

## Introduction to Kokkos

This lab will introduce the Kokkos framework for portable performance.

This mainly follows the training given at SC 2017 and is also available from their GitHub.

**Note:** you should use these build instructions instead of the ones in the slides.

The files for this are on the course repository.

To check out the repository run:

```
git clone https://github.com/EPCCed/cpp4hpc.git
cd cpp4hpc/exercies/kokkos
```

### Problem: Inner product

We will be looking at the inner product:

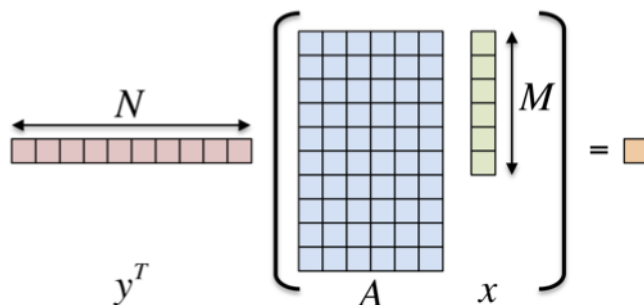


Figure 1: Inner product

where  $x$  and  $y$  are vectors and  $A$  is a matrix.

### Cirrus

Please ensure you are logged into the node login0.

Load required modules:

```
module load gcc cuda kokkos
```

### Plots

We have provided a Jupyter notebook for creating plots of the performance: plot.ipynb.

You can run this on your laptop if you have Jupyter installed or on Cirrus, connecting your local browser via a SSH tunnel.

To run locally, simply download the notebook to your machine and run the notebook which should open in your default browser if correctly configured:

```
jupyter-notebook plot.ipynb
```

To run the notebook on Cirrus, run the script `run_nb_server.sh` with two arguments: the port to listen on (must be a unique number between 1024 and 65536) and a password, e.g.

```
./run_nb_server.sh 6547 s3cret
```

The script will print further instructions.

## 1. Initialise, Use, Finalise

The corresponding source code can be found in `cpp4hpc/exercies/kokkos/1/exercise_1_begin.cpp`

In short, you need to set up Kokkos by calling `Kokkos::initialize` and `Kokkos::finalize` and convert the *outer* loops to use the parallel algorithms. The places where you need to change things are marked with **EXERCISE**.

On Cirrus, you can simply compile with `make` and the executable will then use OpenMP to parallelise the loops across available cores. While you *can* run on the login node for the OpenMP and serial backends, please submit to the queue. An example job script is `submit.sh`. Please ensure you set the number of threads to less than or equal to the number of cores you request in the job script!

When you run you can set the problem size with command line flags. These are passed as a power of 2 (e.g. `10 => 2**10 = 1024`).

- `-N` - the number of rows (default = 12)
- `-M` - the number of columns (default = 10)
- `-S` - the total size (default = 22, must equal sum of M and N)

Can also specify the number of repeats: \* `-nrepeat` (default = 100)

When using OpenMP, specify the number of threads to use by setting the `OMP_NUM_THREADS` environment variable, e.g.:

```
export OMP_NUM_THREADS=1
./01_Exercise.OpenMP -N 12
```

Or instead use the command line argument `--kokkos-threads=n`. You can also use the option `--kokkos-uma=2` if you run across the two sockets on nodes.

Things to look at:

- vary problem size

- vary number of cores
- compare Skylake Gold (GPU nodes) vs Broadwell (regular nodes)

## 2. Use Views

The corresponding source code is in `cpp4hpc/exercies/kokkos/2/exercise_2_begin.cpp`.

In this part, you change the data storage from raw arrays to `Kokkos::View` instantiations. The `View` template class provides access to elements via `operator()` to allow multidimensional indexing and thus encapsulation of the actual layout of data.

Note: we are forcing Kokkos use to unified memory for the CUDA build so you do not need to use mirror views (yet!).

Compile with `make` and run the code on the CPU with OpenMP and on the GPU with CUDA + UVM - see the example submission script for details. Compare the performance you get for the CPU to the GPU for a range of problem sizes.

You can plot results with the plotting notebook explained above.

## 3. Use Mirror Views

The corresponding source code is in `cpp4hpc/exercies/kokkos/3/exercise_3_begin.cpp`.

Here we add `HostMirror` instances to manage transfer of data between host and GPU memories. Search the source for comments saying `EXERCISE` to see where to change things.

Note that we are no longer forcing CUDA to use Unified Memory.

Compile with `make` and run the code on a GPU node - see `submit.sh` for example use. Again, compare performance between CPU and GPU for a range of problem sizes.

## 4. Control the Layout

The corresponding source code is in `cpp4hpc/exercies/kokkos/4/exercise_4_begin.cpp`.

Here you will control the layout of the data and experiment with the combinations of the execution space and data layout. Search the source for comments saying `EXERCISE` to see where to change things.

Compile for a variety of memory layouts and execution spaces and run across a range of problem sizes. Plot the results and try to understand the variation.