The 11th International workshop on OpenCL and SYCL

IWOCL & SYCLcon 2023

Stellar Mergers with HPX-Kokkos and SYCL: Methods of using an Asynchronous Many-Task Runtime System with SYCL

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HPX and SYCL

What is HPX?

- **Asynchronous, Distributed Many-Task Runtime System**

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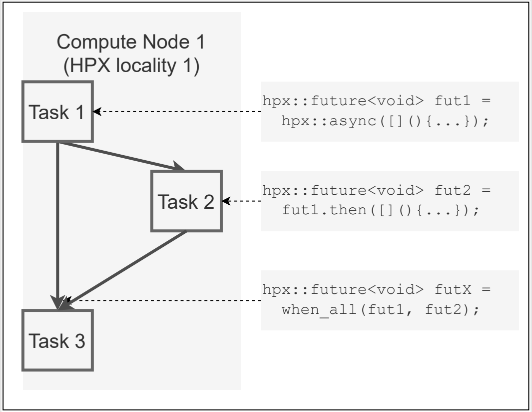
- **Asynchronous**: Build task graph using futures and continuations (`then`, `when_all`)



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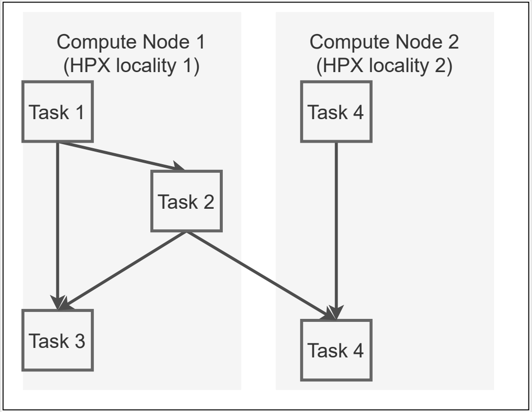
- **Distributed**: Task graph across compute nodes (remote function calls , HPX channels, multiple backends available)



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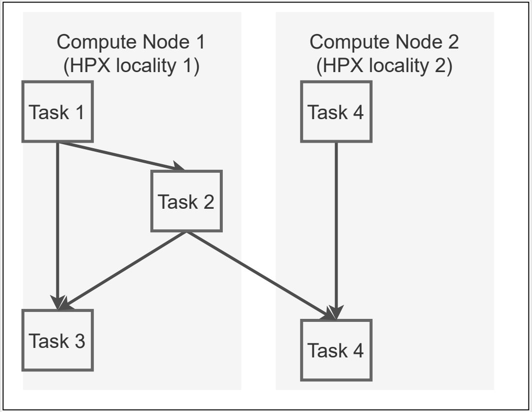
- **Distributed**: Task graph across compute nodes (remote function calls , HPX channels, multiple backends available)
- **Many Tasks**: Few HPX worker threads (one per core) working on millions of lightweight (suspendable) HPX tasks



HPX and SYCL

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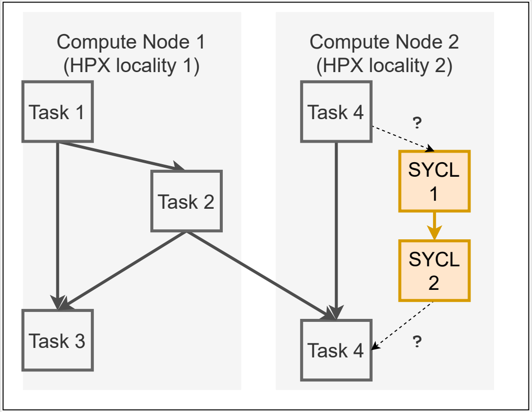
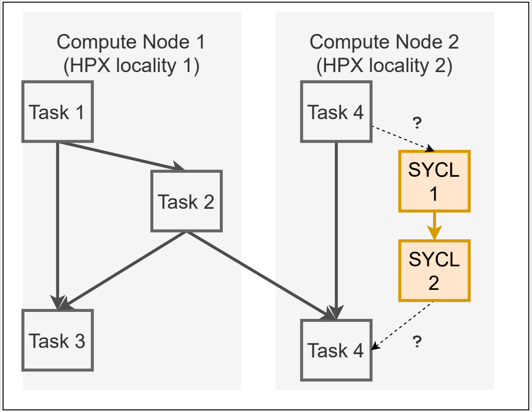


HPX and SYCL

Why combine HPX with SYCL?

- **More choices**: SYCL for HPX applications, HPX for distributed SYCL applications (instead of MPI)
- **Better integrations**: Better integration of HPX with other libraries that use SYCL (Kokkos)
- **More efficiency**: Complement strengths



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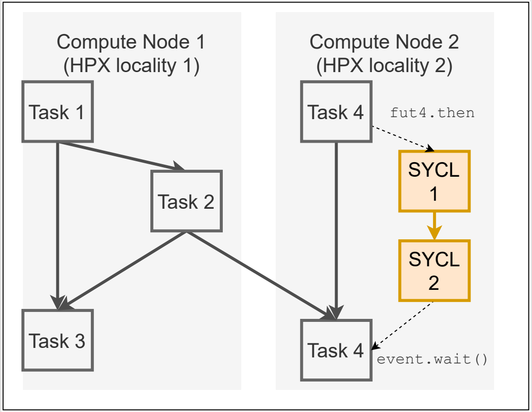
How to combine HPX with SYCL?

- The problem: Integrate task-graphs asynchronously and efficiently

  → **No active waiting** (no `event.wait()`) Avoid barriers / blocking of worker threads

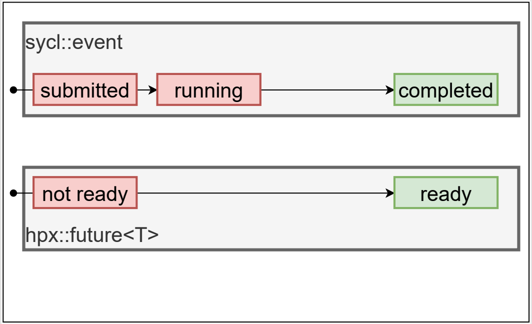
  → **Overhead**?



HPX-SYCL Integration Basics

How to combine HPX with SYCL?

- **We have**: SYCL events to check if asynchronous SYCL actions are done
- **We need**: HPX futures to check if asynchronous SYCL actions are done
- Get an HPX future from a SYCL event without actively waiting or blocking the thread



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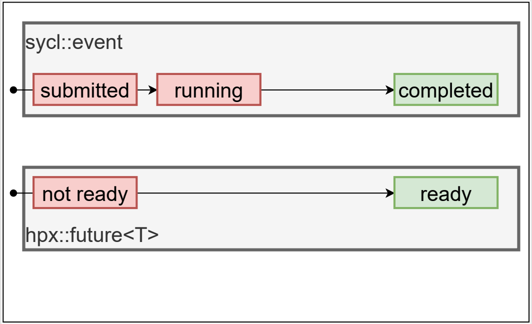

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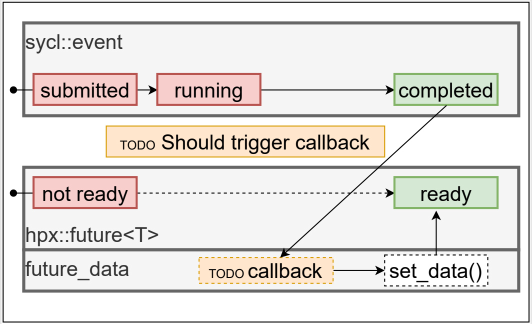

TODOs for integration

- Add specialization for HPX future_data
- Add callback mechanism that is called when the SYCL event is completed
- Use it to set the future to ready

HPX-SYCL Integration Variant 1: Using SYCL `host_task`s

Use SYCL `host_task`s as callback mechanism

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- Advantages:
  - Easiest way to implement the HPX-SYCL integration
- Disadvantages:
  - `host_tasks` not executed by HPX workers
    $\rightarrow$ Overhead/contention problem?

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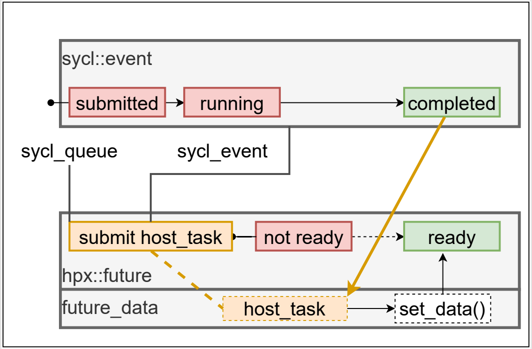

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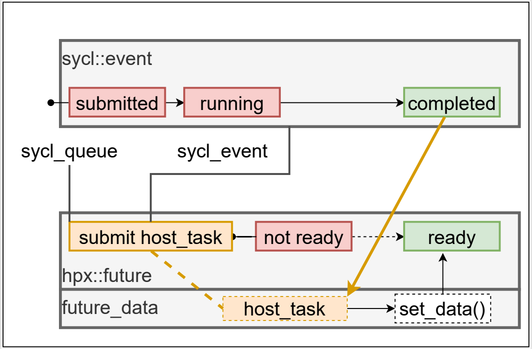


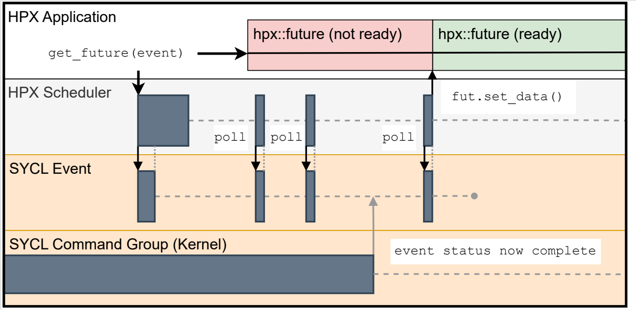
Create Callback during future_data creation

```
sycl_queue.submit([fdp =
    hpx::intrusive_ptr<future_data>(
    this),
    sycl_event](cl::sycl::handler& h) {
  h.depends_on(sycl_event);
  h.host_task ([fdp]() {
    fdp->set_data (hpx::util::unused); });
});
```

HPX-SYCL Integration Variant 2: Using Event Polling

Event polling within the HPX scheduler

- Store event-callback pairs in HPX scheduler
- Worker threads poll events in-between tasks and invoke callbacks
- Only one thread polls (others skip if mutex is already locked)
- Use concurrent queue for adding and mutex-protected vector for later checking



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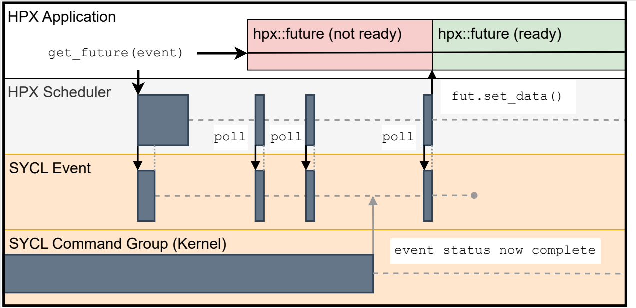
- HPX worker run callbacks themselves → One threadpool
- Works with SYCL implementations that do not yet support `host_tasks`



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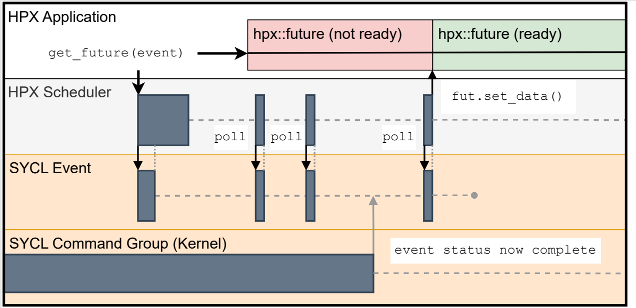

Advantages

- HPX worker run callbacks themselves → One threadpool
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Disadvantages

- Requires additions to the HPX scheduler
- Event creations, deletions and polling can cause overheads

HPX-SYCL Integration: Basic Usage and `get_future`

Dummy SYCL kernel/task

```
sycl::event my_event = queue.submit([&](sycl::handler& h) {
    /* insert SYCL dependencies */
    h.parallel_for(num_items, [=](auto i) {
            /* insert numeric code here */ });/
});
```

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Call HPX-SYCL integration

```
hpx::future<void> my_future =
   hpx::sycl::experimental::detail::get_future(my_event);
```

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Add HPX continuation asynchronously

```
hpx::future<void> continuation_future =
   my_future.then([](auto&& fut) { /* insert CPU work,communication,... */});
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Suspend calling HPX task until everything is done

```
continuation_future.get()
```

HPX-SYCL Integration: HPX-SYCL Executor with `hpx::async`

Use HPX-SYCL Executor for convenience

- Wrapper for in-order SYCL queues
- Allows passing SYCL queue functions directly to hpx::async

Use HPX-SYCL Executor for convenience

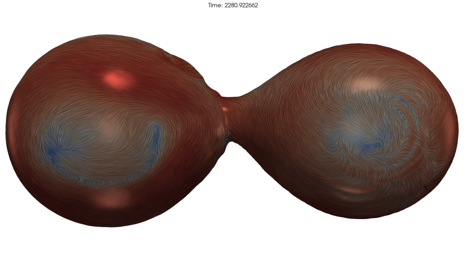
```
hpx::sycl::experimental::sycl_executor
  exec(sycl::default_selector{});
auto fut = hpx::async(exec,
      &sycl::queue::submit, [&](sycl::handler& h) {
          /* insert buffer accessesors */
          h.parallel_for(num_items, [=](auto i) {
          /* insert numeric code here */ });
      });
```

Scientific Application as a Benchmark: Octo-Tiger

Octo-Tiger: Overview

- **Simulation of interacting binary star systems and stellar mergers**
  - Double white dwarf mergers
  - Contact binary v1309 and its merger
  - R Coronae Borealis stars
- Intended for large scale, distributed runs
  - Previous runs: Cori, Piz Daint, Summit
  - Current target: Perlmutter
- Based on the HPX runtime

Octo-Tiger



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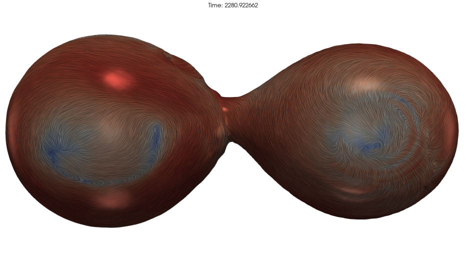

Octo-Tiger as an HPX-SYCL Benchmark

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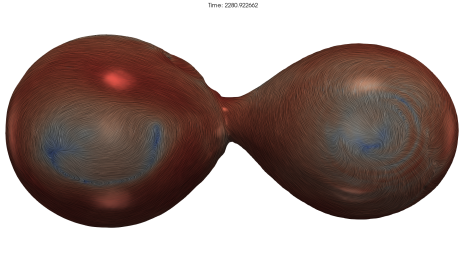
- Kokkos supports various CPU/GPU execution and memory spaces (CUDA, HIP, HPX and **SYCL** spaces available)



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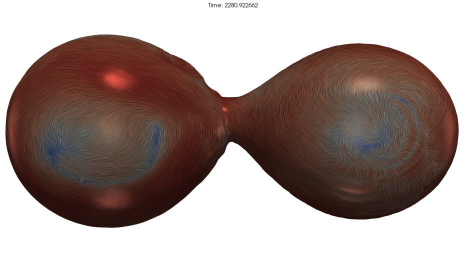

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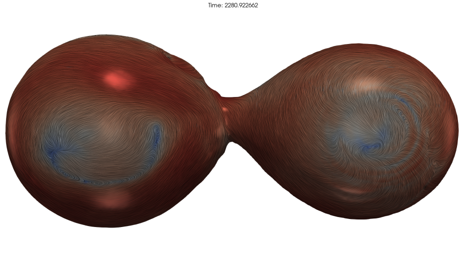
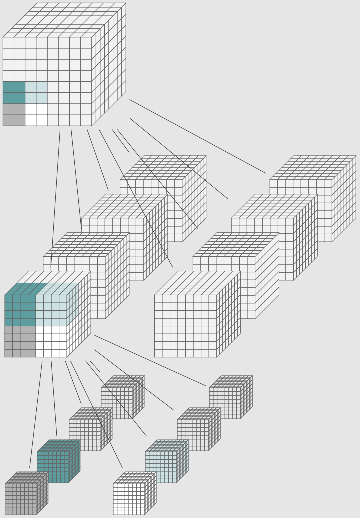
- **HPX-SYCL integration $\rightarrow$ non-blocking HPX futures for Kokkos kernels running on the SYCL space**



Octo-Tiger: Datastructure and Solvers

Self-gravitating astrophysical fluids

- Inviscid Euler equations (Hydro) $\rightarrow$ Finite Volumes
- Newtonian Gravity (Gravity) $\rightarrow$ Fast Multipole Method



From [1]

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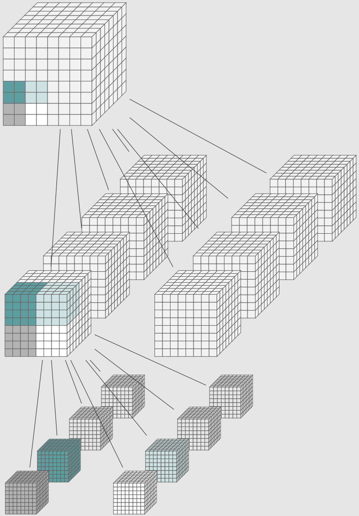
- Octree refined to maximize resolution for the atmosphere between the stars
- Entire sub-grid in each tree-node



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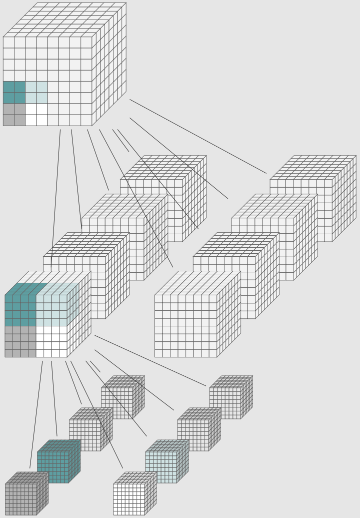
- Solvers traverse the tree, calling compute kernels on each sub-grid individually
- Each Kokkos kernel works on one sub-grid with many concurrent kernels being launched



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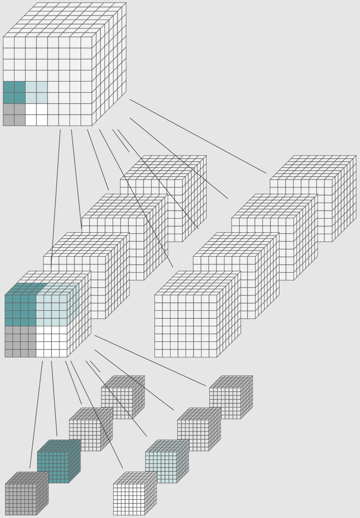
- Even small scenarios contains thousands of kernel launches within $< 250ms$ $\rightarrow$ good stress test
- Not launching enough kernels in parallel can cause starvation (smallish kernels)



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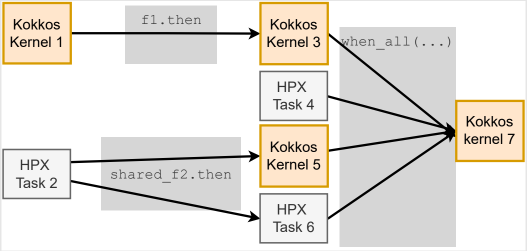

Adapted from [2]

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Kernel GPU Execution:

- SIMD template types get instantiated with scalar types
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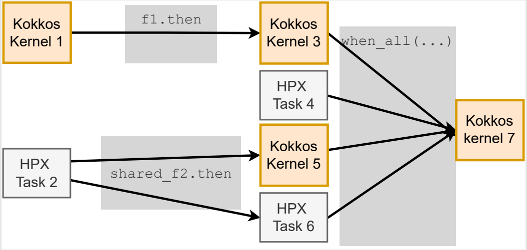

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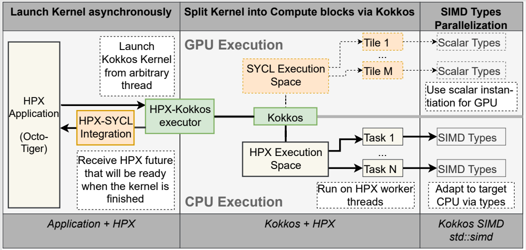

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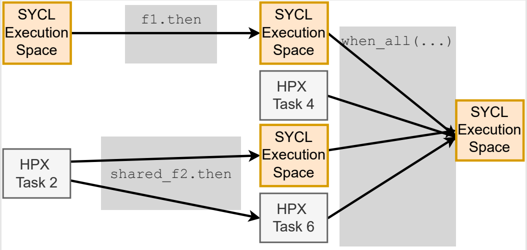

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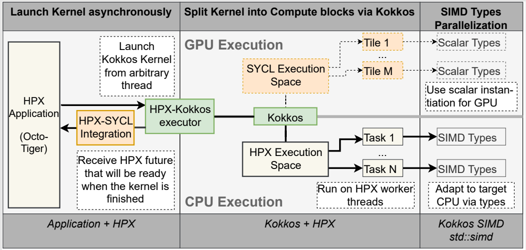

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  - **Changes**: Plug in the HPX-SYCL `get_future` call. Add `deep_copy_async` overload using the SYCL event directly
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- **CPPuddle**:
  - **Purpose**: Memory and executor utility library for task-based programming. Provides memory recycling allocators
  - **Changes**: Add allocators for SYCL memory pools on the device
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  - **Changes**: Add allocators for SYCL memory pools on the device
  - **PR**: `https://github.com/SC-SGS/CPPuddle/pull/15`
- **Octo-Tiger**:
  - **Changes**: Use correct SYCL execution space and memory allocators
  - **PR**: `https://github.com/STEllAR-GROUP/octotiger/pull/432`

Required (SYCL-related) Software Additions for Octo-Tiger and its Dependencies

- **HPX**:
  - **Changes:** Implemented both presented HPX-SYCL integration variants
  - **PR**: `https://github.com/STEllAR-GROUP/hpx/pull/6085`
- **HPX-Kokkos**:
  - **Purpose**: Compatibility layer for HPX and Kokkos. Allows treating Kokkos kernels as HPX tasks IF the `get_future` functionality exists for the underlying execution space.
  - **Changes**: Plug in the HPX-SYCL `get_future` call. Add `deep_copy_async` overload using the SYCL event directly
  - **PR**: `https://github.com/STEllAR-GROUP/hpx-kokkos/pull/13`
- **CPPuddle**:
  - **Purpose**: Memory and executor utility library for task-based programming. Provides memory recycling allocators
  - **Changes**: Add allocators for SYCL memory pools on the device
  - **PR**: `https://github.com/SC-SGS/CPPuddle/pull/15`
- **Octo-Tiger**:
  - **Changes**: Use correct SYCL execution space and memory allocators
  - **PR**: `https://github.com/STEllAR-GROUP/octotiger/pull/432`
- **Kokkos**:
  - Already contained SYCL execution and memory space
  - **Required changes**: Some CMake additions to allow using the SYCL execution space on AMD GPUs
  - **Optional optimization**: Removing internal execution space barriers for in-order queues
  - **PR**: Not yet upstreamed

Experiment Setup

Scenario Size, Number of Kernel Calls per Time-Step

Grid parameters			GPU metrics per time-step	
Sub-grid size	Overall number of cells	Number of (leaf) sub-grids	Kernel calls	CPU-GPU data transfers
8^3 **(512)**	**262144**	**512**	**7680**	**15360**

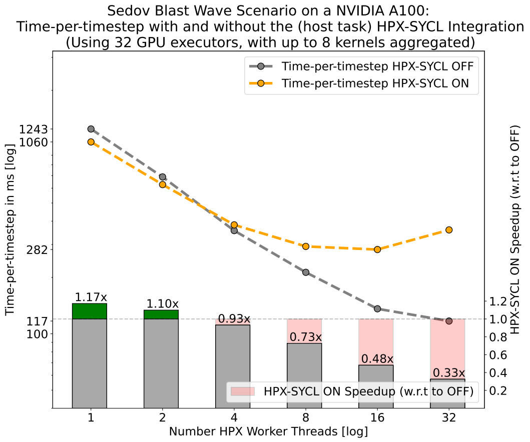
Scenario

- **Goal: Evaluate performance with and without the HPX-SYCL integration** turned on
- Use patch to turn of the integration by inserting event wait commands and returning ready futures
- Vary number of HPX worker threads (steers contention)
- **Simple Node-Level Hydro-Only Scenario**: Sedov-Taylor Blast Wave
- Using Intel DPC++/OneAPI

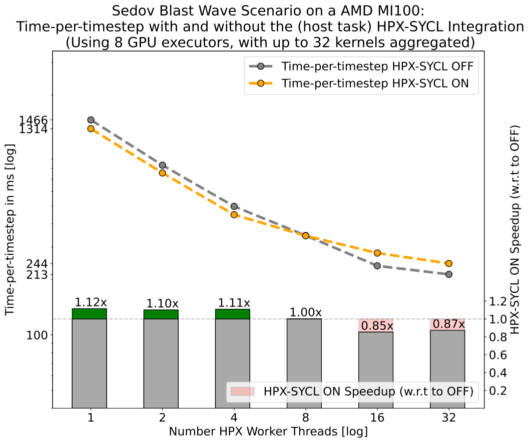
Hardware

- NVIDIA® GPU node
  - CPU: Intel® Xeon® Platinum 8358 CPU
  - NVIDIA A100 GPU
- AMD® GPU node
  - CPU: AMD EPYC™ 7H12 CPU.
  - GPU: AMD MI100 GPU
- Use **best combination of performance parameters** for each node (number of concurrent GPU executors, dynamic work aggregation limit)

Results: Host Task Integration

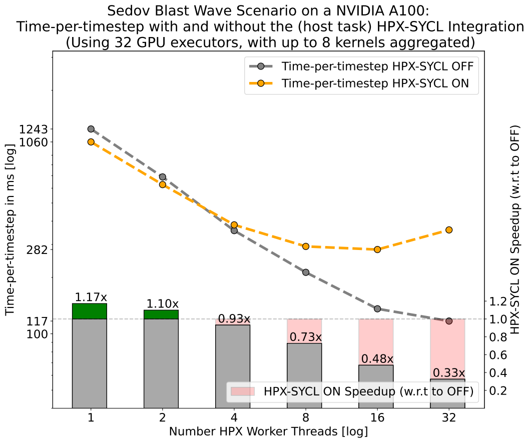


(a) A100: Best combinations

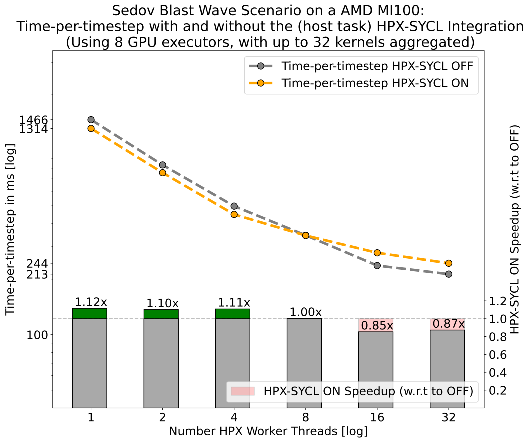


(b) MI100: Best combinations

Results: Host Task Integration



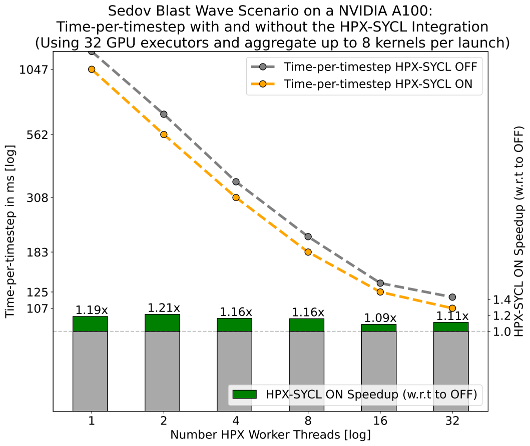
(a) A100: Best combinations



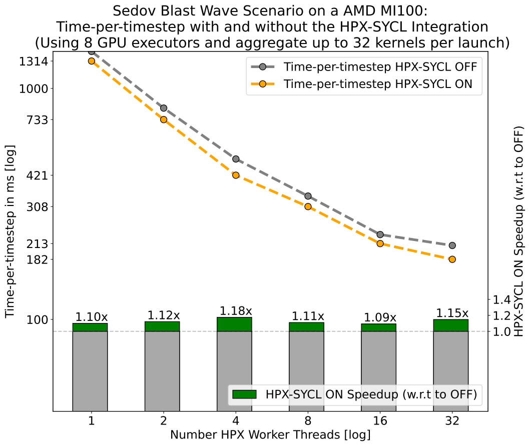
(b) MI100: Best combinations

→ Runtime degrades when using the `host_task`-based HPX-SYCL integration (at least when using all CPU cores)

Results: Event Polling Integration

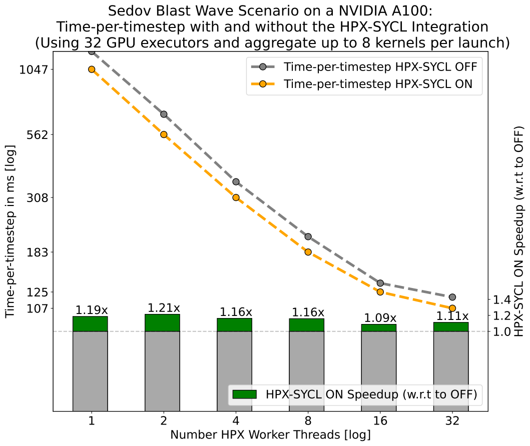


(a) A100: Best combinations

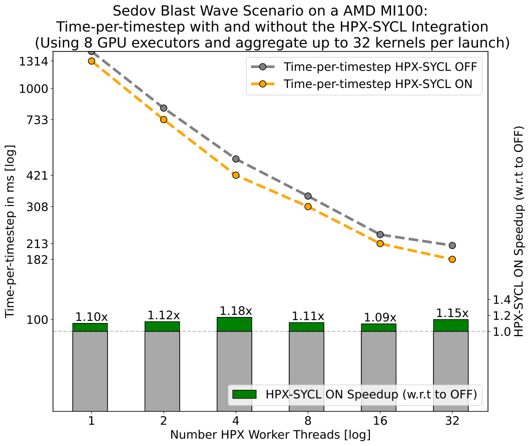


(b) MI100: Best combinations

Results: Event Polling Integration



(a) A100: Best combinations



(b) MI100: Best combinations

→ Runtime consistently improves when using the event polling HPX-SYCL integration (even for this small scenario)

Conclusion

Conclusion

- Developed HPX-SYCL integration allowing us to treat SYCL events as HPX tasks
- Adapted entire Octo-Tiger software stack for SYCL to benchmark the integration(s)
- Event polling integration performs better than (DPC++) host tasks integration
- Integration is beneficial (over synchronous execution without it), even when just running simple, single-node scenarios
- Software stack is still experimental, lots of potential for optimizations

Outlook

- Intel GPUs?
- Integration speedup with distributed runs?

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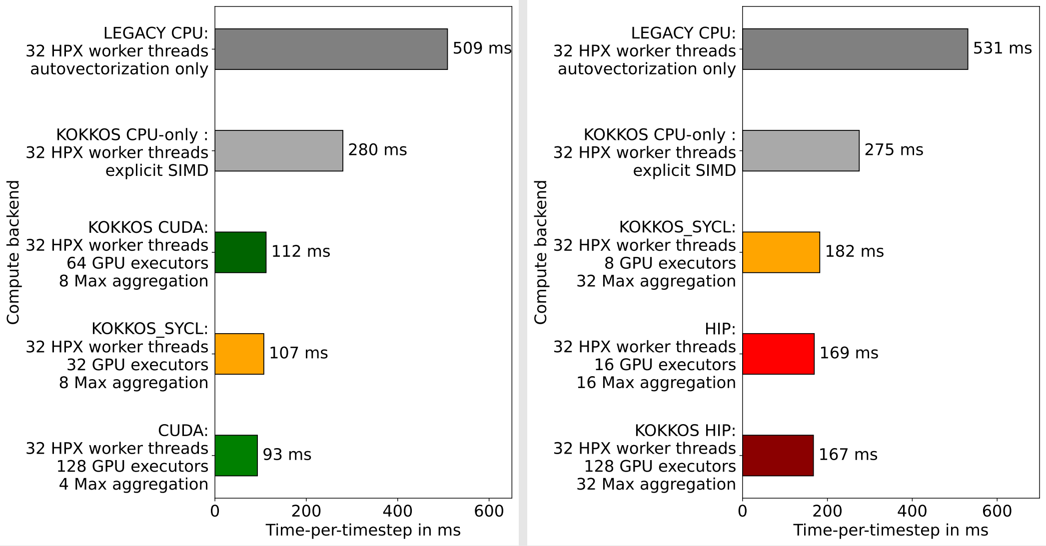
Thank you for your attention!

- D. Pfander, G. Daiß, D. Marcello, H. Kaiser, and D. Pflüger, "Accelerating Octo-Tiger: Stellar mergers on Intel Knights Landing with HPX," in *Proceedings of the International Workshop on OpenCL*, ser. IWOCL '18. New York, NY, USA: ACM, 2018, pp. 19:1–19:8.
- G. Daiß *et al.* (video presentation) hips 2021: Beyond fork-join: Integration of performance portable kokkos kernels with hpx. Youtube. [Online]. Available: https://www.youtube.com/watch?v=CQaA9AYlm1I
- G. Daiß, S. Singanaboina, P. Diehl, H. Kaiser, and D. Pflüger, "From merging frameworks to merging stars: Experiences using hpx, kokkos and simd types," in *2022 IEEE/ACM 7th International Workshop on Extreme Scale Programming Models and Middleware (ESPM2)*. Los Alamitos, CA, USA: IEEE Computer Society, nov 2022, pp. 10–19. [Online]. Available: https://doi.ieeecomputersociety.org/10.1109/ESPM256814.2022.00007

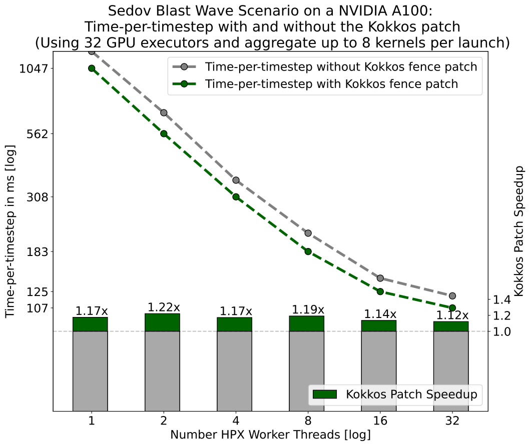
Performance using various execution spaces:



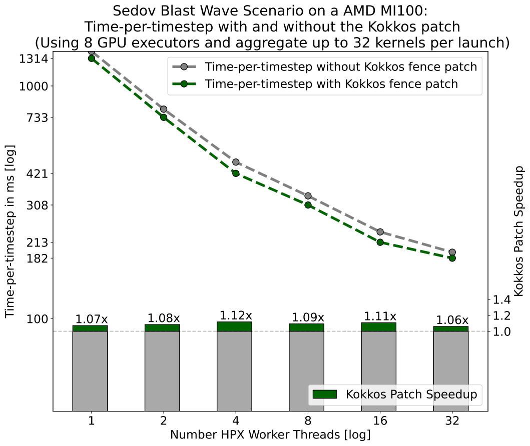
(a) Best runs on the NVIDIA A100

(b) Best runs on the AMD MI100

Speedup when removing barriers within Kokkos for in-order queues:

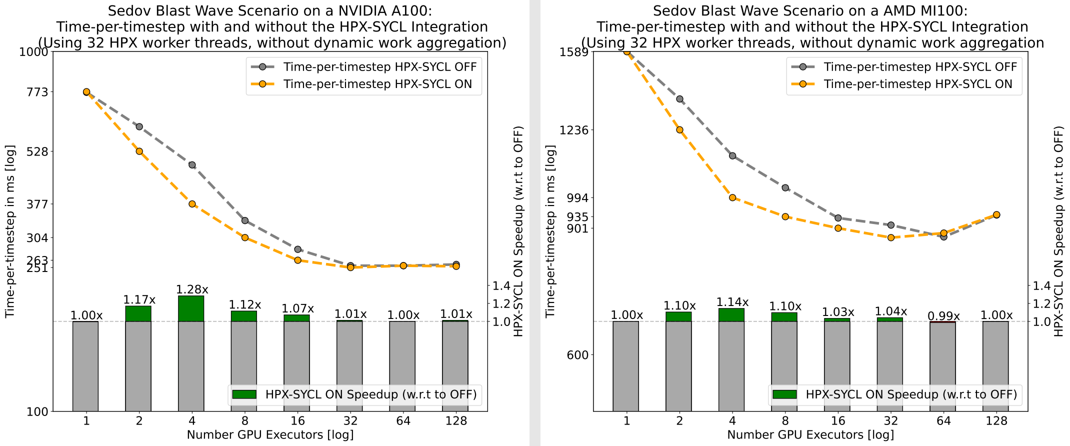


(a) A100: Best combinations



(b) MI100: Best combinations

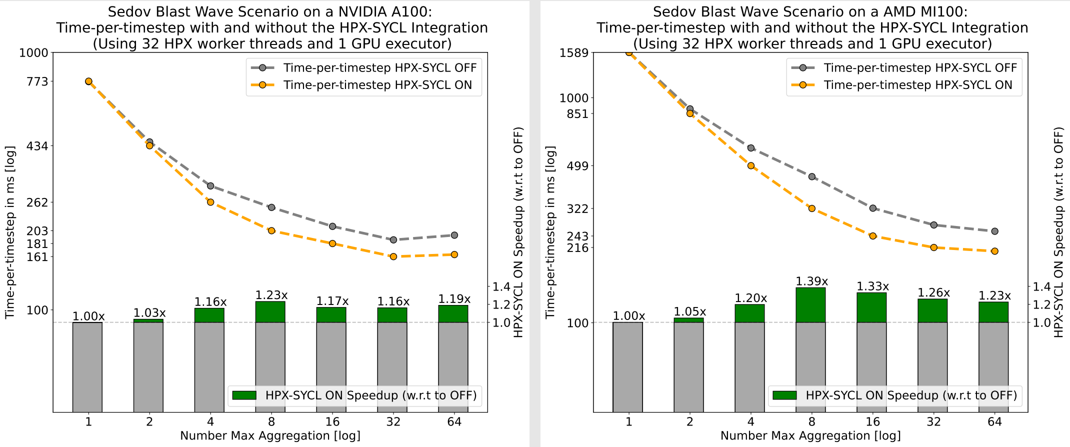
Event polling integration: Runtime with varying number of executors



(a) A100: Increasing Number of GPU executors

(b) MI100: Increasing Number of GPU executors

Event polling integration: Runtime with varying number of aggregated kernels



(c) A100: Increasing number of kernels aggregated

(d) MI100: Increasing number of kernels aggregated