

Vulkan

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Abstract

Thesis about Vulkan

Dedication

Bla Bla Bla

Acknowledgments

I want to thank...

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Chapter 1

Vulkan

1.1 What is Vulkan?



Figure 1.1: Vulkan logo

Vulkan is a modern graphics API. It is maintained by the Khronos Group. Vulkan is meant to abstract how modern GPUs work. Using Vulkan, the programmer can write more performant code. The better performance comes at the cost of having a more verbose and low level API compared to other existing APIs such as OpenGL or Direct3D 11 and prior. Vulkan is not the only modern graphics API, other such APIs are Direct3D

12 and Metal. Nonetheless, Vulkan has the advantage of being fully cross platform.

1.2 What problems does Vulkan solve?



Figure 1.2: OpenGL logo

Common graphics APIs like OpenGL or Direct3D were developed during the 1990s. At that time, graphics card hardware was very limited not only in terms of computational power but also from a functionality standpoint. As time progressed, graphics card architectures continued to evolve, offering new functionalities. All these new functionalities had to be integrated with the old existing APIs. The more new functionalities were integrated, the more the GPU's driver complexity

grew. Such complicated GPU drivers are inefficient and are also the cause of many inconsistencies between implementations of the same graphics API but on different GPUs.

1.3 How does Vulkan solve these problems?

Vulkan doesn't suffer from the problems we saw above because it has been designed from scratch and with modern GPU's architecture in mind. It reduces the driver overhead by being more verbose and low level. It is also designed to be multithreaded, allowing the programmer to submit GPU commands from different threads. This is very beneficial to performance, since modern CPUs usually have more than one core.

Chapter 2

Initializing Vulkan

2.1 Create Vulkan Instance

To access any of the functionalities offered by Vulkan we first have to create a Vulkan instance. To do this we call `vkCreateInstance`.

```
1 VkInstance instance = VK_NULL_HANDLE;
2 vkCreateInstance(&createInfo, nullptr, instance);
```

Listing 2.1: Create Vulkan instance

2.1.1 VkInstanceCreateInfo

To call `vkCreateInstance` we need to pass a pointer to a `VkInstanceCreateInfo` struct. This struct collects all the information needed to configure our Vulkan instance.

```
1 VkInstanceCreateInfo createInfo = {};
2 createInfo.sType = VK_STRUCTURE_TYPE_INSTANCE_CREATE_INFO;
3 createInfo.pApplicationInfo = &appInfo;
4 createInfo.enabledLayerCount = layerCount;
5 createInfo.ppEnabledLayerNames = layers;
6 createInfo.enabledExtensionCount = extensionCount;
7 createInfo.ppEnabledExtensionNames = extensions;
```

Listing 2.2: `VkInstanceCreateInfo` initialization

2.1.2 VkApplicationInfo

We can see that the `VkInstanceCreateInfo` struct is not the only thing we need. We have to specify a pointer to a `VkApplicationInfo` struct. Such struct describes our Vulkan application.

```
1 VkApplicationInfo appInfo = {};
2 appInfo.sType = VK_STRUCTURE_TYPE_APPLICATION_INFO;
3 appInfo.pApplicationName = "Vulkan example";
4 appInfo.apiVersion = VK_API_VERSION_1_2;
```

Listing 2.3: `VkApplicationInfo` initialization

2.1.3 Layers

While we initialize our `VkInstanceCreateInfo` struct, we can specify the layers that we want to enable. The specified layers will be loaded after the Vulkan instance creation.

Layers are optional components that hook into Vulkan. Layers can intercept, evaluate and modify existing Vulkan functions. Layers are implemented as libraries and are loaded during instance creation.

If we want to enable error checking, we need to load a layer that provides such functionality. This kind of layer is known as validation layer. There are different validation layers. Here follows an example. Since validation layers cause overhead, we can disable them when we build the application in release mode.

```
1  const char* const layers[] =
2  {
3      #ifdef _DEBUG
4          "VK_LAYER_KHRONOS_validation",
5      #endif
6      // other layers ...
7  };
```

Listing 2.4: Enabling the Khronos validation layer

Checking whether our layers are supported

Before creating our Vulkan instance, we should check if the layers we require are actually supported. To do this we use `vkEnumerateInstanceLayerProperties`. This function returns all the layers supported by our Vulkan installation. If all the layers we require are present, then we can proceed to create our Vulkan instance.

2.1.4 Extensions

While we initialize our `VkInstanceCreateInfo` struct, we can specify the instance extensions that we want to enable. The specified instance extensions will be loaded after the Vulkan instance creation.

Extensions are additional features that Vulkan implementations may provide. Extensions add new functions and structs to the API. Extensions may also change some of the behavior of existing functions. We can either enable extensions at an instance level or at a device level.

We can use an extension to provide a callback to handle the debug messages generated by the validation layers.

```
1  const char* const extensions[] =
2  {
3      #ifdef _DEBUG
4          VK_EXT_DEBUG_UTILS_EXTENSION_NAME,
5      #endif
6      // Other extensions ...
7  };
```

Listing 2.5: Enabling an extension to handle validation layer debug messages

We specify one callback that handles messages generated by instance creation and destruction. We also specify another callback that handles all other API

debug messages.

```
1  #ifdef _DEBUG
2  VkDebugUtilsMessengerCreateInfoEXT dbgInfo = {};
3  dbgInfo.sType =
4      VK_STRUCTURE_TYPE_DEBUG_UTILS_MESSENGER_CREATE_INFO_EXT;
5  dbgInfo.messageSeverity = severity;
6  dbgInfo.messageType = type;
7  dbgInfo.pfnUserCallback = VulkanDebugCallback;
8  #endif
9  VkInstanceCreateInfo createInfo = {};
10 #ifdef _DEBUG
11 createInfo.pNext = (VkDebugUtilsMessengerCreateInfoEXT*)(dbgInfo);
12 #endif
13
14 // ... after instance creation
15
16 // Enabling debug callback for all other API functions
17 #ifdef _DEBUG
18 VkDebugUtilsMessengerEXT debugMessenger = VK_NULL_HANDLE;
19 CreateDebugUtilsMessengerEXT(instance, &dbgInfo, nullptr, &
20     debugMessenger)
21 #endif
```

Listing 2.6: Setting up debug extension callbacks

The function that creates the `VkDebugUtilsMessengerEXT` object comes from the extension we have enabled. Because of this, we have to load it manually into our address space using `vkGetInstanceProcAddr`. An elegant way to solve this issue is to create a proxy function that handles this matter for us.

```
1  static VkResult CreateDebugUtilsMessengerEXT
2  (
3      VkInstance instance,
4      const VkDebugUtilsMessengerCreateInfoEXT* pCreateInfo,
5      const VkAllocationCallbacks* pAllocator,
6      VkDebugUtilsMessengerEXT* pDebugMessenger
7  )
8  {
9      PFN_vkCreateDebugUtilsMessengerEXT f = (
10         PFN_vkCreateDebugUtilsMessengerEXT)(vkGetInstanceProcAddr(
11             instance, "vkCreateDebugUtilsMessengerEXT"));
12     return f(instance, pCreateInfo, pAllocator, pDebugMessenger);
13 }
```

Listing 2.7: Extension function proxy

Checking whether our extensions are supported

Before creating our Vulkan instance, we should check if the instance extensions we require are actually supported. To do this we use `vkEnumerateInstanceExtensionProperties`. This function returns all the instance extensions that are supported by our Vulkan installation. If all the instance extensions we require are present, then we can proceed to create our Vulkan instance.

2.1.5 Vulkan Instance Cleanup

When our application is shutting down, we need to destroy the debug messenger and destroy our vulkan instance. `DestroyDebugUtilsMessengerEXT` is an

extension function proxy.

```
1  #ifdef _DEBUG
2  DestroyDebugUtilsMessengerEXT(instance, debugMessenger, nullptr);
3  #endif
4
5  vkDestroyInstance(instance, nullptr);
```

Listing 2.8: Vulkan Instance Cleanup

2.2 Open A Window

After creating our Vulkan instance we need to open a window. To do this we have two options. We can use a cross platform library that will do all the heavy lifting for us, so that we don't have to worry about directly interacting with the OS, freeing us from the burden of knowing how its windowing API works. We can also decide to not use a library and opening the window ourselves. We will do the latter, since it's interesting to know how things work under the surface.

Since I'm on Windows, I'll be dealing with the Win32 API. We won't go in depth about the specifics of this API since it's beyond our scope.

2.2.1 Create Window Handle

To create a handle to a window we use `CreateWindowEx`. We use `windowStyle` and `windowExtendedStyle` variables to configure how we want our window.

```
1  DWORD windowStyle = (WS_OVERLAPPEDWINDOW | WS_VISIBLE | WS_CAPTION)
2                      & (~WS_THICKFRAME) & (~WS_MINIMIZEBOX) & (~WS_MAXIMIZEBOX);
3
4  DWORD windowExtendedStyle = 0;
5
6  HWND handle = CreateWindowEx(
7      windowExtendedStyle,
8      WINDOW_CLASS_NAME,
9      name,
10     windowStyle,
11     CW_USEDEFAULT, CW_USEDEFAULT,
12     windowWidth, windowHeight,
13     0,
14     GetModuleHandle(0),
15     0);
```

Listing 2.9: Creating a window handle using Win32 API

2.2.2 Computing Window Dimensions

Before creating our window, we need to compute its width and height. This is due to the fact that a window comprises of a client area and a non client area. We usually want our client area to be of a certain size, but `CreateWindowEx` takes the whole window width and the whole window height as arguments.

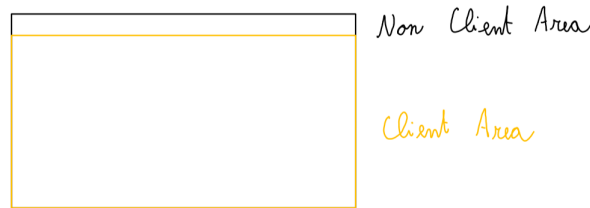


Figure 2.1: Anatomy of a Win32 Window

```

1  RECT windowDimensions = { 0, 0, clientWidth, clientHeight };
2  AdjustWindowRectEx(&windowDimensions, windowStyle, false,
    windowExtendedStyle);
3  i32 windowWidth = windowDimensions.right - windowDimensions.left;
4  i32 windowHeight = windowDimensions.bottom - windowDimensions.top;

```

Listing 2.10: Compute window width and height

2.2.3 Register Window Class

Before creating our window, we need to register its window class. To do this we use `RegisterClassEx`. This function takes a pointer to a `WNDCLASSEX` struct. This struct is used to configure our window class;

```

1  WNDCLASSEX windowClass = {};
2  windowClass.cbSize = sizeof(windowClass);
3  windowClass.style = CS_HREDRAW | CS_VREDRAW;
4  windowClass.lpfnWndProc = WindowProcedure;
5  windowClass.hInstance = GetModuleHandle(0);
6  windowClass.hIcon = LoadIcon(0, IDI_APPLICATION);
7  windowClass.hCursor = LoadCursor(0, IDC_ARROW);
8  windowClass.lpszClassName = WINDOW_CLASS_NAME;
9  windowClass.hIconSm = LoadIcon(0, IDI_APPLICATION);
10
11 RegisterClassEx(&windowClass);

```

Listing 2.11: Register Window Class

2.2.4 Window Procedure

While filling in our `WNDCLASSEX` struct, we also passed a `WindowProcedure`. This is a callback function that we have to define. We use this function to handle the events that our window will receive during the lifespan of our application.

The Win32 API also provides a default window procedure. Our custom window procedure will call this default procedure when we don't want to handle particular events ourselves.

```

1  static LRESULT CALLBACK WindowProcedure(HWND hwnd, UINT msg, WPARAM
    wparam, LPARAM lparam)
2  {
3      LRESULT result = 0;
4      switch (msg)
5      {
6          case WM_QUIT:
7          case WM_CLOSE:
8          case WM_DESTROY: { PostQuitMessage(0); } break;
9          default: { result = DefWindowProcA(hwnd, msg, wparam, lparam);
    } break;
10     };
11
12     return result;
13 }

```

Listing 2.12: Window Procedure

2.2.5 Window Cleanup

When our application is shutting down, we need to destroy our window and unregister its class.

```

1  DestroyWindow(handle);
2  UnregisterClass(WINDOW_CLASS_NAME, GetModuleHandle(0));

```

Listing 2.13: Window Cleanup

2.3 Create A Presentation Surface

We need to link our newly created window to our Vulkan instance. To do this we need to create a presentation (or window) surface. This operation is platform specific. Since we are using Windows, to create our presentation surface we need to use `vkCreateWin32SurfaceKHR`.

```

1  VkSurfaceKHR surface = VK_NULL_HANDLE;
2  vkCreateWin32SurfaceKHR(instance, &createInfo, nullptr, &surface);

```

Listing 2.14: Create Presentation Surface

2.3.1 VkWin32SurfaceCreateInfoKHR

When we call `vkCreateWin32SurfaceKHR`, we need to pass a pointer to a `VkWin32SurfaceCreateInfoKHR` struct. Such struct lets us configure our presentation surface creation.

```

1  VkWin32SurfaceCreateInfoKHR createInfo = {};
2  createInfo.sType = VK_STRUCTURE_TYPE_WIN32_SURFACE_CREATE_INFO_KHR;
3  createInfo.hinstance = GetModuleHandleA(0);
4  createInfo.hwnd = handle;

```

Listing 2.15: Filling in a `VkWin32SurfaceCreateInfoKHR` struct

2.3.2 Required Instance Extensions

Vulkan, being cross platform, cannot interact directly with the OS windowing system. To do this we need to use extensions.

The first extension that we need to enable is the instance level KHR surface extension. This extension exposes a `VkSurfaceKHR` object that represents a surface to present rendered images to. This surface will be backed by the window we have created.

The second extension we need to enable is platform specific and is needed to create our `VkSurfaceKHR` object. In our case, since we are using Windows, we need to enable the instance level KHR win32 surface extension.

```
1  #define VK_USE_PLATFORM_WIN32_KHR
2  #include "Vulkan.h"
3
4  const char* const* extensions[] =
5  {
6      VK_KHR_SURFACE_EXTENSION_NAME,
7      VK_KHR_WIN32_SURFACE_EXTENSION_NAME,
8      // ... other extensions
9  }
```

Listing 2.16: Presentation Surface Extensions

Notice the define preprocessor directive right before including our Vulkan header. We need to do this to access our native platform functions.

2.3.3 Presentation Surface Cleanup

When our application is shutting down, we need to destroy our presentation surface.

```
1  vkDestroySurfaceKHR(instance, surface, nullptr);
```

Listing 2.17: Presentation Surface Cleanup

2.4 Pick A Physical Device

2.5 Create A Logical Device

2.6 Create A Swapchain

Chapter 3

Clear The Window

Chapter 4

Our First Pipeline

Chapter 5

Vertex Buffer

Chapter 6

Staging Buffer

Chapter 7

Uniform Buffer

Chapter 8

Depth Buffer

Chapter 9

Setting Up A Simple Scene

Chapter 10

Blinn-Phong Lighting

Chapter 11

Multisample Anti Aliasing

Chapter 12

Conclusion

Appendix A

Appendix

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