THE ARAB AMERICAN UNIVERSITY

FACULTY OF ENGINEERING

Parallel and Distributed Computing

Parallel and Distributed Computing PROJECT I

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Section: -1-

Total	/100

Good Luck! Mr. Hussein Younis

Introduction

In this project, we implemented a matrix transposition algorithm using two methods:

- Sequential, using regular loops in C++.
- Parallel, using the Pthreads library to divide the work across multiple threads.

This algorithm was chosen because it is simple in concept, but its implementation on large matrices can take a long time, making it suitable for parallelization.

The matrix transposition process relies on swapping rows with columns. This is an operation in which each element can be executed independently, so there is no need for synchronization between threads and no data conflicts, making it highly suitable for parallel execution.

The goal of the project is to compare the performance of the two versions and measure the time difference between sequential and parallel execution when using matrices of different sizes and different numbers of threads.

Sequential Implementation

In this phase, we wrote a C++ program to implement matrix transposition using a sequential approach.

We used two matrices: A (original data) and B (result after transposition). The operation was performed using two nested for loops, where each value from A[i][j] is assigned to B[j][i].

The matrix A was filled with random values using the rand() function, and we measured the execution time using the chrono library.

At the end, we added a simple validation function that compares matrix B with the expected result to ensure correctness.

Parallelization Strategy

In the parallel implementation of the matrix transposition algorithm, the matrix rows were divided equally among multiple threads using the POSIX Threads (Pthreads) library.
Each thread was assigned a specific range of rows to process, calculated by dividing the total number of rows (N) by the number of threads (NUM_THREADS).

The thread then performed the transposition for those rows by copying values from matrix A to their corresponding transposed positions in matrix B.

Since each thread worked on independent rows and wrote to distinct locations in the output matrix, there were no shared writable data or race conditions. As a result, no synchronization mechanisms such as mutexes were required.

To launch the threads, the pthread_create() function was used, passing a dynamically allocated array containing the startRow and endRow values. After all threads were created, the main thread used pthread_join() to wait for them to finish before measuring the final execution time.

This approach was chosen for its simplicity and efficiency, as it ensures balanced workload distribution and allows full utilization of CPU cores with minimal overhead.

Experiments

Hardware Specifications

The performance experiments were conducted using a WINDOS system. With hardware as follows:

Machine (LENOVO LOQ):

- Processor: AMD Ryzen 7 7435HS 3.10 GHz
- Physical Cores: 4
- Logical Threads: 8
- Host RAM: 16 GB

Input Sizes and Thread Counts Tested

To thoroughly evaluate the performance and scalability of the sequential and parallel implementations of the matrix transposition algorithm, we designed a set of experiments involving multiple matrix sizes and a range of thread counts.

The selected matrix sizes were:

- **500×500** – representing a small-scale matrix
- **1000×1000**, **5000×5000**, **8000×8000** – representing medium to large sizes • **16000×16000**, **32000×32000** – representing very large matrices that challenge memory usage and parallel efficiency

These sizes were chosen to investigate how the algorithm performs under increasing computational load and memory requirements. For each matrix size, the transposition was carried out using the parallel implementation with varying numbers of threads to assess the impact of multithreading on performance.

The number of threads used in testing were:

- **1 thread** – serving as a baseline for comparison with the sequential version •

2 threads
• 4 threads
• 8 threads

For every combination of matrix size and thread count, we measured both the **execution time** and the resulting **speedup**, calculated as:

Speedup=Sequential Time/Parallel TimeSpeedup=Parallel TimeSequential Time

Each experiment was repeated several times to ensure consistency, and the average values were recorded. These values were then visualized using two comparative charts:

1. **Speedup vs. Thread Count**
2. – to observe how the speedup scales with parallelism
3. **Execution Time vs. Thread Count** – to illustrate the actual runtime trends of different matrix sizes

Results

The following charts summarize the results of these performance tests.

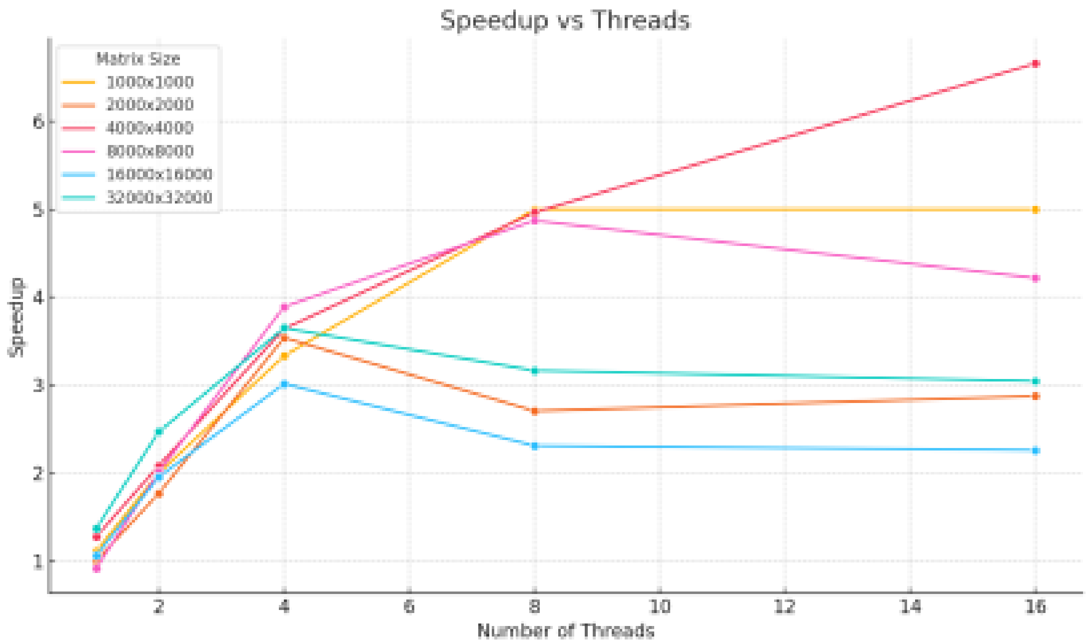

Figure 1:Speedup vs. Thread Count

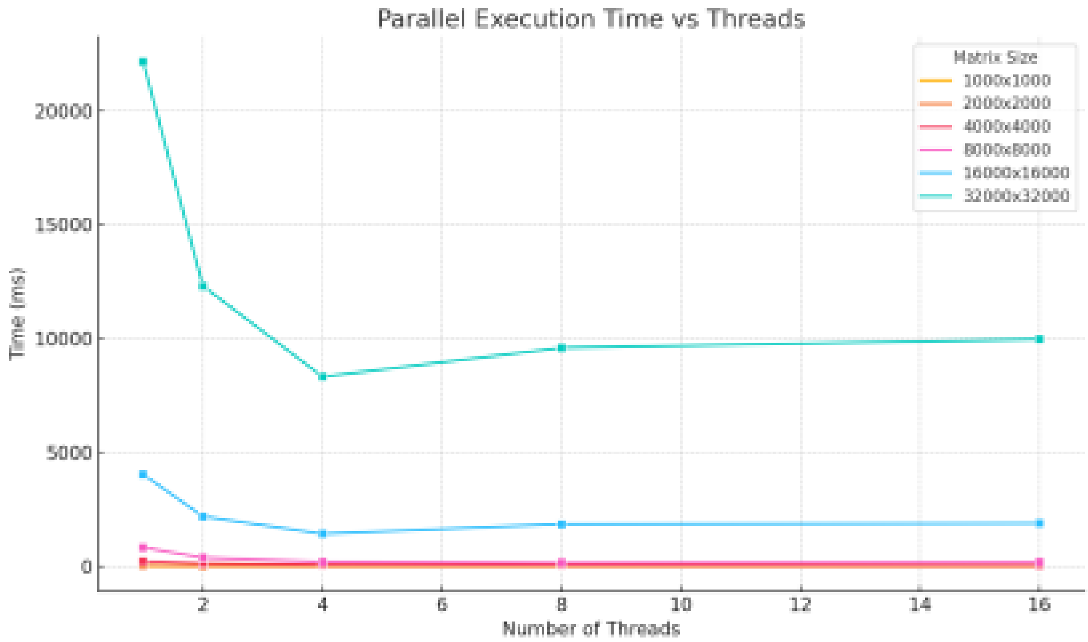

Figure 2:Execution Time vs. Thread Count

Matrix Size	Threads	Sequential Time (ms)	Parallel Time (ms)	Speedup
1000x1000	1	10	9	1.111111111
1000x1000	2	10	5	2
1000x1000	4	10	3	3.333333333
1000x1000	8	10	2	5
1000x1000	16	10	2	5
2000x2000	1	46	46	1
2000x2000	2	46	26	1.769230769
2000x2000	4	46	13	3.538461538
2000x2000	8	46	17	2.705882353
2000x2000	16	46	16	2.875
4000x4000	1	273	214	1.275700935
4000x4000	2	273	131	2.083969466
4000x4000	4	273	75	3.64
4000x4000	8	273	55	4.963636364
4000x4000	16	273	41	6.658536585
8000x8000	1	755	821	0.919610231
8000x8000	2	755	375	2.013333333
8000x8000	4	755	194	3.891752577
8000x8000	8	755	155	4.870967742
8000x8000	16	755	179	4.217877095
16000x16000	1	4272	4030	1.060049628
16000x16000	2	4272	2184	1.956043956

16000x16000	4	4272	1417	3.014820042
16000x16000	8	4272	1849	2.310438075
16000x16000	16	4272	1890	2.26031746
32000x32000	1	30373	22148	1.37136536
32000x32000	2	30373	12298	2.469751179
32000x32000	4	30373	8326	3.647970214
32000x32000	8	30373	9592	3.166492911
32000x32000	16	30373	9969	3.046744909

Table 1:result data

Discussion

The experimental results show that parallel execution becomes more effective as the matrix size increases. For small matrices like 1000×1000, the speedup was minimal due to overhead. However, for larger sizes such as 8000×8000 and 16000×16000, the parallel version achieved noticeable speedup, especially up to 8 threads.

The highest speedup was observed around 4× to 6× with 8 or 16 threads, but performance gains started to level off or slightly decrease after 8 threads due to overhead and memory limitations.

Execution time consistently decreased as thread count increased, but the benefit varied by matrix size. For very large matrices (32000×32000), parallel execution time was reduced by more than half compared to the sequential version.

Overall, the results confirm that multithreading improves performance for large data sizes, but excessive threading can reduce efficiency.

Conclusion

This project explored the implementation and performance of a matrix transposition algorithm using both sequential and parallel approaches. Through extensive testing with varying matrix sizes and thread counts, we observed clear improvements in execution time when applying multithreading—particularly for large data sizes.

The experimental results confirmed that parallelism significantly reduces processing time and achieves notable speedup, especially up to 8 threads. However, excessive threading beyond this point can introduce overhead and memory limitations that reduce overall efficiency.

In conclusion, parallel programming offers a powerful method to accelerate computations, but its effectiveness depends on carefully balancing thread count with workload size. The insights gained from this project highlight the importance of optimizing thread usage to achieve maximum performance with minimal resource waste.

** This project benefited from the use of ChatGPT to clarify multithreading concepts, structure the C++ code for matrix transposition.

Screenshots of Code Execution

```
ect1 > parallel.cpp > N
#include <iostream>
#include <chrono>

using namespace std;
using namespace std::chrono;

const int N = 2000;
int num_threads = 1;

vector<vector<int>> A(N, vector<int>(N));
vector<vector<int>> B(N, vector<int>(N));
vector<vector<int>> C(N, vector<int>(N, 0));

void fillMatrix(vector<vector<int>>& matrix) {
    for (int i = 0; i < N; ++i)
        for (int j = 0; j < N; ++j)
            matrix[i][j] = rand() % 10;
}

int computeChecksum(const vector<vector<int>>& matrix) {
    int checksum = 0;
    for (auto& row : matrix)
        for (auto val : row)
```

```
OBLEMS   OUTPUT   DEBUG CONSOLE   TERMINAL   PORTS        Filter        Code

unning] cd "/home/project1/" && g++ sequential.cpp -o sequential -pthread && "/home/project1/"sequential
quential time: 1.01488 seconds
ecksum: -1759435004

one] exited with code=0 in 1.649 seconds

unning] cd "/home/project1/" && g++ parallel.cpp -o parallel -pthread && "/home/project1/"parallel
rallel time (1 threads): 1.06815 seconds
ecksum: -1759435004

one] exited with code=0 in 1.549 seconds
                                                  Ln 10, Col 16   Spaces: 4   UTF-8   LF   {} C
```

```
#include <iostream>
#include <chrono>

using namespace std;
using namespace std::chrono;

const int N = 2000;
int num_threads = 1;

vector<vector<int>> A(N, vector<int>(N));
vector<vector<int>> B(N, vector<int>(N));
vector<vector<int>> C(N, vector<int>(N, 0));

void fillMatrix(vector<vector<int>>& matrix) {
    for (int i = 0; i < N; ++i)
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            matrix[i][j] = rand() % 10;
}

int computeChecksum(const vector<vector<int>>& matrix) {
    int checksum = 0;
    for (auto& row : matrix)
        for (auto val : row)
```
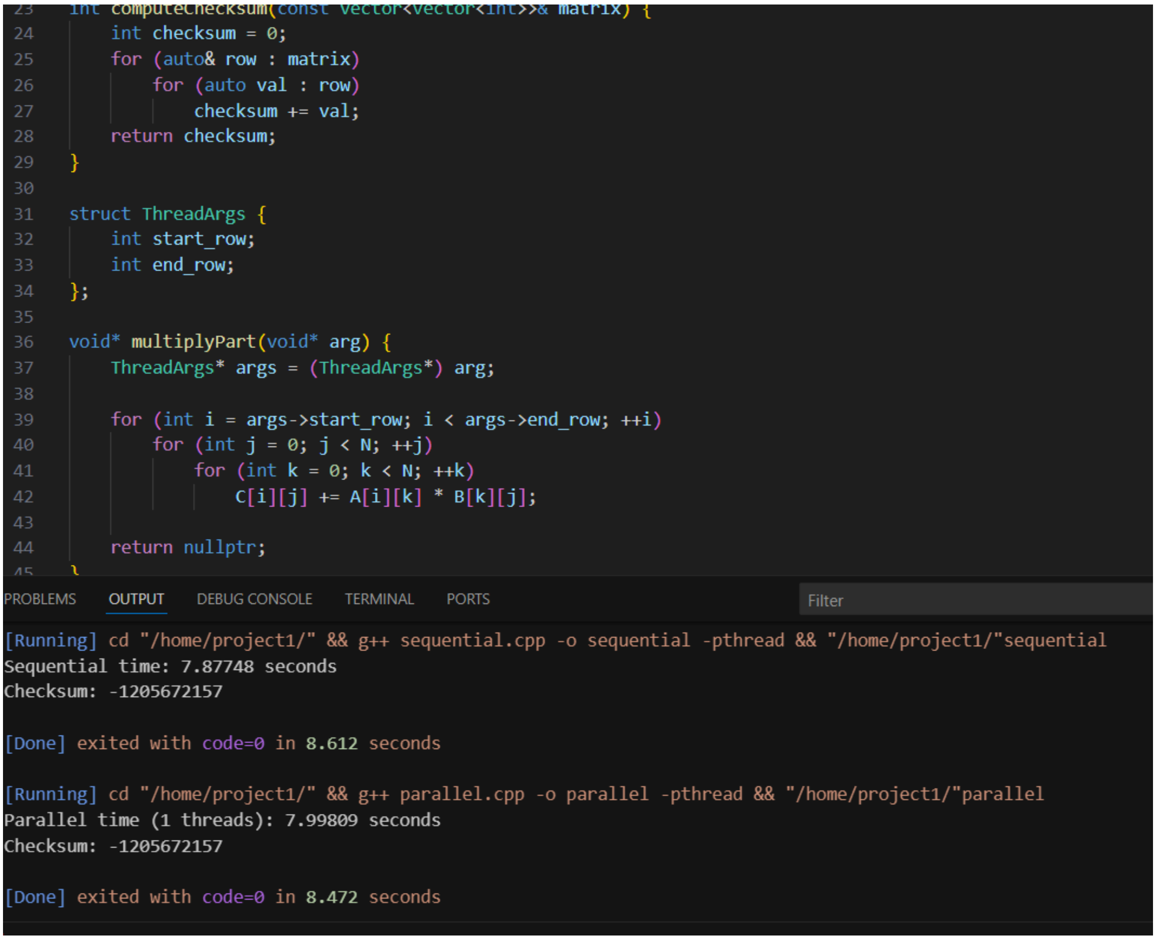

```
PROBLEMS   OUTPUT   DEBUG CONSOLE   TERMINAL   PORTS        Filter
[Running] cd "/home/project1/" && g++ parallel.cpp -o parallel -pthread && "/home/project1/"parallel
Parallel time (2 threads): 0.531621 seconds
Checksum: -1759435004

[Done] exited with code=0 in 1.148 seconds

[Running] cd "/home/project1/" && g++ parallel.cpp -o parallel -pthread && "/home/project1/"parallel
Parallel time (4 threads): 0.294472 seconds
Checksum: -1759435004

[Done] exited with code=0 in 0.751 seconds
```



```
int computeChecksum(const vector<vector<int>>& matrix) {
    int checksum = 0;
    for (auto& row : matrix)
        for (auto val : row)
            checksum += val;
    return checksum;
}

struct ThreadArgs {
    int start_row;
    int end_row;
};

void* multiplyPart(void* arg) {
    ThreadArgs* args = (ThreadArgs*) arg;

    for (int i = args->start_row; i < args->end_row; ++i)
        for (int j = 0; j < N; ++j)
            for (int k = 0; k < N; ++k)
                C[i][j] += A[i][k] * B[k][j];

    return nullptr;
}
```

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS Filter

```
[Running] cd "/home/project1/" && g++ sequential.cpp -o sequential -pthread && "/home/project1/"sequential
Sequential time: 7.87748 seconds
Checksum: -1205672157

[Done] exited with code=0 in 8.612 seconds

[Running] cd "/home/project1/" && g++ parallel.cpp -o parallel -pthread && "/home/project1/"parallel
Parallel time (1 threads): 7.99809 seconds
Checksum: -1205672157

[Done] exited with code=0 in 8.472 seconds
```

oject1 > parallel.cpp > ...

```cpp

int computeChecksum(const vector<vector<int>>& matrix) {
    int checksum = 0;
    for (auto& row : matrix)
        for (auto val : row)
            checksum += val;
    return checksum;
}

struct ThreadArgs {
    int start_row;
    int end_row;
};

void* multiplyPart(void* arg) {
    ThreadArgs* args = (ThreadArgs*) arg;

    for (int i = args->start_row; i < args->end_row; ++i)
        for (int j = 0; j < N; ++j)
            for (int k = 0; k < N; ++k)
                C[i][j] += A[i][k] * B[k][j];

    return nullptr;
```

ROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS Filter

```
Running] cd "/home/project1/" && g++ parallel.cpp -o parallel -pthread && "/home/project1/"paral
arallel time (4 threads): 1.89297 seconds
hecksum: -1205672157

Done] exited with code=0 in 2.364 seconds

Running] cd "/home/project1/" && g++ parallel.cpp -o parallel -pthread && "/home/project1/"paral
arallel time (8 threads): 1.44827 seconds
hecksum: -1205672157

Done] exited with code=0 in 1.914 seconds
```

Tools and Resources Used

Tool/Software	Purpose
C++	(sequential and parallel)Compiling C++ code
VSCode	Writing and editing C++ code
GitHub	Hosting the project repository