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Activity:	Performance Analysis of Matrix Multiplication Using Sequential and Parallel Computing with OpenMP
Course Name:	Parallel and Distributed Computing
Submitted To:	*Sir. Nasir Mahmood*
Submission Date:	8st March, 2025

Project & Git Initialization:

Commit 1: Initialize project structure

Created a Git repository and added files like .gitignore to ignore unnecessary files and READMD.md with a brief project overview.

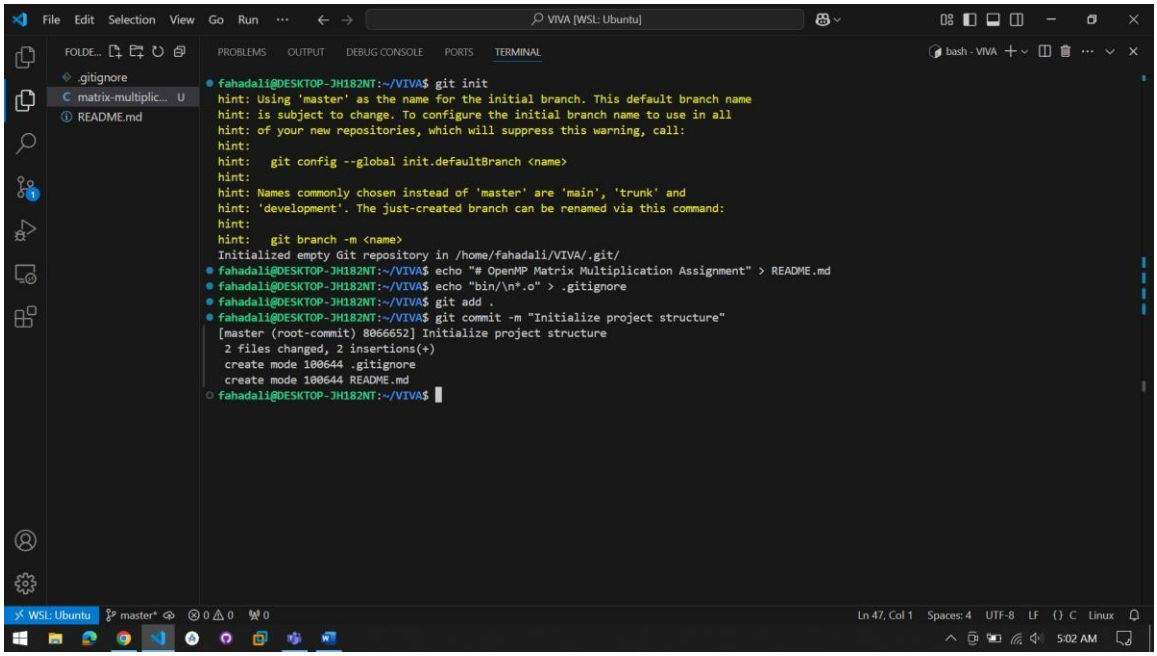


Figure 1

Implemented the code of the Sequential Matrix Multiplication

Commit 2: adding the sequential matrix multiplication code

Here I implemented the matrix multiplication using sequential method without using the OpenMP. And executed the program 10 times and recorded the results along with the average of the execution time.

Here, I'm using 2 matrixes of dimensions 2 with a size of 500 each.

The multiplication is done here using traditional loop method.

Code:

Two functions multiply_matrices() and get_execution_time() is used here. The first function is responsible for multiplying the 2 matrixes. The other function is responsible for assigning random values to the matrixes and then calculating the execution time.

```
#include <stdio.h>

#include <stdlib.h>
#include <time.h>

#define N 500  void multiply_matrices(int A[N][N], int B[N][N], int C[N][N]) {     for
(int i = 0; i < N; i++) {         for (int j = 0; j < N; j++) {             C[i][j] = 0;
          for (int k = 0; k < N; k++) {
             C[i][j] += A[i][k] * B[k][j];
          }
       }
   }
}  double get_execution_time() {     int A[N][N],
B[N][N], C[N][N];     for (int i = 0; i < N; i++) {
for (int j = 0; j < N; j++) {             A[i][j] = rand()
% 10;
          B[i][j] = rand() % 10;
       }     }     clock_t start = clock();
multiply_matrices(A, B, C);     clock_t
end = clock();
       return (double)(end - start) / CLOCKS_PER_SEC;
}
int main() {     double total_time =
0.0;     int runs = 10;

   for  (int  i  =  0;  i  <  runs;  i++)  {                 total_time  +=
get_execution_time();
   }     printf("Average Execution Time (Sequential): %.6f seconds\n", total_time / runs);
```

```
    return 0;
}
```

Output:

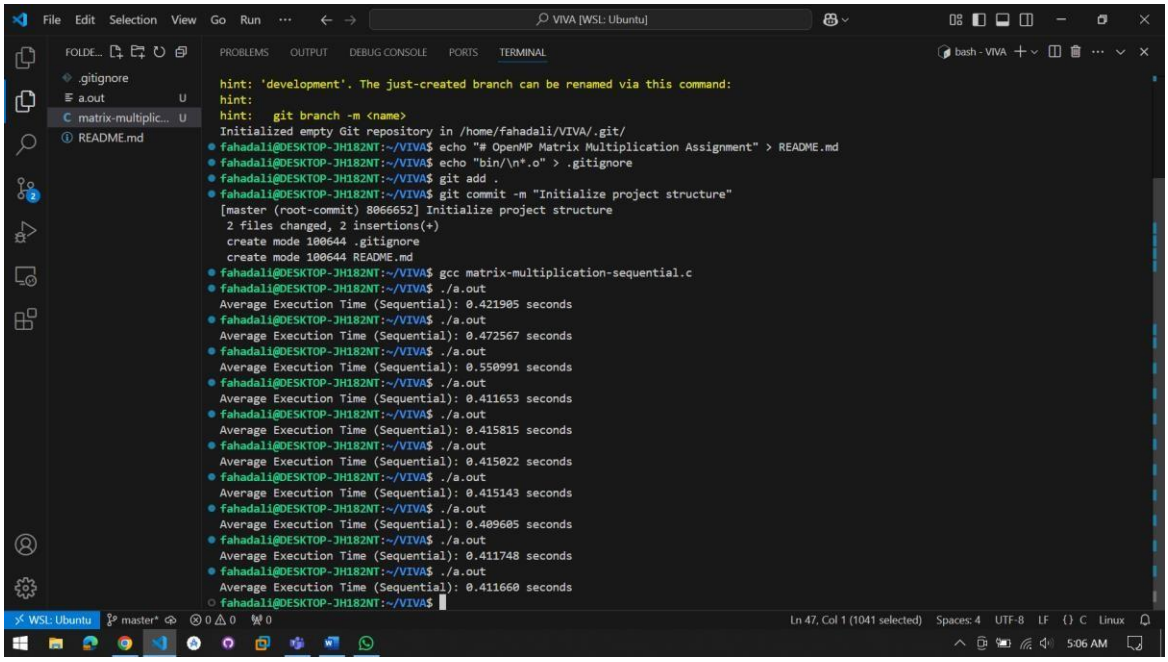


Figure 2

As you can see I've compiled the .c file and then executed it using **./a.out** command. And on console I got the Average Execution time which is basically the average of time required to perform matrix multiplication 10 times. This program was tested for 10 times and the range of Average Execution time we got is **(0.411653s – 0.550991s)** note mostly the out was near to **0.4s.**

Git:

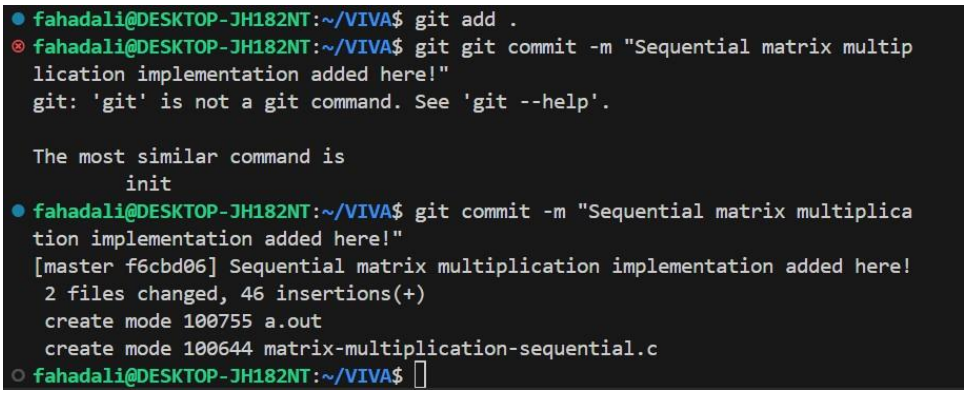


Figure 3

Implemented the code of OpenMP Matrix multiplication

Commit 3: OpenMP parallelization matrix multiplication

Here we can see by using OpenMP, the execution time has decreased and it makes the multiplication more efficient and increases its overall performance.

Used the **#pragma omp parallel for** for loop parallelization.

The use of both static and dynamic scheduling along the correct variable scope is ensured here.

Code:

Two functions multiply_matrices_parallel() and get_execution_time_parallel() is used here. The first function is responsible for multiplying the 2 matrixes using schedule and parallel loop. The other function is responsible for assigning random values to the matrixes and then calculating the execution time.

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

#define N 500
#define NUM_THREADS 4
 void multiply_matrices_parallel(int A[N][N], int B[N][N], int C[N][N]) {     #pragma omp
parallel for schedule(dynamic) num_threads(NUM_THREADS)     for (int i = 0; i < N; i++) {
for (int j = 0; j < N; j++) {             C[i][j] = 0;
          for (int k = 0; k < N; k++) {
             C[i][j] += A[i][k] * B[k][j];
          }
       }
   }
}

  double get_parallel_execution_time() {
```

```
    int A[N][N], B[N][N], C[N][N];
    for (int i = 0; i < N; i++) {        for (int j = 0; j
< N; j++) {            A[i][j] = rand() % 10;
            B[i][j] = rand() % 10;
        }
    }    double start = omp_get_wtime();
multiply_matrices_parallel(A, B, C);    double end =
omp_get_wtime();
        return end - start;
}  int main() {    double total_time =
0.0;    int runs = 10;
    for (int i = 0; i < runs; i++) {        total_time +=
get_parallel_execution_time();
    }    printf("Average Execution Time (Parallel): %.6f seconds\n", total_time / runs);    return 0;
}
```

Output:

```
fahadali@DESKTOP-JH182NT:~/VIVA$ gcc -fopenmp matrix-multiplication-openmp.c -o openmp
fahadali@DESKTOP-JH182NT:~/VIVA$ ./openmp
Average Execution Time (Parallel): 0.321205 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./openmp
Average Execution Time (Parallel): 0.233341 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./openmp
Average Execution Time (Parallel): 0.234858 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./openmp
Average Execution Time (Parallel): 0.237917 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./openmp
Average Execution Time (Parallel): 0.246764 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./openmp
Average Execution Time (Parallel): 0.242406 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./openmp
Average Execution Time (Parallel): 0.246214 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./openmp
Average Execution Time (Parallel): 0.247185 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./openmp
Average Execution Time (Parallel): 0.243969 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./openmp
Average Execution Time (Parallel): 0.278214 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$
```

Figure 4

As you can see I've compiled the .c file and then executed it using **./openmp.out** command. And on console I got the Average Execution time which is basically the average of time required to perform matrix multiplication 10 times. This program was tested for 10 times and the range of Average Execution time we got is **(0.233341s – 0.278214s)** note mostly the out was near to **0.23s.**

Static Scheduling:

Using Static Scheduling:

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

#define N 500  // Matrix size
#define NUM_THREADS 4  // Adjust based on CPU cores

void multiply_matrices_parallel(int A[N][N], int B[N][N], int C[N][N]) {
    #pragma omp parallel for num_threads(NUM_THREADS)
    for (int i = 0; i < N; i++) {
        for (int j = 0; j < N; j++) {
            C[i][j] = 0;
            for (int k = 0; k < N; k++) {
                C[i][j] += A[i][k] * B[k][j];
            }
        }
    }
}

double get_parallel_execution_time() {
    int A[N][N], B[N][N], C[N][N];

    // Initialize matrices with random values
    for (int i = 0; i < N; i++) {
        for (int j = 0; j < N; j++) {
            A[i][j] = rand() % 10;
            B[i][j] = rand() % 10;
        }
    }

    double start = omp_get_wtime();
    multiply_matrices_parallel(A, B, C);
    double end = omp_get_wtime();
```

```
    return end - start;
}

int main() {
    double total_time = 0.0;
    int runs = 10;

    for (int i = 0; i < runs; i++) {
        total_time += get_parallel_execution_time();
    }

    printf("Average Execution Time (Parallel): %.6f seconds\n", total_time / runs);
    return 0;
}
```

Output:

```
fahadali@DESKTOP-JH182NT:~/VIVA$ ./staticopenmp
Average Execution Time (Parallel): 0.311977 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./staticopenmp
Average Execution Time (Parallel): 0.322596 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./staticopenmp
Average Execution Time (Parallel): 0.333372 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./staticopenmp
^[[AAverage Execution Time (Parallel): 0.338408 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./staticopenmp
^[[A^[[BAverage Execution Time (Parallel): 0.281393 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./staticopenmp
Average Execution Time (Parallel): 0.274327 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./staticopenmp
Average Execution Time (Parallel): 0.487850 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./staticopenmp
Average Execution Time (Parallel): 0.267090 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./staticopenmp
Average Execution Time (Parallel): 0.260043 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$ ./staticopenmp
Average Execution Time (Parallel): 0.417310 seconds
fahadali@DESKTOP-JH182NT:~/VIVA$
```

Git:

```
fahadali@DESKTOP-JH182NT:~/VIVA$ git add .
fahadali@DESKTOP-JH182NT:~/VIVA$ git commit -m "OpenMP parallelized matrix m
ultiplication with static and dynamic scheduling added here!"
[master 36b4a50] OpenMP parallelized matrix multiplication with static and dynamic scheduling added here!
 2 files changed, 49 insertions(+)
 create mode 100644 matrix-multiplication-openmp.c
 create mode 100755 openmp
```

Figure 5

Performance Evaluation

Here we can conclude that the use of OpenMP made the matrix multiplication much faster than using the traditional looping method. This shows how the use of parallel computing and distribution can increase overall performance by utilizing multiple threads efficiently.

Testing Environment:

For the Evaluation, the testing environment was set up in:

PC – Specification:

- Core i7-7th Generation
- 16gb ddr4 RAM
- 512gb SSD Hard Drive
- Intel HD 620 Graphics
- Default cores: 4

Here the calculated execution time is basically an average calculated by executing the code for 10 times and taking the average of all.

The formula used for the calculation of **speedup** is**: Sequential time / (static/parallel)**

Testing Environment # 1:

Matrix Size: 500

Number of Threads: 4

	Sequential	**Parallel**	**Static**
Average Execution Time	0.544170	0.247332	0.262978
Speedup	-	2.200160	2.069260

Testing Environment # 2:

Matrix Size: 500

Number of Threads: 8

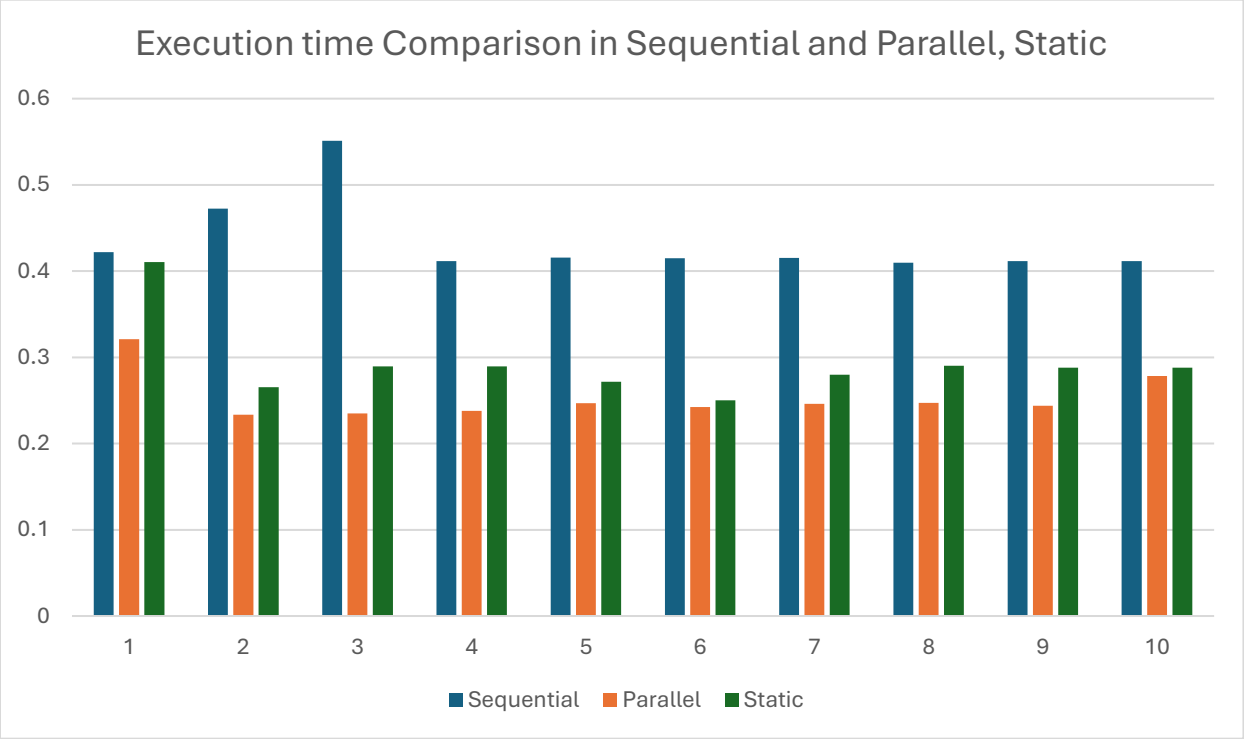
	Sequential	Parallel	Static
Average Execution Time	0.544170	0.272012	0.275591
Speedup	-	2.000536	1.974556

Testing Environment # 3:

Matrix Size: 500

Number of Threads: 12

	Sequential	Parallel	Static
Average Execution Time	0.544170	0.269686	0.287607
Speedup	-	2.017791	1.892061


Execution time Comparison in Sequential and Parallel, Static
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
Sequential
Parallel
Static