Vulkanised 2024

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Vulkan Synchronization Made Easy (without rendergraphs)

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Context

Designing a more approachable API on top of Vulkan

NICE
GRAF

http://nice.graphics

- Graphics API abstraction layer (RHI) with back-ends for Metal and Vulkan.
- Designed to be at the “middle” level of abstraction.
- Sync in Vulkan backend was a serious pain point.

Result

Screenshot Courtesy of Triada Studio

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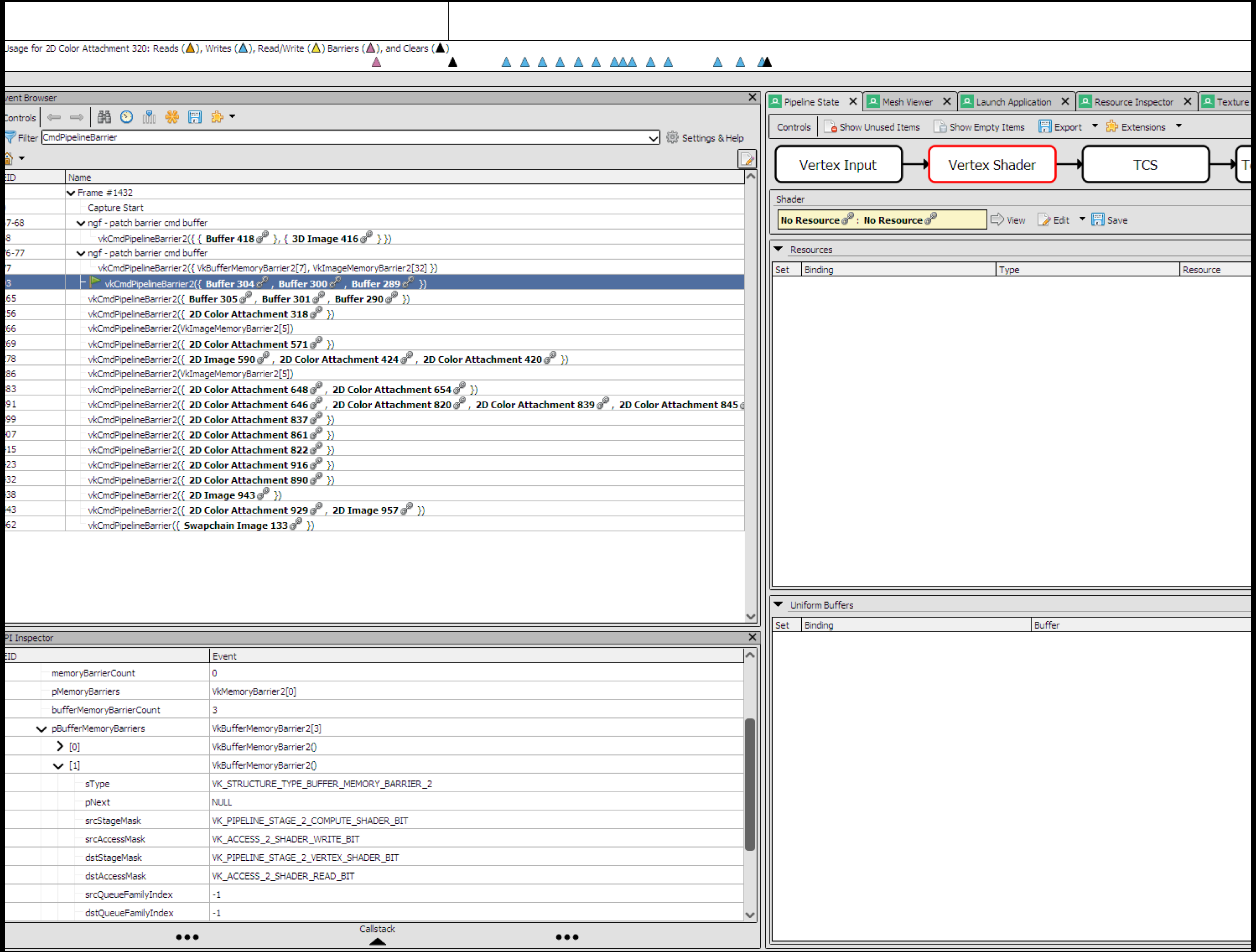
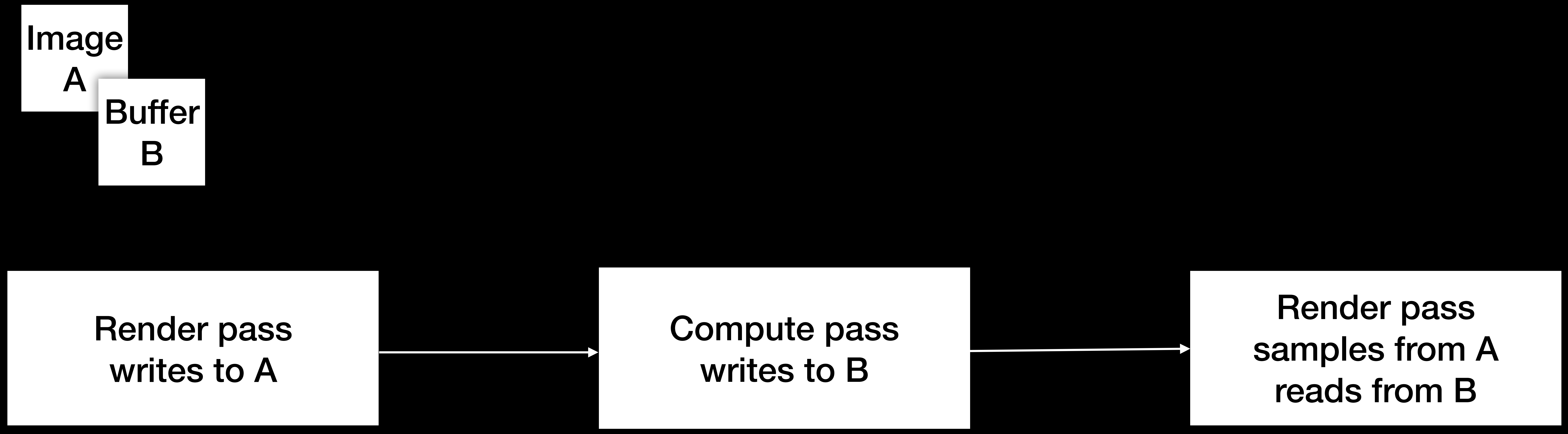


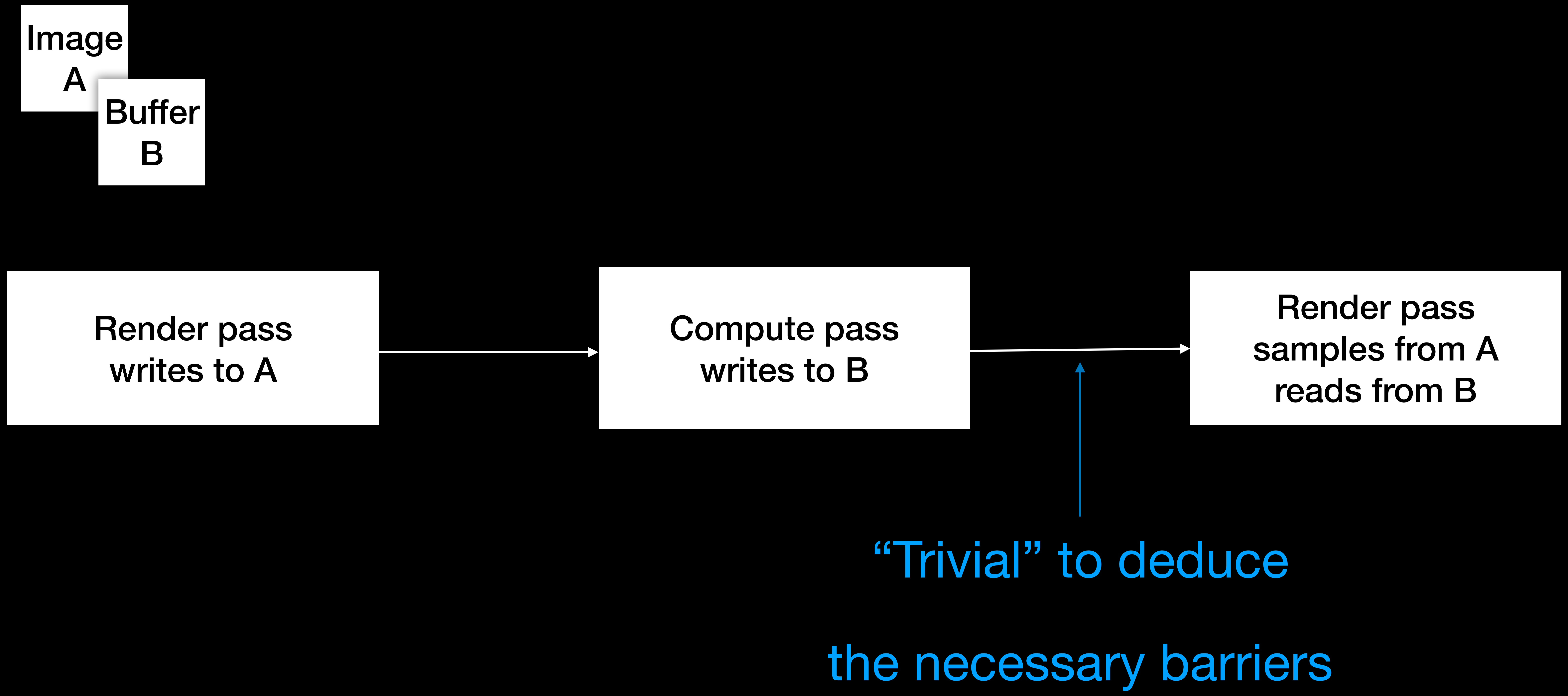
Basic Case

Single command buffer



Basic Case

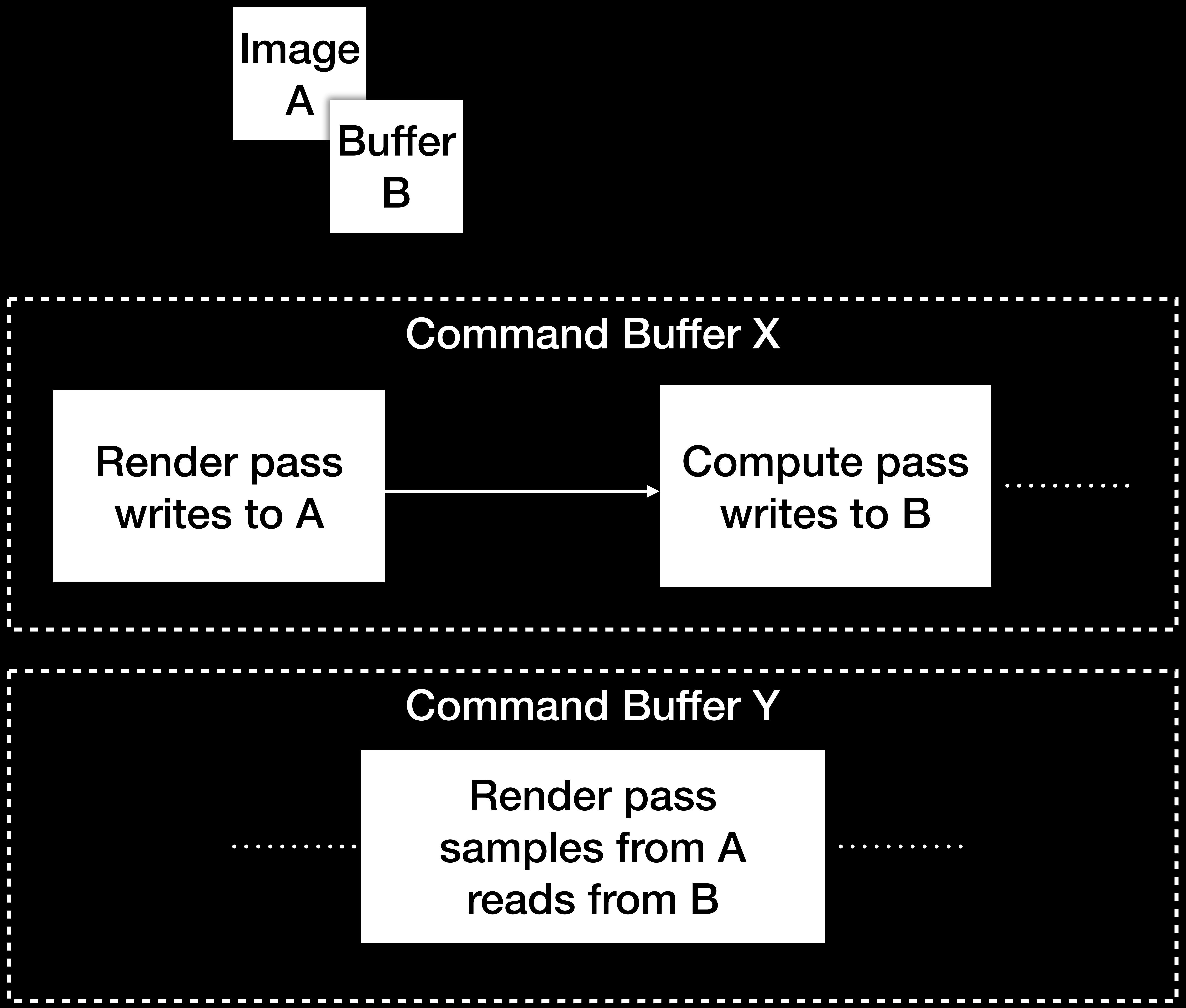
Single command buffer



Not So Basic Case

Multiple command buffers

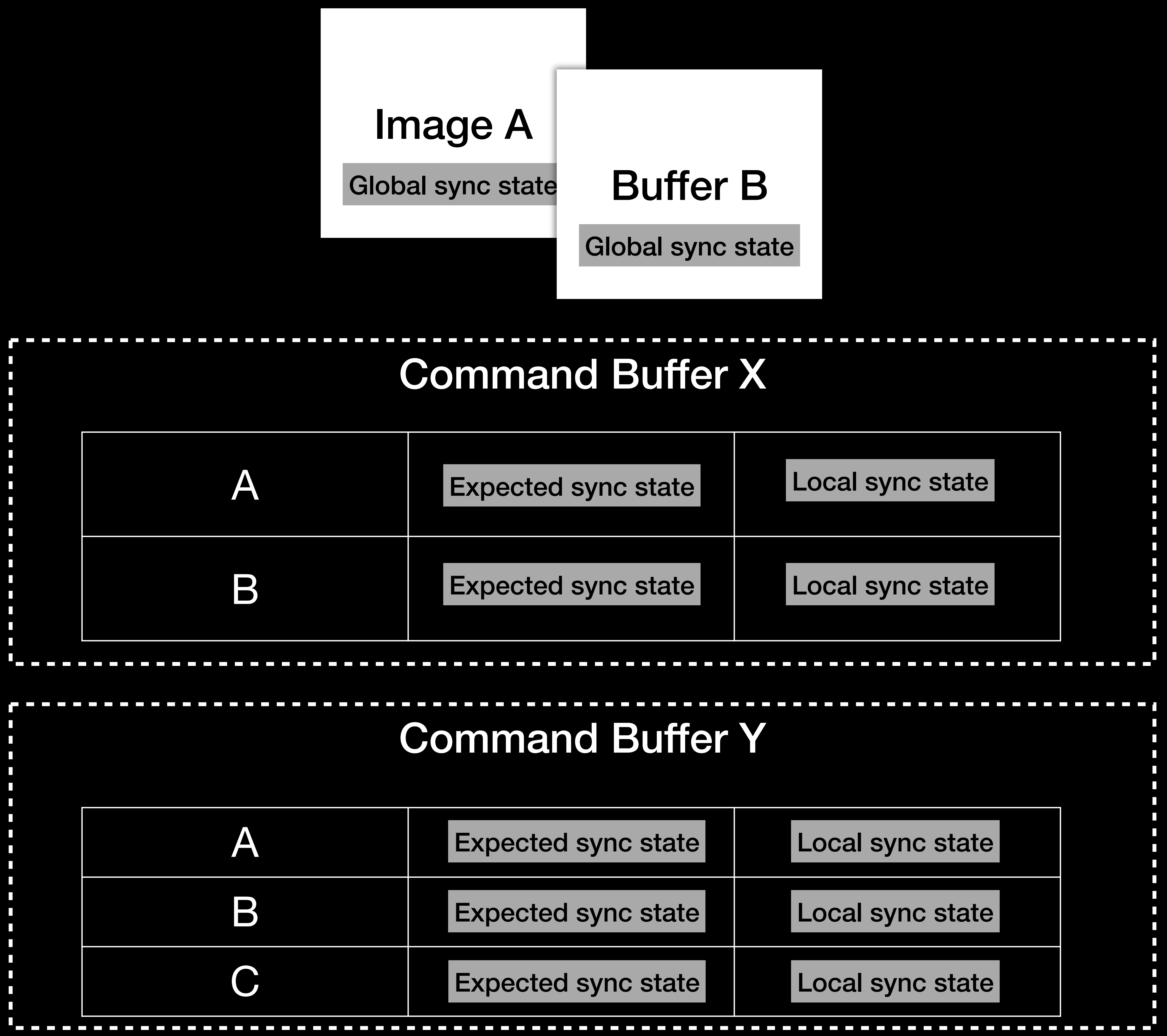
- Order of submission is not known a priori.
- Therefore, can't emit the correct memory barriers as commands are recorded.
- This problem arises with both multi- and single-threaded recording.



Solution: Interim Barriers

Part 1: independently track resources per command buffer

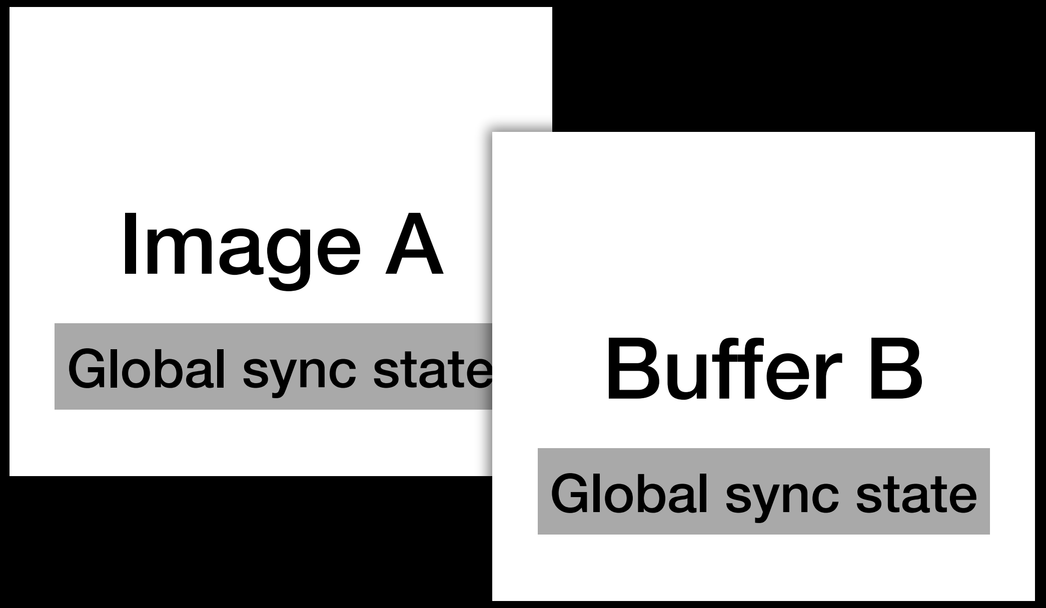
- Each resource has:
  - a single *global* synchronization state
  - one *local* synchronization state per each command buffer it is used in.
- Assume the *first* access of a pipeline stage to a given resource in a command buffer will NOT need synchronization.
- Remember the first accesses of each pipeline stage that touches the resource. Collectively, those are the “expected sync state”.
- Track subsequent accesses of a pipeline stage to the resource using the resource’s local synchronization state.



Solution: Interim Barriers

Part 2: insert barriers between command buffers

- All command buffers are submitted on a single thread, forming an ordered timeline.
- Infer the necessary barriers by comparing the *expected* sync states of the resources participating in the upcoming command buffer to their corresponding *current* global sync states .
- Record and submit the inferred barriers in an auxiliary command buffer before submitting the upcoming “main” command buffer.
- Update the current global states of all the participating resources according to the last known local sync state.



Command Buffer X

A	Expected sync state	Local sync state
B	Expected sync state	Local sync state

Command Buffer Y

A	Expected sync state	Local sync state
B	Expected sync state	Local sync state
C	Expected sync state	Local sync state

Hazard Tracking Inside Command Buffers

Synchronization requests

- Sync requests describe an operation we intend to perform on a resource.
- Issued when we're about to record commands that may result in resource memory being read or modified.
- Might or might not result in a barrier, depending on the resource's sync state.

```c
// Stage + access masks
typedef struct ngfvk_sync_barrier_masks {
  // Ways in which the resource is accessed
  VkAccessFlags access_mask;

  // Pipeline stages accessing the resource.
  VkPipelineStageFlags stage_mask;
} ngfvk_sync_barrier_masks;

// Specifies the intent to access a resource.
typedef struct ngfvk_sync_req {
  // Access/stage masks
  ngfvk_sync_barrier_masks barrier_masks;

  // Requested layout (images only).
  VkImageLayout layout;
} ngfvk_sync_req;
```

Hazard Tracking Inside Command Buffers

Rules for handling sync requests

- Concurrent reads are (almost) always allowed
- Only a single pipeline stage can be modifying the resource at a time.
- Once an access within a stage has “seen” the preceding write, it needs no further synchronization until the resource is modified again.
- Layout transitions need to be treated as writes.

Hazard Tracking Inside Command Buffers

Command buffer resource table

- A flat hash table keyed by a 64-bit resource handle, using open addressing.
- Memory reused between frames.
- We have precise control of re-hashing policy.

Hazard Tracking Inside Command Buffers

Resource table entry

```
typedef struct ngfvk_sync_res_data {
  // Expected sync state.
  ngfvk_sync_req expected_sync_state;

  // Latest synchronization state.
  ngfvk_sync_state local_sync_state;
  //…
} ngfvk_sync_res_data;
```

Hazard Tracking Inside Command Buffers

Resource synchronization state

```c
// Synchronization state
typedef struct ngfvk_sync_state {
  // What access in what stage has modified the resource last.
  ngfvk_sync_barrier_masks last_writer;

  // Which accesses in which stages have seen the last write.
  uint32_t per_stage_readers;

  // …

  // Current layout (images only).
  VkImageLayout layout;
} ngfvk_sync_state;
```

Hazard Tracking Inside Command Buffers

What happens when a pipeline stage needs to access a resource?

- Issue a synchronization request for the access needed by the pipeline stage against the current *local* synchronization state.
  - Keep in mind that local sync state starts out as “blank slate”: no writers, no readers.
- If no barriers have been generated for this resource up until this point, update the expected synchronization state.

Hazard Tracking Inside Command Buffers

Deciding when to emit barriers

- If a pipeline stage is requesting non-modifying access:
  - Has there been a preceding write?
    - No: just update the corresponding access bits in the per stage readers mask. No barrier emitted.
    - Yes:
      - Has this access in this stage already seen the effects of the preceding write?
        - Yes: no-op
        - No: emit barrier, update the corresponding access bits in the per stage readers mask.

```
// Synchronization state
typedef struct ngfvk_sync_state {
  // What access in what stage has
  // modified the resource last.
  ngfvk_sync_barrier_masks last_writer;

  // Which accesses in which stages
  // have seen the last write.
  uint32_t per_stage_readers;

  // Current layout (images only).
  VkImageLayout layout;
} ngfvk_sync_state;
```

Hazard Tracking Inside Command Buffers

Deciding when to emit barriers

- If a pipeline stage is requesting modifying access:
  - Sync with preceding reads/writes (if there are any).
  - Update the last writer.
  - Zero out per stage readers mask.
  - Update current layout.
- A non-modifying access that requires a layout transition is a bit of a special case, need to add the stage/access to per stage readers mask immediately.

```c
// Synchronization state
typedef struct ngfvk_sync_state {
  // What access in what stage has modified the
  // resource last.
  ngfvk_sync_barrier_masks last_writer;

  // Which accesses in which stages have seen
  // the last write.
  uint32_t per_stage_readers;

  // Current layout (images only).
  VkImageLayout layout;
} ngfvk_sync_state;
```

Hazard Tracking Inside Command Buffers

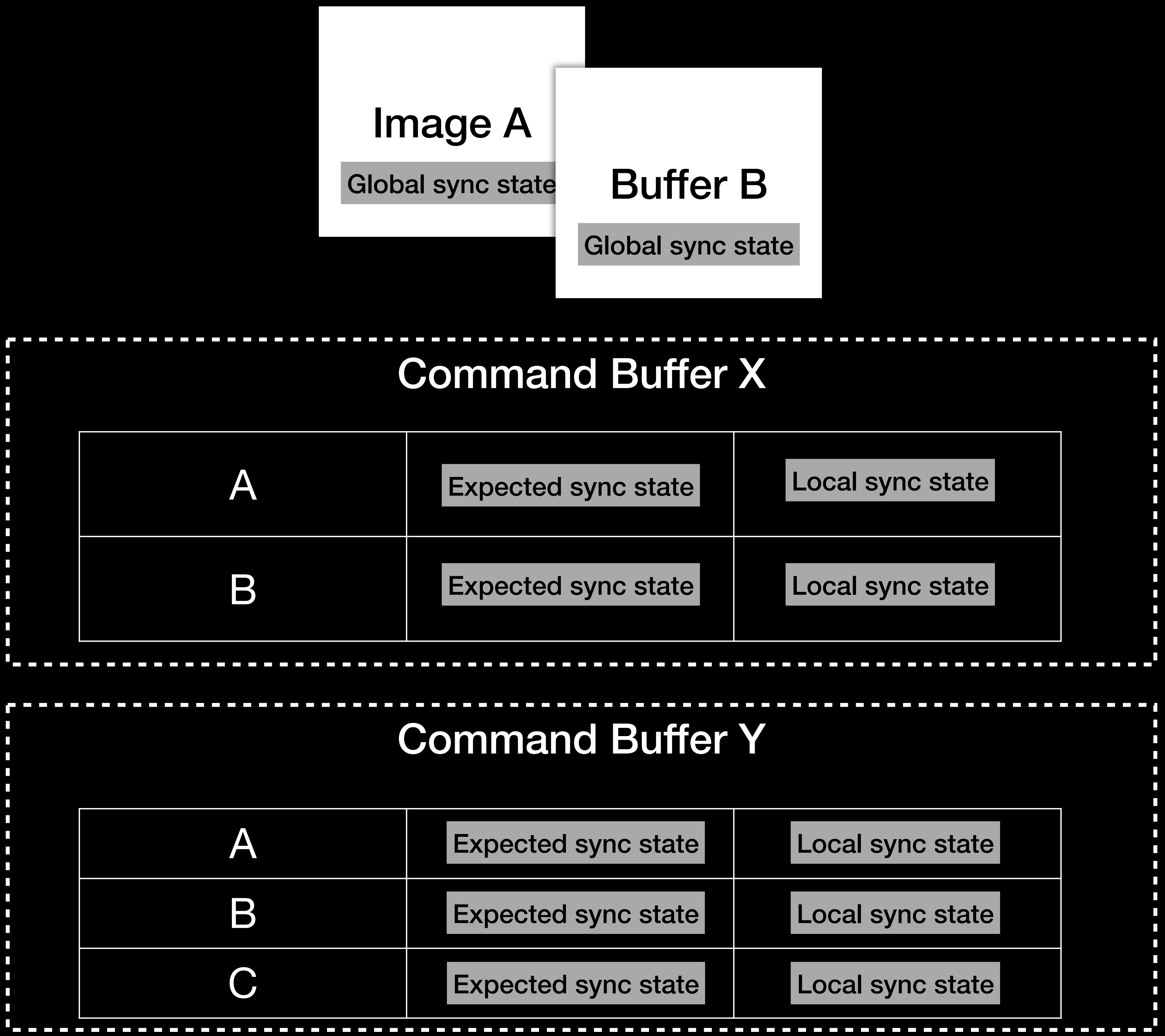
Coalescing barriers

- Pending sync requests are handled in bulk (minimize vkCmdPipelineBarrier calls).
- For compute, handle them just before the dispatch.
- For graphics, handle at the end of the render pass
  - Barrier synchronization scopes are limited to subpass for barriers emitted inside the render pass. We have to emit all the necessary barriers _before_ actually recording the render pass commands.
  - VK_KHR_dynamic_rendering fixes this.
- Use sync2 wherever possible

Hazard Tracking Across Command Buffers

Emitting interim barriers

- All cmd buffers are submitted from the same single thread; it is the only thread that touches resources' global sync states.
- Sync request generation using the *expected* access/layout from the upcoming command buffer's resource table, targeting the global sync state.
- Update the resource's global sync state according to the *final* local sync state from the upcoming command buffer.
- Any barriers generated are coalesced and written to an auxiliary cmd buffer which is submitted before the upcoming main cmd buffer.



Limitations

(Of this particular implementation)

- Single queue only.
  - Theoretically extensible to a multi-queue model. Maybe, someday.
  - Probably want to address it for async compute…
- No resource aliasing.
  - nicegraf does not expose memory allocation so that’s not relevant for us.
- No stores/atomics in vert/frag shaders.
- Poor sync granularity.
  - Could track individual mip levels or predefined disjoint buffer regions.
- Sync commands are issued exactly at the point they’re required, limiting implementation’s ability to overlap e.g. layout transitions with other work.

Future

Can we have VK_LAYER_KHRONOS_synchronization please?!

- VMA has solved memory management:
  - Pretty much industry standard
  - Still possible to have finer grained control (and don't have to choose either/or)
- Why not repeat the same success story for synchronization?

Thanks!

Q & A

Twitter	http://twitter.com/nice_byte
Mastodon	http://mastodon.gamedev.place/@nicebyte