Programming Parallel Computers

Aalto 2023

CP: correlated pairs

Please read the general instructions on this page first, and then check the individual tasks for more details. For each task you can download a zip file that contains the code templates you can use for development.

Task	Attempts	Expected	Points	Max	Rating	Rec.	Deadline for full points
CP1: CPU baseline Implement a simple **sequential** baseline solution. Do not try to use any form of parallelism yet; try to make it work correctly first. Please do all arithmetic with **double-precision** floating point numbers. For this initial exercise, we have disabled auto-vectorization.	0	–	–	5	★	R	2023-04-30 at 23:59:59
CP2a: instruction-level parallelism Parallelize your solution to CP1 by exploiting **instruction-level parallelism**. Make sure that the performance-critical operations are pipelined efficiently. Do not use any other form of parallelism yet in this exercise. Please do all arithmetic with **double-precision** floating point numbers. For this technical exercise, we have disabled auto-vectorization.	0	–	–	3	★	R	2023-05-07 at 23:59:59
CP2b: multicore parallelism Parallelize your solution to CP1 with the help of **OpenMP and multithreading** so that you are exploiting multiple CPU cores in parallel. Do not use any other form of parallelism yet in this exercise. Please do all arithmetic with **double-precision** floating point numbers. For this technical exercise, we have disabled auto-vectorization.	0	–	–	3	★	R	2023-05-07 at 23:59:59
CP2c: vectorization Parallelize your solution to CP1 with the help of **vector operations** so that you can perform multiple useful arithmetic operations with one instruction. Do not use any other form of parallelism yet in this exercise. Please do all arithmetic with **double-precision** floating point numbers. For this technical exercise, we have disabled auto-vectorization.	0	–	–	3	★	R	2023-05-07 at 23:59:59
CP3a: fast solution with doubles Using all resources that you have in the CPU, solve the task **as fast as possible**. You are encouraged to exploit instruction-level parallelism, multithreading, and vector instructions wherever possible, and also to optimize the memory access pattern. Please do all arithmetic with **double-precision** floating point numbers.	0	–	–	5 + 2	★★	R	2023-05-14 at 23:59:59
CP3b: fast solution with floats Using all resources that you have in the CPU, solve the task **as fast as possible**. You are encouraged to exploit instruction-level parallelism, multithreading, and vector instructions wherever possible, and also to optimize the memory access pattern. In this task, you are permitted to use **single-precision** floating point numbers.	0	–	–	5 + 2	★★	R	2023-05-14 at 23:59:59
CP4: GPU baseline Implement a simple baseline solution for the **GPU**. Make sure it works correctly and that it is reasonably efficient. Make sure that all performance-critical parts are executed on the GPU; you can do some lightweight preprocessing and postprocessing also on the CPU. In this task, you are permitted to use **single-precision** floating point numbers.	0	–	–	5	★	R	2023-05-21 at 23:59:59
CP5: fast GPU solution Using all resources that you have in the **GPU**, solve the task **as fast as possible**. In this task, you are permitted to use **single-precision** floating point numbers.	0	–	–	10 + 2	★★	R	2023-05-28 at 23:59:59
CP9a: better algorithm Try to use **Strassen's algorithm** to speed up matrix multiplication. Reimplement your solution to CP3b so that it uses the basic idea of Strassen's algorithm. It is sufficient to use the basic idea of Strassen's algorithm (adapted to our task as needed) in the topmost levels of recursion; you can then fall back to the naive algorithm. Care is needed with rounding errors; you may need to resort to double-precision arithmetic to pass the tests.	0	–	–	5	★★★		2023-06-04 at 23:59:59
CP9c: fast solution with doubles This is a version of CP3a which has extended, **experimental** benchmarks that also try to measure cache traffic. This is a somewhat tricky endeavour, as the exact meaning of cache performance events can be CPU specific. We would therefore like to hear your feedback on how this works **on your local system**, as well as any cases where the reported numbers seem to differ from your expectations.	0	–	–	0	★★		2023-06-04 at 23:59:59

General instructions for this exercise

You are given m input vectors, each with n numbers. Your task is to calculate the correlation between every pair of input vectors.

Interface

You need to implement the following function:

```
void correlate(int ny, int nx, const float* data, float* result)
```

Here `data` is a pointer to the input matrix, with `ny` rows and `nx` columns. For all `0 <= y < ny` and `0 <= x < nx`, the element at row `y` and column `x` is stored in `data[x + y*nx]`.

The function has to solve the following task: for all `i` and `j` with `0 <= j <= i < ny`, calculate the correlation coefficient between row `i` of the input matrix and row `j` of the input matrix, and store the result in `result[i + j*ny]`.

Note that the correlations are symmetric, so we will only compute the upper triangle of the result matrix. You can leave the lower triangle `i < j` undefined.

The arrays `data` and `result` are already allocated by whoever calls this function; you do not need to do any memory management related to these arrays. You should not assume that `result` contains any valid values at the point of call. In particular, it is not guaranteed to be initialized with zeros.

Details

The input and output are always given as single-precision floating point numbers (type `float`). However, depending on the task, we will do arithmetic with either single or double-precision numbers:

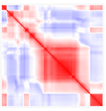
- If the task specifies that you must use double-precision floating point numbers, then all arithmetic operations must be done with type `double`, all intermediate results must be stored in variables of type `double`, and you will only round the final result to single precision.
- If the task specifies that you can use single-precision floating point numbers, then you are encouraged to use the type `float` whenever possible.

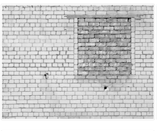
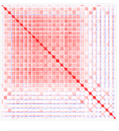
However, in each case you will have to make sure the numerical precision of the results is sufficiently high. The grading tool makes sure the error is sufficiently small. The error thresholds are chosen so that a straightforward and efficient solution is typically good enough, but please feel free to ask the course staff for hints if you are struggling with the rounding errors.

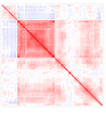
Examples

These examples show what a correct implementation will do if you apply it to a bitmap image:

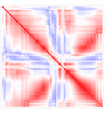
- Input (first image): vector i = row i of the image.
- Output (second image): red pixel at (i, j) = positive correlation between rows i and j, blue pixel = negative correlation.









Hints