

ME 759
High Performance Computing for Engineering Applications
Assignment 3
Due Thursday 09/28/2023 at 9:00 PM

Submit responses to all tasks which don't specify a file name to Canvas in a file called assignment3.{txt, docx, pdf, rtf, odt} (choose one of these formats). Submit all plots (if any) on Canvas. Do not zip your Canvas submission.

All *source files* should be submitted in the **HW03** subdirectory on the **main** branch of your GitLab repo. Please use the name **HW03** exactly as shown here (both in terms of capitalization & name). The **HW03** subdirectory should have no subdirectories. For this assignment, your **HW03** folder should contain **task1.cu**, **task2.cu**, **task3.cu**, and **vscale.cu**.

All commands or code must work on *Euler* with only the **nvidia/cuda/11.8.0** module loaded. The commands may behave differently on your computer, so be sure to test on *Euler* before you submit.

Please submit clean code. Consider using a formatter like **clang-format**.

IMPORTANT: Before you begin, copy any provided files from **Assignments/HW03** directory of the **ME759 Resource Repo**. Do not change any of the provided files since these files will be overwritten with clean, reference copies when grading.

1. Write a C++ program using CUDA in a file called **task1.cu** which computes the factorial of integers from 1 to 8, by launching a GPU kernel with **1 block and 8 threads**. Inside the kernel, each thread should use **std::printf** to write out **a!=b** (followed by a newline), where **a** is one of the 8 integers, and **b** is the result of **a!**. (Follow your kernel call with a call to **cudaDeviceSynchronize()** so that the host waits for the kernel to finish printing before returning from **main**.)
 - Compile: **nvcc task1.cu -Xcompiler -O3 -Xcompiler -Wall -Xptxas -O3 -std=c++17 -o task1**
 - Run (on Euler, use Slurm sbatch!): **./task1**
 - Expected output (showing only 4 out of the 8 lines expected; lines could be out of order):

```
1!=1
2!=2
3!=6
4!=24
```
 - It is ok to publish your sbatch script on Piazza. For this assignment, you will need to ask Slurm to execute your program on **a node that has GPU cards**

2. Write a C++ program using CUDA in a file called `task2.cu` which does the following:

- From the host, allocates an array of 16 ints on the device called `dA`.
- Launches a kernel with 2 blocks, each block having 8 threads.
- Each thread computes `ax+y` and writes the result in one distinct entry of the `dA` array. Here,
 - `x` is the thread's `threadIdx`;
 - `y` is the thread's `blockIdx`;
 - `a` is an integer argument that the kernel takes (so all threads use the same `a`). You need to generate `a` randomly and then call the kernel with it. It is up to you how you generate this random number, one possible approach is described here [BestPractice](#).
- Copies back the data stored in the device array `dA` into a host array called `hA`.
- Prints (from the host) the 16 values stored in the host array separated by a single space each.

How to go about it, and what the expected output looks like:

- Compile: `nvcc task2.cu -Xcompiler -O3 -Xcompiler -Wall -Xptxas -O3 -std=c++17 -o task2`
- Run (on Euler, use Slurm sbatch!): `./task2`
- Expected output (followed by newline; yours could be different depending on the random number generation): `0 10 20 30 40 50 60 70 1 11 21 31 41 51 61 71`

3. a) Implement in a file called `vscale.cu`, the `vscale` kernel function as declared and described in `vscale.cuh`. This function should take in two arrays, `a` and `b`, and do an element-wise multiplication of the two arrays: $b_i = a_i \cdot b_i$. In the process, `b` gets overwritten. Each thread should do at most one of the multiplication operations.

Example:

$$\mathbf{a} = [-5.0, 2.0, 1.5], \quad \mathbf{b} = [0.8, 0.3, 0.6], \quad n = 3$$

The resulting `b` array is:

$$\mathbf{b} = [-4.0, 0.6, 0.9].$$

- b) Write a file `task3.cu` which does the following:
- Creates two arrays of length `n` filled by random numbers¹ where `n` is read from the first command line argument. The range of values for array `a` is $[-10.0, 10.0]$, whereas the range of values for array `b` is $[0.0, 1.0]$.
 - Calls your `vscale` kernel with a 1D execution configuration that uses 512 threads per block.
 - Prints the amount of time taken to execute the kernel in *milliseconds* using CUDA events².
 - Prints the first element of the resulting array.
 - Prints the last element of the resulting array.

How to go about it, and what the expected output looks like:

- Compile: `nvcc task3.cu vscale.cu -Xcompiler -O3 -Xcompiler -Wall -Xptxas -O3 -std=c++17 -o task3`
 - Run (where `n` is a positive integer): `./task3 n`
 - Example expected output (followed by newline):
0.012
1.3
2.3
- c) On an Euler *compute node*, run `task3` for each value $n = 2^{10}, 2^{11}, \dots, 2^{29}$ and generate a plot `task3.pdf` which plots the time taken by your `vscale` as a function of `n`. Overlay another plot which shows the scaling results when using 16 threads per block.

¹Details about random number generation can be found in [random_numbers.md](#).

²Recall the GPU timing section of the document [timing.md](#).