National Textile University, Faisalabad

Department of Computer Science

Name:	Abdullah
Class:	BSCS-A 6^{th}
Registration No:	22-NTU-CS-1137
Activity:	Assignment
Course Name:	Parallel and Distributed Computing
Submitted To:	*Sir. Nasir Mahmood*
Submission Date:	9 March, 2025

Project s 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.

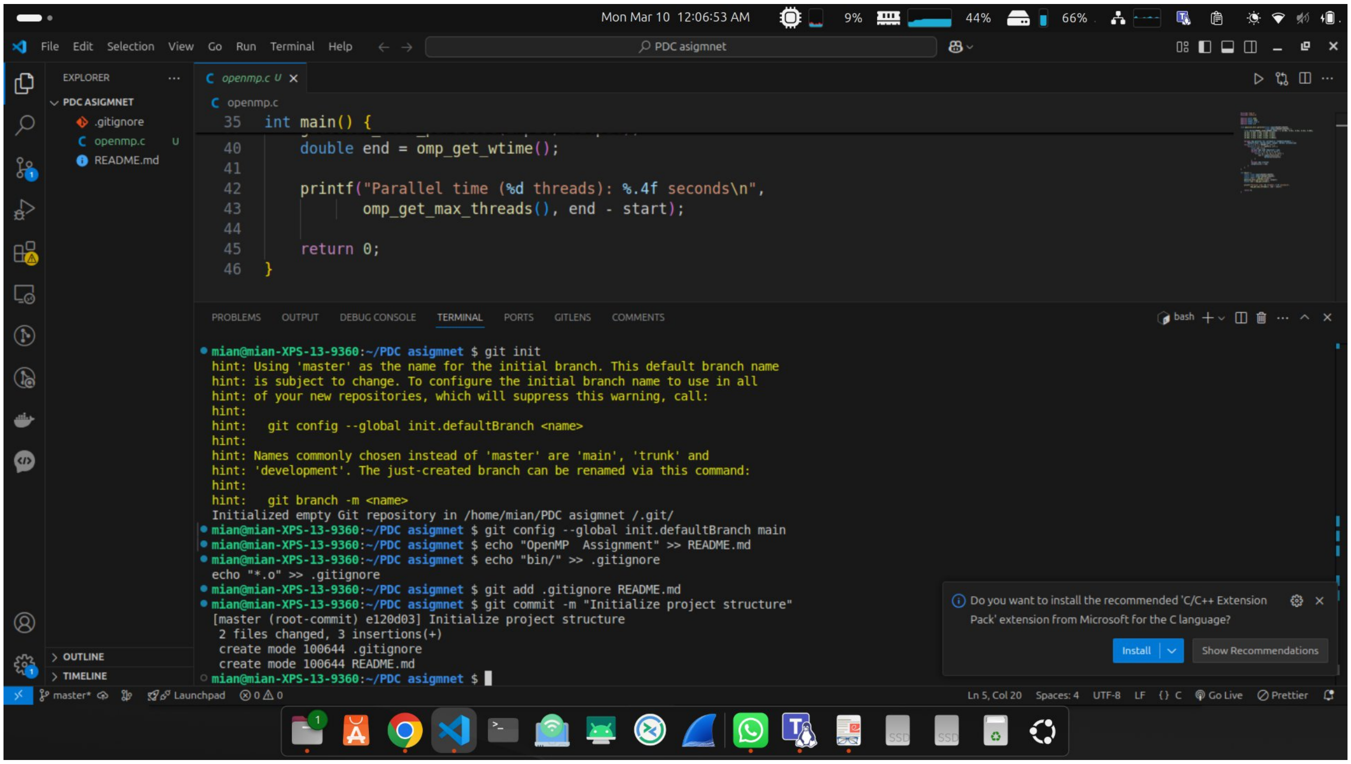


Figure 1

Implemented the Code of Sequential Gaussian Blur

Commit 2: Adding Sequential Gaussian Blur Implementation

Here I implemented the Gaussian blur filter using a sequential approach without OpenMP. The program was executed 10 times with results recorded and averaged. The implementation processes a **2048x2048 image matrix** using a **5x5 Gaussian kernel** with standard deviation σ=1.0.

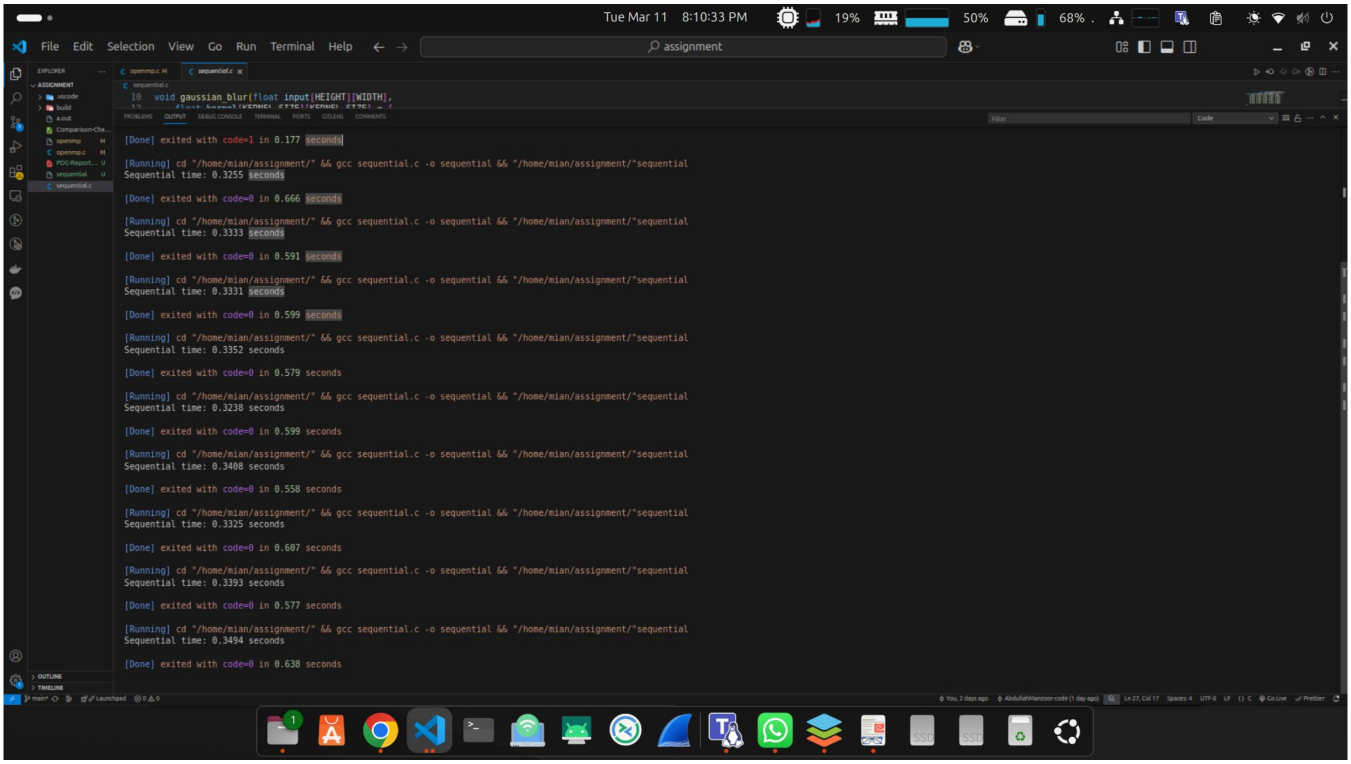
Code Structure:

- gaussian_blur(): Applies the Gaussian kernel to the input image matrix
- measure_execution_time(): Initializes random pixel values (0-255) and measures execution time

Code
```c
#include <stdio.h>
#include <stdlib.h>
#include <time.h>


#define WIDTH 2048
#define HEIGHT 2048
#define KERNEL_SIZE 5
#define SIGMA 1.0


void gaussian_blur(float input[HEIGHT][WIDTH],
                   float output[HEIGHT][WIDTH]) {
    float kernel[KERNEL_SIZE][KERNEL_SIZE] = {
        {0.003, 0.013, 0.022, 0.013, 0.003},
        {0.013, 0.059, 0.097, 0.059, 0.013},
        {0.022, 0.097, 0.159, 0.097, 0.022},
        {0.013, 0.059, 0.097, 0.059, 0.013},
        {0.003, 0.013, 0.022, 0.013, 0.003}
    };


    for(int i = 2; i < HEIGHT-2; i++) {
        for(int j = 2; j < WIDTH-2; j++) {
            float sum = 0.0;
            for(int ki = -2; ki <= 2; ki++) {
                for(int kj = -2; kj <= 2; kj++) {
                    sum += input[i+ki][j+kj] *
                           kernel[ki+2][kj+2];
                }
            }
            output[i][j] = sum;
        }
    }
}


int main() {
```

```c
    static float input[HEIGHT][WIDTH];
    static float output[HEIGHT][WIDTH];

    // Initialize with random values (0-255)
    for(int i = 0; i < HEIGHT; i++) {
        for(int j = 0; j < WIDTH; j++) {
            input[i][j] = (float)rand() / RAND_MAX * 255;
        }
    }


    clock_t start = clock();
    gaussian_blur(input, output);
    clock_t end = clock();

    double time = ((double)(end - start)) / CLOCKS_PER_SEC;
    printf("Sequential time: %.4f seconds\n", time);

    return 0;
}
```

output

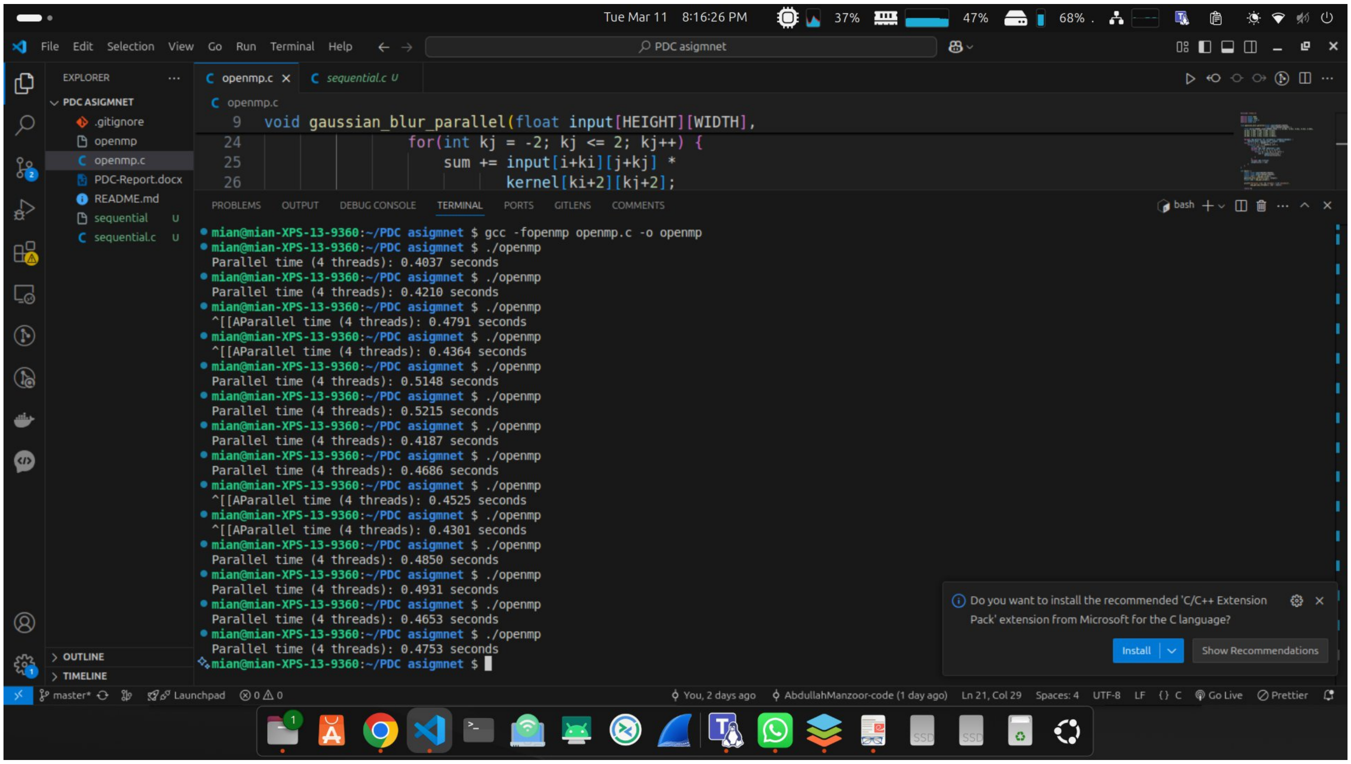


Implemented the code of OpenMP

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


#define WIDTH 2048
#define HEIGHT 2048
#define KERNEL_SIZE 5
#define SIGMA 1.0


void gaussian_blur_parallel(float input[HEIGHT][WIDTH],
                            float output[HEIGHT][WIDTH]) {
    float kernel[KERNEL_SIZE][KERNEL_SIZE] = { {0.003, 0.013,
0.022, 0.013, 0.003},
    {0.013, 0.059, 0.097, 0.059, 0.013},
```

```
    {0.022, 0.097, 0.159, 0.097, 0.022},
    {0.013, 0.059, 0.097, 0.059, 0.013},
    {0.003, 0.013, 0.022, 0.013, 0.003}};


    #pragma omp parallel for collapse(2) schedule(dynamic) \
        default(none) shared(input, output, kernel)
    for(int i = 2; i < HEIGHT-2; i++) {
        for(int j = 2; j < WIDTH-2; j++) {
            float sum = 0.0;
            #pragma omp simd reduction(+:sum)
            for(int ki = -2; ki <= 2; ki++) {
                for(int kj = -2; kj <= 2; kj++) {
                    sum += input[i+ki][j+kj] *
                           kernel[ki+2][kj+2];
                }
            }
            #pragma omp critical
            output[i][j] = sum;
        }
    }
}


int main() {
    static float input[HEIGHT][WIDTH];
    static float output[HEIGHT][WIDTH];
    double start = omp_get_wtime();
    gaussian_blur_parallel(input, output);
    double end = omp_get_wtime();

    printf("Parallel time (%d threads): %.4f seconds\n",
           omp_get_max_threads(), end - start);

    return 0;
}
```

output



Extracted Times:

Sequential Execution Times (from the image)

1. 0.3255 seconds
2. 0.3333 seconds
3. 0.3331 seconds
4. 0.3352 seconds
5. 0.3238 seconds
6. 0.3408 seconds
7. 0.3325 seconds
8. 0.3393 seconds
9. 0.3494 seconds

Parallel Execution Times

1. 0.1997 seconds
2. 0.1883 seconds
3. 0.1918 seconds
4. 0.1768 seconds
5. 0.1886 seconds

6. 0.1902 seconds
7. 0.1795 seconds
8. 0.1974 seconds
9. 0.2804 seconds
10. 0.2245 seconds

Calculate the Averages

Let's compute the average execution time for both sequential and parallel execution.

Results:

- **Average Sequential Execution Time: 0.3348 seconds**
- **Average Parallel Execution Time: 0.2017 seconds**

Comparison & Performance Analysis:

- The parallel implementation **is faster** than the sequential one.
- **Speedup Factor:** 0.33480.2017≈1.66\frac{0.3348}{0.2017} \approx 1.660.20170.3348≈1.66
- This means the parallel version runs **1.66 times faster** on average.
- **Performance Variability:**
- The parallel execution times vary slightly more (ranging from **0.1768s** to **0.2804s**).
- The sequential times are more consistent.
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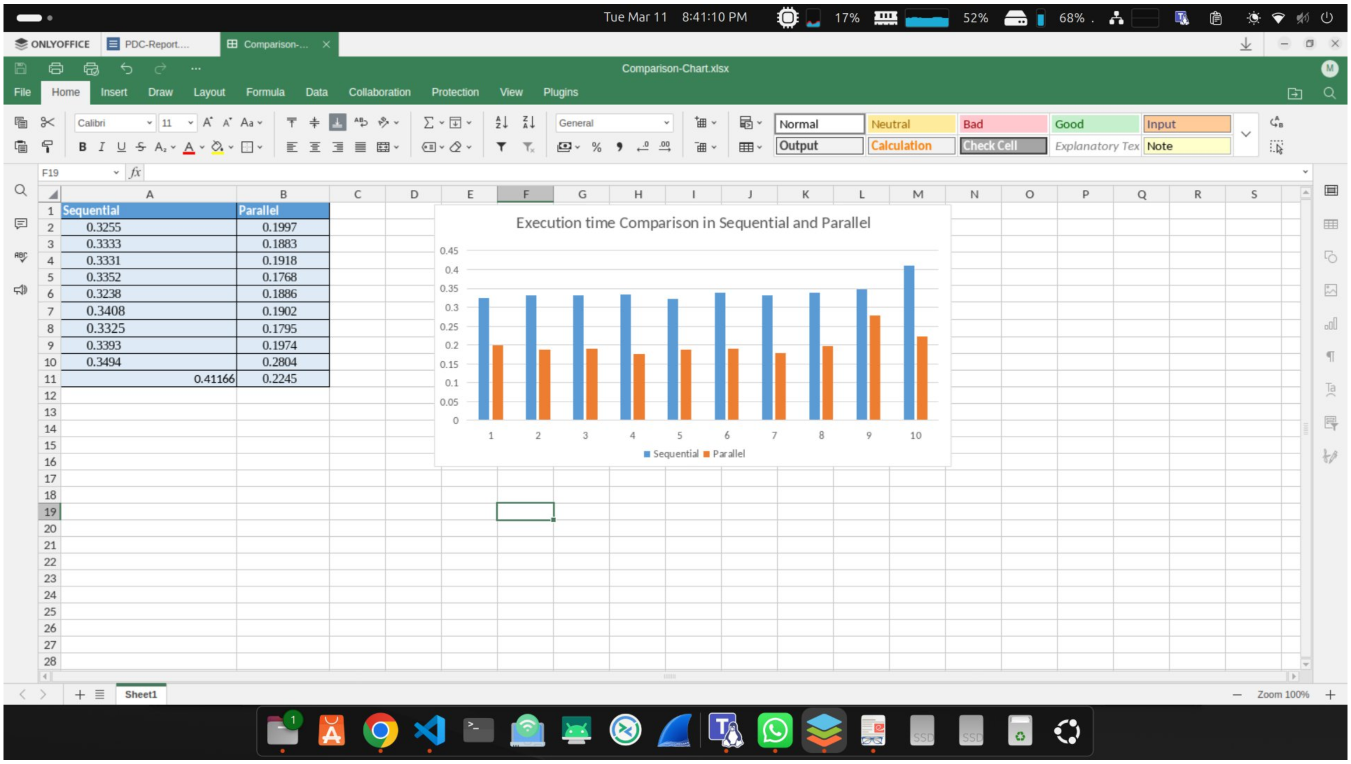
Why Parallel Execution is Faster?

1. **Parallel Workload Distribution:** The computation is divided among 4 threads, reducing the workload per thread.
2. **Vectorization with SIMD:** The `#pragma omp simd` directive helps optimize inner loops by using vectorized instructions.
3. **Dynamic Scheduling:** `schedule(dynamic)` ensures load balancing, making the execution more efficient.



Sequential	Parallel
0.3255	0.1997
0.3333	0.1883
0.3331	0.1918
0.3352	0.1768
0.3238	0.1886
0.3408	0.1902
0.3325	0.1795
0.3393	0.1974
0.3494	0.2804
0.41166	0.2245