AMD

OPTIMISING A AAA VULKAN TITLE ON DESKTOP

LOU KRAMER

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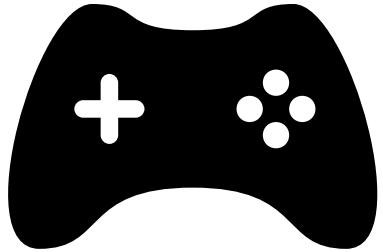
DEVELOPER TECHNOLOGY ENGINEER
AMD



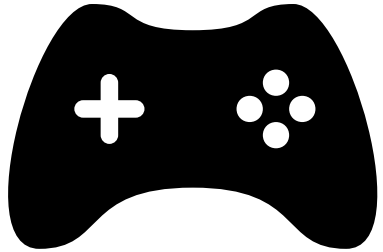
THE GAME

First Vulkan game using the engine

Engine had existing DX11 and DX12 support on top of an internal rendering API

Once the Vulkan version was somewhat stable, we started to look at the performance side of things ☺

THE GAME



- Best practices

-> hopefully minor changes only

- Other optimization opportunities?

-> require probably a bit more work

-> start early enough, can introduce new problems

BEST PRACTICES

- Is compression enabled for the G-buffer render targets?
- How do the barriers look?
- Can we make use of the copy queue?
- What about the shader building infrastructure?
- … usage flags, use of correct layouts, etc.

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This is a checklist you can follow through and verify for your own engine

OTHER OPTIMIZATION OPPORTUNITIES

- Very engine specific
- In this particular case, there was a great **async compute** opportunity

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Vulkan specific feature

AGENDA

- DCC – Delta Color Compression
- Barriers 🤓 and other synchronization hassles
- Other small things
- Q&A

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OR THE PREVIOUSLY MENTIONED CHECKLIST

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- Barriers 🤓 and other synchronization hassles
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+ async compute opportunity

DCC – DELTA COLOR COMPRESSION

- What is DCC?
- Why do we want it

-> Performance impact

- How to enable DCC?

-> the journey of enabling DCC for this game 

WHAT IS DCC?

- DCC – Delta Color Compression
- Takes advantage of the fact that render targets tend to store slowly varying data
  - E.g. a blue sky will have little variance between the pixels

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- Takes advantage of the fact that render targets tend to store slowly varying data
  - E.g. a blue sky will have little variance between the pixels

- Stores whole blocks – one value is stored with full precision, rest is stored as delta
- It‘s lossless

WHY DO WE WANT DCC?

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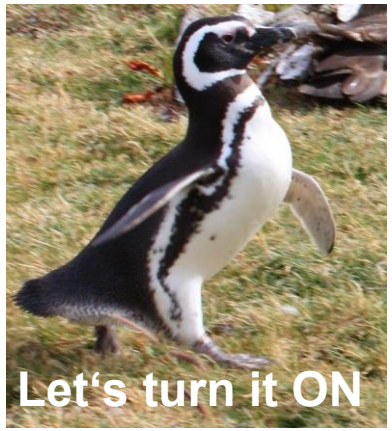
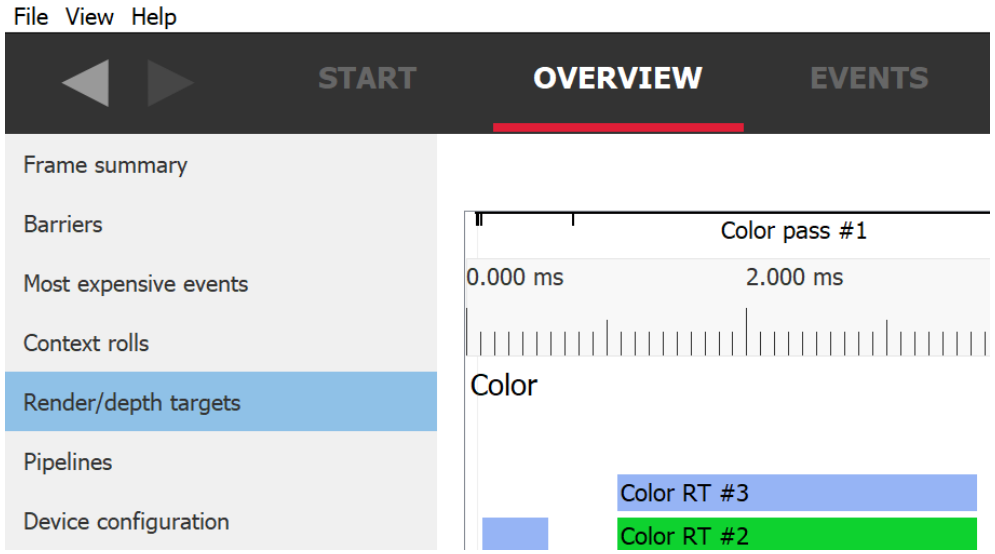


AMD

HOW DO I KNOW DCC IS ENABLED?

Use Radeon GPU Profiler (RGP):



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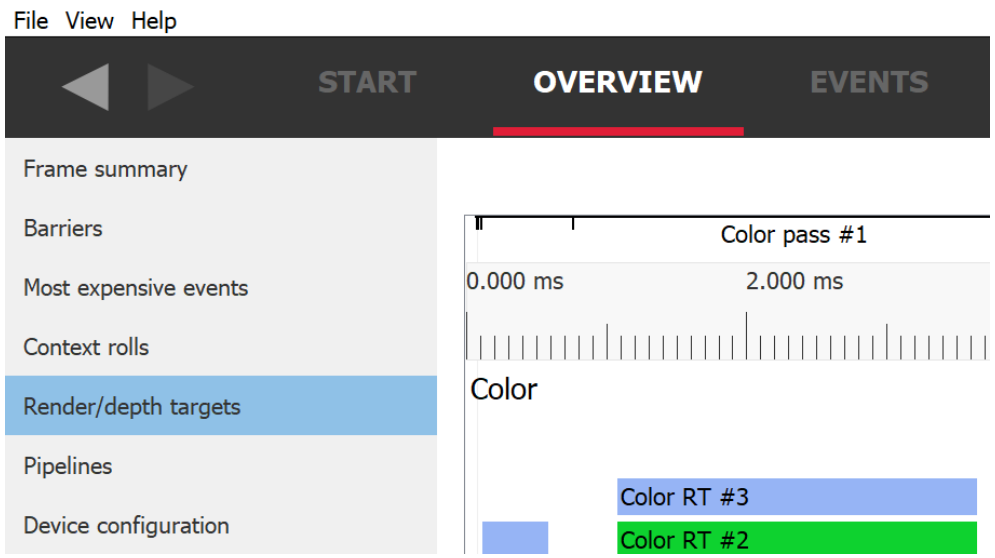

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	Color RT #0	VK_FORMAT_R8G8B8A8_SRGB	3840	2160	32 MB	1874	OFF	178%	1	0 / 1874	5.044 ms
	Color RT #1	VK_FORMAT_A2R10G10B10_UNORM_PACK32	3840	2160	32 MB	1577	OFF	178%	1	0 / 1577	3.761 ms
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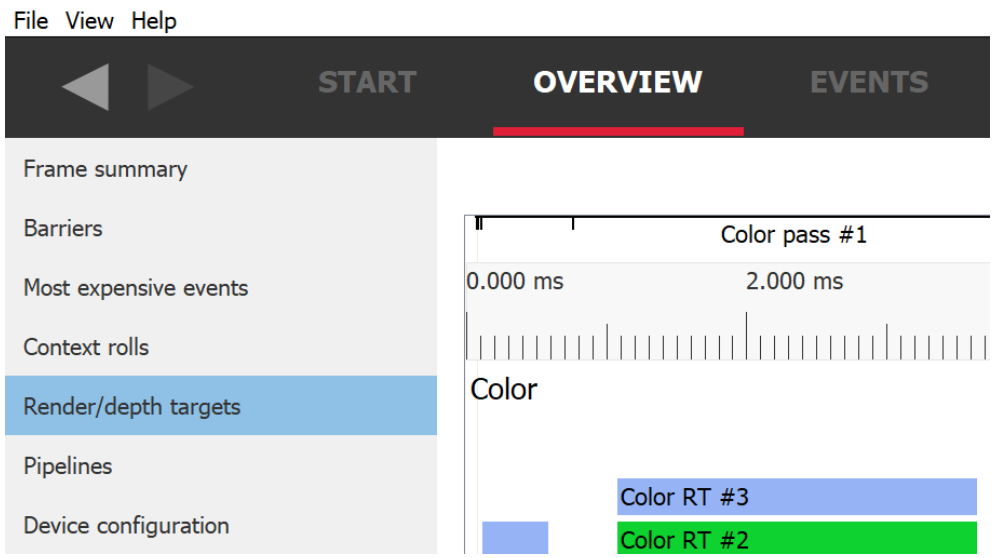

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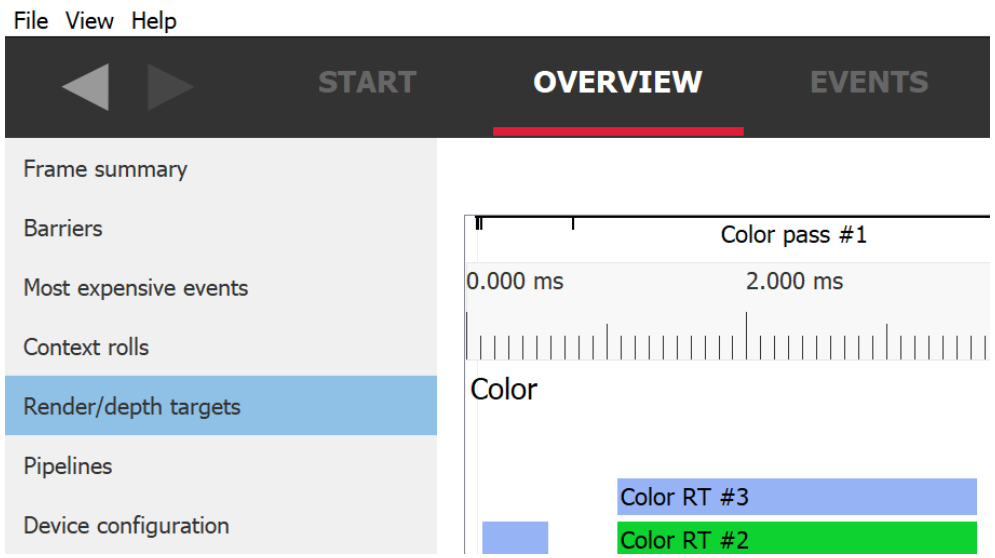

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- All of the below are supported

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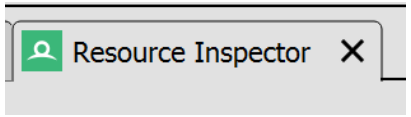

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CreateInfo	VkImageCreateInfo()
sType	VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO
pNext	NULL
flags	VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT
imageType	VK_IMAGE_TYPE_2D
format	VK_FORMAT_R8G8B8A8_SRGB
extent	VkExtent3D()
mipLevels	1
arrayLayers	1
samples	VK_SAMPLE_COUNT_1_BIT
tiling	VK_IMAGE_TILING_OPTIMAL
usage	VK_IMAGE_USAGE_TRANSFER_SRC_BIT | VK_IMAGE_USAGE_TRANSFER_DST_BIT | VK_IMAGE_USAGE_SAMPLED_BIT | VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT
sharingMode	VK_SHARING_MODE_EXCLUSIVE
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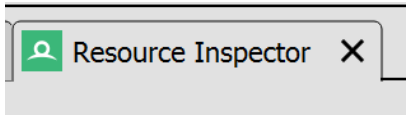

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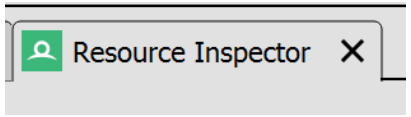

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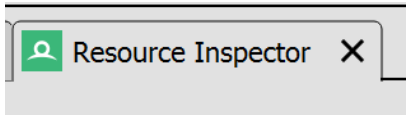

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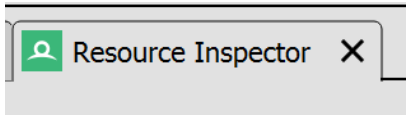

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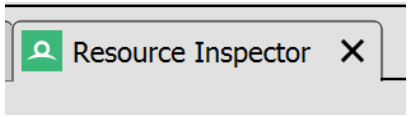

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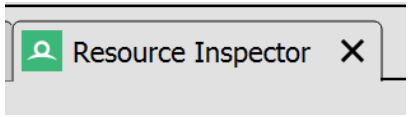

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VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT disables DCC

WHY?

AMD

VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT

DCC only works for float **XOR** integer formats

-> R8G8B8A8_SFLOAT, DCC is supported

-> R8G8B8A8_UNORM, DCC is supported

Etc.

VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT

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How does the driver know the format of the image?

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VkImageCreateInfo imageCreateInfo = {};
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What happens when the mutable bit is set?

VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT

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> “VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT specifies that the image can be used to create a VkImageView with a **different format** from the image.”

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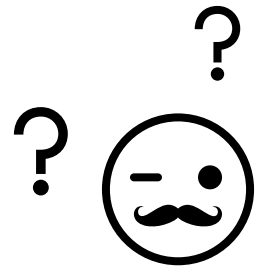
For **float XOR integer**, the driver needs to distinguish between:

1. Image views with integer **AND** float formats are used on the image -> DCC must be **disabled**
2. Unsupported format is used -> DCC must be **disabled**
3. **Only integer** formats are used, e.g. UNORM and SRGB -> DCC can be **enabled**
4. **Only float** formats are used -> DCC can be **enabled**

The driver can’t know if enabling DCC is safe by simply looking at the mutable bit.



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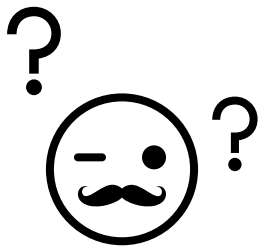

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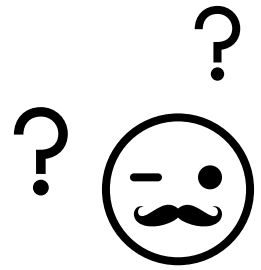

VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT

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-> provide additional information by using

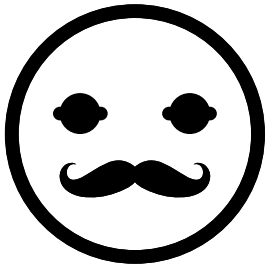
VK_KHR_image_format_list

```
typedef struct VkImageFormatListCreateInfoKHR {
    VkStructureType    sType;
    const void*        pNext;
    uint32_t           viewFormatCount;
    const VkFormat*    pViewFormats;
} VkImageFormatListCreateInfoKHR;
```

VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT

```
VkImageFormatListCreateInfoKHR imageFormatList = {};
imageFormatList.sType = VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO_KHR
imageFormatList.pNext = … ;
imageFormatList.viewFormatCount = formatCount;
imageFormatList.pViewFormats = formats;  // array of VkFormat

VkImageCreateInfo imageCreateInfo = {};
imageCreateInfo.format = VK_FORMAT_R8G8B8A8_SRGB;
imageCreateInfo.flags = VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT;
imageCreateInfo.pNext = &imageFormatList;
…
```

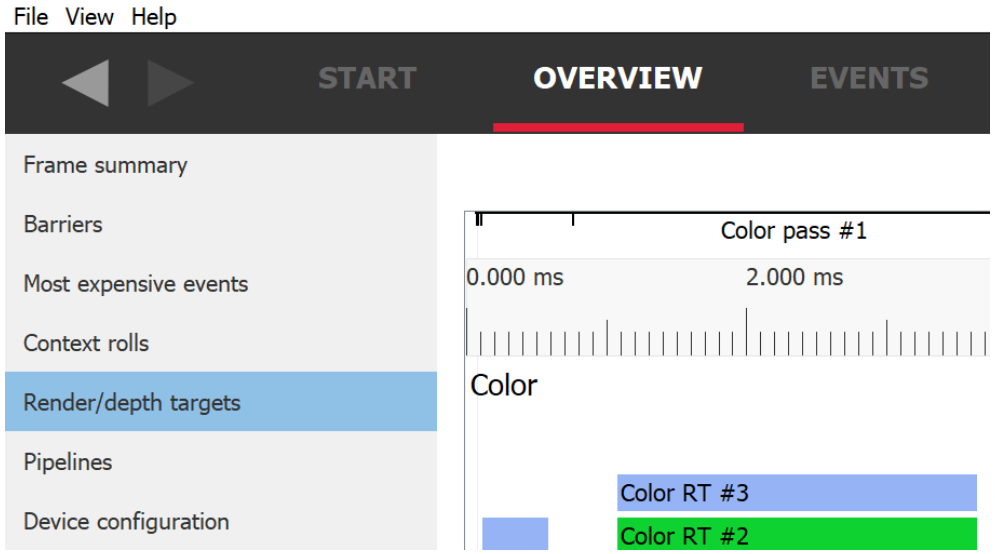


VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT

vkCreateImage	
device	**Device 10**
CreateInfo	VkImageCreateInfo()
sType	VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO
pNext	VkImageFormatListCreateInfoKHR()
sType	VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO_KHR
pNext	NULL
viewFormatCount	2
pViewFormats	VkFormat[]
[0]	VK_FORMAT_R8G8B8A8_UNORM
[1]	VK_FORMAT_UNDEFINED
flags	VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT
imageType	VK_IMAGE_TYPE_2D
format	VK_FORMAT_R8G8B8A8_SRGB
extent	VkExtent3D()
mipLevels	1
arrayLayers	1
samples	VK_SAMPLE_COUNT_1_BIT
tiling	VK_IMAGE_TILING_OPTIMAL
usage	VK_IMAGE_USAGE_TRANSFER_SRC_BIT | VK_IMAGE_USAGE_TRANSFER_DST_BIT | VK_IMAGE_USAGE_SAMPLED_BIT | VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT
sharingMode	VK_SHARING_MODE_CONCURRENT
queueFamilyIndexCount	3
pQueueFamilyIndices	uint32_t[]
initialLayout	VK_IMAGE_LAYOUT_UNDEFINED

DOUBLE-CHECK IF THE CHANGE HAD THE INTENDED EFFECT …

Use Radeon GPU Profiler (RGP):



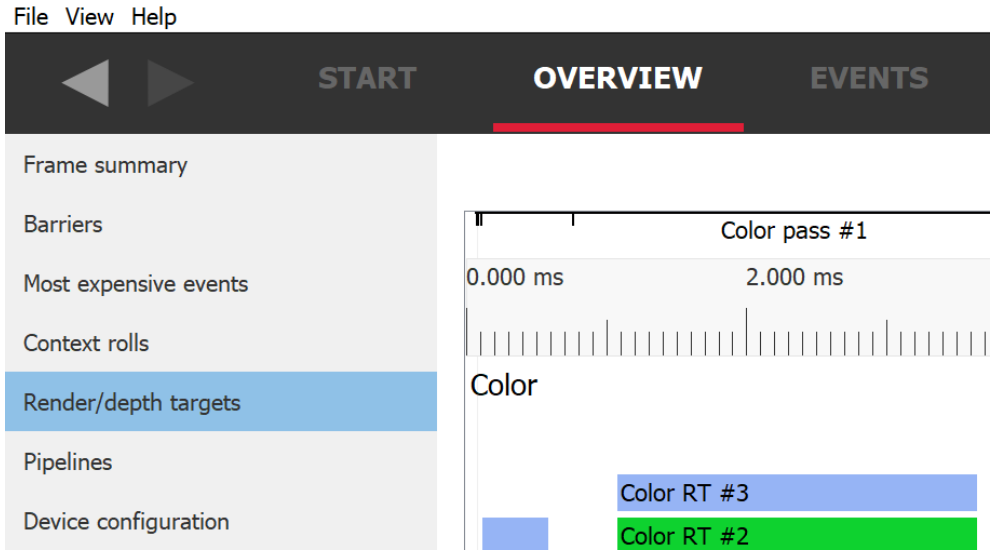
	Name	Format	Width	Height	Size in memory	Draw calls	Compression	Pixel wavefront ratio	Sample count	Out of order draw calls	Duration
	Color RT #0	VK_FORMAT_R8G8B8A8_SRGB	3840	2160	32 MB	1874	OFF	178%	1	0 / 1874	5.044 ms
	Color RT #1	VK_FORMAT_A2R10G10B10_UNORM_PACK32	3840	2160	32 MB	1577	OFF	178%	1	0 / 1577	3.761 ms
	Color RT #2	VK_FORMAT_R8G8B8A8_UNORM	3840	2160	32 MB	1870	OFF	178%	1	0 / 1870	4.332 ms
	Color RT #3	VK_FORMAT_R8G8B8A8_UNORM	3840	2160	32 MB	1871	OFF	178%	1	0 / 1871	4.671 ms

AMD

DOUBLE-CHECK IF THE CHANGE HAD THE INTENDED EFFECT …

Use Radeon GPU Profiler (RGP):

It did not … 



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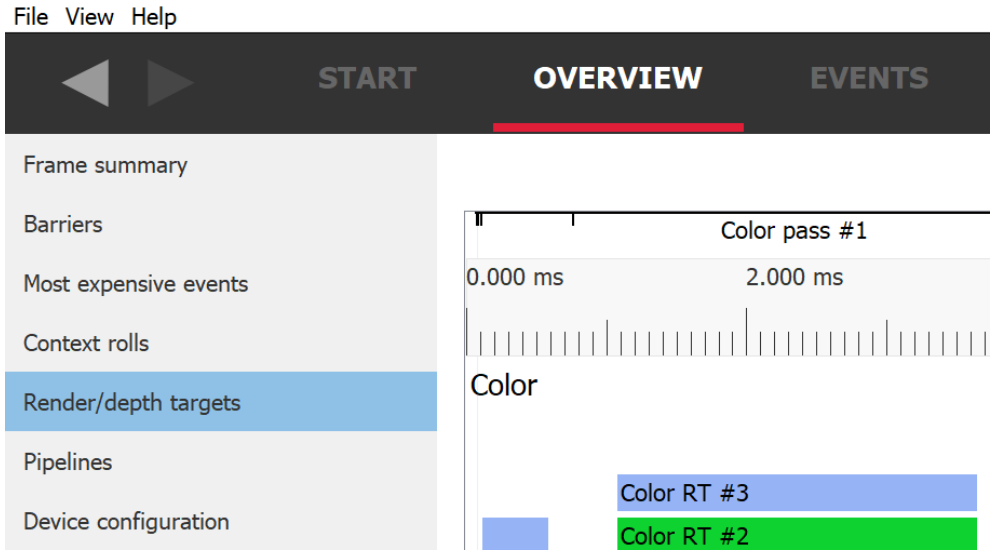
	Color RT #1	VK_FORMAT_A2R10G10B10_UNORM_PACK32	3840	2160	32 MB	1577	OFF	178%	1	0 / 1577	3.761 ms
	Color RT #2	VK_FORMAT_R8G8B8A8_UNORM	3840	2160	32 MB	1870	OFF	178%	1	0 / 1870	4.332 ms
	Color RT #3	VK_FORMAT_R8G8B8A8_UNORM	3840	2160	32 MB	1871	OFF	178%	1	0 / 1871	4.671 ms

DOUBLE-CHECK IF THE CHANGE HAD THE INTENDED EFFECT …

Use Radeon GPU Profiler (RGP):

It did not …

WHY?



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	Color RT #3	VK_FORMAT_R8G8B8A8_UNORM	3840	2160	32 MB	1871	OFF	178%	1	0 / 1871	4.671 ms

AMD

LET‘S EXAMINE CREATE IMAGE INFO AGAIN

vkCreateImage	
device	**Device 10**
CreateInfo	VkImageCreateInfo()
sType	VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO
pNext	VkImageFormatListCreateInfoKHR()
sType	VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO_KHR
pNext	NULL
viewFormatCount	2
pViewFormats	VkFormat[]
[0]	VK_FORMAT_R8G8B8A8_UNORM
[1]	VK_FORMAT_UNDEFINED
flags	VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT
imageType	VK_IMAGE_TYPE_2D
format	VK_FORMAT_R8G8B8A8_SRGB
extent	VkExtent3D()
mipLevels	1
arrayLayers	1
samples	VK_SAMPLE_COUNT_1_BIT
tiling	VK_IMAGE_TILING_OPTIMAL
usage	VK_IMAGE_USAGE_TRANSFER_SRC_BIT | VK_IMAGE_USAGE_TRANSFER_DST_BIT | VK_IMAGE_USAGE_SAMPLED_BIT | VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT
sharingMode	VK_SHARING_MODE_CONCURRENT
queueFamilyIndexCount	3
pQueueFamilyIndices	uint32_t[]
initialLayout	VK_IMAGE_LAYOUT_UNDEFINED

LET‘S EXAMINE CREATE IMAGE INFO AGAIN

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device	**Device 10**
CreateInfo	VkImageCreateInfo()
sType	VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO
pNext	VkImageFormatListCreateInfoKHR()
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extent	VkExtent3D()
mipLevels	1
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usage	VK_IMAGE_USAGE_TRANSFER_SRC_BIT | VK_IMAGE_USAGE_TRANSFER_DST_BIT | VK_IMAGE_USAGE_SAMPLED_BIT | VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT
sharingMode	VK_SHARING_MODE_CONCURRENT
queueFamilyIndexCount	3
pQueueFamilyIndices	uint32_t[]
initialLayout	VK_IMAGE_LAYOUT_UNDEFINED

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imageType	VK_IMAGE_TYPE_2D
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sharingMode	VK_SHARING_MODE_CONCURRENT
queueFamilyIndexCount	3
pQueueFamilyIndices	uint32_t[]
initialLayout	VK_IMAGE_LAYOUT_UNDEFINED

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vkCreateImage	
device	**Device 10**
CreateInfo	VkImageCreateInfo()
sType	VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO
pNext	VkImageFormatListCreateInfoKHR() ✓
sType	VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO_KHR
pNext	NULL
viewFormatCount	2
pViewFormats	VkFormat[]
[0]	VK_FORMAT_R8G8B8A8_UNORM
[1]	VK_FORMAT_UNDEFINED
flags	VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT
imageType	VK_IMAGE_TYPE_2D
format	VK_FORMAT_R8G8B8A8_SRGB ✓
extent	VkExtent3D()
mipLevels	1
arrayLayers	1
samples	VK_SAMPLE_COUNT_1_BIT
tiling	VK_IMAGE_TILING_OPTIMAL
usage	VK_IMAGE_USAGE_TRANSFER_SRC_BIT | VK_IMAGE_USAGE_TRANSFER_DST_BIT | VK_IMAGE_USAGE_SAMPLED_BIT | VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT ✓
sharingMode	VK_SHARING_MODE_CONCURRENT
queueFamilyIndexCount	3
pQueueFamilyIndices	uint32_t[]
initialLayout	VK_IMAGE_LAYOUT_UNDEFINED

Async compute support was added to the engine!

As a side-effect, now all resources have by default sharing mode concurrent

LET‘S EXAMINE CREATE IMAGE INFO AGAIN

vkCreateImage	
device	**Device 10**
CreateInfo	VkImageCreateInfo()
sType	VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO
pNext	VkImageFormatListCreateInfoKHR() ✓
sType	VK_STRUCTURE_TYPE_IMAGE_FORMAT_LIST_CREATE_INFO_KHR
pNext	NULL
viewFormatCount	2
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[0]	VK_FORMAT_R8G8B8A8_UNORM
[1]	VK_FORMAT_UNDEFINED
flags	VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT
imageType	VK_IMAGE_TYPE_2D
format	VK_FORMAT_R8G8B8A8_SRGB ✓
extent	VkExtent3D()
mipLevels	1
arrayLayers	1
samples	VK_SAMPLE_COUNT_1_BIT
tiling	VK_IMAGE_TILING_OPTIMAL
usage	VK_IMAGE_USAGE_TRANSFER_SRC_BIT | VK_IMAGE_USAGE_TRANSFER_DST_BIT | VK_IMAGE_US…BIT ✓
sharingMode	VK_SHARING_MODE_CONCURRENT
queueFamilyIndexCount	3
pQueueFamilyIndices	uint32_t[]
initialLayout	VK_IMAGE_LAYOUT_UNDEFINED

Async compute support was added to the engine!

As a side-effect, now all resources have by default sharing mode concurrent

VK_SHARING_MODE_CONCURRENT

Spec:

> “VK_SHARING_MODE_CONCURRENT specifies that concurrent access to any range or image subresource of the object from multiple queue families is supported.”

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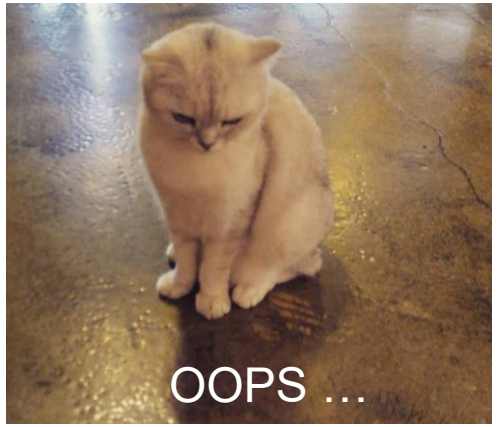
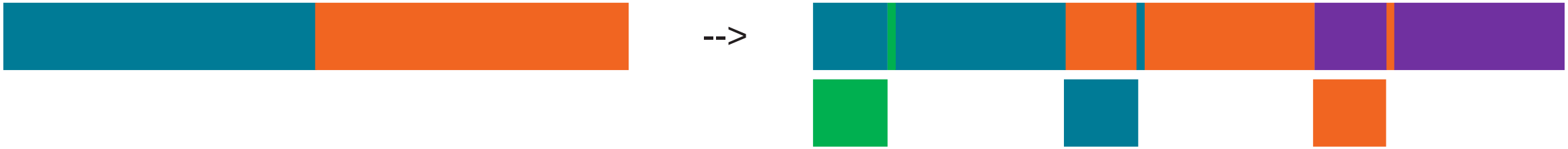
> “VK_SHARING_MODE_CONCURRENT specifies that concurrent access to any range or image subresource of the object from multiple queue families is supported.”

With VK_SHARING_MODE_CONCURRENT **DCC is disabled**



VK_SHARING_MODE_CONCURRENT

Quick side note on async compute ☺

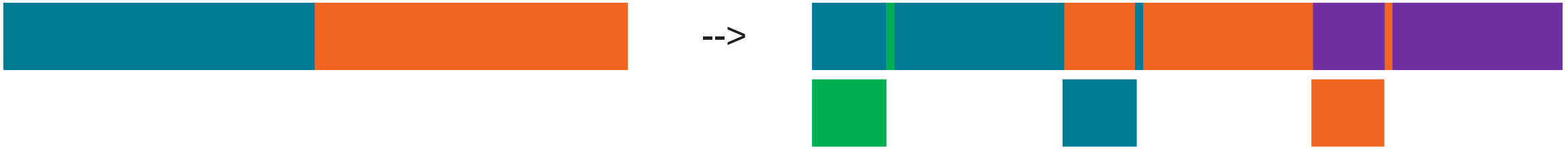


Improved performance of up to ~10%

AMD

VK_SHARING_MODE_CONCURRENT

Quick side note on async compute ☺



Improved performance of up to ~10%

What about DCC?

VK_ SHARING_MODE_CONCURRENT

How to go back to VK_SHARING_MODE_EXCLUSIVE to get DCC enabled?

-> Obviously, if a resource is accessed only by **one** queue, just switch back to EXCLUSIVE

But what about resources, which are accessed by several queue families?

-> transfer queue family ownership

TRANSFER QUEUE FAMILY OWNERSHIP

Done in 2 steps

1. **Release** the exclusive ownership from the **source** queue family
2. **Acquire** the exclusive ownership for the **destination** queue family

TRANSFER QUEUE FAMILY OWNERSHIP

Done in 2 steps

1. **Release** the exclusive ownership from the **source** queue family
2. **Acquire** the exclusive ownership for the **destination** queue family

Example:

Queue family 0 holds currently the exclusive ownership of image A

Queue family 1 wants to acquire exclusive ownership of image A

RELEASE THE EXCLUSIVE OWNERSHIP

```
VkImageMemoryBarrier imageMemoryBarrier = {};
imageMemoryBarrier.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
imageMemoryBarrier.srcAccessMask = …
imageMemoryBarrier.dstAccessMask = 0;
imageMemoryBarrier.oldLayout = oldLayoutImageA;
imageMemoryBarrier.newLayout = newLayoutImageA;
imageMemoryBarrier.srcQueueFamilyIndex = 0;
imageMemoryBarrier.dstQueueFamilyIndex = 1;
imageMemoryBarrier.image = imageA;
imageMemoryBarrier .subresourceRange = subresourceRangeImageA;
…
vkCmdPipelineBarrier(cmdBuf, …);
…
vkQueueSubmit(queueFamily0,…, submitInfo, …);
```

RELEASE THE EXCLUSIVE OWNERSHIP

```
VkImageMemoryBarrier imageMemoryBarrier = {};
imageMemoryBarrier.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
imageMemoryBarrier.srcAccessMask = …
imageMemoryBarrier.dstAccessMask = 0;
imageMemoryBarrier.oldLayout = oldLayoutImageA;
imageMemoryBarrier.newLayout = newLayoutImageA;
imageMemoryBarrier.srcQueueFamilyIndex = 0;
imageMemoryBarrier.dstQueueFamilyIndex = 1;
imageMemoryBarrier.image = imageA;
imageMemoryBarrier .subresourceRange = subresourceRangeImageA;
…
vkCmdPipelineBarrier(cmdBuf, …);
…
vkQueueSubmit(queueFamily0,…, submitInfo, …);
```

Associated to a commandPool

RELEASE THE EXCLUSIVE OWNERSHIP

```
VkImageMemoryBarrier imageMemoryBarrier = {};
imageMemoryBarrier.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
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imageMemoryBarrier.oldLayout = oldLayoutImageA;
imageMemoryBarrier.newLayout = newLayoutImageA;
imageMemoryBarrier.srcQueueFamilyIndex = 0;
imageMemoryBarrier.dstQueueFamilyIndex = 1;
imageMemoryBarrier.image = imageA;
imageMemoryBarrier .subresourceRange = subresourceRangeImageA;
…
vkCmdPipelineBarrier(cmdBuf, …);
…
vkQueueSubmit(queueFamily0,…, submitInfo, …);
```

Associated to a commandPool → Associated to queue family **0**

RELEASE THE EXCLUSIVE OWNERSHIP

```
VkImageMemoryBarrier imageMemoryBarrier = {};
imageMemoryBarrier.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
imageMemoryBarrier.srcAccessMask = …
imageMemoryBarrier.dstAccessMask = 0;
imageMemoryBarrier.oldLayout = oldLayoutImageA;
imageMemoryBarrier.newLayout = newLayoutImageA;
imageMemoryBarrier.srcQueueFamilyIndex = 0;
imageMemoryBarrier.dstQueueFamilyIndex = 1;
imageMemoryBarrier.image = imageA;
imageMemoryBarrier .subresourceRange = subresourceRangeImageA;
…
vkCmdPipelineBarrier(cmdBuf, …);
…
vkQueueSubmit(queueFamily0,…, submitInfo, …);
```

Semaphore to sync across queues

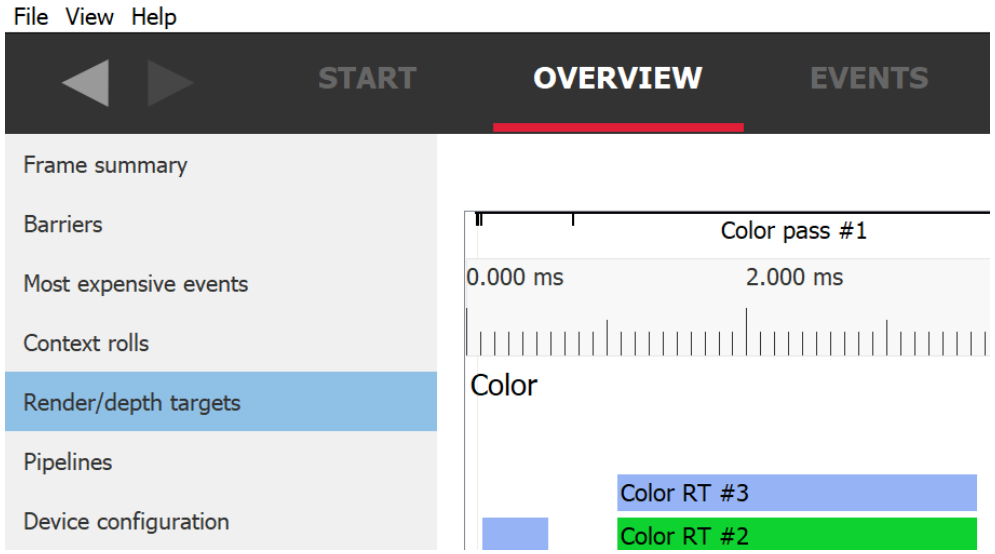
ACQUIRE THE EXCLUSIVE OWNERSHIP

```
VkImageMemoryBarrier imageMemoryBarrier = {};
imageMemoryBarrier.sType = VK_STRUCTURE_TYPE_IMAGE_MEMORY_BARRIER;
imageMemoryBarrier.srcAccessMask = 0;
imageMemoryBarrier.dstAccessMask = …
imageMemoryBarrier.oldLayout = oldLayoutImageA;
imageMemoryBarrier.newLayout = newLayoutImageA;
imageMemoryBarrier.srcQueueFamilyIndex = 0;
imageMemoryBarrier.dstQueueFamilyIndex = 1;
imageMemoryBarrier.image = imageA;
imageMemoryBarrier .subresourceRange = subresourceRangeImageA;
…
vkCmdPipelineBarrier(cmdBuf, …);
…
vkQueueSubmit(queueFamily1,…, submitInfo, …);
```

Associated to a commandPool → Associated to queue family **1**

LET‘S CHECK AGAIN ☺

Use Radeon GPU Profiler (RGP):

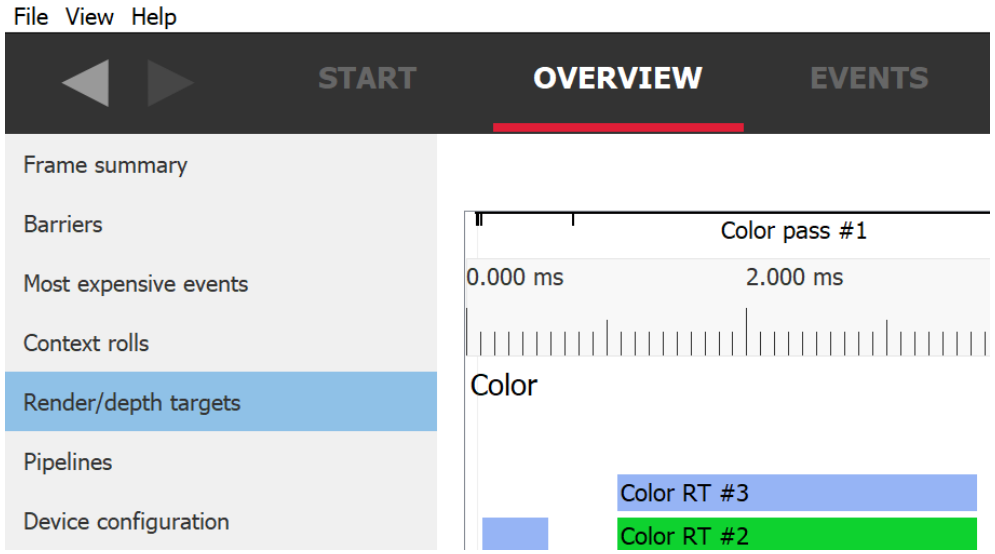


	Name	Format	Width	Height	Size in memory	Draw calls	Compression	Pixel wavefront ratio	Sample count	Out of order draw calls	Duration
	Color RT #0	VK_FORMAT_R8G8B8A8_SRGB	1920	1080	8 MB	1917	ON	202%	1	0 / 1917	1.853 ms
	Color RT #1	VK_FORMAT_A2R10G10B10_UNORM_PACK32	1920	1080	8 MB	1596	ON	202%	1	0 / 1596	1.468 ms
	Color RT #2	VK_FORMAT_R8G8B8A8_UNORM	1920	1080	8 MB	1913	OFF	202%	1	0 / 1913	1.617 ms
	Color RT #3	VK_FORMAT_R8G8B8A8_UNORM	1920	1080	8 MB	1914	ON	202%	1	0 / 1914	1.722 ms

AMD

LET‘S CHECK AGAIN ☺

Use Radeon GPU Profiler (RGP):



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	Color RT #2	VK_FORMAT_R8G8B8A8_UNORM	1920	1080	8 MB	1913	OFF	202%	1	0 / 1913	1.617 ms
	Color RT #3	VK_FORMAT_R8G8B8A8_UNORM	1920	1080	8 MB	1914	ON	202%	1	0 / 1914	1.722 ms

AMD

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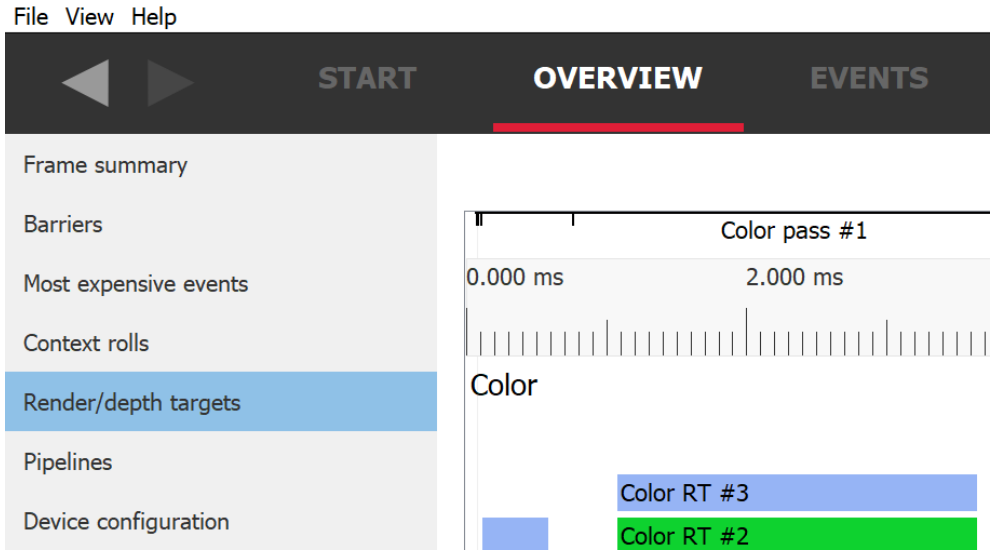

The performance increased about ~5-10%, depending on AMD graphics card

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AMD

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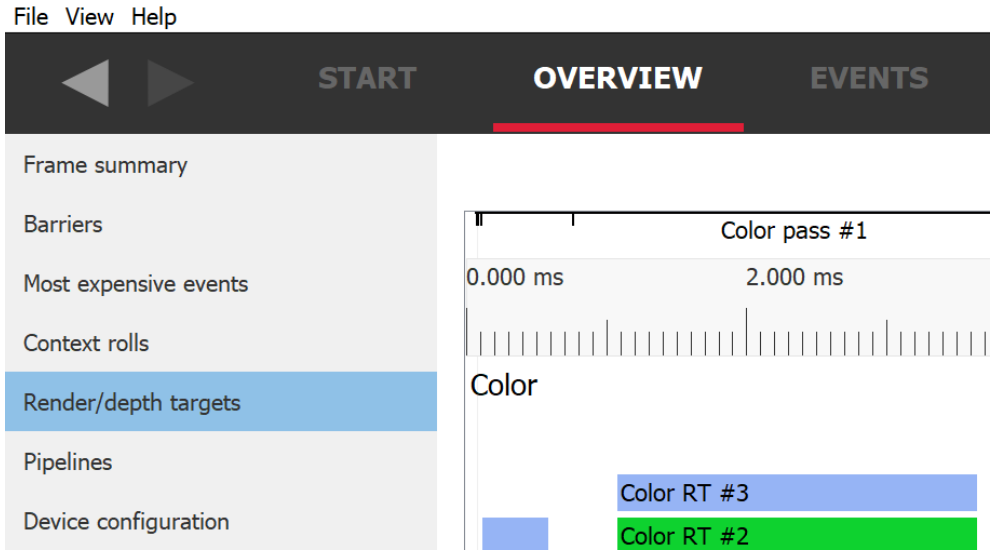

The performance increased about ~5-10%, depending on AMD graphics card

	Name	Format	Width	Height	Size in memory	Draw calls	Compres				Out of order draw calls	Duration
	Color RT #0	VK_FORMAT_R8G8B8A8_SRGB	1920	1080	8 MB	1917	ON				0 / 1917	1.853 ms
	Color RT #1	VK_FORMAT_A2R10G10B10_UNORM_PACK32	1920	1080	8 MB	1596	ON		202%	1	0 / 1596	1.468 ms
	Color RT #2	VK_FORMAT_R8G8B8A8_UNORM	1920	1080	8 MB	1913	OFF		202%	1	0 / 1913	1.617 ms
	Color RT #3	VK_FORMAT_R8G8B8A8_UNORM	1920	1080	8 MB	1914	ON		202%	1	0 / 1914	1.722 ms

What about this one?

AMD

AND ONCE AGAIN … ☺

Color RT #2 – G-buffer resource #2

⌄ CreateInfo	VkImageCreateInfo()
sType	VK_STRUCTURE_TYPE_IMAGE_CREATE_INFO
› pNext	VkImageFormatListCreateInfoKHR() ✓
flags	VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT
imageType	VK_IMAGE_TYPE_2D
format	VK_FORMAT_R8G8B8A8_UNORM ✓
› extent	VkExtent3D()
mipLevels	1
arrayLayers	1
samples	VK_SAMPLE_COUNT_1_BIT
tiling	VK_IMAGE_TILING_OPTIMAL
usage	VK_IMAGE_USAGE_TRANSFER_SRC_BIT | VK_IMAGE_USAGE_TRANSFER_DST_BIT | VK_IMAGE_USAGE_SAMPLED_BIT | VK_IMAGE_USAGE_STORAGE_BIT | VK_IMAGE_USAGE_COLOR_ATTACHMENT_BIT
sharingMode	VK_SHARING_MODE_EXCLUSIVE ✓
queueFamilyIndexCount	0
pQueueFamilyIndices	uint32_t[]
initialLayout	VK_IMAGE_LAYOUT_UNDEFINED

AND ONCE AGAIN … ☺

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USAGE FLAGS

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sharingMode	VK_SHARING_MODE_EXCLUSIVE ✓
queueFamilyIndexCount	0
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Post process moved to the compute queue due to async compute

-> VK_IMAGE_USAGE_STORAGE_BIT is now required for G-buffer resource #2

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Post process moved to the compute queue due to async compute

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WHY?

VK_IMAGE_USAGE_STORAGE_BIT

Spec:

„VK_IMAGE_USAGE_STORAGE_BIT specifies that the image can be used to create a VkImageView suitable for occupying a VkDescriptorSet slot of type VK_DESCRIPTOR_TYPE_STORAGE_IMAGE “

Spec:

„ A storage image (VK_DESCRIPTOR_TYPE_STORAGE_IMAGE) is a descriptor type associated with an image resource via an image view that load, **store**, and atomic operations can be performed on.“

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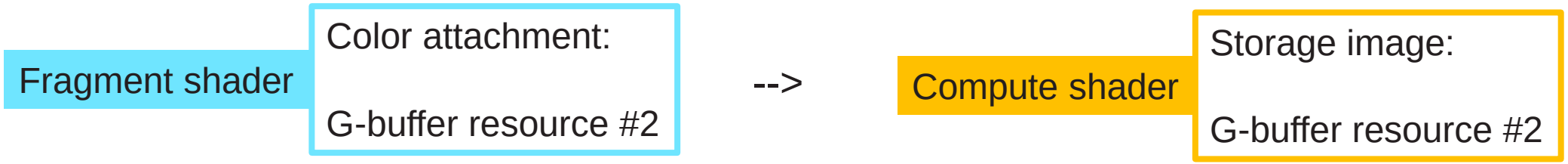

USAGE FLAGS

Usage flags influencing DCC:

- VK_IMAGE_USAGE_STORAGE_BIT – **disables** DCC
- VK_IMAGE_USAGE_SAMPLED_BIT – makes DCC **less** efficient

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Always use what you need, but not more

SUMMARY

VK_IMAGE_CREATE_MUTABLE_FORMAT_BIT

- use VK_KHR_image_format_list

VK_SHARING_MODE_EXCLUSIVE

- don‘t use sharing mode concurrent in production ready code
- use SHARING_MODE_EXCLUSIVE and transfer queue family ownership when required

USAGE FLAGS

- set all the usage flags you need, but not more

OTHER NIT-PICKS CONCERNING DCC

Decompression

- During transfer operations
- General layout

Depth targets

- Compressed differently
- Above guidelines don‘t apply here

There is no rule without expection 

- There might be some tweaks in the driver for specific cards

OTHER NIT-PICKS CONCERNING DCC

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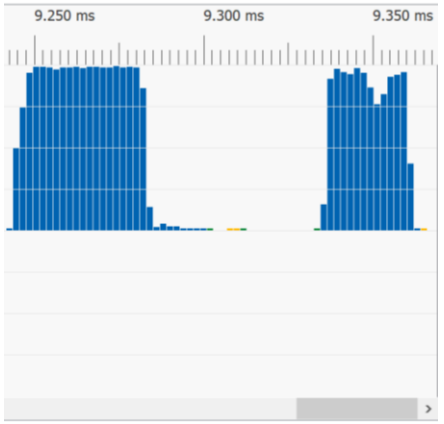

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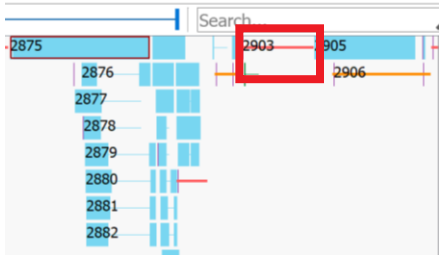

There is no rule without expection 😈

- There might be some tweaks in the driver for specific cards

SYNCHRONIZATION

Barriers

- Placing
- Batching
- Pipeline stage masks

Cross queue synchronization

BARRIERS

- Experience with barriers in this particular game
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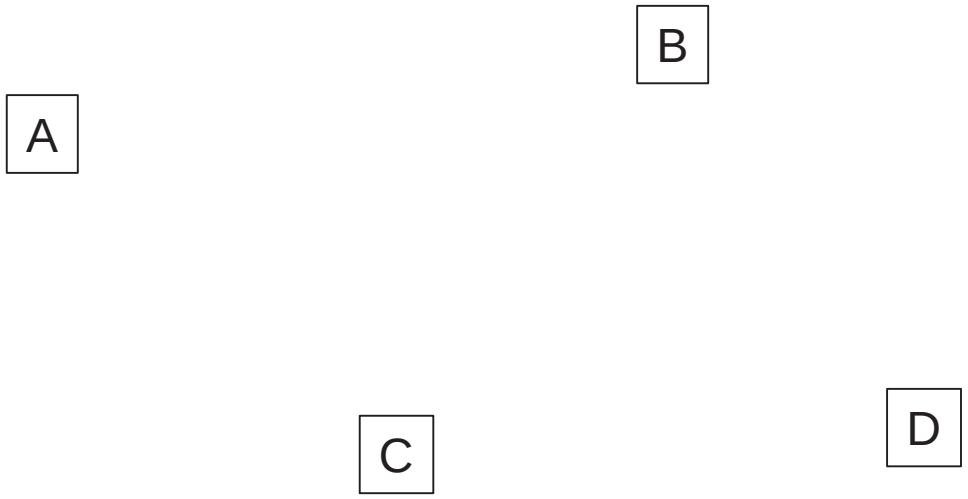
- Other findings

-> Where specifying barriers as precise as possible really pays of

BARRIERS – ORIGINAL SETUP

- The rendering work is logically organized in components – e.g. one shadow map component, one lighting component etc.



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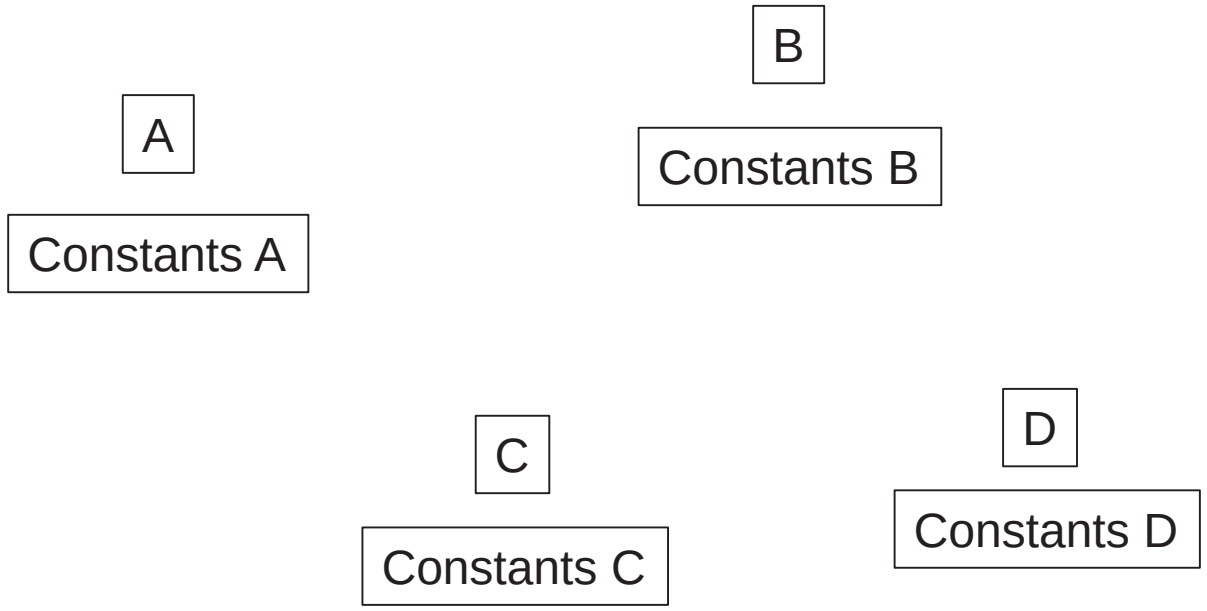

BARRIERS – ORIGINAL SETUP

- Constants information is gathered on the CPU side in the beginning of each frame
- Constants A, B and C are equal, constants D are different
- Component A is independent from Component B
- Component C depends on Component A and B
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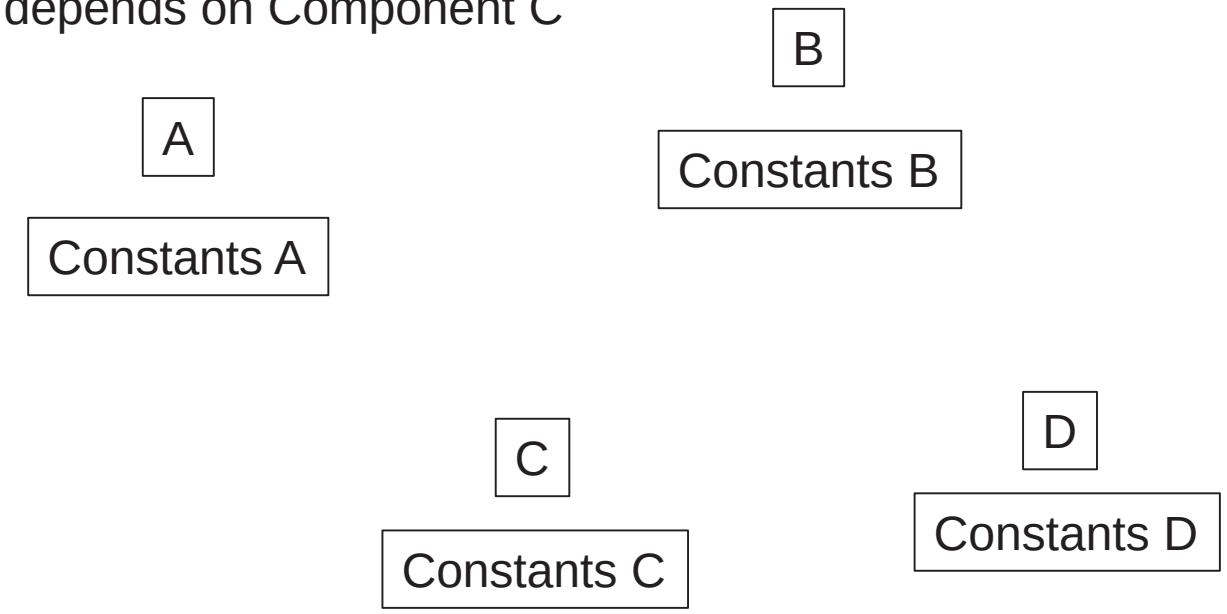

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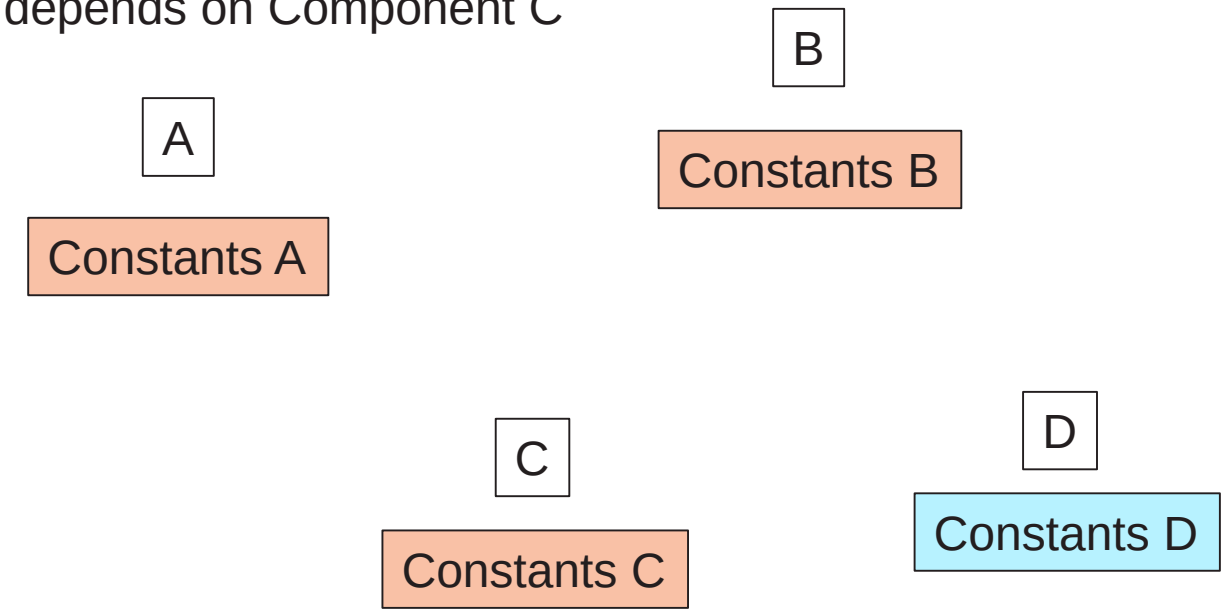

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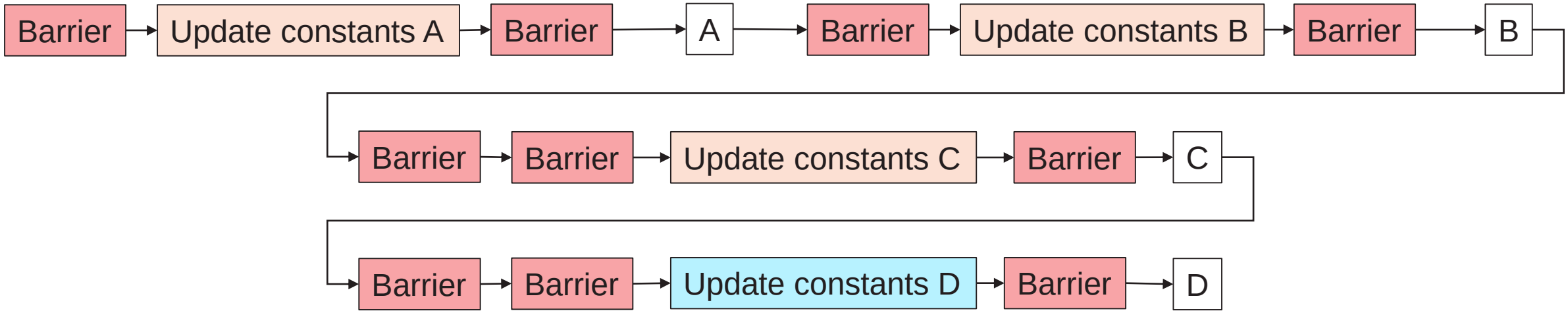

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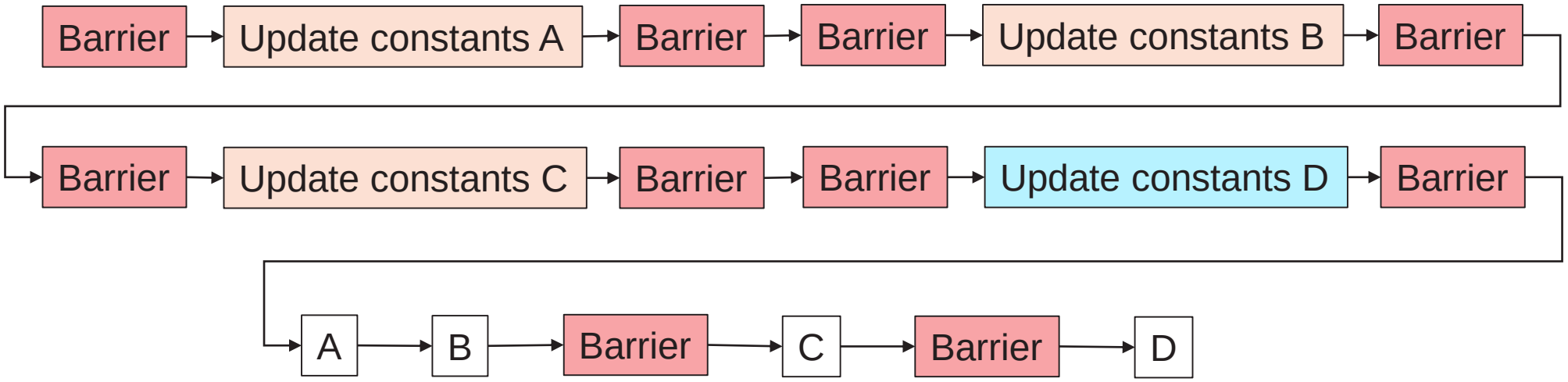

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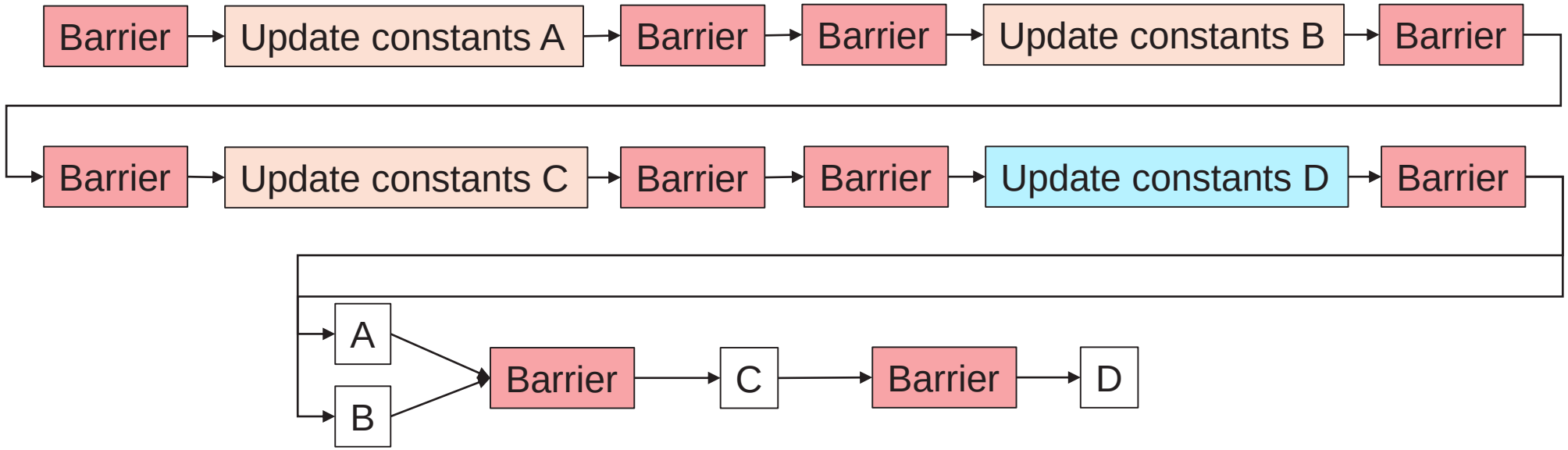

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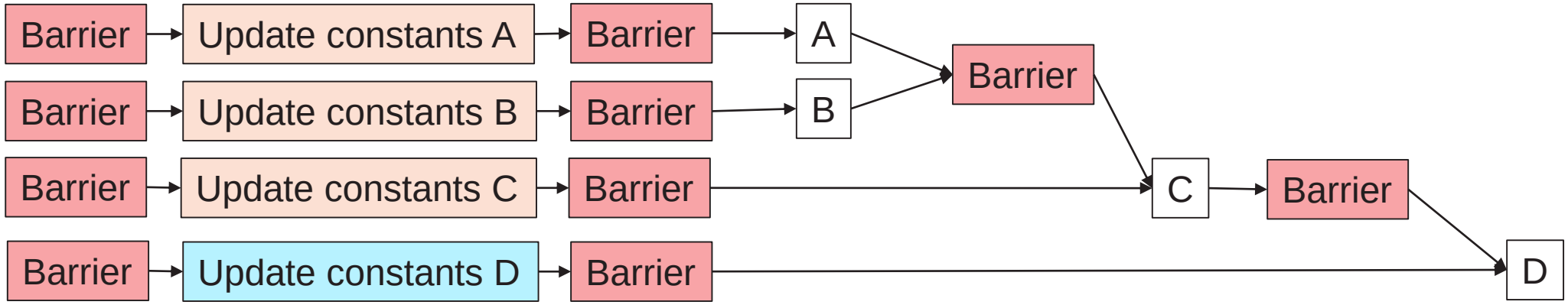

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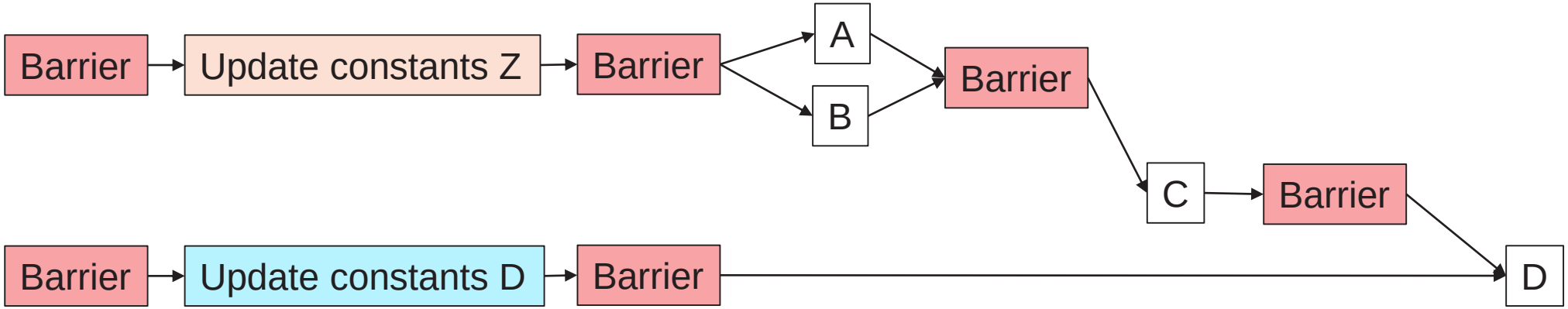
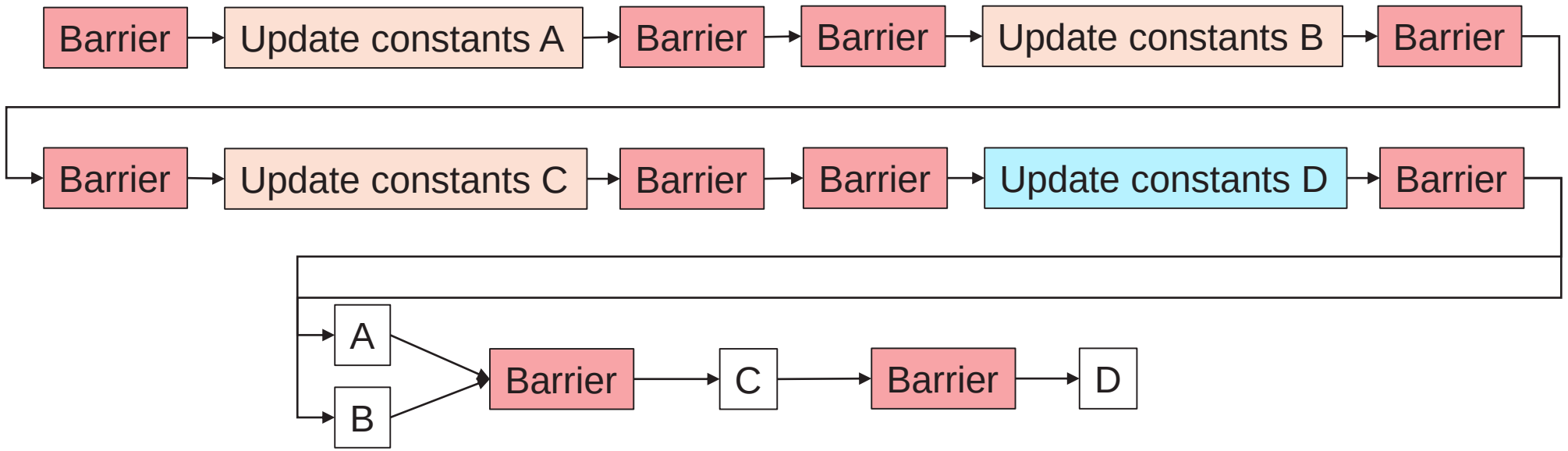


BARRIERS – OPTIMIZED

- This is what we ended up with – but it already had observable changes



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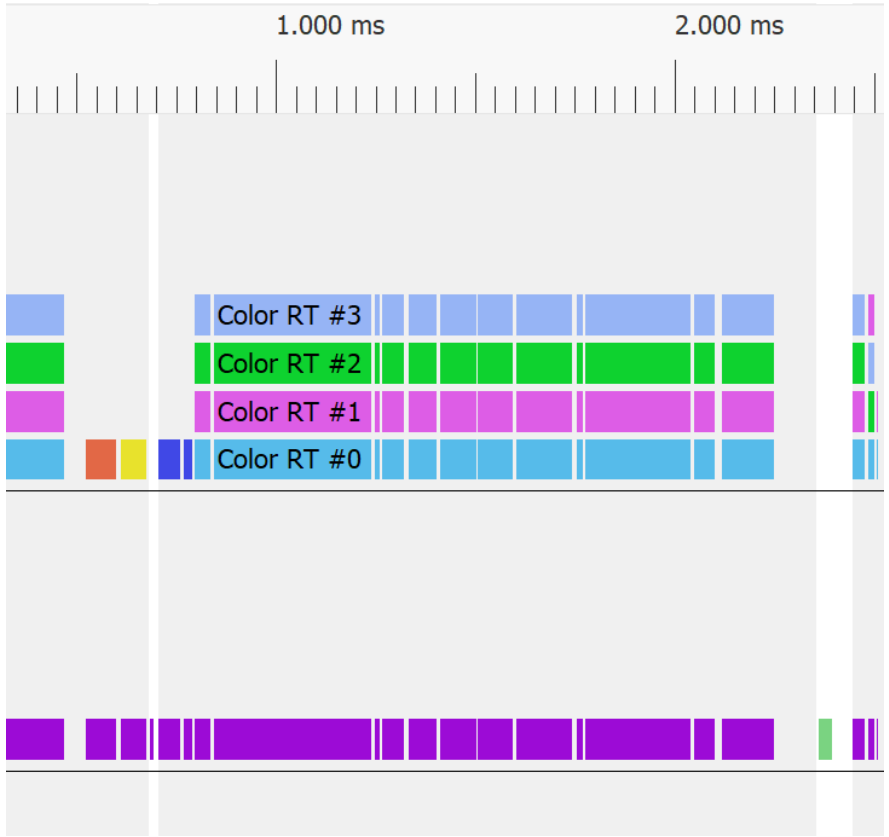
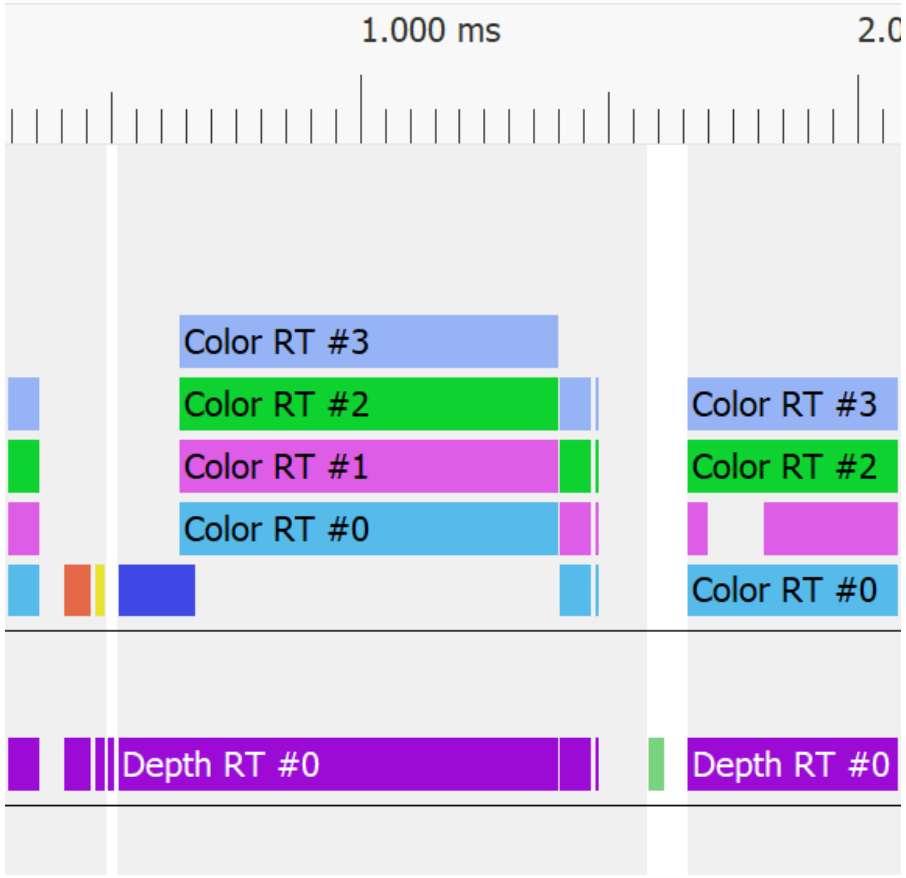


~15%
-->



AMD

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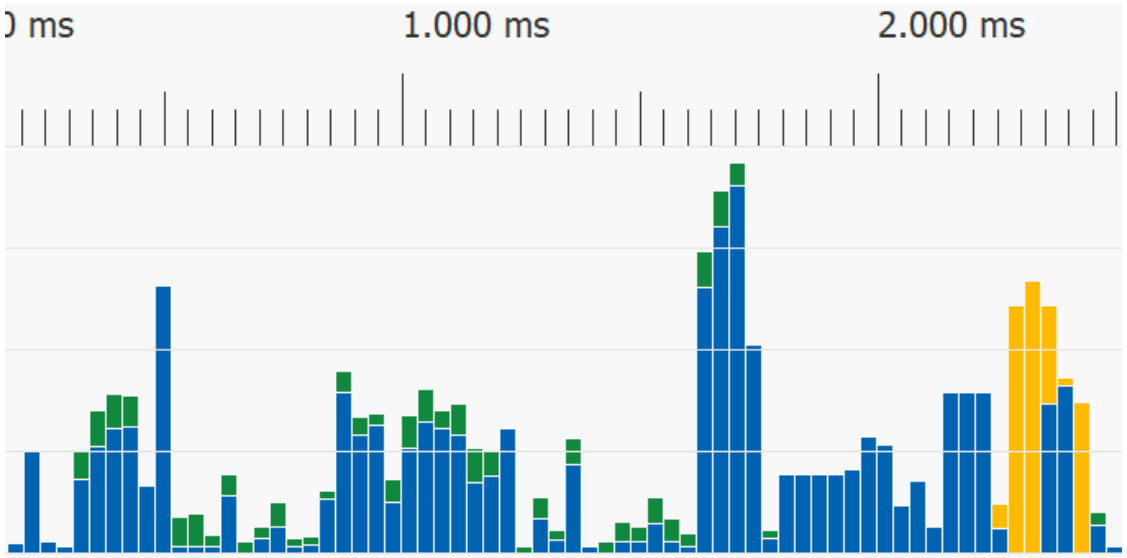

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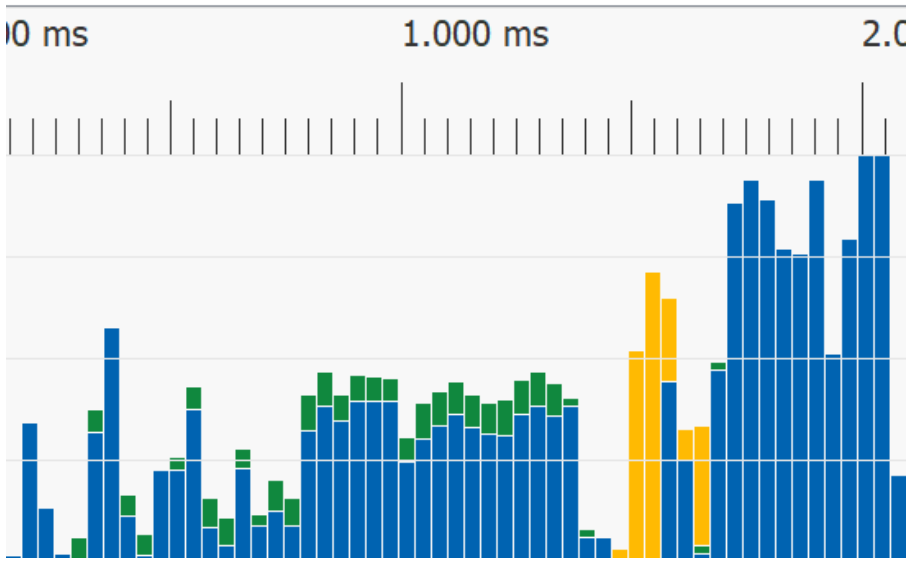

AMD

BARRIER BATCHING

Early builds had several consecutive barriers:

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```
void vkCmdPipelineBarrier(
VkCommandBuffer                 commandBuffer,
VkPipelineStageFlags            srcStageMask,
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VkDependencyFlags               dependencyFlags,
uint32_t                        memoryBarrierCount,
const VkMemoryBarrier*          pMemoryBarriers,
uint32_t                        bufferMemoryBarrierCount,
const VkBufferMemoryBarrier*    pBufferMemoryBarriers,
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Example: 2 image layout transitions

```
vkCmdPipelineBarrier(…, 0, NULL, 0, NULL, 0, &imageBarrierA);
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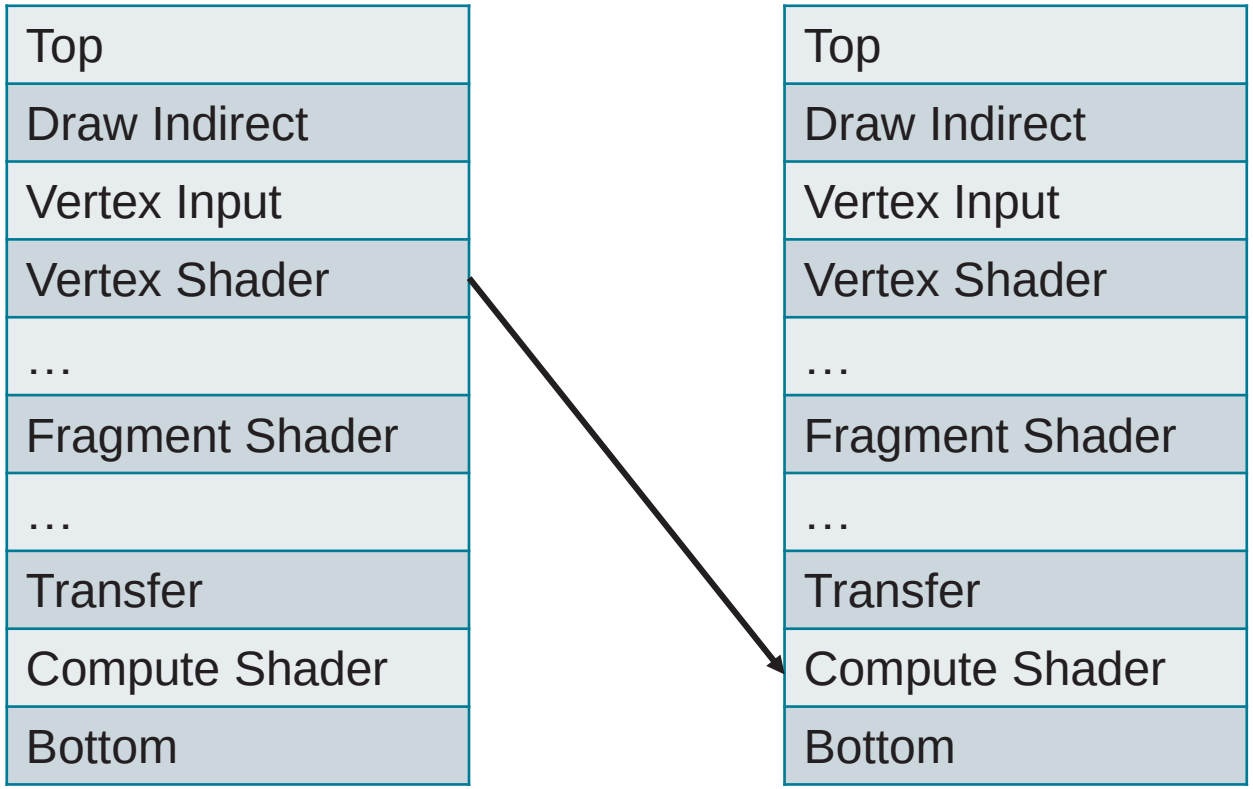
->
  VkImageMemoryBarrier[2] imageBarriers = {imageBarrierA, imageBarrierB};
  vkCmdPipelineBarrier(…, 0, NULL, 0, NULL, 2, &imageBarriers);
```

PIPELINE STAGE MASKS



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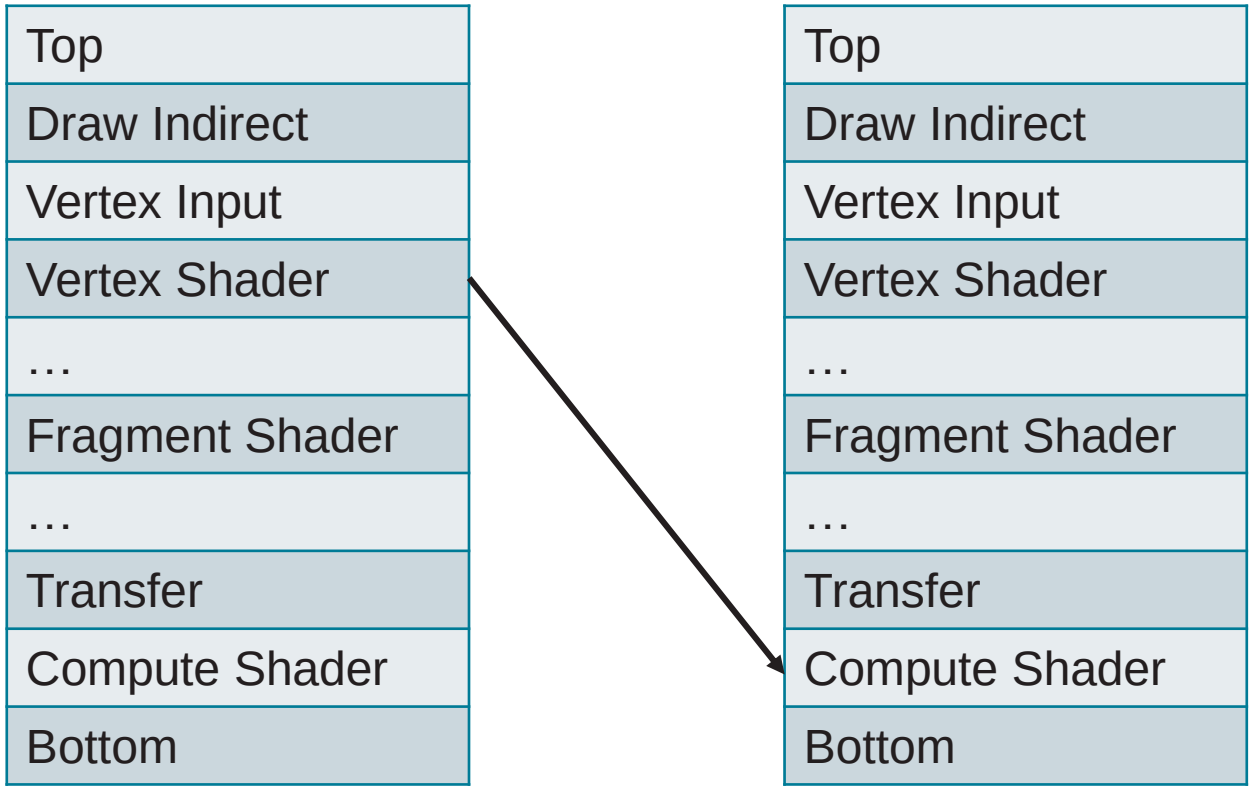

ALL_COMMANDS_BIT

Spec:

"VK_PIPELINE_STAGE_ALL_COMMANDS_BIT is equivalent to the logical OR of every other pipeline stage flag that is supported on the queue it is used with."

ALL_COMMANDS_BIT – COMPUTE PIPELINE

Top
Draw Indirect
Vertex Input
Vertex Shader
…
Fragment Shader
…
Transfer
Compute Shader
Bottom

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The bottom bit adds a wait on end of pipe + timestamp
-> can take up to ~64k cycles on the async queue ☹

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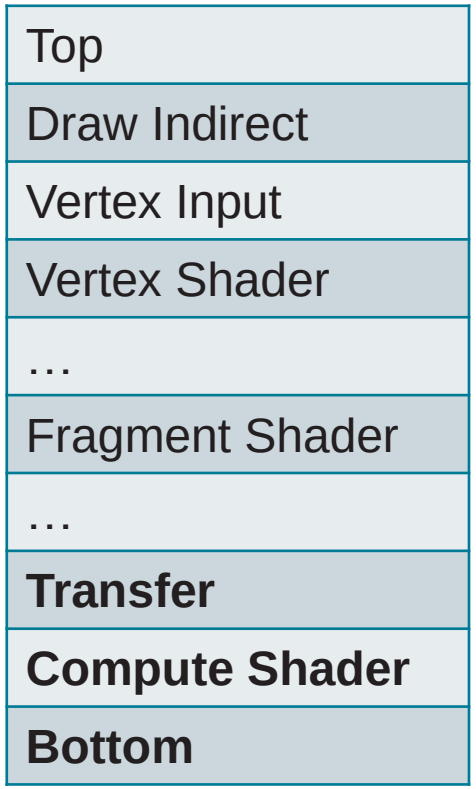

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-> Use the specific pipeline stage mask instead of all_commands, e.g.:
VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT |
VK_PIPELINE_STAGE_TRANSFER_BIT

The bottom bit adds a wait on end of pipe + timestamp
-> can take up to ~64k cycles on the async queue ☹

ALL_COMMANDS_BIT – COMPUTE PIPELINE

Start time	11.262 ms
End time	11.306 ms
Duration	0.044 ms
Hardware context	0

Frontend

Synchronization: FULL

Caches

Invalidated: K L1

Flushed: None

Barrier type: APP

Layout transitions

None

->

VK_PIPELINE_STAGE_ALL_COMMANDS_BIT
on async compute queue

ALL_COMMANDS_BIT – COMPUTE PIPELINE

Start time	10.183 ms
End time	10.186 ms
Duration	0.003 ms
Hardware context	0

Frontend

Synchronization: CS

Caches

Invalidated: K L1

Flushed: None

Barrier type: APP

Layout transitions

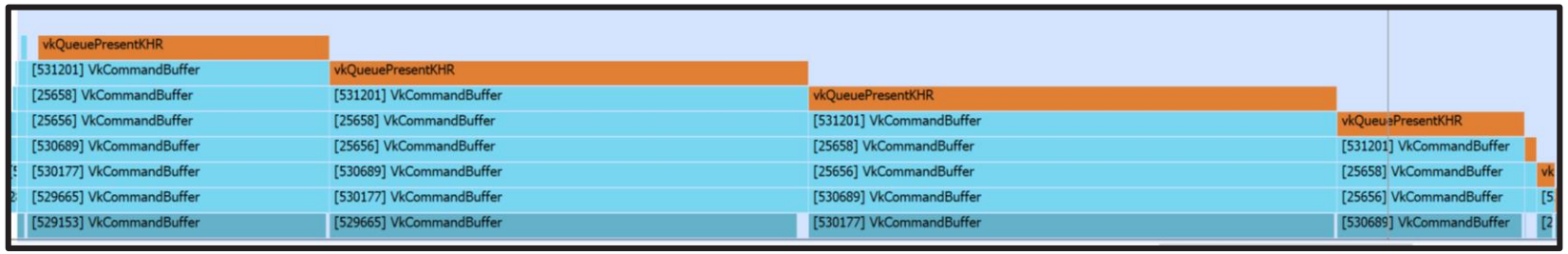
None

->

VK_PIPELINE_STAGE_COMPUTE_SHADER_BIT | VK_PIPELINE_STAGE_TRANSFER_BIT
on async compute queue

CROSS QUEUE SYNCHRONIZATION

The engine used to have ~7 command buffers per frame



AMD

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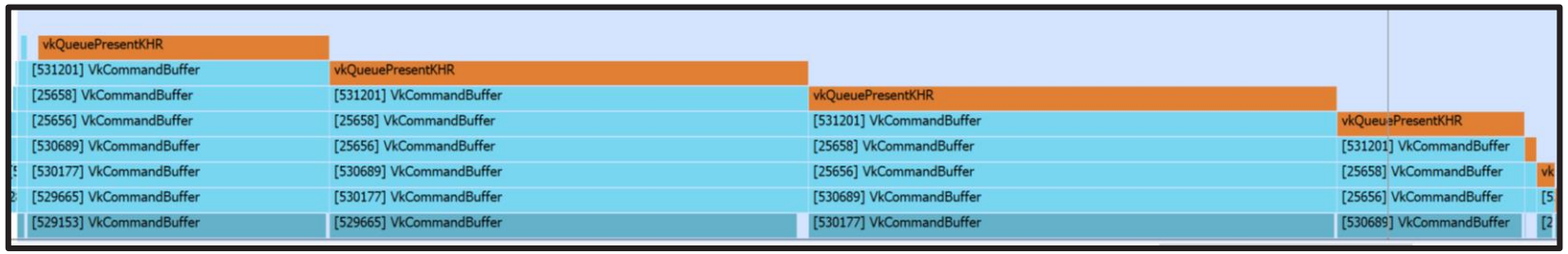
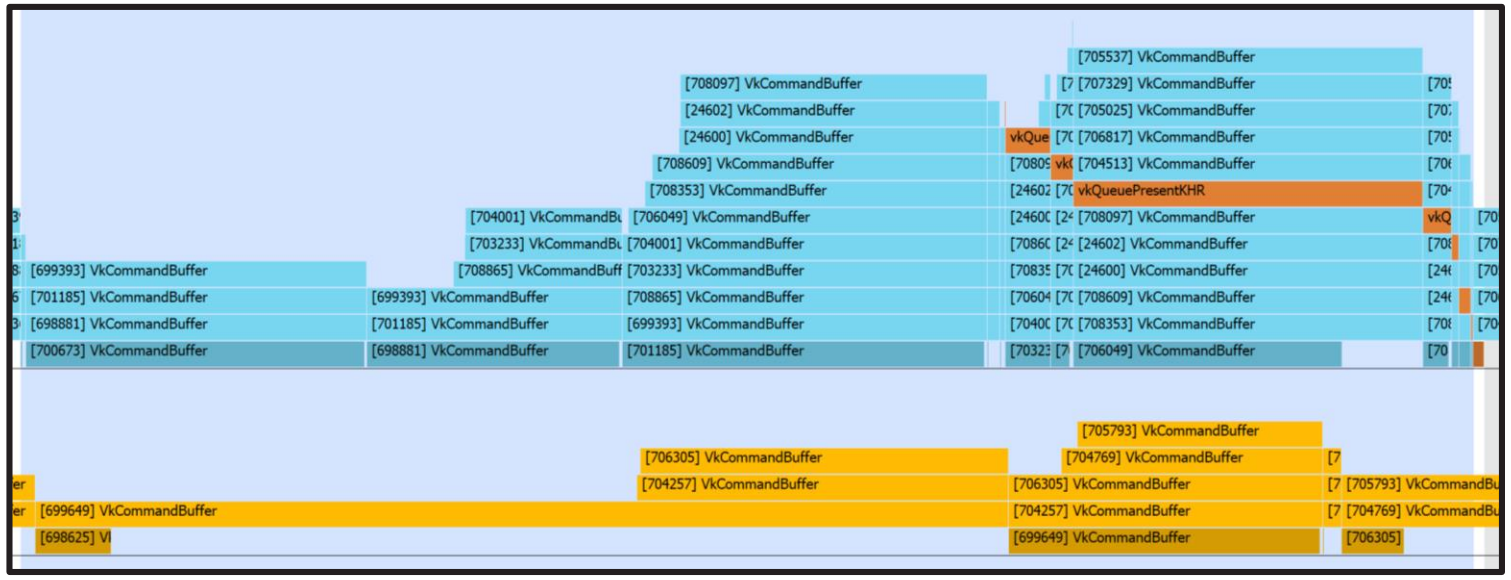


After async compute support was added, the number of command buffers doubled



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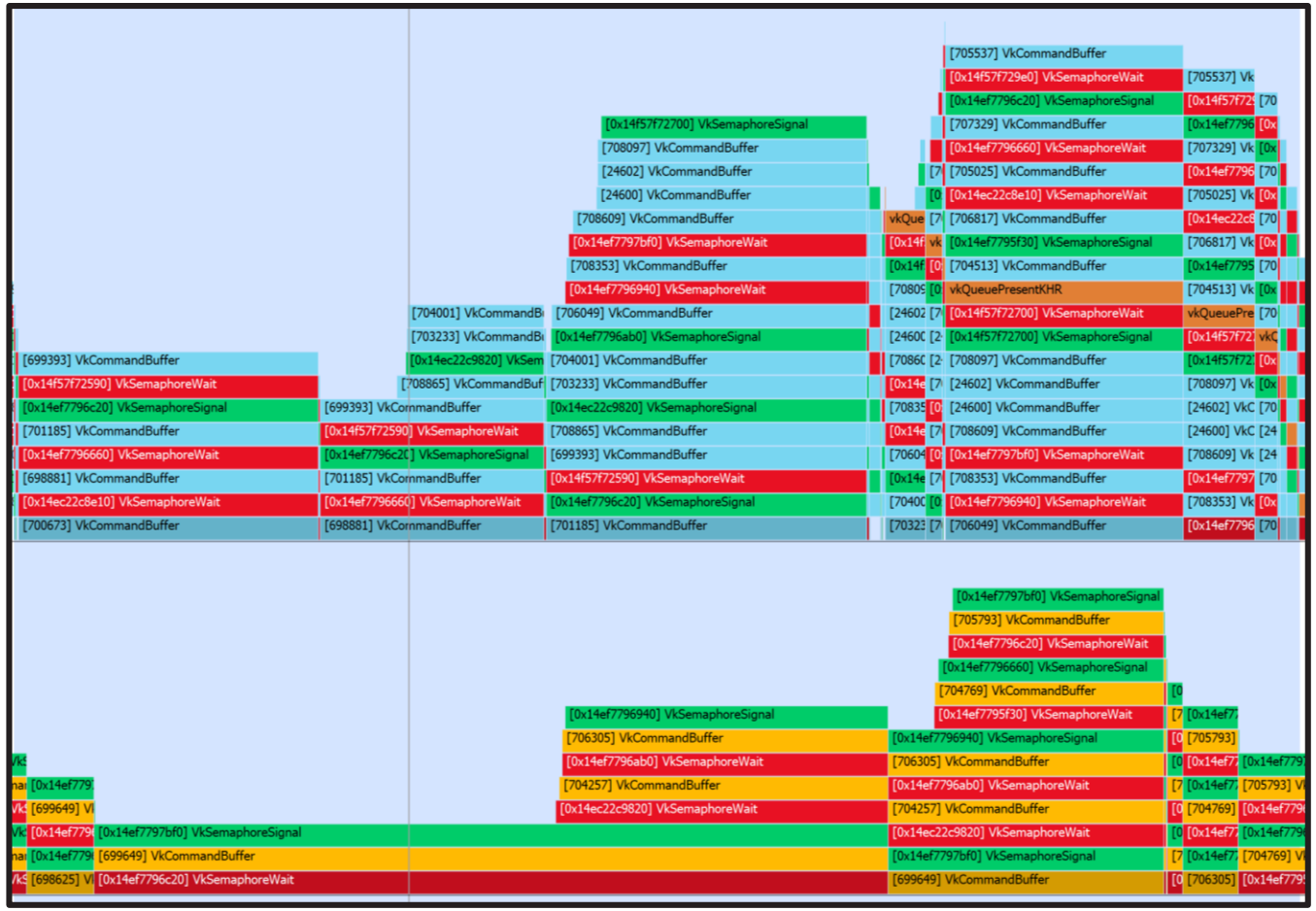
CROSS QUEUE SYNCHRONIZATION

Cross queue synchronization is only possible at submission boundaries



AMD

SUMMARY

- Check your barriers if you can rearrange them
- Batch consecutive barriers to a single barrier
- Specify your barriers as precise as possible
- Cross queue synchronization is only possible at submission boundaries

OTHER SMALL THINGS

- Copy queue
- Compute queue & the swapchain
- Shader building infrastructure

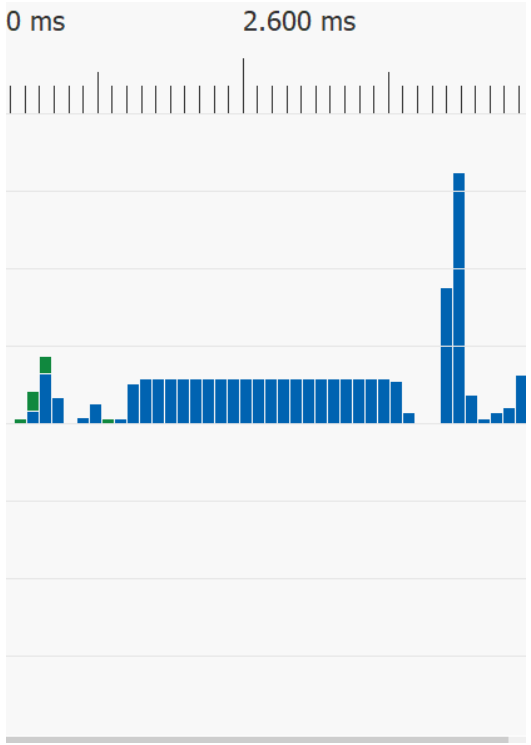
COPY QUEUE

Resource was copied from GPU to CPU

- Generated on GPU during previous frame
- After the copy overwritten with updated data from current frame

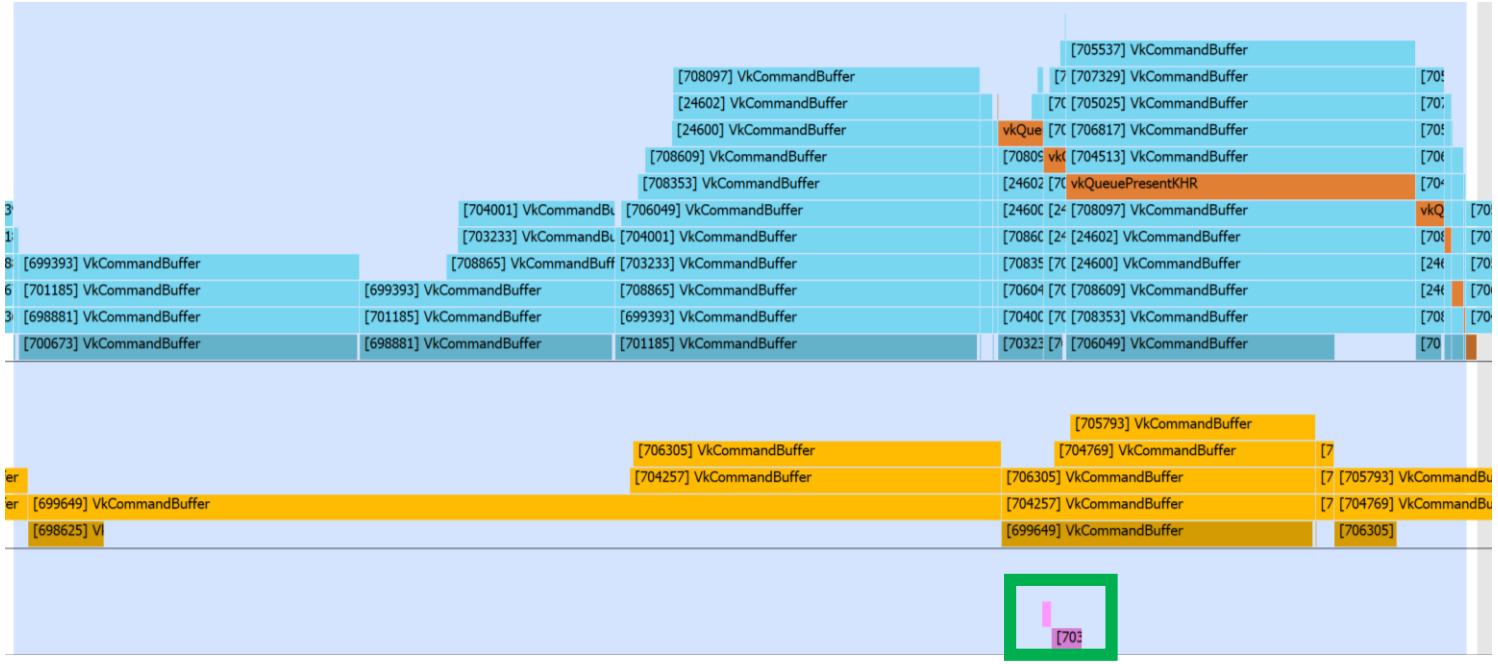
This copy blocked the whole GPU.

-> ~1-2% of frame time



COPY QUEUE

By using the copy queue, we won the time previously spend for vkCmdCopyImage() back.



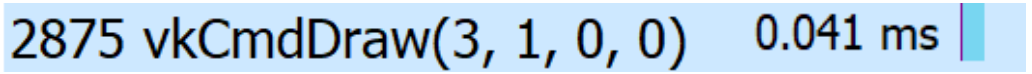
AMD

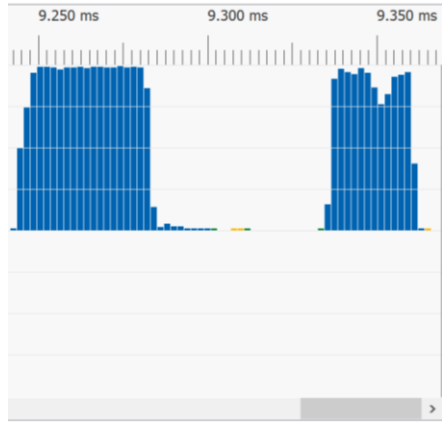
COMPUTE QUEUE & SWAPCHAIN

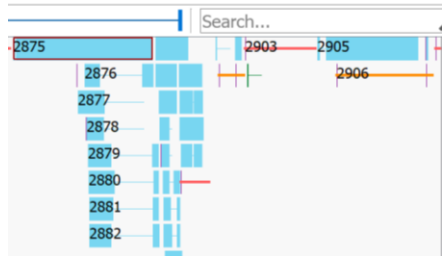
Write directly from compute to the swapchain

COMPUTE QUEUE & SWAPCHAIN

Write directly from compute to the swapchain







AMD

COMPUTE QUEUE & SWAPCHAIN

Write directly from compute to the swapchain

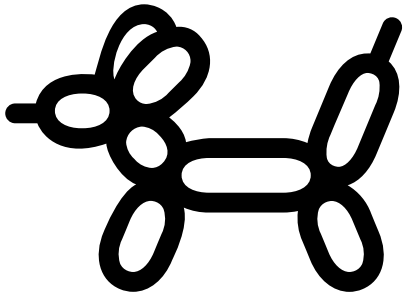
Possibly present from compute

Vulkan specific feature

SHADER BUILDING INFRASTRUCTURE

SUMMARY

- Check for compression, especially for the G-buffer render targets
- Take special care of the barriers ☺
- Can you make good use of the copy queue?
- The compute queue can write directly to the swapchain
- Use the DXC compiler



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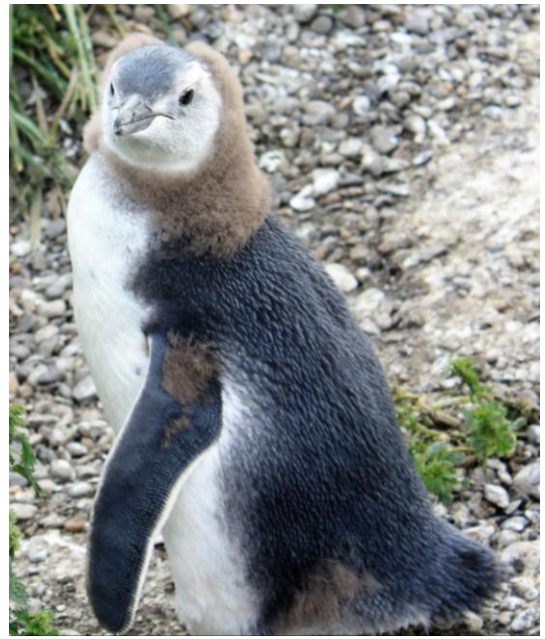

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