THE MOST COMMON VULKAN MISTAKES

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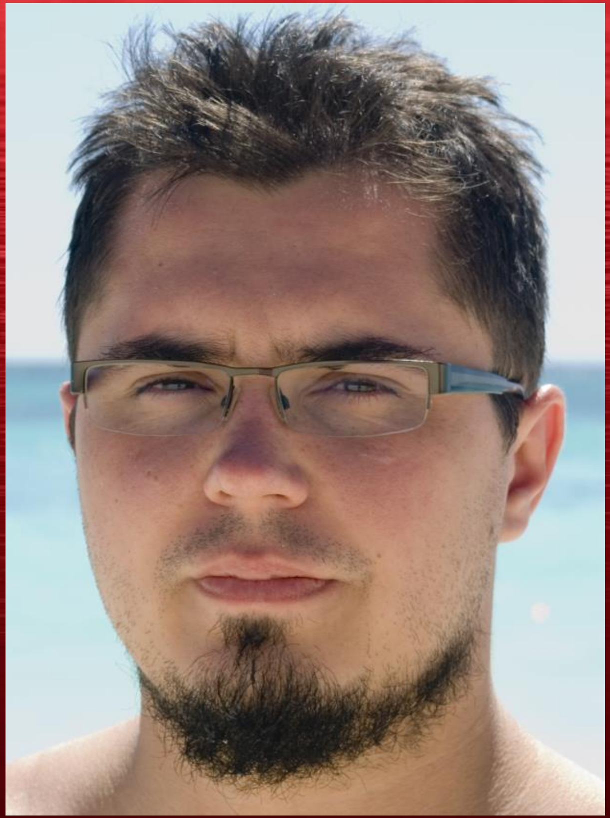
WHO?

- **Dominik Witczak**
- **MTS Software Development Engineer** at **AMD**

- **Regular contributor** to the following **standards**:
  - OpenGL (4.x)
  - OpenGL ES (3.0 and beyond)
  - **Vulkan**

- After-hours **demoscene activist**:
  - Event organizer
  - Programmer

- Trivia:
  - Graduated from WMiI department back in 2010

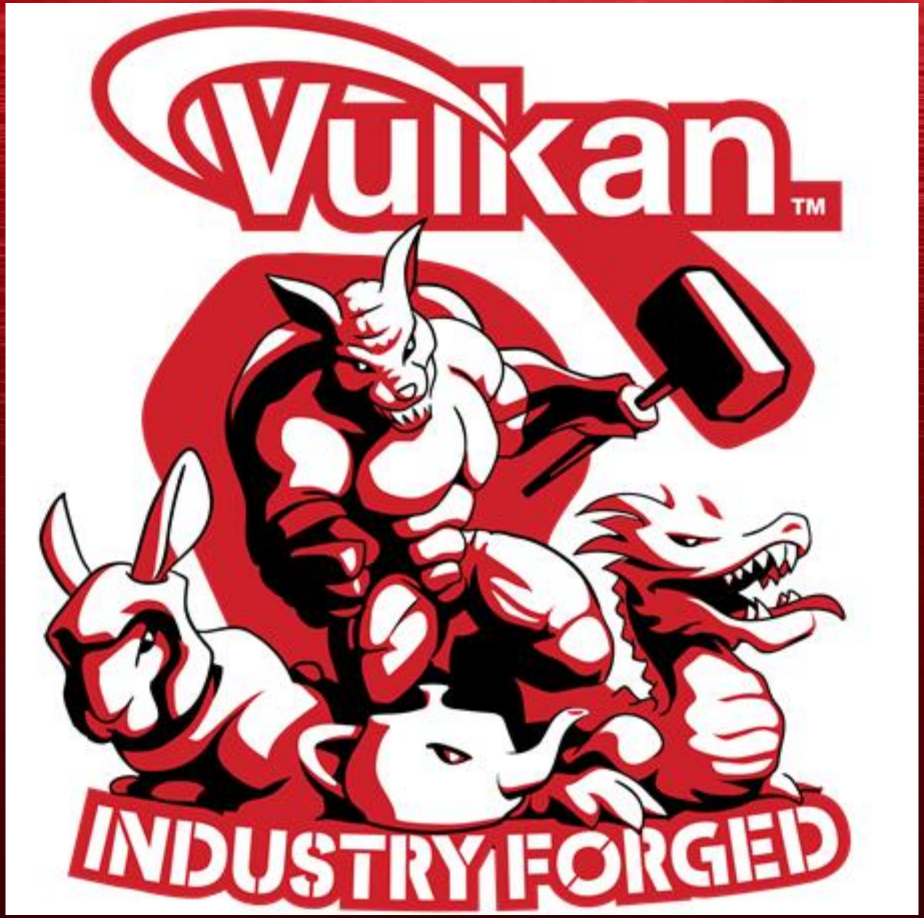


WHAT?

Agenda for today:

- **What** is **Vulkan**?
- What **is it** and **is it not** about?
- **Who** is it **for**?

- **Problematic areas:**
  - Command queues
  - Descriptor sets
  - Images
  - Memory barriers
  - Memory management
  - Renderpasses
  - Synchronization



VULKAN

THE BEGINNINGS

A **simplified view** of a typical **OpenGL** or **<DX 10** app rendering pipeline:

- **CPU thread:**
- **GPU usage:**

Why?

VULKAN
THE BEGINNINGS

A **simplified view** of a typical OpenGL or <DX 10 app rendering pipeline:

- **CPU thread:**
- **GPU usage:**

Why?

- CPU->GPU command submission is **time-consuming:**
  - Only **submit** and start executing GPU-side if:
    - **All commands** for a **frame** have been submitted..
    - Command buffer **fills up**
    - Upon app's **explicit request**.
- App can submit **different** commands **every frame**:
  - **Cannot** bake command buffers **in advance**!

Typical OpenGL or <DX 10 app rendering pipeline (more advanced apps):

- **CPU thread 1:** Generate data
- **CPU thread 2:** Generate data
- **CPU thread (N-1):** Generate data
- **CPU thread N:** Generate data
- **Rendering thread:** Wait → (upload data to GPU) → (change state) → Dispatch/draw! → Swap buffers
- **GPU usage:**

Can we do any better?

Typical OpenGL or <DX 10 app rendering pipeline (more advanced apps):

- CPU thread 1: Generate data
- CPU thread 2: Generate data
- CPU thread (N-1): Generate data
- CPU thread N: Generate data
- Rendering thread: Wait → (upload data to GPU) → (change state) → Dispatch/draw! → Swap buffers
- GPU usage:

Use multiple rendering threads to streamline data uploads

Generate as much data on GPU as possible

Batch draw calls by state configuration

Use compute shaders to calculate data in parallel on some HW

Render as many frames in advance as possible to reduce GPU bubbles

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THE BEGINNINGS

- These workarounds **do not** solve **the biggest problem**:
  - GPUs are **highly asynchronous** constructs:
  - Designed to perform many kinds of tasks **in parallel**:
    - **Computations**
    - **DMA transfers**
    - **Rasterization**
    - **Other** (eg. accelerated image data conversion)
- But from API standpoint:
  - GPU can only be requested to execute **work chunks** from **one** rendering thread!
  - Apps **cannot be trusted** – **CPU time** spent on **API call validation**..

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THE BEGINNINGS

- <u>Do we really care?</u>
  - More and more CPU-**bound apps** are showing up on the market.
    - Driver thread(s) consuming CPU time
    - Increasing app complexity
  - No **easy way** to address these in a **cross-platform way**.
  - **Tilers** cannot leverage their full power on **OpenGL ES**.
  - Only **vendor-specific** solutions exist (eg. Pixel Local Storage)
- <u>Not to mention use cases like:</u>
  - Multiple GPU support
  - VR

VULKAN

DO I NEED IT?

- **Vulkan** addresses all of the discussed issues:
  - Exposes **GPU** as a set of **command queue families**.
  - **Command buffers** can be **submitted to queues** from **multiple threads**.
  - **Application** is **responsible for**:
    - submitting **work chunks** to the right **command queues**.
    - **synchronization** of **GPU jobs' execution**.
  - Exposes available **GPU memory** as a set of **memory heaps**.
  - Application is responsible for **flushes** / **invalidation** / **management**.
- **Applications** are **required** to adapt to the **running** GPU's capabilities.
- Misbehave and **hang the GPU**.

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DO I NEED IT?

- Who **NEEDS** Vulkan?
  - CPU**-bound applications**:
    - Vast majority of information required to compute / render – **prebaked at loading time**.
    - A frame can be rendered with just **two commands**!
    - **No driver-side validation** = more **CPU time** for stuff that really matters.
  - GPU**-bound applications**:
    - Improve **GPU utilization** by:
      - **Submitting** compute / graphics jobs to relevant **queue families**.
      - Performing **VRAM -> VRAM** & **RAM <-> VRAM** copy ops with **transfer queues**.
    - No **sudden performance drops** or **spikes**:
      - All **GPU-side caches** are **flushed**, according to app-specified information, at predictable times.
      - Driver **no longer** needs to do any **guess-work**.

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DO I NEED IT?

- Who **MAY** need Vulkan?
  - Existing **GL 4.x** / <= **DX 11** applications:
    - Moving to Vulkan **may** or **may not** bring performance benefits.
    - Likely to spend less CPU power.
- Who does **NOT** need Vulkan?
  - Prototype applications requiring **rapid development time**:
    - Validation layers do **not** cover whole specification **yet**.
    - Many **incorrect use cases** are still **not** detected.
    - **Steep** learning curve.
  - **Simple applications** which are **not CPU- or GPU-bound**:
    - Unless for **learning purposes**, these are unlikely to benefit from Vulkan.

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PROBLEMATIC AREAS: INTRODUCTION

- **Our driver** has been out for **a few months** now.

- **Top-level observations:**
  - Vulkan is **demanding** to use, both **app-side** and **time-wise**.
  - If an app works with GPU A, it **doesn't have** to hold for GPU B.
  - **Common pit-falls**:
    - Barriers
    - Correct data uploads
    - Image transitions
    - Renderpasses
  - ISVs: generally **reluctant** to use **validation layers**.
    - **Please do**. This saves both you and us **a lot** of time

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PROBLEMATIC AREAS: COMMAND QUEUES

- **CPU-side:**
  - **No rendering threads** in Vulkan
  - **Work chunks** submittable from multiple threads to GPU-side **command queue**.
- **GPU-side:**
  - **Command queues** are grouped by type(s) of **commands** they can execute.
- **Problem**:
  - Number of **command queues** – **hardware-dependent!**
  - Number of **queue families** – **hardware-dependent!**

VULKAN

PROBLEMATIC AREAS: COMMAND QUEUES

- **Why is this a problem?**
  - Efficient **GPU task distribution** is now **Vulkan app's responsibility**.
  - The solution must be able to **up-** and **down-scale**, depending on device caps.
  - No **open-source solutions** available yet
  - Only a single **compute+gfx queue family** guaranteed in **Vulkan 1.0**.
  - Simple apps will likely rely **solely** on the presence of the **universal queue**..
  - ..but wasn't Vulkan written with **performance** in the 1st place?!
- **Solution:**
  - Test your rendering engine on various Vulkan implementations.

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PROBLEMATIC AREAS: COMMAND BUFFERS

- In Vulkan, **command buffers**:
  - ..hold **commands** to be executed **GPU-side**
  - ..are **reusable**, unless explicitly stated **otherwise** by the app.

- **Problem:**
  - Apps often **re-record** **command buffers** every frame.

- **Why is this a problem?**
  - Wastes a lot of **CPU** **time**.
  - **Not required** in many cases.

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PROBLEMATIC AREAS: COMMAND BUFFERS

- **Problem:**
  - Apps **re-record** **command buffers** every frame.

- **Solution:**
  - Move **all parameters** that affect the **rendering logic** to **images** / **SBs** / **UBs**.
  - **Pre-bake** all **command buffers** once per each **swapchain image**, if necessary.
  - Use **indirect dispatch/draw** **commands** if they improve command buffer reusability

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PROBLEMATIC AREAS: MEMORY MANAGEMENT

- **Memory management** is also Vulkan app's responsibility:
  - **Physical device** reports **>= 1 memory heaps**
  - Each **memory heap**:
    - has **platform-specific size**.
    - **may**, but **needs not** be **device-local**.
  - Memory heaps – **not directly** accessible to apps.
  - Instead, the driver exposes **an array** of HW-specific „**memory types**":

```
typedef struct VkMemoryType {
    VkMemoryPropertyFlags    propertyFlags;
    uint32_t                 heapIndex;
} VkMemoryType;
```

```
typedef enum VkMemoryPropertyFlagBits {
    VK_MEMORY_PROPERTY_DEVICE_LOCAL_BIT = 0x00000001,
    VK_MEMORY_PROPERTY_HOST_VISIBLE_BIT = 0x00000002,
    VK_MEMORY_PROPERTY_HOST_COHERENT_BIT = 0x00000004,
    VK_MEMORY_PROPERTY_HOST_CACHED_BIT = 0x00000008,
    VK_MEMORY_PROPERTY_LAZILY_ALLOCATED_BIT = 0x00000010,
} VkMemoryPropertyFlagBits;
```

  - When alloc'ing **GPU memory**, Vulkan app specifies **memory type index**.

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PROBLEMATIC AREAS: MEMORY MANAGEMENT

- **What’s the hard part?**
  - Vulkan<->app contract is **very thin.**
  - The following is **guaranteed**:
    - At least **one memory type** is **host-visible** & **host-coherent**.
    - At least **one memory type** is **device-local**.
  - **Buffer** & **image memory** alloc’s must come from driver-specific **memory types**
  - The types **MAY** vary, depending on:
    - Object properties
    - Object type
  - But the best is yet to come..

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PROBLEMATIC AREAS: MEMORY MANAGEMENT

- **What's the hardest part?**
  - ISVs tend to **ignore** the ***maxMemoryAllocationCount*** limit:

- `maxMemoryAllocationCount` is the maximum number of device memory allocations, as created by `vkAllocateMemory`, which can simultaneously exist.

  - The **min max** for the **simultaneous live allocations limit** is **4096**.
    - **Very easy** to reach in **complex applications**.
    - The **usual** value reported by **desktop Vulkan implementations**.

- **Solution:**
  - **Pre-allocate** & **manage** available GPU memory **app-side**.
  - **Avoid** small memory allocations, **sub-allocate them** from **larger ones**.

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PROBLEMATIC AREAS: DESCRIPTOR POOLS

- Majority of **shaders** access **external data**.
- In **Vulkan**:
  - These are exposed via **descriptors**.
  - **Descriptors** cannot be created **directly**.
  - Instead, they are retrieved from a **descriptor pool** instantiated by the **app**:

```
VkResult vkCreateDescriptorPool(
    VkDevice                                    device,
    const VkDescriptorPoolCreateInfo*           pCreateInfo,
    const VkAllocationCallbacks*                pAllocator,
    VkDescriptorPool*                           pDescriptorPool);
```

```
typedef struct VkDescriptorPoolCreateInfo {
    VkStructureType                sType;
    const void*                    pNext;
    VkDescriptorPoolCreateFlags    flags;
    uint32_t                       maxSets;
    uint32_t                       poolSizeCount;
    const VkDescriptorPoolSize*    pPoolSizes;
} VkDescriptorPoolCreateInfo;
```

```
typedef struct VkDescriptorPoolSize {
    VkDescriptorType    type;
    uint32_t            descriptorCount;
} VkDescriptorPoolSize;
```

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PROBLEMATIC AREAS: DESCRIPTOR POOLS

- **Problem:**
  - <maxSets> does **not** work as ISVs seem to expect.

- **Frequently seen misunderstanding:**
  - *„I can allocate <maxSets> * {poolSizeCount * pPoolSizes} descriptors"*
  - *„No? Your driver sucks, that's what I can do with vendor X's driver!"*

- **Correct understanding:**
  - Up to **N** of **prealloc'ed descriptors** can be distributed to up to <maxSets> DSes.

```
typedef struct VkDescriptorPoolCreateInfo {
    VkStructureType                 sType;
    const void*                     pNext;
    VkDescriptorPoolCreateFlags     flags;
    uint32_t                        maxSets;
    uint32_t                        poolSizeCount;
    const VkDescriptorPoolSize*     pPoolSizes;
} VkDescriptorPoolCreateInfo;
```

```
typedef struct VkDescriptorPoolSize {
    VkDescriptorType    type;
    uint32_t            descriptorCount;
} VkDescriptorPoolSize;
```

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PROBLEMATIC AREAS: SPARSE DESCRIPTOR BINDINGS

- **Descriptors** are then grouped into **Descriptor Sets** for later usage.
  - Descriptor type <-> binding relations is defined by a **DS layout**.
  - Actual **buffers** / **images** for **GPU consumption** are bound in **command buffers**.

- A **DS layout** is created with:

```
typedef struct VkDescriptorSetLayoutCreateInfo {
    VkStructureType                        sType;
    const void*                            pNext;
    VkDescriptorSetLayoutCreateFlags       flags;
    uint32_t                               bindingCount;
    const VkDescriptorSetLayoutBinding*    pBindings;
} VkDescriptorSetLayoutCreateInfo;
```

```
VkResult vkCreateDescriptorSetLayout(
    VkDevice                                 device,
    const VkDescriptorSetLayoutCreateInfo*   pCreateInfo,
    const VkAllocationCallbacks*             pAllocator,
    VkDescriptorSetLayout*                   pSetLayout);
```

```
typedef struct VkDescriptorSetLayoutBinding {
    uint32_t              binding;
    VkDescriptorType      descriptorType;
    uint32_t              descriptorCount;
    VkShaderStageFlags    stageFlags;
    const VkSampler*      pImmutableSamplers;
} VkDescriptorSetLayoutBinding;
```

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PROBLEMATIC AREAS: SPARSE DESCRIPTOR BINDINGS

- **Problem:**
  - How should a **DS layout** look for the following **descriptor set**:
    - Binding **0**: Storage buffer
    - Binding **2**: Storage image
  - Do I need to include a `VkDescriptorSetLayoutBinding` item for **binding 1** or **not**?

```
typedef struct VkDescriptorSetLayoutCreateInfo {
    VkStructureType                        sType;
    const void*                            pNext;
    VkDescriptorSetLayoutCreateFlags       flags;
    uint32_t                               bindingCount;
    const VkDescriptorSetLayoutBinding*    pBindings;
} VkDescriptorSetLayoutCreateInfo;
```

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typedef struct VkDescriptorSetLayoutBinding {
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    uint32_t              descriptorCount;
    VkShaderStageFlags    stageFlags;
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PROBLEMATIC AREAS: SPARSE DESCRIPTOR BINDINGS

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  - Do I need to include a `VkDescriptorSetLayoutBinding` item for **binding 1** or **not**?
- **Solution:**
  - The app is **inefficient**, dummy bindings **negatively** affect **performance**.
  - But if you really need them: **yes**, the binding is **needed**.
  - Make sure to set `::descriptorCount` to **0** for each unused binding.

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PROBLEMATIC AREAS: IMAGES

- In Vulkan, **texture**:
  - **state** is stored in **Image Objects**
  - **data** is stored in **Memory Objects**, bound to an **Image Object**

- **Image Objects** are created by specifying **properties** of the image data:
  - The usual bits and bobs such as:
    - **Type** (1D, 2D or 3D)
    - **Base mipmap size**
    - **Number of mipmaps**
  - **Tiling type**
  - **Usage flags**
  - Other miscellanea..

VULKAN

PROBLEMATIC AREAS: IMAGES

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  - **Usage flags**
  - Other miscellanea..

!

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PROBLEMATIC AREAS: IMAGE USAGE FLAGS

- Vulkan requires **up-front** image usage declaration at **creation time**.
  - Usage is a **bit combination** of one or more flags below:

```
typedef enum VkImageUsageFlagBits {
    VK_IMAGE_USAGE_TRANSFER_SRC_BIT = 0x00000001,
    VK_IMAGE_USAGE_TRANSFER_DST_BIT = 0x00000002,
    VK_IMAGE_USAGE_SAMPLED_BIT = 0x00000004,
    VK_IMAGE_USAGE_STORAGE_BIT = 0x00000008,
    VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT = 0x00000010,
    VK_IMAGE_USAGE_DEPTH_STENCIL_ATTACHMENT_BIT = 0x00000020,
    VK_IMAGE_USAGE_TRANSIENT_ATTACHMENT_BIT = 0x00000040,
    VK_IMAGE_USAGE_INPUT_ATTACHMENT_BIT = 0x00000080,
} VkImageUsageFlagBits;
```

- A driver **may not** provide format support for **certain** image usages
- When it does, usage setting **restricts**:
  - supported **memory types**
  - maximum **image resolution**, **number of samples**, etc.

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PROBLEMATIC AREAS: IMAGE USAGE FLAGS

- **Common problem**: App specifies incorrect **image usage**.
- **Example:**
  - Consider an image created with **VK_IMAGE_USAGE_TRANSFER_DST_BIT** usage.
  - The image **must not** be used as a **color attachment**.
  - App does not care.
- **Outcome:**
  - Undefined behavior
- Solution:
  - This class of problems can be easily detected when validation is enabled.

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PROBLEMATIC AREAS: IMAGE TILING

- **Tiling** setting determines **image** **data layout** used by the GPU:
  - Linear: **row-major** image row arrangement, each row **potentially padded**
  - Optimal: **platform-specific** data arrangement, optimized for **speed**.
- **Properties** of **linearly-tiled images**:
  - Support a **subset of functionality** provided for **optimally-tiled images**
  - **Less performant**
- Why bother wih **linear images** then?
  - Crucial if you need to **read back** image data **rendered by GPU**.

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PROBLEMATIC AREAS: IMAGE TILING

- **Common problem**: ISVs copy data **directly** to **optimally-tiled images**.
- **Typical scenario:**
  - Image **A** is created with `VK_IMAGE_TILING_OPTIMAL` tiling setting.
  - Application calls `vkGetImageSubresourceLayout()` for **image A**:

```
void vkGetImageSubresourceLayout(
    VkDevice                                device,
    VkImage                                 image,
    const VkImageSubresource*               pSubresource,
    VkSubresourceLayout*                    pLayout);
```

```
typedef struct VkImageSubresource {
    VkImageAspectFlags    aspectMask;
    uint32_t              mipLevel;
    uint32_t              arrayLayer;
} VkImageSubresource;
```

```
typedef struct VkSubresourceLayout {
    VkDeviceSize    offset;
    VkDeviceSize    size;
    VkDeviceSize    rowPitch;
    VkDeviceSize    arrayPitch;
    VkDeviceSize    depthPitch;
} VkSubresourceLayout;
```

  - Application tries to upload data using the „reported" characteristics.

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PROBLEMATIC AREAS: IMAGE TILING

- **Solution:**
  - Use a **staging buffer** to **copy** data to **optimally-tiled images**:
    1. **Create** a **buffer object** and **bind** a **memory region** to it.
    2. **Fill** it with data.
    3. **Transition** the image to **`GENERAL`** or **`TRANSFER_DST_OPTIMAL`** layout.
    4. Schedule a **copy op** by calling **`vkCmdCopyBufferToImage()`**.
    5. **Submit** the **command buffer**, wait till it finishes executing.
    6. **Release** the **temporary** **buffer object**.
  - Remember: **buffer** -> **image** **copy ops** will **not** work for **MS images**.
  - To upload data there, you'll need to use an actual **dispatch**/**draw** call.

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PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS

- GPUs **may (de-)compress** or **rearrange** data **on-the-fly**
  - Less **bandwidth pressure** => better **performance**
  - **DX <=11** and **OpenGL**: transparent, heuristics-driven process.
  - **Vulkan**: happens at **image layout transition** time.
  - **Example**: DCC (see http://gpuopen.com/dcc-overview/)
- **Hardware-level optimizations:**
  - **Differ** between **HW architectures** & **HW generations**.
  - Generally **vendor-specific**

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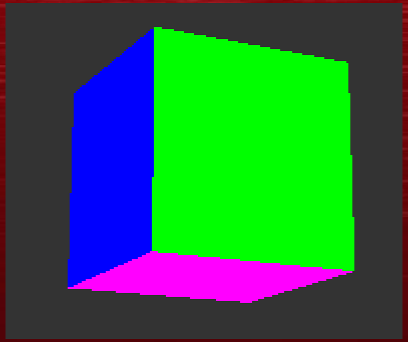
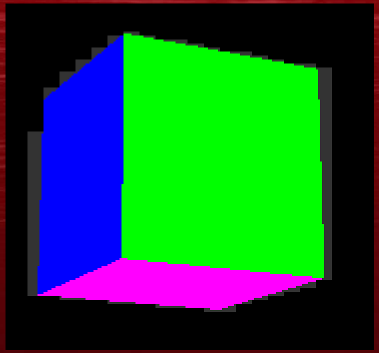
PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS

- In Vulkan:
  - Images **must** be **moved** to the **right layout** before **usage**.
  - This can be requested by:
    - injecting **image barriers** into **command buffers**
    - correct **renderpass** & **subpass** configuration
  - Get it wrong and visual corruption **may** occur:





```
typedef enum VkImageLayout {
    VK_IMAGE_LAYOUT_UNDEFINED = 0,
    VK_IMAGE_LAYOUT_GENERAL = 1,
    VK_IMAGE_LAYOUT_COLOR_ATTACHMENT_OPTIMAL = 2,
    VK_IMAGE_LAYOUT_DEPTH_STENCIL_ATTACHMENT_OPTIMAL = 3,
    VK_IMAGE_LAYOUT_DEPTH_STENCIL_READ_ONLY_OPTIMAL = 4,
    VK_IMAGE_LAYOUT_SHADER_READ_ONLY_OPTIMAL = 5,
    VK_IMAGE_LAYOUT_TRANSFER_SRC_OPTIMAL = 6,
    VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL = 7,
    VK_IMAGE_LAYOUT_PREINITIALIZED = 8,
} VkImageLayout;
```

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PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS

Image A is created
(UNDEFINED layout)

Command buffer 1

Image A
(UNDEFINED -> COLOR_ATTACHMENT_OPTIMAL layout)

Command buffer 2

Render to Image A

Image A
(COLOR_ATTACHMENT_OPTIMAL -> SHADER_READ_ONLY_OPTIMAL layout)

Dispatch call
(fetches texels from Image A)

Image A
(SHADER_READ_ONLY_OPTIMAL -> COLOR_ATTACHMENT_OPTIMAL layout)

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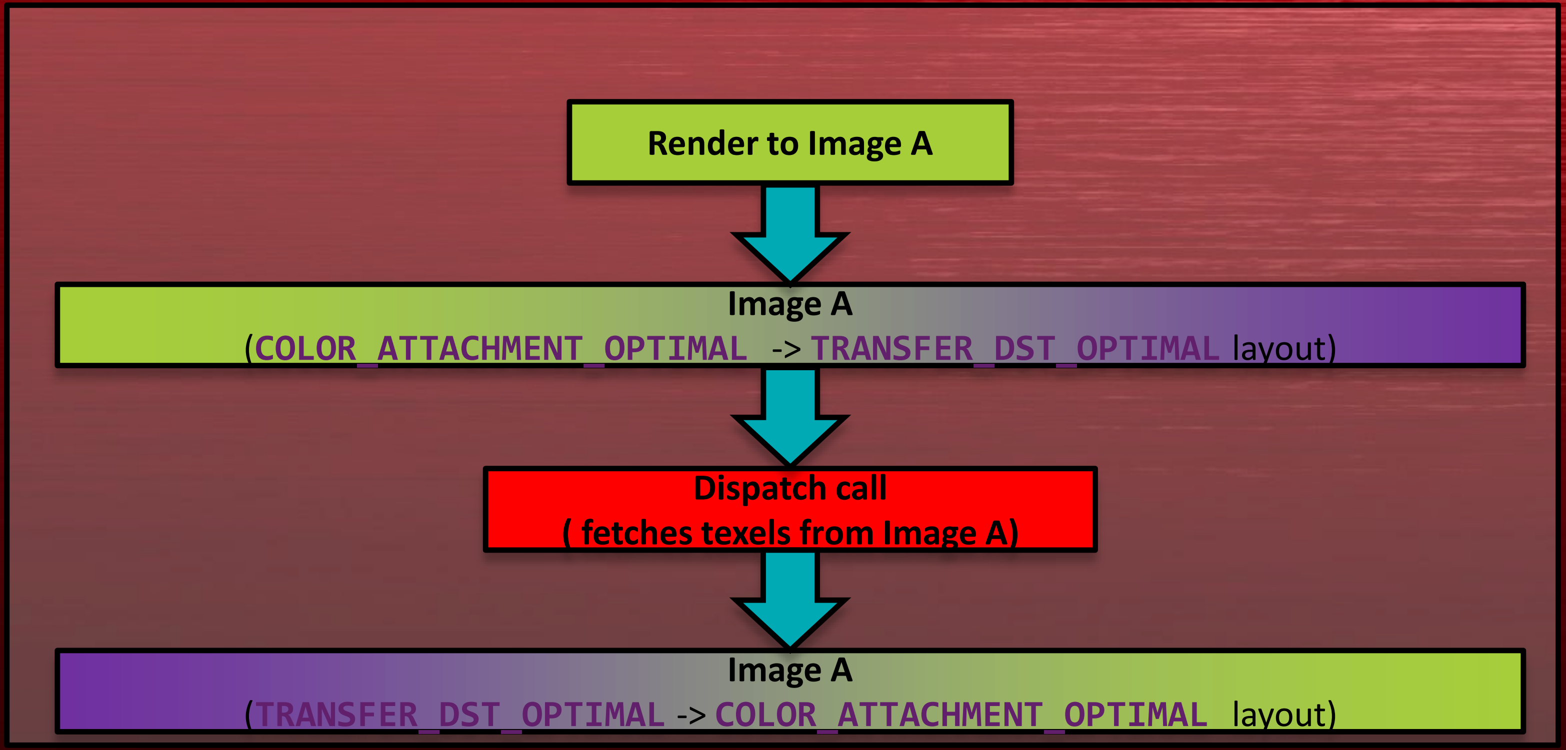
PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS

- **Common problems:**
  1. **Image** is **transitioned** into an **invalid** **layout**.



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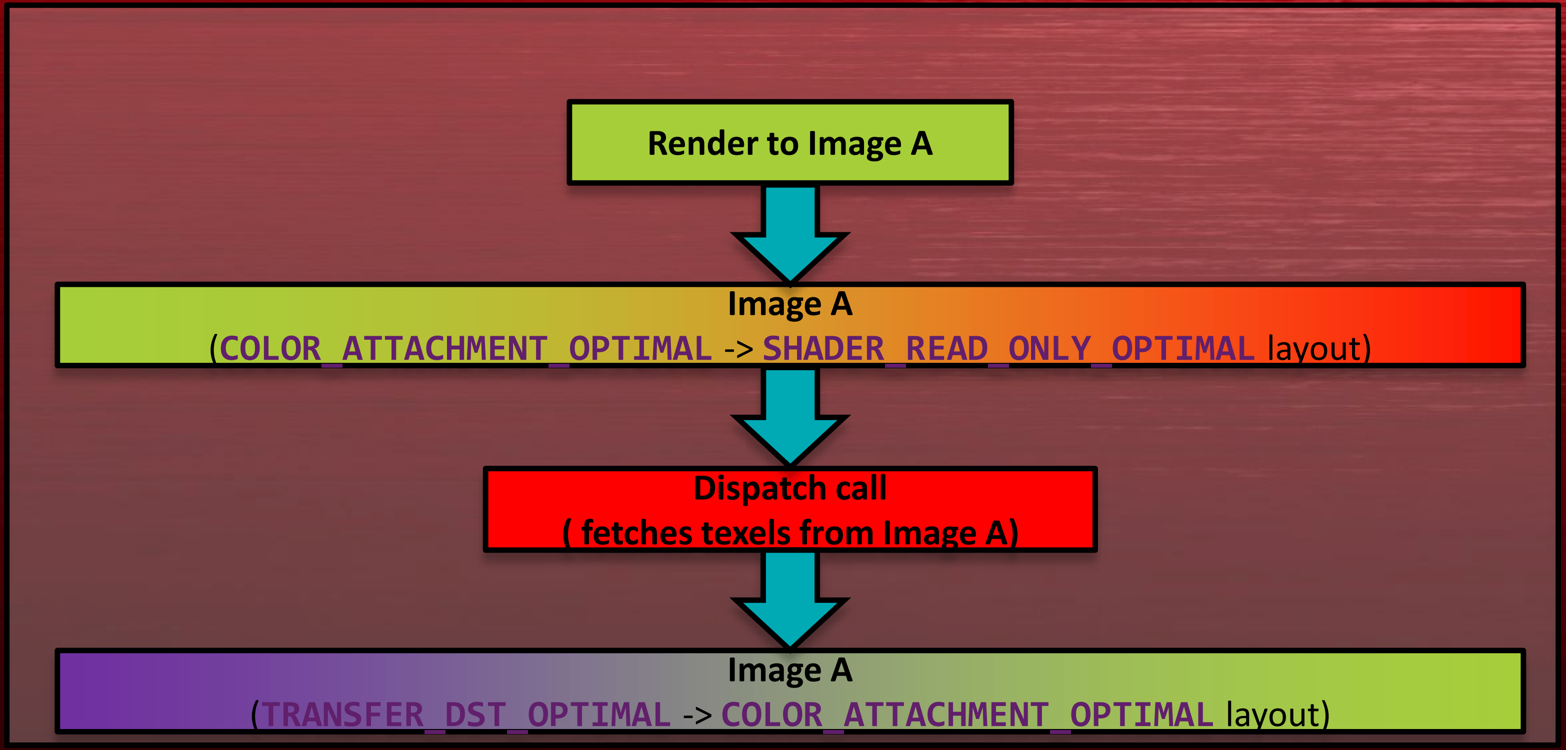
PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS

- **Common problems:**
  2. **Old layout** defined in an **image barrier** is **incorrect**.



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PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS

- **Common problems:**
  3. „Hey AMD, my app works on **vendor Y's driver**, your driver **sucks**!"

  – Some vendors ignore **image barriers**. We **do not**.
  – Whose driver is **wrong** then? ☺

- **Solution:**
  – **Validation layers** are constantly improving – use them!
  – Test your software on **various Vulkan implementations**.

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PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS & RENDERPASSES

- **Common problems:**

4. ISVs misunderstand how **renderpasses** transition **image subresources**.

– Renderpasses are a **novel**, **complex** concept in **Vulkan**.

– Introduced to let the driver „**travel in time**" and know in advance:

  – what **color/DS attachments** will be **rasterized to** or **accessed** (**When**? **How**?)

  – which **image subresource ranges** need to be **synchronized** (**When? How?**)

  – what **layouts** **image subresources** should be **transitioned to**, and **when**.

– That's a lot of info to get wrong, especially when described manually ☺

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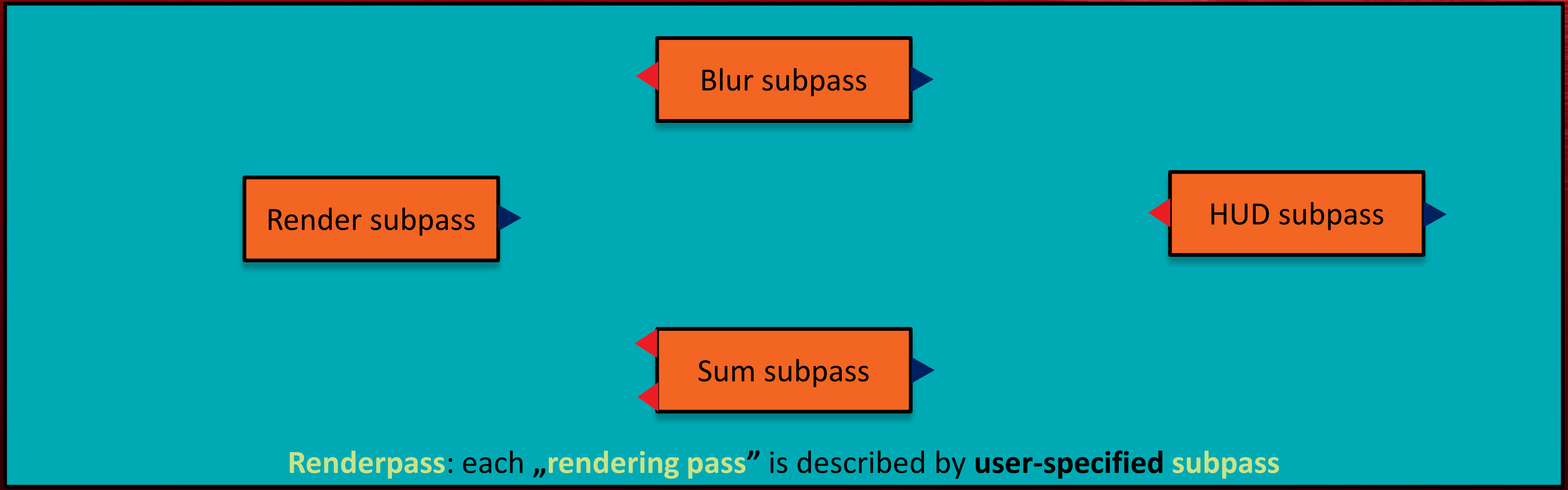
PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS & RENDERPASSES

- **Common problems:**
  4. ISVs misunderstand how **renderpasses** transition **image subresources**.



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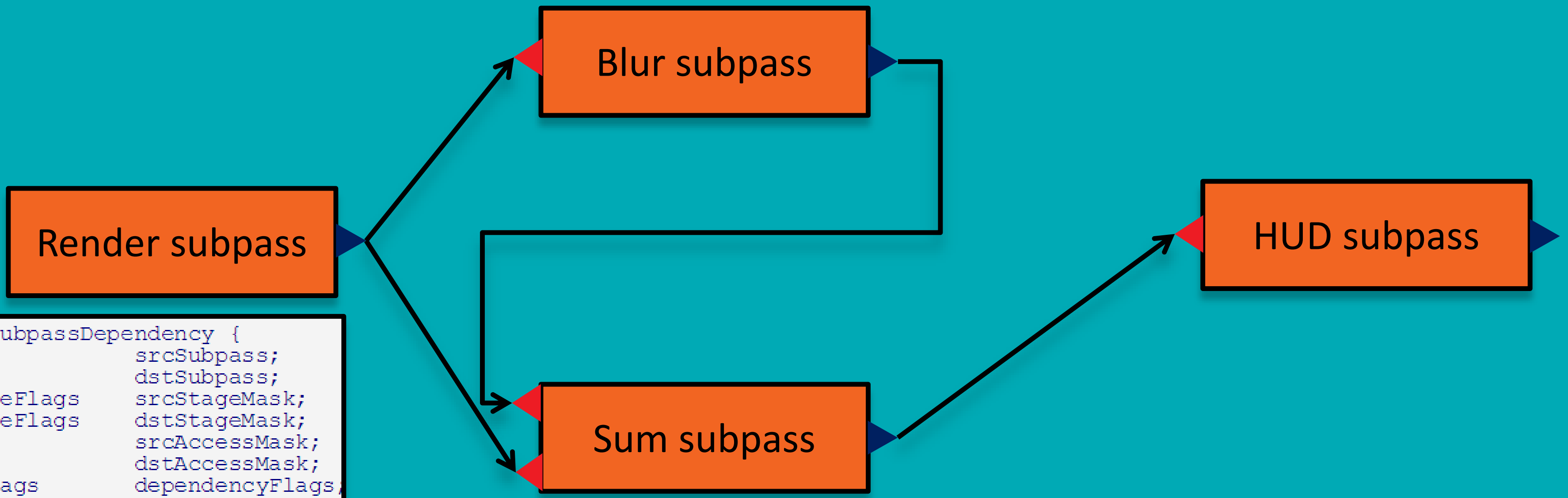
PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS & RENDERPASSES

- **Common problems:**
  4. ISVs misunderstand how **renderpasses** transition **image subresources**.



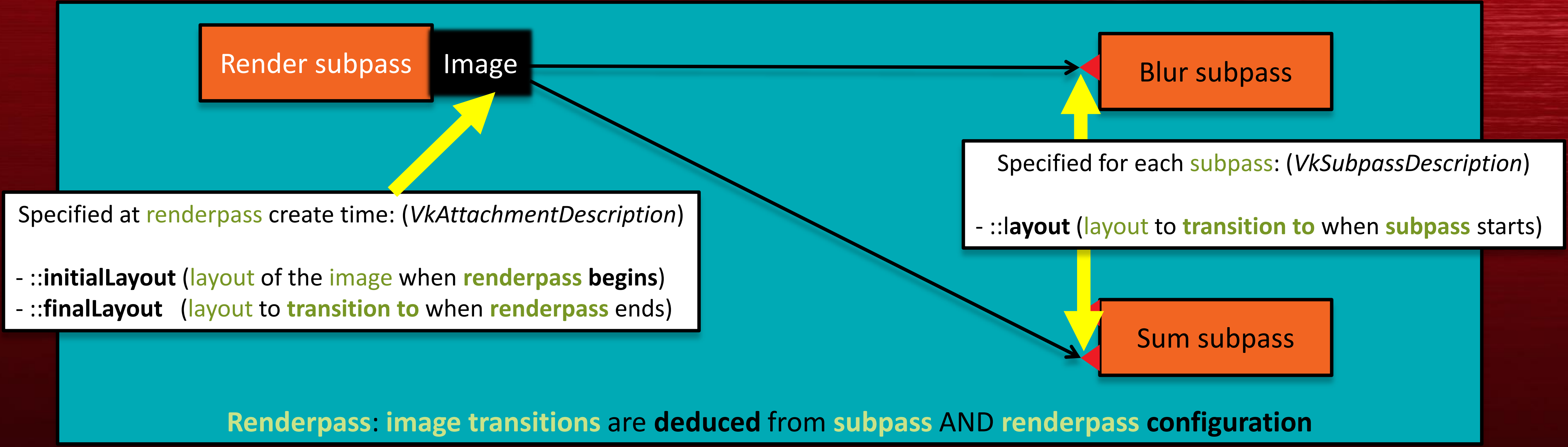

```
typedef struct VkSubpassDependency {
    uint32_t                srcSubpass;
    uint32_t                dstSubpass;
    VkPipelineStageFlags    srcStageMask;
    VkPipelineStageFlags    dstStageMask;
    VkAccessFlags           srcAccessMask;
    VkAccessFlags           dstAccessMask;
    VkDependencyFlags       dependencyFlags;
} VkSubpassDependency;
```

Renderpass: **execution order** is **deduced** from **user-specified dependencies**.

VULKAN

PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS & RENDERPASSES

- **Common problems:**
  4. ISVs misunderstand how **renderpasses** transition **image subresources**.



- **Common problems:**
  4. ISVs misunderstand how **renderpasses** transition **image subresources**.

Render subpass

Image

Specified at renderpass create time: (*VkAttachmentDescription*)

- ::**initialLayout** (layout of the image when **renderpass begins**)
- ::**finalLayout** (layout to **transition to** when **renderpass ends**)

```
typedef struct VkAttachmentDescription {
    VkAttachmentDescriptionFlags    flags;
    VkFormat                        format;
    VkSampleCountFlagBits           samples;
    VkAttachmentLoadOp              loadOp;
    VkAttachmentStoreOp             storeOp;
    VkAttachmentLoadOp              stencilLoadOp;
    VkAttachmentStoreOp             stencilStoreOp;
    VkImageLayout                   initialLayout;
    VkImageLayout                   finalLayout;
} VkAttachmentDescription;
```

Renderpass: **image transitions** are **deduced** from **subpass** AND **renderpass configuration**

VULKAN

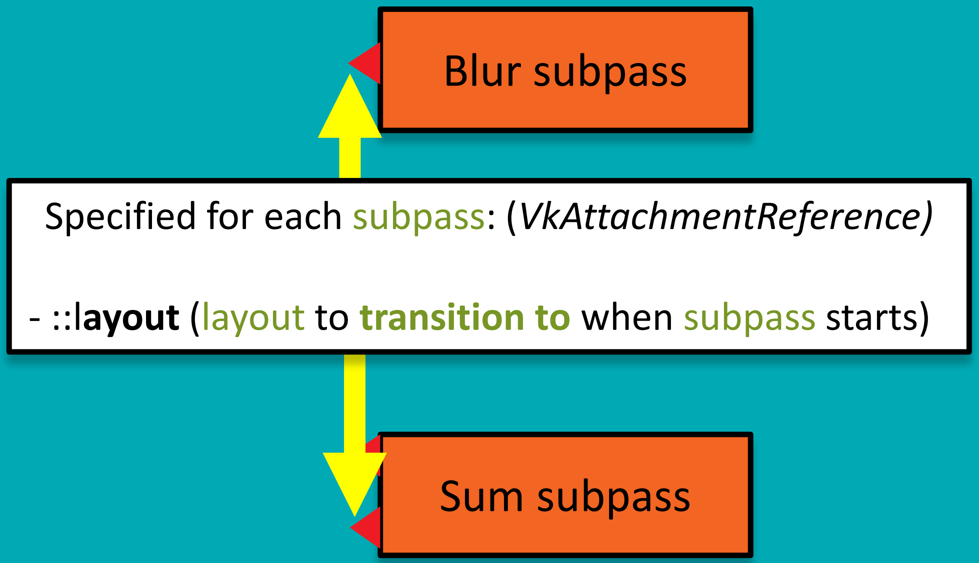
PROBLEMATIC AREAS: IMAGE LAYOUT TRANSITIONS & RENDERPASSES

- **Common problems:**

  4. ISVs misunderstand how **renderpasses** transition **image subresources**.

```
typedef struct VkSubpassDescription {
    VkSubpassDescriptionFlags       flags;
    VkPipelineBindPoint             pipelineBindPoint;
    uint32_t                        inputAttachmentCount;
    const VkAttachmentReference*    pInputAttachments;
    uint32_t                        colorAttachmentCount;
    const VkAttachmentReference*    pColorAttachments;
    const VkAttachmentReference*    pResolveAttachments;
    const VkAttachmentReference*    pDepthStencilAttachment;
    uint32_t                        preserveAttachmentCount;
    const uint32_t*                 pPreserveAttachments;
} VkSubpassDescription;
```

```
typedef struct VkAttachmentReference {
    uint32_t         attachment;
    VkImageLayout    layout;
} VkAttachmentReference;
```



Renderpass: **image transitions** are deduced from **subpass** AND **renderpass configuration**

VULKAN

PROBLEMATIC AREAS: GPU-SIDE SYNCHRONIZATION

- Uber-general Vulkan's **GPU-side command execution rules**:

  1. **Command queues** run **independently** of **each other**.
  2. When submitted to **queue A**, command buffers execute in the **specified order**
  3. Unless order is **enforced** by **barriers** / **renderpass** / **sync primitives**:
     1. Submitted commands **may be executed in parallel**
     2. Submitted commands **may be executed out-of-order**.

- The following **sync objects** are **available**:
  – **Events** (**intra-queue** synchronization)
  – **Semaphores** (**inter-queue** synchronization)
  – **Fence** (blocks **CPU thread** until submitted job chunk<s> finish<es> running)

VULKAN

PROBLEMATIC AREAS: GPU-SIDE SYNCHRONIZATION

- **Problem:**
  - ISVs sometimes create **sync objects** every frame.

- **Solution:**
  - **Avoid** at **all cost**!
  - Remember that:
    1. **Events** can be **reset CPU- and GPU-side**
    2. **Fences** can be reset **CPU-side**
    3. **Semaphores** automatically reset after being successfully **waited upon**.

  - If more **feasible**, bake **per-swapchain** image set of **sync objects** in advance

ANY QUESTIONS?

THANK YOU