SIGGRAPHASIA2009

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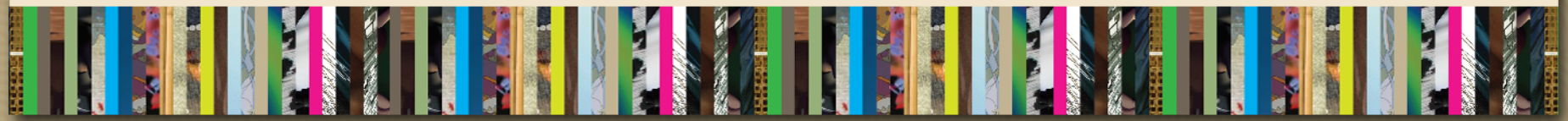

Advanced OpenCL Event Model Usage

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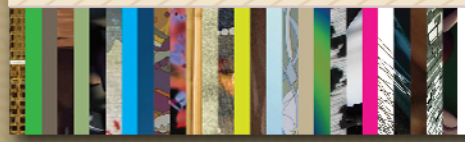
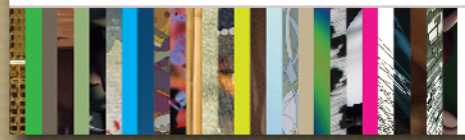
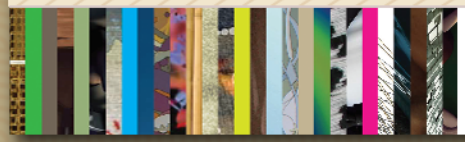


OpenCL Event Model Usage

- **Outline**
  - Execution Model
  - Usage Patterns
  - Synchronisation
  - Event Model
  - Examples

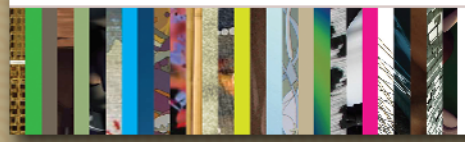


Execution Model



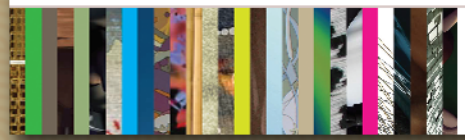
Execution Model

- **Command queues are used to submit work to a device**
  - Commands are queued in-order
  - Commands execute in-order or out-of-order

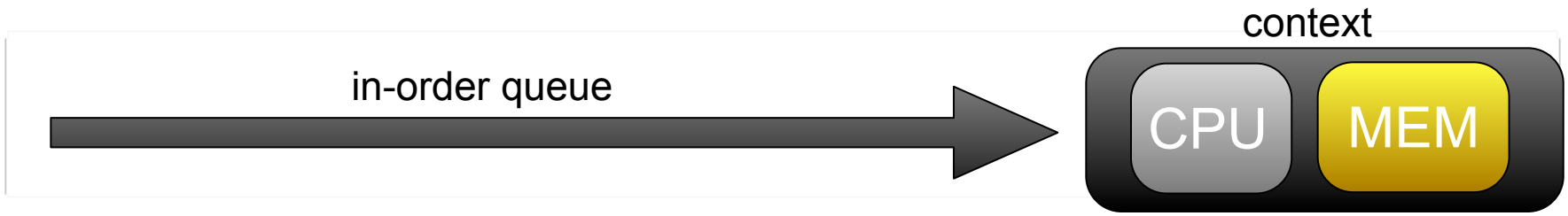


Execution Model

- **Explicit synchronisation is required for ...**
  - Out-of-order command queues
  - Multiple command queues



Single Device In-Order Usage Model



- **1x In-Order Queue, 1x Context, 1x Device**
  - Simple and straightforward **in-order** queue
  - All commands execute on single device
  - All memory operations occur in single memory pool

Single Device In-Order Usage Model

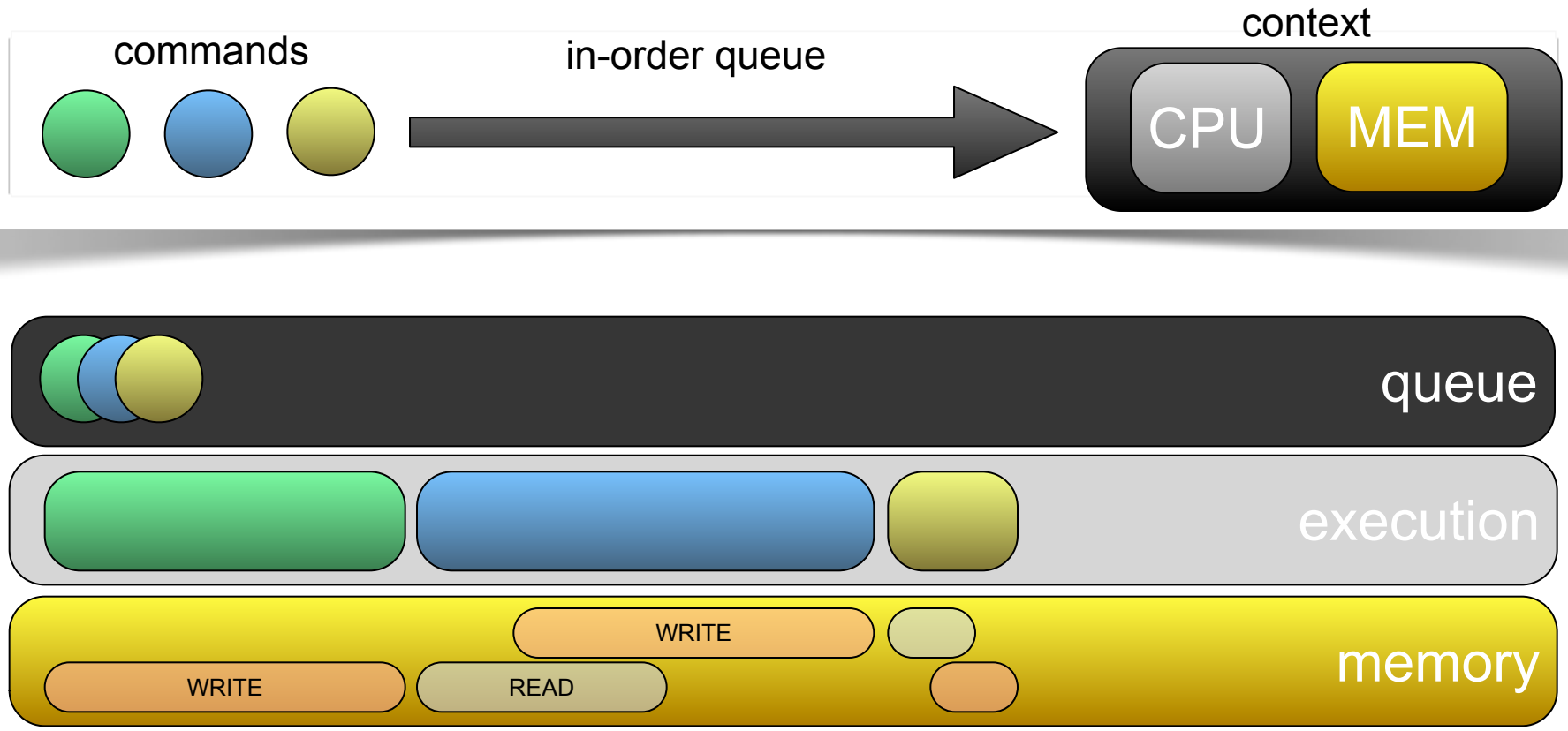

```
cl_uint num_devices;
cl_device_id devices[1];

err = clGetDeviceIDs(NULL, CL_DEVICE_TYPE_CPU, 1, &devices[0], &num_devices);
context = clCreateContext(0, 1, devices, NULL, NULL, &err);

cl_command_queue queue_cpu;
queue_cpu = clCreateCommandQueue(context, devices[0], 0 /* IN-ORDER */, &err);

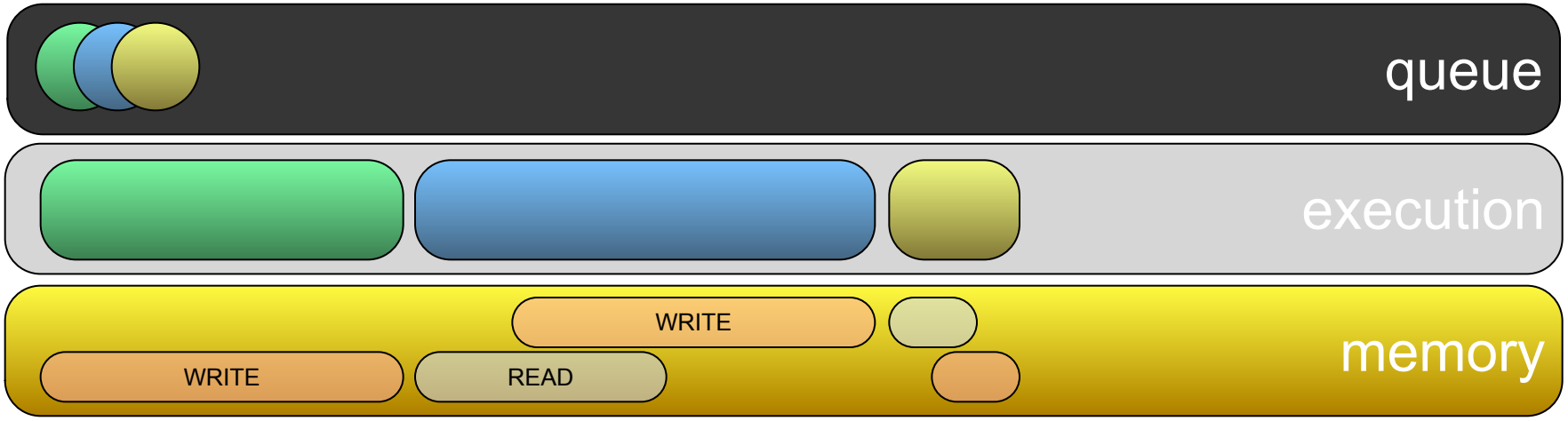
/* ... enqueue work ... */
```

Single Device In-Order Usage Model

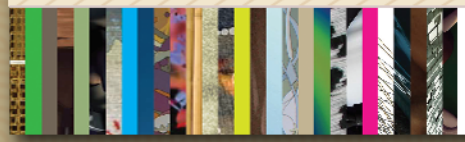


Single Device In-Order Usage Model

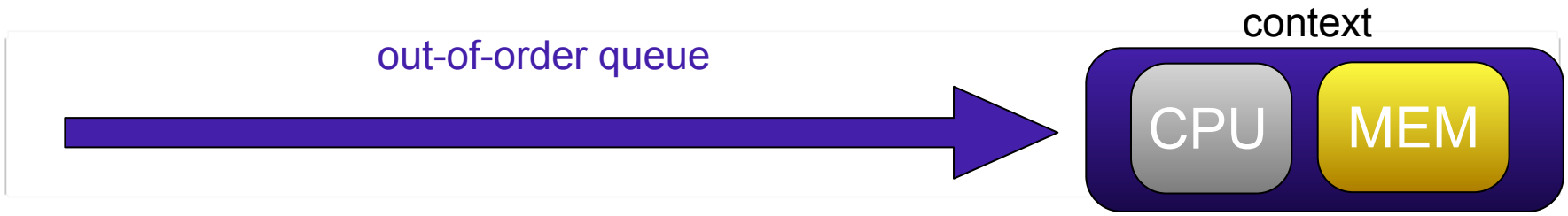
- Device executes commands after the previous one finishes
- Memory transactions have consistent view



Other Usage Patterns Which Require Synchronisation

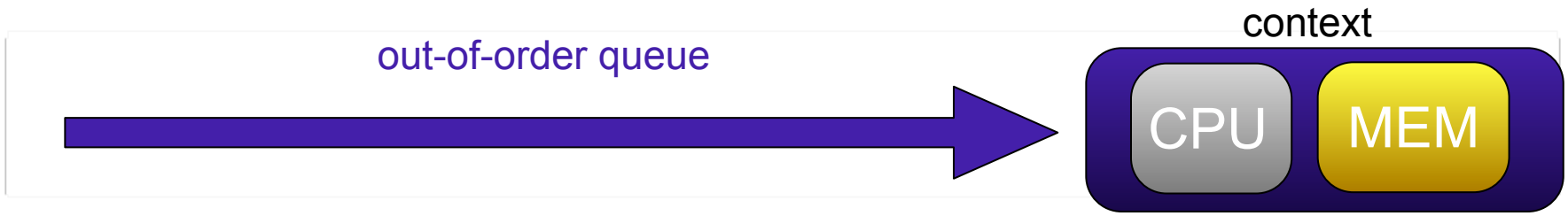


Single Device Out-of-Order Usage Model



- **1x Out-of-Order Queue, 1x Context, 1x Device**
  - Same as before but with an out-of-order queue
  - All commands execute on single device
  - All memory operations occur in single memory pool
  - Execution order has no guarantees....

Single Device Out-of-Order Usage Model



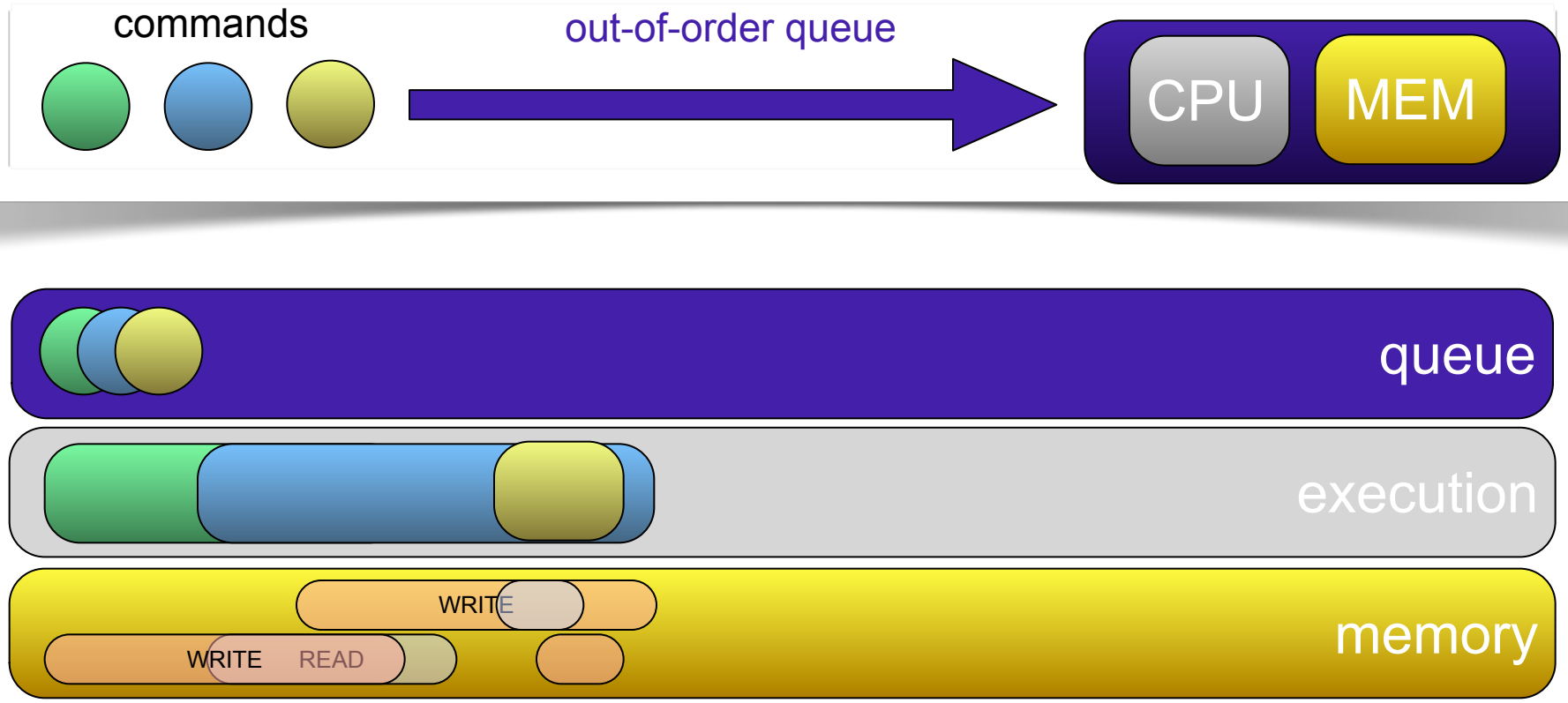

```
cl_uint num_devices;
cl_device_id devices[1];

err = clGetDeviceIDs(NULL, CL_DEVICE_TYPE_CPU, 1, &devices[0], &num_devices);
context = clCreateContext(0, 1, devices, NULL, NULL, &err);

cl_command_queue queue_cpu;
queue_cpu = clCreateCommandQueue(context, devices[0],
                                 CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE, &err);

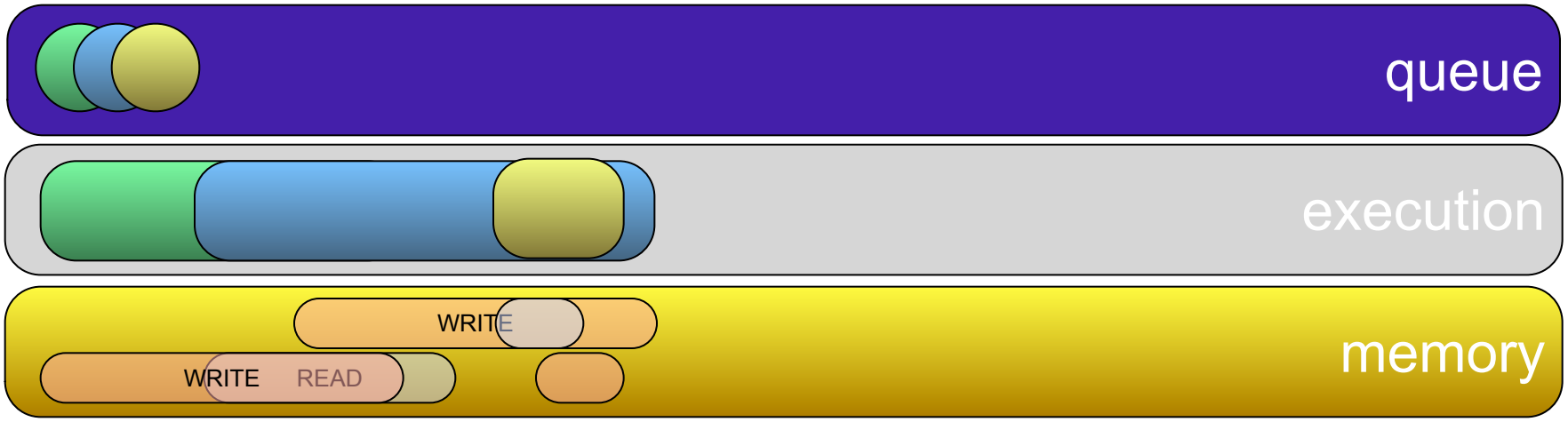
/* ... enqueue work ... */
```

Single Device Out-of-Order Usage Model

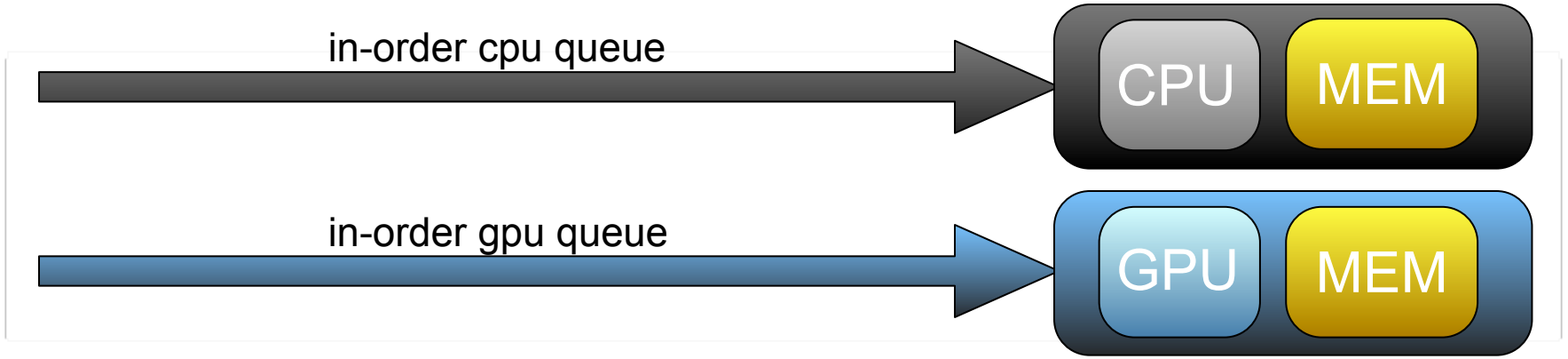


Single Device Out-of-Order Usage Model

- Device starts executing commands as soon as it can
- Memory transactions overlap and clobber data!

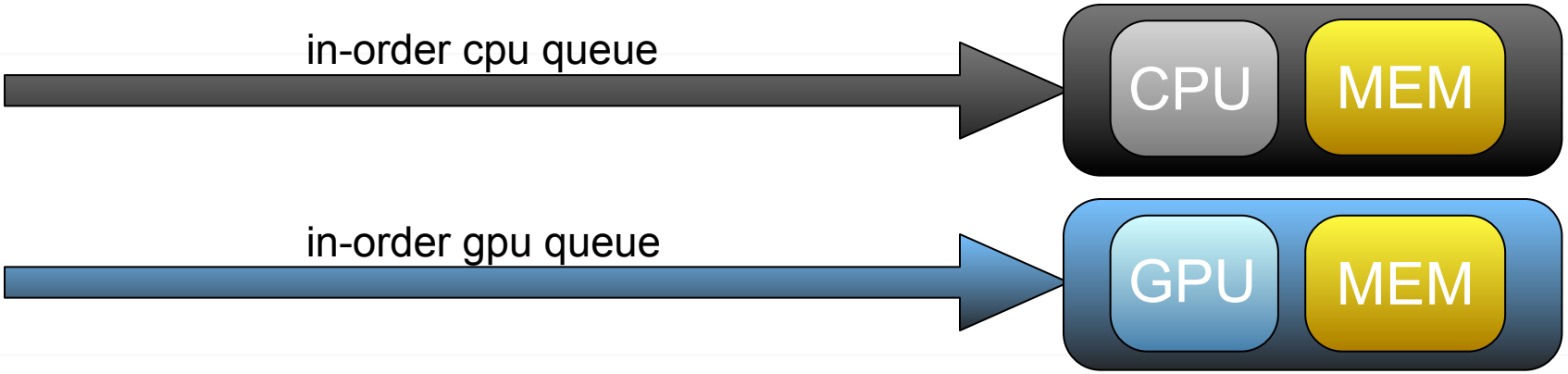


Separate Multi-Device Usage Model



- **2x In-Order Queues, 2x Separate Contexts, 2x Devices**
  - Commands execute on the device associated with the queue
  - Memory operations occur in two **separate memory** pools
  - Completely **separate queues in different contexts**

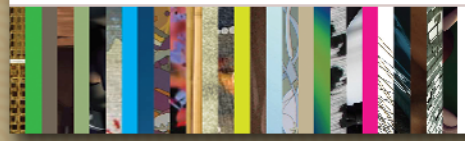
Separate Multi-Device Usage Model



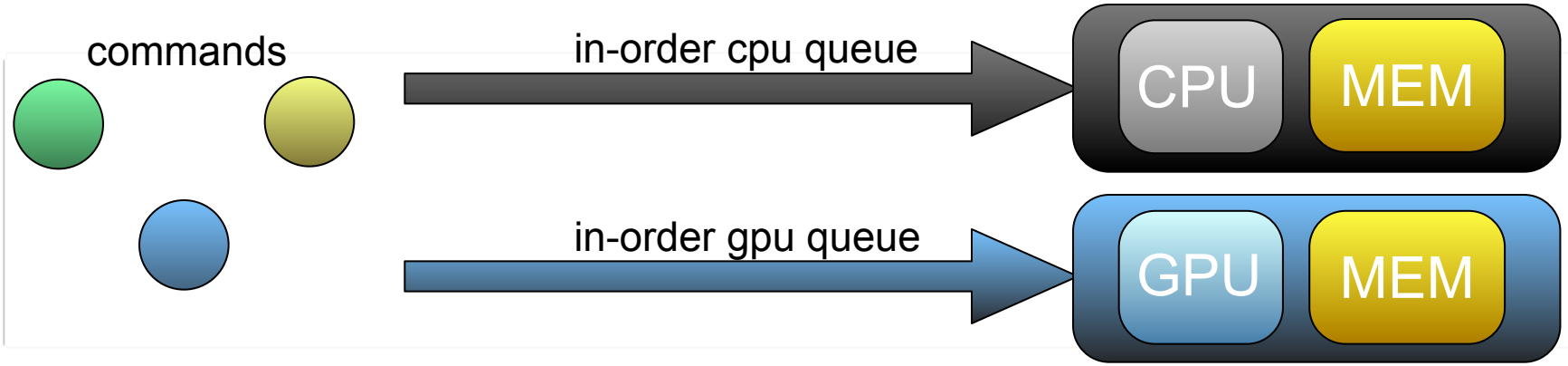

```
cl_uint num_devices;
cl_device_id devices[2];

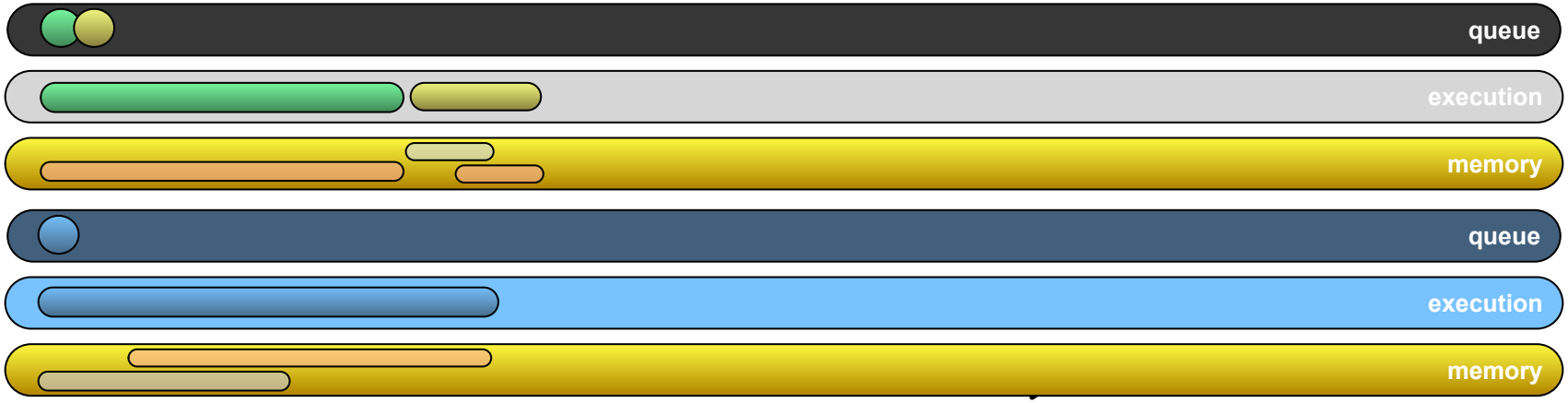
err = clGetDeviceIDs(NULL, CL_DEVICE_TYPE_CPU, 1, &devices[0], &num_devices);
err = clGetDeviceIDs(NULL, CL_DEVICE_TYPE_GPU, 1, &devices[1], &num_devices);
context_cpu = clCreateContext(0, 1, &devices[0], NULL, NULL, &err);
context_gpu = clCreateContext(0, 1, &devices[1], NULL, NULL, &err);

cl_command_queue queue_cpu, queue_gpu;
queue_cpu = clCreateCommandQueue(context_cpu, devices[0], 0 /* IN-ORDER */, &err);
queue_gpu = clCreateCommandQueue(context_gpu, devices[1], 0 /* IN-ORDER */, &err);
```



Separate Multi-Device Usage Model

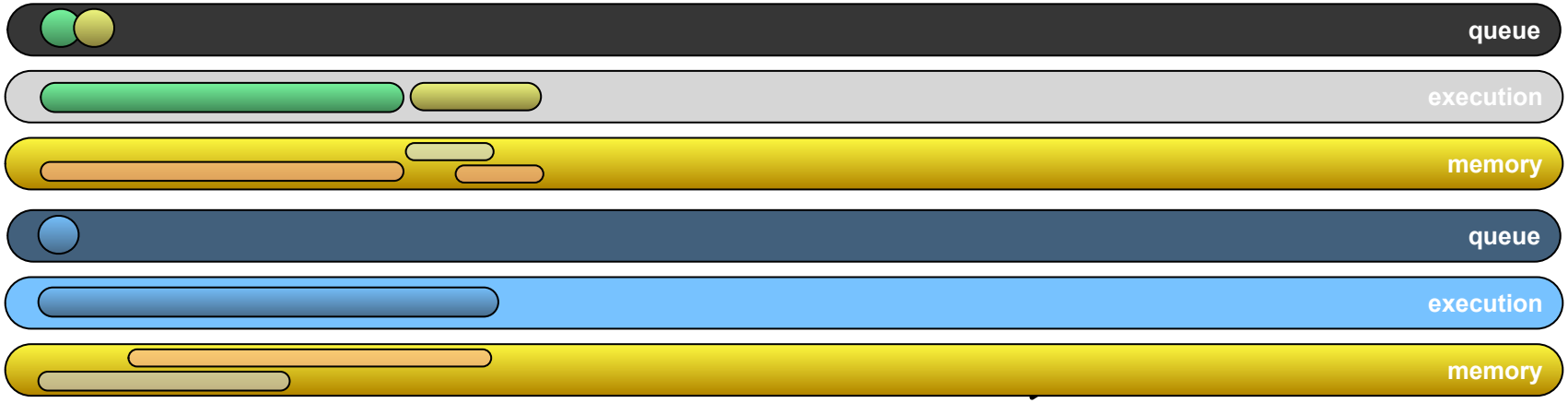




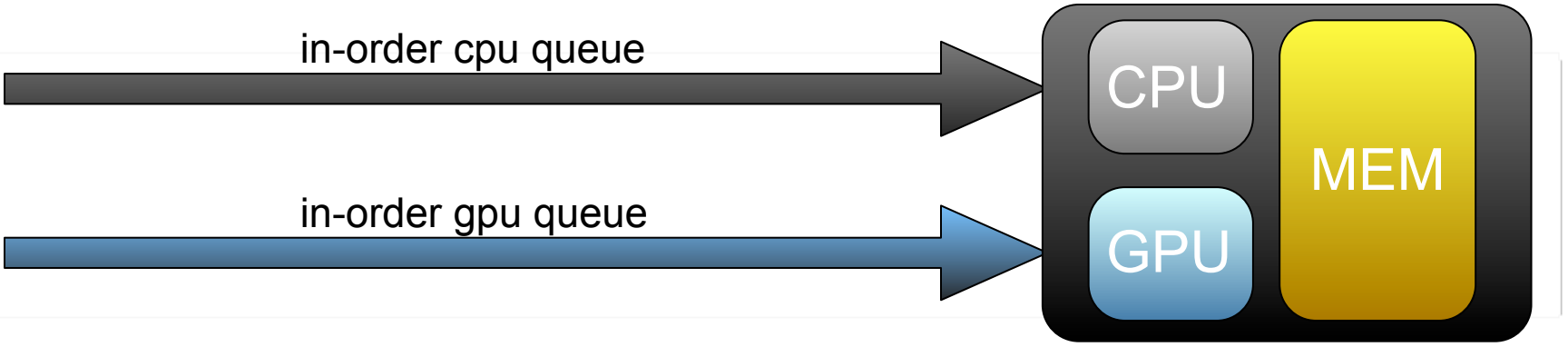
time

Separate Multi-Device Usage Model

- Command queues can't synchronise across contexts!
- Neither device sees the memory pool of the other!
- Won't work unless you use clFinish(), and copy across contexts!
- In short, this is not what you want! Don't do this!

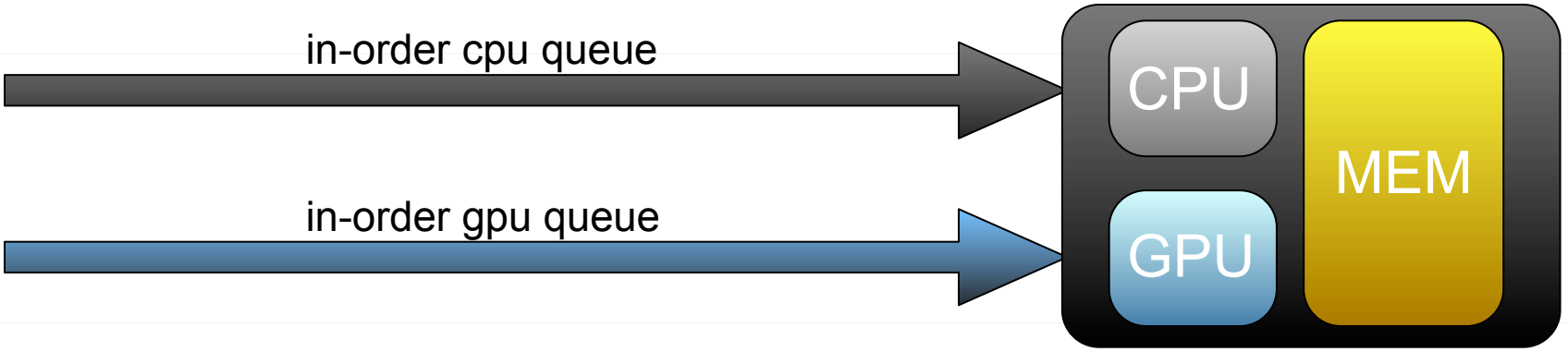


Cooperative Multi-Device Usage Model



- **2x In-Order Queues, 1x Combined Context, 2x Devices**
  - Commands execute on the device associated with the queue
  - Memory operations occur in one **combined memory** pool
  - **Combined memory** pool being modified by multiple devices

Cooperative Multi-Device Usage Model

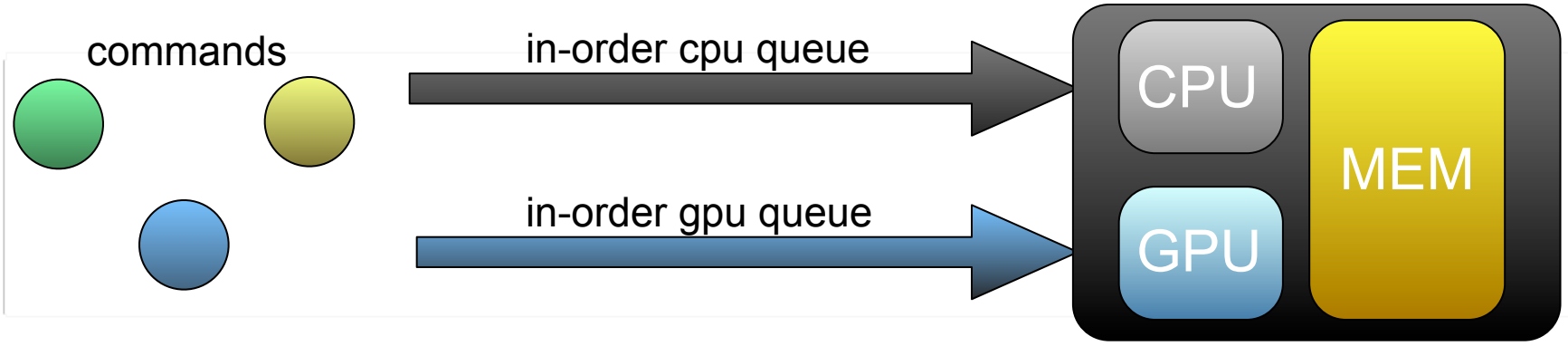


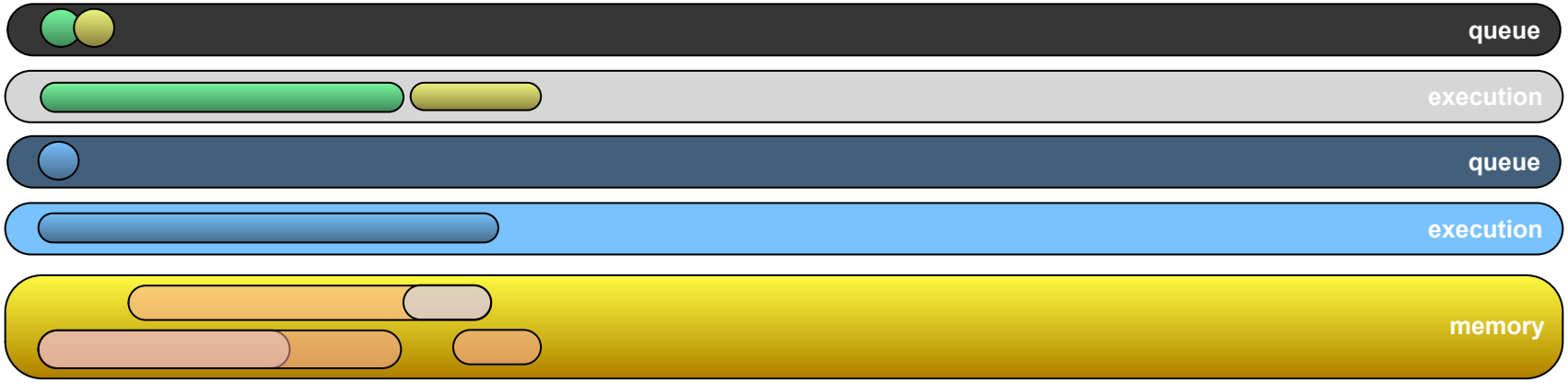

```
cl_uint num_devices;
cl_device_id devices[2];

err = clGetDeviceIDs(NULL, CL_DEVICE_TYPE_CPU, 1, &devices[0], &num_devices);
err = clGetDeviceIDs(NULL, CL_DEVICE_TYPE_GPU, 1, &devices[1], &num_devices);
context = clCreateContext(0, 2, devices, NULL, NULL, &err);

cl_command_queue queue_cpu, queue_gpu;
queue_cpu = clCreateCommandQueue(context, devices[0], 0 /* IN-ORDER */, &err);
queue_gpu = clCreateCommandQueue(context, devices[1], 0 /* IN-ORDER */, &err);
```

Cooperative Multi-Device Usage Model

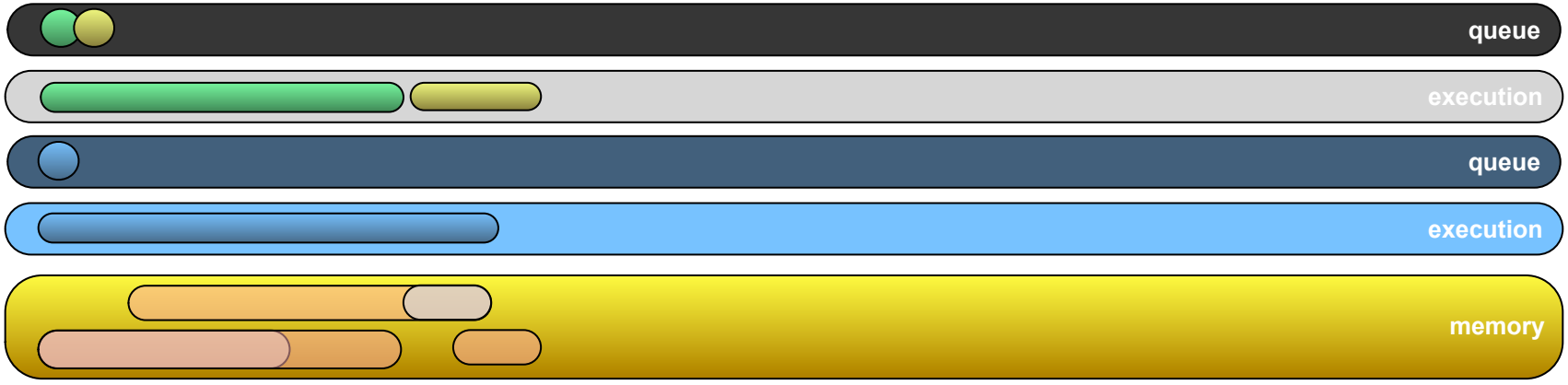




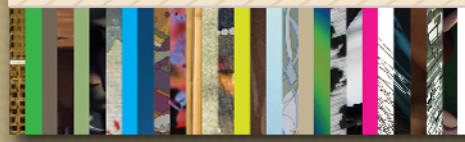
time

Cooperative Multi-Device Usage Model

- **Still wrong!**
- Both devices start executing commands as soon as they can!
- Memory transactions overlap and clobber combined memory!



Synchronisation Mechanisms

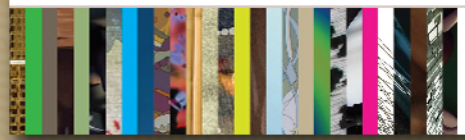


Synchronisation Mechanisms

- **Command Queue Control Methods**
  - clFlush()

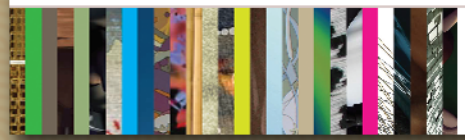
    Send all commands in the queue to the compute device
  - clFinish()

    Flush, and then wait for all commands to finish



Synchronisation Mechanisms

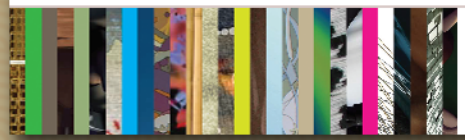
- **Command Queue Control Methods**
  - clFlush()
    Send all commands in the queue to the compute device
  - clFinish()
    Flush, and then wait for all commands to finish
- **Both are brute force, and lack fine-grained control**



Synchronisation Mechanisms

- **Command Execution Barriers**
  - clEnqueueBarrier()

    Enqueue a fence which insures that all preceding commands in the queue are complete before any commands which get enqueued afterwards are processed



Synchronisation Mechanisms

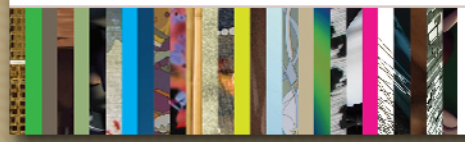
- **Event Based Synchronisation**

  – Event objects

    Unique objects which can be used to determine command status

  – Event wait lists

    Array of events used to indicate commands which must be complete before further commands are allowed to proceed

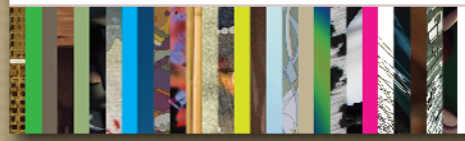


Event-Based Synchronisation

- **Event objects are used to determine command status**
  - clGetEventStatus()

    Returns command status for an event

```
CL_QUEUED       - Command is in a queue
CL_SUBMITTED    - Command has been submitted to device
CL_RUNNING      - Device is currently executing command
CL_COMPLETE     - Command has finished execution
```

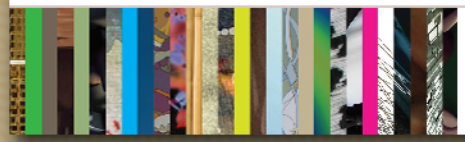


Event-Based Synchronisation

- **All clEnqueue() methods can return event objects**

- clEnqueueNDRangeKernel
- clEnqueueTask
- clEnqueueNativeKernel
- clEnqueueCopyImageToBuffer
- clEnqueueCopyBufferToImage

- clEnqueueRead {Image|Buffer}
- clEnqueueWrite {Image|Buffer}
- clEnqueueMap {Image|Buffer}
- clEnqueueCopy {Image|Buffer}
- clEnqueueCopyImageToBuffer
- clEnqueueCopyBufferToImage

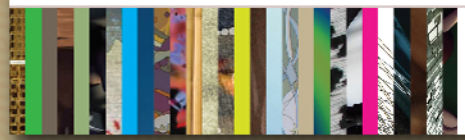


Event-Based Synchronisation

- **All clEnqueue() methods can return event objects**

```
cl_event returned_event;

err = clEnqueueReadBuffer(queue, buffer,
                          CL_FALSE /* non-blocking */,
                          0, 0, ptr, , 0,
                          &returned_event);
```



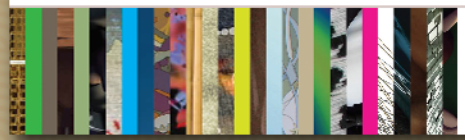
Event-Based Synchronisation

- **All clEnqueue() methods can return event objects**

```
cl_event returned_event;

err = clEnqueueReadBuffer(queue, buffer,
                          CL_FALSE /* non-blocking */,
                          0, 0, ptr, , 0,
                          &returned_event);
```

- **When blocking is false, call returns immediately!**

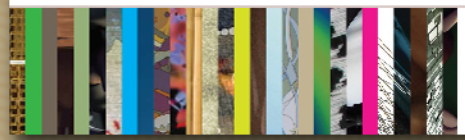


Event-Based Synchronisation

- **Event objects can be used as synchronisation points**

  - clWaitForEvents(num_events, event_list)

    Waits and blocks until all commands identified by events in the given event list are complete



Event-Based Synchronisation

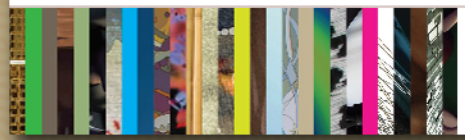
- **Event objects can be used as synchronisation points**

```
cl_event read_event;

err = clEnqueueReadBuffer(queue, buffer,
                          CL_FALSE /* blocking_read */,
                          0, 0, ptr, 0, 0,
                          &read_event);

err = clWaitOnEvents(1, &read_event);
```

- **Above example is equivalent to blocking call**

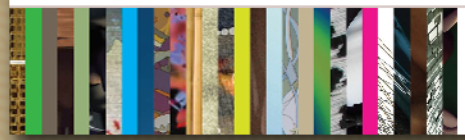


Event-Based Synchronisation

- All clEnqueue() methods also accept event wait lists

```
cl_uint num_events_in_waitlist = 2;
cl_event event_waitlist[2] = { event_one, event_two };

err = clEnqueueReadBuffer(queue, buffer,
                          CL_FALSE /* non-blocking */,
                          0, 0,
                          num_events_in_waitlist,
                          event_waitlist, NULL);
```



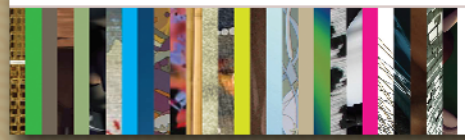
Event-Based Synchronisation

- **All clEnqueue() methods also accept event wait lists**

```
cl_uint num_events_in_waitlist = 2;
cl_event event_waitlist[2] = { event_one, event_two };

err = clEnqueueReadBuffer(queue, buffer,
                          CL_FALSE /* non-blocking */,
                          0, 0,
                          num_events_in_waitlist,
                          event_waitlist, NULL);
```

- **Read won't occur until events in wait list are complete!**



Event-Based Synchronisation

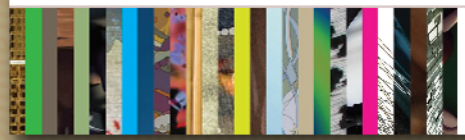
- **All clEnqueue() methods also accept event wait lists**

```
cl_uint num_events_in_waitlist = 2;
cl_event event_waitlist[2];

err = clEnqueueReadBuffer(queue, buffer0, CL_FALSE /* non-blocking */, 0, 0,
                          0, NULL, &event_waitlist[0]);

err = clEnqueueReadBuffer(queue, buffer1, CL_FALSE /* non-blocking */, 0, 0,
                          0, NULL, &event_waitlist[1]);

/* last read buffer waits on previous two read buffer events */
err = clEnqueueReadBuffer(queue, buffer2, CL_FALSE /* non-blocking */, 0, 0,
                          num_events_in_waitlist, event_waitlist, NULL);
```



Event-Based Synchronisation

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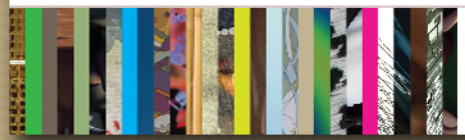
/* last read buffer waits on previous two read buffer events */
err = clEnqueueReadBuffer(queue, buffer2, CL_FALSE /* non-blocking */, 0, 0,
                          num_events_in_waitlist, event_waitlist, NULL);
```

- **Last read buffer waits on previous other two to complete!**



Event-Based Synchronisation

- **Events can also provide profiling information**

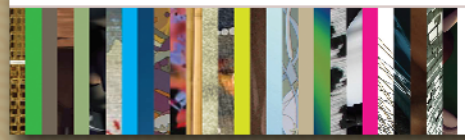
```
cl_event read_event;
cl_ulong start, end;

queue = clCreateCommandQueue(context, device, CL_QUEUE_PROFILING_ENABLED, ...
err = clEnqueueReadBuffer(queue, buffer, 0, 0, 0, 0, NULL, &read_event);
err = clWaitOnEvents(1, read_event);

err = clGetEventProfilingInfo(read_event, CL_PROFILING_COMMAND_END,
                              sizeof(cl_ulong), &end, NULL);

err = clGetEventProfilingInfo(read_event, CL_PROFILING_COMMAND_START,
                              sizeof(cl_ulong), &start, NULL);

float milliseconds = (end - start) * 1.0e-6f;
```



Event-Based Synchronisation

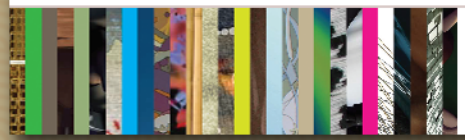
- **Event-Based Barrier Methods**

  - clEnqueueWaitList()

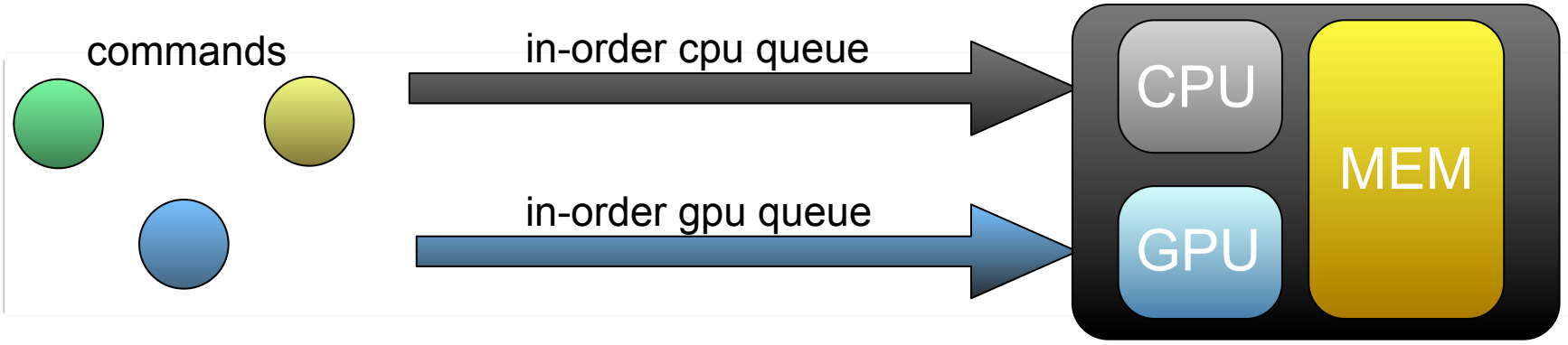
    Enqueue a list of events to wait for such that all events need to complete before this particular command can be executed

  - clEnqueueMarker()

    Enqueue a command which marks this location in the queue with a unique event object that can be used for synchronisation



Cooperative Multi-Device Usage Model



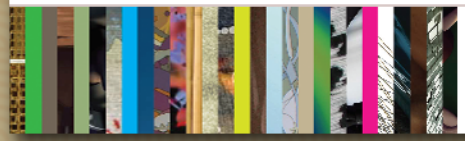

```
cl_event event0_cpu, event1_gpu;

err = clEnqueueNDRangeKernel(queue_cpu, kernel0_cpu, 2, NULL, global, local,
                             0, NULL, &event0_cpu);

err = clEnqueueNDRangeKernel(queue_gpu, kernel1_gpu, 2, NULL, global, local,
                             1, &event0_cpu, &event1_gpu);

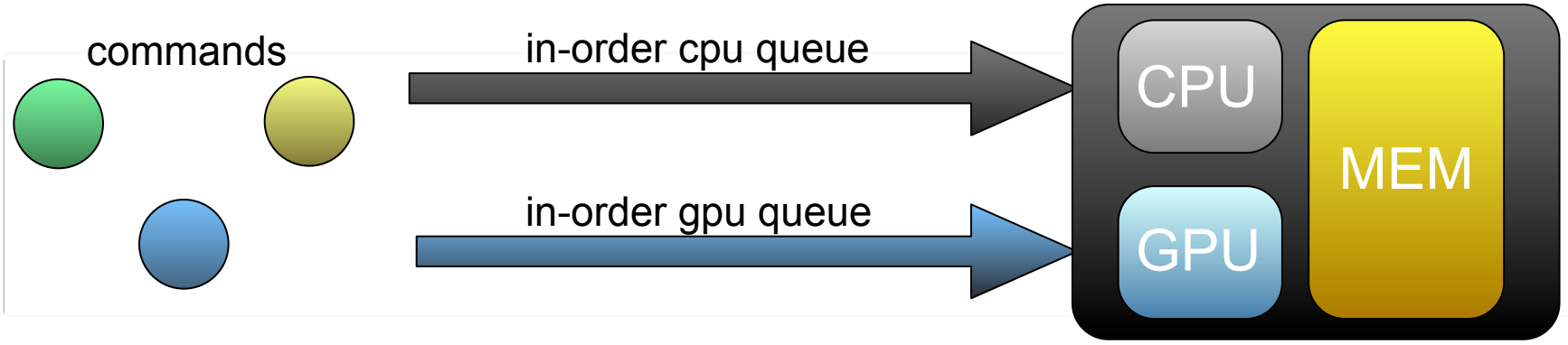
err = clEnqueueNDRangeKernel(queue_cpu, kernel2_cpu, 2, NULL, global, local,
                             1, &event1_gpu, NULL);

 clFlush(queue_cpu);  clFlush(queue_gpu);
```



time

Cooperative Multi-Device Usage Model



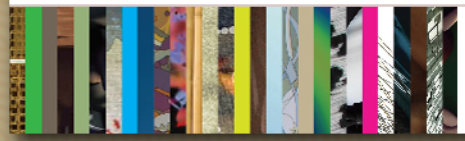

```
cl_event event0_cpu, event1_gpu;

err = clEnqueueNDRangeKernel(queue_cpu, kernel0_cpu, 2, NULL, global, local,
                             0, NULL, &event0_cpu);

err = clEnqueueNDRangeKernel(queue_gpu, kernel1_gpu, 2, NULL, global, local,
                             1, &event0_cpu, &event1_gpu);

err = clEnqueueNDRangeKernel(queue_cpu, kernel2_cpu, 2, NULL, global, local,
                             1, &event1_gpu, NULL);

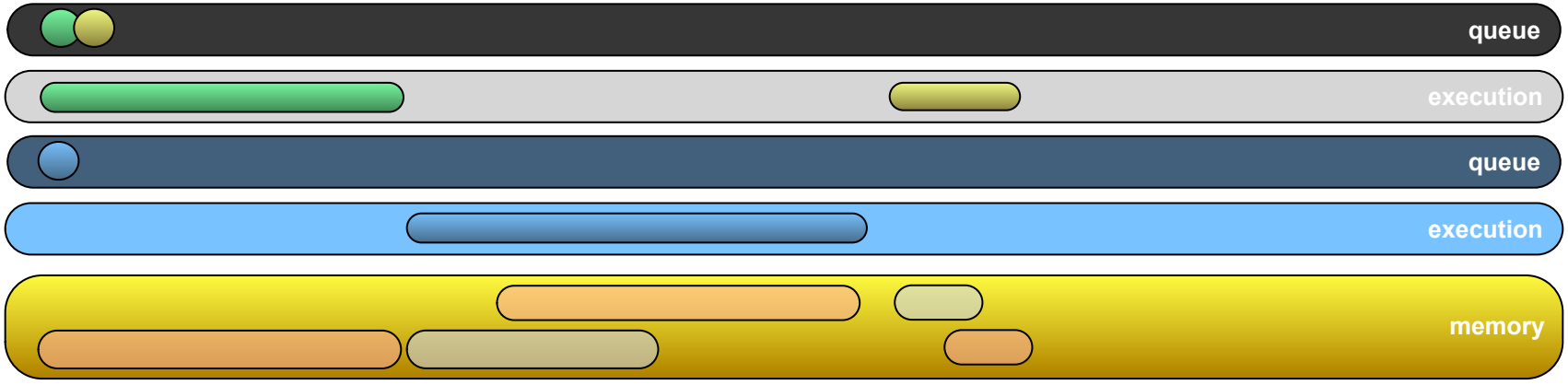
 clFlush(queue_cpu);  clFlush(queue_gpu);
```



time

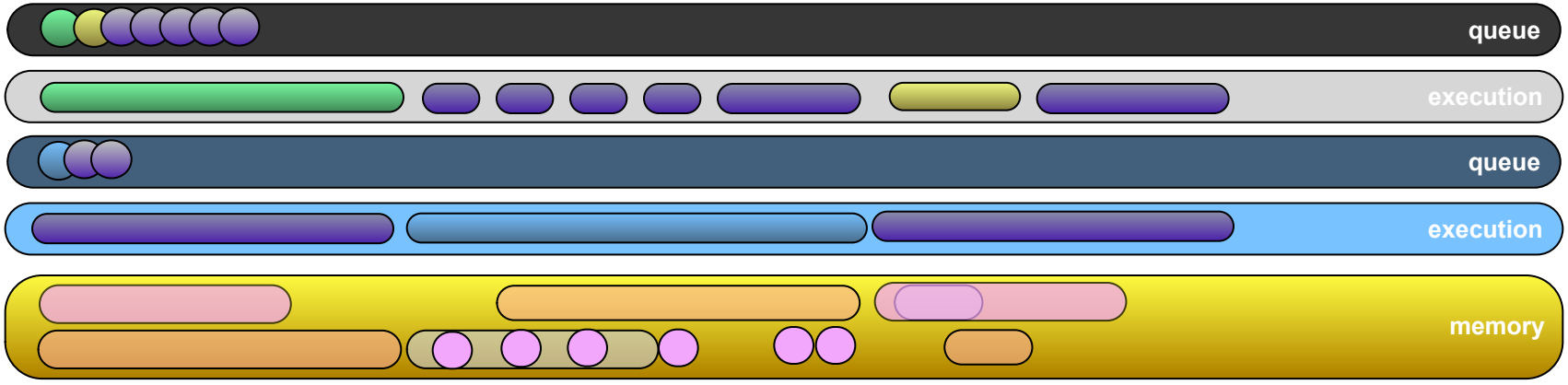
Cooperative Multi-Device Usage Model

- Event wait lists provide synchronised execution
- Execution is dependant on prior command execution status
- View of shared memory pool is consistent during execution



Cooperative Multi-Device Usage Model

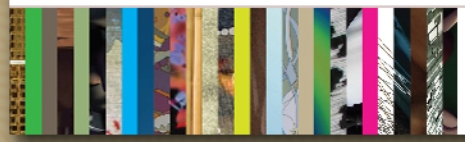
- Event wait lists provide synchronised execution
- Execution is dependant on prior command execution status
- View of shared memory pool is consistent during execution
- Could submit other work to fill in the time gaps!



Event-Based Synchronisation

- **Event Model Summary**

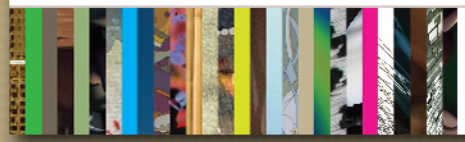
  - Event objects identify unique commands in a queue
  - Event objects can be used to determine command status
  - Event objects also provide profiling information
  - Event objects can be used as synchronisation points



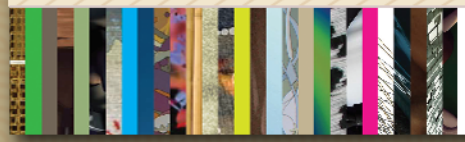
Event-Based Synchronisation

- **Event Model Summary**

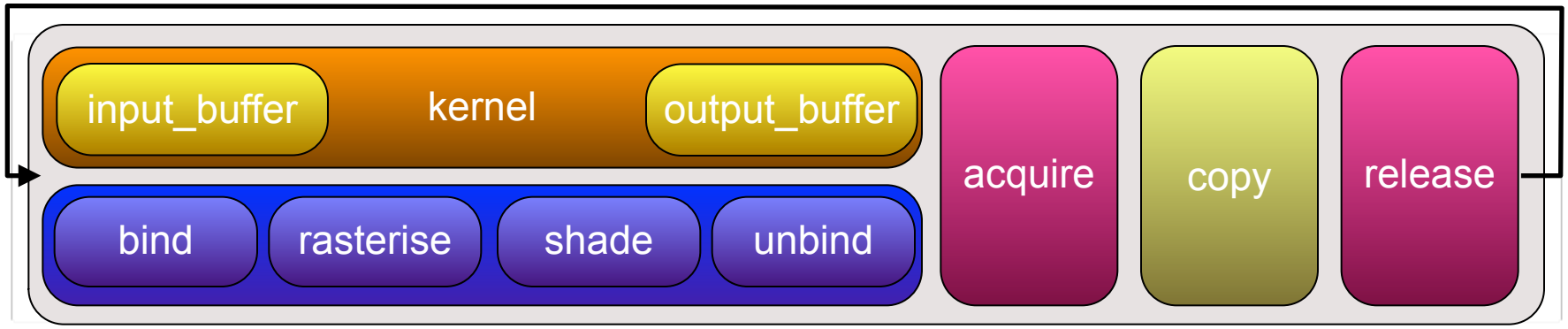
  - Event objects identify unique commands in a queue
  - Event objects can be used to determine command status
  - Event objects also provide profiling information
  - Event objects can be used as synchronisation points
  - **Event objects provide command-level control!**
  - **Event wait lists allow execution graphs!**



Example Usage

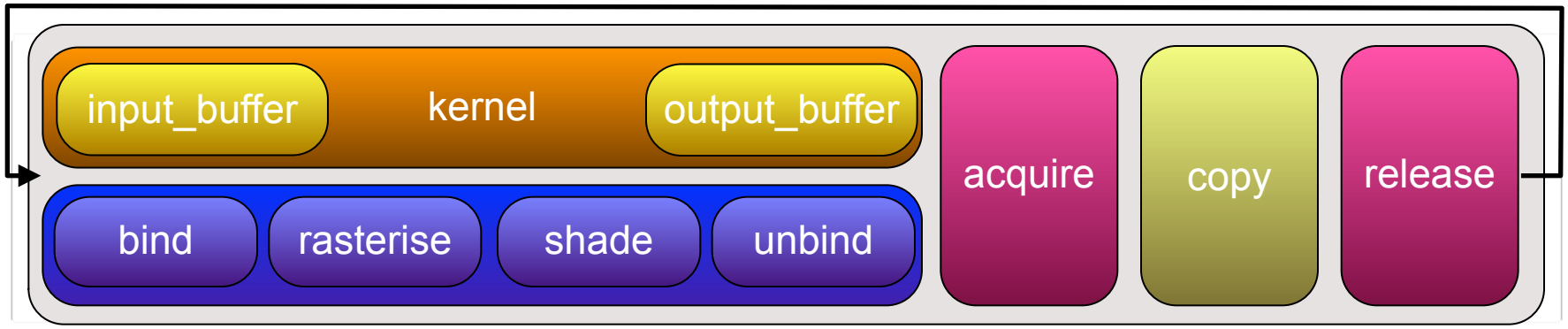


Format Conversion for OpenGL Interop



- Some OpenCL kernels may be better off using buffers
- Some OpenGL commands may be better off using textures
- Use acquire and release interop methods to hint API usage
- Use copy format methods to convert memory

Format Conversion for OpenGL Interop



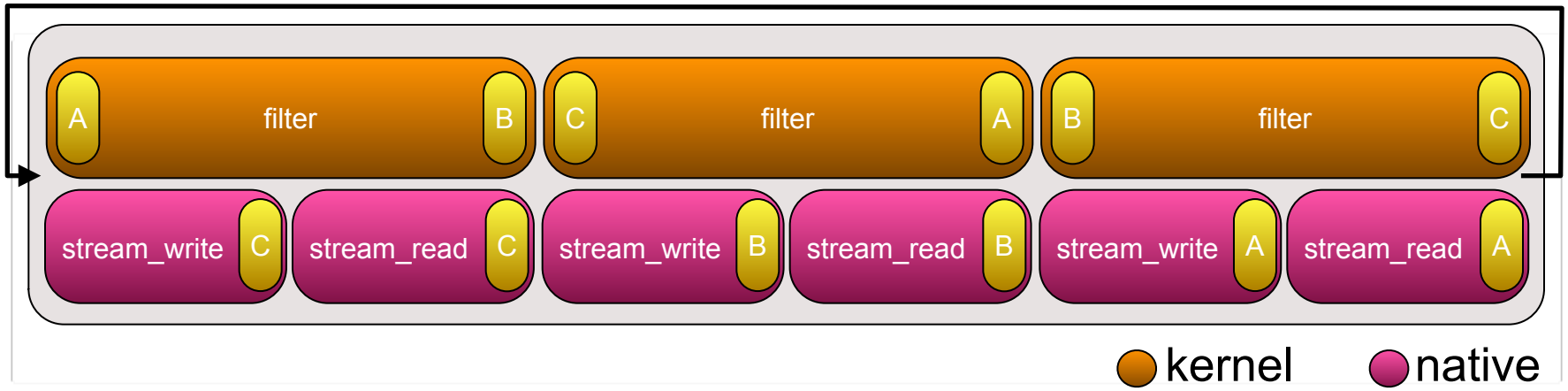

```
size_t origin[] = { 0, 0, 0 };
size_t region[] = { width, height, 1 };
cl_event convert_event;

err = clEnqueueAcquireGLObjects(queue, 1, &image, 0, 0, 0);

err = clEnqueueCopyBufferToImage(queue, buffer, image, 0,
                                 origin, region, 0, NULL, &convert_event);

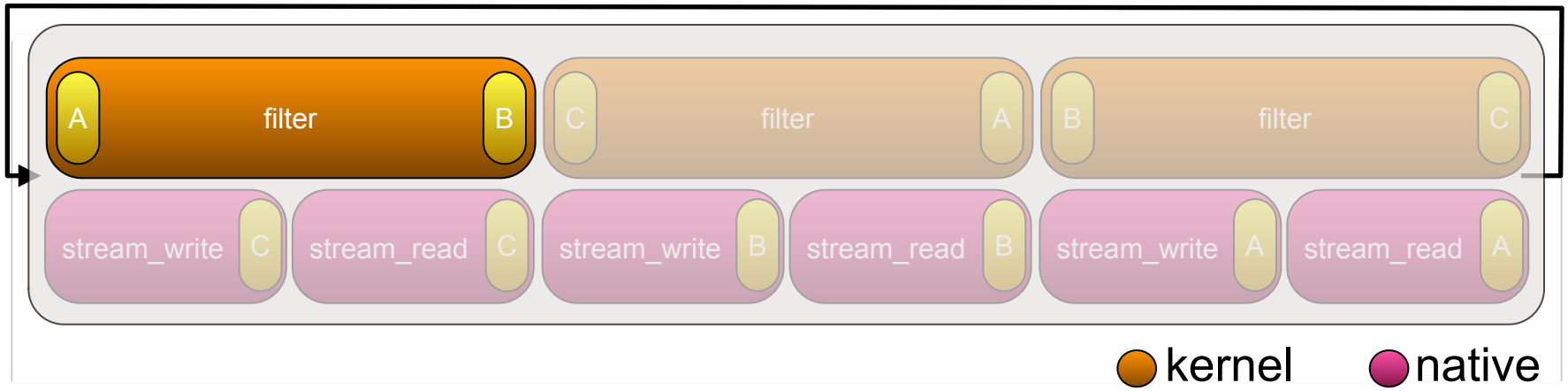
err = clEnqueueReleaseGLObjects(queue, 1, &image, 0, 0, 0);
```

Streaming Data



- Overlap streaming data operations with compute
- Use device to do all computation with kernels
- Use host to do all streaming operations w/native functions
- Use event wait lists for execution order

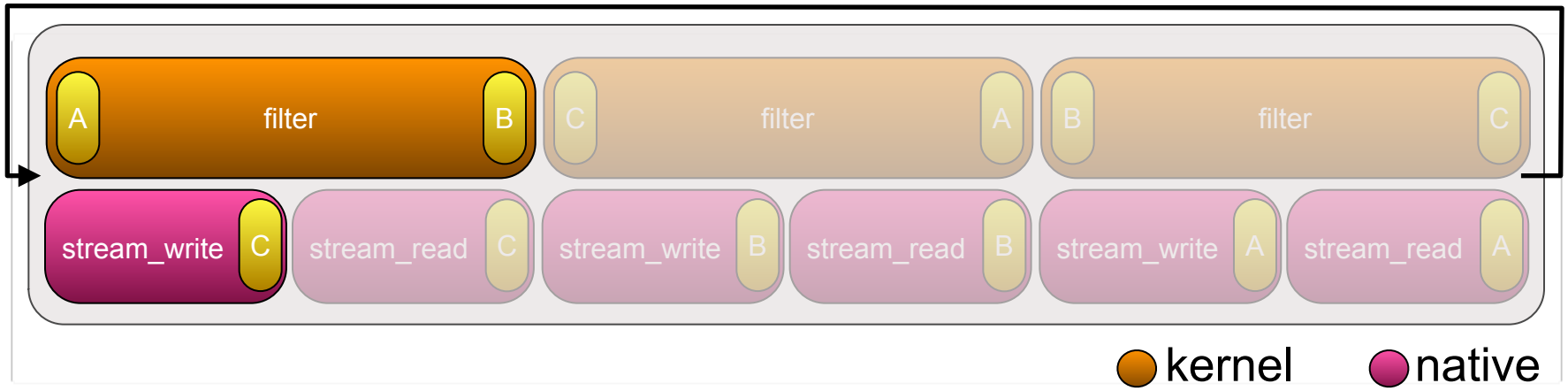
Streaming Data



- On the device:

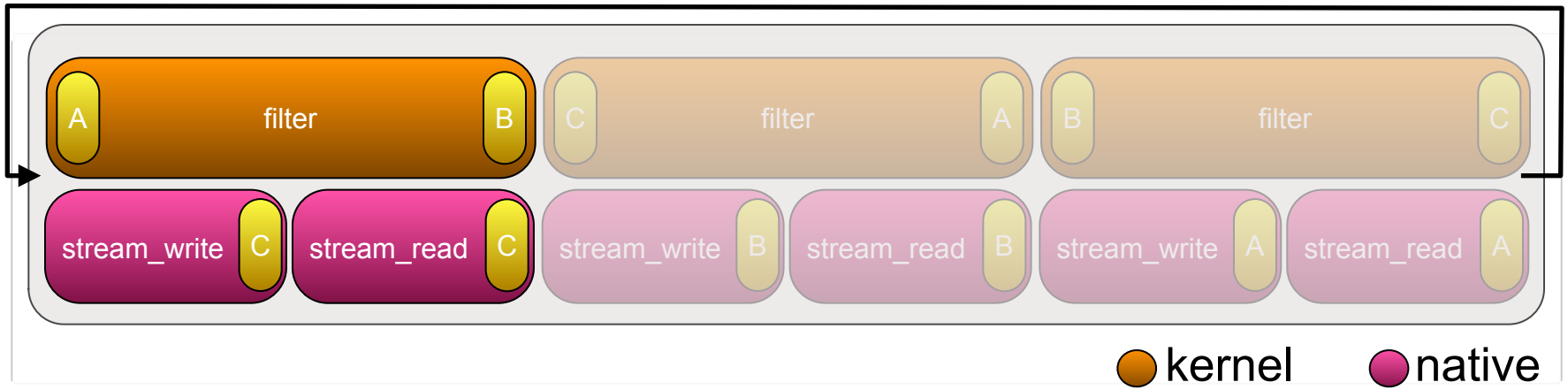
  filter kernel reads from cl_mem A writes to cl_mem B

Streaming Data



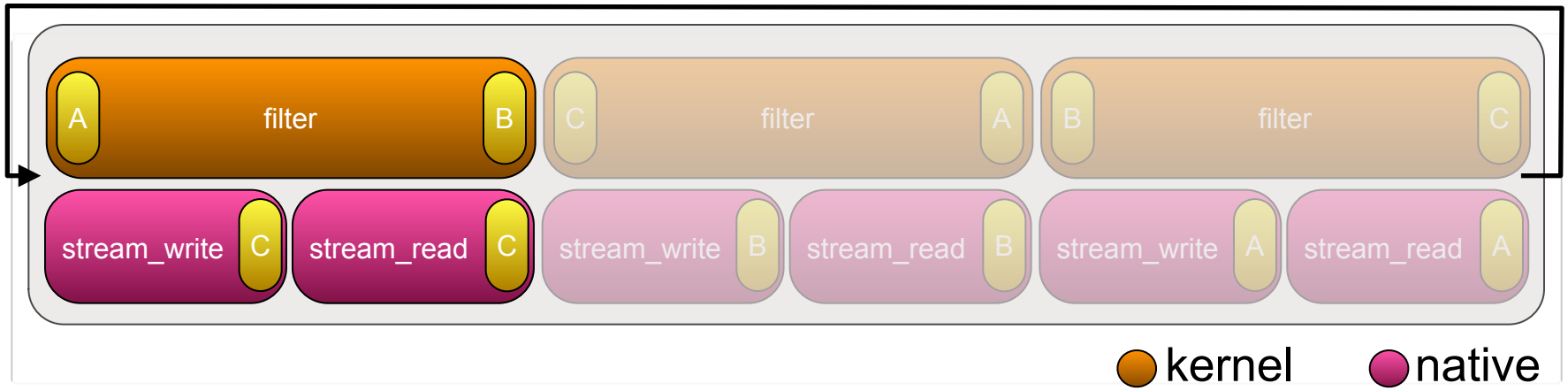
- On the device:
  filter kernel reads from cl_mem A writes to cl_mem B
- Meanwhile, on the host:
  stream_write method outputs previous cl_mem C

Streaming Data



- On the device:
  filter kernel reads from cl_mem A writes to cl_mem B
- Meanwhile, on the host:
  stream_write method outputs previous cl_mem C
  stream_read method prefetches and fills cl_mem C

Streaming Data



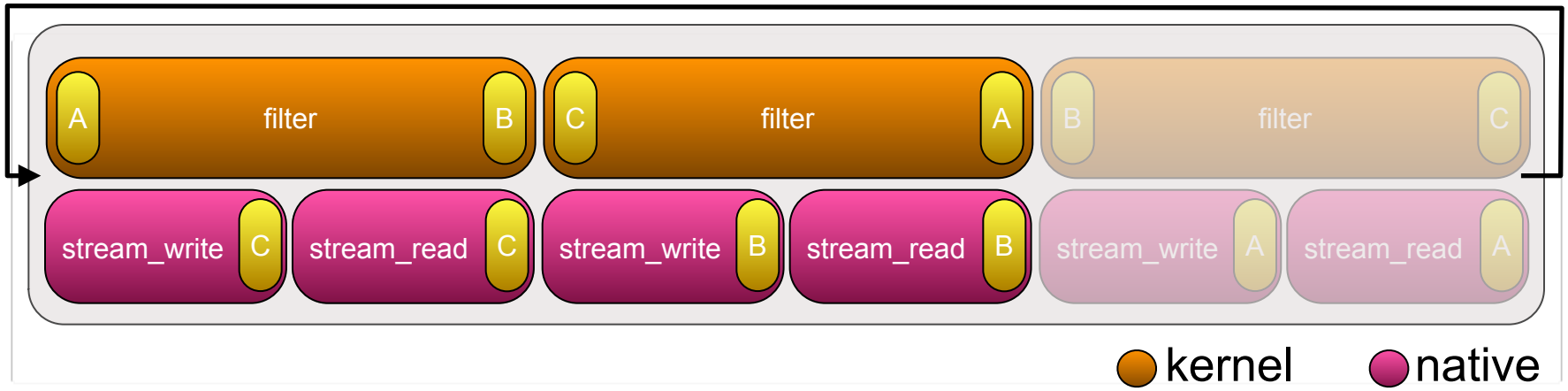
- Continue and alternative memory locations....

  filter kernel: (A – B)

  stream_write: (C)

  stream_read: (C)

Streaming Data



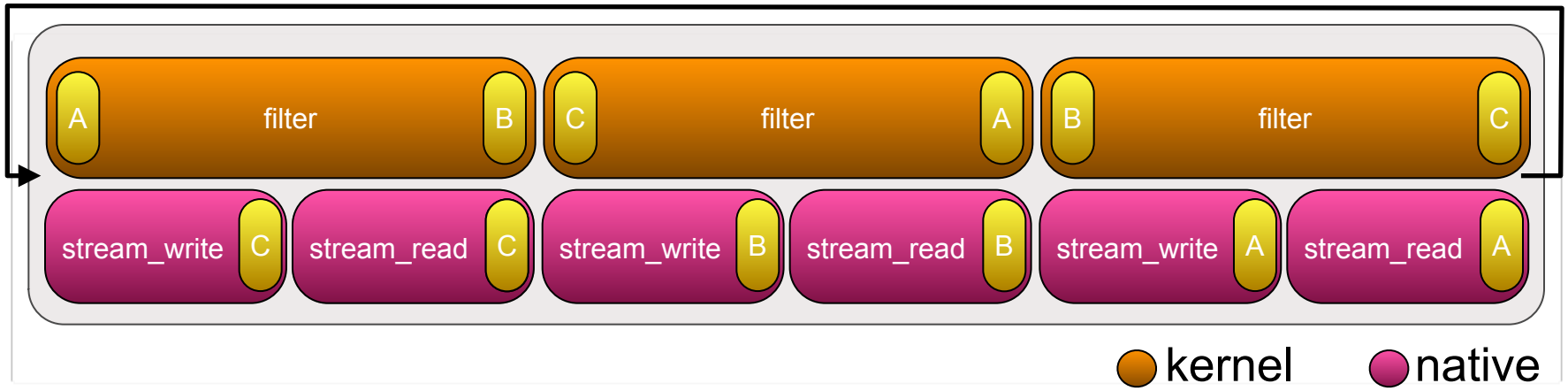
- Continue and alternative memory locations....

  filter kernel: (A – B) (C – A)

  stream_write: (C) (B)

  stream_read: (C) (B)

Streaming Data



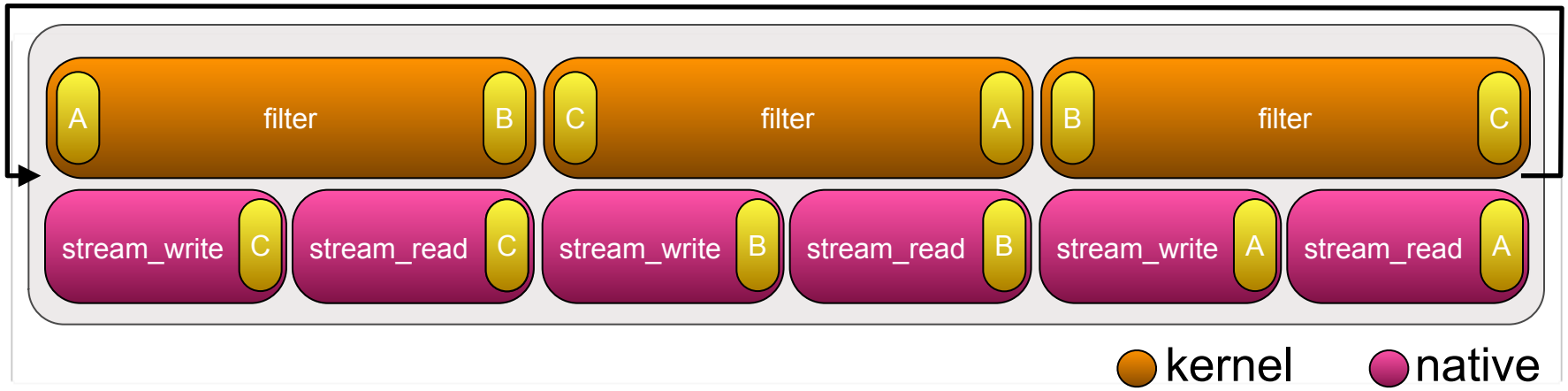
- Continue and alternative memory locations....

filter kernel: (A – B) (C – A) (B – C)

stream_write: (C) (B) (A)

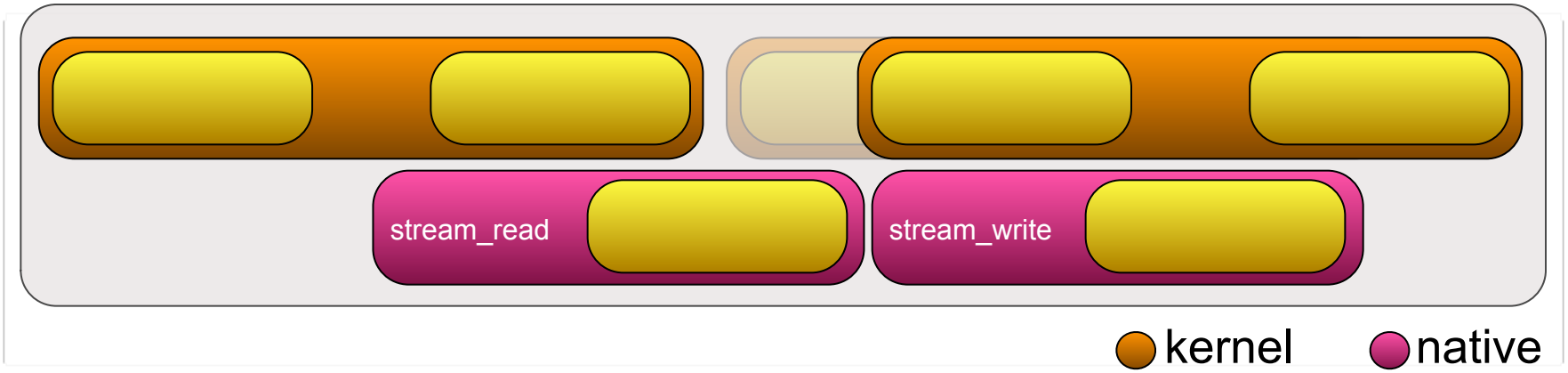
stream_read: (C) (B) (A)

Streaming Data



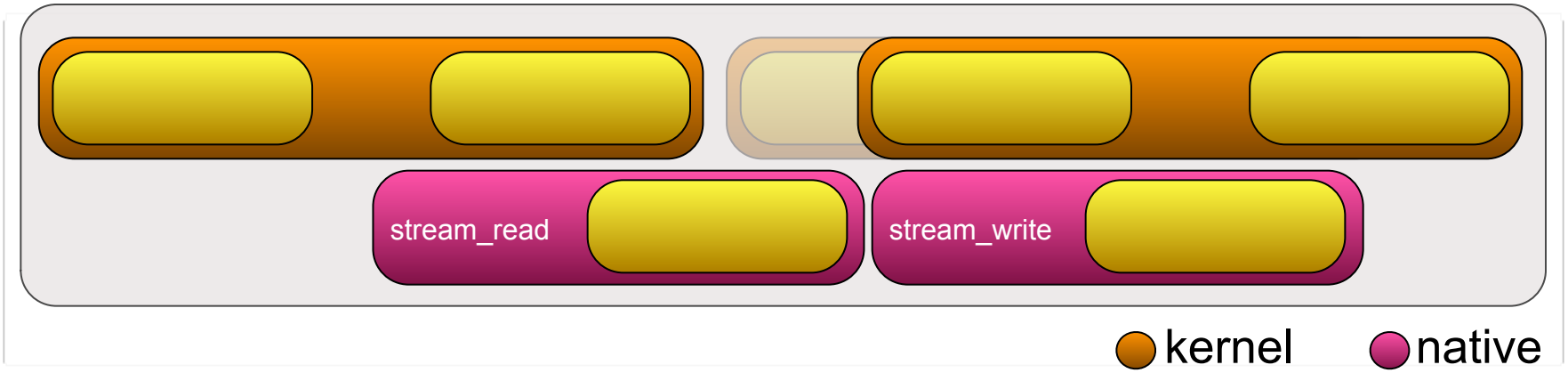
- **Some caveats....**
  - Size of data stream must be large to offset transfer costs
  - Complexity of filter must be large to offset launch costs
  - Both stream_write and stream_read methods must be timely

Streaming Data



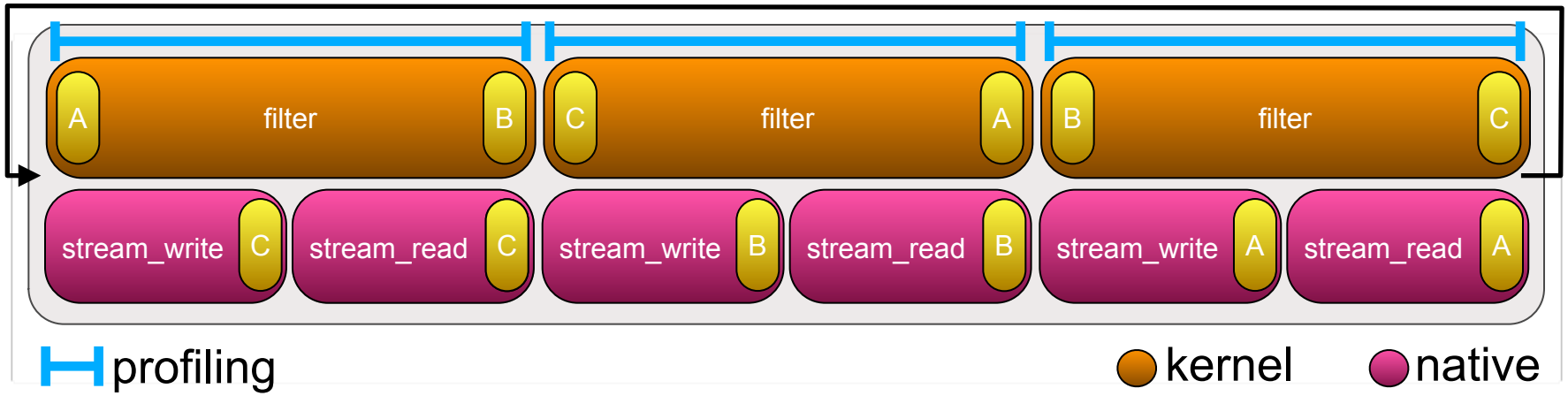
- **If data size is too large....**
  - stream_read can't fill full data size in memory
  - stream_write can't output full data size

Streaming Data



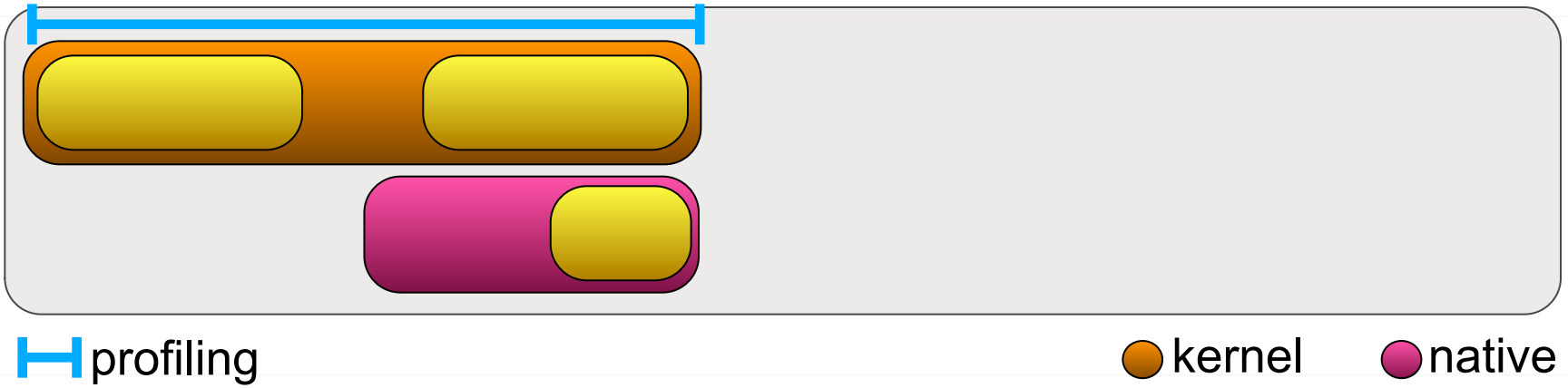
- **Don’t want to delay device** kernel
  - Not willing to sacrifice efficiency
  - Might have strict time constraints for device results

Streaming Data



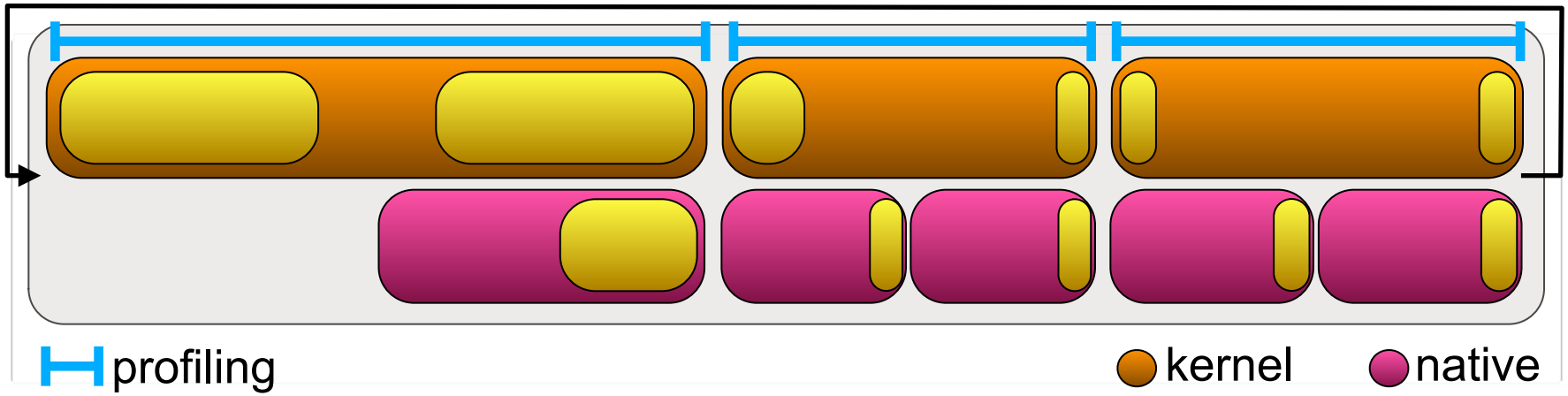
- Use event profiling to identify time window for stream operations

Streaming Data



- **Allocate large fixed size memory buffers**
  - Use best estimate based on kernel execution time
  - Pass in data size as kernel argument
  - Adjust data size in stream operation

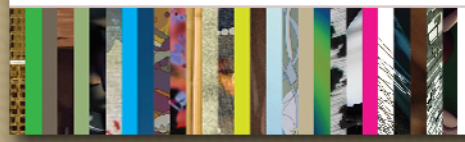
Streaming Data



- **Dynamically adjust streaming data size**
  - Estimate reasonable time window for first stream operation
  - Use measured time window to adjust data size in stream operation

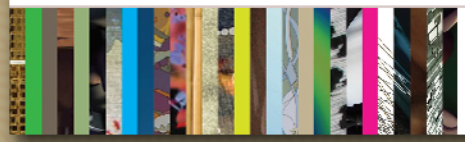
OpenCL Event Model Usage

- **Summary**
  - Use the execution model to your advantage
  - Use synchronisation to your benefit
  - Use events for fine grained control
  - Plenty of flexibility already (even with immutable queues)



OpenCL Developer Insights

- **Know Your Platform**
  - Understand the cost of API calls
  - Profile the overhead of your platform and commands
  - Even compliant vendor implementations differ
  - Give feedback to platform vendors
  - Work with Khronos to improve OpenCL



Acknowledgements

- **Course Organisers**
  - **AMD / NVIDIA / Khronos / Apple**
- **University of Western Australia**
  - **CMCA / WASP / iVEC**

Derek Gerstmann

University of Western Australia

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