

Lab: Accelerating Code: From Python Baseline to Architecture-Aware Optimization

Objective

You (in teams of 2) start from a given **Python baseline** of a real-world numerical algorithm and iteratively accelerate it using **architecture-level design optimizations** — up to **AVX-512 vectorization** and multicore exploitation. The idea is to study the performance impact and understand Measurement and reproducibility of real performance (GFLOPs, speedup, scaling) using:

- **Multicore parallelism** (threads, task scheduling, synchronization)
- **Cache-friendly data layouts** and blocking
- **SIMD / VLIW-style vectorization (SSE, AVX2, AVX-512)**
- **Memory hierarchy & prefetching**
- **NUMA-aware memory allocation**
- **Branch prediction & instruction-level parallelism**
- **Compiler and build optimizations (-O3, -march, -funroll-loops)**

[Leaderboard will rank submissions by *speedup over baseline*.]

We will do two challenge problems --- one from Linear Algebra [Dense Matrix-Matrix Multiplication (GEMM)] and another from Computational Biology/Smith–Waterman string alignment OR Optimization / ML Gradient Descent on synthetic dataset. We will give a base line implementation for both challenges.

```
# baseline_gemm.py
import numpy as np
from multiprocessing import Pool

def multiply_block(args):
    A_block, B_block = args
    return np.dot(A_block, B_block)

if __name__ == "__main__":
    N = 1024
    A = np.random.rand(N, N)
    B = np.random.rand(N, N)
    with Pool(4) as p:
        results = p.map(multiply_block, [(A[i::4], B) for i in range(4)])
    C = np.vstack(results)
```

You can *reimplement* in **C / C++ / optimized Python** — but must maintain the same functionality and correctness. All optimizations must be documented and reproducible.

You may do one or many of the following:

You may **NOT**

- Call pre-optimized BLAS routines directly (like `cblas_dgemm`) — unless they implement similar optimizations manually or via library introspection.
- Change the algorithm's semantics (must compute same result)

Measurement

I have given you the directory structure with the associated scripts. Please use that to create your submission tarball which we will autograde.

```
kolin@mosaic:~/col7418/labFinal$ tree
.
├── baseline
│   └── gemm_baseline.py
├── leaderboard
├── Makefile
├── optimized
│   ├── cpp
│   │   └── gemm_opt.cpp
│   └── gemm_opt
├── README.md
├── report_template.md
├── run.sh
└── submit.sh

3 directories, 9 files
```

You will measure wall-clock time for both baseline and optimized code. You will report Runtime (sec), GFLOPs or GB/s throughput, Speedup factor, Core count, Instruction vector width (SSE, AVX2, AVX-512) and L1/L2/L3 miss rates with appropriate graphs/visualization. You can use `perf` for to get performance counter stats.

```
Serial sum = 100000000, time = 0.244 sec
Parallel sum = 100000000, time = 0.017 sec
Number of logical CPUs available: 32
Speedup = 14.75x

Performance counter stats for './a.out':

      1,393.94 msec task-clock           #    1.887 CPUs utilized
         59      context-switches      #    42.326 /sec
          1      cpu-migrations         #     0.717 /sec
    1,95,451      page-faults          #   140.215 K/sec
  4,25,73,83,614      cycles            #     3.054 GHz
  4,48,34,89,980      instructions     #     1.05 insn per cycle
   51,04,34,834      branches           #   366.183 M/sec
    1,47,317      branch-misses        #     0.03% of all branches

0.738770142 seconds time elapsed

1.159144000 seconds user
0.234859000 seconds sys
```

Grading

The assignment will be graded on three counts:

Metric	Description	Weight
Speedup	Baseline time / Optimized time	60%
Scalability	Speedup vs #cores (1–N scaling curve)	20%
Technical Depth	Demonstrated architecture-level reasoning in report	20%

Submission

Code repository

- baseline/ and optimized/ directories
- run.sh to build and test reproducibly
- Documentation of compiler flags, cores used, and assumptions

Report (4–6 pages)

- Description of optimizations and reasoning (with diagrams of data blocking)
- Profiling evidence (cache miss reductions, IPC improvements)
- Performance vs. baseline plots
- Reflection: what architectural factor dominated performance?

To standardize things, I have give you a script to create the tarball. You will run `./submit.sh entryNumbers` inside the directory to create the tarball.

```

kolin@mosaic:~/col7418/labFinal$ ./submit.sh mcs259999mcs258888
Created submission package: submit_mcs259999mcs258888_20251019_070704.tar.gz
Please upload submit_mcs259999mcs258888_20251019_070704.tar.gz in Moodle

```