An introduction to alpaka

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CERN - EP/CMD

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overview

- yesterday we have seen
  - what *performance portability* means and discovered the Alpaka library
  - how to set up Alpaka for a simple project
  - how to compile a single source file for different back-ends
  - what are Alpaka platforms, devices, queues and events

- today we will learn
  - how to work with host and device memory
  - how to write device functions and kernels
  - how to use an Alpaka accelerator and work division to launch a kernel
  - and see a complete example !

memory operations

Buffers and Views

- can refer to memory on the host or on any device
  - general purpose host memory (e.g. as returned by `malloc` or `new`)
  - pinned host memory, visible by devices on a given platform (e.g. as returned by `cudaMallocHost`)
  - global device memory (e.g. as returned by `cudaMalloc`)
- can have arbitrary dimensions
- 0-dimensional buffers and views wrap and provide access to a single element:

```
float x = *buffer;
float y = buffer->pt();
```

- 1-dimensional buffers and views wrap and provide access to an array of elements:

```
float x = buffer[i];
```

- N-dimensional buffers and views wrap arbitrary memory areas:

```
float* p = std::data(buffer);
```

  - expect a nicer accessor syntax with c++23 `std::mdspan` and improved `operator[]`
  - alpaka can already use experimental `mdspan` support based on https://github.com/kokkos/mdspan

memory buffers

- buffers *own* the memory they point to
  - a host memory buffer can use either standard host memory, or pinned host memory mapped to be visible by the GPUs in a given platform
  - a buffer knows what device the memory is on, and how to free it
- buffers have shared ownership of the memory
  - like `shared_ptr<T>`
  - making a copy of a buffer creates a second handle to the same underlying memory
  - the memory is automatically freed when the last buffer object is destroyed (*e.g.* goes out of scope)
  - with *async* or *queue-ordered buffers*, memory is freed when the work submitted to the queue associated to the buffer is complete
- note that buffers always allow modifying their content
  - a `Buffer<const T>` would not be useful, because its contents could never be set
  - a `const Buffer<T>` does not prevent changes to the contents, as they can be modified through a copy

allocating memory

- buffer allocations and deallocations can be *immediate* or *queue-ordered*
  - immediate operations
    - allocate and free the memory immediately
    - may result in a device-wide synchronisation
    - *e.g.* `malloc` / `free` or `cudaMalloc` / `cudaFree`

```
// allocate an array of "size" floats in standard host memory
auto buffer = alpaka::allocBuf<float, uint32_t>(host, size);

// allocate an array of "size" floats in pinned host memory
// mapped to be efficiently copiable to/from all the devices on the platform
auto buffer = alpaka::allocMappedBuf<float, uint32_t>(host, platform, size);

// allocate an array of "size" floats in global device memory
auto buffer = alpaka::allocBuf<float, uint32_t>(device, size);
```

  - queue-ordered operations are usually asynchronous, and may cache allocations
    - guarantee that the memory is allocated before any further operations submitted to the queue are executed
    - guarantee that the memory will be freed once all pending operation in the queue are complete
    - *e.g.* `cudaMallocAsync` / `cudaFreeAsync`

```
// allocate an array of "size" floats in global gpu memory, ordered along queue
auto buffer = alpaka::allocAsyncBuf<float, uint32_t>(queue, size);
```

    - available only on device that support it (CPUs, NVIDIA CUDA ≥ 11.2, AMD ROCm ≥ 5.4)

using buffers

https://github.com/fwyzard/intro_to_alpaka/blob/master/alpaka/03_memory.cc

```
// use the single host device
HostPlatform host_platform;
Host host = alpaka::getDevByIdx(host_platform, 0u);
std::cout << "Host:   " << alpaka::getName(host) << '\n';

// allocate a buffer of floats in pinned host memory
uint32_t size = 42;
auto host_buffer =
  alpaka::allocMappedBuf<float, uint32_t>(host, platform, size);
std::cout
  << "pinned host memory buffer at " << std::data(host_buffer) << "\n\n";

// fill the host buffers with values
for (uint32_t i = 0; i < size; ++i) {
  host_buffer[i] = i;
}

// initialise the accelerator platform
Platform platform;
// use the first device
Device device = alpaka::getDevByIdx(platform, 0u);
std::cout << "Device: " << alpaka::getName(device) << '\n';

// create a work queue
Queue queue{device};
```

```
{
  // allocate a buffer of floats in global device memory, asynchronously
  auto device_buffer =
    alpaka::allocAsyncBuf<float, uint32_t>(queue, size);
  std::cout << "memory buffer on "
            << alpaka::getName(alpaka::getDev(device_buffer))
            << " at " << std::data(device_buffer) << "\n\n";

  // set the device memory to all zeros (byte-wise, not element-wise)
  alpaka::memset(queue, device_buffer, 0x00);

  // copy the contents of the device buffer to the host buffer
  alpaka::memcpy(queue, host_buffer, device_buffer);

  // the device buffer goes out of scope, but the memory is freed only
  // once all enqueued operations have completed
}

// wait for all operations to complete
alpaka::wait(queue);

// read the content of the host buffer
for (uint32_t i = 0; i < size; ++i) {
  std::cout << host_buffer[i] << ' ';
}
```

using buffers

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// use the single host device
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Host host = alpaka::getDevByIdx(host_platform, 0u);
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std::cout
  << "pinned host memory buffer at " << std::data(host_buffer) << "\n\n";

// fill the host buffers with values
for (uint32_t i = 0; i < size; ++i) {
  host_buffer[i] = i;
}

// initialise the accelerator platform
Platform platform;
// use the first device
Device device = alpaka::getDevByIdx(platform, 0u);
std::cout << "Device: " << alpaka::getName(device) << '\n';

// create a work queue
Queue queue{device};
```

```
{
  // allocate a buffer of floats in global device memory, asynchronously
  auto device_buffer =
    alpaka::allocAsyncBuf<float, uint32_t>(queue, size);
  std::cout << "memory buffer on "
            << alpaka::getName(alpaka::getDev(device_buffer))
            << " at " << std::data(device_buffer) << "\n\n";

  // set the device memory to all zeros (byte-wise, not element-wise)
  alpaka::memset(queue, device_buffer, 0x00);

  // copy the contents of the device buffer to the host buffer
  alpaka::memcpy(queue, host_buffer, device_buffer);

  // the device buffer goes out of scope, but the memory is freed only
  // once all enqueued operations have completed
}

// wait for all operations to complete
alpaka::wait(queue);

// read the content of the host buffer
for (uint32_t i = 0; i < size; ++i) {
  std::cout << host_buffer[i] << ' ';
}
```

allocate buffers

using buffers

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auto host_buffer =
  alpaka::allocMappedBuf<float, uint32_t>(host, platform, size);
std::cout
  << "pinned host memory buffer at " << std::data(host_buffer) << "\n\n";

// fill the host buffers with values
for (uint32_t i = 0; i < size; ++i) {
  host_buffer[i] = i;
}

// initialise the accelerator platform
Platform platform;
// use the first device
Device device = alpaka::getDevByIdx(platform, 0u);
std::cout << "Device: " << alpaka::getName(device) << '\n';

// create a work queue
Queue queue{device};
```

get the buffers' memory addresses

```
{
  // allocate a buffer of floats in global device memory, asynchronously
  auto device_buffer =
    alpaka::allocAsyncBuf<float, uint32_t>(queue, size);
  std::cout << "memory buffer on "
            << alpaka::getName(alpaka::getDev(device_buffer))
            << " at " << std::data(device_buffer) << "\n\n";

  // set the device memory to all zeros (byte-wise, not element-wise)
  alpaka::memset(queue, device_buffer, 0x00);

  // copy the contents of the device buffer to the host buffer
  alpaka::memcpy(queue, host_buffer, device_buffer);

  // the device buffer goes out of scope, but the memory is freed only
  // once all enqueued operations have completed
}

// wait for all operations to complete
alpaka::wait(queue);

// read the content of the host buffer
for (uint32_t i = 0; i < size; ++i) {
  std::cout << host_buffer[i] << ' ';
}
```

using buffers

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```
// use the single host device
HostPlatform host_platform;
Host host = alpaka::getDevByIdx(host_platform, 0u);
std::cout << "Host:   " << alpaka::getName(host) << '\n';

// allocate a buffer of floats in pinned host memory
uint32_t size = 42;
auto host_buffer =
  alpaka::allocMappedBuf<float, uint32_t>(host, platform, size);
std::cout
  << "pinned host memory buffer at " << std::data(host_buffer) << "\n\n";

// fill the host buffers with values
for (uint32_t i = 0; i < size; ++i) {
  host_buffer[i] = i;
}

// initialise the accelerator platform
Platform platform;
// use the first device
Device device = alpaka::getDevByIdx(platform, 0u);
std::cout << "Device: " << alpaka::getName(device) << '\n';

// create a work queue
Queue queue{device};
```

write to and read from the host buffer like a vector or array

```
{
  // allocate a buffer of floats in global device memory, asynchronously
  auto device_buffer =
    alpaka::allocAsyncBuf<float, uint32_t>(queue, size);
  std::cout << "memory buffer on "
            << alpaka::getName(alpaka::getDev(device_buffer))
            << " at " << std::data(device_buffer) << "\n\n";

  // set the device memory to all zeros (byte-wise, not element-wise)
  alpaka::memset(queue, device_buffer, 0x00);

  // copy the contents of the device buffer to the host buffer
  alpaka::memcpy(queue, host_buffer, device_buffer);

  // the device buffer goes out of scope, but the memory is freed only
  // once all enqueued operations have completed
}

// wait for all operations to complete
alpaka::wait(queue);

// read the content of the host buffer
for (uint32_t i = 0; i < size; ++i) {
  std::cout << host_buffer[i] << ' ';
}
```

using buffers

https://github.com/fwyzard/intro_to_alpaka/blob/master/alpaka/03_memory.cc

```
// use the single host device
HostPlatform host_platform;
Host host = alpaka::getDevByIdx(host_platform, 0u);
std::cout << "Host:   " << alpaka::getName(host) << '\n';

// allocate a buffer of floats in pinned host memory
uint32_t size = 42;
auto host_buffer =
  alpaka::allocMappedBuf<float, uint32_t>(host, platform, size);
std::cout
  << "pinned host memory buffer at " << std::data(host_buffer) << "\n\n";

// fill the host buffers with values
for (uint32_t i = 0; i < size; ++i) {
  host_buffer[i] = i;
}

// initialise the accelerator platform
Platform platform;
// use the first device
Device device = alpaka::getDevByIdx(platform, 0u);
std::cout << "Device: " << alpaka::getName(device) << '\n';

// create a work queue
Queue queue{device};
```

memset and memcpy operations are always asynchronous

```
{
  // allocate a buffer of floats in global device memory, asynchronously
  auto device_buffer =
    alpaka::allocAsyncBuf<float, uint32_t>(queue, size);
  std::cout << "memory buffer on "
            << alpaka::getName(alpaka::getDev(device_buffer))
            << " at " << std::data(device_buffer) << "\n\n";

  // set the device memory to all zeros (byte-wise, not element-wise)
  alpaka::memset(queue, device_buffer, 0x00);

  // copy the contents of the device buffer to the host buffer
  alpaka::memcpy(queue, host_buffer, device_buffer);

  // the device buffer goes out of scope, but the memory is freed only
  // once all enqueued operations have completed
}

// wait for all operations to complete
alpaka::wait(queue);

// read the content of the host buffer
for (uint32_t i = 0; i < size; ++i) {
  std::cout << host_buffer[i] << ' ';
}
```

memory views

- views wrap memory allocated by some other mechanism to provide a common interface
  - *e.g.* a local variable on the stack, or memory owned by an `std::vector`
  - views *do not own* the underlying memory
  - the lifetime of a view should not exceed that of the memory it points to

```
float* data = new float[size];
auto view = alpaka::createView(host, data, size);                    // define a view for a C++ array
alpaka::memcpy(queue, view, device_buffer);                          // copy the data to the array
```

- views to standard containers
  - Alpaka provides adaptors and can automatically use `std::array<T, N>` and `std::vector<T>` as views

```
std::vector<float> data(size);
alpaka::memcpy(queue, data, device_buffer);                          // copy the data to the vector
```

- using views to emulate buffers to constant objects
  - buffers always allow modifying their content
  - but we can wrap them in a constant view: `alpaka::ViewConst<Buffer<T>>`

```
auto const_view = alpaka::ViewConst(device_buffer);
alpaka::memcpy(queue, host_buffer, const_view);                      // copy the data to the host
```

using views

https://github.com/fwyzard/intro_to_alpaka/blob/master/alpaka/04_views.cc

```cpp
// use the single host device
HostPlatform host_platform;
Host host = alpaka::getDevByIdx(host_platform, 0u);
std::cout << "Host:   " << alpaka::getName(host) << '\n';

// initialise the accelerator platform
Platform platform;

// allocate a buffer of floats in mapped host memory
uint32_t size = 42;
std::vector<float> host_data(size);
std::cout << "host vector at " << std::data(host_data) << "\n\n";

// fill the host buffers with values
for (uint32_t i = 0; i < size; ++i) {
  host_data[i] = i;
}

// use the first device
Device device = alpaka::getDevByIdx(platform, 0u);
std::cout << "Device: " << alpaka::getName(device) << '\n';

// create a work queue
Queue queue{device};
```

```cpp
{
  // allocate a buffer of floats in global device memory, asynchronously
  auto device_buffer = alpaka::allocAsyncBuf<float, uint32_t>(queue, size);
  std::cout << "memory buffer on "
            << alpaka::getName(alpaka::getDev(device_buffer))
            << " at " << std::data(device_buffer) << "\n\n";

  // set the device memory to all zeros (byte-wise, not element-wise)
  alpaka::memset(queue, device_buffer, 0x00);

  // create a read-only view to the device data
  auto const_view = alpaka::ViewConst(device_buffer);

  // copy the contents of the device buffer to the host buffer
  alpaka::memcpy(queue, host_data, const_view);

  // the device buffer goes out of scope, but the memory is freed only
  // once all enqueued operations have completed
}

// wait for all operations to complete
alpaka::wait(queue);

// read the content of the host buffer
for (uint32_t i = 0; i < size; ++i) { std::cout << host_data[i] << ' '; }
```

using views

https://github.com/fwyzard/intro_to_alpaka/blob/master/alpaka/04_views.cc

```
// use the single host device
HostPlatform host_platform;
Host host = alpaka::getDevByIdx(host_platform, 0u);
std::cout << "Host:    " << alpaka::getName(host) << '\n';

// initialise the accelerator platform
Platform platform;

// allocate a buffer of floats in mapped host memory
uint32_t size = 42;
std::vector<float> host_data(size);
std::cout << "host vector at " << std::data(host_data) << "\n\n";

// fill the host buffers with values
for (uint32_t i = 0; i < size; ++i) {
  host_data[i] = i;
}

// use the first device
Device device = alpaka::getDevByIdx(platform, 0u);
std::cout << "Device: " << alpaka::getName(device) << '\n';

// create a work queue
Queue queue{device};
```

use a vector directly

```
{
  // allocate a buffer of floats in global device memory, asynchronously
  auto device_buffer = alpaka::allocAsyncBuf<float, uint32_t>(queue, size);
  std::cout << "memory buffer on "
            << alpaka::getName(alpaka::getDev(device_buffer))
            << " at " << std::data(device_buffer) << "\n\n";

  // set the device memory to all zeros (byte-wise, not element-wise)
  alpaka::memset(queue, device_buffer, 0x00);

  // create a read-only view to the device data
  auto const_view = alpaka::ViewConst(device_buffer);

  // copy the contents of the device buffer to the host buffer
  alpaka::memcpy(queue, host_data, const_view);

  // the device buffer goes out of scope, but the memory is freed only
  // once all enqueued operations have completed
}

// wait for all operations to complete
alpaka::wait(queue);

// read the content of the host buffer
for (uint32_t i = 0; i < size; ++i) { std::cout << host_data[i] << ' '; }
```

using views

https://github.com/fwyzard/intro_to_alpaka/blob/master/alpaka/04_views.cc

```
// use the single host device
HostPlatform host_platform;
Host host = alpaka::getDevByIdx(host_platform, 0u);
std::cout << "Host:   " << alpaka::getName(host) << '\n';

// initialise the accelerator platform
Platform platform;

// allocate a buffer of floats in mapped host memory
uint32_t size = 42;
std::vector<float> host_data(size);
std::cout << "host vector at " << std::data(host_data) << "\n\n";

// fill the host buffers with values
for (uint32_t i = 0; i < size; ++i) {
  host_data[i] = i;
}

// use the first device
Device device = alpaka::getDevByIdx(platform, 0u);
std::cout << "Device: " << alpaka::getName(device) << '\n';

// create a work queue
Queue queue{device};
```

```
{
  // allocate a buffer of floats in global device memory, asynchronously
  auto device_buffer = alpaka::allocAsyncBuf<float, uint32_t>(queue, size);
  std::cout << "memory buffer on "
            << alpaka::getName(alpaka::getDev(device_buffer))
            << " at " << std::data(device_buffer) << "\n\n";

  // set the device memory to all zeros (byte-wise, not element-wise)
  alpaka::memset(queue, device_buffer, 0x00);

  // create a read-only view to the device data
  auto const_view = alpaka::ViewConst(device_buffer);

  // copy the contents of the device buffer to the host buffer
  alpaka::memcpy(queue, host_data, const_view);

  // the device buffer goes out of scope, but the memory is freed only
  // once all enqueued operations have completed
}

// wait for all operations to complete
alpaka::wait(queue);

// read the content of the host buffer
for (uint32_t i = 0; i < size; ++i) { std::cout << host_data[i] << ' '; }
```

copy from a constant view to garantee not changing the device buffer

alpaka device API

device functions

- device functions are marked with the `ALPAKA_FN_ACC` macro

```
ALPAKA_FN_ACC
float my_func(float arg) { … }
```

- backend-specific functions
  - if the implementation of a device function may depend on the backend or on the work division into groups and threads, it should be templated on the Accelerator type, and take an Accelerator object

```
template <typename TAcc>
ALPAKA_FN_ACC
float my_func(TAcc const& acc, float arg) { … }
```

- the availability of C++ features depends on the backend and on the device compiler
  - dynamic memory allocation is (partially) supported, but strongly discouraged
  - c++ std containers should be avoid
  - exceptions are usually not supported
  - recursive functions are supported only by some backends (CUDA: yes, but often inefficient; SYCL: no)
  - c++20 is available in CUDA code only starting from CUDA 12.0
  - *etc.*

alpaka device functions

examples:

- mathematical operations are similar to what is available in the c++ standard:
  - *e.g.*
    `alpaka::math::sin(acc, arg)`
- atomic operations are similar to what is available in CUDA and HIP
  - *e.g.*
    `alpaka::atomicAdd(acc, T* address, T value, alpaka::hierarchy::Blocks)`
- warp-level functions are similar to what is available in CUDA and HIP
  - *e.g.*
    `alpaka::warp::ballot(acc, arg)`

kernels

- are implemented as an `ALPAKA_FN_ACC void operator()(…) const` function of a dedicated `struct` or `class`
  - kernels never return anything: `-> void`
  - kernels cannot change any data member on the host: must be declared `const`
- are always templated on the accelerator type, and take an accelerator object as the first argument

```
struct Kernel {
  template <typename TAcc>
  ALPAKA_FN_ACC void operator()(
    TAcc const& acc,
    float const* in1, float const* in2, float* out, size_t size) const
  {
    ...
  }
};
```

- the `TAcc acc` argument identifies the backend and provides the details of the work division

alpaka: grids, blocks, threads ...

- alpaka maintains the work division into blocks and threads used in CUDA and OpenCL:
  - a kernel launch is divided into a grid of **blocks**
    - the various block are scheduled independently, so they may be running concurrently or at different times
    - operations in different blocks cannot be synchronised
    - operations in different blocks can communicate only through the device global memory
  - each block is composed of **threads** running in parallel
    - threads in a block tend to run concurrently, but may diverge or be scheduled independently from each other
    - operations in a block can be synchronised, *e.g.* with `alpaka::syncBlockThreads(acc);`
    - operations in a block can communicate through shared memory
  - blocks can be decomposed into sub-groups, *i.e.* **warps**
    - threads in the same warp can synchronise and exchange data using more efficient primitives

… and elements ?

- to support efficient algorithms running on a CPU, alpaka introduces an additional level in the execution hierarchy: **elements**
  - each thread in a block may process multiple consecutive elements
  - CPU backends usually run with multiple elements per thread
    - a good choice might be 16 elements, so 16 consecutive integers or floats can be loaded into a cache line
    - in principle, this could allow a host compiler to auto-vectorise the code, but more testing and development is needed !
  - GPU backends usually run with a single element per thread
    - memory accesses are already coalesced at the warp level
    - in principle, 2 elements per thread could be used with `short` or `float16` data

- kernel should be written to allow for different number of elements per thread
  - a common approach is to use
    - N blocks, M threads per block, 1 element per thread on a GPU
    - N blocks, 1 thread per block, M elements per thread on a CPU

a simple strided loop

- alpaka provides helper to implement a N-dimensional strided loops
  - the launch grid is tiled and repeated as many times as needed to cover the problem size
  - this is usually an efficient approach when all threads can work independently

```
struct Kernel {
  template <typename TAcc>
  ALPAKA_FN_ACC void operator()(
    TAcc const& acc,
    float const* in1, float const* in2, float* out, size_t size) const
  {
    for (auto index : alpaka::uniformElements(acc, size)) {
      out[index] = in1[index] + in2[index];
    }
  }
};
```

  - also available for N-dimensional loops

```
    for (auto ndindex : alpaka::uniformElementsND(acc, {z,y,x})) { ... }
```

  - split across different dimensions, for non-uniform blocks, *etc.*
- for more complicated cases, use the `alpaka::getWorkDiv` and `alpaka::getIdx` functions

launching kernels

alpaka: work submission

`Accelerator`

- describes "how" a kernel runs on a device
  - N-dimensional work division (1D, 2D, 3D, …)
  - on the CPU, serial vs parallel execution at the thread and block level (single thread, multi-threads, TBB tasks, …)
  - implementation of shared memory, atomic operations, *etc.*
- the `Accelerator` c++ type is available only when alpaka is being compiled for a specific back-end
  - the accelerator type can be used to specialise code and implement per-accelerator behaviour
  - for example, an algorithm can be implemented in device code using a parallel approach for a GPU-based accelerator, and a serial approach for a CPU-based accelerator
- accelerator objects are created when a kernel is executed, and can only be accessed in device code
  - each device function can (should) be templated on the accelerator type, and take an accelerator as its first argument
  - the accelerator object can be used to extract the execution configuration (blocks, threads, elements)

`Tag`

- identifies an `Accelerator` back-end, without the hardware and work division details
  - *e.g.* `TagCpuSerial`, `TagGpuCudaRt`, `TagGpuHipRt`, …
- unlike the `Accelerator`, the `Tag` C++ type is always available

launching a kernel

- a kernel launch requires
  - the type of the accelerator where the kernel will run
  - the queue to submit the work to
  - the work division into blocks, threads, and elements
  - an instance of the type that implements the kernel
  - the arguments to the kernel function

- we provide some helper types and functions
  - `config.h` includes the aliases `Acc1D`, `Acc2D`, `Acc3D` for 1D, 2D and 3D kernels
  - `WorkDiv.hpp` provides the helper function `makeWorkDiv<TAcc>(blocks, threads_or_elements)`
    - taken from Alpaka tests

```
// launch a 1-dimensional kernel with 32 groups of 32 threads (GPU) or elements (CPU)
auto grid = makeWorkDiv<Acc1D>(32, 32);
alpaka::exec<Acc1D>(queue, grid, Kernel{}, a.data(), b.data(), sum.data(), size);
```

a complete alpaka example

a complete alpaka example

- running on the CPU

https://github.com/fwyzard/intro_to_alpaka/blob/master/alpaka/05_kernel.cc

```
$ ./05_kernel_cpu
Host:   AMD EPYC 7352 24-Core Processor
Device: AMD EPYC 7352 24-Core Processor
Testing VectorAddKernel with scalar indices with a grid of (32) blocks x (1) threads x (32) elements...
success
Testing VectorAddKernel1D with vector indices with a grid of (32) blocks x (1) threads x (32) elements...
success
Testing VectorAddKernel3D with vector indices with a grid of (5, 5, 1) blocks x (1, 1, 1) threads x (4, 4, 4) elements...
success
```

- running on the GPU

```
$ ./05_kernel_cuda
Host:   AMD EPYC 7352 24-Core Processor
Device: Tesla T4
Testing VectorAddKernel with scalar indices with a grid of (32) blocks x (32) threads x (1) elements...
success
Testing VectorAddKernel1D with vector indices with a grid of (32) blocks x (32) threads x (1) elements...
success
Testing VectorAddKernel3D with vector indices with a grid of (5, 5, 1) blocks x (4, 4, 4) threads x (1, 1, 1) elements...
success
```

alpaka on different back-ends

parallel execution on CPUs

- parallel CPU back-end, using the Intel Threading Building Blocks library

```
g++ -std=c++17 -O2 -g -pthread \
    -I$ALPAKA_BASE/include -DALPAKA_ACC_CPU_B_TBB_T_SEQ_ENABLED -ltbb \
    05_kernel.cc \
    -o 05_kernel_tbb
```

```
$ ./05_kernel_tbb
Host:   AMD EPYC 7352 24-Core Processor
Device: AMD EPYC 7352 24-Core Processor
Testing VectorAddKernel with scalar indices with a grid of (32) blocks x (1) threads x (32) elements...
success
Testing VectorAddKernel1D with vector indices with a grid of (32) blocks x (1) threads x (32) elements...
success
Testing VectorAddKernel3D with vector indices with a grid of (5, 5, 1) blocks x (1, 1, 1) threads x (4, 4, 4) elements...
success
```

offloading to AMD GPUs

- AMD GPUs, using the HIP/ROCm runtime back-end

```
hipcc -std=c++17 -O2 -g -pthread \
    -I$ALPAKA_BASE/include -DALPAKA_ACC_GPU_HIP_ENABLED \
    05_kernel.cc \
    -o 05_kernel_hip
```

```
$ ./05_kernel_hip
Host:   AMD EPYC 7A53 64-Core Processor
Device: AMD Instinct MI250X
Testing VectorAddKernel with scalar indices with a grid of (32) blocks x (32) threads x (1) elements...
success
Testing VectorAddKernel1D with vector indices with a grid of (32) blocks x (32) threads x (1) elements...
success
Testing VectorAddKernel3D with vector indices with a grid of (5, 5, 1) blocks x (4, 4, 4) threads x (1, 1, 1) elements...
success
```

Alpaka on the LUMI supercomputer !

offloading to Intel GPUs

- Intel GPUs, using the oneAPI back-end

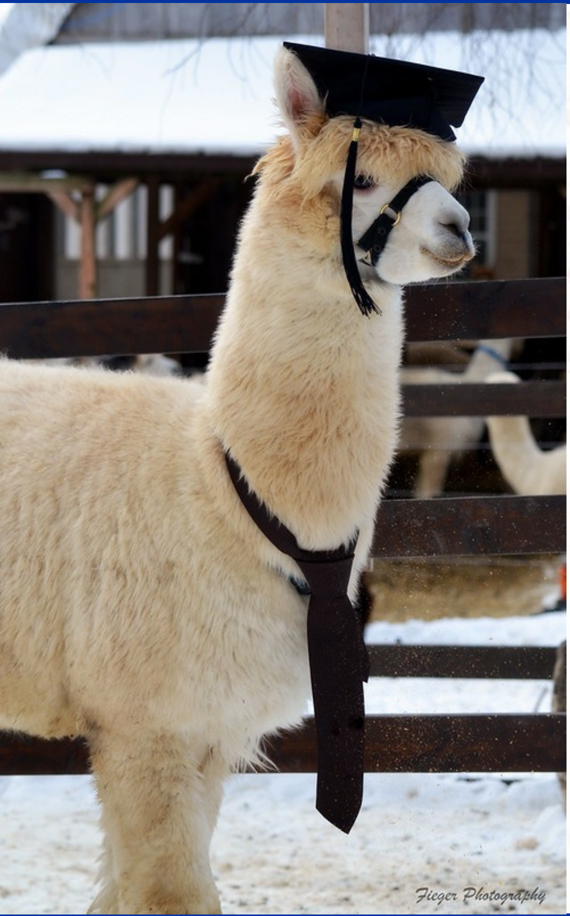
```
icpx -fsycl -std=c++17 -O2 -g -pthread \
    -I$ALPAKA_BASE/include -DALPAKA_ACC_SYCL_ENABLED -DALPAKA_SYCL_ONEAPI_GPU \
    05_kernel.cc \
    -o 05_kernel_sycl
```

```
$ ./05_kernel_sycl
Host:   Intel(R) Xeon(R) Platinum 8480+
Device: Intel(R) Data Center GPU Max 1100
Testing VectorAddKernel with scalar indices with a grid of (32) blocks x (32) threads x (1) elements...
success
Testing VectorAddKernel1D with vector indices with a grid of (32) blocks x (32) threads x (1) elements...
success
Testing VectorAddKernel3D with vector indices with a grid of (5, 5, 1) blocks x (4, 4, 4) threads x (1, 1, 1) elements...
success
```

Alpaka on the Aurora supercomputer ?

summary

summary



- during the first part we learned
  - what *performance portability* means and discovered the Alpaka library
  - how to set up Alpaka for a simple project
  - how to compile a single source file for different back-ends
  - what are Alpaka platforms, devices, queues and events
- today we learned
  - how to work with host and device memory
  - how to write device functions and kernels
  - how to use an Alpaka accelerator and work division to launch a kernel
  - and see a complete example !
- congratulations!
  - now you can write *portable* and *performant* applications

(more) questions ?