Vulkanised 2024
The 6th Vulkan Developer Conference
Sunnyvale, California | February 5-7, 2024

6 Years of Teaching Vulkan with Example for Video Extensions

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Computer Science at University of Vienna, Austria

- Founded in 1365, 10600 staff, 84600 students, 15 Faculties, 5 centers

- Wintersemester: October – January
- Summersemester: March – June
- https://informatik.univie.ac.at/en/

- Bachelor 6 semesters / 180 ECTS credits → **Computer Science**
  Business Informatics

  German
  Students from Austria, Germany

- Master: 4 semesters / 120 ECTS credits → **Computer Science**
  Media Informatics
  Business Informatics
  Data Science
  Medical Informatics
  Business Analytics
  Digital Humanities

  English
  International Erasmus Exchange

- PhD: 6 semesters

Courses related to Vulkan API

Bachelor program:

- *Electives*
- Bachelor´s thesis

Master program:

- *Electives*
- Gaming Technologies (**VVE**)
- Lab 1
- Lab 2
- Master´s thesis

Cluster Computer Graphics

- Foundations of Computer Graphics (Gatekeeper)
- **Real-Time Computer Graphics (Vulkan API)**
- **Cloud Gaming (VVE)**
- Real-Time Ray Tracing (OpenGL)
- Image Synthesis

Cluster Algorithms
Cluster Data Analysis
….

History of Real-Time Computer Graphics: DirectX 9 – DirectX 10 – Direct X 11 – Vulkan

Real-Time Computer Graphics – Lecture

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~580 slides
All lectures are **recorded** and can be downloaded from the Moodle: **14x 90 min videos**

- Introduction to the Vulkan API and the **Vulkan Tutorial**
- C++ Primer
- Mathematics 1: LinAlg, Rotation, Affine Mappings, Reference Frames
- Mathematics 2: Model - View – Projection, NDC, Viewports
- Vulkan API - Introduction, Instance, Debug, Surface
- Vulkan API - Device + Queue, Swapchain, Command Pools/Buffers
- Vulkan API - Synchronization, Render Pass + Frame Buffer
- Vulkan API - Memory, VMA, Buffers, Images
- Vulkan API - Descriptor Sets and Layouts, Pipeline Objects / Blending
- Vulkan API - Pipeline Objects, GLSL
- Lighting and Shading - BRDF, Light types, Phong
- Lighting and Shading - PBR, Fresnel, Micro Facet, Geometry, Metal/Roughness
- Maps (Texture, Normal, Shadow)

A Sample Lecture

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Creating Surfaces

```
E.g., Win32:
VkResult vkCreateWin32SurfaceKHR(
        VkInstance instance,
        const VkWin32SurfaceCreateInfoKHR* pCreateInfo,
        const VkAllocationCallbacks* pAllocator,
        VkSurfaceKHR* pSurface);

typedef struct VkWin32SurfaceCreateInfoKHR {
        VkStructureType sType;
        const void* pNext;
        VkWin32SurfaceCreateFlagsKHR flags;
        HINSTANCE hinstance;        //Win32 HINSTANCE for Win32 window
        HWND hwnd;                  //Win32 HWND
} VkWin32SurfaceCreateInfoKHR;

E.g., GLFW:
GLFWwindow* window = glfwCreateWindow( 640, 480, "Window Title", NULL, NULL);
VkSurfaceKHR surface;
VkResult err = glfwCreateWindowSurface( instance, window, NULL, &surface);
```


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Querying Surfaces

```
VkResult vkGetPhysicalDeviceSurfaceSupportKHR(
        VkPhysicalDevice    physicalDevice,
        uint32_t            queueFamilyIndex,
        VkSurfaceKHR        surface,
        VkBool32*           pSupported);
```

*To determine whether a **queue family** of a physical device **supports presentation** to a given **surface***

Get supoprted byte formats and color spaces

- Implementation **must provide** format
  VK_FORMAT_B8G8R8A8_UNORM
  and color space
  VK_COLOR_SPACE_SRGB_NONLINEAR_KHR

```
VkResult vkGetPhysicalDeviceSurfaceFormatsKHR(
        VkPhysicalDevice        physicalDevice,
        VkSurfaceKHR            surface,
        uint32_t*               pSurfaceFormatCount,
        VkSurfaceFormatKHR*     pSurfaceFormats);
```

```
typedef struct VkSurfaceFormatKHR {
    VkFormat format;
    VkColorSpaceKHR colorSpace;
} VkSurfaceFormatKHR;
```

*To query the basic capabilities of a surface, needed in order to **create** a **swapchain***

```
VkResult vkGetPhysicalDeviceSurfaceCapabilitiesKHR(
        VkPhysicalDevice            physicalDevice,
        VkSurfaceKHR                surface,
        VkSurfaceCapabilitiesKHR* pSurfaceCapabilities
```

```
typedef struct VkSurfaceCapabilitiesKHR {
  uint32_t minImageCount;
  uint32_t maxImageCount;
  VkExtent2D currmaxImageCountentExtent;
  VkExtent2D minImageExtent;
  VkExtent2D maxImageExtent;
  uint32_t maxImageArrayLayers;
  VkSurfaceTransformFlagsKHR supportedTransforms;
  VkSurfaceTransformFlagBitsKHR currentTransform;
  VkCompositeAlphaFlagsKHR supportedCompositeAlpha;
  VkImageUsageFlags supportedUsageFlags;
} VkSurfaceCapabilitiesKHR;
```


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Surface Present Modes

```
VkResult vkGetPhysicalDeviceSurfacePresentModesKHR(
    VkPhysicalDevice                    physicalDevice,
    VkSurfaceKHR                        surface,
    uint32_t*                           pPresentModeCount,
    VkPresentModeKHR*                   pPresentModes);

typedef enum VkPresentModeKHR {
    VK_PRESENT_MODE_IMMEDIATE_KHR = 0,
    VK_PRESENT_MODE_MAILBOX_KHR = 1, //1 element in queue, replace previous
    VK_PRESENT_MODE_FIFO_KHR = 2,    //N elements, wait if full (must support)
    VK_PRESENT_MODE_FIFO_RELAXED_KHR = 3,
    VK_PRESENT_MODE_SHARED_DEMAND_REFRESH_KHR = 1000111000,
    VK_PRESENT_MODE_SHARED_CONTINUOUS_REFRESH_KHR = 1000111001,
    VK_PRESENT_MODE_MAX_ENUM_KHR = 0x7FFFFFFF
} VkPresentModeKHR;
```


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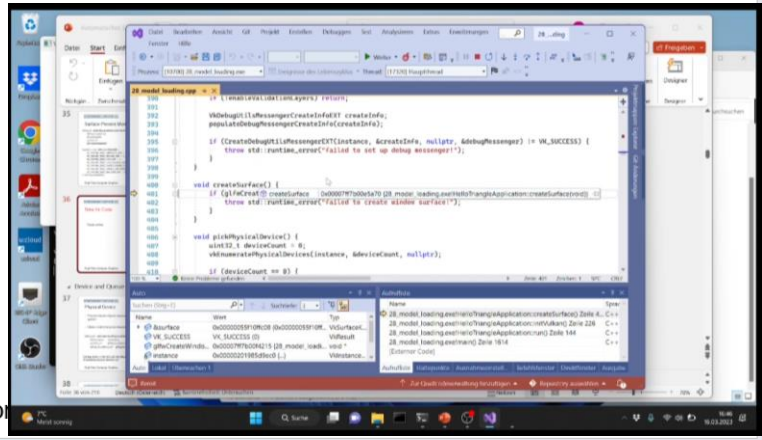
Time for Code

Create surface



Real-Time Computer Graphics – Lab Assignments

6-7 assignments + a personal game project

1. Install the Vulkan SDK, compile and run the Vulkan Tutorial
2. Scenegraph Worldmatrix and Vulkan Basics
3. Physical Device, Swap Chain, Command Pools and Buffers, Synchronization
4. **Memory, Buffers and Images** + Game Topic
5. Descriptor Sets, Pipeline, View port and GLSL Programming + Game Design Document
6. Blinn-Phong BRDF and more objects (and textures)
7. **Your Game**

A Sample Assignment – Task 04 – Memory, Buffers and Images

1) …

2) …

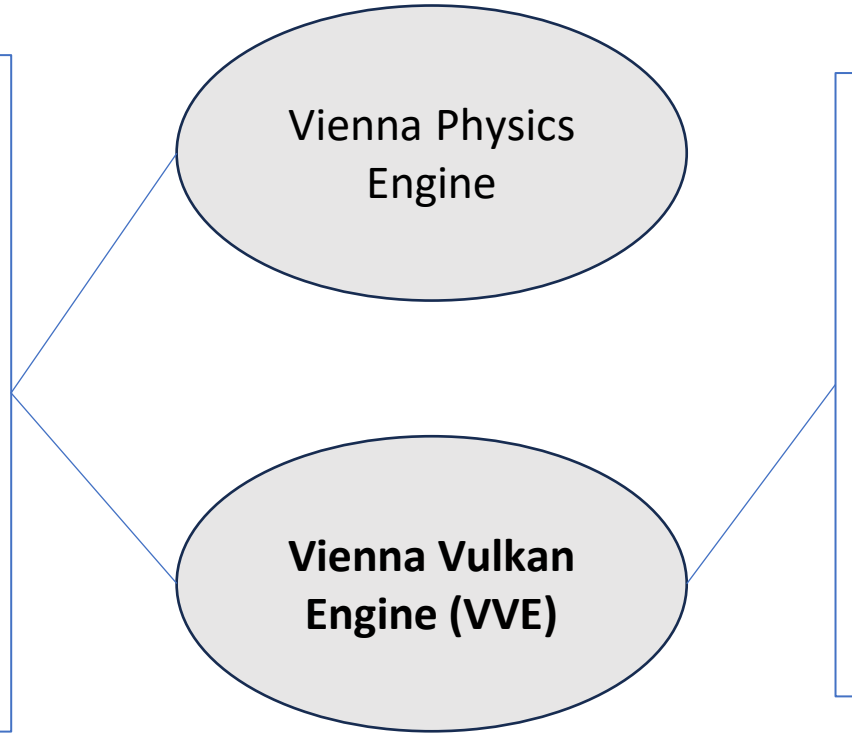
3) …

4) Change the tutorial code, so that it no longer uses vkCmdDrawIndexed(), but so that it uses vkCmdDraw(). This means you no longer use an index buffer for drawing! Now triangles are defined only by three successive vertices in the vertex buffer!
   So after having loaded vertex and index information from disk, create another vertex buffer that holds exactly 3 vertices for each triangle (and therefore many redundant copies of vertices.). Then use this vertex buffer for drawing.
   …

Other Vulkan Related Courses and the VVE

Gaming Technologies

- **Physics** simulation: Time stepping, rigid body kinematics, collision detection/resolution, …
- **AI** for Games (NPCs): Movement, Path finding, FSM, Decision/Behavior Trees, MCTS, GOAP, …
- Your Game (using AI and physics)



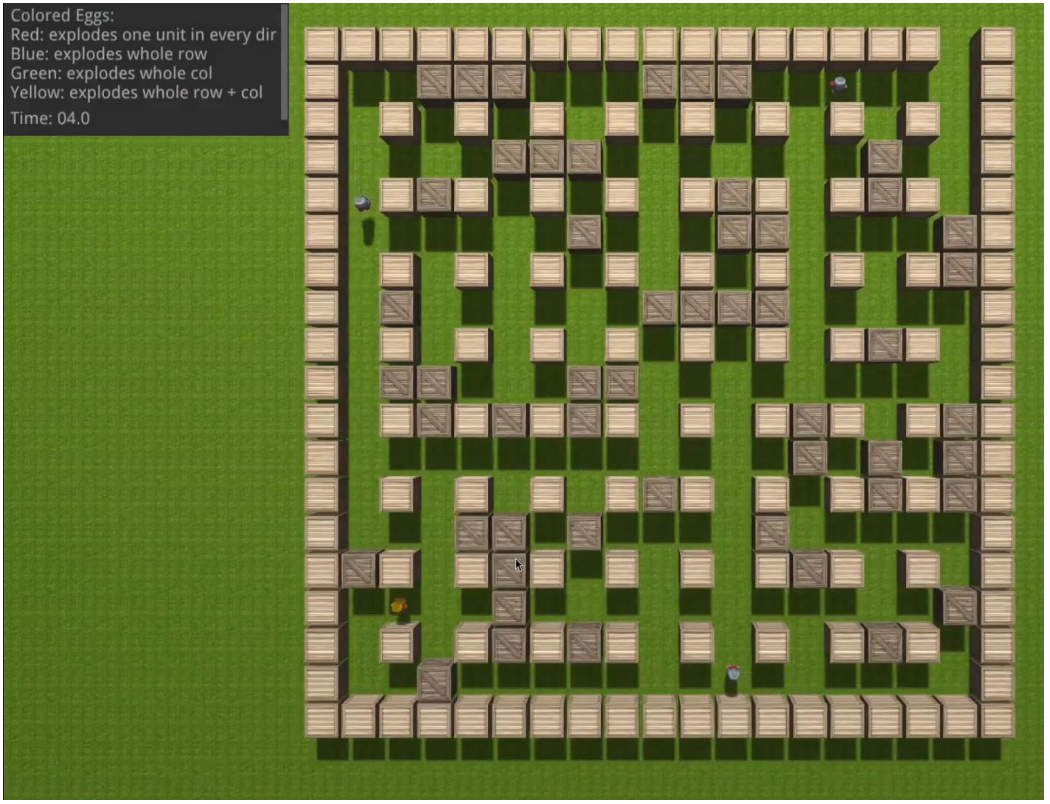
Cloud Gaming

- Video encoding (FFMPEG) and streaming
- Multimedia Networking: IP 4/6, UDP/TCP, STUN/TURN, RTP, SIP, buffer dynamics, …
- GUI frameworks
- Audio
- Your Cloud Game (Server, Client)

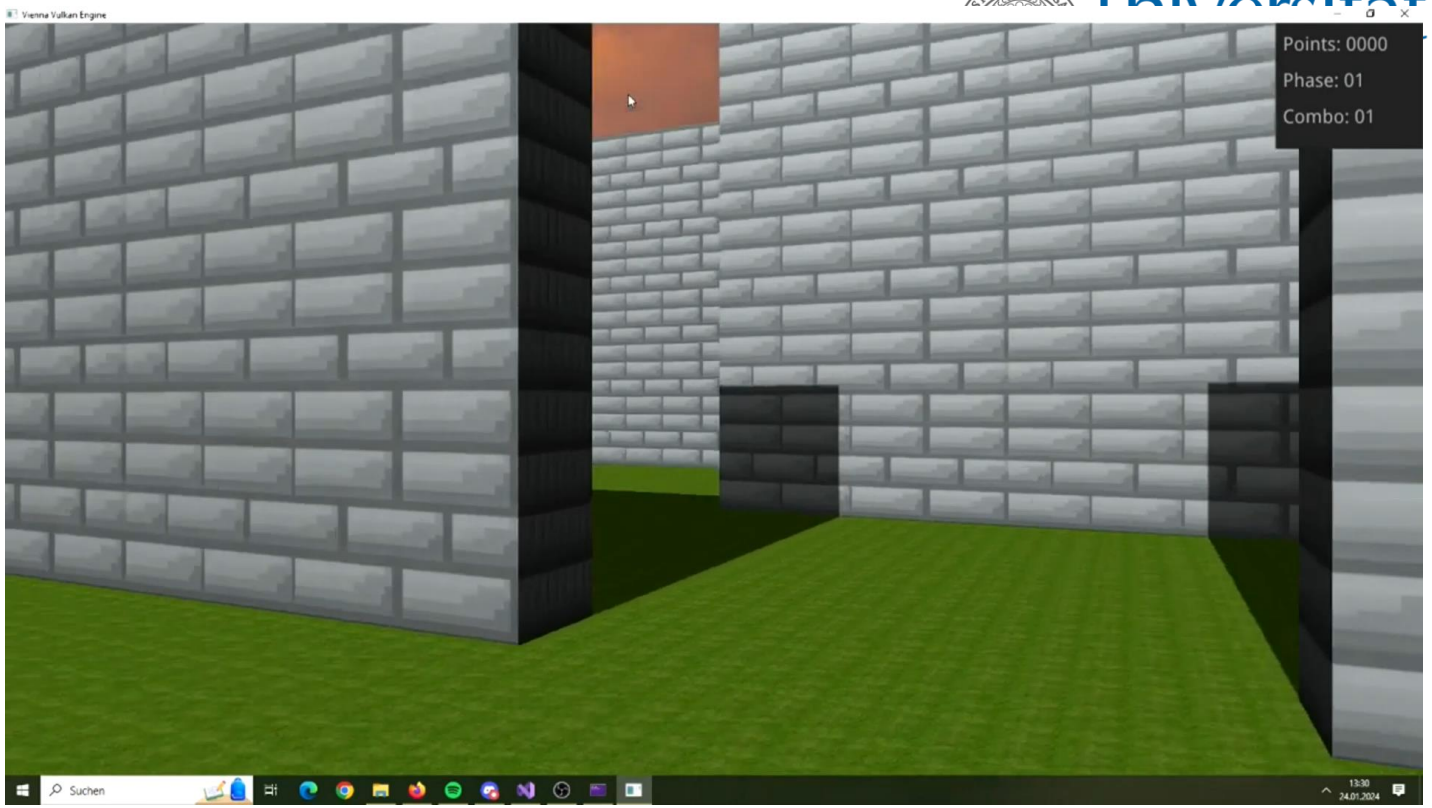
The Vienna Vulkan Engine (VVE)

- C++ rendering framework
- Windows / Linux / ~MacOS
- Vulkan API / GLSL
- GLM / GLFW / Assimp / Nuklear
- Shadow maps
- Threadpool, Screenshots
- **Eventlisteners**
- Rendering, learning Vulkan, basis for implementing new stuff
- https://github.com/hlavacs

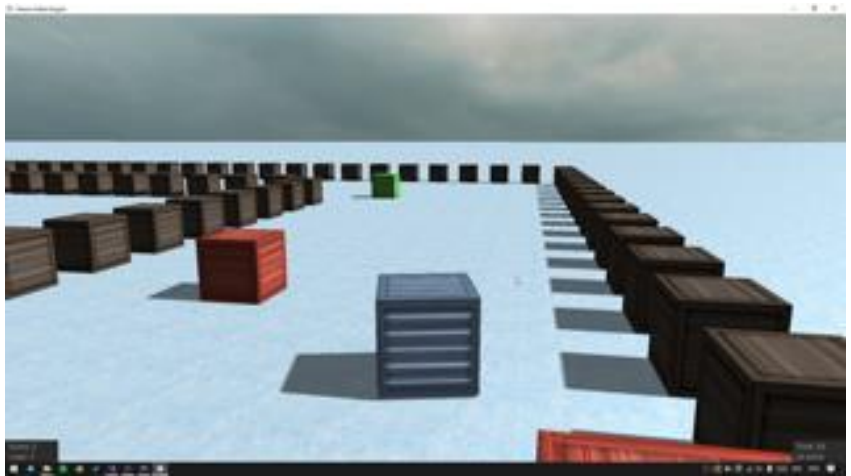
Quackblast (Lamies Abbas)



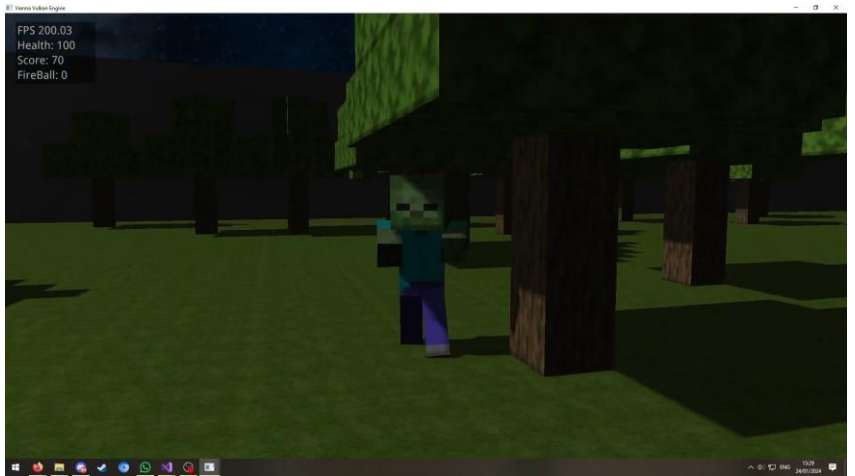
Sphere Fighter (Paul Friedrich Pesak)



Cubemania (Orcun Ilker Döger)



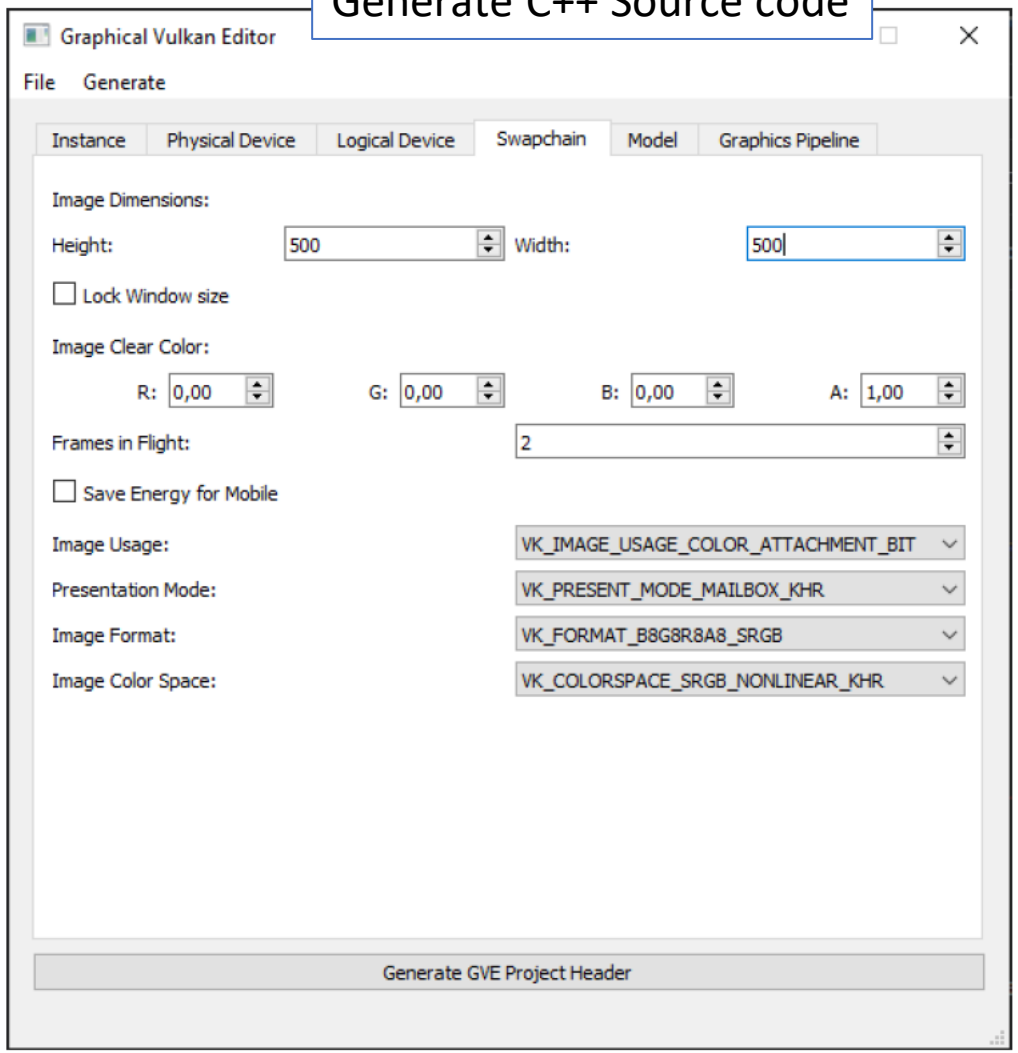
Zombie Fighter (Jan Mesner)



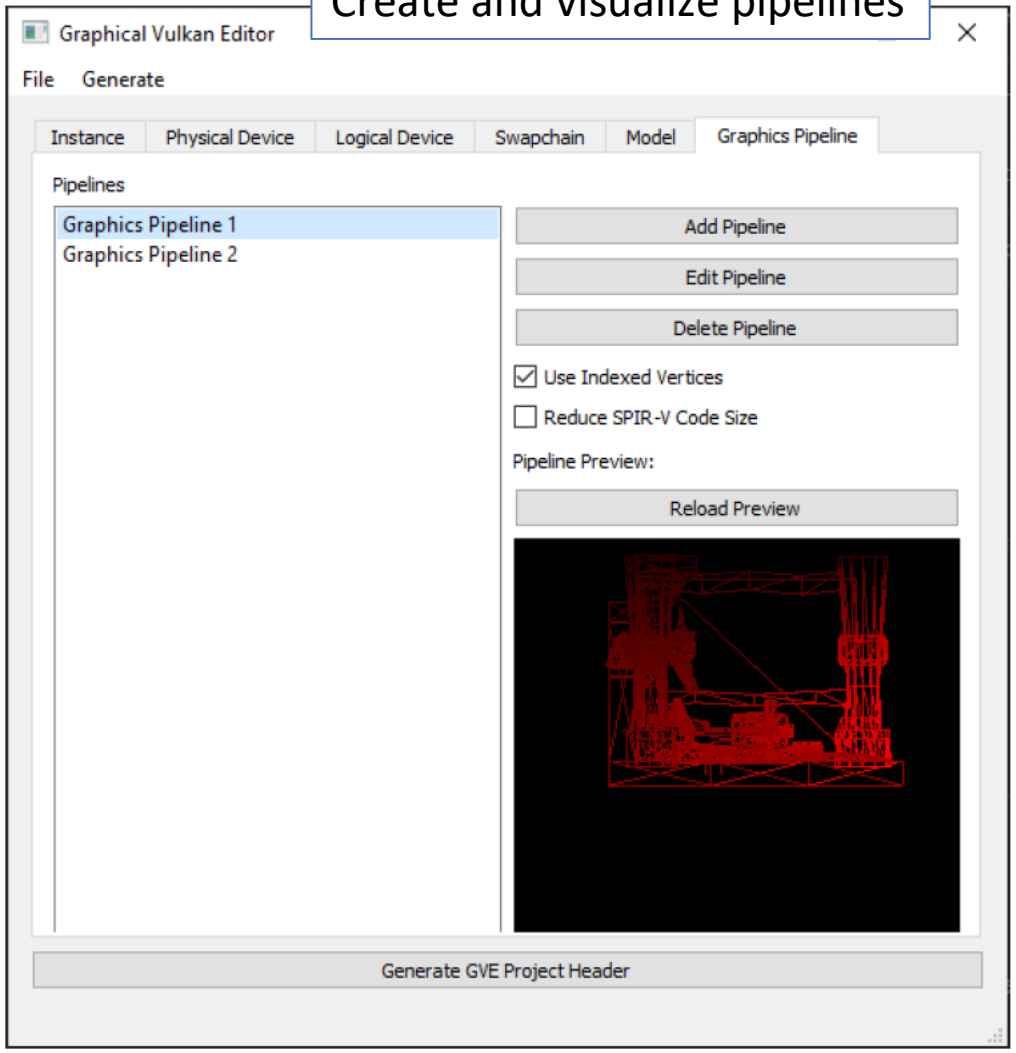
Example Bachelor´s Thesis: Graphical Vulkan Editor

Riccardo Pfeiler, *Graphical Vulkan Editor*, Bachelor´s Thesis, University of Vienna, 2023.
https://github.com/Schokolado/GraphicalVulkanEditor

Generate C++ Source code

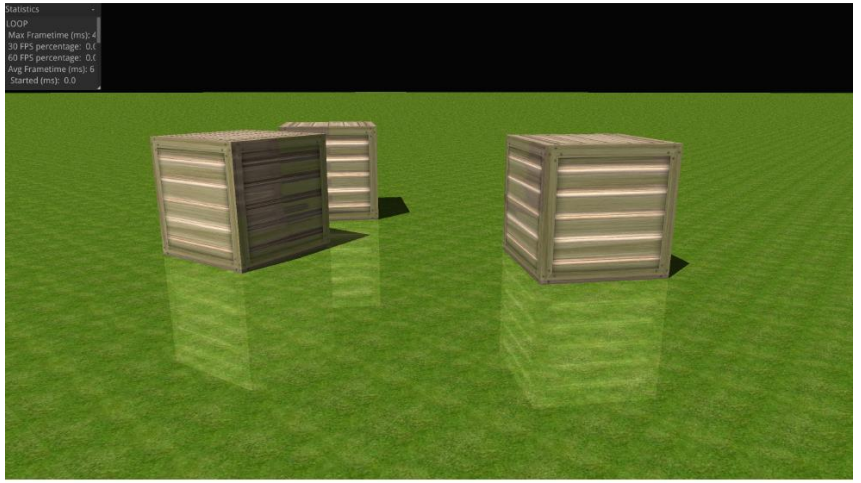


Create and visualize pipelines



Example Master´s Thesis: 3 Vulkan Renderers

Alexander Fomin, *Computer graphics based on Vulkan API. Comparation studies of rendering algorithms performance.* Master's Thesis, University of Vienna, 2022.



Implementation for the Vienna Vulkan Engine

- Deferred renderer
- Ray Tracing renderer (NVIDIA extension)
- Ray Tracing renderer (Khronos extension)

Research questions

- Which rendering algorithm performs better on specific hardware?
- Performance Ray Tracing vs rasterization?
- Performance Nvidia extension vs Khronos extension?

Lessons Learned in 6 Years Wrestling the API

It's a gundam!

Teacher Instrospection

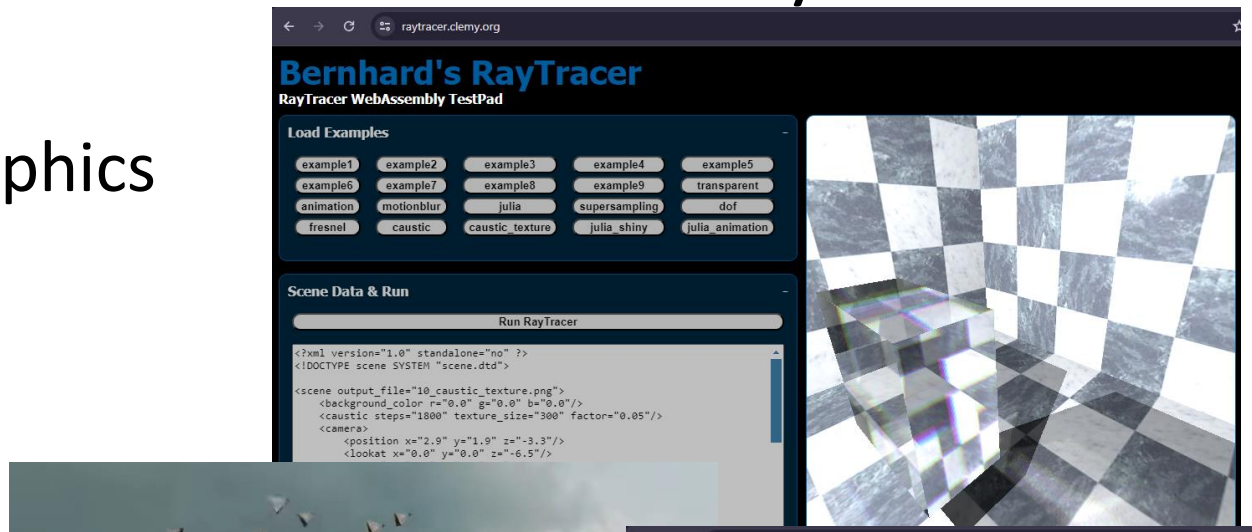
- Massive work learning the API
- Making the engine is a challenge but good investment
- Recording pays in the long run but lecture rooms get quite lonely
- Bring all to the same level at the start
- Huge amount of content – all or nothing
- Balance with other content? Lighting, shading, mapping, shadows, AO, …
- C or C++ interface?
- Include Queries? Render Pass?

Extraspection – Students

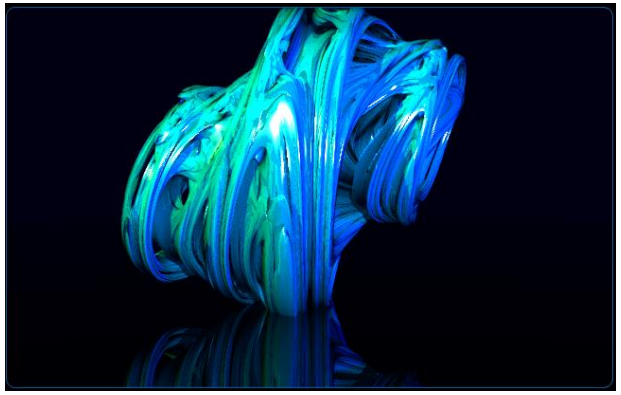
- Great interest in games related courses
- International students inhomogeneous
- Differences in Mathematics / C++
- Make good use of the Moodle forum
- In summer 2023 20% failed RTCG
- Afterwards students do know the API
- Very creative wrt game ideas
- High motivation, like heavy implementation
- Some wait until the last day – and then some
- Presentations are big fun and surprising

My Computer Graphics Course Journey

1. Foundations of Computer Graphics
2. Real-Time Ray Tracing
3. Gaming Technologies
4. Cloud Gaming
5. Lab 1: Vulkan Video Encoding
6. Lab 2: Vulkan Video Decoding
7. Upcoming: Master Thesis



My experience during the courses



- First: Learning a good mathematical base
- Followed by: State of the art technology and APIs
- Perfectly guided through every topic by small tasks
- Much fun with own projects
- Finding: I am not a designer, but
- I love writing code &
- working on game engines

- Finally: Inspiration where I can continue
  - master thesis

Cloud Gaming / Video Encoding

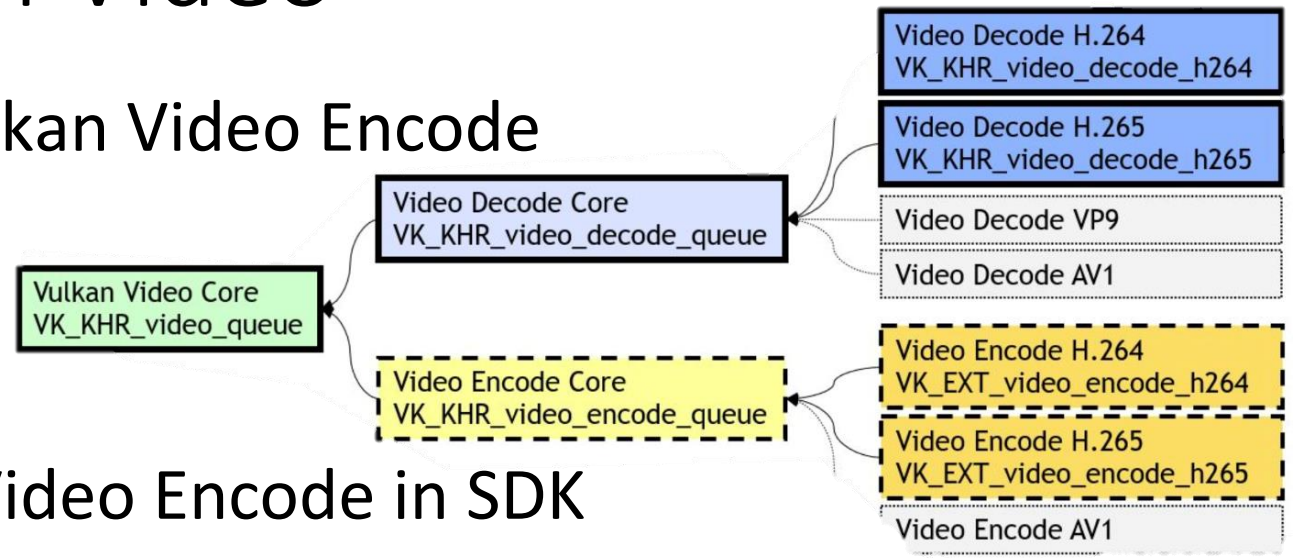
- Why this topic for my lab courses & master thesis?
- Course Cloud Gaming – easy approach:
  - Grab pictures to host memory
  - Encode with FFMPEG
  - Send to client

Source: Stable Diffusion

- I wanted to improve that -> do it on the GPU
- Game Engine: Vulkan based
- Vulkan Video Extensions just on their way to get released (1 year ago)

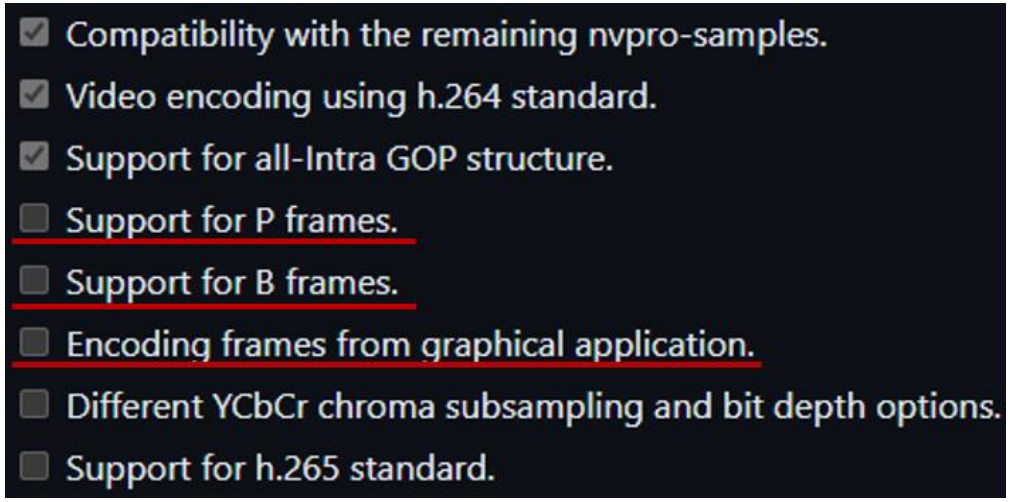
Starting Point – Vulkan Video

- Provisional Specifications for Vulkan Video Encode
- NVIDIA Vulkan Beta Driver



Source: https://www.khronos.org/blog/khronos-finalizes-vulkan-video-extensions-for-accelerated-h.264-and-h.265-decode

- No validation layer support for Video Encode in SDK
- One sample: nvpro-samples/vk_video_samples
  - Encoding from YCbCr raw data file
  - Producing Intra frames only
  - Working with one specific revision



Source: https://github.com/nvpro-samples/vk_video_samples

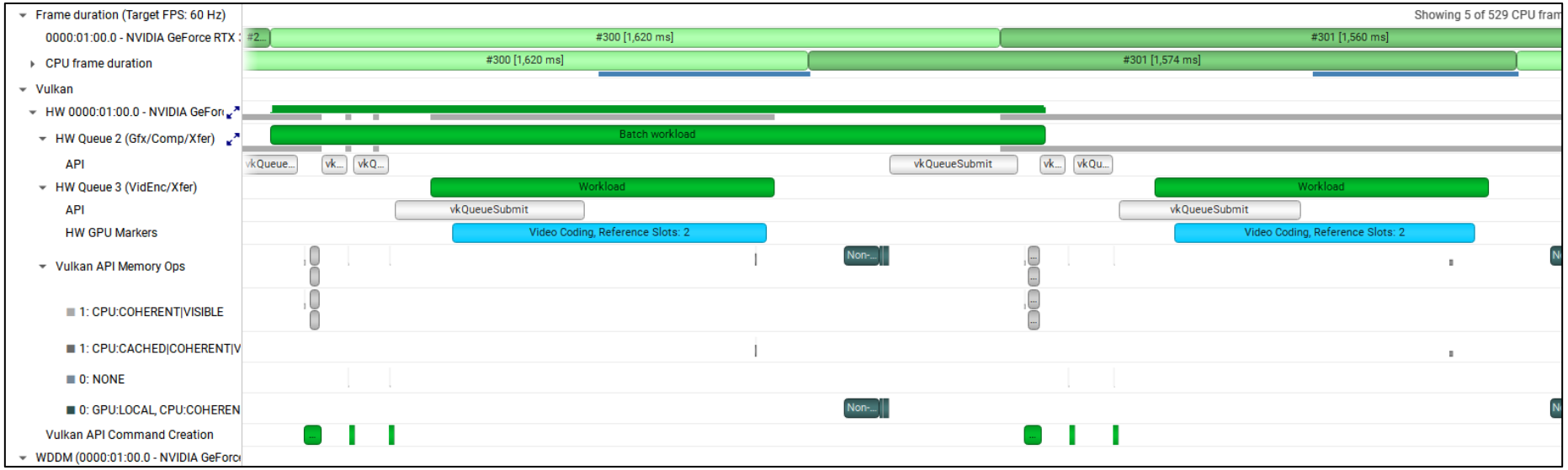
The progress / What to do differently

- Many Ups and Downs
- Extracting the relevant code from the example
- First working own code, took some time
- Even longer way until first P frame (reference picture list)
- Stopped working after every specification revision update
- Many bugs found after final SDK release (with validation layer)

- Next time: Get more in contact with the involved people
- Tip: Read the proposal document containing example snippets

What I learned technically

- Better understanding of Synchronization in Vulkan
- Working with multiple queues
- Working with different image layouts
- Working with provisional Vulkan APIs
- Too much details about H.264



- All this based on a solid base learned during the lectures before

Outcome & Deliverables

- Vulkan Video integrated in Vienna Vulkan Engine
  - Video Textures from H.264 files
  - Get rendered content as H.264 stream
    - GOP structure with I and P frames
- Simple example code for
  - Vulkan Video Encode Extension (updated for the finally released revision)
  - Vulkan Video Decode Extension
  - One CPP file each
- Not a complete H.264 implementation, but trimmed for education
  - As base for other implementations and future experiments
  - github.com/hlavacs/ViennaVulkanEngine/tree/vulkanvideo_encode
  - github.com/clemy/ViennaVulkanEngine/tree/videodecode

Summary as Student

- Vulkan as base for all courses
  - Gaining knowledge in modern computer graphics APIs
  - HW & OS independent: Students can use any platform
  - Immediately use the knowledge for visualization in related courses:
    - AI for NPCs
    - Game Physics
  - Reuse own code and ideas and improve it in every course
- Perfectly supported my interests in
  - Coding
  - Math
  - New Technologies
- Outlook: A solid base for multiple possibilities
  - An academic career
  - A job in the (game) industry