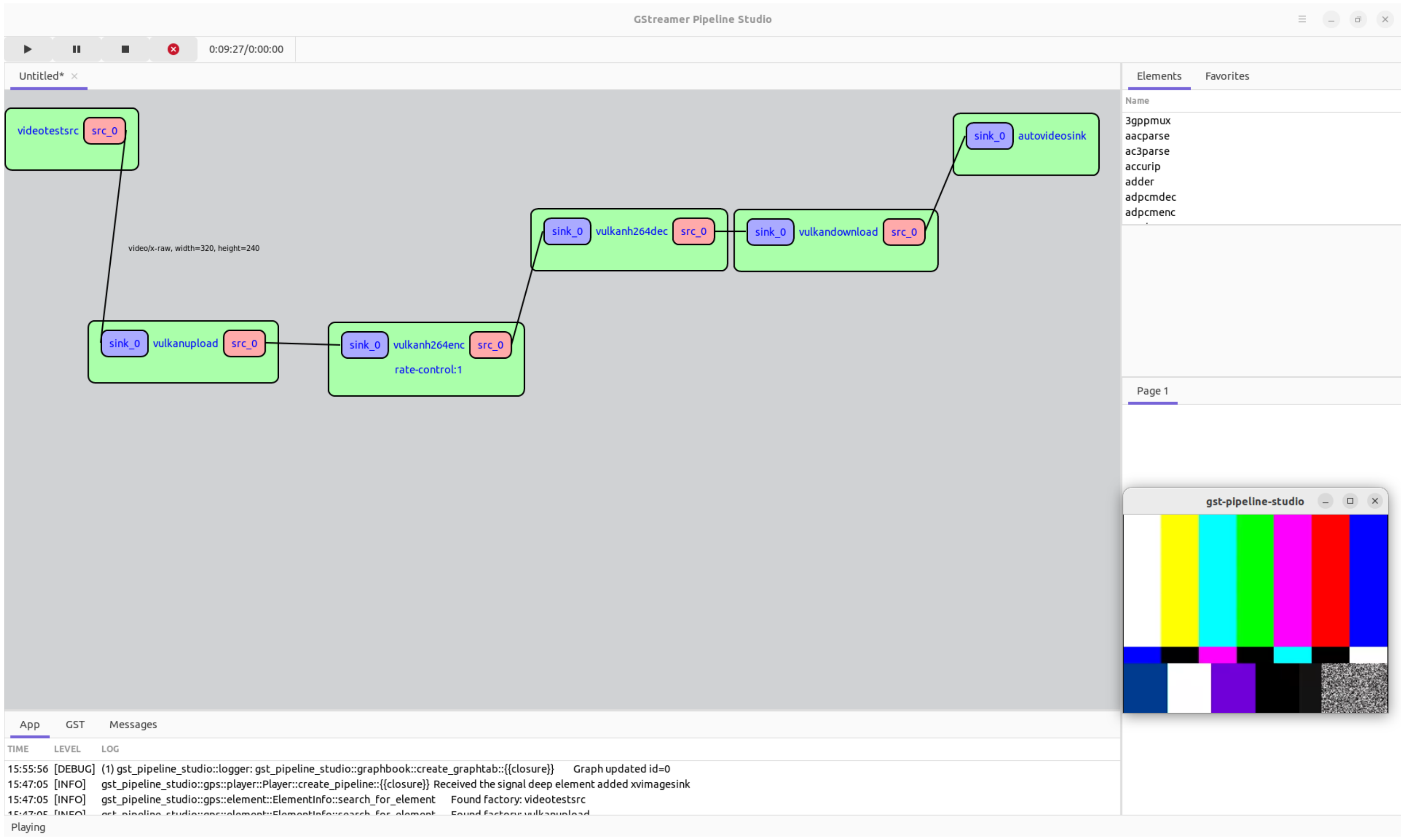
- GPU hang.
  - Not enough useful tools to investigate.
- Lots of generations of Intel GPUs.
  - Different commands, parameters, memory size, alignment, etc...

Plan 2024

- Land h264/h265 encoding support.
- AV1 support.
- Support other GPUs?

- a 20-year-old framework for streaming media applications.
- Black boxes interconnection system
- Native, multiplatform, highly-optimized framework

GStreamer pipeline

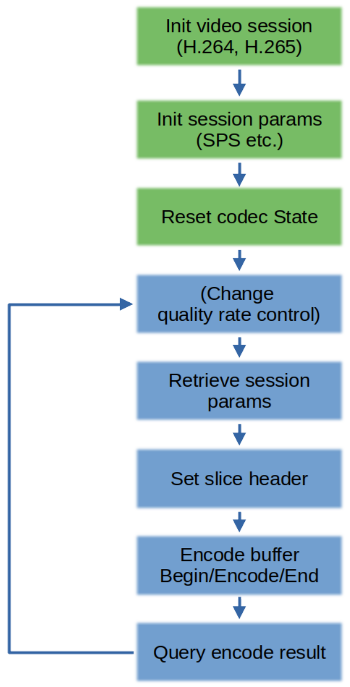


```
15:55:56 [DEBUG] (1) gst_pipeline_studio::logger: gst_pipeline_studio::graphbook::create_graphtab::{{closure}}      Graph updated id=0
15:47:05 [INFO]  gst_pipeline_studio::gps::player::Player::create_pipeline::{{closure}} Received the signal deep element added xvimagesink
15:47:05 [INFO]  gst_pipeline_studio::gps::element::ElementInfo::search_for_element     Found factory: videotestsrc
15:47:05 [INFO]  gst_pipeline_studio::gps::element::ElementInfo::search_for_element     Found factory: vulkanupload
```

Vulkan Video support

- Follow **Vulkan Video Status**
- Vulkan H.264 decoder **merged** in December 2023
- Vulkan H.264/H.265 encoder **under review**.

State machine


Init video session (H.264, H.265)
Init session params (SPS etc.)
Reset codec State
(Change quality rate control)
Retrieve session params
Set slice header
Encode buffer Begin/Encode/End
Query encode result

Challenges

Cross platform API

- Hardware crashes, Thanks Validation Layers!
- Exact behavior varies by hardware vendor
- Rate control and quality issues

Synchronization

- Major issues with both decoder and encoder
  - Old memories from Vulkanised 2023, green screen…
  - Rework of GStreamer state machine with memory barriers, fences.
  - GstVulkanOperation to handle commands synchronization.

DPB management

- Understand the correct use of Begin and Encode reference slots.
  - Need to declare the reference within *Begin* command and use it during the *Encode* command.
- Various crashes in drivers not detected by the Validation Layers when the standard H.26x parameters (SPS, slice header) were not filled properly.
- Vulkan reference slots management.

Vulkan tooling

- Validation Layers:
  - Help validate we understand the specifications correctly
  - Do not prevent a misconfiguration of the std parameters
  - Mesa drivers helped to understand driver's pitfalls when VL was clear.
- GFXReconstruct, VK_LAYER_LUNARG_api_dump layer.
- CTS: Help with a reference design reviewed by IHVs.

Demos

Questions ?

Thanks

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