Vulkanised 2025

The 7th Vulkan Developer Conference
Cambridge, UK | February 11-13, 2025

Teaching Update & Thesis Vulkan Video Extension for Mesa Lavapipe

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Vulkan at the University of Vienna

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- Bachelor / Master / PhD
- **Do first:** *Foundations of Computer Graphics*

Vulkan **Tutorial**

- ***Real-Time Computer Graphics***

Vulkan Ray Tracing **Engine**

- *Real-Time Ray Tracing*

Vienna Vulkan **Engine**

- *Gaming Technologies*
- *Cloud Gaming*
- *Bachelor / Master‘s theses*

Repeatability, Communication, Updating

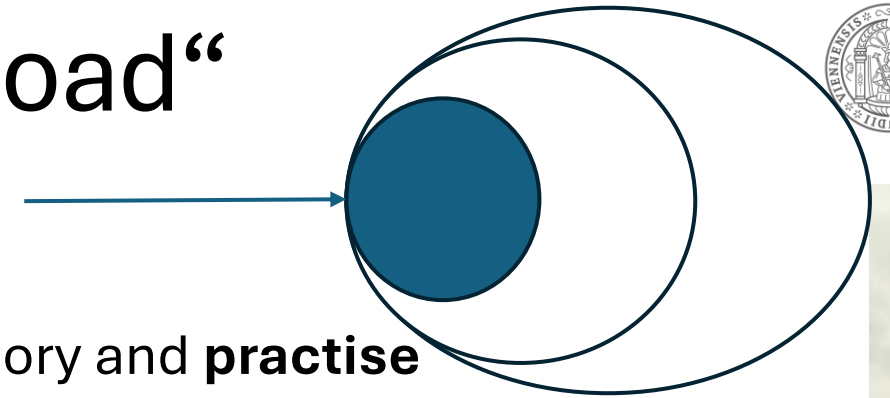
- **Recording the lectures**
- **Moodle page** with examples, resources, slides, dates
- Always know what is expected
- **Forum, active tutors**
- Teach each other
- Who got it working? **Sharing code**
- **Debugging sessions**
- **Keep informed about new developments**

What doesn‘t Work

Theory overload

- Too much (unnessary) theory, too many details
- Too fast progress
- Little or no: practise, time for reflection, understanding
- -> Confusion instead of learning
- -> Unable to use the concepts

Avoid “Theory Overload“



- Focus on essential theory subset
- **Slow** theory progress, **balance** theory and **practise**
- Learn programming by programming -> **habit** formation
- **Scaffolding**
  - Bootstrap, provide **overview** and **guides**, control complexity
  - **Provide working *overall* simple implementation from A to Z**
  - **Look** at existing code, **adapt** this code to **add** new functionality
  - **Reduce line count by fusing lines e.g.**

```
if( condition ) { do_this(); }
```

  - **Grow this base to arrive at your own engine or game**
- Reserve **time** at course **end** to **focus** solely on **programming -> understanding, using, playing around with the subject**

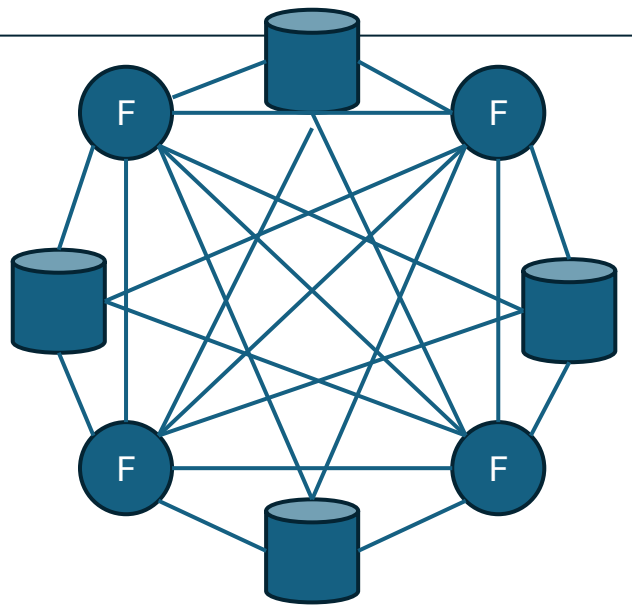
Separation btw. Intent and Implementation

- https://docs.vulkan.org/tutorial/latest/00_Introduction.html
- https://github.com/Overv/VulkanTutorial
- GLFW
- GLM

```
void initVulkan() {
    createInstance();
    setupDebugMessenger();
    createSurface();
    pickPhysicalDevice();
    createLogicalDevice();
    createSwapChain();
    createImageViews();
    createRenderPass();
    createDescriptorSetLayout();
    createGraphicsPipeline();
    createCommandPool();
    createDepthResources();
    createFramebuffers();
    createTextureImage();
    createTextureImageView();
    createTextureSampler();
    loadModel();
    createVertexBuffer();
    createIndexBuffer();
    createUniformBuffers();
    createDescriptorPool();
    createDescriptorSets();
    createCommandBuffers();
    createSyncObjects();
}
```

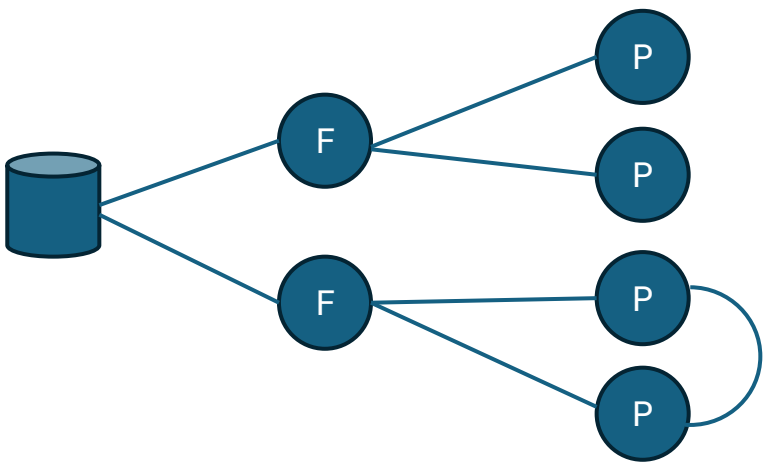
Lower Complexity (!)

```
void function1(…) {
   … // read/write shared data
   function2(…);
   …// read/write shared data
}
```



Intent (stateful)

Implementation (stateless)



Avoid if possible

Adapted Tutorial

- **Pure functions**
- GLM
- **SDL2**
- **Imgui**
- **VMA**
- **Volk**
- **Slang**

https://github.com/hlavacs/AdaptedVulkanTutorial

```
void initVulkan() {
    createInstance(&m_instance, m_validationLayers);
    setupDebugMessenger(m_instance);
    createSurface(m_instance, m_surface);
    pickPhysicalDevice(m_instance, m_deviceExtensions, m_surfac
    createLogicalDevice(m_surface, m_physicalDevice, m_queueFar
    initVMA(m_instance, m_physicalDevice, m_device, m_vmaAlloca
    createSwapChain(m_surface, m_physicalDevice, m_device, m_sw
    createImageViews(m_device, m_swapChain);
    createRenderPass(m_physicalDevice, m_device, m_swapChain, m
    createDescriptorSetLayout(m_device, m_descriptorSetLayout),
    createGraphicsPipeline(m_device, m_renderPass, m_descriptor
    createCommandPool(m_surface, m_physicalDevice, m_device, m_
    createDepthResources(m_physicalDevice, m_device, m_vmaAlloc
    createFramebuffers(m_device, m_swapChain, m_depthImage, m_i
    createDescriptorPool(m_device, m_descriptorPool);

    createObject(m_physicalDevice, m_device, m_vmaAllocator, m_
      glm::mat4{1.0f}, m_MODEL_PATH, m_TEXTURE_PATH, m_objects)

     createCommandBuffers(m_device, m_commandPool, m_commandBuf
     createSyncObjects(m_device, m_syncObjects);
    setupImgui(m_instance, m_physicalDevice, m_queueFamilies, m
        , m_descriptorPool, m_renderPass);
}
```

Vienna Vulkan Engine 2.0 and Helper Layer

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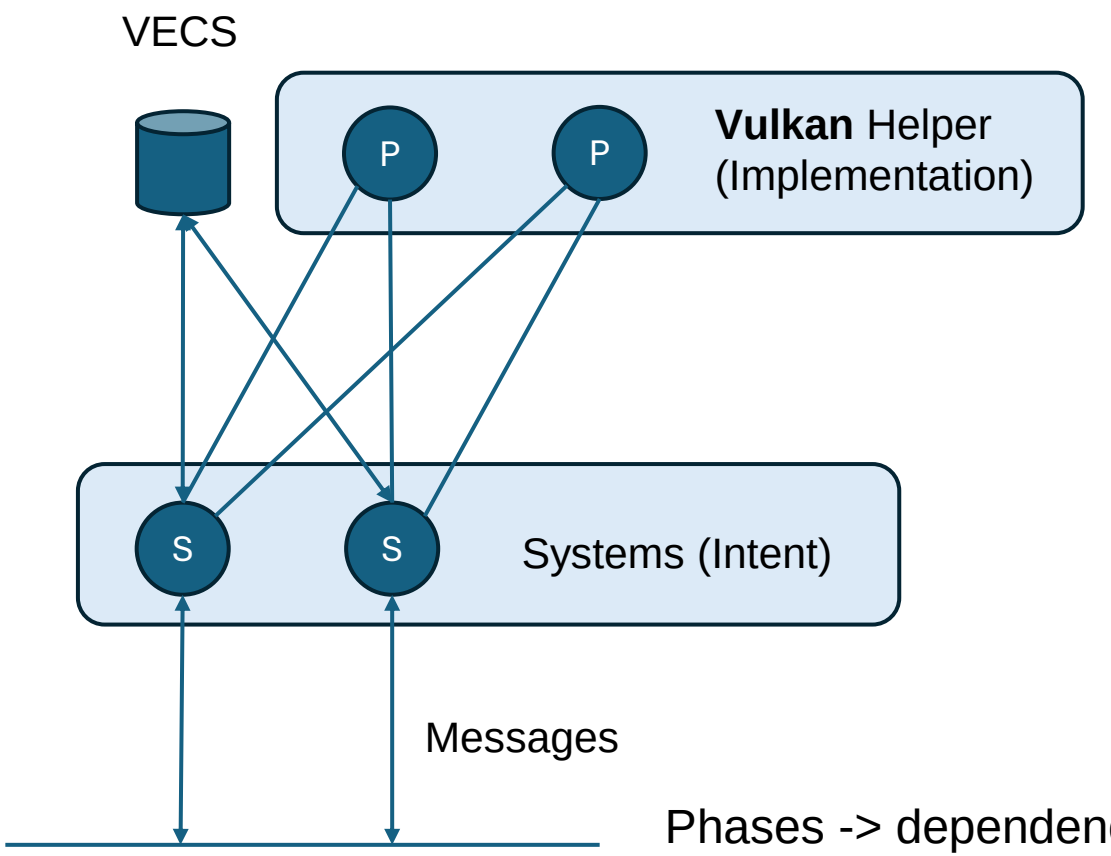
Shared global state
(dynamic entities)



- Pure functions
- Function names show intent and filename
- Single concern
- Stateless,
- Call Vulkan API

- Stateful, single concern
- **No** direct call of Vulkan API
- Show intent, not the details
- Do not offer any public interface
- Isolated

Be Creative and Have Fun

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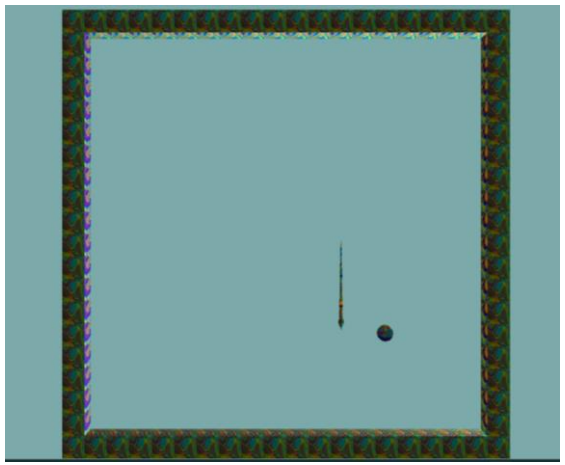
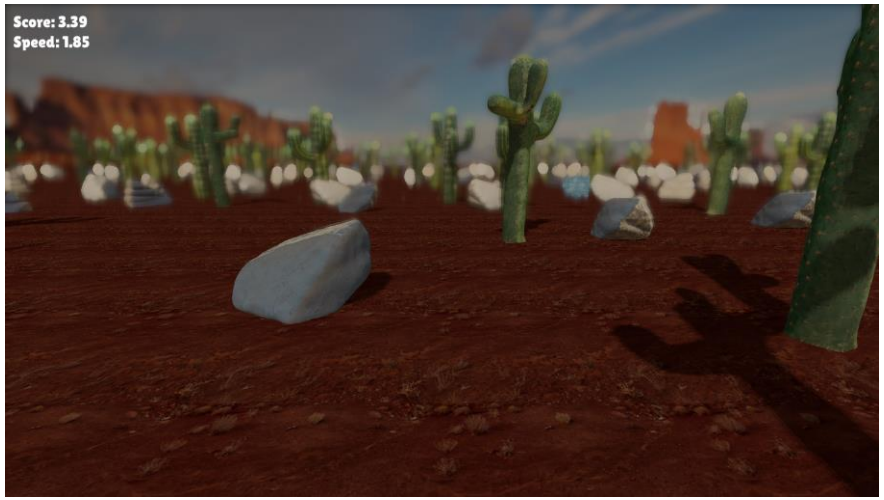
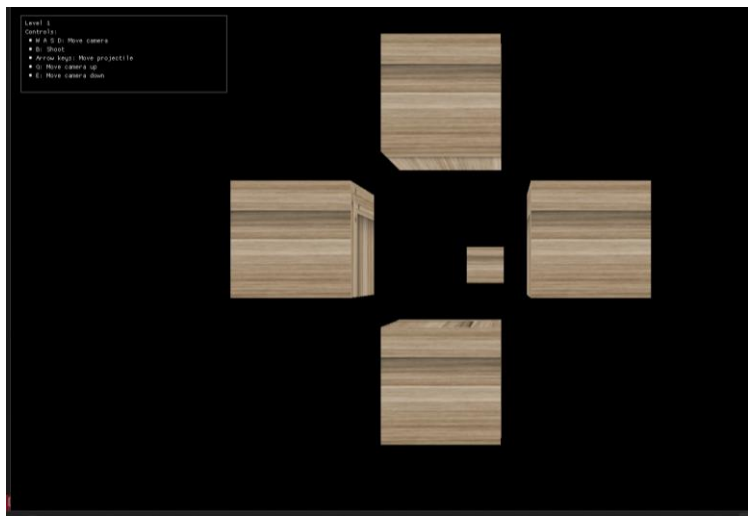
Snake (Tuncer Kerem)



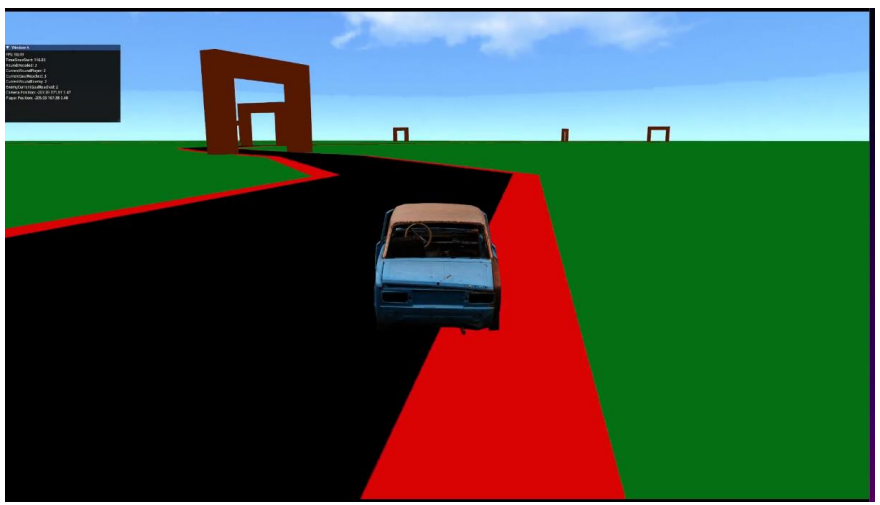
Desert Run (Bernhard C. Schrenk)



Cube Puzzler (Andrei Goje)



Manuel Kart (Manuel Zechmann)



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University Students vs. Tech Engineers

1.5 - 2 hour lectures + progr.

- Math 1 : Linear algebra
- Math 2: Projection
- C++ primer, C interface
- **Vulkan API**
- Color theory
- Shader language (**Slang**)
- Shading (Phong, PBR, …)
- Lighting, mapping, shadows, GI

20 - 30 minute units + programming

- C++ interface, RAII
- **Vulkan API** + more on
  - Extensions and Layers
  - Maintenance
  - Specification **versions**
  - Synchronization2
  - More examples: MSAA, CS, …
  - Tools

Resources and Contact

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- Adapted Tutorial: https://github.com/hlavacs/AdaptedVulkanTutorial
- Vienna Vulkan Engine: https://github.com/hlavacs/ViennaVulkanEngine
- **Recorded Lectures**: helmut.hlavacs@univie.ac.at
  Introduction: https://www.youtube.com/watch?v=7Ijalz6RLr4
- Linked-In: https://www.linkedin.com/in/helmut-hlavacs-972b9aa/

Thesis: Evaluation of the Feasibility of Implementing Vulkan Video Extensions on CPUs

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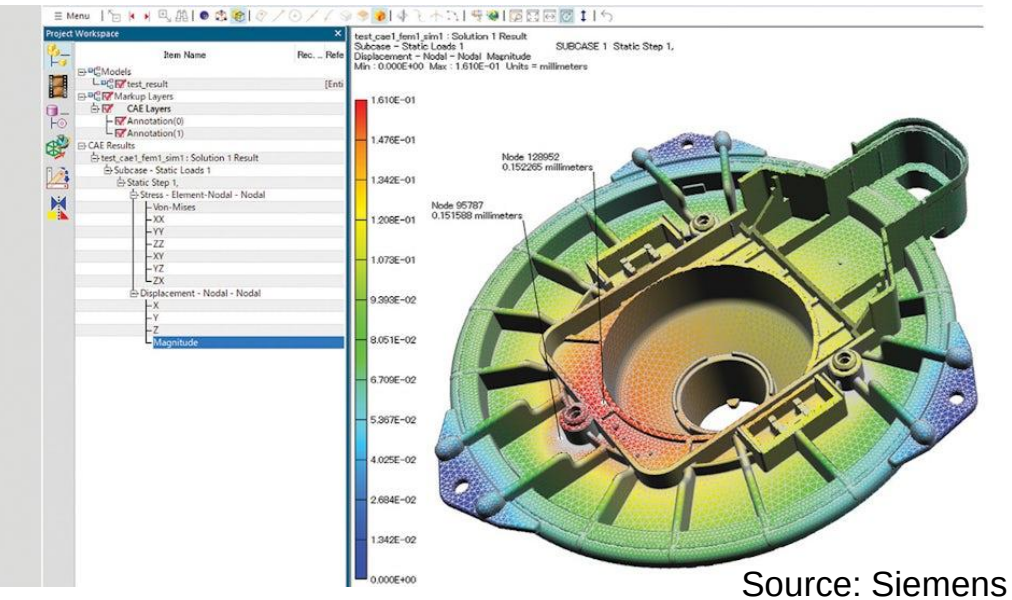
➔ Can Vulkan Video Extensions be fully implemented on CPUs?

- **Non-Academic Relevance?**

  There is need in the industry:
  - Testing and Reference implementations
  - Legacy systems
  - Visualization Systems without video encoder hardware



Source: Siemens

Video Codec APIs – A Survey

- Grouped by **Availability:**
  - Vendor specific (Nvidia Video Codec SDK, Intel VPL, ...)
  - Operating-System specific (Direct3D 12 Video, ...)
  - Vendor & OS neutral (Vulkan Video Extensions)

- Key **Challenges:**
  - **One API usable everywhere** -> Reduces application implementation effort
  - **Software Codec (CPU) fallback** -> Works without dedicated video HW

- Survey **Conclusion:**
  - ***Missing:*** Vendor & OS independent API with software fallback

Vulkan Video Extensions Use Cases

- **Game Streaming** / Cloud Gaming: low latency
- In-Game **Video Playback:** see video
- **Scientific** Data **Visualization** with video output
- **Video Editing:** live preview, live filter (shader)
- **Video Transcode**
- **Surveillance:** decode multiple video streams
- **AI Video Applications:** decode video & apply AI algorithms directly on the GPU
- and many more…

From my last year's talk:
Vienna Vulkan Engine with
Vulkan Video Decode support:
Streaming video directly onto a texture

Where to begin?

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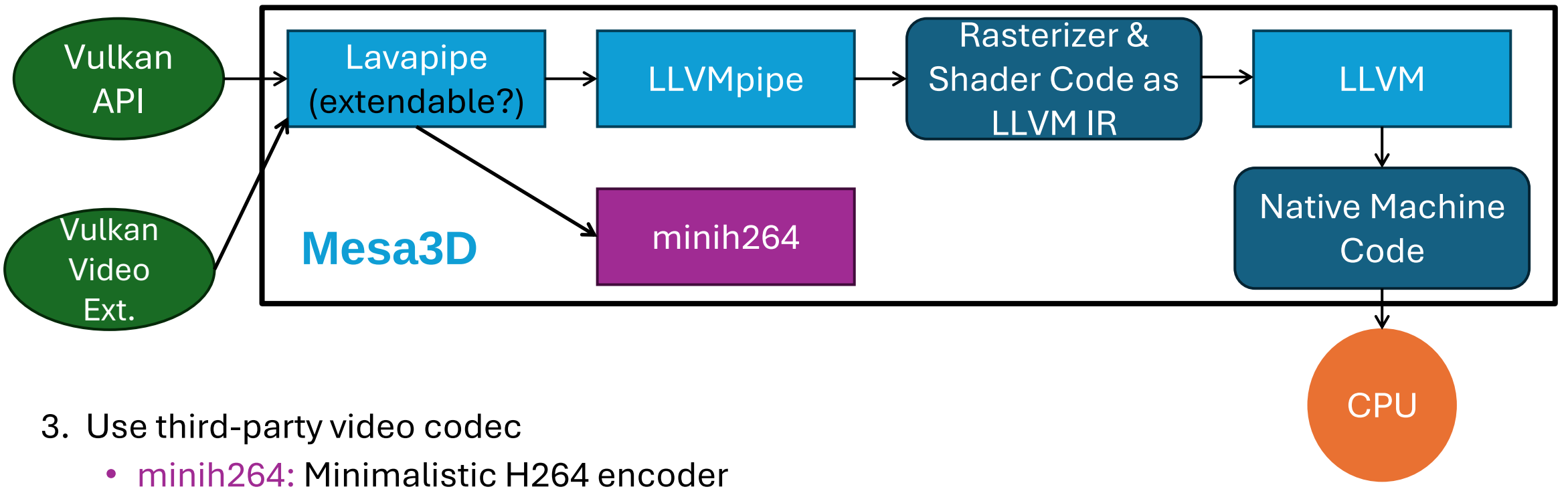
1. Define a subset to begin with (H.264 Baseline Profile, Encode only)
2. Use existing Vulkan graphics API implementation as base
   - **Mesa3D Lavapipe:** Software (CPU-based) rasterizer (3D renderer) with Vulkan API



3. Use third-party video codec
   - minih264: Minimalistic H264 encoder

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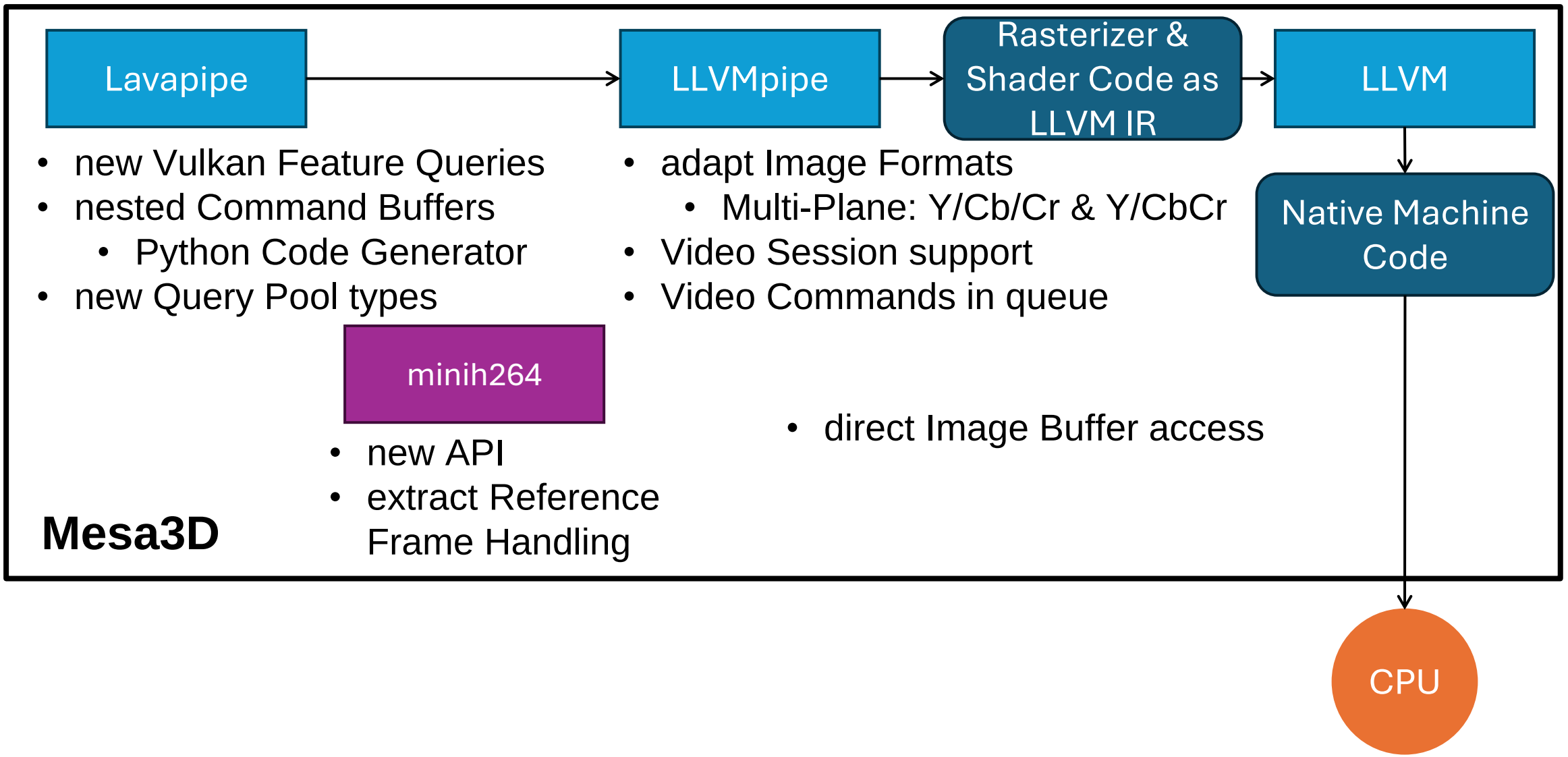
Mesa3D/Gallium Lavapipe

CPU-based Rasterizer with Vulkan API

- mesa
  - src
    - gallium
      - drivers
        - llvmpipe
      - frontends
        - lavapipe
    - vulkan

- available for Windows & Linux
- No need for dedicated hardware (but much slower)
- Vulkan 1.4 compliant
- Good platform for experiments with Vulkan Extensions (driver side)
- Minimum dependencies – easy to compile

What to add?


Lavapipe
LLVMpipe
Rasterizer & Shader Code as LLVM IR
LLVM
Native Machine Code
CPU
• new Vulkan Feature Queries
• nested Command Buffers
• Python Code Generator
• new Query Pool types
• adapt Image Formats
• Multi-Plane: Y/Cb/Cr & Y/CbCr
• Video Session support
• Video Commands in queue
minih264
• new API
• extract Reference Frame Handling
• direct Image Buffer access
Mesa3D

How to Evaluate?

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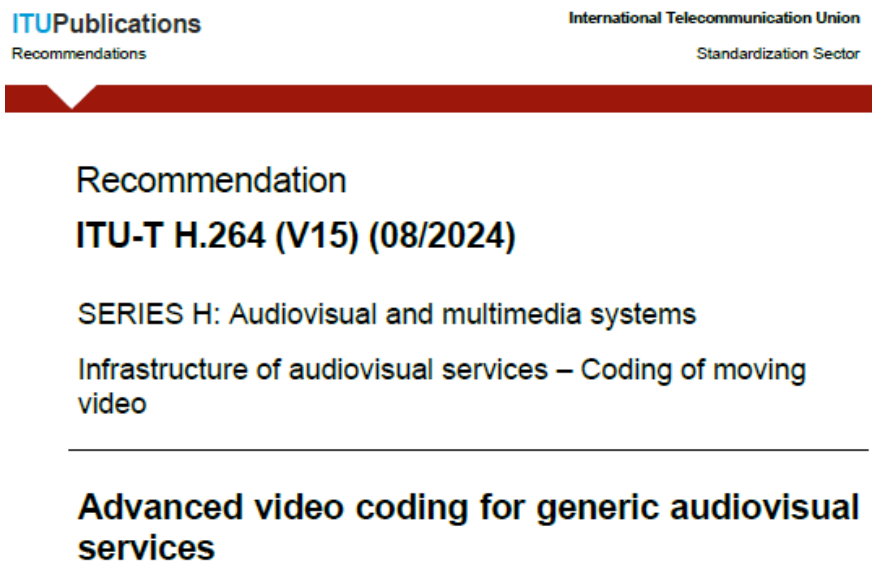
- Does the implementation *conform* to
  1. the *Vulkan specification* and
  2. the *video encoding standards*?
- **Environment:**
  - **Linux & Windows -** Extended Lavapipe used as Vulkan Graphics Driver
- **Functionality Tests:**
  - **Vulkan Video Sample Code** (1. Nvidia, 2. my own)
  - **Vienna Vulkan Engine** with Video Encoding support
- **Conformance Tests:**
  - **Vulkan Conformance Test Suite** (Vulkan CTS) for Drivers & Hardware
  - Decompressing encoded video and comparison (**Reconstruction Quality Metric**)

Vulkan® 1.4.304 - A Specification (with all registered extensions)


ITUPublications
Recommendations

International Telecommunication Union
Standardization Sector

Recommendation
ITU-T H.264 (V15) (08/2024)

SERIES H: Audiovisual and multimedia systems

Infrastructure of audiovisual services – Coding of moving video

Advanced video coding for generic audiovisual services

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Vulkan CTS

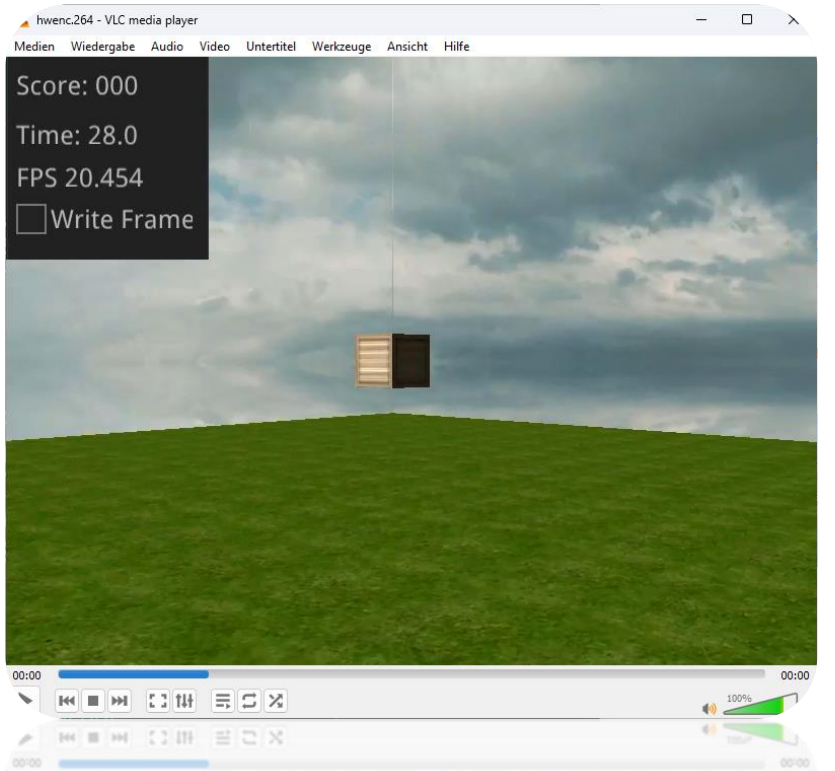
Vulkan Conformance Test Suite

- Thousands of automated tests for Vulkan drivers
- Windows & Linux
- Growing number of tests for video extensions
- Easy setup – own script for fetching dependencies
- Required to pass for conformant products
- Also suitable as example code

Results

Functional Tests:

- Encoder Examples: working ✅
- Rendering & Video Encoding with Vienna Vulkan Engine: working ✅
- Advantage: **Modifying the application not necessary** -> simply use Mesa driver as Vulkan device

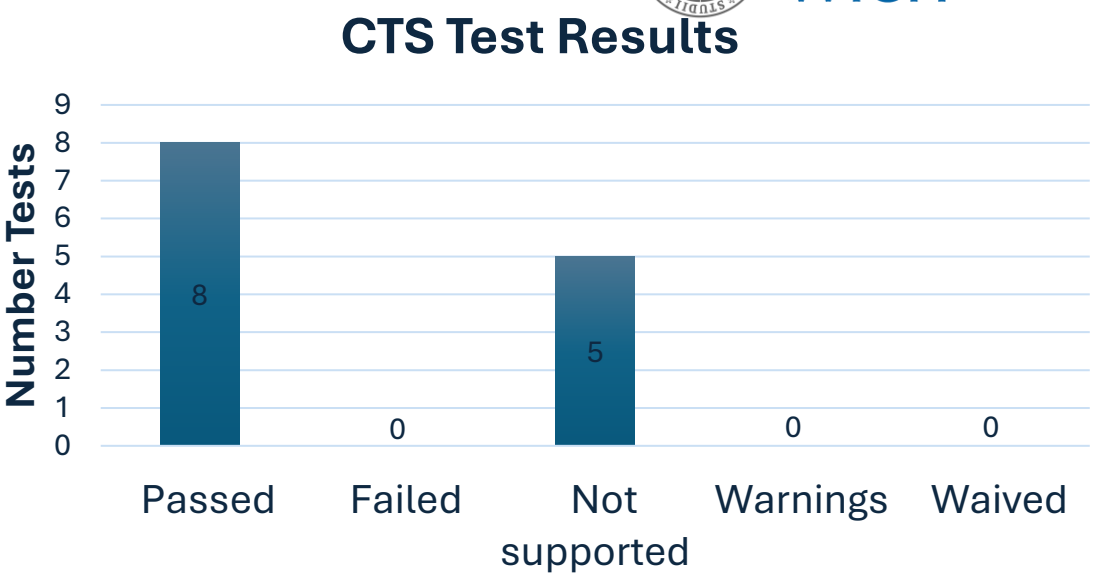


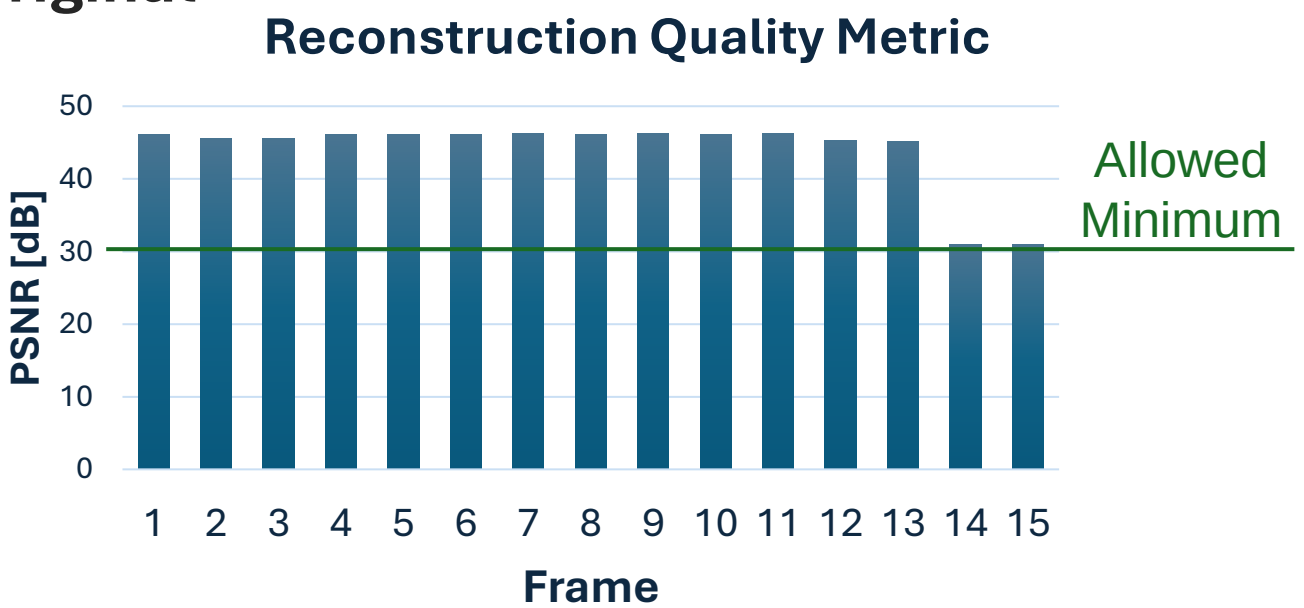
H.264 video file encoded on CPU by
Vienna Vulkan Engine
with Vulkan Video support
running with Mesa3D Lavapipe driver

Results

Conformance Tests:

- Vulkan Conformance Test Suite:
  Test Set:
  “dEQP-VK.video.encode.h264.*”
  100% of supported Tests passed
- Encoded Video is **equivalent to original** video
  - CTS criteria: PSNR > 30 dB (Peak Signal to Noise Ratio)
  - Frame 14+15: reduced resolution test





Outcome

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- CPU based **H.264 encoding** as **Vulkan Video Extension** in **Lavapipe**
- Can be used together with LLVMpipe rasterizer or with another video source
- Provides a **viable solution** for systems **without dedicated** video compression **hardware**
- Can be used as second Vulkan device to combine with GPUs not supporting Video Extensions

- What can come next**:**
  - Add **video decode** support
  - **Extend feature** support (higher profiles, B frames, …)
  - **Performance** (Speed) Evaluation & Optimizations
  - Integrate with **faster codecs** depending on licensing situation (x264 is under GPL)
  - Extend support to **additional coding standards** (AV1)
  - **Merge** support **upstream** into official Mesa drivers