That's right, the same C++ STL asynchronous parallel code runs on CPUs & GPUs

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Motivation

Various programming models are used to accelerate C++ HPC applications on heterogeneous supercomputers.

This leads to many challenges in software performance, code portability, and programming productivity.

Introduction

std::execution (*or* ***stdexec***) -- the proposed C++26 standard feature -- provides an asynchronous parallel framework enabling running standard C++ code on CPUs & GPUs with minimal modifications.

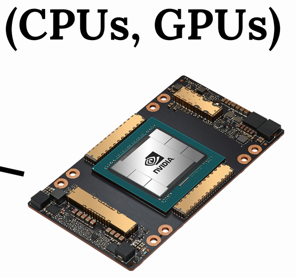
We leverage ***stdexec***, ***stdpar*** & modern C++ to implement & evaluate multiple HPC scientific apps on the ***Perlmutter*** supercomputer.

std::execution components

1) ***schedulers*** - obtained from execution contexts

```
scheduler c = cpu.schedule();
scheduler g = gpu.schedule();
```

execution contexts (CPUs, GPUs)



2) ***senders*** - send the ***composed*** work to scheduler **g**

```
sender auto s = schedule(g)
```

```
| bulk (N, par_alg1())
| bulk (N, par_alg2())
| transfer (c)
| then (serial_alg1());
```

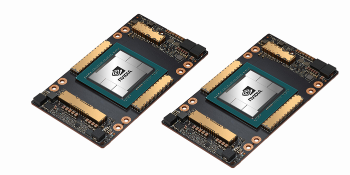
3) ***composable algorithms*** - compose the algorithmic task graph (DAG) using pipe symbol (**|**)

4) ***receivers*** - wait and receive the execution results for sender **s**

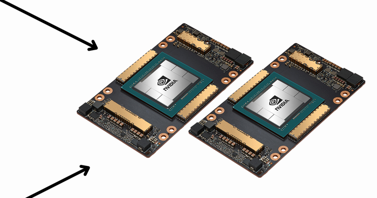
```
auto [r] = sync_wait(s).value();
```

App 1: AMReX 2D Stencil

```
// nvexec multi gpu stream context and scheduler
nvexec::multi_gpu_stream_context ctx;
auto gpus = ctx.get_scheduler();
// std::spans to ensure trivially copyable
std::span phi_old, phi_new;
```



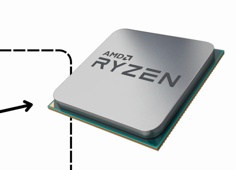
```
// send initialize phi_old to gpus
sender auto s1 = transfer_just (gpus, phi_old)
  | bulk (phi_old, init);
sync_wait(s1);
```

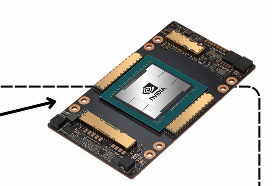


```
for (i in nsteps) {
  // send heat equation loop to gpus
  sender auto s2 = transfer_just (gpus, phi_old, phi_new)
    | bulk (phi_old, phi_new, fill_boundary(old, new))
    | bulk (phi_old, phi_new, heat_equation(old, new))
    | bulk (phi_old, phi_new, parallel_copy(old, new)); }
```

App 2: Recursive 1D Stecil

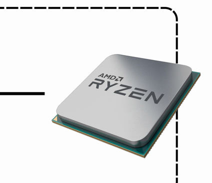
```
// recursive stencil computation
auto stencil (nsteps) -> any_space_sender {
  // initialize & return phi on cpu
  if (nsteps == 0) {
    mdspan phi = std::for_each(stdexec::seq, init);
    return just (phi); }

  return just(nsteps - 1)
    | let_value((step) { return stencil(step); })
    | then((auto phi_old) {

    // stencil on GPU using stdpar
    mdspan phi_new;
    std::for_each(stdexec::par, jacobi(phi_new, phi_old));
    return phi_new; }); }
```



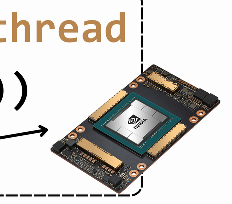


App 3: ADEPT Drivers

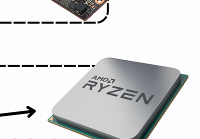
```
// thread pool context and scheduler
static_thread_pool ctx {N};
scheduler cpus = ctx.get_scheduler();
```



```
// compose adept pipeline - one CUDA kernel per thread
sender adept = schedule(cpus) | then(init_adept())
  | bulk(N, partition_launch_cuda(N));
```



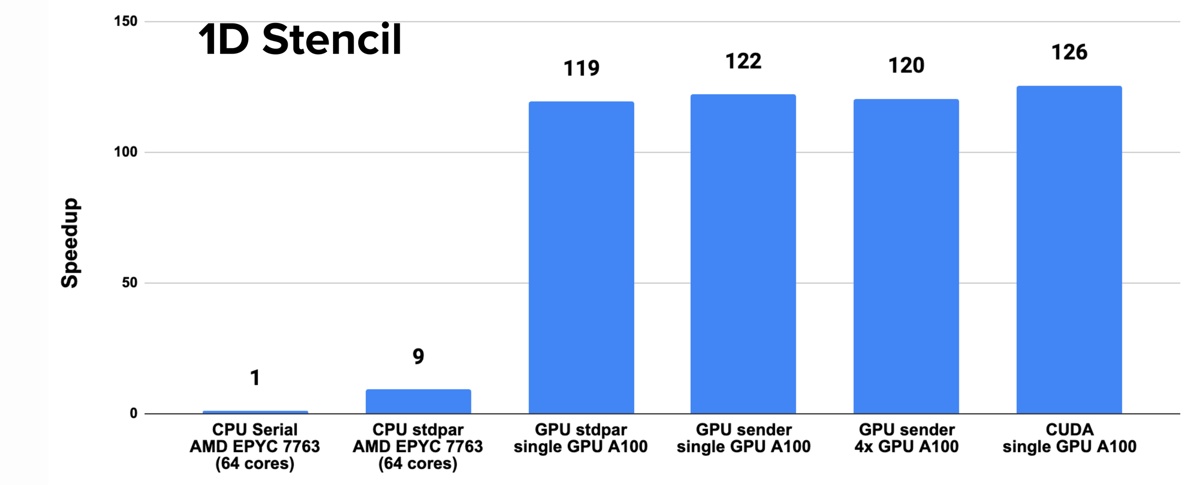
```
// do other async work while adept is running
sender otherwork = schedule(cpus) | then(otherwork());
```

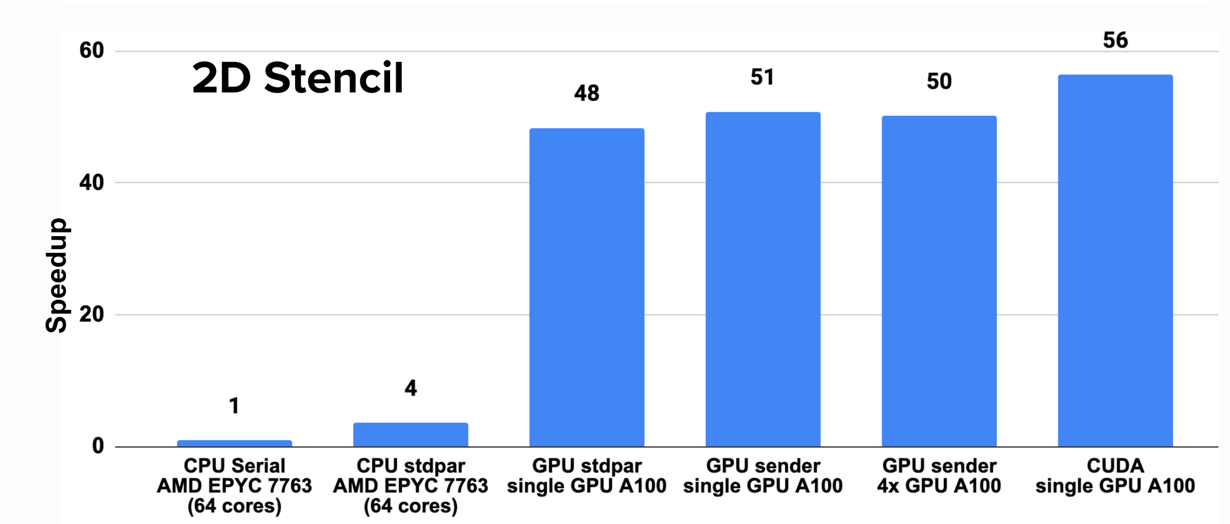


Preliminary Results

Experimental Setup: Perlmutter GPU (NVIDIA A100 SXM), AMD EPYC 7763, NVHPC/23.7, GCC/12.2, NVIDIA/stdexec

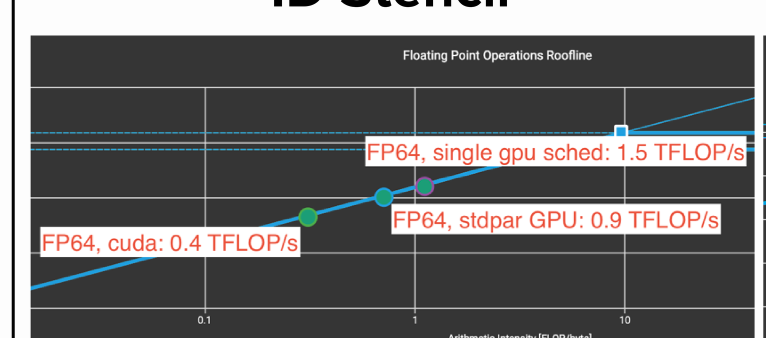
Speedups



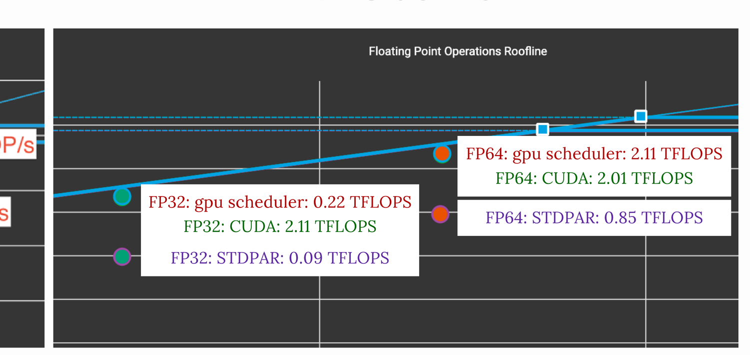


Roofline Analysis

1D Stencil

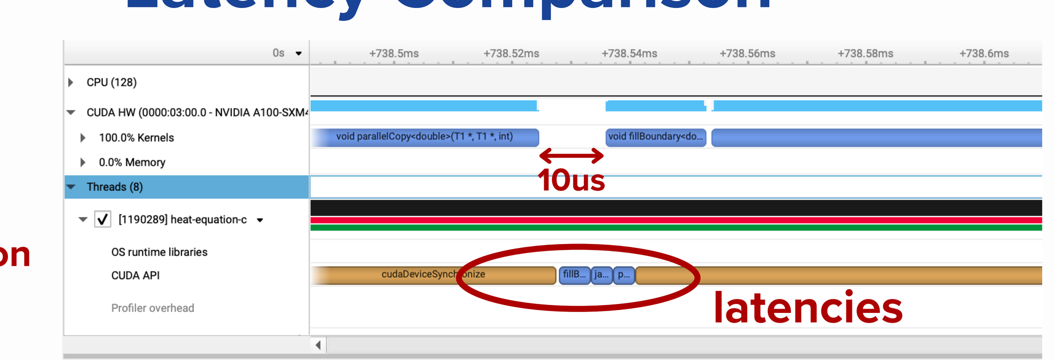


2D Stencil

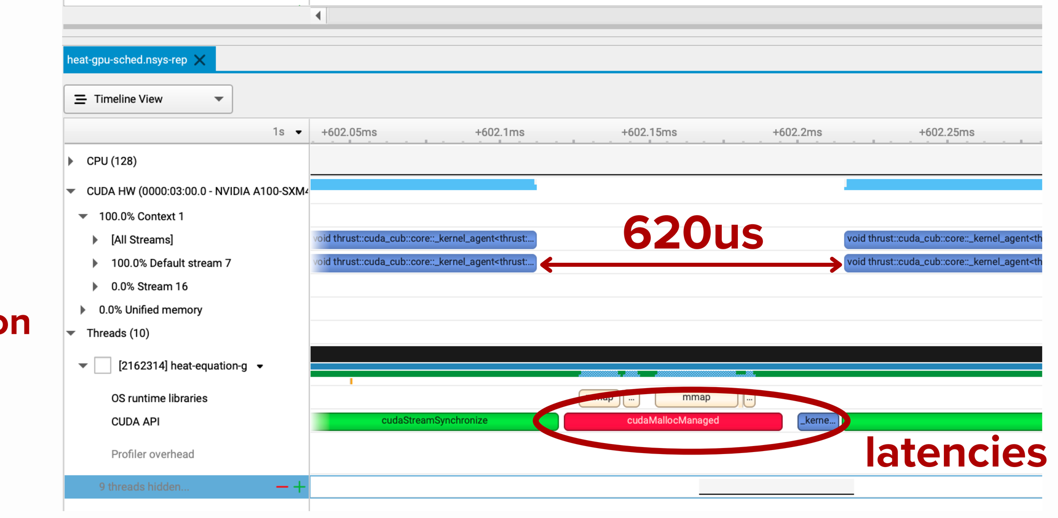


Latency Comparison

CUDA Implementation



stdexec Implementation



Discussion

Advantages

Performance: Virtually no overheads from ***stdexec***, possible to consolidate launch latencies.

Productivity: Same code runs on multiple CPUs and GPUs - simply swap **schedulers (stdexec)** or **compiler flags (stdpar)**

Portability: Standard C++ code can be compiled with other compilers for various architectures.

Generalizability: Architecture-independent model to program asynchronous task and data parallel codes.

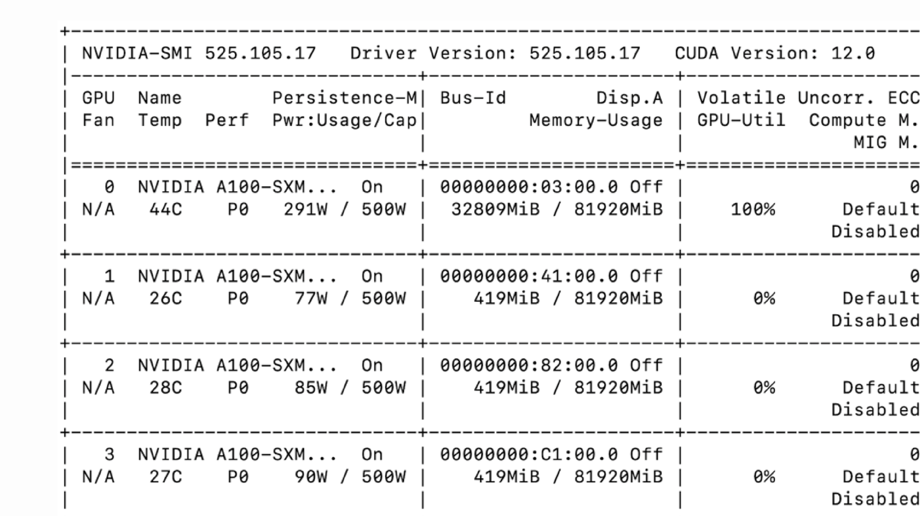
Limitations

Optimizations: Hardware or language specific optimizations are unavailable at user-level.

Parallelism Control: No explicit control over parallelism - number of blocks, threads or grid size.

Initial Setup: Learning curve to correctly use and set up language features, compilers, libraries, and dependencies.

Load Imbalance: MultiGPU and/or Multinode schedulers may introduce severe load imbalance depending on their implementations.



References

our code repo

stdexec proposal

nvidia stdexec

C++26 ADEPT