National Textile University, Faisalabad



Department of Computer Science

Name:	Fahad Ali
Class:	BSCS-A 6 th
Registration No:	22-NTU-CS-1154
Activity:	Assignment
Course Name:	Parallel and Distributed Computing
Submitted To:	Sir. Nasir Mahmood
Submission Date:	8 st 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.

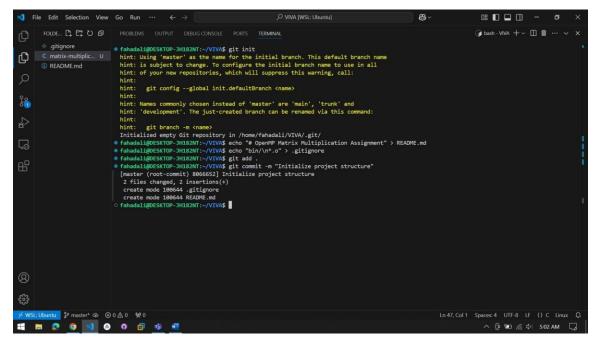


Figure 1

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:

```
▼ File Edit Selection View Go Run ··· ← →

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               FOLDE. C; C; O D PROBLEMS OUTPUT DEBUG CONSOLE PORTS TERMINAL
                                                                                                                                                                                                                                                                                                                                              🍞 bash - VIVA 🕂 🗆 📋 … 🗸
                                                                 hint: 'development'. The just-created branch can be renamed via this communication:
hint:
hint: git branch -m <name>
Initialized empty Git repository in /home/fahadali/VIVA/.git/

* FahadaligDESKTOP.JH32AT:-/VIVA$ echo "# OpenMP Matrix Multiplication Assignment" > README.md

* FahadaligDESKTOP.JH32AT:-/VIVA$ echo "bin/\n*.o" > .gitignore

* FahadaligDESKTOP.JH32AT:-/VIVA$ git add.

* FahadaligDESKTOP.JH32AT:-/VIVA$ git communication = "Initialize project structure"
[master (root-commit) 8066652] Initialize project structure

2 files changed 2 insertions(+)
create mode 109644 README.md

* FahadaligDESKTOP.JH32AT:-/VIVA$ gcc matrix-multiplication-sequential.c

* FahadaligDESKTOP.JH32AT:-/VIVA$ /.a.out
                                                                      hint: 'development'. The just-created branch can be renamed via this command:
               C matrix-multiplic... U
                                                                     databaligOESKTOP-JHB2NT:-//IVMS /_a.out
Average Execution Time (Sequential): 0.421905 seconds

fahadaligOESKTOP-JHB2NT:-//IVMS /_a.out
Average Execution Time (Sequential): 0.472567 seconds

fahadaligOESKTOP-JHB2NT:-//IVMS /_a.out

fahadaligOESKTOP-JHB2NT:-//IVMS /_a.out
                                                                         fahadali@DESKTOP-JH182NT:~/VIVA$ ./a.out
Average Execution Tize (Sequential): 0.550991 seconds
                                                                          fahadali@DESKTOP-JH182NT:~/VIVA$ ./a.out
Average Execution Time (Sequential): 0.411653 seconds
                                                                    • fahadali@DESKTOP-JH182NT:-/VIVA$ ./a.out
Average Execution Time (Sequential): 0.415815 seconds
• fahadali@DESKTOP-JH182NT:-/VIVA$ ./a.out
Average Execution Time (Sequential): 0.415022 seconds
                                                                    • fahadali@DESKTOP-JH182NT:~/VIVA$ ./a.out

Average Execution Time (Sequential): 0.415143 seconds
• fahadali@DESKTOP-JH182NT:~/VIVA$ /a.out
                                                                         fahadali@DESKTOP-JH182NT:~/VIVA$ ./a.out
Average Execution Time (Sequential): 0.409605 seconds
                                                                       fahadali@OESKTOP-JH182NT:~/VIVA$ ./a.out
Average Execution Time (Sequential): 0.411748 seconds
fahadali@OESKTOP-JH182NT:~/VIVA$ ./a.out
Average Execution Time (Sequential): 0.411660 seconds
fahadali@OESKTOP-JH182NT:~/VIVA$
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                        tu 🖁 master* 🖘 ⊗ 0 🛆 0 💖 0
                                                                                                                                                                                                                                                                                       Ln 47, Col 1 (1041 selected) Spaces: 4 UTF-8 LF {} C Linux Q
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```

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:

```
fahadali@DESKTOP-JH182NT:~/VIVA$ git add .
fahadali@DESKTOP-JH182NT:~/VIVA$ git git commit -m "Sequential matrix multip lication implementation added here!"
git: 'git' is not a git command. See 'git --help'.

The most similar command is
    init
fahadali@DESKTOP-JH182NT:~/VIVA$ git commit -m "Sequential matrix multiplica tion implementation added here!"
[master f6cbd06] Sequential matrix multiplication implementation added here!
2 files changed, 46 insertions(+)
    create mode 100755 a.out
    create mode 100644 matrix-multiplication-sequential.c
fahadali@DESKTOP-JH182NT:~/VIVA$
```

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.

```
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];
            }
}</pre>
```

```
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
       ali@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
    nadali@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
        li@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.

Sequential	Parallel	Static 💌
0.421905	0.321205	0.410416
0.472567	0.233341	0.265303
0.550991	0.234858	0.289572
0.411653	0.237917	0.289325
0.415815	0.246764	0.271743
0.415022	0.242406	0.250287
0.415143	0.246214	0.279877
0.409605	0.247185	0.290251
0.411748	0.243969	0.287972
0.41166	0.278214	0.288046
0.433611	0.253207	0.292279

From this table we can conclude that the parallel openmp for 4 threads and size 400 is better than the static openmp sceduling.

