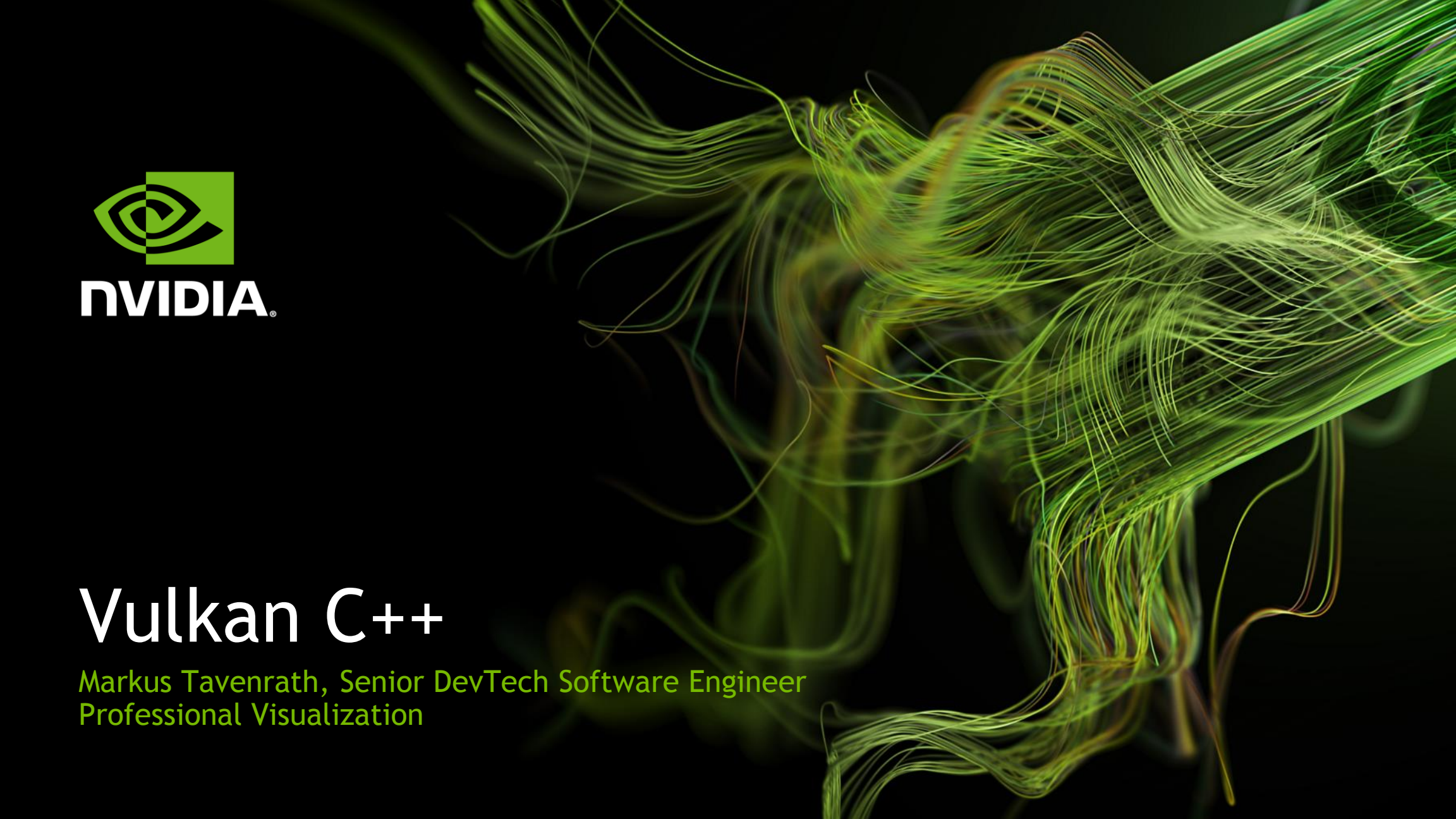


Vulkan C++

Markus Tavenrath, Senior DevTech Software Engineer
Professional Visualization

Who am I?

Markus Tavenrath

- Senior Dev Tech Software Engineer - Professional Visualization
- Joined NVIDIA 8 years ago to work on middleware
  - Goal: Make graphics programming easy and efficient
- Working with CAD ISVs to optimizing their graphics pipelines
- Working with driver team on Vulkan and OpenGL performance

What is Vulkan?

What developers have been asking for

Reduce CPU overhead

Scale well with multiple threads

Precompiled shaders

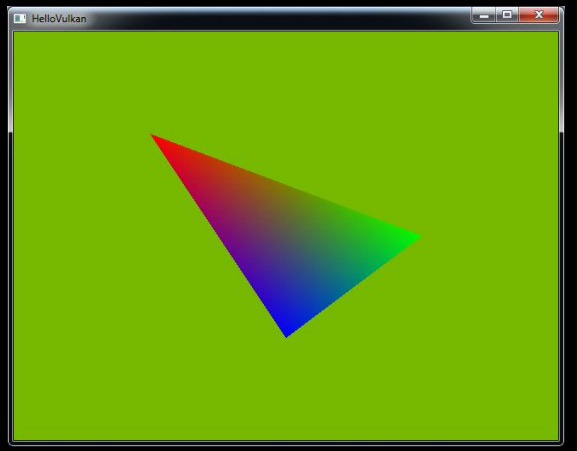
Predictable – no hitching

Clean, modern and consistent API – no cruft

Native tiling and mobile GPU support

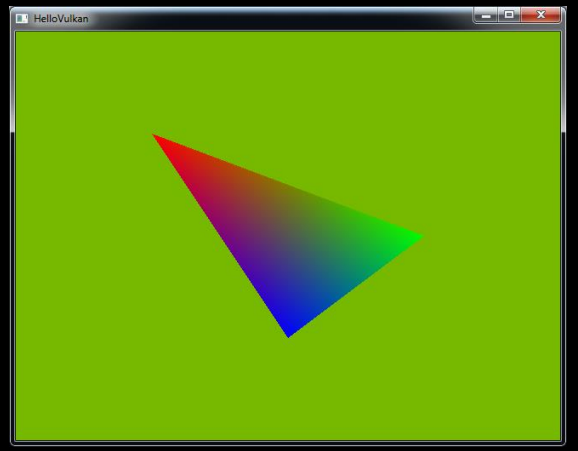
What is Vulkan?
Downsides

- Vulkan moves responsibility from driver to application
  - Application has to write ‘driver‘-code
  - Simple HelloWorld is ~750 lines of code
- So much to do, hard to start
- It‘s easy make errors
- It‘s hard to find those errors
- Is there a way to simplify Vulkan usage, especially for beginners?



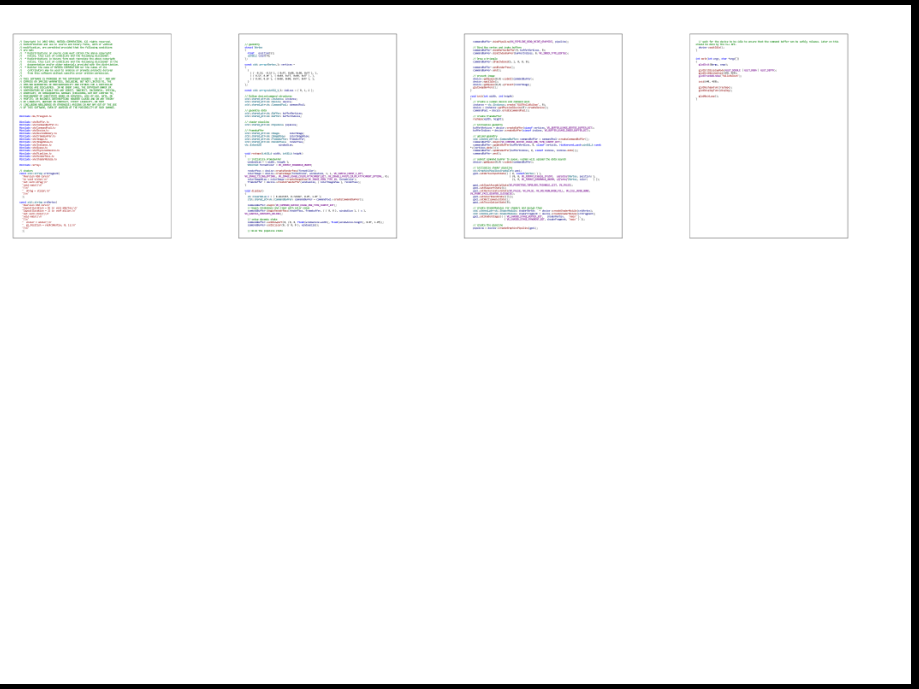
Goals

Preview



Native (~750loc)

VkCPP (~200loc)



Goals

C++11 API on top of Vulkan

- Simplify Vulkan usage by
  - reducing risk of errors, i.e. type safety, automatic initialization of sType, …
  - Reduce #lines of written code, i.e. constructors, initalizer lists for arrays, …
  - Add utility functions for common tasks (suballocators, resource tracking, …)

- Make it easy to use Vulkan!

Implementation

- Two C++ based layers
  - Autogenerated ‚low-level‘ layer using vulkan.xml
    - Type safety
    - Syntactic sugar
  - Hand-coded ‚high level‘ layer
    - Reduce code complexity
    - Exception safety, RAII, resource lifetime tracking, …
- Layers are work in progress, showing current state

Low Level Layer
vk namespace

- All Vulkan symbols replicated in vk namespace to avoid conflicts
  - Structs
    `VkRect2D -> vk::Rect2D`
  - Functions
    `VkCmdDraw(…) -> vk::cmdDraw(…)`
  - Enums
    `VkImageViewType -> vk::ImageViewType`
  - Flags
    `VkQueueFlags -> vk::QueueFlags`
  - …

Low Level Layer
Enums

- Enforce type safety for enums by using scoped enums
  - `VK_IMAGE_VIEW_TYPE_CUBE -> vk::ImageViewType::CUBE`
  - Special case:
    - Symbols starting with a number are prefixed with a '_'
    - `VK_IMAGE_VIEW_TYPE_1D -> vk::ImageViewType::_1D`

Low Level Layer
Flags

- Enfore type safety for flags with vk::Flags template class
  - `typedef vk::Flags<QueueFlagBits> QueueFlags;`
  - `QueueFlags flags(vk::QueueFlagBits::GRAPHICS)`
  - Most bit-operators supported
    - `flags = vk::QueueFlagBits::GRAPHICS | vk::QueueFlagBits::COMPUTE;`
    - `flags |= vk::QueueFlagBits::COMPUTE;`
    - `flags &= vk::QueueFlagBits::COMPUTE;`

    …

Low Level Layer

Basic struct initialization

- Implement class vk::* for struct Vk*
  - ```
    class Extent2D {
    public:
      Rect2D(int width, int height) // add constructors

      operator vkRect2D const &() { return m_rect2D; } // nop in release
    private:
      vkRect2D m_rect2D;
    };
    ```
  - C++ style `vk::Rect2D r(vk::Offset2D(0,0), vk::Extent2D(1920, 1080));`
  - C++11 style `vk::Rect2D r {{0,0}, {1920, 1080}}`
    ```

Low Level Layer

C99 designated initializers style

- Named parameter idiom closest thing one can get in C++
- ```
  class Extent2D {
  public:
    …
    Extent2D& width(int width_) // setter
    int const &width();         // getter
  };
  ```
- ```
  Vk::Extent2D e = vk::Extent2D().width(1920).height(1080);
  ```
- Just set what you need - in any order

Low Level Layer
*CreateInfo initialization

- *CreateInfo structs initialization simplified
  - `sType` and `pNext` set automatically in constructor
  - Native:
```
VkMemoryAllocateInfo mai = {VK_MEMORY_ALLOCATE_INFO};
mai.allocationSize = 1024;
mai.memoryTypeIndex = 0;
```
  - vkcpp:
```
vk::MemoryAllocateInfo mai(1024, 0);
or
vk::MemoryAllocateInfo mai = {1024, 0};
```

Low Level Layer

Unions

- Add one constructor for each enum type
- ```
  struct ClearColorValue {
   ClearColorValue(std::array<float,4> float32
     = { 0.0f, 0.0f, 0.0f, 0.0f } );
   ClearColorValue(std::array<int32_t,4> int32);
   ClearColorValue(std::array<uint32_t,4> uint32);
   …
  };
  ```
- `ClearColorValue c = {1, 0, 0, 0};` uses expected constructor (int32_t);
  but
  VkClearColorValue c = {1, 0, 0, 0}; interprets values as floats (on msvc)


  ```

Low Level Layer
Default Parameters?

- Constructors would allow to define default parameters
  - Useful in some cases
- Unfortunately no default parameters available in vulkan.xml
  - What are good defaults?
- Enhance vulkan.xml or add separate xml file?
- Could be quite useful in combination with named parameter idiom

Low Level layer
Conclusion

- Autogenerated C++ wrapper removes some potential errors
  - Wrong enums for member variables or bitfields
  - Passing Enums for non-enums fields
  - Missing/Incorrect pType field in createInfos
  - Uninitialized fields when using constructors
- Constructors make code horizontal, less lines of code

Low Level Layer
Conclusion

- Low level layer good for ‚ninjas‘ which prefer C++-style over C-style
  - Still hard to use for people who ‚just want to render‘ a large number of objects
- Introduce higher level interface for people who ‚just want to use Vulkan‘
  - ‘Close‘ to native Vulkan
  - Common tasks handled by utility functions or interfaces
  - Object lifetime, resource allocation, resource tracking, …

High Level Layer
Initialization

- RAII with shared_ptrs and factories

```
std::shared_ptr<nvk::Instance> instance;
instance = nvk::Instance::create("GLUTHelloVulkan", 0, …);
```

Application Version

Application Name

- Parameterized interface, keep code horizontal

Initialization

Device creation & hierarchy

- PhysicalDevices are permanent -> getPhysicalDevice

```
// get first physical device
std::shared_ptr<nvk::PhysicalDevice> physicalDevice;
physicalDevice = instance->getPhysicalDevice(0);

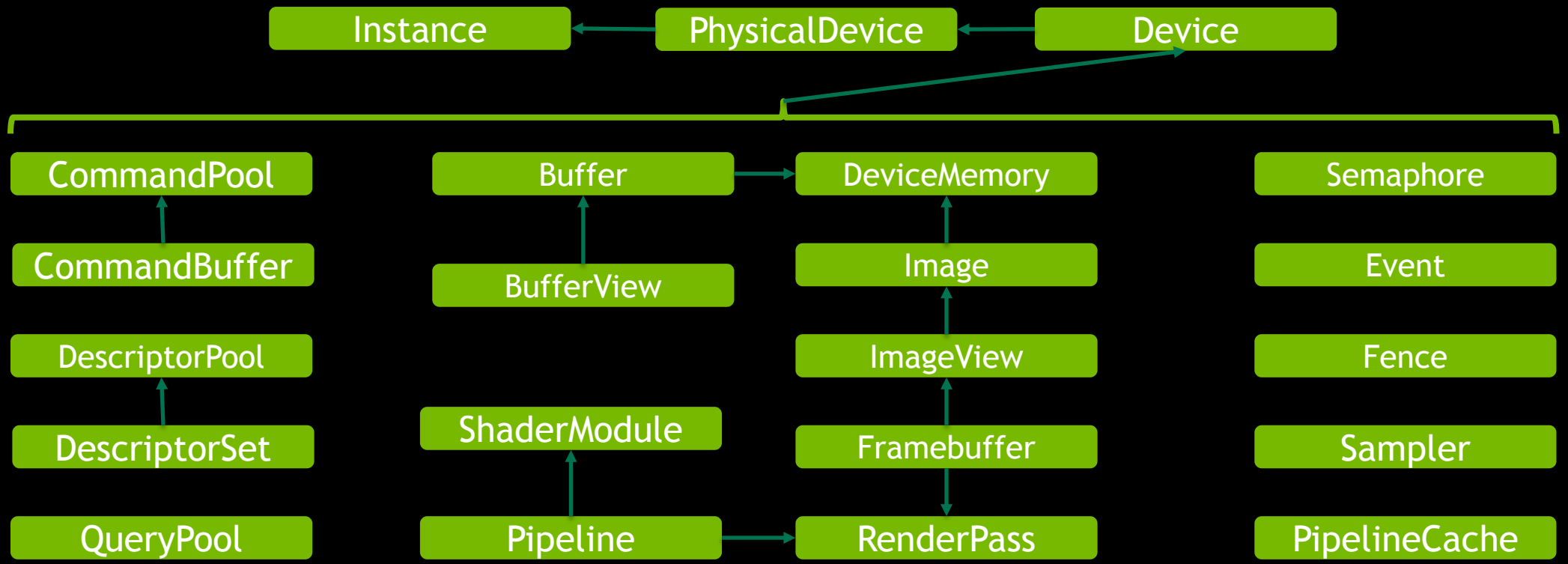

// create device from PhysicalDevice
std::shared_ptr<nvk::Device> device;
device = physicalDevice->createDevice();
```

High Level Layer
Hierarchy Lifetime

- Instance must not be deleted before all devices had been destroyed
- Use shared_ptr to establish object hierarchy lifetime upwards
- Use weak_ptr for ‚permanent‘ object like PhysicalDevice and Queue

High Level Layer

Hierarchy Lifetime

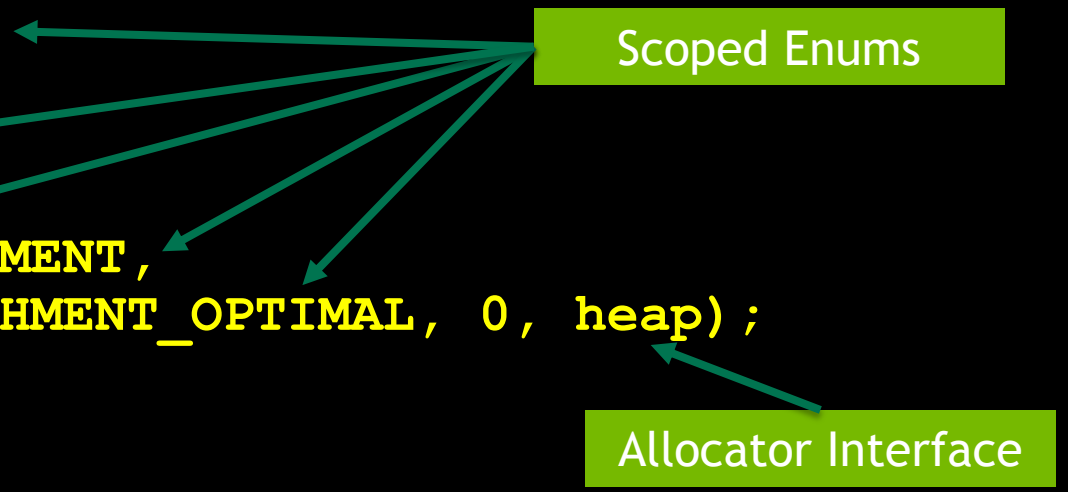


Framebuffer creation

Image creation

- Create Image for color buffer

```
colorImage = device->createImage(
 vk::Format::R8G8B8A8_UNORM,
 windowSize, 1, 1,
 vk::SampleFormat::_1,
 vk::ImageTiling::OPTIMAL,
 vk::ImageUsage::COLOR_ATTACHMENT,
 vk::ImageLayout::COLOR_ATTACHMENT_OPTIMAL, 0, heap);
```



Low-level memory control

Heap interface

Interface class by Heap
std::shared_ptr<vk::DeviceMemory>, offset

- Introduce new Heap interface
- ```
  class Heap {
    virtual std::shared_ptr<nvk::Allocation> allocate(Requirements) = 0;
  };
  ```
- Allocation keeps reference to Heap and
- ~Allocation responsible for free
- Device provides default heap
  ```

Framebuffer creation

ImageView creation

- It‘s not uncommon that imageView has colorFormat and imageType as Image
- Query information from vk::Image, avoid ‚conflicting‘ types
- Creating ImageViews with different types also possible

```
colorImageView = colorImage->createImageView();
```

Framebuffer creation
Framebuffer

- Framebuffer gets
  - windowSize (redundant, query from imageView?)
  - std::vector<nvk::ImageView> for attachments
  - RenderPass

```
framebuffer = device->createFramebuffer(
                  windowSize, { colorImageView }, renderPass);
```

std::vector of
std::shared_ptr<vk::ImageView>

GraphicsPipeline creation

VertexInputState

- nvk::GraphicsPipelineCreateInfo is class for full GraphicsPipeline creation state
- Sets ‘good’ defaults upon initialization, i.e. 1 Viewport, triangles, …

std::vector<VertexInputBindingDescription>

```
nvk::GraphicsPipelineCreateInfo gpci;
gpci.setVertexInputState(
{{0, sizeof(Vertex)}},
{{0, 0, vk::Format::R32G32_SFLOAT,  offsetof(Vertex,  position)},
 {1, 0, vk::Format::R8G8B8A8_UNORM, offsetof(Vertex, color)    }
});
```

std::vector<VertexInputAttributeDescription>

GraphicsPipeline creation

Shader

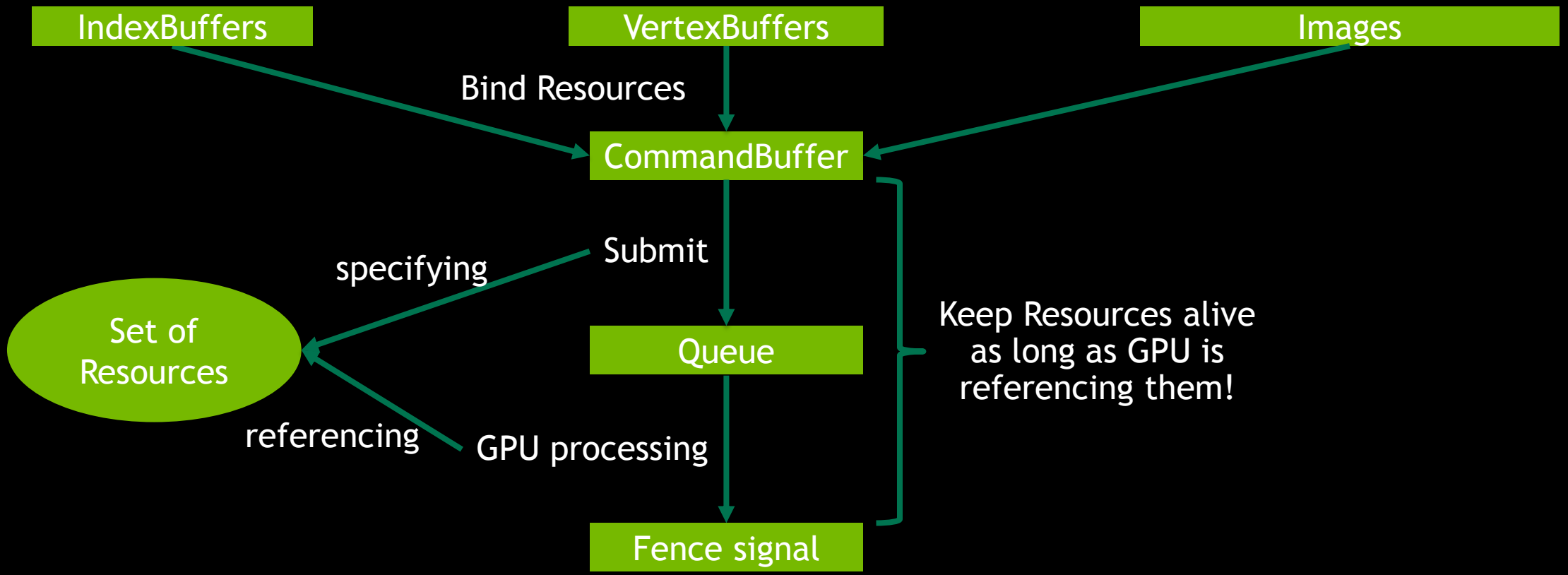
```
shaderVertex   = device->createShaderModule(srcVertex);
shaderFragment = device->createShaderModule(srcFragment);
gpci.setShaderStages(
{ { vk::ShaderStage::VERTEX,   shaderVertex,   "main" },
  { vk::ShaderStage::FRAGMENT, shaderFragment, "main" } }

);

// create actual pipeline
pipeline = device->createGraphicsPipeline(gpci);
```

Resource Tracking

Lifetime



ResourceTracking

Automation

- Introduce ResourceTracker, used by CommandBuffer

```
class ResourceTracker {
  // track resources
  void track(std::shared_ptr<vk::Buffer> const & buffer);
  void track(std::shared_ptr<vk::Event> const & event);

  // track usage on GPU
  void addFence(std::shared_ptr<vk::Fence> const & fence);

  // check if used on GPU, also removes finished entries
  bool isUsed();
};
```

ResourceTracking

Automation

- CommandBuffer holds ResourceTracker implementation
- Calls resourceTracker->add() for used resources, build up resource set
- On queue->submit() add entry to a map<sp<Fence>, sp<ResourceTracker>>
- Queue keeps ResourceTracker alive as long as Fence hasn‘t been reached
  -> ResourceTracker keeps references to resources

ResourceTracking
Automation

- Potential problems
  - Performance, tracking all resources each frame might be slow
    - ResourceTracker is interface, write your own tracker which keeps track of frameset
    - In debug mode you could validate if all resources are referenced
  - How to trigger resource cleanup
    - Async: Wait for fence in a separate thread
    - Sync: Provide function Queue::releaseResources() which frees resources for all reached fences

Questions?

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