matrix-multi-thread

January 18, 2024

1 Assignment 1

Write a program of matrix multiplication to demonstrate the performance enhancement done by parallelizing the code through Open MP threads. Analyze the speedup and efficiency of the parallelized code.

- Vary the size of your matrices from 5, 50, 100, 500, 750, 1000, and 2000 and measure the runtime with one thread.
- For each matrix size, change the number of threads from 2,4,8,10,15,20 and plot the speedup versus the number of threads. Compute the efficiency.
- Display a visualization of performance comparison between serial, parallel and NumPY code.
- Explain whether or not the scaling behavior is as expected.

[9]:
```
import numpy as np
import threading
import time
import pandas as pd
import matplotlib.pyplot as plt
```

[10]:
```
def multiply_matrix(A, B, result, start_row, end_row):
    try:
        for i in range(start_row, end_row):
            for j in range(N):
                result[i, j] = 0
                for k in range(N):
                    result[i, j] += A[i, k] * B[k, j]
    except NameError as e:
        pass
        # Handle the exception as per your requirements
#         print(f"Exception in thread {threading.current_thread().name}: {e}")
```

[11]:
```
def measure_time(matrix_size, num_threads=1):
    A = np.random.rand(matrix_size, matrix_size)
    B = np.random.rand(matrix_size, matrix_size)
    result = np.zeros((matrix_size, matrix_size))

    # Ensure at least one row per thread
```

```
    chunk_size = max(1, matrix_size // num_threads)
    threads = []

    start_time = time.time()

    for i in range(0, matrix_size, chunk_size):
        end_row = min(i + chunk_size, matrix_size)
        thread = threading.Thread(target=multiply_matrix, args=(A, B, result,␣
↪i, end_row))
        thread.start()
        threads.append(thread)

    for thread in threads:
        thread.join()

    end_time = time.time()

    return max(end_time - start_time, 1e-10)
```

[12]:
```
def main():
    matrix_sizes = [5, 50, 100, 250, 500, 750, 1000, 2000, 5000]
    thread_counts = [1, 2, 4, 8, 10, 15, 20]

    results = []

    for size in matrix_sizes:
        serial_time = measure_time(size, num_threads=1)

        for threads in thread_counts:
            parallel_time = measure_time(size, num_threads=threads)
            speedup = serial_time / parallel_time
            efficiency = speedup / threads
            results.append({
                'Matrix Size': size,
                'Threads': threads,
                'Serial Time': serial_time,
                'Parallel Time': parallel_time,
                'Speedup': speedup,
                'Efficiency': efficiency
            })

    df = pd.DataFrame(results)
    df.to_csv('matrix_multiplication_results.csv', index=False)
```

[13]:
```
if __name__ == "__main__":
    main()
```

[14]:
```
df2 = pd.read_csv('matrix_multiplication_results.csv')
df2
```

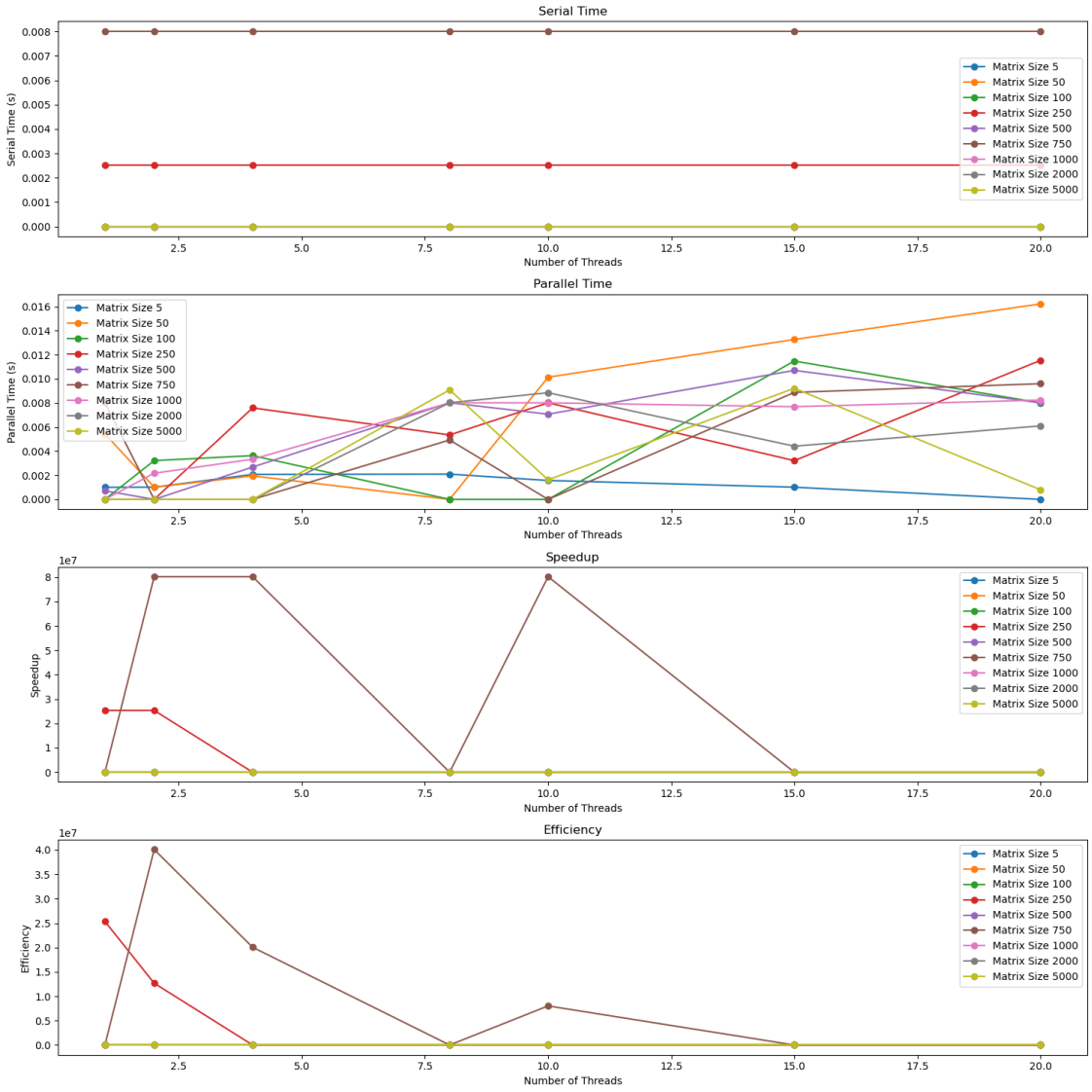
[14]:

	Matrix Size	Threads	Serial Time	Parallel Time	Speedup	Efficiency
0	5	1	1.000000e-10	1.002073e-03	9.979310e-08	9.979310e-08
1	5	2	1.000000e-10	1.012325e-03	9.878248e-08	4.939124e-08
2	5	4	1.000000e-10	2.073288e-03	4.823257e-08	1.205814e-08
3	5	8	1.000000e-10	2.097368e-03	4.767880e-08	5.959850e-09
4	5	10	1.000000e-10	1.571417e-03	6.363684e-08	6.363684e-09
..	…	…	…	…	…	…
58	5000	4	1.000000e-10	1.000000e-10	1.000000e+00	2.500000e-01
59	5000	8	1.000000e-10	9.087563e-03	1.100405e-08	1.375506e-09
60	5000	10	1.000000e-10	1.626253e-03	6.149104e-08	6.149104e-09
61	5000	15	1.000000e-10	9.224892e-03	1.084024e-08	7.226824e-10
62	5000	20	1.000000e-10	7.979870e-04	1.253153e-07	6.265766e-09

[63 rows x 6 columns]

[15]:
```
def plot_matrix_size(df2, matrix_size):
    plt.figure(figsize=(15, 15))

    # Plot Serial Time
    plt.subplot(4, 1, 1)
    for size in matrix_sizes:
        data = df2[df2['Matrix Size'] == size]
        plt.plot(data['Threads'], data['Serial Time'], label=f'Matrix Size␣
 ↪{size}', marker='o')
    plt.title('Serial Time')
    plt.xlabel('Number of Threads')
    plt.ylabel('Serial Time (s)')
    plt.legend()

    # Plot Parallel Time
    plt.subplot(4, 1, 2)
```

```
    for size in matrix_sizes:
        data = df2[df2['Matrix Size'] == size]
        plt.plot(data['Threads'], data['Parallel Time'], label=f'Matrix Size␣
↪{size}', marker='o')
    plt.title('Parallel Time')
    plt.xlabel('Number of Threads')
    plt.ylabel('Parallel Time (s)')
    plt.legend()

    # Plot Speedup
    plt.subplot(4, 1, 3)
    for size in matrix_sizes:
        data = df2[df2['Matrix Size'] == size]
        plt.plot(data['Threads'], data['Speedup'], label=f'Matrix Size {size}',␣
↪marker='o')
    plt.title('Speedup')
    plt.xlabel('Number of Threads')
    plt.ylabel('Speedup')
    plt.legend()

    # Plot Efficiency
    plt.subplot(4, 1, 4)
    for size in matrix_sizes:
        data = df2[df2['Matrix Size'] == size]
        plt.plot(data['Threads'], data['Efficiency'], label=f'Matrix Size␣
↪{size}', marker='o')
    plt.title('Efficiency')
    plt.xlabel('Number of Threads')
    plt.ylabel('Efficiency')
    plt.legend()

    plt.tight_layout()
    plt.show()

matrix_sizes = df2['Matrix Size'].unique()
plot_matrix_size(df2, matrix_sizes)
```



with using numpy

[16]:
```
def measure_time_np(matrix_size):
    A = np.random.rand(matrix_size, matrix_size)
    B = np.random.rand(matrix_size, matrix_size)

    start_time = time.time()
    result = np.dot(A, B)
    end_time = time.time()

    return end_time - start_time
```

[17]:
```
def main_np():
    matrix_sizes = [5, 50, 100, 250, 500, 750, 1000, 2000, 5000]
    thread_counts = [1, 2, 4, 8, 10, 15, 20]

    results_np = []

    for size in matrix_sizes:
        serial_time_np = measure_time_np(size)

        for threads in thread_counts:
            parallel_time_np = measure_time_np(size)

            # Ensure parallel_time_np is not zero before calculating speedup␣
 ↪and efficiency
            if parallel_time_np != 0:
                speedup_np = serial_time_np / parallel_time_np
                efficiency_np = speedup_np / threads
            else:
                speedup_np = 0
                efficiency_np = 0

            results_np.append({
                'Matrix Size': size,
                'Threads': threads,
                'Serial Time': serial_time_np,
                'Parallel Time': parallel_time_np,
                'Speedup': speedup_np,
                'Efficiency': efficiency_np
            })

    df_np = pd.DataFrame(results_np)
    df_np.to_csv('matrix_multiplication_results_np2.csv', index=False)
```

[18]:
```
if __name__ == "__main__":
    main_np()
```

[19]:
```
df3 = pd.read_csv('matrix_multiplication_results_np2.csv')
df3
```

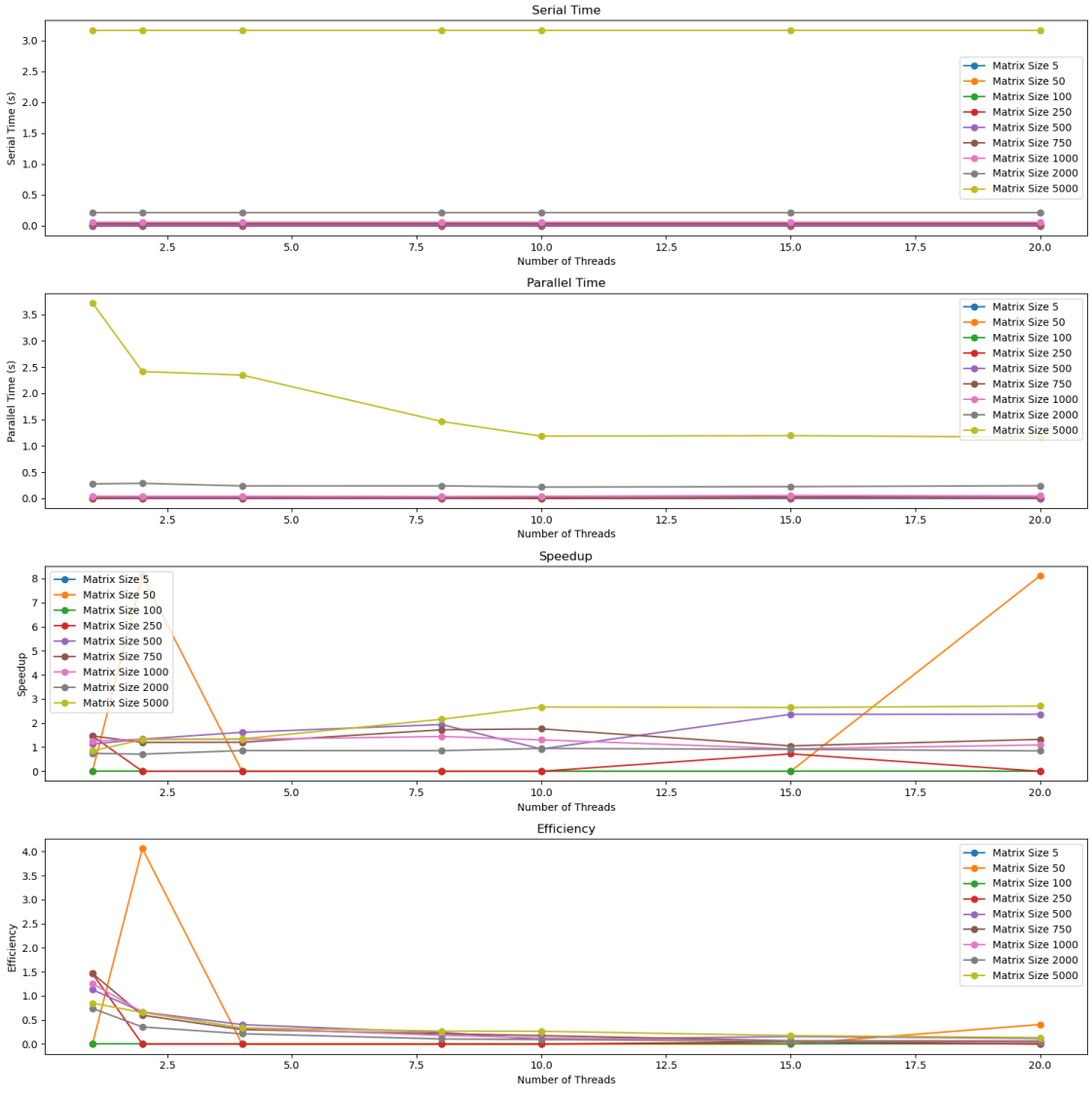
[19]:

	Matrix Size	Threads	Serial Time	Parallel Time	Speedup	Efficiency
0	5	1	0.0000	0.000000	0.000000	0.000000
1	5	2	0.0000	0.000000	0.000000	0.000000
2	5	4	0.0000	0.000000	0.000000	0.000000
3	5	8	0.0000	0.000000	0.000000	0.000000
4	5	10	0.0000	0.000000	0.000000	0.000000
..	…	…	…	…	…	…
58	5000	4	3.1658	2.348449	1.348038	0.337010

```
59          5000         8       3.1658       1.465680  2.159953    0.269994
60          5000        10       3.1658       1.186051  2.669194    0.266919
61          5000        15       3.1658       1.195132  2.648913    0.176594
62          5000        20       3.1658       1.168196  2.709990    0.135500

[63 rows x 6 columns]
```

[20]:
```python
def plot_matrix_size(df3, matrix_size):
    plt.figure(figsize=(15, 15))

    # Plot Serial Time
    plt.subplot(4, 1, 1)
    for size in matrix_sizes:
        data = df3[df3['Matrix Size'] == size]
        plt.plot(data['Threads'], data['Serial Time'], label=f'Matrix Size␣
↪{size}', marker='o')
    plt.title('Serial Time')
    plt.xlabel('Number of Threads')
    plt.ylabel('Serial Time (s)')
    plt.legend()

    # Plot Parallel Time
    plt.subplot(4, 1, 2)
    for size in matrix_sizes:
        data = df3[df3['Matrix Size'] == size]
        plt.plot(data['Threads'], data['Parallel Time'], label=f'Matrix Size␣
↪{size}', marker='o')
    plt.title('Parallel Time')
    plt.xlabel('Number of Threads')
    plt.ylabel('Parallel Time (s)')
    plt.legend()

    # Plot Speedup
    plt.subplot(4, 1, 3)
    for size in matrix_sizes:
        data = df3[df3['Matrix Size'] == size]
        plt.plot(data['Threads'], data['Speedup'], label=f'Matrix Size {size}',␣
↪marker='o')
    plt.title('Speedup')
    plt.xlabel('Number of Threads')
    plt.ylabel('Speedup')
    plt.legend()

    # Plot Efficiency
    plt.subplot(4, 1, 4)
    for size in matrix_sizes:
        data = df3[df3['Matrix Size'] == size]
```

```
        plt.plot(data['Threads'], data['Efficiency'], label=f'Matrix Size␣
↪{size}', marker='o')
    plt.title('Efficiency')
    plt.xlabel('Number of Threads')
    plt.ylabel('Efficiency')
    plt.legend()

    plt.tight_layout()
    plt.show()

matrix_sizes = df3['Matrix Size'].unique()
plot_matrix_size(df3, matrix_sizes)
```



Q. Explain whether or not the scaling behavior is as expected.

- Increasing the number of threads in the manual loop implementation results in decreasing gains in speed and efficiency, particularly for bigger matrix sizes. The numPY implementation, on the other hand, shows better scaling behavior, with notable increases in speed and efficiency as the number of threads rises, suggesting a more successful parallelization approach. so we can say the scaling behavior is as expected.