# HPC

## Lab 1 — Introduction to Parallel Programming with OpenMP

some commands to be used:

gcc -fopenmp hello.c  ... to compile file

./a.out  ... to run the file

export OMP_NUM_THREADS=7  ...  state number of threads to use

The objective of this lab is to learn how to run **multiple threads** on a **shared-memory** machine and see how OpenMP splits work.

→ **OpenMP** is a library/API for **parallel programming on one machine** (shared memory).

Task 1:

- We implemented a basic OpenMP program to demonstrate parallel execution on a shared-memory system.
- Using the directive `#pragma omp parallel`, the program creates multiple threads inside a single process. Each thread executes the same code concurrently.
- The function `omp_get_thread_num()` is used to identify which thread is running. Each thread prints its own ID, showing that multiple threads are active at the same time.
- The parallel region is executed repeatedly using a loop in order to clearly observe thread behavior. The order of the output changes between runs, which demonstrates the non-deterministic nature of parallel execution.
- The number of threads is controlled using the environment variable `OMP_NUM_THREADS`. This confirms that OpenMP enables parallelism through threads rather than multiple processes.

```
#include <stdio.h>
#include <omp.h>

int main() {

#pragma omp parallel
{
    int tid = omp_get_thread_num();

    for (long long i = 0; i < 1000000000LL; i++) {
        if (i % 200000000 == 0) {
            printf("Thread %d at iteration %lld\\n", tid,
i);
        }
    }

    printf("Thread %d finished\\n", tid);
}

return 0;

}
```

Task 2: Parallel vector computation

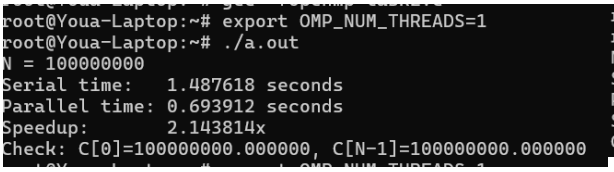
```
#include <stdio.h>
#include <stdlib.h>
#include <omp.h>

int main() {
const long N = 100000000; // 100 million
double *A = (double*)malloc(N * sizeof(double));
double *B = (double*)malloc(N * sizeof(double));
double *C = (double*)malloc(N * sizeof(double));
if (!A || !B || !C) {
```

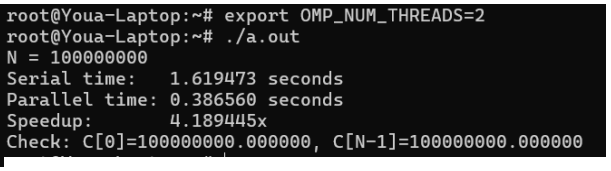
```
    printf("Memory allocation failed!\\n");
    return 1;
}

// Initialize arrays
for (long i = 0; i < N; i++) {
    A[i] = (double)i;
    B[i] = (double)(N - i);
}

// ---------------- SERIAL ----------------
double t1 = omp_get_wtime();
for (long i = 0; i < N; i++) {
    C[i] = A[i] + B[i];
}
double t2 = omp_get_wtime();
double serial_time = t2 - t1;

// ---------------- PARALLEL (MANUAL SPLIT) ---------------
-
double t3 = omp_get_wtime();

#pragma omp parallel
{
    int tid = omp_get_thread_num();
    int nthreads = omp_get_num_threads();

    long chunk = N / nthreads;
    long start = tid * chunk;
    long end = (tid == nthreads - 1) ? N : start + chunk;
// last thread takes remainder

    for (long i = start; i < end; i++) {
        C[i] = A[i] + B[i];
    }
}

double t4 = omp_get_wtime();
```

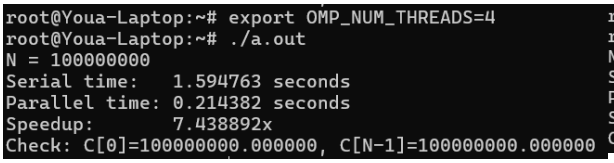
```
double parallel_time = t4 - t3;

printf("N = %ld\\n", N);
printf("Serial time:   %f seconds\\n", serial_time);
printf("Parallel time: %f seconds\\n", parallel_time);
printf("Speedup:       %fx\\n", serial_time / parallel_tim
e);
printf("Check: C[0]=%f, C[N-1]=%f\\n", C[0], C[N-1]);

free(A);
free(B);
free(C);
return 0;
}
```

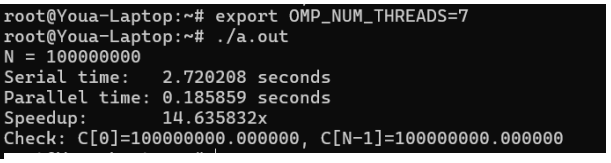
- In this experiment, vector addition was executed using different numbers of OpenMP threads. The work was manually divided among threads using `#pragma omp parallel`.

The correctness check confirms that the results are correct for all runs.




## Note 1:

Using `omp parallel` allows manual control over how work is divided among threads, which can be more efficient than `omp for` when the programmer understands the task and workload distribution well.

## Note 2:

The speedup cannot increase infinitely when adding more threads. According to Amdahl's Law, the maximum possible speedup is limited by the serial part of the program and is given by Speedup ≤ 1 / s, where s is the fraction of the code

that must run serially and cannot be parallelized.

Task 3: Parallel Matrix Computation

```
#include <stdio.h>
#include <stdlib.h>
#include <omp.h>

/*
  Matrix multiplication: C = A * B
  A, B, C are N x N (stored in 1D arrays, row-major).
*/

int main(int argc, char *argv[]) {
    int N = 800;               // default size (change late
r or pass as argument)
    if (argc >= 2) N = atoi(argv[1]);

    // Allocate memory
    double *A = (double*)malloc((size_t)N * N * sizeof(doub
le));
    double *B = (double*)malloc((size_t)N * N * sizeof(doub
le));
    double *C = (double*)malloc((size_t)N * N * sizeof(doub
le));

    if (!A || !B || !C) {
        printf("Memory allocation failed. Try smaller
N.\n");
        return 1;
    }

    // Initialize A and B with simple values
    for (int i = 0; i < N; i++) {
```

```
        for (int j = 0; j < N; j++) {
            A[i*N + j] = (double)(i + j);
            B[i*N + j] = (double)(i - j);
            C[i*N + j] = 0.0;
        }
    }

    // ---------------- SERIAL ----------------
    double t1 = omp_get_wtime();

    for (int i = 0; i < N; i++) {
        for (int j = 0; j < N; j++) {
            double sum = 0.0;
            for (int k = 0; k < N; k++) {
                sum += A[i*N + k] * B[k*N + j];
            }
            C[i*N + j] = sum;
        }
    }

    double t2 = omp_get_wtime();
    double serial_time = t2 - t1;

    // Reset C
    for (int i = 0; i < N*N; i++) C[i] = 0.0;

    // ---------------- PARALLEL (MANUAL SPLIT WITH omp par
allel) ----------------
    double t3 = omp_get_wtime();

    #pragma omp parallel
    {
        int tid = omp_get_thread_num();
        int nthreads = omp_get_num_threads();

        // Split rows among threads
        int chunk = N / nthreads;
        int start = tid * chunk;
```

```
        int end = (tid == nthreads - 1) ? N : start + chun
k;

        for (int i = start; i < end; i++) {
            for (int j = 0; j < N; j++) {
                double sum = 0.0;
                for (int k = 0; k < N; k++) {
                    sum += A[i*N + k] * B[k*N + j];
                }
                C[i*N + j] = sum;
            }
        }
    }

    double t4 = omp_get_wtime();
    double parallel_time = t4 - t3;

    // Print results
    printf("N = %d\n", N);
    printf("Serial time:   %f seconds\n", serial_time);
    printf("Parallel time: %f seconds\n", parallel_time);
    printf("Speedup:       %fx\n", serial_time / parallel_t
ime);

    // Small correctness check (print a couple of values)
    printf("Check: C[0][0]=%f, C[N-1][N-1]=%f\n", C[0], C
[(N-1)*N + (N-1)]);

    free(A);
    free(B);
    free(C);
    return 0;
}
```

- In this task, I performed matrix multiplication of two square matrices using both serial and parallel implementations. The overall matrix size used was 600 × 600, meaning each matrix had 600 rows and 600 columns.

- First, the serial version was executed using a single thread. This version computes all rows of the result matrix sequentially and serves as a baseline for performance comparison.
- Then, the parallel version was implemented using `#pragma omp parallel`. The rows of the result matrix were manually divided among the available threads. Each thread computed a different subset of rows, allowing multiple parts of the matrix multiplication to be executed at the same time.

- Execution time was measured using `omp_get_wtime()`. The parallel version was significantly faster than the serial version because the workload was shared across multiple CPU cores.

As the number of threads increased, execution time decreased and speedup improved. However, the speedup did not increase infinitely due to thread overhead, memory access limitations, and the serial portion of the program, as explained by Amdahl's Law.

This experiment shows that matrix multiplication benefits from parallelization, especially for larger matrix sizes such as 600 × 600.