IWOCL 2024

The 12th International Workshop on OpenCL and SYCL

Emulating Command Buffer Extensions with OpenCL Layers

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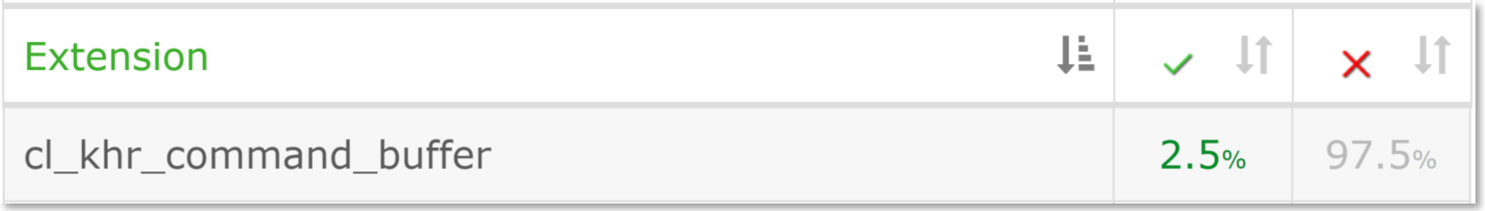
APRIL 8-11, 2024 | CHICAGO, USA | IWOCL.ORG

OpenCL Command Buffers were provisionally released November 2021!

… but implementation support remains low



Extension	✓	✗
cl_khr_command_buffer	2.5%	97.5%

(Data from opencl.gpuinfo.org, March 2024)

Problem Statement

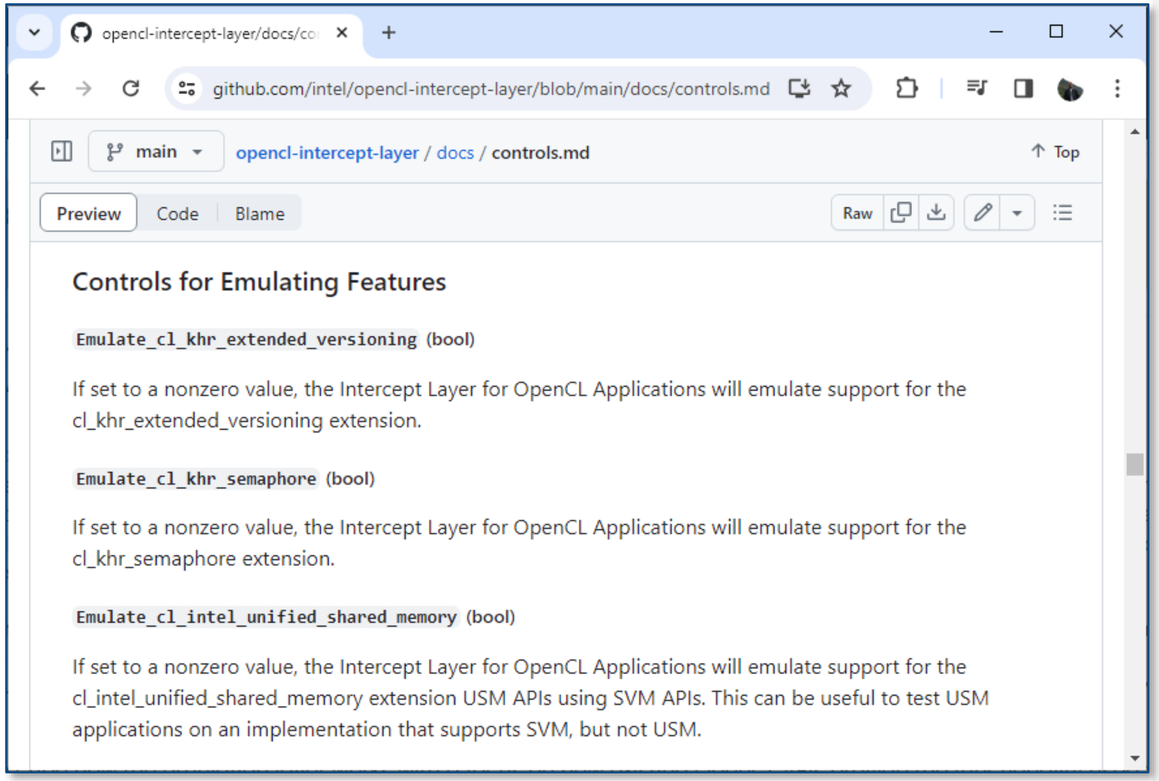
- Some OpenCL extensions take a long time to implement
- Some OpenCL devices may never support an OpenCL extension
- Lack of implementations hinders adoption:
  - Applications won’t support an extension without implementations
  - Other implementors won’t support an extension without applications
- We need a way to break this cycle!
  - Improve developer confidence that a feature will be available
  - Provide a competent fallback when an implementation is unavailable

We implemented support for command buffers in an OpenCL layer, demonstrating one way to break the cycle.

Prior Work

OpenCL Intercept Layer

- The OpenCL Intercept Layer can emulate some OpenCL extensions
- How does this work?
  - Augment existing APIs, e.g. `clGetDeviceInfo`
  - Implement new APIs by hooking `clGetExtensionFunctionAddress`
- Functional, but a heavyweight solution



opencl-intercept-layer/docs/co
github.com/intel/opencl-intercept-layer/blob/main/docs/controls.md
main
opencl-intercept-layer / docs / controls.md
Top
Preview
Code
Blame
Raw

Controls for Emulating Features

`Emulate_cl_khr_extended_versioning` (bool)

If set to a nonzero value, the Intercept Layer for OpenCL Applications will emulate support for the cl_khr_extended_versioning extension.

`Emulate_cl_khr_semaphore` (bool)

If set to a nonzero value, the Intercept Layer for OpenCL Applications will emulate support for the cl_khr_semaphore extension.

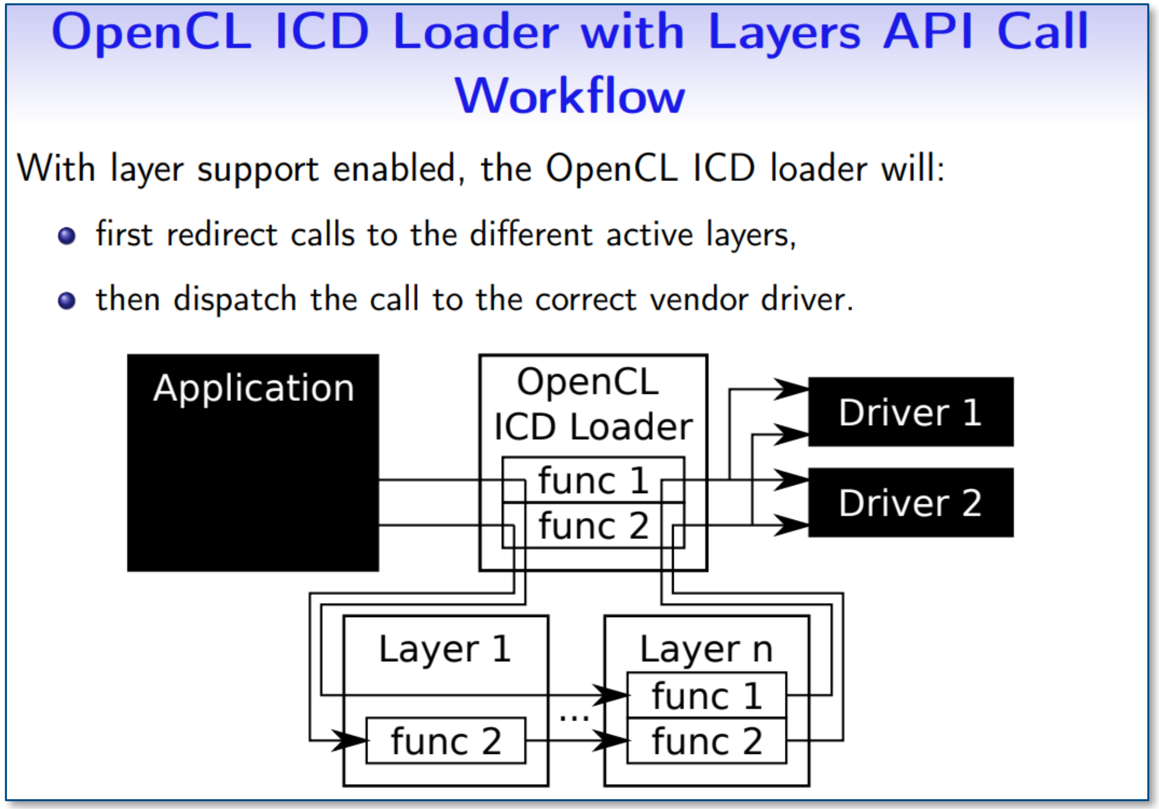
`Emulate_cl_intel_unified_shared_memory` (bool)

If set to a nonzero value, the Intercept Layer for OpenCL Applications will emulate support for the cl_intel_unified_shared_memory extension USM APIs using SVM APIs. This can be useful to test USM applications on an implementation that supports SVM, but not USM.

https://github.com/intel/opencl-intercept-layer/blob/main/docs/controls.md#controls-for-emulating-features

Installable OpenCL Layers

- Installable OpenCL Layers can also intercept and augment OpenCL functions
- Lighter weight, easy to enable and disable individual layers
- Most prior work for tracing and validation
    - No (known) prior work to emulate extensions
- We decided to try this mechanism – and it worked!



OpenCL ICD Loader with Layers API Call Workflow

With layer support enabled, the OpenCL ICD loader will:

- first redirect calls to the different active layers,
- then dispatch the call to the correct vendor driver.

From: https://github.com/Kerilk/OpenCL-Layers-Tutorial/blob/main/presentation/LayersForOpenCL.pdf (IWOCL 2021)

How the Emulation Layer Works

Three Classes of Layer Functions

1. Emulation Functions: new functionality, implemented entirely within the layer

```
cl_int CL_API_CALL clCommandBarrierWithWaitListKHR_EMU(
    cl_command_buffer_khr cmdbuf,
    cl_command_queue command_queue,
    cl_uint num_sync_points_in_wait_list,
    const cl_sync_point_khr* sync_point_wait_list,
    cl_sync_point_khr* sync_point,
    cl_mutable_command_khr* mutable_handle)
{
    if (!CommandBuffer::isValid(cmdbuf)) {
        return CL_INVALID_COMMAND_BUFFER_KHR;
    }
    if (cl_int errorCode = cmdbuf->checkRecordErrors(
            command_queue,
            num_sync_points_in_wait_list,
            sync_point_wait_list,
            mutable_handle)) {
        return errorCode;
    }

    cmdbuf->addCommand(
        BarrierWithWaitList::create(cmdbuf, command_queue),
        num_sync_points_in_wait_list,
        sync_point_wait_list,
        sync_point,
        mutable_handle);
    return CL_SUCCESS;
}
```

Three Classes of Layer Functions

1. **Emulation Functions**: new functionality, implemented entirely within the layer
2. **Override Functions**: add functionality in some cases, otherwise pass along

```
static cl_int CL_API_CALL clGetDeviceInfo_layer(
    cl_device_id device,
    cl_device_info param_name,
    size_t param_value_size,
    void* param_value,
    size_t* param_value_size_ret)
{
    cl_int  errorCode = CL_SUCCESS;

    if (clGetDeviceInfo_override(
            device,
            param_name,
            param_value_size,
            param_value,
            param_value_size_ret,
            &errorCode) == false) {
        return g_pNextDispatch->clGetDeviceInfo(
            device,
            param_name,
            param_value_size,
            param_value,
            param_value_size_ret);
    }

    return errorCode;
}
```

Three Classes of Layer Functions

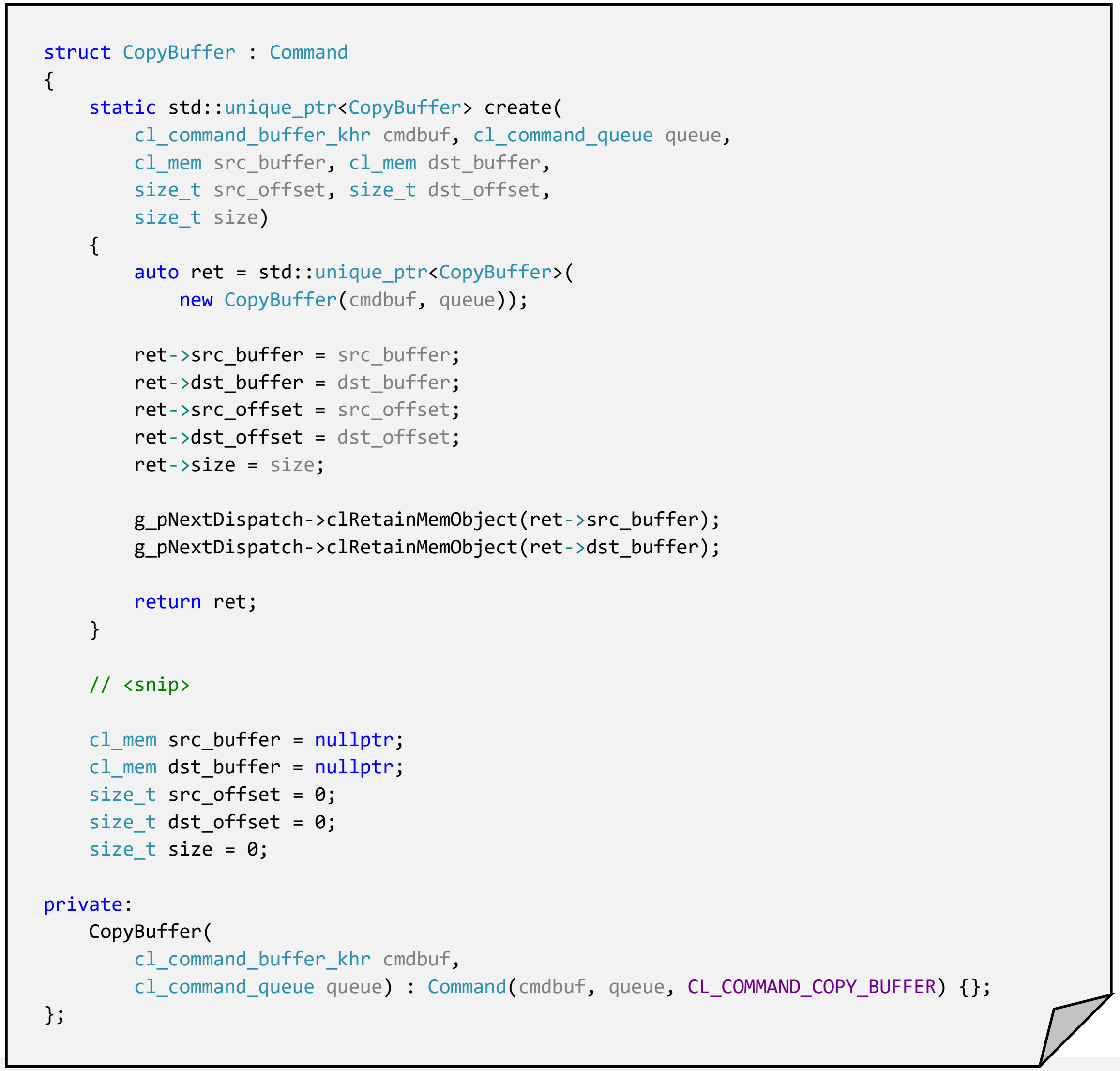
1. Emulation Functions: new functionality, implemented entirely within the layer
2. Override Functions: add functionality in some cases, otherwise pass along
3. Bookkeeping Functions: record some info, then unconditionally pass along

```
static cl_int CL_API_CALL clReleaseEvent_layer(
    cl_event event)
{
    cl_uint refCount = 0;
    g_pNextDispatch->clGetEventInfo(
        event,
        CL_EVENT_REFERENCE_COUNT,
        sizeof(refCount),
        &refCount,
        nullptr);
    if (refCount == 1) {
        auto& context = getLayerContext();
        auto it = context.EventMap.find(event);
        if (it != context.EventMap.end()) {
            g_pNextDispatch->clReleaseEvent(it->second);
            context.EventMap.erase(it);
        }
    }

    return g_pNextDispatch->clReleaseEvent(event);
}
```

Command Buffer Construction “Records” Commands

- Record each command in the command buffer
  - Plus, any arguments
  - Plus, some bookkeeping info
- Notes:
  - Need to retain OpenCL objects!
  - Need to clone OpenCL kernels to preserve kernel args!



```
struct CopyBuffer : Command
{
    static std::unique_ptr<CopyBuffer> create(
        cl_command_buffer_khr cmdbuf, cl_command_queue queue,
        cl_mem src_buffer, cl_mem dst_buffer,
        size_t src_offset, size_t dst_offset,
        size_t size)
    {
        auto ret = std::unique_ptr<CopyBuffer>(
            new CopyBuffer(cmdbuf, queue));

        ret->src_buffer = src_buffer;
        ret->dst_buffer = dst_buffer;
        ret->src_offset = src_offset;
        ret->dst_offset = dst_offset;
        ret->size = size;

        g_pNextDispatch->clRetainMemObject(ret->src_buffer);
        g_pNextDispatch->clRetainMemObject(ret->dst_buffer);

        return ret;
    }

    // <snip>

    cl_mem src_buffer = nullptr;
    cl_mem dst_buffer = nullptr;
    size_t src_offset = 0;
    size_t dst_offset = 0;
    size_t size = 0;

private:
    CopyBuffer(
        cl_command_buffer_khr cmdbuf,
        cl_command_queue queue) : Command(cmdbuf, queue, CL_COMMAND_COPY_BUFFER) {};
};
```

Command Buffer Enqueue “Plays Back” Commands

- Enqueues each recorded command into the provided command queue
- Notes:
  - Need to map sync points to events
  - May need to insert command queue barriers in some cases (not shown)

```
struct CopyBuffer : Command
{
    // <snip>

    int playback(
        cl_command_queue queue,
        std::vector<cl_event>& deps) const override
    {
        auto wait_list = getEventWaitList(deps);
        auto signal = getEventSignalPtr(deps);
        return g_pNextDispatch->clEnqueueCopyBuffer(
            queue,
            src_buffer,
            dst_buffer,
            src_offset,
            dst_offset,
            size,
            static_cast<cl_uint>(wait_list.size()),
            wait_list.data(),
            signal);
    }

    // <snip>
};
```

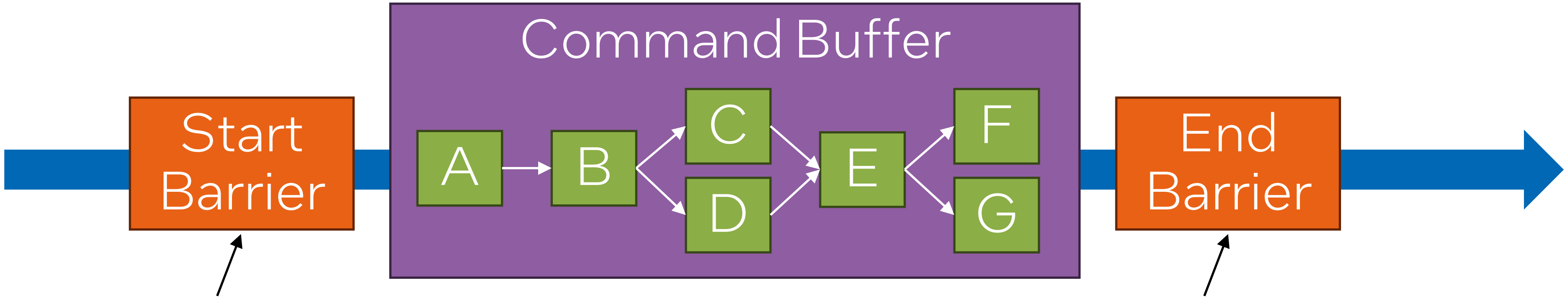
Brief Retrospective

Most things went well!

- OpenCL installable layer mechanism is solid!
- Many OpenCL features make layering easy:
  - Built-in Reference Counting and Object Queries
  - `clCloneKernel` to Clone Kernels and their Arguments

Some things were tricky...

- How can we do event profiling for command buffers?
  - Need to profile a group of commands
- Solution: add barriers with event profiling

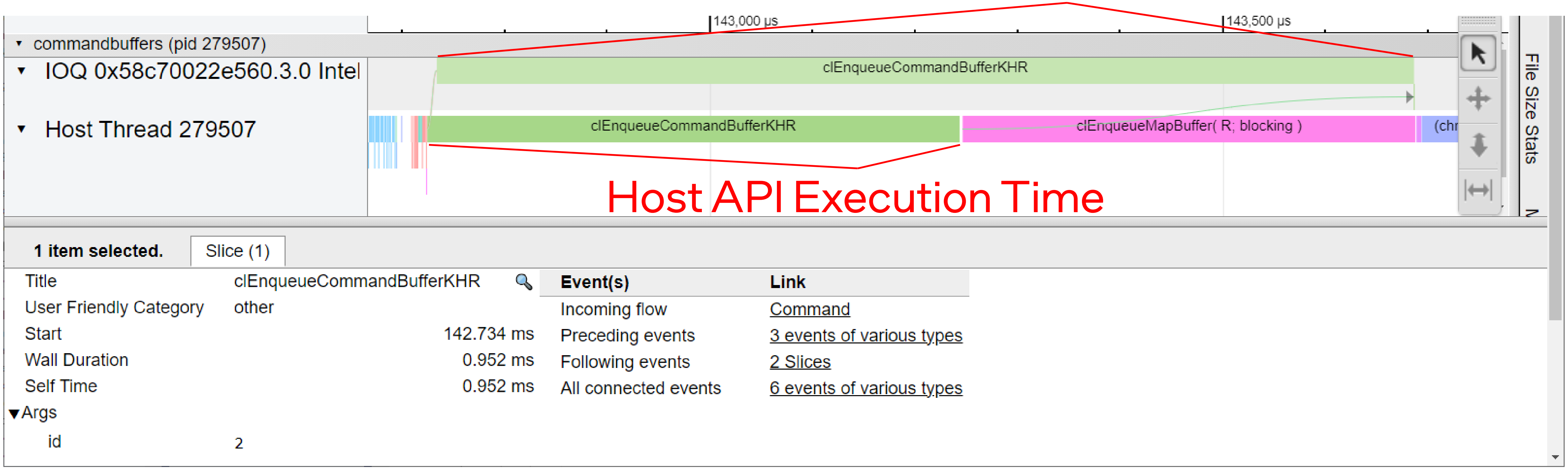


Use this event for:
`CL_PROFILING_COMMAND_QUEUED,`
`CL_PROFILING_COMMAND_SUBMIT,`
`CL_PROFILING_COMMAND_START`

Use this event for:
`CL_PROFILING_COMMAND_END`

Verdict: Success!

Device Execution Time


143,000 µs
143,500 µs
commandbuffers (pid 279507)
IOQ 0x58c70022e560.3.0 Intel
Host Thread 279507
clEnqueueCommandBufferKHR
clEnqueueCommandBufferKHR
clEnqueueMapBuffer(R; blocking)
(chr
File Size Stats

Host API Execution Time

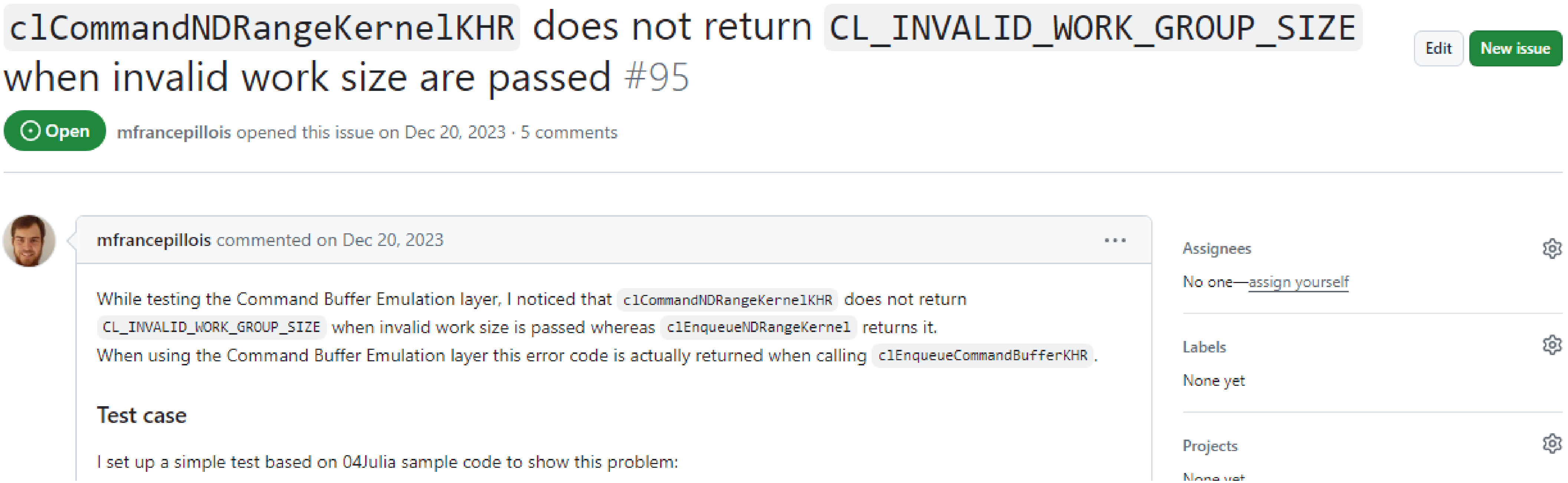
1 item selected. Slice (1)

		Event(s)	Link
Title	clEnqueueCommandBufferKHR	Incoming flow	Command
User Friendly Category	other	Preceding events	3 events of various types
Start	142.734 ms	Following events	2 Slices
Wall Duration	0.952 ms	All connected events	6 events of various types
Self Time	0.952 ms		
▾Args			
id	2		

(Data collected with the OpenCL Intercept Layer, IWOCL 2018)

Some things were tricky…

- How can we do error checking when commands are recorded?



`clCommandNDRangeKernelKHR` does not return `CL_INVALID_WORK_GROUP_SIZE` when invalid work size are passed #95

mfrancepillois opened this issue on Dec 20, 2023 · 5 comments

mfrancepillois commented on Dec 20, 2023

While testing the Command Buffer Emulation layer, I noticed that `clCommandNDRangeKernelKHR` does not return `CL_INVALID_WORK_GROUP_SIZE` when invalid work size is passed whereas `clEnqueueNDRangeKernel` returns it.
When using the Command Buffer Emulation layer this error code is actually returned when calling `clEnqueueCommandBufferKHR`.

Test case

I set up a simple test based on 04Julia sample code to show this problem:

Assignees

No one—assign yourself

Labels

None yet

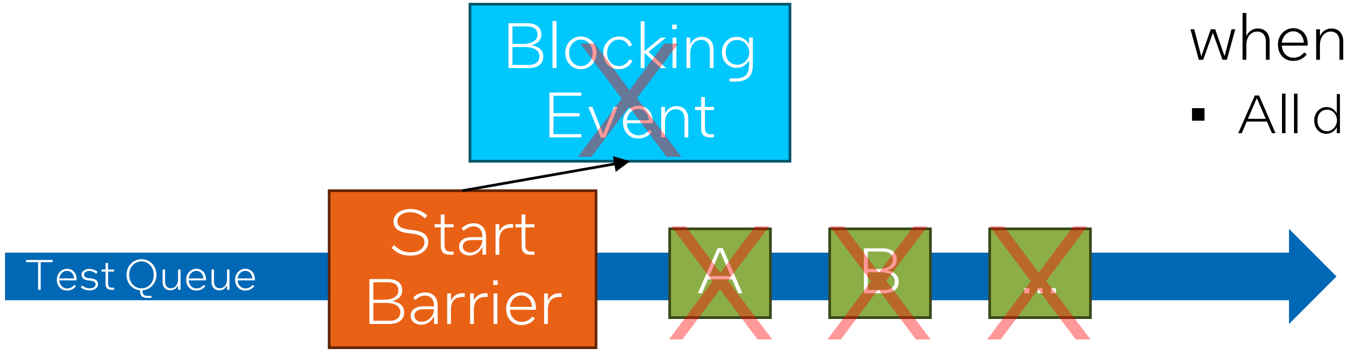
Projects

None yet

Tentative Solution:

Setup:

1. Create a "Test Queue" when command buffer is created
2. Also, create a "Blocking Event" when command buffer is created
3. Enqueue a Barrier dependent on the "Blocking Event"



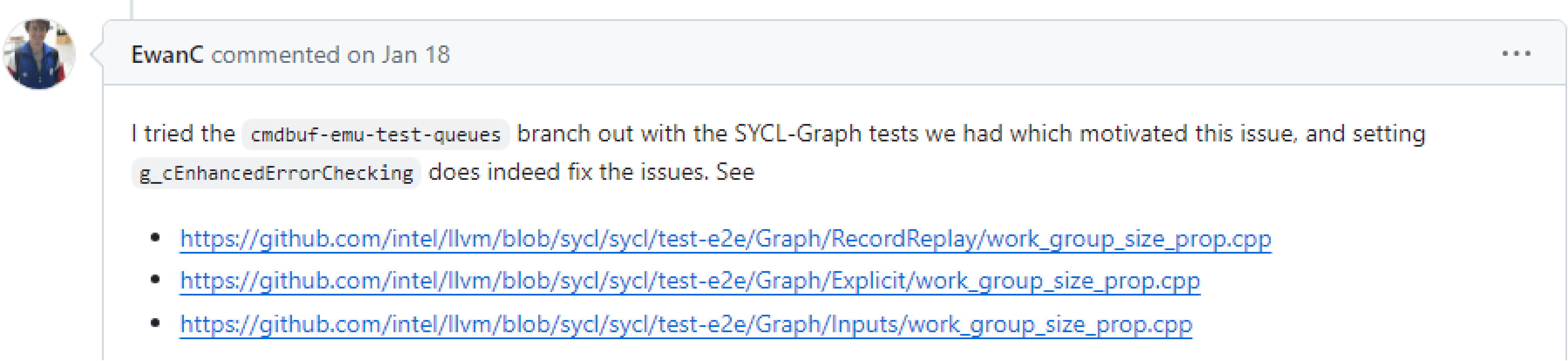
Recording:

4. Enqueue commands to "Test Queue" before recording
   - Command does not execute due to barrier dependency
   - But error checking is performed!

Finalization:

5. Set "Blocking Event" to error state when command buffer is finalized
   - All dependent command discarded!

Verdict: Partial Success?



EwanC commented on Jan 18

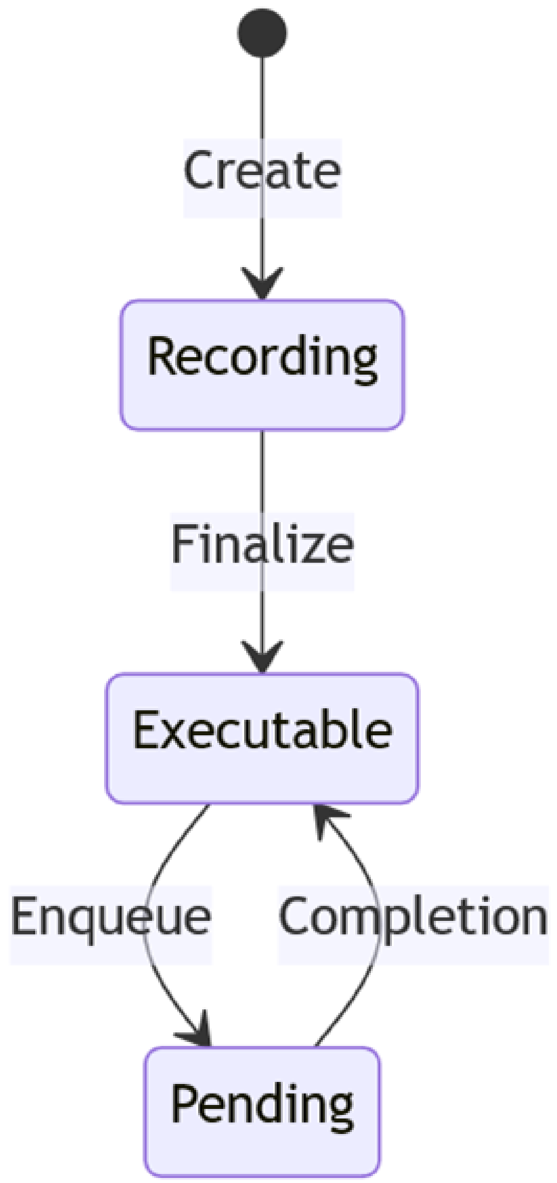
I tried the `cmdbuf-emu-test-queues` branch out with the SYCL-Graph tests we had which motivated this issue, and setting `g_cEnhancedErrorChecking` does indeed fix the issues. See

- https://github.com/intel/llvm/blob/sycl/sycl/test-e2e/Graph/RecordReplay/work_group_size_prop.cpp
- https://github.com/intel/llvm/blob/sycl/sycl/test-e2e/Graph/Explicit/work_group_size_prop.cpp
- https://github.com/intel/llvm/blob/sycl/sycl/test-e2e/Graph/Inputs/work_group_size_prop.cpp

- Relies on tricky behavior / dusty corners of the spec
- Still in a branch, probably will not be enabled by default

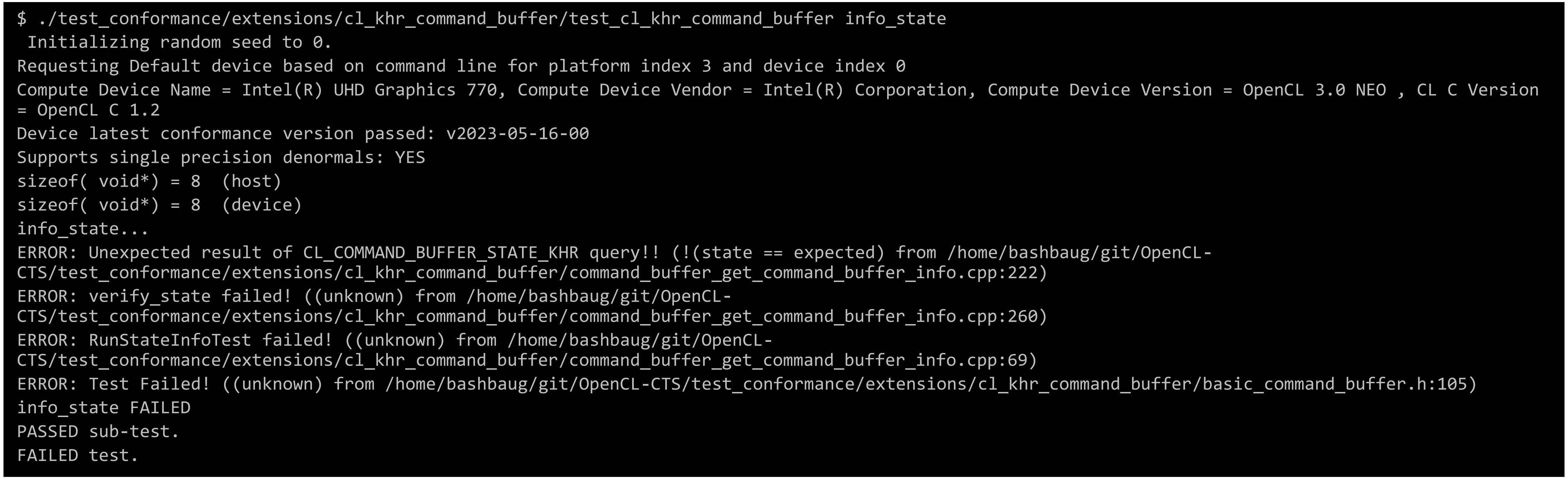
Some things were tricky…

- How can we track command buffer states?
  - `RECORDING` is straightforward…
  - `EXECUTABLE` is straightforward, too…
  - `PENDING` is complicated!
- No current solution
- Possibility:
  - Track event for the last enqueue, test if it is `COMPLETE`?
  - Might work, but adds complexity and overhead



Some things were tricky…

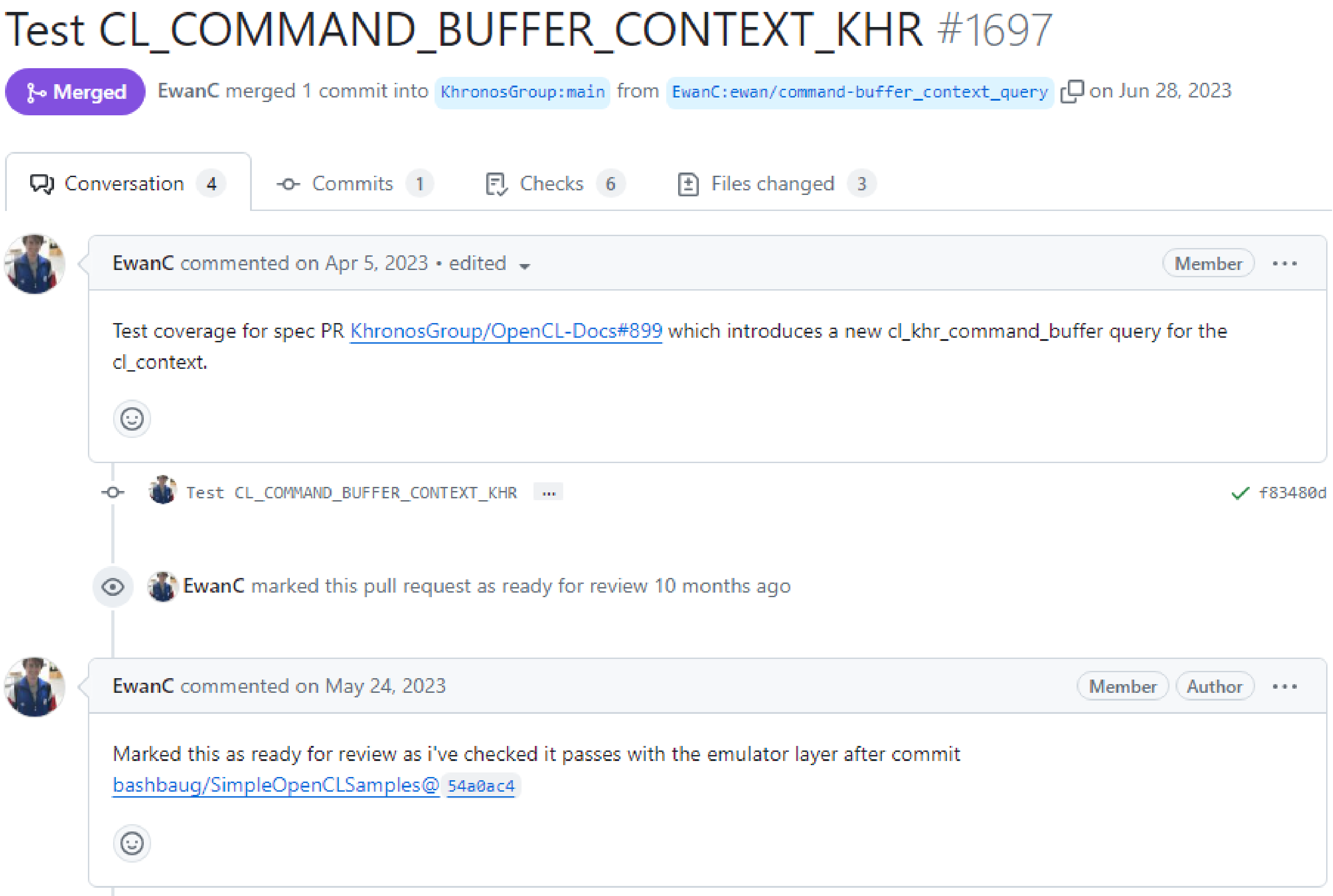
- The `PENDING` state is the only layer CTS failure!
- Nice to fix, but probably doesn’t affect much code in practice…



```
$ ./test_conformance/extensions/cl_khr_command_buffer/test_cl_khr_command_buffer info_state
 Initializing random seed to 0.
Requesting Default device based on command line for platform index 3 and device index 0
Compute Device Name = Intel(R) UHD Graphics 770, Compute Device Vendor = Intel(R) Corporation, Compute Device Version = OpenCL 3.0 NEO , CL C Version
= OpenCL C 1.2
Device latest conformance version passed: v2023-05-16-00
Supports single precision denormals: YES
sizeof( void*) = 8  (host)
sizeof( void*) = 8  (device)
info_state...
ERROR: Unexpected result of CL_COMMAND_BUFFER_STATE_KHR query!! (!(state == expected) from /home/bashbaug/git/OpenCL-
CTS/test_conformance/extensions/cl_khr_command_buffer/command_buffer_get_command_buffer_info.cpp:222)
ERROR: verify_state failed! ((unknown) from /home/bashbaug/git/OpenCL-
CTS/test_conformance/extensions/cl_khr_command_buffer/command_buffer_get_command_buffer_info.cpp:260)
ERROR: RunStateInfoTest failed! ((unknown) from /home/bashbaug/git/OpenCL-
CTS/test_conformance/extensions/cl_khr_command_buffer/command_buffer_get_command_buffer_info.cpp:69)
ERROR: Test Failed! ((unknown) from /home/bashbaug/git/OpenCL-CTS/test_conformance/extensions/cl_khr_command_buffer/basic_command_buffer.h:105)
info_state FAILED
PASSED sub-test.
FAILED test.
```

Current Usage Examples

Conformance Test Suite Development



Test CL_COMMAND_BUFFER_CONTEXT_KHR #1697

Merged EwanC merged 1 commit into `KhronosGroup:main` from `EwanC:ewan/command-buffer_context_query` on Jun 28, 2023

EwanC commented on Apr 5, 2023 • edited — Member

Test coverage for spec PR KhronosGroup/OpenCL-Docs#899 which introduces a new cl_khr_command_buffer query for the cl_context.

`Test CL_COMMAND_BUFFER_CONTEXT_KHR` ... ✓ `f83480d`

EwanC marked this pull request as ready for review 10 months ago

EwanC commented on May 24, 2023 — Member Author

Marked this as ready for review as i've checked it passes with the emulator layer after commit bashbaug/SimpleOpenCLSamples@ `54a0ac4`

Develop and debug the CTS on any device!

Bonus: CTS found a few bugs in the layer, too…

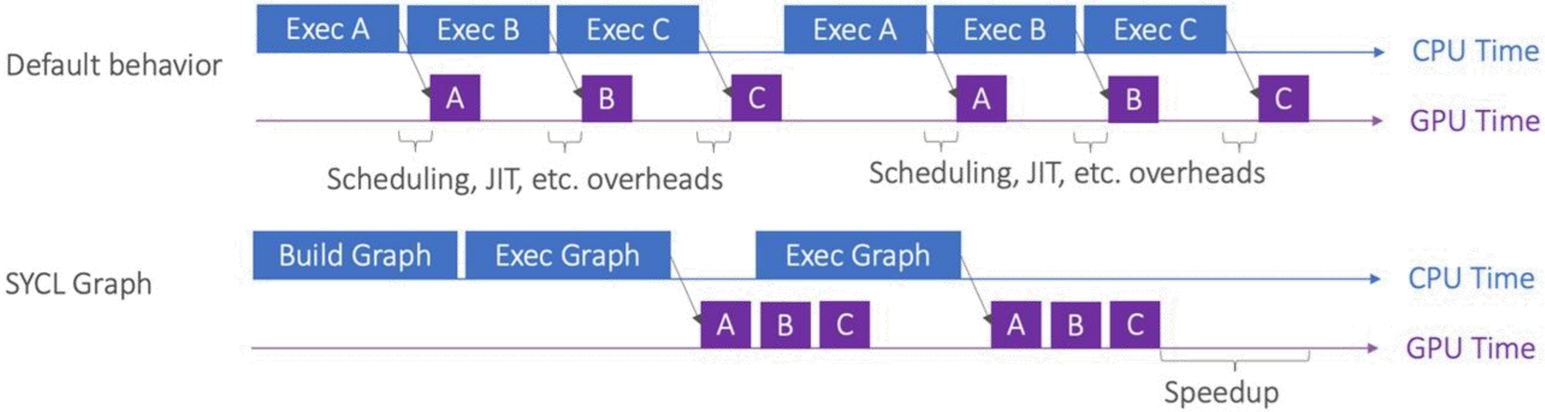
Layered Extension Development

- `cl_khr_command_buffer` is a base specification, designed to support additional functionality via layered extensions
  - Examples:
  - `cl_khr_command_buffer_multi_device`
  - `cl_khr_command_buffer_mutable_dispatch`
  - `cl_khr_command_buffer_mutable_memory_commands`

Emulation layer provides a convenient mechanism to quickly prototype layered extensions!

High-Level Language Feature Development

- SYCL Graph is an experimental oneAPI extension to build and execute entire graphs of commands:



- For OpenCL backends, graphs are recorded into command buffers

Emulation layer provides a convenient mechanism to develop, debug, and test the SYCL Graph extension!

(Diagram from "Towards Deferred Execution of a SYCL Command Graph", IWOCL 2023)

A Brief Look at Performance

Key Performance Questions

- Is the layer expensive?
  - How does layer performance compare to non-command buffer performance?
- Test Parameters:
  - Submission time or completion time?
  - How many kernels?

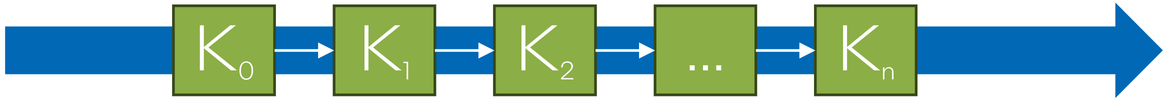
- Is the layer effective?
  - How does layer performance compare to native command buffer performance?
- Test Parameters:
  - Submission time or completion time?
  - How many kernels?
  - In-order or out-of-order?

Developed microbenchmarks to answer these questions!

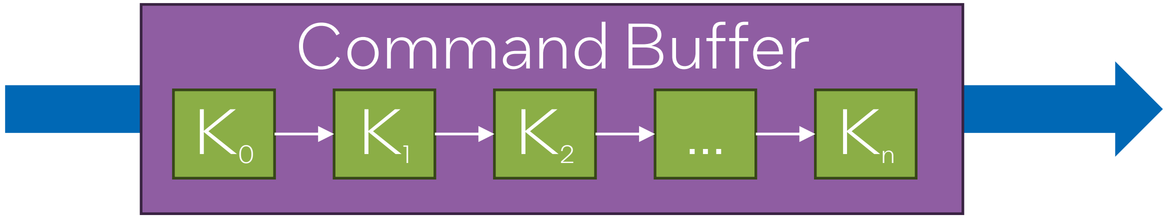
(“How to Optimize Compute Drivers? Let’s Start with Writing Good Benchmarks!”, IWOCL 2022)

Microbenchmark #1: ExecuteCommandBuffer

- Enqueue N kernels directly?



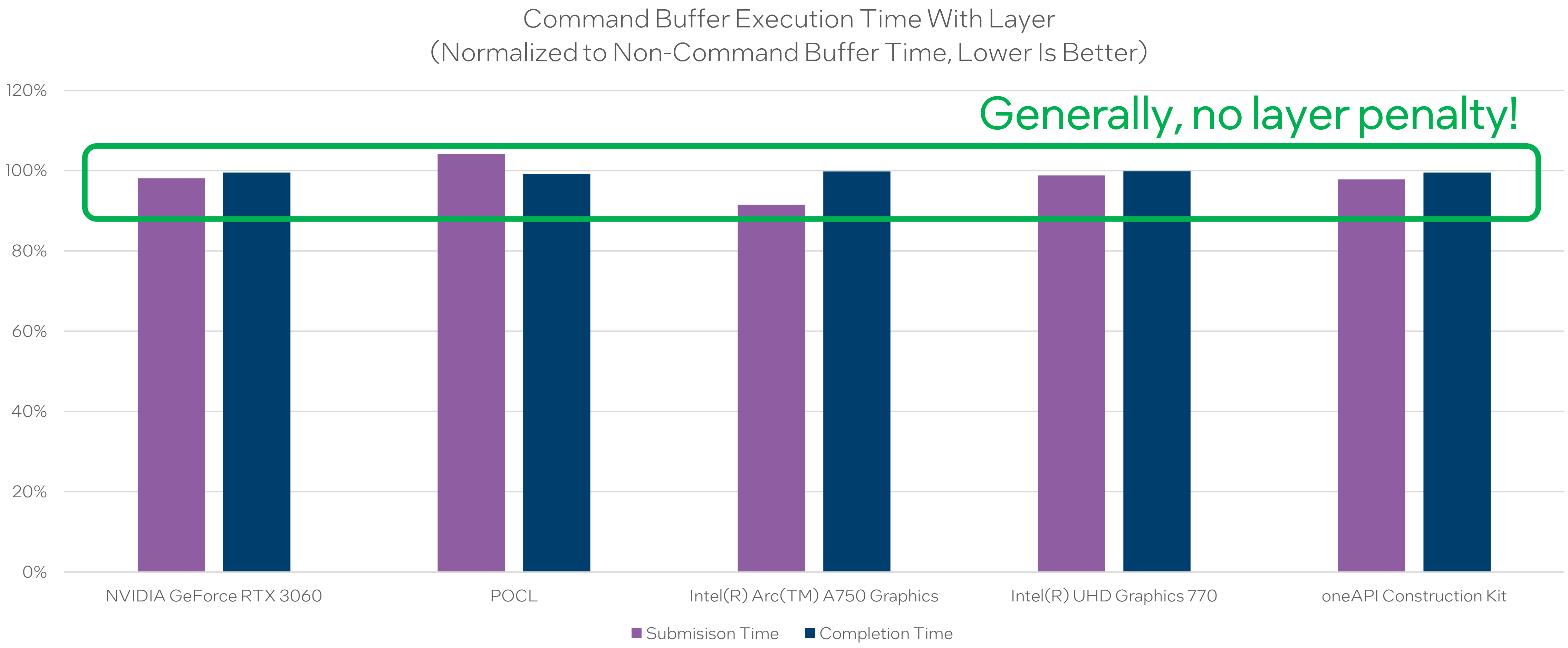
- Or enqueue N kernels in a Command Buffer?



- Measure submission time or completion time

https://github.com/bashbaug/compute-benchmarks/blob/micros-for-iwocl-2024/source/benchmarks/api_overhead_benchmark/implementations/ocl/execute_command_buffer_ocl.cpp

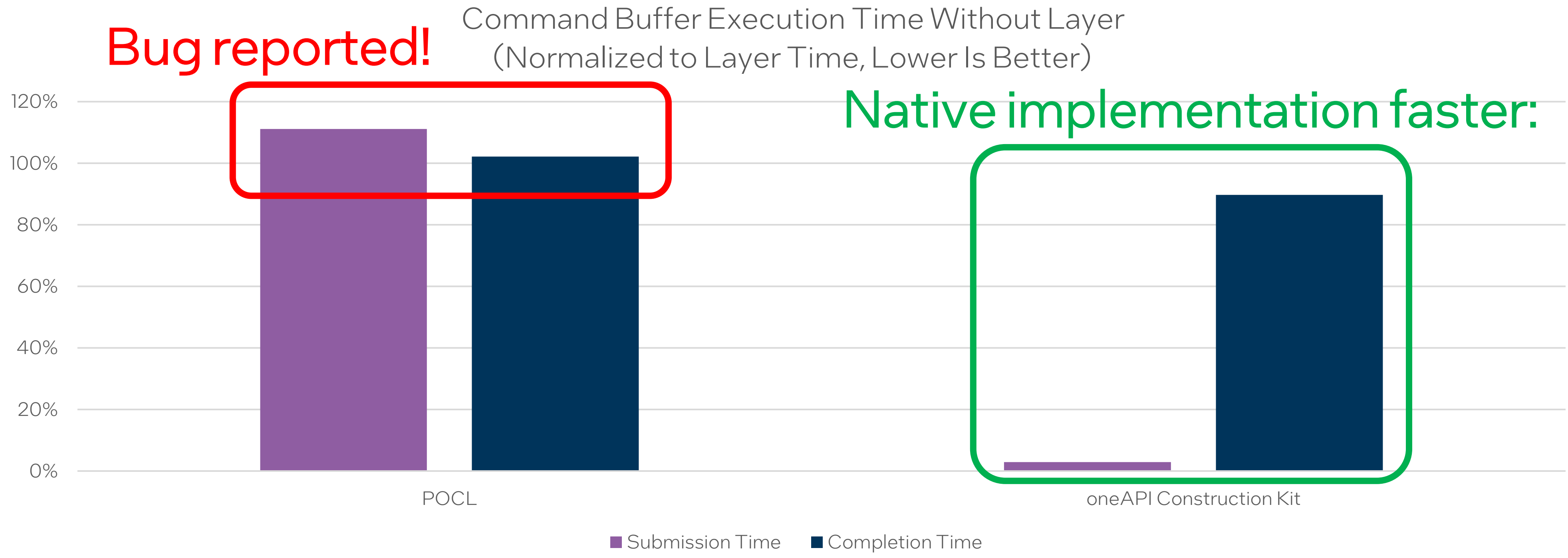
ExecuteCommandBuffer Results



Generally, no layer penalty!

Submission Time: `ExecuteCommandBuffer(api=ocl UseCommandBuffers=1 NumKernels=10 KernelExecutionTime=1 MeasureCompletionTime=0)`
Completion Time: `ExecuteCommandBuffer(api=ocl UseCommandBuffers=1 NumKernels=10 KernelExecutionTime=1 MeasureCompletionTime=1)`

ExecuteCommandBuffer Results



Layer performance is acceptable.

Submission Time: `ExecuteCommandBuffer(api=ocl UseCommandBuffers=1 NumKernels=10 KernelExecutionTime=1 MeasureCompletionTime=0)`
Completion Time: `ExecuteCommandBuffer(api=ocl UseCommandBuffers=1 NumKernels=10 KernelExecutionTime=1 MeasureCompletionTime=1)`

Summary and Conclusion

Summary and Conclusion

- Successfully emulated command buffers with an OpenCL layer!
  - Almost all features are implemented, layer is *almost* conformant

- Command buffer emulation layer is useful!
  - Accelerates layered extension design and development
  - Accelerates CTS development
  - Accelerates SYCL Graph development
  - Handy alternative for debugging and performance analysis

- OpenCL layer mechanism is robust, performant, and capable
  - Consider emulation for future extensions to improve adoption?

- Thank you!

Disclaimers

Related Links and References

- Command Buffer Emulation Layer
  - https://github.com/bashbaug/SimpleOpenCLSamples/tree/main/layers/10_cmdbufemu
- Command Buffer Microbenchmarks
  - https://github.com/bashbaug/compute-benchmarks/tree/micros-for-iwocl-2024

- Referenced IWOCL Presentations
  - Layers for OpenCL (IWOCL 2021) (slides)
  - Debugging and Analyzing Programs Using the Intercept Layer for OpenCL Applications (IWOCL 2018) (slides)
  - Towards Deferred Execution of a SYCL Command Graph (IWOCL 2023) (slides)
  - How to Optimize Compute Drivers? Let's Start with Writing Good Benchmarks! (IWOCL 2022) (slides)

System Configuration

Host:	
OS:	Linux bashbaug-newpc 6.5.0-26-generic #26~22.04.1-Ubuntu SMP PREEMPT_DYNAMIC Tue Mar 12 10:22:43 UTC 2 x86_64 x86_64 x86_64 GNU/Linux
CPU:	12th Gen Intel(R) Core(TM) i9-12900K
Drivers:	
NVIDIA GeForce RTX 3060	535.86.10
Intel(R) Arc(TM) A750 Graphics	24.09.28717.12
Intel(R) UHD Graphics 770	24.09.28717.12
POCL	PoCL 5.0 Linux, RelWithDebInfo, RELOC, SPIR, SPIR-V, LLVM 14.0.0, SLEEF, POCL_DEBUG (built from tag v5.0, commit 0bffce0)
oneAPI Construction Kit	ComputeAorta 4.0.0 Linux x86_64 (RelWithDebInfo, 85dfbf7e) (built from commit 85dfbf7, with LLVM 19.0.0)
Software:	
Emulation Layer	(built from commit 80222e5)
Compute-Benchmarks	(built from commit 17b58e0)

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