Lab Manual

of

High Performance Computing

(20DS509P)

By

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23MDS006

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Sr. No.	Problem Statement	Date	Sign.
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, and 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.	17/1/2024	
2.	Write a program for Leibniz series for PI calculation to demonstrate the performance enhancement done by parallelizing the code through Open MP work-sharing of loops. Display a visualization of performance comparison between serial and parallel, a visual analysis of delay/speedup with the help of varying thread counts and maximum terms in the series for Pi value calculation. • Implement the code with different thread count and different maximum number of terms to be calculated for the series such as thread count 10, 20 and terms 100, 1000, 10000, 1000000. • Display a visualization of performance comparison between serial and parallel, a visual analysis of delay/speedup with the help of varying thread counts and maximum terms in the series for Pi value calculation.	24/1/2024	
3.	Implement Producer-Consumer problem (PCP). Analyze the significance of semaphore, mutex, bounded buffer, producer thread, and consumer thread using the code available on Producer-Consumer Problem in Python - AskPython. Demonstrate how PCP occurs for an application of your choice.	29/1/2024	
4.	Write a program to generate and print Fibonacci series, one thread must generate the series up to number and other thread must print them. Ensure proper synchronization.	31/1/2024	
5.	Consider a scenario where a person visits a supermarket for shopping. S/He purchases various items in different sections such as clothing, grocery, utensils. Write an OpenMP program to process the bill parallelly	31/1/2024	

	in each section and display the final amount to be paid by the customer. Analyze the time take by sequential and parallel processing.		
6.	Implement the following programs of OpenMPI • Print "Welcome to PDPU from process (processno_totalprocesses)". • Apply denoising algorithm to a set of n images with 4 processes. (n=4, 8). • Analyze time taken by serial and openMPI processes. • Try for 100 or more number of images.	7/2/2024	
7.	1. Write a program to implement arithmetic calculations using MPI processes. 2. Write a program with different processes to apply following functions to an image in parallel. • Read an image. • Convert above RGB image to grayscale. • Find edges in the image. • Show the original image.	14/2/2024	
8.	Write a program to pass message from one process to another and print output. • In synchronous communication • In asynchronous communication. Show using overlapping of task in non-blocking mode.	14/2/2024	
9.	Calculate Pi value using openMPI send and receive messages for atleast 35-40 terms. Try the below mentioned commands, explain their task in one line and paste the output for each of them • Change the value on n as 2, 4, 8, 16. • Analyze the performance improvement using number of processes.	14/2/2024	
10.	Write a program to show collective communication by taking suitable example such that computing average of n numbers or computing sum or product of two matrices: • Bcast function • Scatter function • Gather function	14/2/2024	
11.	1. Describe Canon's Matrix Multiplication algorithm. 2. Implement Canon's Matrix Multiplication using collective communication. 3. Analyze the efficiency of the code.	19/2/2024	
12.	1. Write about derived data types used in MPI programming. 2. Steps to create and use derived data types. 3. Write its uses.	19/3/2024	

	4. Implement communication of derived data using one suitable example.			
13.	lshw (List Hardware) lsusb (List USB Devices) lspci (List PCI Devices) lsblk (List Block Devices) lscpu (List CPU) df (Disk Free) dmidecode (DMI Table Decode) ip a (IP Addresse)	top htop nvidia-smi lstopo perf numactl sar		
	For the given Python scripts that queries the CPU usage on a Linux-based system, understand the same and note the output for your device.		11/3/2024	
14.	Perform the following Image Processing Operations using the given images: • Image Blurring • Image Thresholding • Histogram based image analysis • Image Filtering/Denoising • Image Gray scaling		26/3/2024	
15.	Empirically understand and document the answers to the following: • What is CUDA? • What is the prerequisite for learning CUDA? • What are the languages that support CUDA? • What do you mean by a CUDA ready architecture? • How CUDA works? • What are the benefits and limitations of CUDA programming? • Understand and explain the CUDA program structure with an example. • Explain CUDA thread organization • Install and try CUDA sample program and explain the same. (installation steps)		1/4/2024	
16.	Implement following CUDA programs: 1. To print hello message on the screen using kernal function 2. To add two vectors of size 100 and 20000 and analyze the performance comparison between cpu and gpu processing 3. To multply two matrix of size 20 X 20 and 1024 X 1024 analyze the performance comparison between cpu and gpu processing 4. To obtain CUDA device information and print the output		15/4/2024	
17.	Implement the following Image Processing operations in sequential and parallel using CUDA Programming. 1. Gaussian Blur • Describe Gaussian Blur in brief.		22/4/2024	

	• Where parallelism can be inserted? • Analyze the performance in serial and parallel model. 2. FFT- Fast Fourier Transform • Describe FFT in brief. • Where parallelism can be inserted? • Analyze the performance in serial and parallel model.		
18.	Final Learning Synopsis Submission		

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)
```

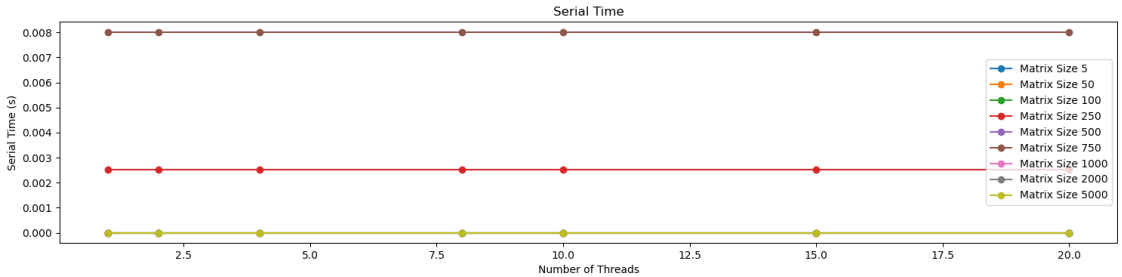
[13]:
```
if __name__ == "__main__":
    main()
```

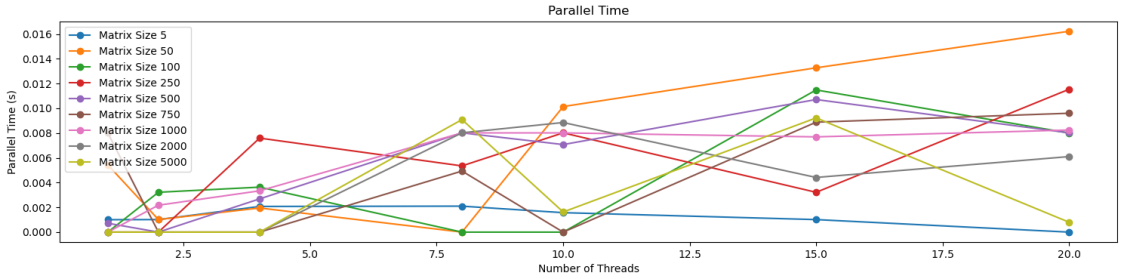
[14]:
```
df2 = pd.read_csv('matrix_multiplication_results.csv')
df2
```

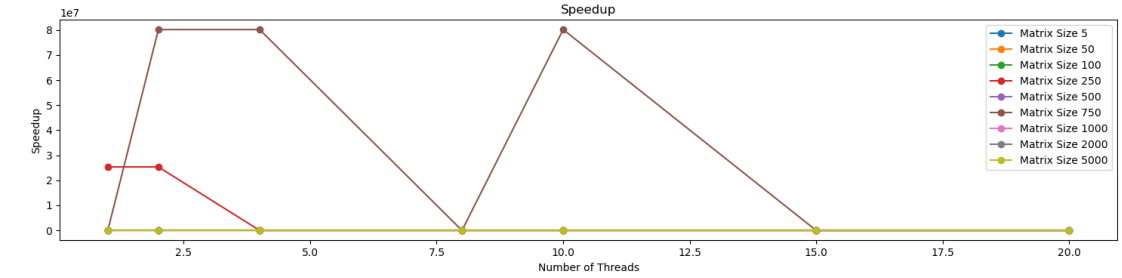
[14]:
```
    Matrix Size  Threads   Serial Time  Parallel Time       Speedup  \
0             5        1  1.000000e-10   1.002073e-03  9.979310e-08
1             5        2  1.000000e-10   1.012325e-03  9.878248e-08
2             5        4  1.000000e-10   2.073288e-03  4.823257e-08
3             5        8  1.000000e-10   2.097368e-03  4.767880e-08
4             5       10  1.000000e-10   1.571417e-03  6.363684e-08
..          ...      ...           ...            ...           ...
58         5000        4  1.000000e-10   1.000000e-10  1.000000e+00
59         5000        8  1.000000e-10   9.087563e-03  1.100405e-08
60         5000       10  1.000000e-10   1.626253e-03  6.149104e-08
61         5000       15  1.000000e-10   9.224892e-03  1.084024e-08
62         5000       20  1.000000e-10   7.979870e-04  1.253153e-07

      Efficiency
0   9.979310e-08
1   4.939124e-08
2   1.205814e-08
3   5.959850e-09
4   6.363684e-09
..           ...
58  2.500000e-01
59  1.375506e-09
60  6.149104e-09
61  7.226824e-10
62  6.265766e-09

[63 rows x 6 columns]
```

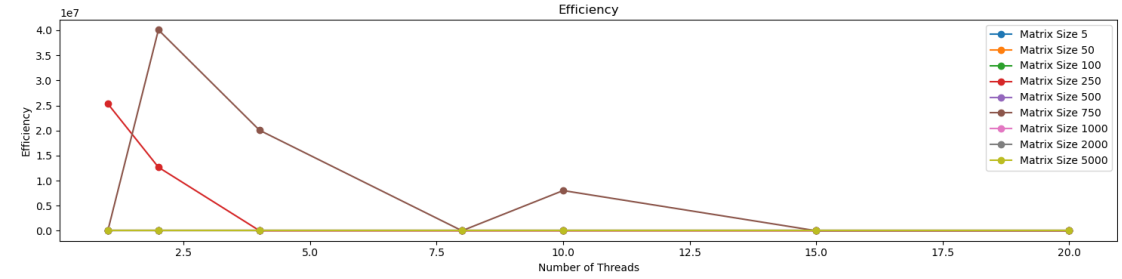
[15]:
```
def plot_matrix_size(df2, matrix_size):
    plt.figure(figsize=(15, 15))

    # 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
```

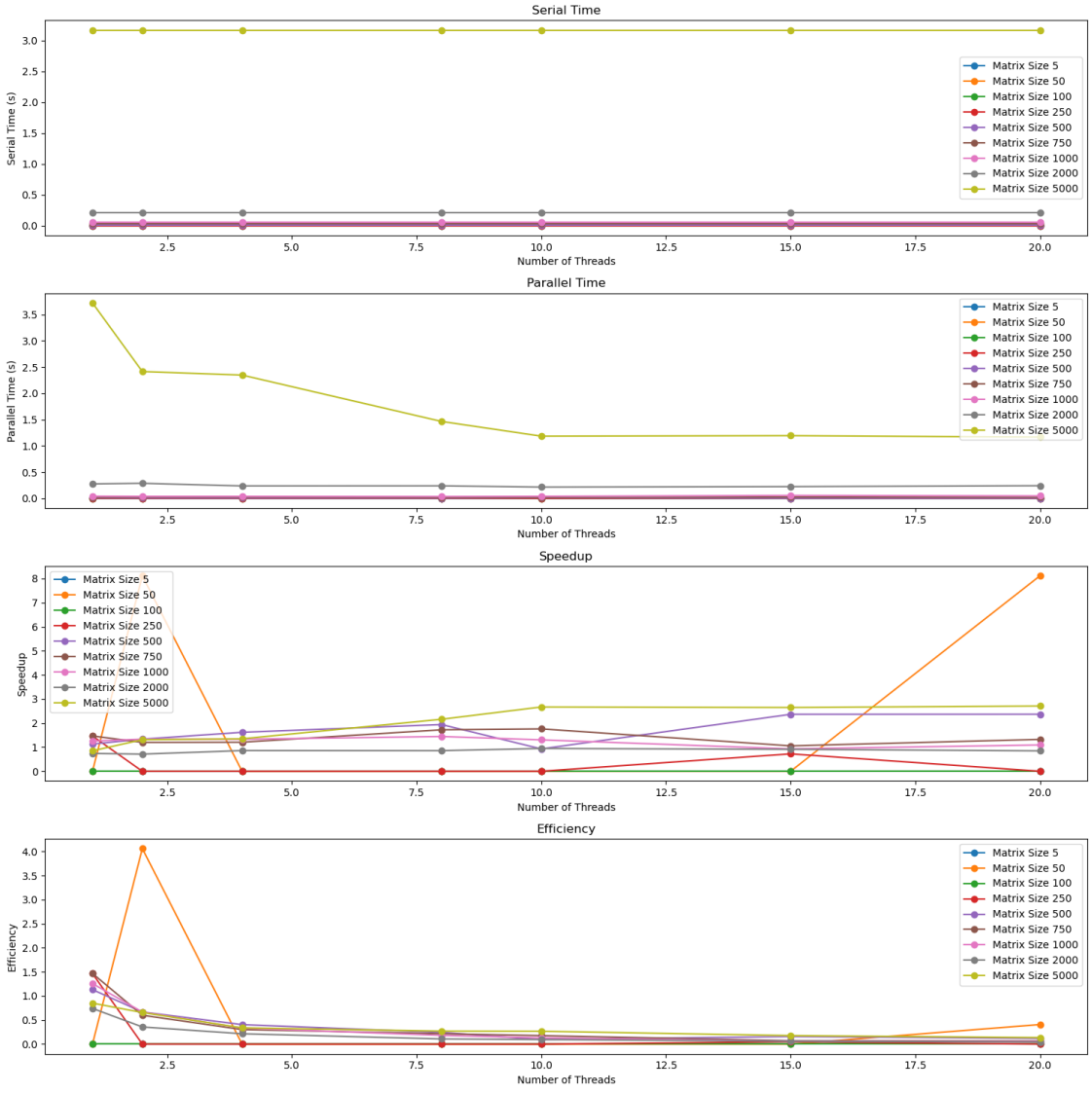
[19]:

	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.

pi_value

January 25, 2024

1 Assignment 2

Write a program for Leibniz series for PI calculation to demonstrate the performance enhancement done by parallelizing the code through Open MP work-sharing of loops.

- Implement the code with different thread count and different maximum number of terms to be calculated for the series such as thread count 10, 20 and terms 100, 1000, 10000, 1000000.
- Display a visualization of performance comparison between serial and parallel, a visual analysis of delay/speedup with the help of varying thread counts and maximum terms in the series for Pi value calculation.

[1]:
```
import numpy as np
import threading
import time
import pandas as pd
import matplotlib.pyplot as plt
```

[2]:
```
# sequential using leibniz method
```

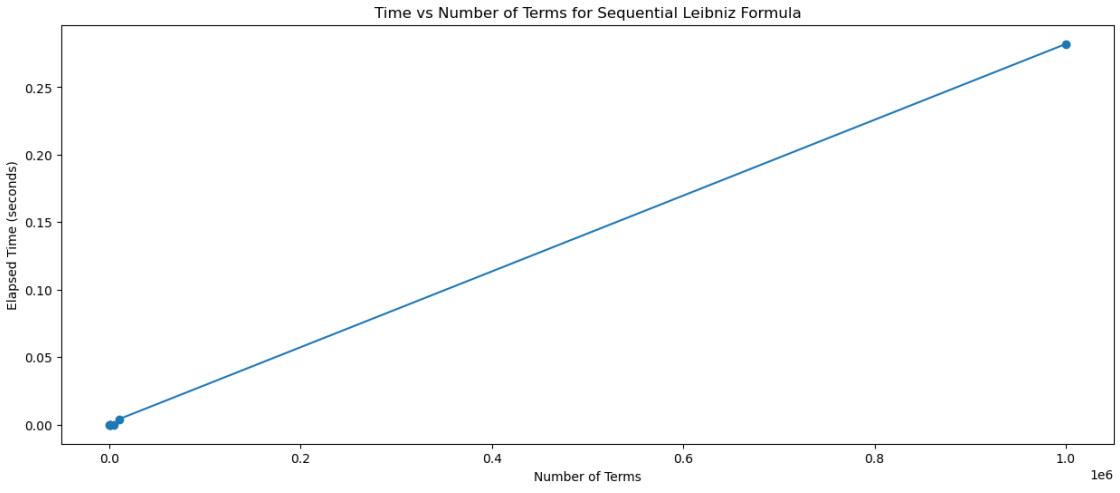
[3]:
```
def estimate_pi_leibniz_sequential(num_terms):
    pi_estimate = 0

    start_time = time.time()

    for k in range(num_terms):
        term = (-1) ** k / (2 * k + 1)
        pi_estimate += term

    pi_estimate *= 4

    end_time = time.time()
    elapsed_time = end_time - start_time

    return pi_estimate, elapsed_time
```

[4]:
```
num_terms_list = [100, 500, 700, 1000, 5000, 10000, 1000000]
pi_estimates = []
elapsed_times = []
```

[5]:
```
for num_terms in num_terms_list:
    pi_estimate, elapsed_time = estimate_pi_leibniz_sequential(num_terms)
    pi_estimates.append(pi_estimate)
    elapsed_times.append(elapsed_time)
    print(f"Number of Terms: {num_terms}, Estimated Pi: {pi_estimate}, Elapsed␣
 ↪Time: {elapsed_time:.6f} seconds")
```

```
Number of Terms: 100, Estimated Pi: 3.1315929035585537, Elapsed Time: 0.000000
seconds
Number of Terms: 500, Estimated Pi: 3.139592655589785, Elapsed Time: 0.000000
seconds
Number of Terms: 700, Estimated Pi: 3.1401640828900845, Elapsed Time: 0.000000
seconds
Number of Terms: 1000, Estimated Pi: 3.140592653839794, Elapsed Time: 0.000000
seconds
Number of Terms: 5000, Estimated Pi: 3.141392653591791, Elapsed Time: 0.000000
seconds
Number of Terms: 10000, Estimated Pi: 3.1414926535900345, Elapsed Time: 0.004056
seconds
Number of Terms: 1000000, Estimated Pi: 3.1415916535897743, Elapsed Time:
0.282051 seconds
```

[6]:
```
plt.figure(figsize=(15, 6))

plt.plot(num_terms_list, elapsed_times, marker='o')
plt.title('Time vs Number of Terms for Sequential Leibniz Formula')
plt.xlabel('Number of Terms')
plt.ylabel('Elapsed Time (seconds)')

plt.show()
```



[7]:
```
# sequential using math module
```

[8]:
```
import math
```

[9]:
```
def calculate_pi():
    start_time = time.time()

    # Accessing the built-in pi constant
    pi_estimate = math.pi

    end_time = time.time()
    elapsed_time = end_time - start_time

    return pi_estimate, elapsed_time
```

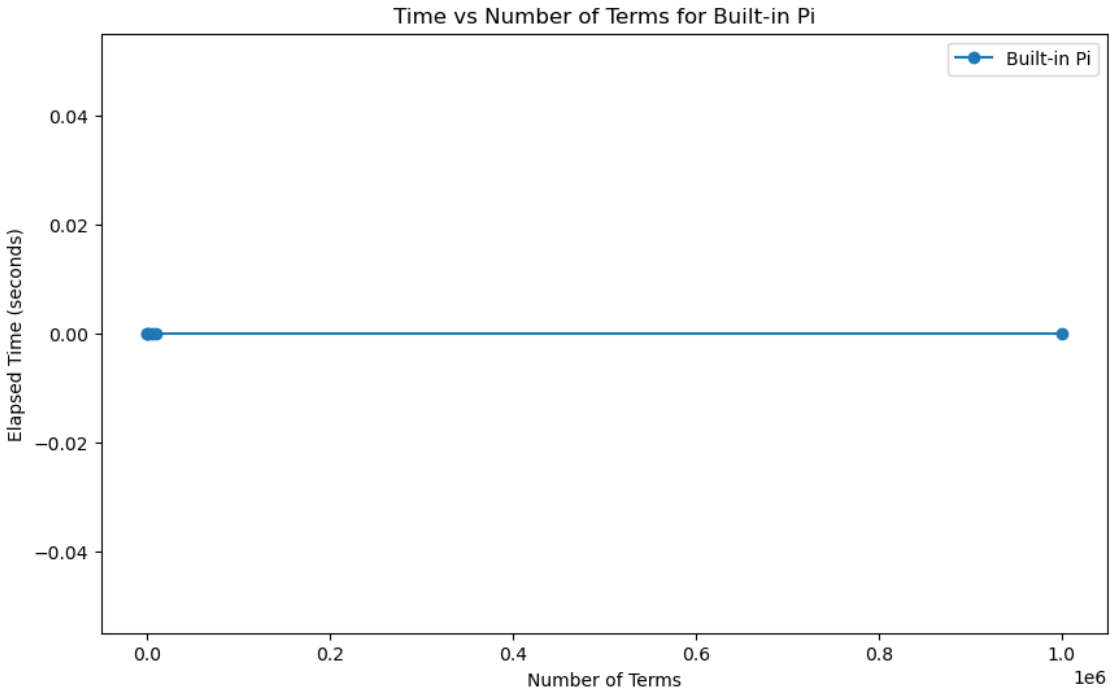
[10]:
```
num_terms_list = [100, 500, 1000, 5000, 10000, 1000000]
pi_estimates_builtin = []
elapsed_times_builtin = []
```

[11]:
```
for num_terms in num_terms_list:
    pi_estimate, elapsed_time = calculate_pi()
    pi_estimates_builtin.append(pi_estimate)
    elapsed_times_builtin.append(elapsed_time)
    print(f"Number of Terms: {num_terms}, Built-in Pi: {pi_estimate}, Elapsed␣
 ↪Time: {elapsed_time:.6f} seconds")
```

```
Number of Terms: 100, Built-in Pi: 3.141592653589793, Elapsed Time: 0.000000
seconds
Number of Terms: 500, Built-in Pi: 3.141592653589793, Elapsed Time: 0.000000
seconds
Number of Terms: 1000, Built-in Pi: 3.141592653589793, Elapsed Time: 0.000000
seconds
Number of Terms: 5000, Built-in Pi: 3.141592653589793, Elapsed Time: 0.000000
seconds
Number of Terms: 10000, Built-in Pi: 3.141592653589793, Elapsed Time: 0.000000
seconds
Number of Terms: 1000000, Built-in Pi: 3.141592653589793, Elapsed Time: 0.000000
seconds
```

[12]:
```
# Plotting the results
plt.figure(figsize=(10, 6))

plt.plot(num_terms_list, elapsed_times_builtin, marker='o', label='Built-in Pi')
plt.title('Time vs Number of Terms for Built-in Pi')
plt.xlabel('Number of Terms')
plt.ylabel('Elapsed Time (seconds)')
plt.legend()
```

```
plt.show()
```



[13]:
```
# parallel processing using leibniz method
```

[14]:
```
def estimate_pi_leibniz_parallel(num_terms, num_threads):
    pi_estimate = 0
    terms_per_thread = num_terms // num_threads
    threads = []

    def calculate_terms(start, end):
        nonlocal pi_estimate
        for k in range(start, end):
            term = (-1) ** k / (2 * k + 1)
            pi_estimate += term

    start_time = time.time()

    for i in range(num_threads):
        start = i * terms_per_thread
        end = (i + 1) * terms_per_thread if i < num_threads - 1 else num_terms
        thread = threading.Thread(target=calculate_terms, args=(start, end))
        thread.start()
        threads.append(thread)
```

```
    for thread in threads:
        thread.join()

    pi_estimate *= 4

    end_time = time.time()
    elapsed_time = end_time - start_time

    return pi_estimate, elapsed_time
```

[15]:
```
num_terms_list = [100, 500, 1000, 5000, 10000, 1000000]
num_threads_list = [2, 4, 8, 10, 20]
pi_estimates_parallel = []
elapsed_times_parallel = []
```

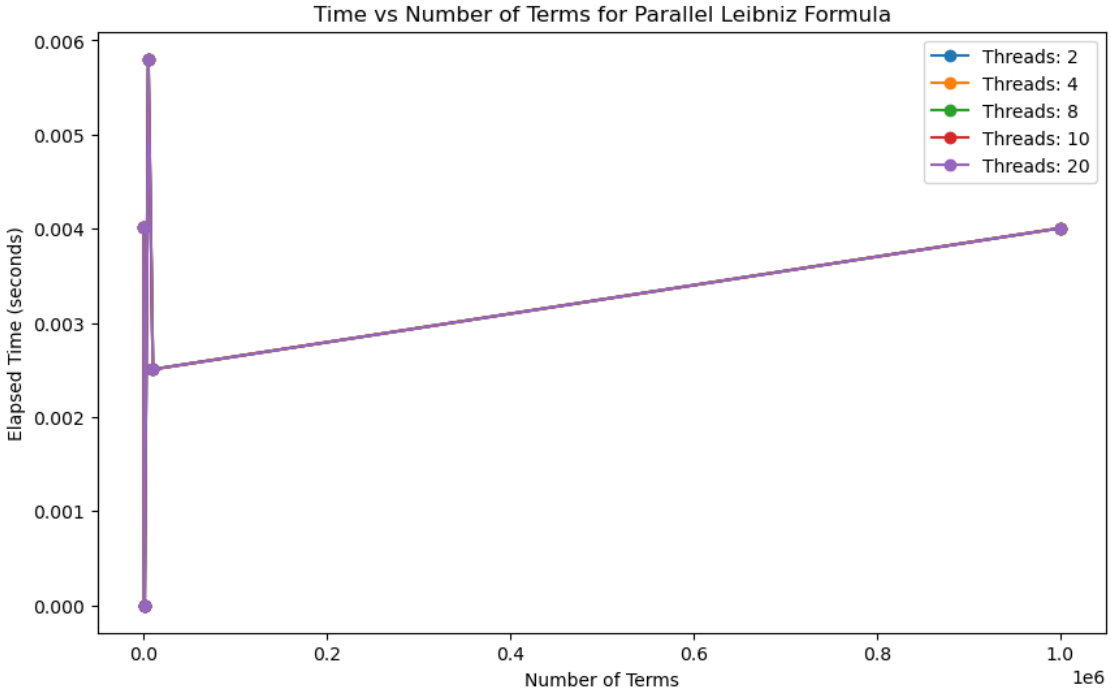
[16]:
```
for num_terms in num_terms_list:
    for num_threads in num_threads_list:
        pi_estimate, elapsed_time = estimate_pi_leibniz_parallel(num_terms,␣
 ↪num_threads)
        pi_estimates_parallel.append(pi_estimate)
        elapsed_times_parallel.append(elapsed_time)
        print(f"Number of Terms: {num_terms}, Threads: {num_threads}, Estimated␣
 ↪Pi: {pi_estimate}, Elapsed Time: {elapsed_time:.6f} seconds")
```

```
Number of Terms: 100, Threads: 2, Estimated Pi: 3.1315929035585537, Elapsed
Time: 0.004011 seconds
Number of Terms: 100, Threads: 4, Estimated Pi: 3.1315929035585537, Elapsed
Time: 0.000000 seconds
Number of Terms: 100, Threads: 8, Estimated Pi: 3.1315929035585537, Elapsed
Time: 0.000000 seconds
Number of Terms: 100, Threads: 10, Estimated Pi: 3.1315929035585537, Elapsed
Time: 0.005803 seconds
Number of Terms: 100, Threads: 20, Estimated Pi: 3.1315929035585537, Elapsed
Time: 0.002507 seconds
Number of Terms: 500, Threads: 2, Estimated Pi: 3.139592655589785, Elapsed Time:
0.004007 seconds
Number of Terms: 500, Threads: 4, Estimated Pi: 3.139592655589785, Elapsed Time:
0.000000 seconds
Number of Terms: 500, Threads: 8, Estimated Pi: 3.139592655589785, Elapsed Time:
0.000000 seconds
Number of Terms: 500, Threads: 10, Estimated Pi: 3.139592655589785, Elapsed
Time: 0.000000 seconds
Number of Terms: 500, Threads: 20, Estimated Pi: 3.139592655589785, Elapsed
Time: 0.004000 seconds
Number of Terms: 1000, Threads: 2, Estimated Pi: 3.140592653839794, Elapsed
Time: 0.000000 seconds
Number of Terms: 1000, Threads: 4, Estimated Pi: 3.140592653839794, Elapsed
Time: 0.000000 seconds
```

```
Number of Terms: 1000, Threads: 8, Estimated Pi: 3.140592653839794, Elapsed
Time: 0.000000 seconds
Number of Terms: 1000, Threads: 10, Estimated Pi: 3.140592653839794, Elapsed
Time: 0.005448 seconds
Number of Terms: 1000, Threads: 20, Estimated Pi: 3.140592653839794, Elapsed
Time: 0.003509 seconds
Number of Terms: 5000, Threads: 2, Estimated Pi: 3.141392653591791, Elapsed
Time: 0.000000 seconds
Number of Terms: 5000, Threads: 4, Estimated Pi: 3.141392653591791, Elapsed
Time: 0.000000 seconds
Number of Terms: 5000, Threads: 8, Estimated Pi: 3.141392653591791, Elapsed
Time: 0.004584 seconds
Number of Terms: 5000, Threads: 10, Estimated Pi: 3.141392653591791, Elapsed
Time: 0.000000 seconds
Number of Terms: 5000, Threads: 20, Estimated Pi: 3.141392653591791, Elapsed
Time: 0.003506 seconds
Number of Terms: 10000, Threads: 2, Estimated Pi: 3.1414926535900345, Elapsed
Time: 0.005043 seconds
Number of Terms: 10000, Threads: 4, Estimated Pi: 3.1414926535900345, Elapsed
Time: 0.003009 seconds
Number of Terms: 10000, Threads: 8, Estimated Pi: 3.1414926535900345, Elapsed
Time: 0.000000 seconds
Number of Terms: 10000, Threads: 10, Estimated Pi: 3.1414926535900345, Elapsed
Time: 0.008009 seconds
Number of Terms: 10000, Threads: 20, Estimated Pi: 3.1414926535900345, Elapsed
Time: 0.005652 seconds
Number of Terms: 1000000, Threads: 2, Estimated Pi: 3.1415916535897734, Elapsed
Time: 0.324527 seconds
Number of Terms: 1000000, Threads: 4, Estimated Pi: 3.1415916535897743, Elapsed
Time: 0.308578 seconds
Number of Terms: 1000000, Threads: 8, Estimated Pi: 3.1415916535897734, Elapsed
Time: 0.317601 seconds
Number of Terms: 1000000, Threads: 10, Estimated Pi: 3.141591653589775, Elapsed
Time: 0.291449 seconds
Number of Terms: 1000000, Threads: 20, Estimated Pi: 3.1415916535897743, Elapsed
Time: 0.299970 seconds
```

[17]:
```python
plt.figure(figsize=(10, 6))

for num_threads in num_threads_list:
    plt.plot(num_terms_list, elapsed_times_parallel[:len(num_terms_list)],␣
 ↪marker='o', label=f'Threads: {num_threads}')

plt.title('Time vs Number of Terms for Parallel Leibniz Formula')
plt.xlabel('Number of Terms')
plt.ylabel('Elapsed Time (seconds)')
plt.legend()
```

```
plt.show()
```


Time vs Number of Terms for Parallel Leibniz Formula
Threads: 2
Threads: 4
Threads: 8
Threads: 10
Threads: 20
Elapsed Time (seconds)
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0.0
0.2
0.4
0.6
0.8
1.0
1e6
Number of Terms

HPC-29-1

January 30, 2024

1 Assignment 3

1. Implement Producer-Consumer problem (PCP). Analyze the significance of semaphore, mutex, bounded buffer, producer thread, consumer thread using the code available on Producer-Consumer Problem in Python - AskPython.
   (a) Write a brief about the problem and solution.
   (b) Code and Output
2. Demonstrate how PCP occurs for a application of your choice.

Ans.

The producer-consumer problem is a classic synchronization problem in OS, especially in concurrent programming and multi-threading. It involves two types of processes:

1. Producers: These processes generate data or items and store them in the shared buffer;
2. Consumers: These processes retrieve and consume items from the buffer.

The challenge is to make sure that the following happen: * Producers do not produce items if the buffer is full * Consumers do not consume items if the buffer is empty.

The main objective is to keep producers and consumers in sync so as to avoid problems like data corruption, race conditions, and deadlocks.

Solution:

Here is a straightforward solution that makes use of bounded buffers and semaphores:

1. Shared Buffer:

- A fixed-size buffer is shared between producers and consumers.

2. Semaphore for Empty Slots (empty):

- Initialized to the size of the buffer.
- Represents the number of empty slots in the buffer.
- Decrements by producers when they add an item.
- Decrements by consumers when they remove an item.

3. Semaphore for Full Slots (full):

- Initialized to 0.
- Represents the number of filled slots in the buffer.
- Incremented by producers when they add an item.
- Decrements by consumers when they remove an item.

4. Mutex Lock:

- Protects access to the shared buffer to race conditions.

[2]:
```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
```

[3]:
```
import threading
import time
```

[4]:
```
# Shared Memory variables
CAPACITY = 10
buffer = [-1 for i in range(CAPACITY)]
in_index = 0
out_index = 0
```

[5]:
```
# Declaring Semaphores
mutex = threading.Semaphore()
empty = threading.Semaphore(CAPACITY)
full = threading.Semaphore(0)
```

[6]:
```
# Producer Thread Class
class Producer(threading.Thread):
  def run(self):

    global CAPACITY, buffer, in_index, out_index
    global mutex, empty, full

    items_produced = 0
    counter = 0

    while items_produced < 20:
      empty.acquire()
      mutex.acquire()

      counter += 1
      buffer[in_index] = counter
      in_index = (in_index + 1)%CAPACITY
      print("Producer produced : ", counter)

      mutex.release()
      full.release()

      time.sleep(0)

      items_produced += 1
```

[7]:
```
# Consumer Thread Class
class Consumer(threading.Thread):
  def run(self):

    global CAPACITY, buffer, in_index, out_index, counter
    global mutex, empty, full

    items_consumed = 0

    while items_consumed < 20:
      full.acquire()
      mutex.acquire()

      item = buffer[out_index]
      out_index = (out_index + 1)%CAPACITY
      print("Consumer consumed item : ", item)

      mutex.release()
      empty.release()

      time.sleep(0.5)

      items_consumed += 1
```

[8]:
```
producer = Producer()
consumer = Consumer()

consumer.start()
producer.start()

producer.join()
consumer.join()
```

```
Producer produced :  1
Consumer consumed item :  1
Producer produced :  2
Producer produced :  3
Producer produced :  4
Producer produced :  5
Producer produced :  6
Producer produced :  7
Producer produced :  8
Producer produced :  9
Producer produced :  10
Producer produced :  11
Consumer consumed item :  2
Producer produced :  12
Consumer consumed item :  3
```

```
Producer produced :  13
Consumer consumed item :  4
Producer produced :  14
Consumer consumed item :  5
Producer produced :  15
Consumer consumed item :  6
Producer produced :  16
Consumer consumed item :  7
Producer produced :  17
Consumer consumed item :  8
Producer produced :  18
Consumer consumed item :  9
Producer produced :  19
Consumer consumed item :  10
Producer produced :  20
Consumer consumed item :  11
Consumer consumed item :  12
Consumer consumed item :  13
Consumer consumed item :  14
Consumer consumed item :  15
Consumer consumed item :  16
Consumer consumed item :  17
Consumer consumed item :  18
Consumer consumed item :  19
Consumer consumed item :  20
```

Implemantation use if else and for loop

[9]:
```
import time
```

[10]:
```
CAPACITY = 10
buffer = [-1 for i in range(CAPACITY)]
in_index = 0
out_index = 0
```

[11]:
```
mutex = threading.Semaphore()
empty = threading.Semaphore(CAPACITY)
full = threading.Semaphore(0)
```

[12]:
```
class Producer(threading.Thread):
    def run(self):
        global CAPACITY, buffer, in_index
        global mutex, empty, full

        for counter in range(1, 21):
            empty.acquire()
            mutex.acquire()
```

```
            buffer[in_index] = counter
            in_index = (in_index + 1) % CAPACITY
            print("Producer produced:", counter)

            mutex.release()
            full.release()

            time.sleep(0)
```

[13]:
```
class Consumer(threading.Thread):
    def run(self):
        global CAPACITY, buffer, out_index
        global mutex, empty, full

        for _ in range(20):
            full.acquire()
            mutex.acquire()

            item = buffer[out_index]
            out_index = (out_index + 1) % CAPACITY
            print("Consumer consumed item:", item)

            mutex.release()
            empty.release()

            time.sleep(0.5)
```

[14]:
```
producer = Producer()
consumer = Consumer()

consumer.start()
producer.start()

producer.join()
consumer.join()
```

```
Producer produced: 1
Consumer consumed item: 1
Producer produced: 2
Producer produced: 3
Producer produced: 4
Producer produced: 5
Producer produced: 6
Producer produced: 7
Producer produced: 8
Producer produced: 9
Producer produced: 10
Producer produced: 11
```

```
Consumer consumed item: 2
Producer produced: 12
Consumer consumed item: 3
Producer produced: 13
Consumer consumed item: 4
Producer produced: 14
Consumer consumed item: 5
Producer produced: 15
Consumer consumed item: 6
Producer produced: 16
Consumer consumed item: 7
Producer produced: 17
Consumer consumed item: 8
Producer produced: 18
Consumer consumed item: 9
Producer produced: 19
Consumer consumed item: 10
Producer produced: 20
Consumer consumed item: 11
Consumer consumed item: 12
Consumer consumed item: 13
Consumer consumed item: 14
Consumer consumed item: 15
Consumer consumed item: 16
Consumer consumed item: 17
Consumer consumed item: 18
Consumer consumed item: 19
Consumer consumed item: 20
```

example useage

[15]:
```
import queue
import random
```

Example

Event Handling in GUI:

- Producers: User input events (clicks, keystrokes).
- Consumers: Event handlers or listeners.
- Buffer: Event queue.

[16]:
```
MAX_QUEUE_SIZE = 5
event_queue = queue.Queue(MAX_QUEUE_SIZE)
mutex = threading.Lock()
empty = threading.Semaphore(MAX_QUEUE_SIZE)
full = threading.Semaphore(0)
```

[17]:
```
class UserClickProducer(threading.Thread):
    def run(self):
        global MAX_QUEUE_SIZE, event_queue
        global mutex, empty, full

        for _ in range(10):
            print("User clicked")

            empty.acquire()
            mutex.acquire()

            event_queue.put("Click")

            mutex.release()
            full.release()

            time.sleep(random.uniform(0.1, 0.5))
```

[18]:
```
class EventHandlerConsumer(threading.Thread):
    def run(self):
        global MAX_QUEUE_SIZE, event_queue
        global mutex, empty, full

        for _ in range(10):
            full.acquire()
            mutex.acquire()

            event = event_queue.get()
            print(f"Handling event: {event}")

            mutex.release()
            empty.release()

            time.sleep(random.uniform(0.1, 0.5))
```

[19]:
```
user_click_producer = UserClickProducer()
event_handler_consumer = EventHandlerConsumer()

user_click_producer.start()
event_handler_consumer.start()

user_click_producer.join()
event_handler_consumer.join()
```

```
User clicked
Handling event: Click
User clicked
Handling event: Click
```

```
User clicked
Handling event: Click
User clicked
Handling event: Click
User clicked
User clicked
User clicked
User clicked
Handling event: Click
Handling event: Click
User clicked
Handling event: Click
User clicked
Handling event: Click
Handling event: Click
Handling event: Click
```

Fibonacci

January 31, 2024

1 Assignment 4

Write a program to generate and print Fibonacci series, one thread must generate the series upto number and other thread must print them. Ensure proper synchronization.

[1]:
```
import threading
import time
```

[2]:
```
def generate_fibonacci(n, fib_list, lock, start_time):
    a, b = 0, 1
    for _ in range(n):
        with lock:
            fib_list.append((a, time.time() - start_time))
        a, b = b, a + b
```

[3]:
```
def print_fibonacci(fib_list, lock):
    with lock:
        for entry in fib_list:
            thread_id = threading.current_thread().ident
            current_time = time.strftime("%Y-%m-%d %H:%M:%S", time.localtime())
            fibonacci_value, time_taken = entry
            print(f"{fibonacci_value}, Thread ID {thread_id} at {current_time}:␣
 ↪, Time Taken: {time_taken:.6f} seconds")
```

[4]:
```
def main():
    n = int(input("Enter the number of Fibonacci numbers to generate: "))

    fib_list = []
    lock = threading.Lock()
    start_time = time.time()

    # Create two threads
    generate_thread = threading.Thread(target=generate_fibonacci, args=(n,␣
 ↪fib_list, lock, start_time))
    print_thread = threading.Thread(target=print_fibonacci, args=(fib_list,␣
 ↪lock))

    # Start the threads
```

```
    generate_thread.start()
    print_thread.start()

    # Wait for both threads to finish
    generate_thread.join()
    print_thread.join()

if __name__ == "__main__":
    main()
```

```
Enter the number of Fibonacci numbers to generate:  15

0, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
1, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
1, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
2, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
3, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
5, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
8, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
13, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
21, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
34, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
55, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
89, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
144, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
233, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
377, Thread ID 21104 at 2024-01-31 22:05:23: , Time Taken: 0.001002 seconds
```

super_market_shopping

February 2, 2024

1 Assignment 5

- Consider a scenario where a person visits a supermarket for shopping. S/He purchases various items in different sections such as clothing, grocery, utensils. Write an OpenMP program to process the bill parallelly in each section and display the final amount to be paid by the customer.
- Analyze the time take by sequential and parallel processing.

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

[10]:
```
class ProcessingThread(threading.Thread):
    def __init__(self, processing_function, num_items):
        super().__init__()
        self.processing_function = processing_function
        self.num_items = num_items
        self.results = []

    def run(self):
        for _ in range(self.num_items):
            result = self.processing_function()
            self.results.append(result)
```

[11]:
```
def process_clothing():
    print("Processing clothing item...")
    time.sleep(0.1)
    return 50
```

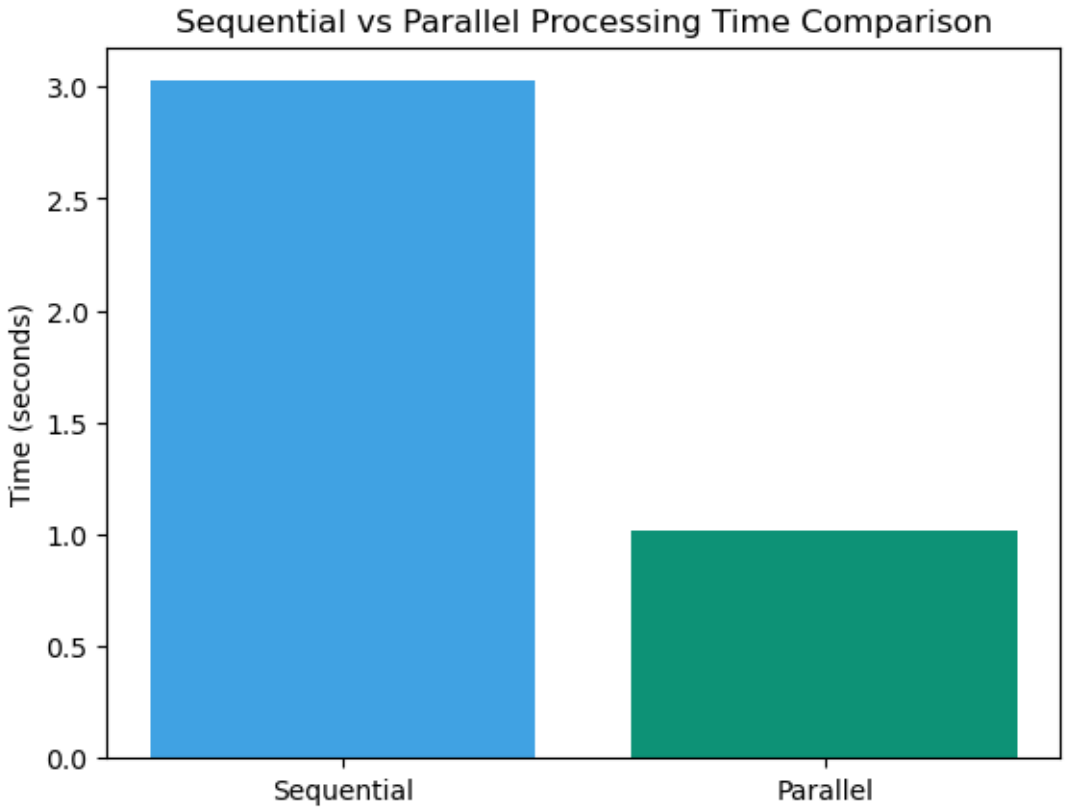
[12]:
```
def process_grocery():
    print("Processing grocery item...")
    time.sleep(0.1)
    return 50
```

[13]:
```python
def process_utensils():
    print("Processing utensils item...")
    time.sleep(0.1)
    return 20
```

[15]:
```python
if __name__ == "__main__":
    # For Sequential Processing
    start_time = time.time()

    clothing_cost = sum(process_clothing() for _ in range(10))
    grocery_cost = sum(process_grocery() for _ in range(10))
    utensils_cost = sum(process_utensils() for _ in range(10))

    total_cost = clothing_cost + grocery_cost + utensils_cost
    sequential_time = time.time() - start_time
    print(f"Total amount to be paid (Sequential): ${total_cost:.2f}")
    print(f"Time taken (Sequential): {sequential_time:.2f} seconds\n")

    # For Parallel Processing
    start_time = time.time()

    # Create threads for parallel processing
    num_items = 10
    threads = [
        ProcessingThread(process_clothing, num_items),
        ProcessingThread(process_grocery, num_items),
        ProcessingThread(process_utensils, num_items)
    ]

    for thread in threads:
        thread.start()

    for thread in threads:
        thread.join()

    total_cost_parallel = sum(sum(thread.results) for thread in threads)
    parallel_time = time.time() - start_time
    print(f"Total amount to be paid (Parallel): ${total_cost_parallel:.2f}")
    print(f"Time taken (Parallel): {parallel_time:.2f} seconds")

    labels = ['Sequential', 'Parallel']
    times = [sequential_time, parallel_time]

    plt.bar(labels, times, color=['#40A2E3', '#0D9276'])
    plt.ylabel('Time (seconds)')
    plt.title('Sequential vs Parallel Processing Time Comparison')
    plt.show()
```

```
Processing clothing item…
Processing clothing item…
Processing clothing item…
Processing clothing item…
Processing clothing item…
Processing clothing item…
Processing clothing item…
Processing clothing item…
Processing clothing item…
Processing clothing item…
Processing grocery item…
Processing grocery item…
Processing grocery item…
Processing grocery item…
Processing grocery item…
Processing grocery item…
Processing grocery item…
Processing grocery item…
Processing grocery item…
Processing grocery item…
Processing utensils item…
Processing utensils item…
Processing utensils item…
Processing utensils item…
Processing utensils item…
Processing utensils item…
Processing utensils item…
Processing utensils item…
Processing utensils item…
Processing utensils item…
Total amount to be paid (Sequential): $1200.00
Time taken (Sequential): 3.03 seconds

Processing clothing item…
Processing grocery item…
Processing utensils item…
Processing grocery item…
Processing clothing item…
Processing utensils item…
Processing utensils item…
Processing grocery item…
Processing clothing item…
Processing grocery item…
Processing utensils item…
Processing clothing item…
Processing utensils item…
Processing grocery item…
Processing clothing item…
```

```
Processing grocery item…
Processing clothing item…
Processing utensils item…
Processing grocery item…
Processing clothing item…
Processing utensils item…
Processing grocery item…
Processing utensils item…
Processing clothing item…
Processing grocery item…Processing utensils item…

Processing clothing item…
Processing utensils item…
Processing grocery item…
Processing clothing item…
Total amount to be paid (Parallel): $1200.00
Time taken (Parallel): 1.02 seconds
```



HPC-5-2

February 8, 2024

1 Assignment 6

a) Print "Welcome to PDPU from process (processno_totalprocesses)".

[1]:
```
import mpi4py
from mpi4py import MPI
```

[2]:
```
comm = MPI.COMM_WORLD # get the communicator object
rank = comm.Get_rank() # get the rank of the current process
name = MPI.Get_processor_name() # get the name of the current processor
size = comm.Get_size() # get the number of processes
universe_size = comm.Get_attr(MPI.UNIVERSE_SIZE) # get the expected number of␣
↪processes
```

[3]:
```
print("Welcome to PDPU!")
print("Process name:", name)
print("Process id:", rank)
print("Number of cores:", size)
```

```
Welcome to PDPU!
Process name: Kavan
Process id: 0
Number of cores: 1
```

[4]:
```
!mpiexec -n 10 python hpc_mpi.py
```

```
Welcome to PDPU Process name: Kavan Process id: 4 Number of cores: 10
Welcome to PDPU Process name: Kavan Process id: 8 Number of cores: 10
Welcome to PDPU Process name: Kavan Process id: 2 Number of cores: 10
Welcome to PDPU Process name: Kavan Process id: 5 Number of cores: 10
Welcome to PDPU Process name: Kavan Process id: 7 Number of cores: 10
Welcome to PDPU Process name: Kavan Process id: 0 Number of cores: 10
Welcome to PDPU Process name: Kavan Process id: 6 Number of cores: 10
Welcome to PDPU Process name: Kavan Process id: 3 Number of cores: 10
Welcome to PDPU Process name: Kavan Process id: 1 Number of cores: 10
Welcome to PDPU Process name: Kavan Process id: 9 Number of cores: 10
```

b) Apply denoising algorithm to a set of n images with 4 processes. (n=4,8).

[57]:
```
import numpy as np
import time
```

[58]:
```
from scipy.signal import medfilt2d
```

[59]:
```
from PIL import Image
import matplotlib.pyplot as plt
```

[60]:
```
def denoise_image(image):
    if len(image.shape) not in [2, 3]:
        raise ValueError("Invalid image format")
    if len(image.shape) == 3:
        denoised_image = np.stack([medfilt2d(channel, kernel_size=3) for␣
 ↪channel in image.transpose(2, 0, 1)], axis=-1)
    else:
        denoised_image = medfilt2d(image, kernel_size=3)
    return denoised_image
```

[61]:
```
def chunks(lst, n):
    for i in range(0, len(lst), n):
        yield lst[i:i + n]
```

[62]:
```
comm = MPI.COMM_WORLD
rank = comm.Get_rank()
size = comm.Get_size()
```

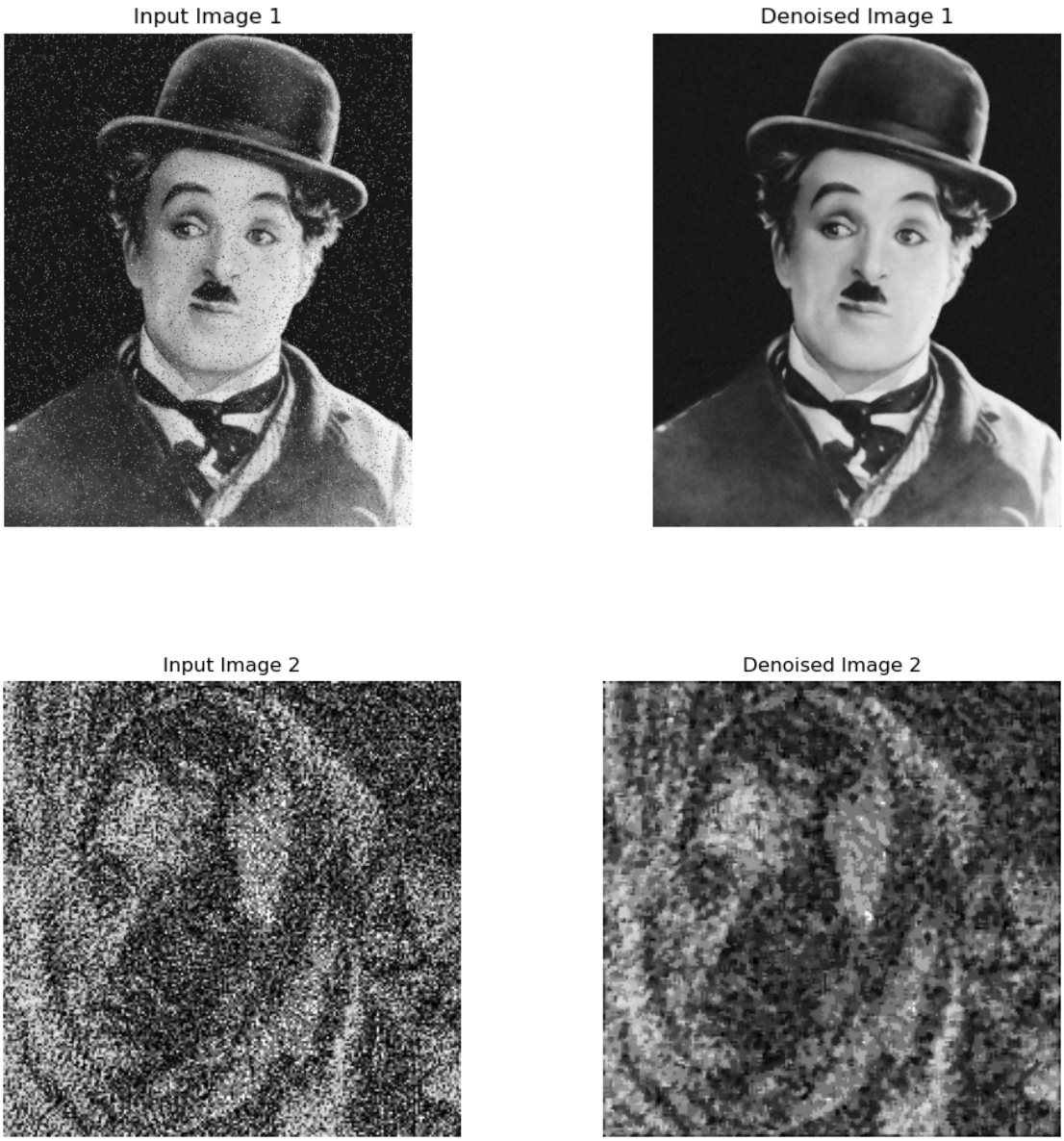
[63]:
```
image_path = ["noice.png","noise2.png","noise3.png","noise4.jpg"]
```

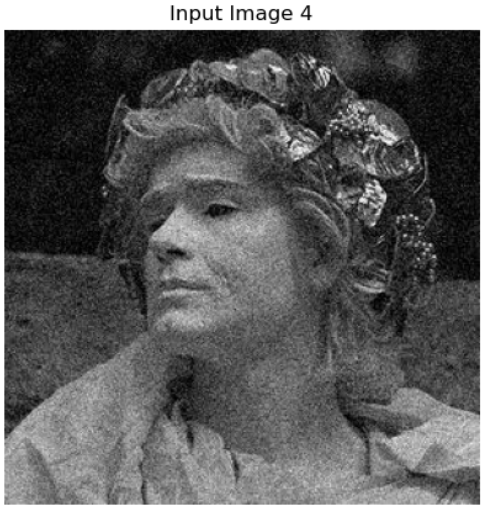
[64]:
```
images = [np.array(Image.open(path)) for path in image_path]
```

[65]:
```
image_chunks = list(chunks(images, len(images) // size))

local_chunks = comm.scatter(image_chunks, root=0)

denoised_chunks = [denoise_image(chunk) for chunk in local_chunks]

all_denoised_chunks = comm.gather(denoised_chunks, root=0)
```

[66]:
```
if rank == 0:
    # Combine denoised chunks into a single list of denoised images
    denoised_images = [image for sublist in all_denoised_chunks for image in␣
 ↪sublist]

    # Plot the input and denoised images for each image
    for i, (input_image, denoised_image) in enumerate(zip(images,␣
 ↪denoised_images)):
        fig, axes = plt.subplots(1, 2, figsize=(12, 5))
```

```
        axes[0].imshow(input_image, cmap='gray')
        axes[0].set_title(f'Input Image {i+1}')
        axes[0].axis('off')
        axes[1].imshow(denoised_image, cmap='gray')
        axes[1].set_title(f'Denoised Image {i+1}')
        axes[1].axis('off')
        plt.show()

start_time = MPI.Wtime()
end_time = MPI.Wtime()

print("Process", rank, "took", end_time - start_time, "seconds")
```






```
Process 0 took 6.0999998822808266e-05 seconds
```

[67]:
```
!mpiexec -n 4 python hpc_4_img.py
```

```
Process 1 took 9.00006853044033e-07 seconds
Process 2 took 1.200009137392044e-06 seconds
Process 3 took 1.300009898841381e-06 seconds
Figure(1200x500)
Figure(1200x500)
Figure(1200x500)
Figure(1200x500)
Process 0 took 8.00006091594696e-07 seconds
```

[78]:
```
image_path = ["D:/data set/sports imags/train/noisy_surf/noisy_001.jpg",
              "D:/data set/sports imags/train/noisy_surf/noisy_002.jpg",
              "D:/data set/sports imags/train/noisy_surf/noisy_003.jpg",
              "D:/data set/sports imags/train/noisy_surf/noisy_004.jpg",
              "D:/data set/sports imags/train/noisy_surf/noisy_005.jpg",
              "D:/data set/sports imags/train/noisy_surf/noisy_006.jpg",
              "D:/data set/sports imags/train/noisy_surf/noisy_007.jpg",
              "D:/data set/sports imags/train/noisy_surf/noisy_008.jpg"]
```

[79]:
```
images = [np.array(Image.open(path)) for path in image_path]
```

[80]:
```
image_chunks = list(chunks(images, len(images) // size))

local_chunks = comm.scatter(image_chunks, root=0)

denoised_chunks = [denoise_image(chunk) for chunk in local_chunks]

all_denoised_chunks = comm.gather(denoised_chunks, root=0)
```

[81]:
```
if rank == 0:
    denoised_images = [image for sublist in all_denoised_chunks for image in␣
 ↪sublist]

    for i, (input_image, denoised_image) in enumerate(zip(images,␣
 ↪denoised_images)):
        fig, axes = plt.subplots(1, 2, figsize=(12, 5))
        axes[0].imshow(input_image, cmap='gray')
        axes[0].set_title(f'Input Image {i+1}')
        axes[0].axis('off')
        axes[1].imshow(denoised_image, cmap='gray')
        axes[1].set_title(f'Denoised Image {i+1}')
        axes[1].axis('off')
        plt.show()

start_time = MPI.Wtime()
end_time = MPI.Wtime()

print("Process", rank, "took", end_time - start_time, "seconds")
```

Input Image 1

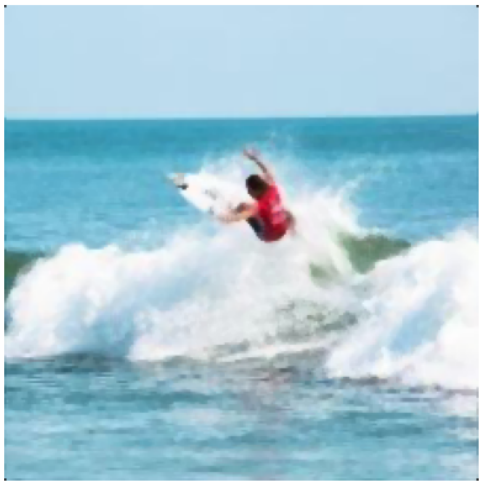
Denoised Image 1

Input Image 2

Denoised Image 2

Input Image 3

Denoised Image 3



Input Image 4

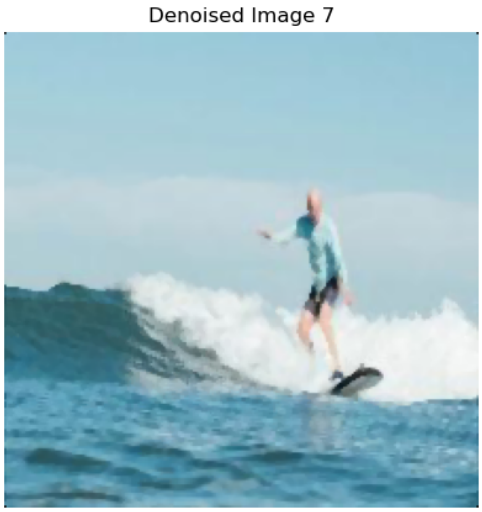
Denoised Image 4

Input Image 5

Denoised Image 5

Input Image 6

Denoised Image 6




```
Process 0 took 6.360001862049103e-05 seconds
```

[83]:
```
!mpiexec -n 4 python hpc_8_img.py
```

```
Process 1 took 7.00005330145359e-07 seconds
Process 2 took 8.00006091594696e-07 seconds
Process 3 took 9.00006853044033e-07 seconds
Figure(1200x500)
Figure(1200x500)
Figure(1200x500)
Figure(1200x500)
Figure(1200x500)
Figure(1200x500)
```

```
Figure(1200x500)
Figure(1200x500)
Process 0 took 9.00006853044033e-07 seconds
```

c) Analyze time taken by serial and openMPI processes.

d) Try for 100 or more number of images.

[95]:
```
import os
import cv2
```

[100]:
```
def add_noise(image):
    noisy_image = image + np.random.normal(loc=0, scale=10, size=image.shape)
    return np.clip(noisy_image, 0, 255).astype(np.uint8)

def denoise(image):
    denoised_image = cv2.fastNlMeansDenoisingColored(image, None, 10, 10, 7, 21)
    return denoised_image

def denoise_images(images, output_folder, rank=None):
    start_time = time.time()
    noisy_output_folder = os.path.join(output_folder, "noisy")
    denoised_output_folder = os.path.join(output_folder, "denoised")
    os.makedirs(noisy_output_folder, exist_ok=True)
    os.makedirs(denoised_output_folder, exist_ok=True)
    for i, image in enumerate(images):
        if image is None:
            print(f"Warning: Image {i} could not be loaded. Skipping.")
            continue
        noisy_image = add_noise(image)
        denoised_image = denoise(noisy_image)
        if rank is None or rank == 0:
            cv2.imwrite(os.path.join(noisy_output_folder, f"noisy_image_{i}.
 ↪jpg"), noisy_image)
            cv2.imwrite(os.path.join(denoised_output_folder,␣
 ↪f"denoised_image_{i}.jpg"), denoised_image)
    end_time = time.time()
    return end_time - start_time

def main():
    comm = MPI.COMM_WORLD
    rank = comm.Get_rank()
    size = comm.Get_size()

    folder_path = folder_path = "D:/data set/sports imags/train/surfing"
    output_folder = os.path.join(folder_path, "output1")
    image_files = os.listdir(folder_path)
```

```
    images = [cv2.imread(os.path.join(folder_path, file)) for file in␣
↪image_files]

    if rank == 0:
        print(f"Number of images: {len(images)}")

    # Serial denoising
    if rank == 0:
        print("Serial Denoising:")
    comm.Barrier()
    serial_time = denoise_images(images, output_folder, rank)
    if rank == 0:
        print(f"Time taken for serial denoising: {serial_time:.2f} seconds")

    # Parallel denoising
    if rank == 0:
        print("Parallel Denoising:")
    comm.Barrier()
    num_images_per_process = len(images) // size
    start_index = rank * num_images_per_process
    end_index = start_index + num_images_per_process
    parallel_time = denoise_images(images[start_index:end_index],␣
↪output_folder, rank)
    max_parallel_time = comm.reduce(parallel_time, op=MPI.MAX, root=0)
    if rank == 0:
        print(f"Time taken for parallel denoising: {max_parallel_time:.2f}␣
↪seconds")

if __name__ == "__main__":
    main()
```

```
Number of images: 143
Serial Denoising:
Warning: Image 142 could not be loaded. Skipping.
Time taken for serial denoising: 82.58 seconds
Parallel Denoising:
Warning: Image 142 could not be loaded. Skipping.
Time taken for parallel denoising: 83.79 seconds
```

[102]:
```
!mpiexec -n 4 python hpc_100_img.py
```

```
Warning: Image 142 could not be loaded. Skipping.
Warning: Image 142 could not be loaded. Skipping.
Warning: Image 142 could not be loaded. Skipping.
Number of images: 143
Serial Denoising:
Warning: Image 142 could not be loaded. Skipping.
Time taken for serial denoising: 76.59 seconds
```

```
Parallel Denoising:
Time taken for parallel denoising: 21.34 seconds

[ WARN:0@0.103] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
[ WARN:0@0.114] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
[ WARN:0@0.092] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
[ WARN:0@0.127] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
```

[103]:
```
!mpiexec -n 8 python hpc_100_img.py
```

```
Warning: Image 142 could not be loaded. Skipping.

[ WARN:0@0.093] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
[ WARN:0@0.120] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
[ WARN:0@0.121] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
[ WARN:0@0.148] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
[ WARN:0@0.136] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
[ WARN:0@0.168] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
[ WARN:0@0.188] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity
[ WARN:0@0.113] global loadsave.cpp:248 cv::findDecoder imread_('D:/data
set/sports imags/train/surfing\output1'): can't open/read file: check file
path/integrity


Warning: Image 142 could not be loaded. Skipping.
Warning: Image 142 could not be loaded. Skipping.
Warning: Image 142 could not be loaded. Skipping.
Warning: Image 142 could not be loaded. Skipping.
```

```
Warning: Image 142 could not be loaded. Skipping.
Warning: Image 142 could not be loaded. Skipping.
Number of images: 143
Serial Denoising:
Warning: Image 142 could not be loaded. Skipping.
Time taken for serial denoising: 160.82 seconds
Parallel Denoising:
Time taken for parallel denoising: 20.70 seconds
```

HPC-12-2

February 14, 2024

1 Assignment 7

1. Write a program to implement arithmetic calculations using MPI processes.
2. Write a program with different processes to apply following functions to an image in parallel.
   - Read an image.
   - Convert above RGB image to grayscale.
   - Find edges in the image.
   - Show the original image.

[1]:
```
import mpi4py
from mpi4py import MPI
```

[2]:
```
import numpy as np
```

[3]:
```
comm = MPI.COMM_WORLD # get the communicator object
rank = comm.Get_rank() # get the rank of the current process
name = MPI.Get_processor_name() # get the name of the current processor
size = comm.Get_size() # get the number of processes
```

[4]:
```
randNum = np.zeros(1)
```

[5]:
```
a = 10
b = 5
```

[ ]:
```
if rank == 0:
    print('rank = ', rank, ',' ,a+b)
if rank == 1:
    print('rank = ', rank, ',' ,a*b)
if rank == 2:
    print('rank = ', rank, ',' ,a/b)
if rank == 3:
    print('rank = ', rank, ',' ,a-b)
```

[7]:
```
!mpiexec -n 4 python hpc-arith.py
```

```
rank =  0 , addition :  15
rank =  2 , division :  2.0
rank =  1 , multiplication : 50
rank =  3 , subtraction :  5
```

[11]:
```
import cv2
```

[12]:
```
def read_image(filename):
    image = cv2.imread(filename)
    return image

def convert_to_grayscale(image):
    grayscale_image = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)
    return grayscale_image

def find_edges(image):
    edges = cv2.Canny(image, 100, 200)
    return edges

def show_image(image, title="Image"):
    cv2.imshow(title, image)
    cv2.waitKey(0)
    cv2.destroyAllWindows()
```

[13]:
```
filename = "1.jpg"
image = read_image(filename)
```

[14]:
```
if rank == 0:
    print('rank =', rank, ',', 'Read the image')
elif rank == 1:
    grayscale_image = convert_to_grayscale(image)
    print('rank =', rank, ',', 'Converted RGB image to grayscale')
elif rank == 2:
    edges_image = find_edges(image)
    print('rank =', rank, ',', 'Found edges in the image')
elif rank == 3:
    show_image(image, title="Original Image")
    print('rank =', rank, ',', 'Displayed the original image')
    grayscale_image = convert_to_grayscale(image)
    show_image(grayscale_image, title="Grayscale Image")
    print('rank =', rank, ',', 'Displayed the grayscale image')
    edges_image = find_edges(image)
    show_image(edges_image, title="Edges Image")
    print('rank =', rank, ',', 'Displayed the edges image')
```

```
rank = 0 , Read the image
```

[15]:
```
!mpiexec -n 4 python hpc-7(2).py
```

```
rank = 0 , Read the image
rank = 1 , Converted RGB image to grayscale
rank = 2 , Found edges in the image
rank = 3 , Displayed the original image
```

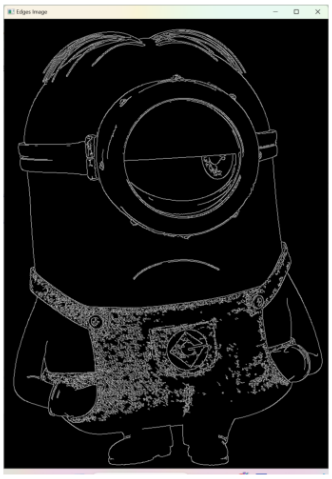
```
rank = 3 , Displayed the grayscale image
rank = 3 , Displayed the edges image
```

[16]:
```python
import matplotlib.pyplot as plt
```

[19]:
```python
# Load the images
image1 = cv2.imread("hpc-7-2-2.png")
image2 = cv2.imread("hpc-7-2-3.png")
image3 = cv2.imread("hpc-7-2-1.png")

# Convert BGR to RGB (Matplotlib uses RGB)
image1_rgb = cv2.cvtColor(image1, cv2.COLOR_BGR2RGB)
image2_rgb = cv2.cvtColor(image2, cv2.COLOR_BGR2RGB)
image3_rgb = cv2.cvtColor(image3, cv2.COLOR_BGR2RGB)

# Display the images
plt.figure(figsize=(15, 10))

plt.subplot(1, 3, 1)
plt.imshow(image1_rgb)
plt.axis('off')
plt.title('grayscaled image')

plt.subplot(1, 3, 2)
plt.imshow(image2_rgb)
plt.axis('off')
plt.title('edges of image')

plt.subplot(1, 3, 3)
plt.imshow(image3_rgb)
plt.axis('off')
plt.title('original image')

plt.show()
```

grayscaled image

edges of image



original image

HPC-14-2

February 14, 2024

1 Assignment 8

1. Write a program to pass message from one process to another and print output.
   - In synchronous communication
   - In asynchronous communication. Show using overlapping of task in non-blocking mode.

[1]:
```
import mpi4py
from mpi4py import MPI
```

[2]:
```
import numpy as np
```

[3]:
```
comm = MPI.COMM_WORLD # get the communicator object
rank = comm.Get_rank() # get the rank of the current process
name = MPI.Get_processor_name() # get the name of the current processor
size = comm.Get_size() # get the number of processes
```

[4]:
```
randNum = np.zeros(1)
```

[ ]:
```
if rank == 0:
    message = "Hello from process 0"
    comm.send(message, dest=1)

    received_message = comm.recv(source=1)
    print(f"Process 0 received message: {received_message}")

elif rank == 1:
    received_message = comm.recv(source=0)
    print(f"Process 1 received message: {received_message}")

    reply = "Hello from process 1"
    comm.send(reply, dest=0)
```

[5]:
```
!mpiexec -n 2 python hpc-12-2.py
```

```
Process 1 received message: Hello from process 0
Process 0 received message: Hello from process 1
```

[ ]:
```
if rank == 0:
    message = "Hello from process 0 (Async)"
    req_send = comm.isend(message, dest=1)
    print(f"Process {rank} sent message: {message}")
    time.sleep(1)
    req_send.wait()
elif rank == 1:
    req_recv = comm.irecv(source=0)
    time.sleep(0.5)
    print(f"Process {rank} waiting to receive message...")
    received_message = req_recv.wait()
    print(f"Process {rank} received message: {received_message}")
```

[8]:
```
!mpiexec -n 2 python hpc-async.py
```

```
Process 0 sent message: Hello from process 0 (Async)
Process 1 waiting to receive message…
Process 1 received message: Hello from process 0 (Async)
```

HPC-14-2(2)

February 17, 2024

1 Assignment 9

1. Calculate Pi value using openMPI send and receive messages for atleast 35-40 terms.
2. Change the value on n as 2, 4, 8, 16.
3. Analyze the performance improvement using number of processes.

[1]:
```
import mpi4py
from mpi4py import MPI
```

[2]:
```
import time
```

[3]:
```
TERMS = 40
```

[4]:
```
def calculate_pi(rank, num_processes, terms):
    partial_sum = 0.0
    for i in range(rank, terms, num_processes):
        if i % 2 == 0:
            partial_sum += 1.0 / (2 * i + 1)
        else:
            partial_sum -= 1.0 / (2 * i + 1)
    return partial_sum * 4
```

[5]:
```
if __name__ == "__main__":
    comm = MPI.COMM_WORLD
    rank = comm.Get_rank()
    size = comm.Get_size()

    terms = 40

    start_time = time.time()

    partial_pi = calculate_pi(rank, size, terms)
    print(f"calculated Rank {rank} : Pi = {partial_pi}, Time = {time.time() -␣
 ↪start_time}")

    if rank == 0:
        total_pi = partial_pi
```

```
        for i in range(1, size):
            partial_result, partial_time = comm.recv(source=i)
            total_pi += partial_result
            print(f"Received from Rank {i}: Pi = {partial_result}, Time =␣
↪{partial_time}")

        print("Number of processes:", size)
        print("Estimated Pi:", total_pi)
        print("Execution time:", time.time() - start_time, "seconds")
    else:
        print(f"Sending from Rank {rank}: Pi = {partial_pi}, Time = {time.
↪time() - start_time}")
        comm.send((partial_pi, time.time() - start_time), dest=0)
```

```
calculated Rank 0 : Pi = 3.116596556793833, Time = 0.0
Number of processes: 1
Estimated Pi: 3.116596556793833
Execution time: 0.0 seconds
```

[6]:
```
!mpiexec -n 2 python hpc-as9.py
```

```
calculated Rank 1 : Pi = -4.0941172405577415, Time = 0.0
Sending from Rank 1: Pi = -4.0941172405577415, Time = 0.0
calculated Rank 0 : Pi = 7.210713797351573, Time = 0.0
Received from Rank 1: Pi = -4.0941172405577415, Time = 0.0
Number of processes: 2
Estimated Pi: 3.116596556793832
Execution time: 0.0030089646911621094 seconds
```

[7]:
```
!mpiexec -n 4 python hpc-as9.py
```

```
calculated Rank 2 : Pi = 1.8840610646940703, Time = 0.0
Sending from Rank 2: Pi = 1.8840610646940703, Time = 0.0
calculated Rank 3 : Pi = -1.5719013009615963, Time = 0.0
Sending from Rank 3: Pi = -1.5719013009615963, Time = 0.0
calculated Rank 1 : Pi = -2.5222159395961445, Time = 0.0
Sending from Rank 1: Pi = -2.5222159395961445, Time = 0.0
calculated Rank 0 : Pi = 5.326652732657504, Time = 0.0
Received from Rank 1: Pi = -2.5222159395961445, Time = 0.0
Received from Rank 2: Pi = 1.8840610646940703, Time = 0.0
Received from Rank 3: Pi = -1.5719013009615963, Time = 0.0
Number of processes: 4
Estimated Pi: 3.1165965567938327
Execution time: 0.005960226058959961 seconds
```

[8]:
```
!mpiexec -n 8 python hpc-as9.py
```

```
calculated Rank 7 : Pi = -0.5949302825943747, Time = 0.0
Sending from Rank 7: Pi = -0.5949302825943747, Time = 0.0
```

```
calculated Rank 3 : Pi = -0.9769710183672217, Time = 0.0
Sending from Rank 3: Pi = -0.9769710183672217, Time = 0.0
calculated Rank 5 : Pi = -0.7259377111012902, Time = 0.0
Sending from Rank 5: Pi = -0.7259377111012902, Time = 0.0
calculated Rank 2 : Pi = 1.2320270111902598, Time = 0.0
Sending from Rank 2: Pi = 1.2320270111902598, Time = 0.0
calculated Rank 4 : Pi = 0.826975379198637, Time = 0.0
Sending from Rank 4: Pi = 0.826975379198637, Time = 0.0
calculated Rank 1 : Pi = -1.7962782284948542, Time = 0.0
Sending from Rank 1: Pi = -1.7962782284948542, Time = 0.0
calculated Rank 6 : Pi = 0.6520340535038104, Time = 0.0
Sending from Rank 6: Pi = 0.6520340535038104, Time = 0.0
calculated Rank 0 : Pi = 4.499677353458866, Time = 0.0
Received from Rank 1: Pi = -1.7962782284948542, Time = 0.0
Received from Rank 2: Pi = 1.2320270111902598, Time = 0.0
Received from Rank 3: Pi = -0.9769710183672217, Time = 0.0
Received from Rank 4: Pi = 0.826975379198637, Time = 0.0
Received from Rank 5: Pi = -0.7259377111012902, Time = 0.0
Received from Rank 6: Pi = 0.6520340535038104, Time = 0.0
Received from Rank 7: Pi = -0.5949302825943747, Time = 0.0
Number of processes: 8
Estimated Pi: 3.116596556793832
Execution time: 0.005739927291870117 seconds
```

[9]:
```
!mpiexec -n 16 python hpc-as9.py
```

```
calculated Rank 14 : Pi = 0.20350480497456191, Time = 0.0
Sending from Rank 14: Pi = 0.20350480497456191, Time = 0.0
calculated Rank 7 : Pi = -0.40240596103779513, Time = 0.0
Sending from Rank 7: Pi = -0.40240596103779513, Time = 0.0
calculated Rank 11 : Pi = -0.2466403162055336, Time = 0.0
Sending from Rank 11: Pi = -0.2466403162055336, Time = 0.0
calculated Rank 8 : Pi = 0.3169267707082833, Time = 0.0
Sending from Rank 8: Pi = 0.3169267707082833, Time = 0.0
calculated Rank 3 : Pi = -0.730330702161688, Time = 0.0
Sending from Rank 3: Pi = -0.730330702161688, Time = 0.0
calculated Rank 5 : Pi = -0.5099929527836504, Time = 0.0
Sending from Rank 5: Pi = -0.5099929527836504, Time = 0.0
calculated Rank 1 : Pi = -1.507320540156361, Time = 0.0
Sending from Rank 1: Pi = -1.507320540156361, Time = 0.0
calculated Rank 15 : Pi = -0.19252432155657961, Time = 0.0
Sending from Rank 15: Pi = -0.19252432155657961, Time = 0.0
calculated Rank 2 : Pi = 0.9660791226008618, Time = 0.0
Sending from Rank 2: Pi = 0.9660791226008618, Time = 0.0
calculated Rank 10 : Pi = 0.265947888589398, Time = 0.0
Sending from Rank 10: Pi = 0.265947888589398, Time = 0.0
calculated Rank 9 : Pi = -0.2889576883384933, Time = 0.0
Sending from Rank 9: Pi = -0.2889576883384933, Time = 0.0
```

```
calculated Rank 6 : Pi = 0.4485292485292486, Time = 0.0
Sending from Rank 6: Pi = 0.4485292485292486, Time = 0.0
calculated Rank 4 : Pi = 0.5967999406021457, Time = 0.0
Sending from Rank 4: Pi = 0.5967999406021457, Time = 0.0
calculated Rank 13 : Pi = -0.21594475831763965, Time = 0.0
Sending from Rank 13: Pi = -0.21594475831763965, Time = 0.0
calculated Rank 12 : Pi = 0.23017543859649123, Time = 0.0
Sending from Rank 12: Pi = 0.23017543859649123, Time = 0.0
calculated Rank 0 : Pi = 4.182750582750582, Time = 0.0
Received from Rank 1: Pi = -1.507320540156361, Time = 0.0
Received from Rank 2: Pi = 0.9660791226008618, Time = 0.0
Received from Rank 3: Pi = -0.730330702161688, Time = 0.0
Received from Rank 4: Pi = 0.5967999406021457, Time = 0.0
Received from Rank 5: Pi = -0.5099929527836504, Time = 0.0
Received from Rank 6: Pi = 0.4485292485292486, Time = 0.0
Received from Rank 7: Pi = -0.40240596103779513, Time = 0.0
Received from Rank 8: Pi = 0.3169267707082833, Time = 0.0
Received from Rank 9: Pi = -0.2889576883384933, Time = 0.0
Received from Rank 10: Pi = 0.265947888589398, Time = 0.0
Received from Rank 11: Pi = -0.2466403162055336, Time = 0.0
Received from Rank 12: Pi = 0.23017543859649123, Time = 0.0
Received from Rank 13: Pi = -0.21594475831763965, Time = 0.0
Received from Rank 14: Pi = 0.20350480497456191, Time = 0.0
Received from Rank 15: Pi = -0.19252432155657961, Time = 0.0
Number of processes: 16
Estimated Pi: 3.1165965567938323
Execution time: 0.006808042526245117 seconds
```

[10]:
```
total_time = [0.0030989646911621094 , 0.005960226058959961 , 0.
 ↪00573992729187011 7 , 0.006808042526245117]
total_time
```

[10]:
```
[0.0030989646911621094,
 0.005960226058959961,
 0.00573992729187011 7,
 0.006808042526245117]
```

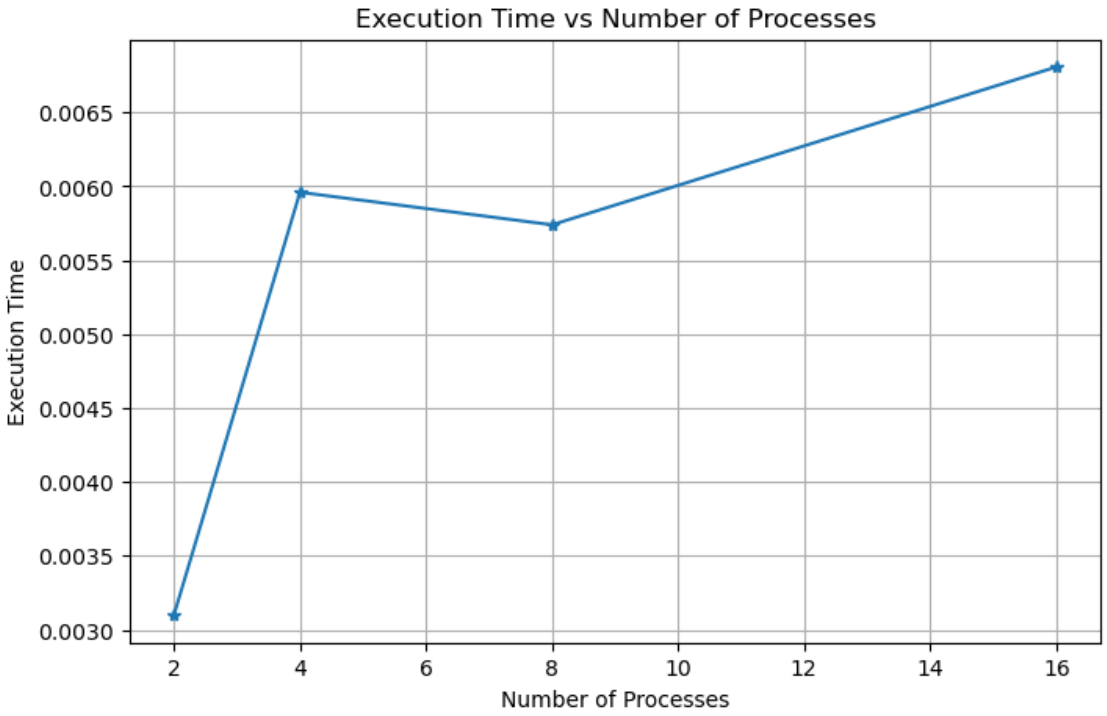
[11]:
```
ranks = [2,4,8,16]
ranks
```

[11]:
```
[2, 4, 8, 16]
```

[13]:
```
import matplotlib.pyplot as plt
```

[14]:
```
plt.figure(figsize=(8, 5))
plt.plot(ranks, total_time, marker='*')
plt.title('Execution Time vs Number of Processes')
plt.xlabel('Number of Processes')
```

```
plt.ylabel('Execution Time')
plt.grid(True)
plt.show()
```



HPC-As10

February 17, 2024

1 Assignment 10

Write a program to show collective communication by taking suitable example such that computing average of n numbers or computing sum or product of two matrices… :

- Bcast function
- Scatter function
- Gather function

[1]:
```
from mpi4py import MPI
import numpy as np
```

[2]:
```
comm = MPI.COMM_WORLD
rank = comm.Get_rank()
size = comm.Get_size()
```

[3]:
```
n = 10
local_sum = np.random.randint(0, 100, n)

local_sum_total = np.sum(local_sum)

global_sum = np.array(0, dtype='i')
comm.Reduce(local_sum_total, global_sum, op=MPI.SUM, root=0)

if rank == 0:
    print("Global sum:", global_sum)
```

```
Global sum: 533
```

[6]:
```
!mpiexec -n 10 python bcast.py
```

```
Rank 0 is broadcasting
Process :  0 received data :  66
Process :  8  , is waiting to receive data from Rank 0
Process :  8 received data :  66
Process :  9  , is waiting to receive data from Rank 0
Process :  9 received data :  66
Process :  1  , is waiting to receive data from Rank 0
Process :  1 received data :  66
Process :  2  , is waiting to receive data from Rank 0
```

```
Process :  2 received data :  66
Process :  3  , is waiting to receive data from Rank 0
Process :  3 received data :  66
Process :  4  , is waiting to receive data from Rank 0
Process :  4 received data :  66
Process :  5  , is waiting to receive data from Rank 0
Process :  5 received data :  66
Process :  6  , is waiting to receive data from Rank 0
Process :  6 received data :  66
Process :  7  , is waiting to receive data from Rank 0
Process :  7 received data :  66
```

[7]:
```
if rank == 0:
    print("Rank 0 is scattering")
else:
    print("Process : ", rank, " , is waiting to receive scattered data from␣
 ↪Rank 0")

if rank == 0:
    send_data = np.arange(size) * 10
else:
    send_data = None

recv_data = np.empty(1, dtype=int)
comm.Scatter(send_data, recv_data, root=0)

print("Process : ", rank, "received data : ", recv_data[0])
```

```
Rank 0 is scattering
Process :  0 received data :  0
```

[8]:
```
!mpiexec -n 10 python scatter.py
```

```
Process :  8  , is waiting to receive scattered data from Rank 0
Process :  8 received data :  80
Rank 0 is scattering
Process :  0 received data :  0
Process :  1  , is waiting to receive scattered data from Rank 0
Process :  1 received data :  10
Process :  4  , is waiting to receive scattered data from Rank 0
Process :  4 received data :  40
Process :  2  , is waiting to receive scattered data from Rank 0
Process :  2 received data :  20
Process :  5  , is waiting to receive scattered data from Rank 0
Process :  5 received data :  50
Process :  6  , is waiting to receive scattered data from Rank 0
Process :  6 received data :  60
Process :  3  , is waiting to receive scattered data from Rank 0
Process :  3 received data :  30
```

```
Process :  9  , is waiting to receive scattered data from Rank 0
Process :  9 received data :  90
Process :  7  , is waiting to receive scattered data from Rank 0
Process :  7 received data :  70
```

[9]:
```python
local_sum = np.random.randint(0, 100)

if rank == 0:
    print("Rank 0 is gathering")

global_sums = None
if rank == 0:
    global_sums = np.empty(size, dtype=int)
comm.Gather(np.array(local_sum, dtype=int), global_sums, root=0)

if rank == 0:
    print("Rank 0 gathered the following local sums : ", global_sums)
```

```
Rank 0 is gathering
Rank 0 gathered the following local sums :  [77]
```

[10]:
```
!mpiexec -n 10 python gather.py
```

```
Rank 0 is gathering
Rank 0 gathered the following local sums :  [25  4 22 96 94 95 54 17 40 76]
```

HPC-19-2

February 21, 2024

1 Assignment 11 (Canon's Matrix Multiplication)

1. Describe Canon's Matrix Multiplication algorithm.

A. Cannon's algorithm is a distributed matrix multiplication algorithm that works particularly well with two-dimensional meshes. Lynn Elliot Cannon described it for the first time in 1969.

```
Algorithm Overview:

* When multiplying two n × n matrices A and B, we need n × n processing nodes
arranged in a 2D.
* Each processing node (PE) performs the following steps:
1. Initialize: k = (i + j) mod n (to ensure different processors access distinct data).
2. Compute: c[i][j] += a[i][k] × b[k][j] concurrently.
3. Communicate:
    * Send a to PE (i, (j + N - 1) mod n).
    * Send b to PE ((i + N - 1) mod n, j).
    * Receive a' from PE (i, (j + 1) mod n).
    * Receive b' from PE ((i + 1) mod n, j).
4. Update: a = a' and b = b'.

* Repeat the above steps for n iterations, ensuring that each processor accesses
different matrix elements.
* The storage requirements remain constant and independent of the number of processors.
```

2. Implement Canon's Matrix Multiplication using collective communication.
3. Analyze the efficiency of the code.

[1]:
```
from mpi4py import MPI
import numpy as np
```

[2]:
```
comm = MPI.COMM_WORLD
rank = comm.Get_rank()
size = comm.Get_size()
```

[3]:
```
import time
import matplotlib.pyplot as plt
```

[4]:
```
N = 2000
```

[5]:
```
if N % size != 0:
    raise ValueError("Matrix size N must be divisible by the number of␣
 ↪processes (size)")

block_size = N // size

print(f"Rank {rank}: Starting execution")

if rank == 0:
    print(f"Rank {rank}: Generating matrices A and B")
    A = np.random.randint(0, 10, (N, N))
    B = np.random.randint(0, 10, (N, N))
    print(f"Rank {rank}: Matrices A and B generated")
else:
    A = None
    B = None

print(f"Rank {rank}: Broadcasting matrices A and B")
```

```
Rank 0: Starting execution
Rank 0: Generating matrices A and B
Rank 0: Matrices A and B generated
Rank 0: Broadcasting matrices A and B
```

[6]:
```
start_time = time.time()
A = comm.bcast(A, root=0)
B = comm.bcast(B, root=0)
end_time = time.time()
print(f"Rank {rank}: Matrices A and B broadcasted")
```

```
Rank 0: Matrices A and B broadcasted
```

[7]:
```
A_rows = np.zeros((block_size, N), dtype=int)
comm.Scatter(A, A_rows, root=0)

start_time_multiplication = time.time()
C_rows = np.dot(A_rows, B)
end_time_multiplication = time.time()

C = None
if rank == 0:
    C = np.zeros((N, N), dtype=int)

comm.Gather(C_rows, C, root=0)

if rank == 0:
    print("Resultant Matrix C:")
    print(C)
```

```
    print("Broadcasting time:", end_time - start_time, "seconds")
    print("Matrix multiplication time:", end_time_multiplication -␣
 ↪start_time_multiplication, "seconds")
```

```
Resultant Matrix C:
[[40747 41349 41354 … 41260 41169 39328]
 [39955 41279 41428 … 40482 42471 40155]
 [40196 41163 40919 … 40635 39846 39888]
 …
 [40674 41117 40256 … 40439 39831 39460]
 [39447 40800 40591 … 40467 40723 40124]
 [40330 40734 40834 … 41727 41303 40117]]
Broadcasting time: 0.039728403091430664 seconds
Matrix multiplication time: 20.929131031036377 seconds
```

[8]:
```
!mpiexec -n 4 python mpi_scatter_gather.py
```

```
Rank 3: Starting execution
Rank 3: Broadcasting matrices A and B
Rank 3: Matrices A and B broadcasted
Rank 1: Starting execution
Rank 1: Broadcasting matrices A and B
Rank 1: Matrices A and B broadcasted
Rank 2: Starting execution
Rank 2: Broadcasting matrices A and B
Rank 2: Matrices A and B broadcasted
Rank 0: Starting execution
Rank 0: Generating matrices A and B
Rank 0: Matrices A and B generated
Rank 0: Broadcasting matrices A and B
Rank 0: Matrices A and B broadcasted
Resultant Matrix C:
[[41048 39762 40853 … 41543 41611 39830]
 [40264 38648 41718 … 40252 40400 39149]
 [41054 40522 41801 … 41724 41400 41007]
 …
 [41452 39388 41118 … 41178 40805 40147]
 [39720 38856 40107 … 40178 40473 39127]
 [40218 38532 40695 … 40379 40558 39088]]
Broadcasting time: 0.03373289108276367 seconds
Matrix multiplication time: 4.518505096435547 seconds
```

[9]:
```
!mpiexec -n 8 python mpi_scatter_gather.py
```

```
Rank 5: Starting execution
Rank 5: Broadcasting matrices A and B
Rank 5: Matrices A and B broadcasted
Rank 7: Starting execution
Rank 7: Broadcasting matrices A and B
```

```
Rank 7: Matrices A and B broadcasted
Rank 6: Starting execution
Rank 6: Broadcasting matrices A and B
Rank 6: Matrices A and B broadcasted
Rank 1: Starting execution
Rank 1: Broadcasting matrices A and B
Rank 1: Matrices A and B broadcasted
Rank 3: Starting execution
Rank 3: Broadcasting matrices A and B
Rank 3: Matrices A and B broadcasted
Rank 2: Starting execution
Rank 2: Broadcasting matrices A and B
Rank 2: Matrices A and B broadcasted
Rank 4: Starting execution
Rank 4: Broadcasting matrices A and B
Rank 4: Matrices A and B broadcasted
Rank 0: Starting execution
Rank 0: Generating matrices A and B
Rank 0: Matrices A and B generated
Rank 0: Broadcasting matrices A and B
Rank 0: Matrices A and B broadcasted
Resultant Matrix C:
[[39642 40083 40950 … 41662 41105 40729]
 [40628 40791 40643 … 41148 41905 39657]
 [40344 41142 40593 … 42146 42763 40476]
 …
 [39234 39860 40460 … 40807 40930 40160]
 [38715 39396 39736 … 41051 39867 39587]
 [40204 40537 40572 … 41915 41841 40698]]
Broadcasting time: 0.066436767578125 seconds
Matrix multiplication time: 2.638921022415161 seconds
```

[10]:
```
!mpiexec -n 16 python mpi_scatter_gather.py
```

```
Rank 5: Starting execution
Rank 5: Broadcasting matrices A and B
Rank 5: Matrices A and B broadcasted
Rank 15: Starting execution
Rank 15: Broadcasting matrices A and B
Rank 15: Matrices A and B broadcasted
Rank 9: Starting execution
Rank 9: Broadcasting matrices A and B
Rank 9: Matrices A and B broadcasted
Rank 11: Starting execution
Rank 11: Broadcasting matrices A and B
Rank 11: Matrices A and B broadcasted
Rank 10: Starting execution
Rank 10: Broadcasting matrices A and B
```

```
Rank 10: Matrices A and B broadcasted
Rank 1: Starting execution
Rank 1: Broadcasting matrices A and B
Rank 1: Matrices A and B broadcasted
Rank 3: Starting execution
Rank 3: Broadcasting matrices A and B
Rank 3: Matrices A and B broadcasted
Rank 2: Starting execution
Rank 2: Broadcasting matrices A and B
Rank 2: Matrices A and B broadcasted
Rank 7: Starting execution
Rank 7: Broadcasting matrices A and B
Rank 7: Matrices A and B broadcasted
Rank 6: Starting execution
Rank 6: Broadcasting matrices A and B
Rank 6: Matrices A and B broadcasted
Rank 4: Starting execution
Rank 4: Broadcasting matrices A and B
Rank 4: Matrices A and B broadcasted
Rank 13: Starting execution
Rank 13: Broadcasting matrices A and B
Rank 13: Matrices A and B broadcasted
Rank 14: Starting execution
Rank 14: Broadcasting matrices A and B
Rank 14: Matrices A and B broadcasted
Rank 12: Starting execution
Rank 12: Broadcasting matrices A and B
Rank 12: Matrices A and B broadcasted
Rank 8: Starting execution
Rank 8: Broadcasting matrices A and B
Rank 8: Matrices A and B broadcasted
Rank 0: Starting execution
Rank 0: Generating matrices A and B
Rank 0: Matrices A and B generated
Rank 0: Broadcasting matrices A and B
Rank 0: Matrices A and B broadcasted
Resultant Matrix C:
[[39895 40041 38242 … 39939 39545 40169]
 [39345 39674 38612 … 39800 40560 38977]
 [40013 39937 38095 … 40518 41096 40771]
 …
 [40008 39913 39012 … 39942 41684 39822]
 [41780 41378 40286 … 41451 42157 41894]
 [40301 40239 39599 … 39864 40844 40837]]
Broadcasting time: 0.22203373908996582 seconds
Matrix multiplication time: 3.5083491802215576 seconds
```

[11]:
```
N = 2000
if N % size != 0:
    raise ValueError("Matrix size N must be divisible by the number of␣
 ↪processes (size)")

block_size = N // size

print(f"Rank {rank}: Starting execution")

if rank == 0:
    print(f"Rank {rank}: Generating matrices A and B")
    A = np.random.randint(0, 10, (N, N))
    B = np.random.randint(0, 10, (N, N))
    print(f"Rank {rank}: Matrices A and B generated")
else:
    A = None
    B = None

print(f"Rank {rank}: Broadcasting matrices A and B")
```

```
Rank 0: Starting execution
Rank 0: Generating matrices A and B
Rank 0: Matrices A and B generated
Rank 0: Broadcasting matrices A and B
```

[12]:
```
start_time = time.time()
A = comm.bcast(A, root=0)
B = comm.bcast(B, root=0)
end_time = time.time()
print(f"Rank {rank}: Matrices A and B broadcasted")

A_rows = np.zeros((block_size, N), dtype=int)
comm.Scatter(A, A_rows, root=0)

start_time_multiplication = time.time()
C_rows = np.dot(A_rows, B)
end_time_multiplication = time.time()

start_time_gather = time.time()
C_all = np.zeros((N, N), dtype=int)
comm.Allgather(C_rows, C_all)
end_time_gather = time.time()

if rank == 0:
    print("Resultant Matrix C:")
    print(C_all)
    print("Broadcasting time:", end_time - start_time, "seconds")
```

```
    print("Gathering time:", end_time_gather - start_time_gather, "seconds")
    print("Matrix multiplication time:", end_time_multiplication -␣
↪start_time_multiplication, "seconds")
```

```
Rank 0: Matrices A and B broadcasted
Resultant Matrix C:
[[40262 41419 41149 … 40627 41185 39118]
 [40512 40635 39829 … 40602 41313 39061]
 [41364 40627 40990 … 40016 41141 40741]
 …
 [40798 40859 41008 … 39674 40921 40082]
 [40201 40859 40919 … 40100 40550 39726]
 [41429 40674 40897 … 39753 41346 39610]]
Broadcasting time: 0.036681175231933594 seconds
Gathering time: 0.007696866989135742 seconds
Matrix multiplication time: 21.168152570724487 seconds
```

[13]:
```
!mpiexec -n 4 python MPI_Allgather.py
```

```
Rank 3: Starting execution
Rank 3: Broadcasting matrices A and B
Rank 3: Matrices A and B broadcasted
Rank 1: Starting execution
Rank 1: Broadcasting matrices A and B
Rank 1: Matrices A and B broadcasted
Rank 2: Starting execution
Rank 2: Broadcasting matrices A and B
Rank 2: Matrices A and B broadcasted
Rank 0: Starting execution
Rank 0: Generating matrices A and B
Rank 0: Matrices A and B generated
Rank 0: Broadcasting matrices A and B
Rank 0: Matrices A and B broadcasted
Resultant Matrix C:
[[39268 39927 39869 … 39620 39577 39546]
 [40260 41715 40449 … 41332 40204 40137]
 [39132 40005 39775 … 40137 39549 40140]
 …
 [40205 40717 40398 … 40964 40263 40094]
 [40544 41437 40248 … 42028 40126 40540]
 [40018 40157 40004 … 41190 39445 40415]]
Broadcasting time: 0.031401872634887695 seconds
Gathering time: 0.011379480361938477 seconds
Matrix multiplication time: 4.781134605407715 seconds
```

[14]:
```
!mpiexec -n 8 python MPI_Allgather.py
```

```
Rank 3: Starting execution
Rank 3: Broadcasting matrices A and B
```

```
Rank 3: Matrices A and B broadcasted
Rank 2: Starting execution
Rank 2: Broadcasting matrices A and B
Rank 2: Matrices A and B broadcasted
Rank 4: Starting execution
Rank 4: Broadcasting matrices A and B
Rank 4: Matrices A and B broadcasted
Rank 7: Starting execution
Rank 7: Broadcasting matrices A and B
Rank 7: Matrices A and B broadcasted
Rank 1: Starting execution
Rank 1: Broadcasting matrices A and B
Rank 1: Matrices A and B broadcasted
Rank 0: Starting execution
Rank 0: Generating matrices A and B
Rank 0: Matrices A and B generated
Rank 0: Broadcasting matrices A and B
Rank 0: Matrices A and B broadcasted
Resultant Matrix C:
[[40351 39324 40644 … 40178 40722 38738]
 [41633 41139 41735 … 41205 41598 40359]
 [42168 40904 41892 … 40341 42459 40579]
 …
 [41025 40337 40735 … 41337 41649 40040]
 [39452 38465 39429 … 39067 39286 38344]
 [41148 40563 41671 … 41142 41364 40395]]
Broadcasting time: 0.06987953186035156 seconds
Gathering time: 0.05123305320739746 seconds
Matrix multiplication time: 2.8613476753234863 seconds
Rank 5: Starting execution
Rank 5: Broadcasting matrices A and B
Rank 5: Matrices A and B broadcasted
Rank 6: Starting execution
Rank 6: Broadcasting matrices A and B
Rank 6: Matrices A and B broadcasted
```

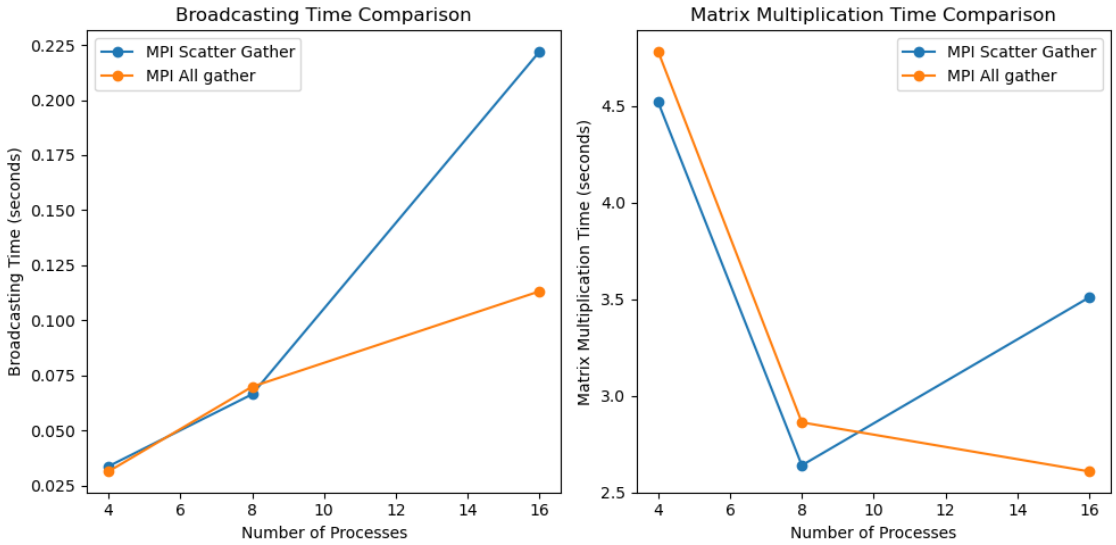
[15]:
```
!mpiexec -n 16 python MPI_Allgather.py
```

```
Rank 9: Starting execution
Rank 9: Broadcasting matrices A and B
Rank 9: Matrices A and B broadcasted
Rank 10: Starting execution
Rank 10: Broadcasting matrices A and B
Rank 10: Matrices A and B broadcasted
Rank 7: Starting execution
Rank 7: Broadcasting matrices A and B
Rank 7: Matrices A and B broadcasted
Rank 8: Starting execution
```

```
Rank 8: Broadcasting matrices A and B
Rank 8: Matrices A and B broadcasted
Rank 5: Starting execution
Rank 5: Broadcasting matrices A and B
Rank 5: Matrices A and B broadcasted
Rank 6: Starting execution
Rank 6: Broadcasting matrices A and B
Rank 6: Matrices A and B broadcasted
Rank 11: Starting execution
Rank 11: Broadcasting matrices A and B
Rank 11: Matrices A and B broadcasted
Rank 13: Starting execution
Rank 13: Broadcasting matrices A and B
Rank 13: Matrices A and B broadcasted
Rank 12: Starting execution
Rank 12: Broadcasting matrices A and B
Rank 12: Matrices A and B broadcasted
Rank 0: Starting execution
Rank 0: Generating matrices A and B
Rank 0: Matrices A and B generated
Rank 0: Broadcasting matrices A and B
Rank 0: Matrices A and B broadcasted
Resultant Matrix C:
[[40098 40513 39370 … 40675 40116 40372]
 [40373 40444 39136 … 40684 39919 40297]
 [40017 40324 39607 … 39830 40199 39921]
 …
 [40336 40603 39674 … 40866 39942 40451]
 [40586 40233 39441 … 40566 39837 40573]
 [40127 41018 40006 … 41142 40468 40251]]
Broadcasting time: 0.11317896842956543 seconds
Gathering time: 0.7809598445892334 seconds
Matrix multiplication time: 2.607423782348633 seconds
Rank 14: Starting execution
Rank 14: Broadcasting matrices A and B
Rank 14: Matrices A and B broadcasted
Rank 15: Starting execution
Rank 15: Broadcasting matrices A and B
Rank 15: Matrices A and B broadcasted
Rank 1: Starting execution
Rank 1: Broadcasting matrices A and B
Rank 1: Matrices A and B broadcasted
Rank 2: Starting execution
Rank 2: Broadcasting matrices A and B
Rank 2: Matrices A and B broadcasted
Rank 4: Starting execution
Rank 4: Broadcasting matrices A and B
Rank 4: Matrices A and B broadcasted
```

```
Rank 3: Starting execution
Rank 3: Broadcasting matrices A and B
Rank 3: Matrices A and B broadcasted
```

[22]:
```
scatter_gather_processes = [4, 8, 16]
scatter_gather_broadcasting_time = [0.03373289108276367, 0.066436767578125, 0.
 ↪22203373908996582]
scatter_gather_multiplication_time = [4.518505096435547, 2.638921022415161, 3.
 ↪5083491802215576]

allgather_processes = [4, 8, 16]
allgather_broadcasting_time = [0.031401872634887695,0.06987953186035156, 0.
 ↪11317896842956543]
allgather_multiplication_time = [4.781134605407715 ,2.8613476753234863, 2.
 ↪607423782348633]

plt.figure(figsize=(10, 5))

plt.subplot(1, 2, 1)
plt.plot(scatter_gather_processes, scatter_gather_broadcasting_time,␣
 ↪marker='o', label='MPI Scatter Gather')
plt.plot(allgather_processes, allgather_broadcasting_time, marker='o',␣
 ↪label='MPI All gather')
plt.xlabel('Number of Processes')
plt.ylabel('Broadcasting Time (seconds)')
plt.title('Broadcasting Time Comparison')
plt.legend()

plt.subplot(1, 2, 2)
plt.plot(scatter_gather_processes, scatter_gather_multiplication_time,␣
 ↪marker='o', label='MPI Scatter Gather')
plt.plot(allgather_processes, allgather_multiplication_time, marker='o',␣
 ↪label='MPI All gather')
plt.xlabel('Number of Processes')
plt.ylabel('Matrix Multiplication Time (seconds)')
plt.title('Matrix Multiplication Time Comparison')
plt.legend()

plt.tight_layout()
plt.show()
```


Broadcasting Time Comparison
MPI Scatter Gather
MPI All gather
Broadcasting Time (seconds)
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
4
6
8
10
12
14
16
Number of Processes
Matrix Multiplication Time Comparison
MPI Scatter Gather
MPI All gather
Matrix Multiplication Time (seconds)
4.5
4.0
3.5
3.0
2.5
4
6
8
10
12
14
16
Number of Processes

HPC_Assignment_12

February 22, 2024

1 Assignment 12 (Derived_data_Type)

1. Write about derived data types used in MPI programming.

- Derived data types in MPI (Message Passing Interface) programming are custom data structures formed by combining basic MPI data types such as integers, floating-point numbers, and characters. These custom data types enable the efficient transmission of complex data structures between MPI processes. Structures, arrays of structures, and arrays of arrays are examples of common derived data types.

2. Steps to create and use derived data types.

- The Procedure to Create and Use Derived Data Types in MPI:
  - Define the data type's structure using the MPI_Type_struct function.
  - Use the MPI_Type_create_struct function to specify the displacement and size of each element in the structure.
  - Use MPI_Type_commit to commit the newly created data type.
  - Use the derived data type for MPI communication functions like MPI_Send and MPI_Recv.

3. Write its uses.

- Applications of derived data types in MPI:
  - Efficient transmission of complex data structures: Derived data types enable the transmission of structured data, such as arrays or nested structures, via a single MPI communication call.
  - Improved performance: By using custom data types tailored to the application's data layout, MPI communication can be made more efficient.
  - Simplified communication code: Derived data types abstract the complexities of data transmission, making code cleaner and easier to maintain.

4. Implement communication of derived data using one suitable example.

[1]:
```
from mpi4py import MPI
import numpy as np
```

[2]:
```
comm = MPI.COMM_WORLD
rank = comm.Get_rank()
size = comm.Get_size()
```

[23]:
```
class Particle:
    def __init__(self, x, y):
        self.x = x
        self.y = y

send_data = None
if rank == 0:
    send_data = Particle(6, 46)

recv_data = comm.scatter([send_data] * size, root=0)

print(f"Process {rank} received data: x={recv_data.x}, y={recv_data.y}")

MPI.Finalize()
```

```
Process 0 received data: x=6, y=46
```

[24]:
```
!mpiexec -n 8 python as-12.py
```

```
Process 5 received data: x=6, y=46
Process 4 received data: x=6, y=46
Process 1 received data: x=6, y=46
Process 0 received data: x=6, y=46
Process 2 received data: x=6, y=46
Process 3 received data: x=6, y=46
Process 6 received data: x=6, y=46
Process 7 received data: x=6, y=46
```

[25]:
```
!mpiexec -n 16 python as-12.py
```

```
Process 2 received data: x=6, y=46
Process 9 received data: x=6, y=46
Process 1 received data: x=6, y=46
Process 10 received data: x=6, y=46
Process 7 received data: x=6, y=46
Process 8 received data: x=6, y=46
Process 3 received data: x=6, y=46
Process 6 received data: x=6, y=46
Process 13 received data: x=6, y=46
Process 11 received data: x=6, y=46
Process 5 received data: x=6, y=46
Process 12 received data: x=6, y=46
Process 14 received data: x=6, y=46
Process 4 received data: x=6, y=46
Process 15 received data: x=6, y=46
Process 0 received data: x=6, y=46
```

Assignment 13

Device Query

❖ Try the below mentioned commands, explain their task in one line and paste the output for each of them.

- All commands run under the WSL (windows subsystem for linux).

➢ **lshw (List Hardware)**

This command list all the hardware details of system. By default it give all of the information to get an specific information command can be filter as below :

sudo lshw -C [option]

Option	usage
network	Gets the details of the network hardware devices.
memory	Displays the details of RAM.
storage	Show the details of the storage.
system	show the details of the motherboard and other things.
multimedia	Details of the sound card of system.
display	Know more about what is powering the display output.
bridge	Displays info about the PCIe bridges.
bus	It will list down buses and their details.
CPU	List the processor details

Output :

```
kavan@Kavan:~$ lshw
WARNING: you should run this program as super-user.
kavan
    description: Computer
    width: 64 bits
    capabilities: smp vsyscall32
  *-core
       description: Motherboard
       physical id: 0
     *-memory
          description: System memory
          physical id: 0
          size: 8064MiB
     *-cpu
          product: 13th Gen Intel(R) Core(TM) i7-13620H
          vendor: Intel Corp.
          physical id: 1
          bus info: cpu@0
          version: 6.186.2
          width: 64 bits
          capabilities: fpu fpu_exception wp vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat pse36 clflush mmx fxsr sse sse2 ss ht syscall nx pdpe1gb rdtscp x86-64 constant_tsc rep_good nopl xtopology tsc_reliable nonstop_tsc cpuid pni pclmulqdq vmx ssse3 fma cx16 sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave avx f16c rdrand hypervisor lahf_lm abm 3dnowprefetch ssbd ibrs ibpb stibp ibrs_enhanced tpr_shadow vnmi ept vpid ept_ad fsgsbase tsc_adjust bmi1 avx2 smep bmi2 erms invpcid rdseed adx smap clflushopt clwb sha_ni xsaveopt xsavec xgetbv1 xsaves avx_vnni umip waitpkg gfni vaes vpclmulqdq rdpid movdiri movdir64b fsrm serialize flush_l1d arch_capabilities
          configuration: microcode=4294967295
     *-generic
```

description: System peripheral

product: Virtio file system

vendor: Red Hat, Inc.

physical id: 2

bus info: pci@4257:00:00.0

version: 01

width: 64 bits

clock: 33MHz

capabilities: bus_master cap_list

configuration: driver=virtio-pci latency=64

resources: iomemory:e0-df iomemory:e0-df iomemory:c0-bf irq:0 memory:e00000000-e00000fff memory:e00001000-e00001fff memory:c00000000-dfffffff

*-virtio1 UNCLAIMED

description: Virtual I/O device

physical id: 0

bus info: virtio@1

configuration: driver=virtiofs

*-display:0

description: 3D controller

product: Microsoft Corporation

vendor: Microsoft Corporation

physical id: 3

bus info: pci@8383:00:00.0

version: 00

width: 32 bits

clock: 33MHz

capabilities: bus_master cap_list

configuration: driver=dxgkrnl latency=0

resources: irq:0

```
   *-scsi
        description: SCSI storage controller
        product: Virtio console
        vendor: Red Hat, Inc.
        physical id: 4
        bus info: pci@8f33:00:00.0
        version: 01
        width: 64 bits
        clock: 33MHz
        capabilities: scsi bus_master cap_list
        configuration: driver=virtio-pci latency=64
        resources: iomemory:90-8f iomemory:90-8f iomemory:90-8f irq:0
memory:9ffe00000-9ffe00fff memory:9ffe01000-9ffe01fff memory:9ffe02000-9ffe02fff
      *-virtio0 UNCLAIMED
           description: Virtual I/O device
           physical id: 0
           bus info: virtio@0
           configuration: driver=virtio_console
   *-display:1
        description: 3D controller
        product: Microsoft Corporation
        vendor: Microsoft Corporation
        physical id: 5
        bus info: pci@abca:00:00.0
        version: 00
        width: 32 bits
        clock: 33MHz
        capabilities: bus_master cap_list
        configuration: driver=dxgkrnl latency=0
        resources: irq:0
```

*-pnp00:00

product: PnP device PNP0b00

physical id: 6

capabilities: pnp

configuration: driver=rtc_cmos

*-network

description: Ethernet interface

physical id: 1

logical name: eth0

serial: 00:15:5d:ba:ac:bb

size: 10Gbit/s

capabilities: ethernet physical

configuration: autonegotiation=off broadcast=yes driver=hv_netvsc driverversion=5.15.146.1-microsoft-standard-W duplex=full firmware=N/A ip=172.19.231.200 link=yes multicast=yes speed=10Gbit/s

WARNING: output may be incomplete or inaccurate, you should run this program as super-user.

- **lsusb (List USB Devices)**

The lsusb command is a utility in Linux that allows users to list the USB (Universal Serial Bus) devices connected to the system.

Output :

kavan@Kavan:~$ lsusb

Bus 002 Device 001: ID 1d6b:0003 Linux Foundation 3.0 root hub

Bus 001 Device 001: ID 1d6b:0002 Linux Foundation 2.0 root hub

- **lspci (List PCI Devices)**

The lspci (list PCI) command is a Linux utility that displays detailed information about all PCI buses and devices in the system. It is based on the libpci library, which provides access to the PCI configuration space on a variety of operating systems.

Output :

kavan@Kavan:~$ lspci

4257:00:00.0 System peripheral: Red Hat, Inc. Virtio file system (rev 01)

8383:00:00.0 3D controller: Microsoft Corporation Device 008e

8f33:00:00.0 SCSI storage controller: Red Hat, Inc. Virtio console (rev 01)

abca:00:00.0 3D controller: Microsoft Corporation Device 008e

- **lsblk (List Block Devices)**

The 'lsblk' stands for 'list block devices', The lsblk command is a Linux command-line utility that lists information about all block devices on the system. This includes hard disk drives (HDDs), solid-state drives (SSDs), optical drives, and other storage devices.

Output :

kavan@Kavan:~$ lsblk

NAME MAJ:MIN RM SIZE RO TYPE MOUNTPOINTS

sda 8:0 0 388.5M 1 disk

sdb 8:16 0 2G 0 disk [SWAP]

sdc 8:32 0 1T 0 disk /snap

/mnt/wslg/distro

/

- **lscpu (List CPU)**

The lscpu command displays a variety of information about the CPU architecture, including The number of CPUs, The number of threads, The number of cores, The number of sockets, The cache details, The CPU architecture, The CPU vendor, The CPU model, The CPU frequency, The CPU flags.

Output :

kavan@Kavan:~$ lscpu

Architecture: x86_64

CPU op-mode(s): 32-bit, 64-bit

Address sizes: 39 bits physical, 48 bits virtual

Byte Order: Little Endian

CPU(s): 16

On-line CPU(s) list: 0-15

Vendor ID: GenuineIntel

Model name: 13th Gen Intel(R) Core(TM) i7-13620H

CPU family: 6

Model: 186

Thread(s) per core: 2

Core(s) per socket: 8

Socket(s): 1

Stepping: 2

BogoMIPS: 5836.79

Flags: fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat pse36 clflush mmx fxsr sse sse2 ss ht syscall nx pdpe1gb rdtscp lm constant_tsc rep_good

nopl xtopology tsc_reliable nonstop_tsc cpuid pni pclmulqdq vmx ssse3 fma cx16 sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave avx f16c rd

rand hypervisor lahf_lm abm 3dnowprefetch ssbd ibrs ibpb stibp ibrs_enhanced tpr_shadow vnmi ept vpid ept_ad fsgsbase tsc_adjust bmi1 avx2 smep bmi2 erms

invpcid rdseed adx smap clflushopt clwb sha_ni xsaveopt xsavec xgetbv1 xsaves avx_vnni umip waitpkg gfni vaes vpclmulqdq rdpid movdiri movdir64b fsrm seri

alize flush_l1d arch_capabilities

Virtualization features:

Virtualization: VT-x

Hypervisor vendor: Microsoft

Virtualization type: full

Caches (sum of all):

L1d: 384 KiB (8 instances)

L1i: 256 KiB (8 instances)

L2: 10 MiB (8 instances)

L3: 24 MiB (1 instance)

Vulnerabilities:

Gather data sampling: Not affected

Itlb multihit: Not affected

L1tf: Not affected

Mds: Not affected

Meltdown: Not affected

Mmio stale data: Not affected

Retbleed: Mitigation; Enhanced IBRS

Spec rstack overflow: Not affected

Spec store bypass: Mitigation; Speculative Store Bypass disabled via prctl and seccomp

Spectre v1: Mitigation; usercopy/swapgs barriers and __user pointer sanitization

Spectre v2: Mitigation; Enhanced IBRS, IBPB conditional, RSB filling, PBRSB-eIBRS SW sequence

Srbds: Not affected

Tsx async abort: Not affected

- **df (Disk Free)**

The df command in Linux is used to display the amount of disk space available on the filesystem. The FileSystem parameter specifies the name of the device on which the file system resides, the directory on which the file system is mounted, or the relative path name of a file system.

Output :

kavan@Kavan:~$ df

Filesystem 1K-blocks Used Available Use% Mounted on

none 3997904 4 3997900 1% /mnt/wsl

none 395990012 136101968 259888044 35% /usr/lib/wsl/drivers

none 3997904 0 3997904 0% /usr/lib/modules

```
none          3997904       0   3997904   0% /usr/lib/modules/5.15.146.1-microsoft-standard-WSL2
/dev/sdc     1055762868   1902524 1000156872   1% /
none          3997904      84   3997820   1% /mnt/wslg
none          3997904       0   3997904   0% /usr/lib/wsl/lib
rootfs        3994648    1884   3992764   1% /init
none          3997904     808   3997096   1% /run
none          3997904       0   3997904   0% /run/lock
none          3997904       0   3997904   0% /run/shm
tmpfs            4096       0      4096   0% /sys/fs/cgroup
none          3997904      76   3997828   1% /mnt/wslg/versions.txt
none          3997904      76   3997828   1% /mnt/wslg/doc
C:\         395990012 136101968  259888044  35% /mnt/c
D:\         601881596 406166716  195714880  68% /mnt/d
G:\          15728640  12185968    3542672  78% /mnt/g
H:\          15728640    458840   15269800   3% /mnt/h
I:\          15728640    786924   14941716   6% /mnt/i
J:\         395990012 149096372  246893640  38% /mnt/j
snapfuse          128      128        0 100% /snap/bare/5
snapfuse        75776    75776        0 100% /snap/core22/864
snapfuse        93952    93952        0 100% /snap/gtk-common-themes/1535
snapfuse        41856    41856        0 100% /snap/snapd/20290
snapfuse       134272   134272        0 100% /snap/ubuntu-desktop-installer/1276
snapfuse       134912   134912        0 100% /snap/ubuntu-desktop-installer/1286
```

- **ip a (IP Address)**

The ip a command in Linux is used to display the network interface addresses and routing table of the system. This will display a list of all the network interfaces on the system, along with their IP addresses, subnet masks, and default gateways.

Output :

kavan@Kavan:~$ ip a

1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group default qlen 1000

link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00

inet 127.0.0.1/8 scope host lo

valid_lft forever preferred_lft forever

inet6 ::1/128 scope host

valid_lft forever preferred_lft forever

2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc mq state UP group default qlen 1000

link/ether 00:15:5d:ba:ac:bb brd ff:ff:ff:ff:ff:ff

inet 172.19.231.200/20 brd 172.19.239.255 scope global eth0

valid_lft forever preferred_lft forever

inet6 fe80::215:5dff:feba:acbb/64 scope link

valid_lft forever preferred_lft forever

- **top**

The top command in Linux is a very useful tool for monitoring system performance. It provides a real-time view of running processes, CPU and memory usage, and other system information. the list shows the process ID (PID), username, CPU usage, memory usage, and command name.

Output :

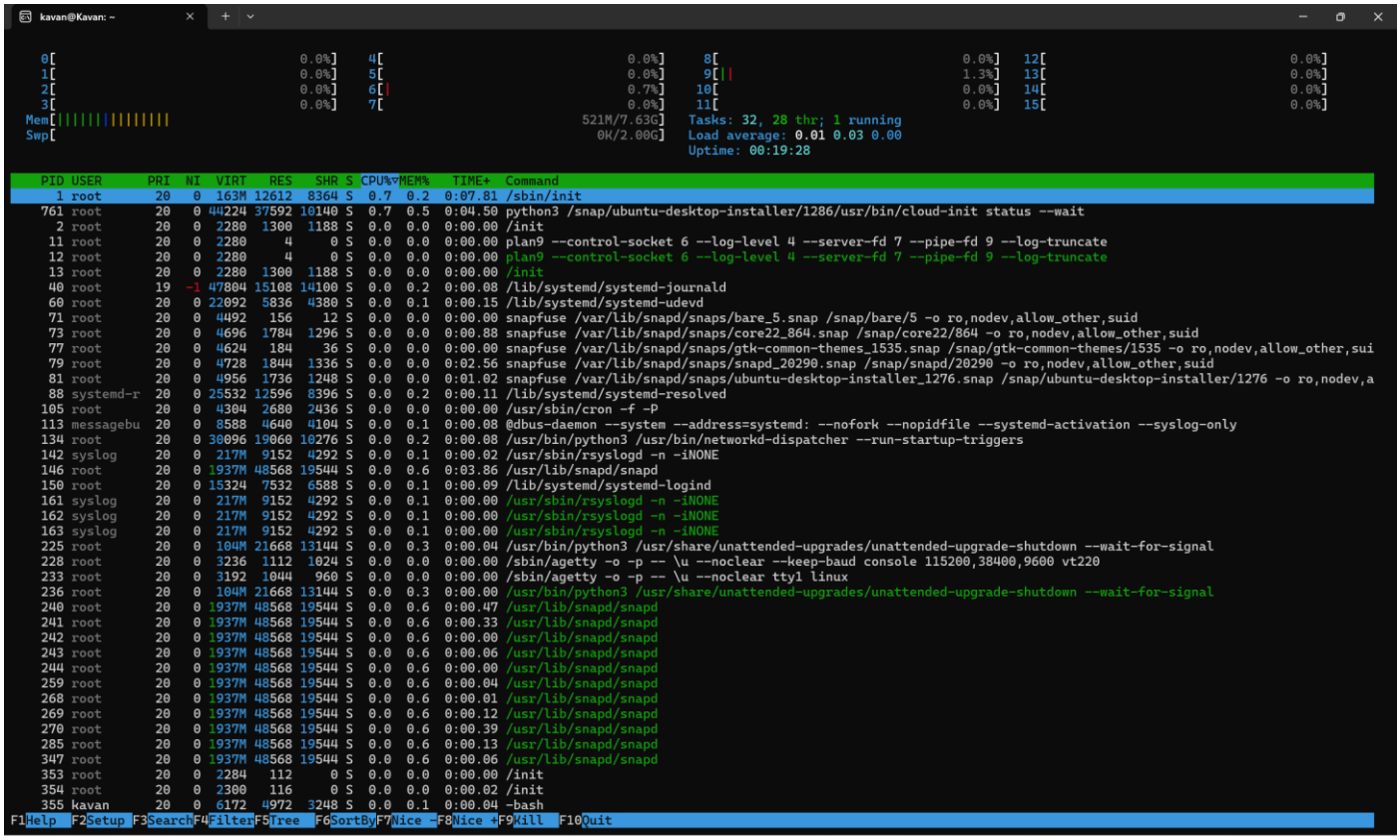
```
kavan@Kavan:~$ top
top - 20:14:07 up 41 min,  1 user,  load average: 0.02, 0.01, 0.00
Tasks:  33 total,   1 running,  32 sleeping,   0 stopped,   0 zombie
%Cpu(s):  0.1 us,  0.1 sy,  0.0 ni, 99.8 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
MiB Mem :   7808.4 total,   6951.5 free,    507.2 used,    349.7 buff/cache
MiB Swap:   2048.0 total,   2048.0 free,      0.0 used.   7071.6 avail Mem

    PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
      1 root      20   0  165860  11216   8244 S   1.0   0.1   0:21.48 systemd
    426 root      20   0   44224  38752  10428 S   0.7   0.5   0:12.13 python3
      2 root      20   0    2280   1300   1188 S   0.0   0.0   0:00.00 init-systemd(Ub
     11 root      20   0    2280      4      0 S   0.0   0.0   0:00.00 init
     40 root      19  -1   47732  15248  14248 S   0.0   0.2   0:00.09 systemd-journal
     60 root      20   0   22092   6040   4544 S   0.0   0.1   0:00.21 systemd-udevd
     71 root      20   0    4848   1808   1340 S   0.0   0.0   0:00.91 snapfuse
     72 root      20   0    4492    180     36 S   0.0   0.0   0:00.00 snapfuse
     75 root      20   0    4624    160      8 S   0.0   0.0   0:00.00 snapfuse
     80 root      20   0    4492    168     20 S   0.0   0.0   0:00.00 snapfuse
     83 root      20   0    4764   1764   1228 S   0.0   0.0   0:02.56 snapfuse
     87 root      20   0    4492    160      8 S   0.0   0.0   0:00.00 snapfuse
     89 root      20   0    4760   1780   1228 S   0.0   0.0   0:01.10 snapfuse
     96 systemd+  20   0   25532  12780   8492 S   0.0   0.2   0:00.09 systemd-resolve
    137 root      20   0    4304   2656   2416 S   0.0   0.0   0:00.00 cron
    143 message+  20   0    8584   4616   4072 S   0.0   0.1   0:00.02 dbus-daemon
    158 root      20   0   30096  19212  10432 S   0.0   0.2   0:00.06 networkd-dispat
    160 syslog    20   0  222400   7084   4272 S   0.0   0.1   0:00.02 rsyslogd
    162 root      20   0 2058580  48152  19360 S   0.0   0.6   0:00.73 snapd
    163 root      20   0   15324   7456   6512 S   0.0   0.1   0:00.07 systemd-logind
    217 root      20   0    4780   3352   3108 S   0.0   0.0   0:00.06 subiquity-serve
    225 root      20   0    3236   1084    996 S   0.0   0.0   0:00.00 agetty
    228 root      20   0    3192   1168   1080 S   0.0   0.0   0:00.00 agetty
    239 root      20   0  107224  21372  13268 S   0.0   0.3   0:00.04 unattended-upgr
    364 root      20   0  934936  87296  24796 S   0.0   1.1   0:04.26 python3.10
    369 root      20   0    2284    112      0 S   0.0   0.0   0:00.00 SessionLeader
    370 root      20   0    2300    116      0 S   0.0   0.0   0:00.00 Relay(371)
    371 kavan     20   0    6208   5064   3344 S   0.0   0.1   0:00.02 bash
    372 root      20   0    7516   4864   3948 S   0.0   0.1   0:00.00 login
    408 kavan     20   0   16916   9024   7564 S   0.0   0.1   0:00.03 systemd
    409 kavan     20   0  168912   3424     12 S   0.0   0.0   0:00.00 (sd-pam)
    414 kavan     20   0    6120   4968   3384 S   0.0   0.1   0:00.01 bash
  10182 kavan     20   0    7940   3700   3104 R   0.0   0.0   0:00.02 top
```

- **htop**

The htop command is a Linux system monitor that provides real-time information about the system's CPU usage, memory, and running processes. It is similar to the top command, but it offers a number of advantages, including:

A more user-friendly interface, The ability to sort processes by different criteria, The ability to kill processes directly from the htop interface, The ability to view detailed information about individual processes

Output :



➢ **nvidia-smi**

The nvidia-smi command is a Linux command-line utility that provides monitoring and management capabilities for NVIDIA GPUs. this displays an status of an NVIDIA GPU, such as its temperature, utilization, and memory usage.

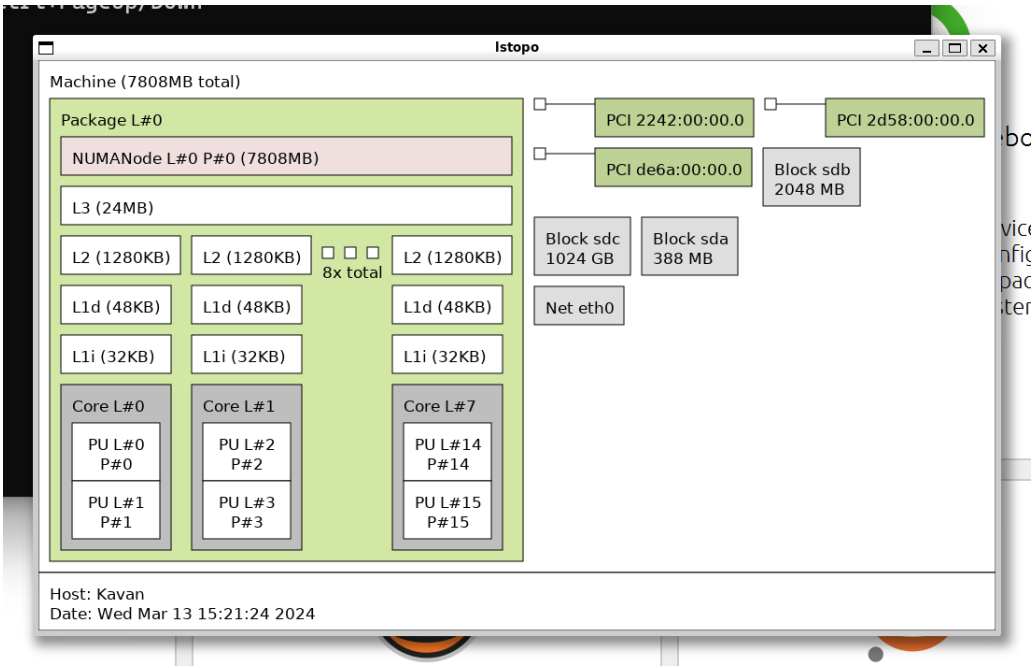
Output :

```
kavan@Kavan:~$ nvidia-smi
Wed Mar 13 20:32:45 2024
+-----------------------------------------------------------------------------------------+
| NVIDIA-SMI 550.60.01              Driver Version: 551.76         CUDA Version: 12.4     |
|-----------------------------------------+------------------------+----------------------+
| GPU  Name                 Persistence-M | Bus-Id          Disp.A | Volatile Uncorr. ECC |
| Fan  Temp   Perf          Pwr:Usage/Cap |           Memory-Usage | GPU-Util  Compute M. |
|                                         |                        |               MIG M. |
|=========================================+========================+======================|
|   0  NVIDIA GeForce RTX 4060 ...    On |   00000000:01:00.0  On |                  N/A |
| N/A   69C    P0             94W /  120W |    5205MiB /   8188MiB |     99%      Default |
|                                         |                        |                  N/A |
+-----------------------------------------+------------------------+----------------------+

+-----------------------------------------------------------------------------------------+
| Processes:                                                                              |
|  GPU   GI   CI        PID   Type   Process name                              GPU Memory |
|        ID   ID                                                               Usage      |
|=========================================================================================|
|  No running processes found                                                             |
+-----------------------------------------------------------------------------------------+
```

➢ lstopo

The lstopo command is a Linux command that displays the topology of a system. This means that it shows how the different hardware components of the system are connected to each other.

Output :



➢ numactl

The numactl command is a utility that allows users to control the NUMA (Non-Uniform Memory Access) policy for processes or shared memory. It can be used to set the memory and processor affinity of a process, as well as to set a persistent policy for shared memory segments or files.

Output :

kavan@Kavan:~$ numactl

usage: numactl [--all | -a] [--interleave= | -i <nodes>] [--preferred= | -p <node>]

[--physcpubind= | -C <cpus>] [--cpunodebind= | -N <nodes>]

[--membind= | -m <nodes>] [--localalloc | -l] command args ...

numactl [--show | -s]

numactl [--hardware | -H]

numactl [--length | -l <length>] [--offset | -o <offset>] [--shmmode | -M <shmmode>]

[--strict | -t]

[--shmid | -I <id>] --shm | -S <shmkeyfile>

[--shmid | -I <id>] --file | -f <tmpfsfile>

[--huge | -u] [--touch | -T]

memory policy | --dump | -d | --dump-nodes | -D

memory policy is --interleave | -i, --preferred | -p, --membind | -m, --localalloc | -l

<nodes> is a comma delimited list of node numbers or A-B ranges or all.

Instead of a number a node can also be:

netdev:DEV the node connected to network device DEV

file:PATH the node the block device of path is connected to

ip:HOST the node of the network device host routes through

block:PATH the node of block device path

pci:[seg:]bus:dev[:func] The node of a PCI device

<cpus> is a comma delimited list of cpu numbers or A-B ranges or all

all ranges can be inverted with !

all numbers and ranges can be made cpuset-relative with +

the old --cpubind argument is deprecated.

use --cpunodebind or --physcpubind instead

<length> can have g (GB), m (MB) or k (KB) suffixes

- **sar**

The sar (System Activity Reporter) command is used for monitoring system performance in Linux. It can be used to collect, report, and save system activity information, such as CPU usage, memory usage, I/O activity, and network traffic.

Output :

To generate a report of CPU usage every second for 5 seconds, used the following command:

sar -u 1 5

```
kavan@Kavan:~$ sar -u 1 5
Linux 5.15.146.1-microsoft-standard-WSL2 (Kavan)        03/13/24        _x86_64_        (16 CPU)

22:16:09        CPU     %user     %nice   %system   %iowait    %steal     %idle
22:16:10        all      0.12      0.00      0.06      0.00      0.00     99.81
22:16:11        all      0.06      0.00      0.12      0.00      0.00     99.81
22:16:12        all      0.06      0.00      0.00      0.00      0.00     99.94
22:16:13        all      0.06      0.00      0.06      0.00      0.00     99.87
22:16:14        all      0.12      0.00      0.00      0.00      0.00     99.88
Average:        all      0.09      0.00      0.05      0.00      0.00     99.86
```

To generate a report of memory usage every minute for 5 minutes, used the following command:

sar -r 60 5

```
kavan@Kavan:~$ sar -r 10 5
Linux 5.15.146.1-microsoft-standard-WSL2 (Kavan)        03/13/24        _x86_64_        (16 CPU)

22:16:18    kbmemfree   kbavail kbmemused  %memused kbbuffers  kbcached  kbcommit   %commit  kbactive   kbinact   kbdirty
22:16:28      6701132   7181868    508012      6.35     15140    662072    889324      8.81    135180    792420         0
22:16:38      6701196   7181932    507944      6.35     15140    662072    889324      8.81    135180    792484         0
22:16:48      6701200   7181936    507936      6.35     15140    662072    889324      8.81    135180    792488         0
22:16:58      6700988   7181724    508140      6.36     15140    662072    889324      8.81    135180    792488         0
22:17:08      6700508   7181248    508604      6.36     15148    662072    889324      8.81    135180    792472        20
Average:      6701005   7181742    508127      6.35     15142    662072    889324      8.81    135180    792470         4
```

To generate a report of I/O activity every 1 seconds for 5 seconds, used the following command:

sar -d 5 30

```
kavan@Kavan:~$ sar -d 1 5
Linux 5.15.146.1-microsoft-standard-WSL2 (Kavan)        03/13/24        _x86_64_        (16 CPU)

22:18:34          DEV       tps     rkB/s     wkB/s     dkB/s   areq-sz    aqu-sz     await     %util
22:18:35          sda      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
22:18:35          sdb      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
22:18:35          sdc      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

22:18:35          DEV       tps     rkB/s     wkB/s     dkB/s   areq-sz    aqu-sz     await     %util
22:18:36          sda      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
22:18:36          sdb      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
22:18:36          sdc      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

22:18:36          DEV       tps     rkB/s     wkB/s     dkB/s   areq-sz    aqu-sz     await     %util
22:18:37          sda      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
22:18:37          sdb      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
22:18:37          sdc      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

22:18:37          DEV       tps     rkB/s     wkB/s     dkB/s   areq-sz    aqu-sz     await     %util
22:18:38          sda      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
22:18:38          sdb      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
22:18:38          sdc      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

22:18:38          DEV       tps     rkB/s     wkB/s     dkB/s   areq-sz    aqu-sz     await     %util
22:18:39          sda      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
22:18:39          sdb      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
22:18:39          sdc      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

Average:          DEV       tps     rkB/s     wkB/s     dkB/s   areq-sz    aqu-sz     await     %util
Average:          sda      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
Average:          sdb      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
Average:          sdc      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
```

all_in_mac

March 28, 2024

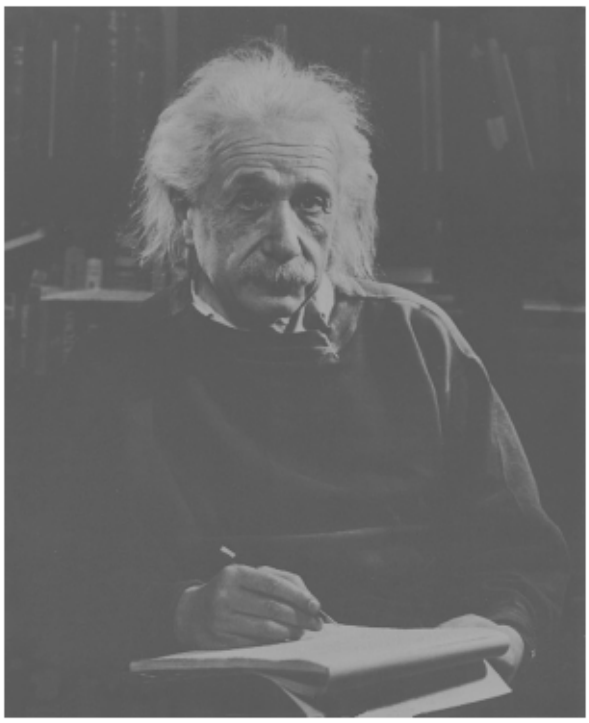
1 Image Filtering

[1]:
```
import cv2
import numpy as np
import matplotlib.pyplot as plt
from PIL import Image, ImageFilter
# from google.colab.patches import cv2_imshow
from skimage.filters import threshold_local
from matplotlib.gridspec import GridSpec
```

```
D:\anaconda\Lib\site-packages\paramiko\transport.py:219:
CryptographyDeprecationWarning: Blowfish has been deprecated
  "class": algorithms.Blowfish,
```

[2]:
```
image_path = "I:\My␣
 ↪Drive\Image_filtering\images\images\Fig0354(a)(einstein_orig).tif"
original_image = cv2.imread(image_path)
```

[3]:
```
plt.imshow(original_image)
plt.axis('off')  # Hide axis
plt.show()
```

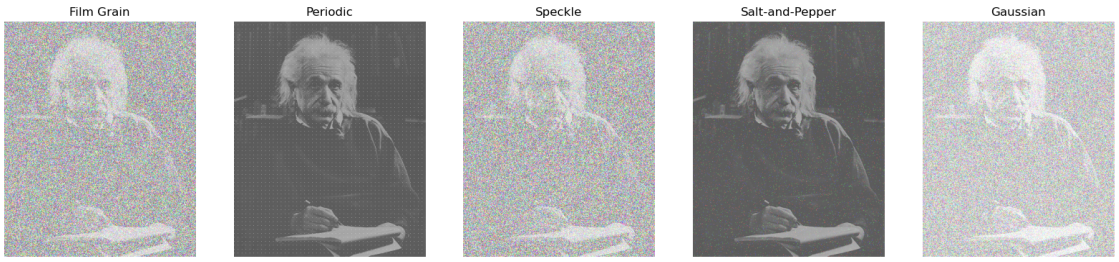


1.1 Image nosing

[4]:
```
if original_image is None:
    print("Error: Unable to load the image.")
else:
    def generate_film_grain(image):
        film_grain_noise = np.random.normal(loc=0, scale=20, size=image.shape).
 ↪astype(np.uint8)
        return cv2.add(image, film_grain_noise)

    def generate_periodic(image):
        periodic_noise = np.zeros(image.shape, dtype=np.uint8)
        periodic_noise[::10, ::10, :] = 255
        return cv2.add(image, periodic_noise)

    def generate_speckle(image):
        speckle_noise = np.random.normal(loc=0, scale=0.1, size=image.shape) *␣
 ↪255
        return cv2.add(image, speckle_noise.astype(np.uint8))

    def generate_salt_and_pepper(image):
        salt_pepper_noise = np.random.choice([0, 255], size=image.shape[:2] +␣
 ↪(image.shape[2],), p=[0.99, 0.01]).astype(np.uint8)
```

```
        return cv2.add(image, salt_pepper_noise)

    def generate_gaussian(image):
        gaussian_noise = np.random.normal(loc=0, scale=100, size=image.shape).
↪astype(np.uint8)
        return cv2.add(image, gaussian_noise)

    noise_generators = {
        'Film Grain': generate_film_grain,
        'Periodic': generate_periodic,
        'Speckle': generate_speckle,
        'Salt-and-Pepper': generate_salt_and_pepper,
        'Gaussian': generate_gaussian
    }

    noisy_images = {noise_type: noise_generator(original_image) for noise_type,␣
↪noise_generator in noise_generators.items()}
```

[5]:
```
plt.figure(figsize=(20, 10))
for i, (noise_type, noisy_image) in enumerate(noisy_images.items(), start=1):
        plt.subplot(1, len(noisy_images), i)
        plt.imshow(cv2.cvtColor(noisy_image, cv2.COLOR_BGR2RGB))
        plt.title(noise_type)
        plt.axis('off')
plt.show()
```



1.2 Linear Filtering

1.2.1 Box Filter

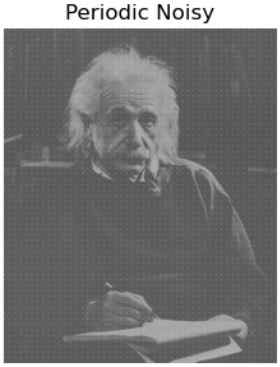
[6]:
```
def apply_box_filter(image):
    return cv2.boxFilter(image, -1, (5, 5))

plt.figure(figsize=(8, 15))

for noise_type, noisy_image in noisy_images.items():
```

```
    plt.subplot(len(noisy_images), 2, 2*(list(noisy_images.keys()).
 ↪index(noise_type)) + 1)
    plt.imshow(cv2.cvtColor(noisy_image, cv2.COLOR_BGR2RGB))
    plt.title(noise_type + ' Noisy', fontsize=12)
    plt.axis('off')

    box_filtered = apply_box_filter(noisy_image)

    plt.subplot(len(noisy_images), 2, 2*(list(noisy_images.keys()).
 ↪index(noise_type)) + 2)
    plt.imshow(cv2.cvtColor(box_filtered, cv2.COLOR_BGR2RGB))
    plt.title(noise_type + ' Box Filtered', fontsize=12)
    plt.axis('off')

plt.tight_layout()
plt.savefig('box_filter_ppt.png', bbox_inches='tight')
plt.show()
```

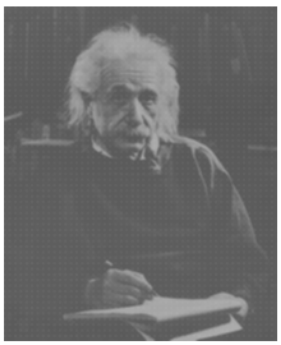
Film Grain Noisy

Film Grain Box Filtered

Periodic Noisy



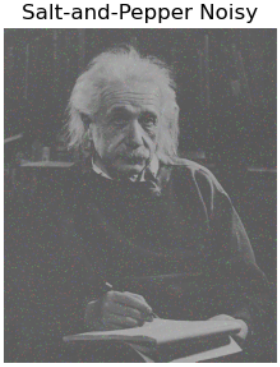
Periodic Box Filtered



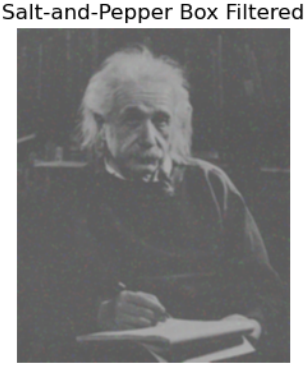
Speckle Noisy

Speckle Box Filtered

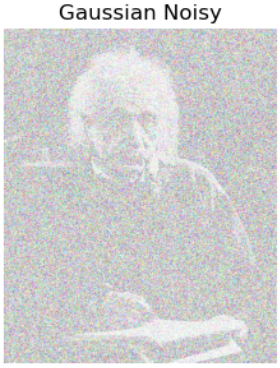
Salt-and-Pepper Noisy



Salt-and-Pepper Box Filtered



Gaussian Noisy



Gaussian Box Filtered

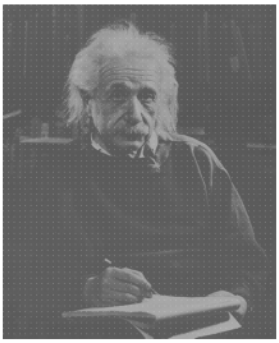
1.2.2 Gaussian Filter

[7]:
```
def apply_gaussian_filter(image):
    return cv2.GaussianBlur(image, (11, 11), sigmaX=1.5)

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items()):
    plt.subplot(len(noisy_images), 2, 2*i + 1)
    plt.imshow(cv2.cvtColor(noisy_image, cv2.COLOR_BGR2RGB))
    plt.title(noise_type + ' Noisy', fontsize=12)
    plt.axis('off')

    gaussian_filtered = apply_gaussian_filter(noisy_image)

    plt.subplot(len(noisy_images), 2, 2*i + 2)
    plt.imshow(cv2.cvtColor(gaussian_filtered, cv2.COLOR_BGR2RGB))
    plt.title(noise_type + ' Gaussian Filtered', fontsize=12)
    plt.axis('off')

plt.tight_layout()
plt.savefig('gaussian_filter_ppt.png', bbox_inches='tight')
plt.show()
```

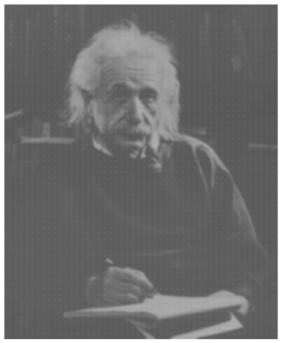
Film Grain Noisy

Film Grain Gaussian Filtered

Periodic Noisy



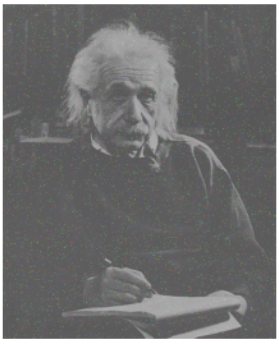
Periodic Gaussian Filtered



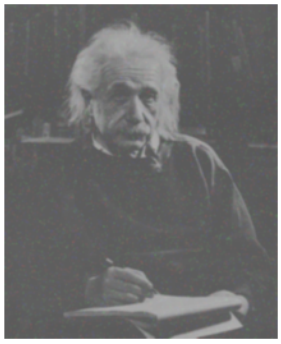
Speckle Noisy

Speckle Gaussian Filtered

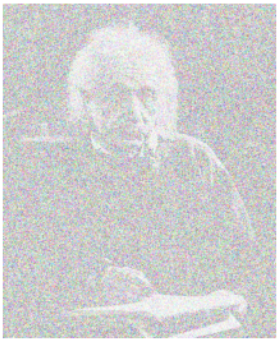
Salt-and-Pepper Noisy



Salt-and-Pepper Gaussian Filtered



Gaussian Noisy



Gaussian Gaussian Filtered

1.2.3 Sobel

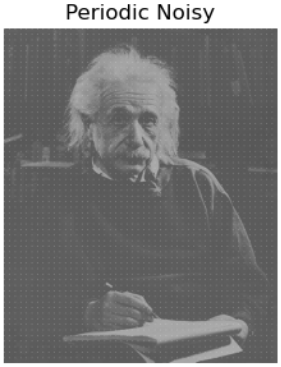
[8]:
```
if original_image is None:
    print("Error: Unable to load the image.")
else:
    sobel_x = cv2.Sobel(original_image, cv2.CV_64F, 1, 0, ksize=3)
    sobel_y = cv2.Sobel(original_image, cv2.CV_64F, 0, 1, ksize=3)

    sobel_mag = np.sqrt(sobel_x**2 + sobel_y**2)

    threshold = 38
    sobel_edges = np.where(sobel_mag > threshold, 255, 0).astype(np.uint8)

    plt.figure(figsize=(10, 5))
    plt.subplot(1, 2, 1)
    plt.imshow(original_image, cmap='gray')
    plt.title('Original Image')
    plt.axis('off')

    plt.subplot(1, 2, 2)
    plt.imshow(sobel_edges, cmap='gray')
    plt.title('Sobel Edges')
    plt.axis('off')

    plt.savefig('sobel_filter_ppt.png', bbox_inches='tight')
    plt.show()
```

[9]:
```python
def detect_edges(image):
    sobel_x = cv2.Sobel(image, cv2.CV_64F, 1, 0, ksize=3)
    sobel_y = cv2.Sobel(image, cv2.CV_64F, 0, 1, ksize=3)
    sobel_mag = np.sqrt(sobel_x**2 + sobel_y**2)
    threshold = 70
    sobel_edges = np.where(sobel_mag > threshold, 255, 0).astype(np.uint8)
    return sobel_edges

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items()):
    plt.subplot(len(noisy_images), 2, 2*i + 1)
    plt.imshow(cv2.cvtColor(noisy_image, cv2.COLOR_BGR2RGB))
    plt.title(noise_type + ' Noisy', fontsize=12)
    plt.axis('off')

    plt.subplot(len(noisy_images), 2, 2*i + 2)
    edges = detect_edges(cv2.cvtColor(noisy_image, cv2.COLOR_BGR2GRAY))
    plt.imshow(edges, cmap='gray')
    plt.title(noise_type + ' Edges', fontsize=12)
    plt.axis('off')

plt.tight_layout()
plt.savefig('sobel_filter2_ppt.png', bbox_inches='tight')
plt.show()
```

Film Grain Noisy

Film Grain Edges

Periodic Noisy

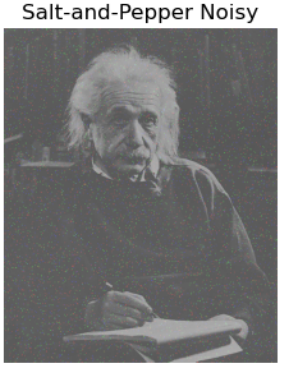


Periodic Edges

Speckle Noisy

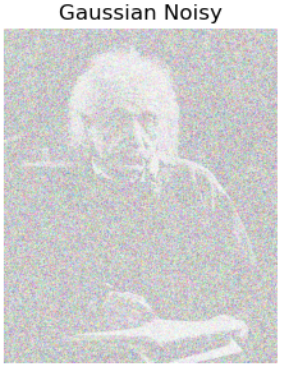
Speckle Edges

Salt-and-Pepper Noisy



Salt-and-Pepper Edges

Gaussian Noisy



Gaussian Edges

1.3 Non-linear Filtering

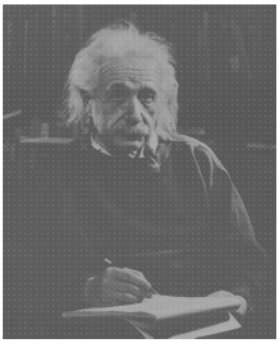
1.3.1 Median Filter

[10]:
```
def apply_median_filter(image):
    return cv2.medianBlur(image, 5)

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items()):
    plt.subplot(len(noisy_images), 2, 2*i + 1)
    plt.imshow(cv2.cvtColor(noisy_image, cv2.COLOR_BGR2RGB))
    plt.title(noise_type + ' Noisy', fontsize=12)
    plt.axis('off')

    noisy_image_gray = cv2.cvtColor(noisy_image, cv2.COLOR_BGR2GRAY)
    median_filtered = apply_median_filter(noisy_image_gray)

    plt.subplot(len(noisy_images), 2, 2*i + 2)
    plt.imshow(median_filtered, cmap='gray')
    plt.title(noise_type + ' Median Filtered', fontsize=12)
    plt.axis('off')

plt.tight_layout()
plt.savefig('median_filter_ppt.png', bbox_inches='tight')
plt.show()
```

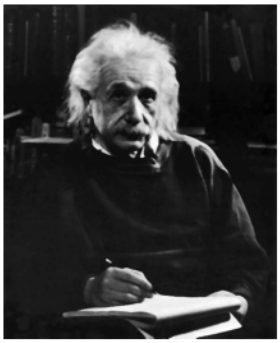
Film Grain Noisy

Film Grain Median Filtered

Periodic Noisy



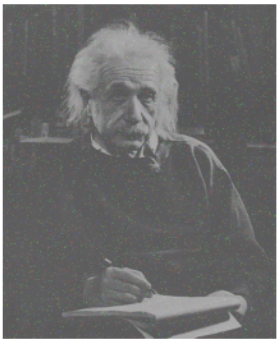
Periodic Median Filtered



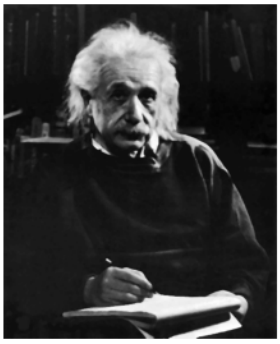
Speckle Noisy

Speckle Median Filtered

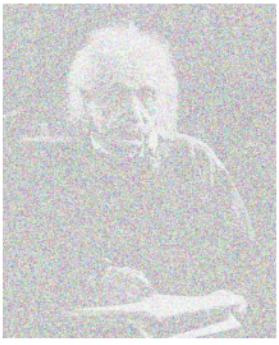
Salt-and-Pepper Noisy



Salt-and-Pepper Median Filtered



Gaussian Noisy



Gaussian Median Filtered

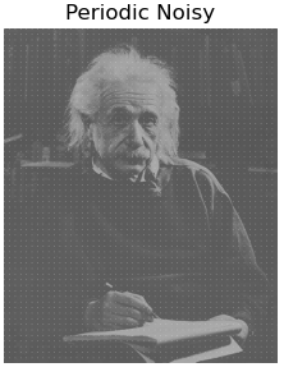
1.3.2 Rank Filter

[11]:
```
def apply_rank_filter(image):
    kernel_size = 3
    rank = 4

    padded_image = cv2.copyMakeBorder(image, 1, 1, 1, 1, cv2.BORDER_REPLICATE)
    filtered_image = np.zeros_like(image)

    for y in range(image.shape[0]):
        for x in range(image.shape[1]):
            neighborhood = padded_image[y:y+kernel_size, x:x+kernel_size]
            sorted_neighborhood = np.sort(neighborhood.flatten())
            filtered_image[y, x] = sorted_neighborhood[rank]

    return filtered_image

num_noises = len(noisy_images)
num_images = num_noises

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items()):
    plt.subplot(len(noisy_images), 2, 2*i + 1)
    plt.imshow(cv2.cvtColor(noisy_image, cv2.COLOR_BGR2RGB))
    plt.title(noise_type + ' Noisy', fontsize=12)
    plt.axis('off')

    noisy_image_gray = cv2.cvtColor(noisy_image, cv2.COLOR_BGR2GRAY)
    rank_filtered = apply_rank_filter(noisy_image_gray)

    plt.subplot(len(noisy_images), 2, 2*i + 2)
    plt.imshow(rank_filtered, cmap='gray')
    plt.title(noise_type + ' Rank Filtered', fontsize=12)
    plt.axis('off')

plt.tight_layout()
plt.savefig('rank_filter_ppt.png', bbox_inches='tight')
plt.show()
```

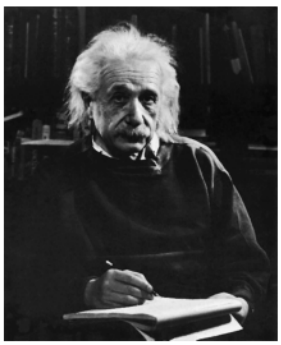
Film Grain Noisy

Film Grain Rank Filtered

Periodic Noisy



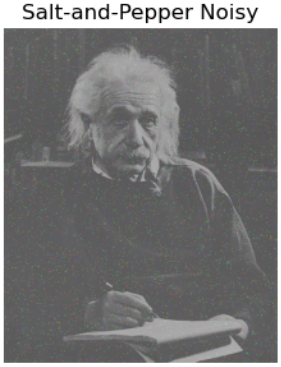
Periodic Rank Filtered



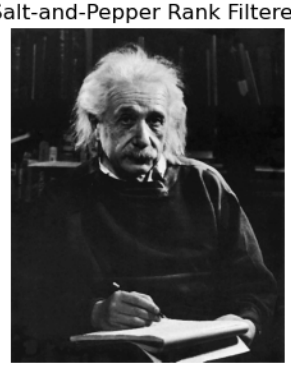
Speckle Noisy

Speckle Rank Filtered

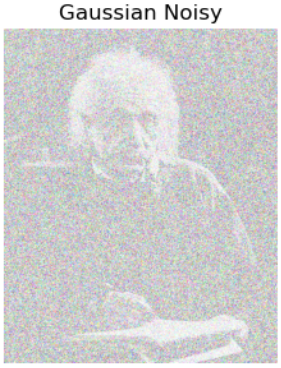
Salt-and-Pepper Noisy



Salt-and-Pepper Rank Filtered



Gaussian Noisy



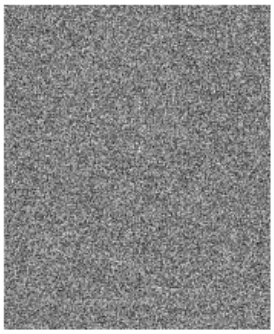
Gaussian Rank Filtered

1.3.3 Adaptive Filter

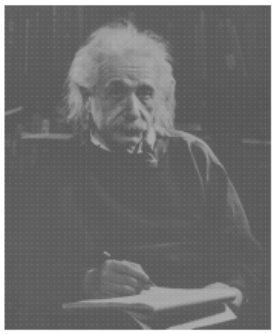
[12]:
```
def apply_adaptive_filter(image):
    gray_image = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)
    return cv2.adaptiveThreshold(gray_image, 255, cv2.
 ↪ADAPTIVE_THRESH_GAUSSIAN_C, cv2.THRESH_BINARY, 11, 2)

num_noises = len(noisy_images)
num_images = num_noises + 1

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items(), start=1):
    plt.subplot(num_images, 2, i * 2 - 1)
    plt.imshow(cv2.cvtColor(noisy_image, cv2.COLOR_BGR2RGB))
    plt.title(noise_type + ' Noisy')
    plt.axis('off')

    adaptive_filtered = apply_adaptive_filter(noisy_image)

    plt.subplot(num_images, 2, i * 2)
    plt.imshow(adaptive_filtered, cmap='gray')
    plt.title(noise_type + ' Adaptive Filtered')
    plt.axis('off')

plt.tight_layout()
plt.savefig('adaptive_filter_ppt.png', bbox_inches='tight')
plt.show()
```

Film Grain Noisy

Film Grain Adaptive Filtered



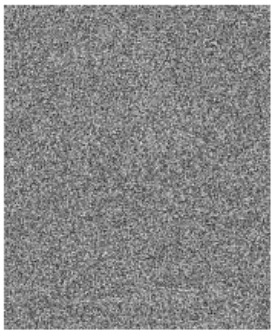
Periodic Noisy



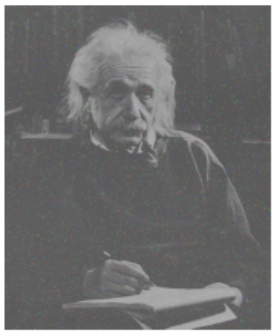
Periodic Adaptive Filtered

Speckle Noisy

Speckle Adaptive Filtered



Salt-and-Pepper Noisy



Salt-and-Pepper Adaptive Filtered

Gaussian Noisy

Gaussian Adaptive Filtered

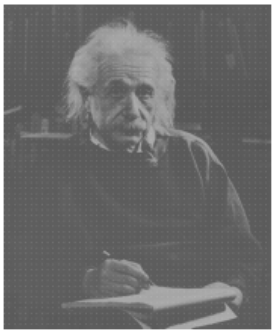
1.3.4 Bilateral Filter

[13]:
```
def apply_bilateral_filter(image):
    return cv2.bilateralFilter(image, 9, 75, 75)

num_noises = len(noisy_images)
num_images = num_noises + 1

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items(), start=1):
    plt.subplot(num_images, 2, i * 2 + 1)
    plt.imshow(cv2.cvtColor(noisy_image, cv2.COLOR_BGR2RGB))
    plt.title(noise_type + ' Noisy')
    plt.axis('off')

    bilateral_filtered = apply_bilateral_filter(noisy_image)

    plt.subplot(num_images, 2, i * 2 + 2)
    plt.imshow(cv2.cvtColor(bilateral_filtered, cv2.COLOR_BGR2RGB))
    plt.title(noise_type + ' Bilateral Filtered')
    plt.axis('off')

plt.tight_layout()
plt.savefig('bilateral_filter_ppt.png', bbox_inches='tight')
plt.show()
```

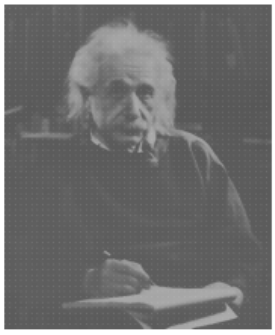
Film Grain Noisy

Film Grain Bilateral Filtered

Periodic Noisy



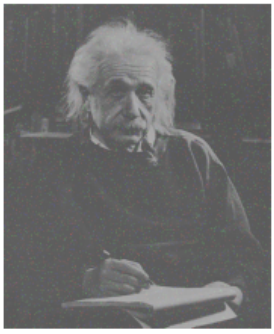
Periodic Bilateral Filtered



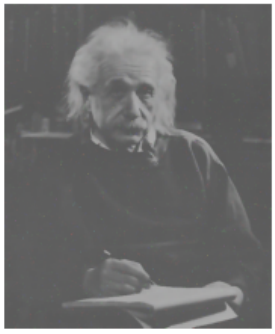
Speckle Noisy

Speckle Bilateral Filtered

Salt-and-Pepper Noisy



Salt-and-Pepper Bilateral Filtered



Gaussian Noisy

Gaussian Bilateral Filtered

2 Image Filtering on colour image

[14]:
```
image_path = "I:/My Drive/Image_filtering/images/images/animated1.jpg"
# image_path = "/Users/user/Downloads/images/animated1.jpg"
bgr_image = cv2.imread(image_path)
original_image = cv2.cvtColor(bgr_image, cv2.COLOR_BGR2RGB)
```

[15]:
```
plt.imshow(original_image)
plt.axis('off')
plt.show()
```

[16]:
```
if original_image is None:
    print("Error: Unable to load the image.")
else:
    def generate_film_grain(image):
        film_grain_noise = np.random.normal(loc=1, scale=1, size=image.shape).
 ↪astype(np.uint8)
        return cv2.add(image, film_grain_noise)

    def generate_periodic(image):
        periodic_noise = np.zeros(image.shape, dtype=np.uint8)
        periodic_noise[::5, ::5, :] = 255
```

```
        return cv2.add(image, periodic_noise)

    def generate_speckle(image):
        speckle_noise = np.random.normal(loc=1, scale=0.5, size=image.shape) *␣
↪255
        return cv2.add(image, speckle_noise.astype(np.uint8))

    def generate_salt_and_pepper(image):
        salt_pepper_noise = np.random.choice([0, 255], size=image.shape[:2] +␣
↪(image.shape[2],), p=[0.89, 0.11]).astype(np.uint8)
        return cv2.add(image, salt_pepper_noise)

    def generate_gaussian(image):
        gaussian_noise = np.random.normal(loc=1, scale=2, size=image.shape).
↪astype(np.uint8)
        return cv2.add(image, gaussian_noise)

    noise_generators = {
        'Film Grain': generate_film_grain,
        'Periodic': generate_periodic,
        'Speckle': generate_speckle,
        'Salt-and-Pepper': generate_salt_and_pepper,
        'Gaussian': generate_gaussian
    }

    noisy_images = {noise_type: noise_generator(original_image) for noise_type,␣
↪noise_generator in noise_generators.items()}
```

[17]:
```
plt.figure(figsize=(15, 15))
for i, (noise_type, noisy_image) in enumerate(noisy_images.items(), start=1):
        plt.subplot(3, 2, i)
        plt.imshow(noisy_image)
        plt.title(noise_type)
        plt.axis('off')
plt.show()
```

2.1 Linear Filtering

2.1.1 BOX Filter

[18]:
```
def apply_box_filter(image):
    return cv2.boxFilter(image, -1, (5, 5))

plt.figure(figsize=(8, 15))

for noise_type, noisy_image in noisy_images.items():
    plt.subplot(len(noisy_images), 2, 2*(list(noisy_images.keys()).
 ↪index(noise_type)) + 1)
```

```
    plt.imshow(noisy_image)
    plt.title(noise_type + ' Noisy', fontsize=12)
    plt.axis('off')

    box_filtered = apply_box_filter(noisy_image)

    plt.subplot(len(noisy_images), 2, 2*(list(noisy_images.keys()).
 ↪index(noise_type)) + 2)
    plt.imshow(box_filtered)
    plt.title(noise_type + ' Box Filtered', fontsize=12)
    plt.axis('off')

plt.tight_layout()
plt.savefig('box_filter_output.png', bbox_inches='tight')
plt.show()
```

Film Grain Noisy

Film Grain Box Filtered

Periodic Noisy

Periodic Box Filtered

Speckle Noisy

Speckle Box Filtered

Salt-and-Pepper Noisy

Salt-and-Pepper Box Filtered

Gaussian Noisy

Gaussian Box Filtered

2.1.2 Gaussian Filter

[19]:
```
def apply_gaussian_filter(image):
    return cv2.GaussianBlur(image, (11, 11), sigmaX=1.5)

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items()):
    plt.subplot(len(noisy_images), 2, 2*i + 1)
    plt.imshow(noisy_image)
    plt.title(noise_type + ' Noisy', fontsize=12)
    plt.axis('off')

    gaussian_filtered = apply_gaussian_filter(noisy_image)

    plt.subplot(len(noisy_images), 2, 2*i + 2)
    plt.imshow(gaussian_filtered)
    plt.title(noise_type + ' Gaussian Filtered', fontsize=12)
    plt.axis('off')

plt.tight_layout()
plt.savefig('gaussian_filter_output.png', bbox_inches='tight')
plt.show()
```

Film Grain Noisy

Film Grain Gaussian Filtered

Periodic Noisy

Periodic Gaussian Filtered

Speckle Noisy

Speckle Gaussian Filtered

Salt-and-Pepper Noisy

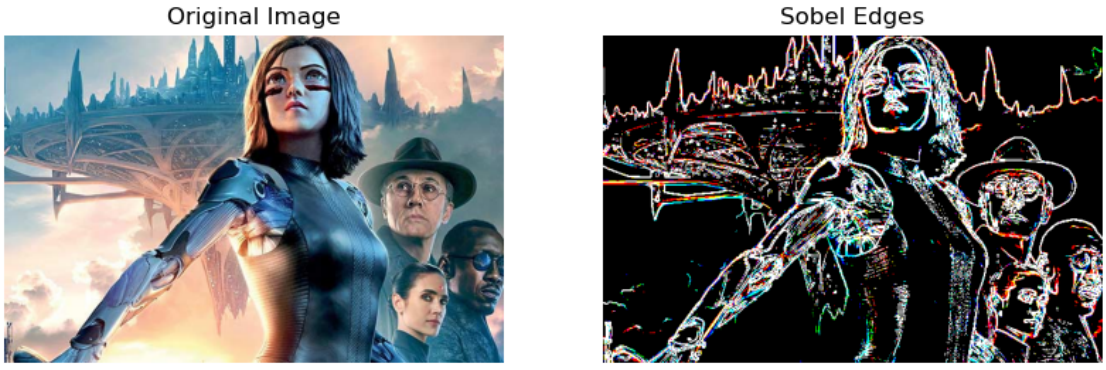
Salt-and-Pepper Gaussian Filtered

Gaussian Noisy

Gaussian Gaussian Filtered

2.1.3 Sobel

[20]:
```
if original_image is None:
    print("Error: Unable to load the image.")
else:
    sobel_x = cv2.Sobel(original_image, cv2.CV_64F, 1, 0, ksize=3)
    sobel_y = cv2.Sobel(original_image, cv2.CV_64F, 0, 1, ksize=3)

    sobel_mag = np.sqrt(sobel_x**2 + sobel_y**2)

    threshold = 130
    sobel_edges = np.where(sobel_mag > threshold, 255, 0).astype(np.uint8)

    plt.figure(figsize=(10, 5))
    plt.subplot(1, 2, 1)
    plt.imshow(original_image, cmap='gray')
    plt.title('Original Image')
    plt.axis('off')

    plt.subplot(1, 2, 2)
    plt.imshow(sobel_edges, cmap='gray')
    plt.title('Sobel Edges')
    plt.axis('off')
    plt.savefig('sobel_filter_output.png', bbox_inches='tight')
    plt.show()
```

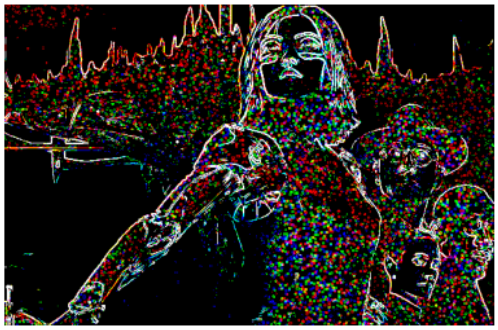


[21]:
```
def detect_edges(image):
    sobel_x = cv2.Sobel(image, cv2.CV_64F, 1, 0, ksize=3)
    sobel_y = cv2.Sobel(image, cv2.CV_64F, 0, 1, ksize=3)
    sobel_mag = np.sqrt(sobel_x**2 + sobel_y**2)
```

```
    threshold = 255
    sobel_edges = np.where(sobel_mag > threshold, 255, 0).astype(np.uint8)
    return sobel_edges

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items()):
    plt.subplot(len(noisy_images), 2, 2*i + 1)
    plt.imshow(noisy_image)
    plt.title(noise_type + ' Noisy', fontsize=12)
    plt.axis('off')

    plt.subplot(len(noisy_images), 2, 2*i + 2)
    edges = detect_edges(noisy_image)
    plt.imshow(edges, cmap='gray')
    plt.title(noise_type + ' Edges', fontsize=12)
    plt.axis('off')

plt.tight_layout()
plt.savefig('sobel_filter2_output.png', bbox_inches='tight')
plt.show()
```

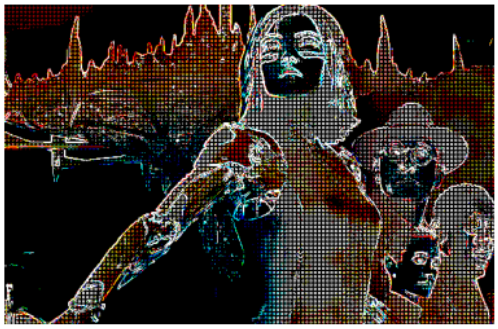
Film Grain Noisy

Film Grain Edges



Periodic Noisy

Periodic Edges



Speckle Noisy

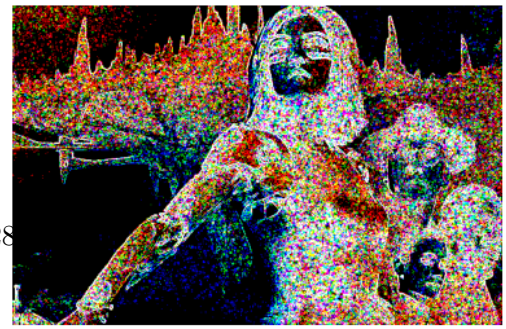
Speckle Edges

Salt-and-Pepper Noisy

Salt-and-Pepper Edges

Gaussian Noisy

Gaussian Edges



2.2 Non-linear Filtering

2.2.1 Median Filter

[22]:
```
def apply_median_filter(image):
    return cv2.medianBlur(image, 5)

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items()):
    plt.subplot(len(noisy_images), 2, 2*i + 1)
    plt.imshow(noisy_image)
    plt.title(noise_type + ' Noisy', fontsize=12)
    plt.axis('off')

    # noisy_image_gray = cv2.cvtColor(noisy_image, cv2.COLOR_BGR2GRAY)
    median_filtered = apply_median_filter(noisy_image)

    plt.subplot(len(noisy_images), 2, 2*i + 2)
    plt.imshow(median_filtered, cmap='gray')
    plt.title(noise_type + ' Median Filtered', fontsize=12)
    plt.axis('off')

plt.tight_layout()
plt.savefig('median_filter_output.png', bbox_inches='tight')
plt.show()
```

Film Grain Noisy

Film Grain Median Filtered

Periodic Noisy

Periodic Median Filtered

Speckle Noisy

Speckle Median Filtered

Salt-and-Pepper Noisy

Salt-and-Pepper Median Filtered

Gaussian Noisy

Gaussian Median Filtered

2.2.2 Rank Filter

[23]:
```
def apply_rank_filter(image):
    kernel_size = 3
    rank = 4

    padded_image = cv2.copyMakeBorder(image, 1, 1, 1, 1, cv2.BORDER_REPLICATE)
    filtered_image = np.zeros_like(image)

    for y in range(image.shape[0]):
        for x in range(image.shape[1]):
            neighborhood = padded_image[y:y+kernel_size, x:x+kernel_size]
            sorted_neighborhood = np.sort(neighborhood.flatten())
            filtered_image[y, x] = sorted_neighborhood[rank]

    return filtered_image

num_noises = len(noisy_images)
num_images = num_noises

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items()):
    plt.subplot(len(noisy_images), 2, 2*i + 1)
    plt.imshow(noisy_image)
    plt.title(noise_type + ' Noisy', fontsize=12)
    plt.axis('off')

    # noisy_image_gray = cv2.cvtColor(noisy_image, cv2.COLOR_BGR2GRAY)
    rank_filtered = apply_rank_filter(noisy_image)

    plt.subplot(len(noisy_images), 2, 2*i + 2)
    plt.imshow(rank_filtered)
    plt.title(noise_type + ' Rank Filtered', fontsize=12)
    plt.axis('off')

plt.tight_layout()
plt.savefig('rank_filter_output.png', bbox_inches='tight')
plt.show()
```

Film Grain Noisy

Film Grain Rank Filtered

Periodic Noisy

Periodic Rank Filtered

Speckle Noisy

Speckle Rank Filtered

Salt-and-Pepper Noisy

Salt-and-Pepper Rank Filtered

Gaussian Noisy

Gaussian Rank Filtered

2.2.3 Adaptive Filter

[24]:
```
def apply_adaptive_filter(image):
    gray_image = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)
    return cv2.adaptiveThreshold(gray_image, 255, cv2.
 ↪ADAPTIVE_THRESH_GAUSSIAN_C, cv2.THRESH_BINARY, 11, 2)

num_noises = len(noisy_images)
num_images = num_noises + 1

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items(), start=1):
    plt.subplot(num_images, 2, i * 2 - 1)
    plt.imshow(noisy_image)
    plt.title(noise_type + ' Noisy')
    plt.axis('off')

    adaptive_filtered = apply_adaptive_filter(noisy_image)

    plt.subplot(num_images, 2, i * 2)
    plt.imshow(adaptive_filtered, cmap='gray')
    plt.title(noise_type + ' Adaptive Filtered')
    plt.axis('off')

plt.tight_layout()
plt.savefig('adaptive_filter_output.png', bbox_inches='tight')
plt.show()
```

Film Grain Noisy

Film Grain Adaptive Filtered

Periodic Noisy

Periodic Adaptive Filtered

Speckle Noisy

Speckle Adaptive Filtered

Salt-and-Pepper Noisy

Salt-and-Pepper Adaptive Filtered

Gaussian Noisy

Gaussian Adaptive Filtered

2.2.4 Bilateral Filter

[25]:
```
def apply_bilateral_filter(image):
    return cv2.bilateralFilter(image, 9, 75, 75)

num_noises = len(noisy_images)
num_images = num_noises + 1

plt.figure(figsize=(8, 15))

for i, (noise_type, noisy_image) in enumerate(noisy_images.items(), start=1):
    plt.subplot(num_images, 2, i * 2 + 1)
    plt.imshow(noisy_image)
    plt.title(noise_type + ' Noisy')
    plt.axis('off')

    bilateral_filtered = apply_bilateral_filter(noisy_image)

    plt.subplot(num_images, 2, i * 2 + 2)
    plt.imshow(bilateral_filtered)
    plt.title(noise_type + ' Bilateral Filtered')
    plt.axis('off')

plt.tight_layout()
# Save the generated output
plt.savefig('output.png', bbox_inches='tight')
plt.savefig('bilateral_filter_output.png', bbox_inches='tight')
plt.show()
```

Film Grain Noisy

Film Grain Bilateral Filtered

Periodic Noisy

Periodic Bilateral Filtered

Speckle Noisy

Speckle Bilateral Filtered

Salt-and-Pepper Noisy

Salt-and-Pepper Bilateral Filtered

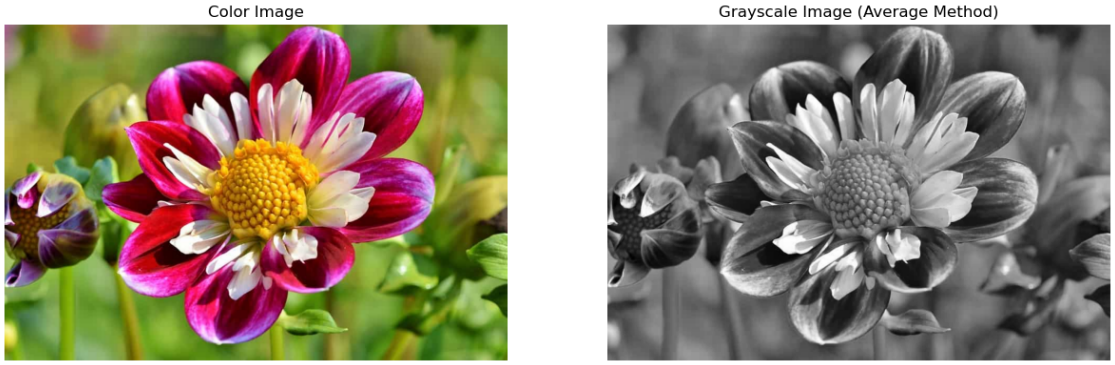
Gaussian Noisy

Gaussian Bilateral Filtered

3 Gray Scale Imaging

3.1 Average Method

[26]:
```
def average_method(img):
    grayscale_img = np.mean(img, axis=2)

    grayscale_img = np.uint8(grayscale_img)

    return grayscale_img

color_img = cv2.imread("I:/My Drive/Image_filtering/images/images/flower1.jpg")

grayscale_img_avg = average_method(color_img)

org = cv2.cvtColor(color_img, cv2.COLOR_BGR2RGB)

plt.figure(figsize=(15, 15))

plt.subplot(1,2,1)
plt.imshow(org)
plt.title('Color Image')
plt.axis('off')  # Hide axis

plt.subplot(1,2,2)
plt.imshow(grayscale_img_avg, cmap='gray')  # Specify grayscale colormap
plt.title('Grayscale Image (Average Method)')
plt.axis('off')  # Hide axis

plt.show()
```



3.2 Luminosity Method

[27]:
```python
def luminosity_method(img):
    R = img[:,:,0]
    G = img[:,:,1]
    B = img[:,:,2]

    grayscale_img = 0.21 * R + 0.72 * G + 0.07 * B
    grayscale_img = np.uint8(grayscale_img)

    return grayscale_img

color_img = cv2.imread("I:/My Drive/Image_filtering/images/images/flower.jpg")

# Convert the color image to grayscale using the luminosity method
grayscale_img_lum = luminosity_method(color_img)

org = cv2.cvtColor(color_img, cv2.COLOR_BGR2RGB)

plt.figure(figsize=(15, 15))

plt.subplot(1,2,1)
plt.imshow(org)
plt.title('Color Image')
plt.axis('off')  # Hide axis

plt.subplot(1,2,2)
plt.imshow(grayscale_img_lum, cmap='gray')  # Specify grayscale colormap
plt.title('Grayscale Image (Luminosity Method)')
plt.axis('off')  # Hide axis

plt.show()
```

3.3 Single Channel Method

[28]:
```
color_img = cv2.imread("I:/My Drive/Image_filtering/images/images/animated2.
 ↪jpg")

green_channel = color_img[:,:,1]

# Extract the red channel
red_channel = color_img[:,:,2]

# Extract the blue channel
blue_channel = color_img[:,:,0]

org = cv2.cvtColor(color_img, cv2.COLOR_BGR2RGB)

plt.figure(figsize=(15, 15))

plt.subplot(2,2,1)
plt.imshow(org)
plt.title('Color Image')
plt.axis('off')  # Hide axis

plt.subplot(2,2,2)
plt.imshow(green_channel , cmap='gray')  # Specify grayscale colormap
plt.title('Grayscale Image (Single Channel - Green)')
plt.axis('off')  # Hide axis

plt.subplot(2,2,3)
plt.imshow(red_channel , cmap='gray')  # Specify grayscale colormap
plt.title('Grayscale Image (Single Channel - Red)')
plt.axis('off')  # Hide axis

plt.subplot(2,2,4)
plt.imshow(blue_channel , cmap='gray')  # Specify grayscale colormap
plt.title('Grayscale Image (Single Channel - Blue)')
plt.axis('off')  # Hide axis

plt.show()
```

4 Image Blurring

[29]:
```
image_path = "I:/My Drive/Image_filtering/images/images/animated1.jpg"
# image_path = "/Users/user/Downloads/images/animated1.jpg"
bgr_image = cv2.imread(image_path)
img = cv2.cvtColor(bgr_image, cv2.COLOR_BGR2RGB)
```

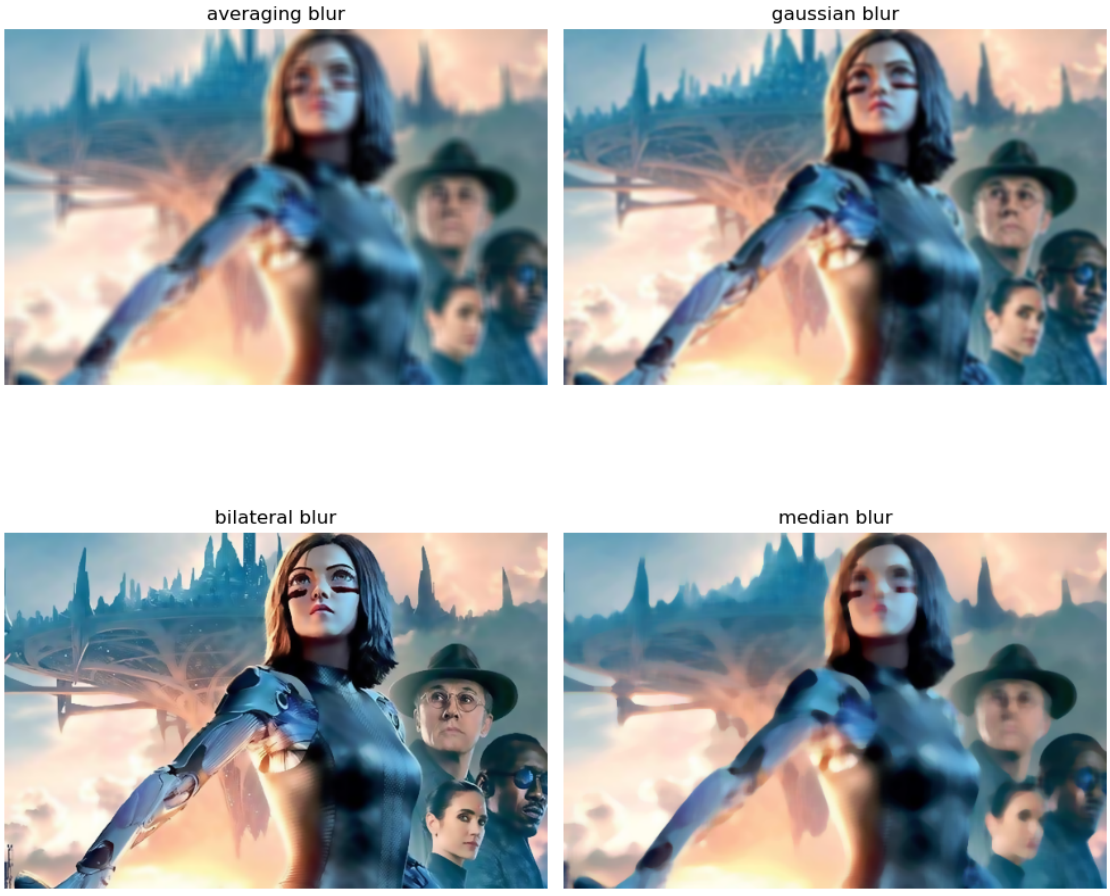
```
plt.imshow(img)
plt.axis('off')  # Hide axis
plt.show()
```

[30]:
```
averaging_blur = cv2.blur(img, (11, 11))
gaussian_blur = cv2.GaussianBlur(img, (11, 11), 0)
bilateral_blur = cv2.bilateralFilter(img, 9, 75, 75)
median_blur = cv2.medianBlur(img, 11)
```

[31]:
```
display_size = (200, 200)
original_display = cv2.resize(img, display_size)
```

[32]:
```
plt.figure(figsize=(10, 10))

plt.subplot(2,2,1)
plt.imshow(averaging_blur)
plt.title('averaging blur')
plt.axis('off')  # Hide axis

plt.subplot(2,2,2)
plt.imshow(gaussian_blur)
plt.title('gaussian blur')
plt.axis('off')  # Hide axis

plt.subplot(2,2,3)
```

```
plt.imshow(bilateral_blur)
plt.title('bilateral blur')
plt.axis('off')

plt.subplot(2,2,4)
plt.imshow(median_blur)
plt.title('median blur')
plt.axis('off')

plt.tight_layout()
plt.show()
```



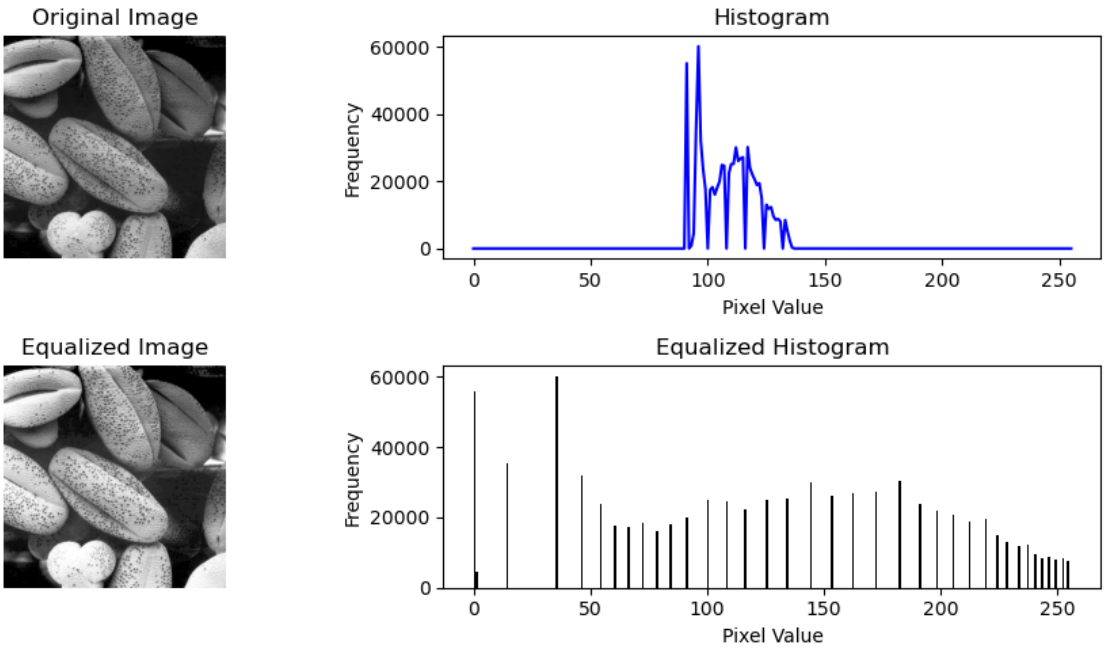
5 Histogram based image analysis

[33]:
```
image_path = "I:/My Drive/Image_filtering/images/images/
  ↪Fig0310(b)(washed_out_pollen_image).tif"
image = Image.open(image_path).convert('L')
```

[34]:
```
def histogram_equalization(image):
    # Calculate histogram
    hist, bins = np.histogram(image.flatten(), 256, [0,256])

    # Calculate cumulative distribution function
    cdf = hist.cumsum()
    cdf_normalized = cdf * hist.max() / cdf.max()

    # Perform histogram equalization
    cdf_m = np.ma.masked_equal(cdf, 0)
    cdf_m = (cdf_m - cdf_m.min())*255 / (cdf_m.max()-cdf_m.min())
    cdf = np.ma.filled(cdf_m, 0).astype('uint8')

    # Apply histogram equalization
    equalized_image = cdf[image]

    return equalized_image, hist
```

[35]:
```
equalized_image, hist = histogram_equalization(np.array(image))
```

[36]:
```
plt.figure(figsize=(10, 5))
plt.subplot(2, 2, 1)
plt.imshow(image, cmap='gray')
plt.title('Original Image')
plt.axis('off')

plt.subplot(2, 2, 3)
plt.imshow(equalized_image, cmap='gray')
plt.title('Equalized Image')
plt.axis('off')

# Display histogram
plt.subplot(2, 2, 2)
plt.plot(hist, color='blue')
plt.title('Histogram')
plt.xlabel('Pixel Value')
plt.ylabel('Frequency')

plt.subplot(2, 2, 4)
plt.hist(equalized_image.flatten(), 256, [0,256], color='black')
plt.title('Equalized Histogram')
plt.xlabel('Pixel Value')
plt.ylabel('Frequency')

plt.tight_layout()
plt.show()
```

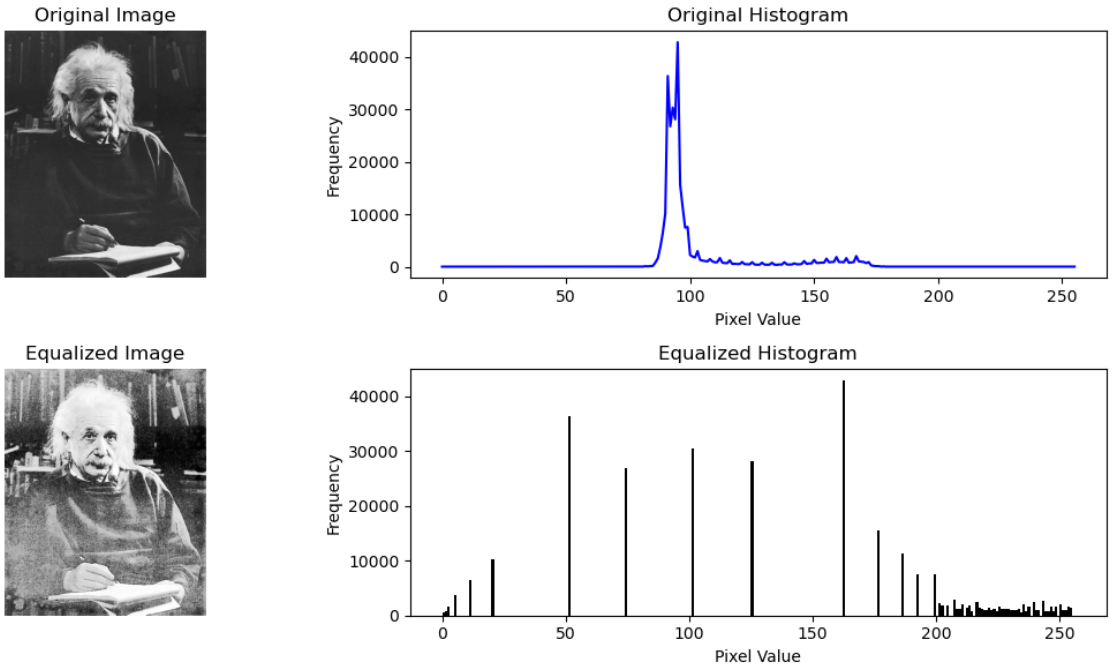


[37]:
```
image_path = "I:/My Drive/Image_filtering/images/images/
 ↪Fig0354(a)(einstein_orig).tif"
image = Image.open(image_path).convert('L')
```

[38]:
```
def histogram_equalization(image):
    # Calculate histogram
    hist, bins = np.histogram(image.flatten(), 256, [0,256])

    # Calculate cumulative distribution function
    cdf = hist.cumsum()
    cdf_normalized = cdf * hist.max() / cdf.max()

    # Perform histogram equalization
    cdf_m = np.ma.masked_equal(cdf, 0)
    cdf_m = (cdf_m - cdf_m.min())*255 / (cdf_m.max()-cdf_m.min())
    cdf = np.ma.filled(cdf_m, 0).astype('uint8')

    # Apply histogram equalization
    equalized_image = cdf[image]

    return equalized_image, hist, cdf
```

[39]:
```
equalized_image, hist_original, cdf_equalized = histogram_equalization(np.
 ↪array(image))
```

[40]:
```
plt.figure(figsize=(12, 6))

plt.subplot(2, 2, 1)
plt.imshow(image, cmap='gray')
plt.title('Original Image')
plt.axis('off')

plt.subplot(2, 2, 3)
plt.imshow(equalized_image, cmap='gray')
plt.title('Equalized Image')
plt.axis('off')

# Display histograms
plt.subplot(2, 2, 2)
plt.plot(hist_original, color='blue')
plt.title('Original Histogram')
plt.xlabel('Pixel Value')
plt.ylabel('Frequency')

plt.subplot(2, 2, 4)
plt.hist(equalized_image.flatten(), 256, [0,256], color='black')
plt.title('Equalized Histogram')
plt.xlabel('Pixel Value')
plt.ylabel('Frequency')

plt.tight_layout()
plt.show()
```



6 Image Scaling

6.1 Nearest neighbor

[41]:
```
from PIL import Image, ImageDraw, ImageFont
from IPython.display import display
```

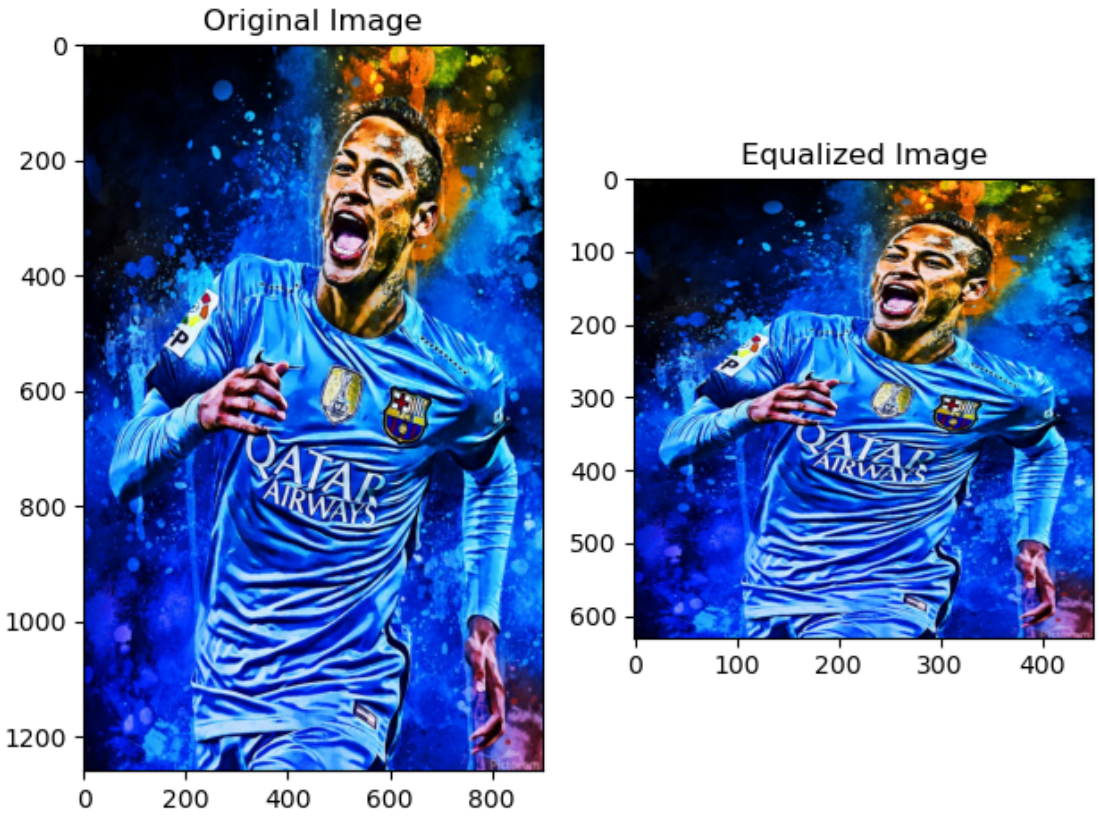
[42]:
```
# original_img = Image.open("/Users/user/Downloads/animated2.jpg")
original_img = Image.open("I:/My Drive/Image_filtering/images/images/animated2.
 ↪jpg")

original_width, original_height = original_img.size

new_width = original_width // 2
new_height = original_height // 2
```

[43]:
```
resized_img = original_img.resize((new_width, new_height), resample=Image.
 ↪NEAREST)
```

[44]:
```
# plt.figure(figsize=(12, 6))

# plt.subplot(1, 2, 1)
# plt.imshow(original_img)
# plt.title('Original Image')

# plt.subplot(1, 2, 2)
# plt.imshow(resized_img)
# plt.title('Equalized Image')

# plt.tight_layout()
# plt.show()
```

[45]:
```
original_width, original_height = original_img.size

plt.subplot(1, 2, 1)
plt.imshow(original_img)
plt.title('Original Image')
plt.gca().set_aspect('auto')  # Ensure the aspect ratio is automatic

plt.subplot(1, 2, 2)
plt.imshow(resized_img)
plt.title('Equalized Image')
plt.gca().set_aspect(original_width/original_height)  # Set aspect ratio based␣
 ↪on original image dimensions
```

```
plt.tight_layout()
plt.show()
```

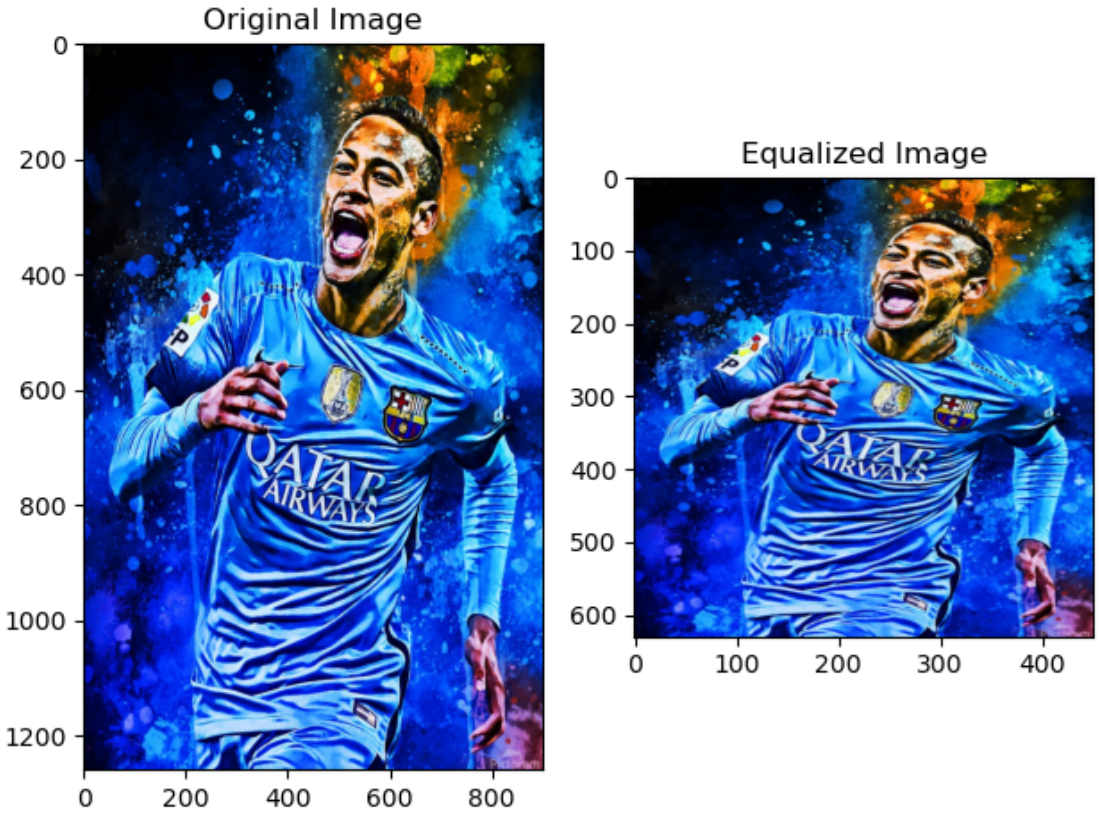


6.2 Bilinar Interpolation

[46]:
```
resized_img = original_img.resize((new_width, new_height), resample=Image.
↪BILINEAR)
```

[47]:
```
original_width, original_height = original_img.size

plt.subplot(1, 2, 1)
plt.imshow(original_img)
plt.title('Original Image')
plt.gca().set_aspect('auto')  # Ensure the aspect ratio is automatic

plt.subplot(1, 2, 2)
plt.imshow(resized_img)
plt.title('Equalized Image')
```

```
plt.gca().set_aspect(original_width/original_height)  # Set aspect ratio based
↪on original image dimensions

plt.tight_layout()
plt.show()
```

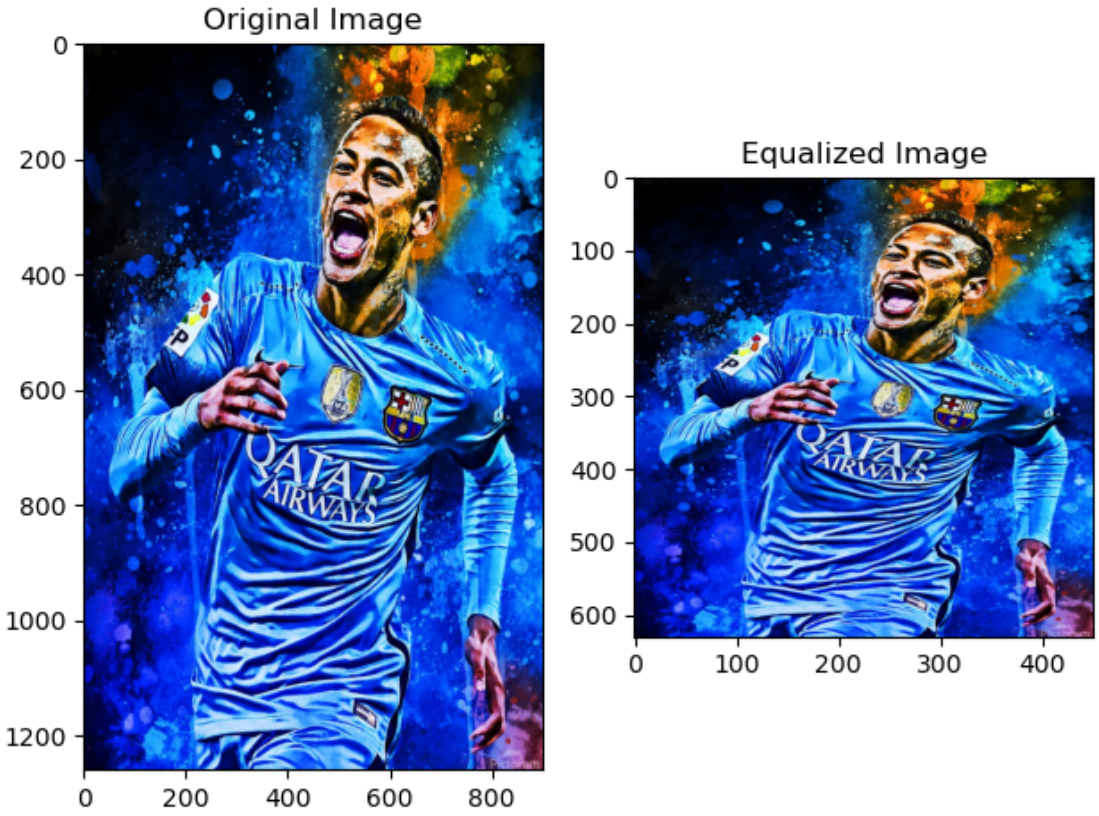


6.3 Bicubic Interpolation

[48]:
```
resized_img = original_img.resize((new_width, new_height), resample=Image.
↪BICUBIC)
```

[49]:
```
original_width, original_height = original_img.size

plt.subplot(1, 2, 1)
plt.imshow(original_img)
plt.title('Original Image')
plt.gca().set_aspect('auto')  # Ensure the aspect ratio is automatic

plt.subplot(1, 2, 2)
plt.imshow(resized_img)
```

```
plt.title('Equalized Image')
plt.gca().set_aspect(original_width/original_height)  # Set aspect ratio based␣
 ↪on original image dimensions

plt.tight_layout()
plt.show()
```

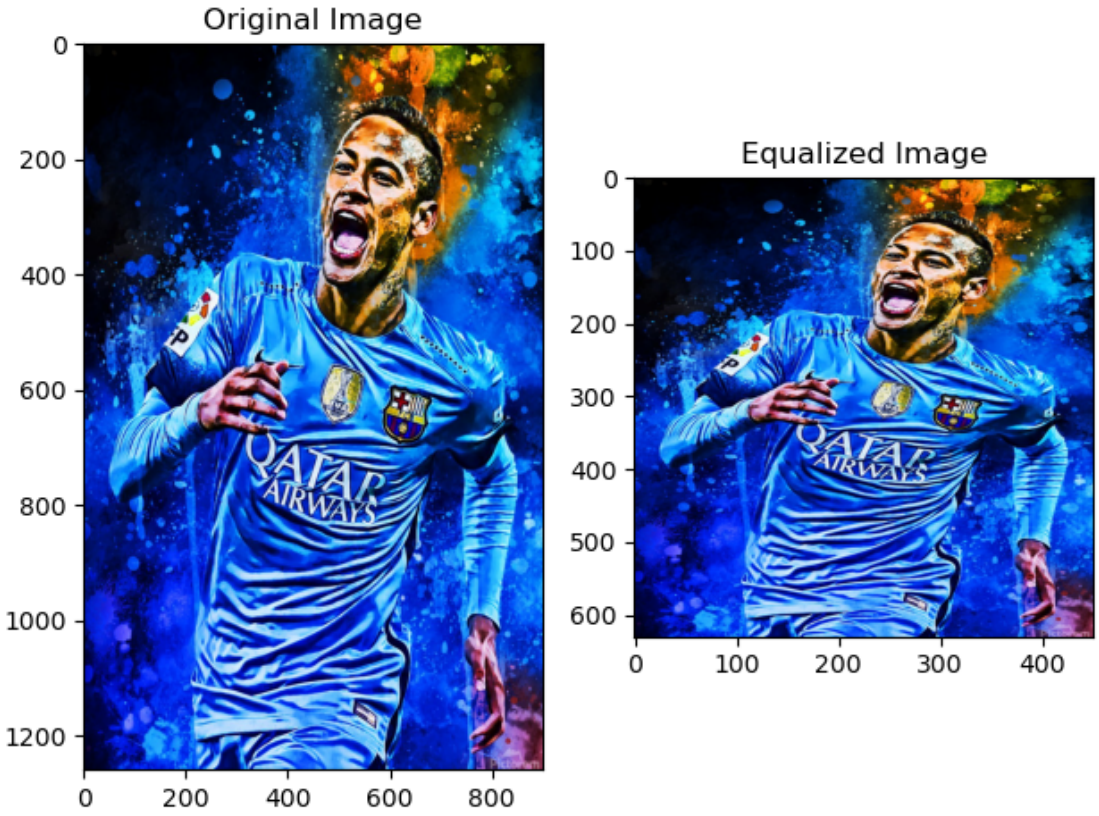


6.4 Lanczos Interpolation

[50]:
```
resized_img = original_img.resize((new_width, new_height), resample=Image.
 ↪LANCZOS)
```

[51]:
```
original_width, original_height = original_img.size

plt.subplot(1, 2, 1)
plt.imshow(original_img)
plt.title('Original Image')
plt.gca().set_aspect('auto')  # Ensure the aspect ratio is automatic

plt.subplot(1, 2, 2)
```

```
plt.imshow(resized_img)
plt.title('Equalized Image')
plt.gca().set_aspect(original_width/original_height)  # Set aspect ratio based␣
 ↪on original image dimensions

plt.tight_layout()
plt.show()
```



Assignment 16

CUDA programming

1. What is CUDA ?

A. CUDA = Compute Unified Device Architecture
CUDA is a parallel computing platform and programming model developed by NVIDIA for general computing on graphical processing units (GPUs).

It allows to access the raw computing power of CUDA GPUs to process data faster than with traditional CPUs. CUDA can achieve higher parallelism and efficiency than general-purpose CPU code using parallel processes. It enables parallel processing by breaking down a task into thousands of smaller "threads" executed independently.

2. What is the prerequisite for learning CUDA?

- Understanding parallel computing concepts such as **threads**, **blocks**, **grids**, and **synchronization** is crucial for CUDA programming.
- Many applications of CUDA involve numerical computations, such as **matrix operations** and **linear algebra**.
- CUDA enable or **capable GPU** devices, also have to installed **CUDA toolkit** and **nvidia developer driver**.

3. Which are the languages that support CUDA?

A. C++, C, C#, Fortran, Python, Java

4. What do you mean by a CUDA ready architecture?

A. CUDA Ready Architecture refers to a hardware architecture designed by NVIDIA to support CUDA and their parallel computing platform and programming model. In short the GPU architecture is designed and optimized to support CUDA

5. How CUDA works?

A. When a processor is given a task, it will pass the instructions for that task to the GPU. The GPU will then do its work, following the instructions from the CPU. GPUs run one

kernel (a group of tasks) at a time. Each kernel consists of blocks, which are independent groups of ALUs. Each block contains threads, which are levels of computation. The threads in each block typically work together to calculate a value. Once the job is completed, the results from the GPU are given back to the CPU.

6. What are the benefits and limitations of CUDA programming?

A. Benefits :

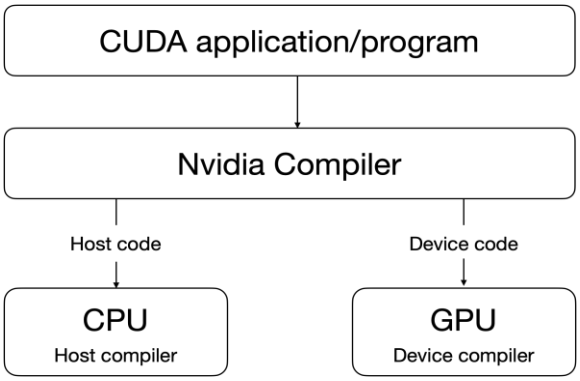
- Massive parallelism
- Performance boost
- Integrated memory and shared memory

Limitations :

- Works only on nvidia GPUs
- Highly Parallelizable Problems Only(Not all problems can be effectively parallelized for GPUs)
- Limited Portability (Porting to other GPU architectures requires significant effort.)

7. Understand and explain the CUDA program structure with an example.

A. CUDA programming includes code for both the GPU and CPU. By default, a typical C programme is a CUDA programme that simply contains the host code. The CPU is referred to as the host, while the GPU is referred to as the device. While the host code can be compiled using a regular C compiler such as GCC, the device code requires a specific compiler to comprehend the API functions that are used. For Nvidia GPUs, the compiler is known as the NVCC (Nvidia C Compiler).



The GPU runs the device code, whereas the CPU runs the host code. The NVCC runs a CUDA programme and isolates the host code from the device code. To do this, specific CUDA keywords are searched for. The code that is intended to run on the GPU (device code) is identified by special CUDA keywords known as 'Kernels' that

label data-parallel functions. The NVCC further compiles the device code, which is then run on the GPU.

8. Explain CUDA thread organization.

A. Organizing CUDA threads is similar to forming a team to collaborate on a large project. Here's a simplified breakdown:

Grids: Think of a grid as the overall project. It is made up of several smaller sections known as blocks.

Blocks: Each block represents a smaller team inside the project. They collaborate on a certain aspect of the project and can interact with one another effortlessly.

Threads: Each block has individual workers known as threads. They function similarly to team members who conduct the real work. Each thread completes a little portion of the job allocated to the block.

Divide the work into grids, which are then divided into blocks, with each block containing many threads. This arrangement helps to organize and perform duties efficiently on the GPU.

9. Install and try CUDA sample program and explain the same. (installation steps).

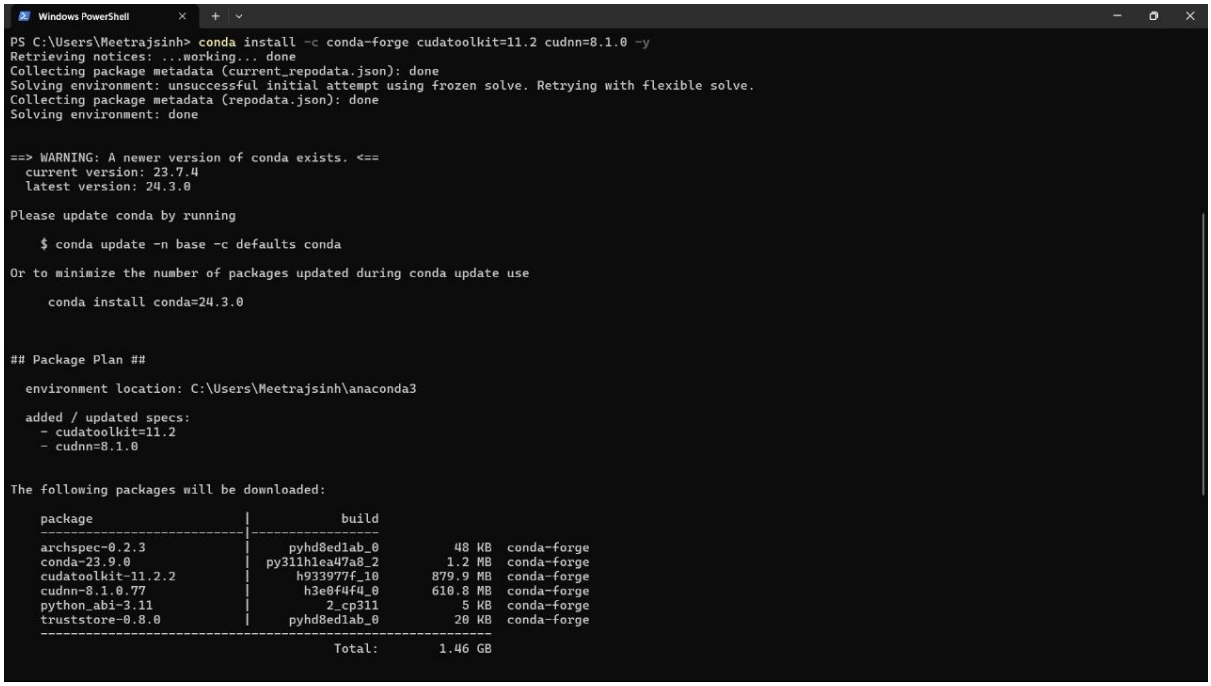
A. CUDA installation :

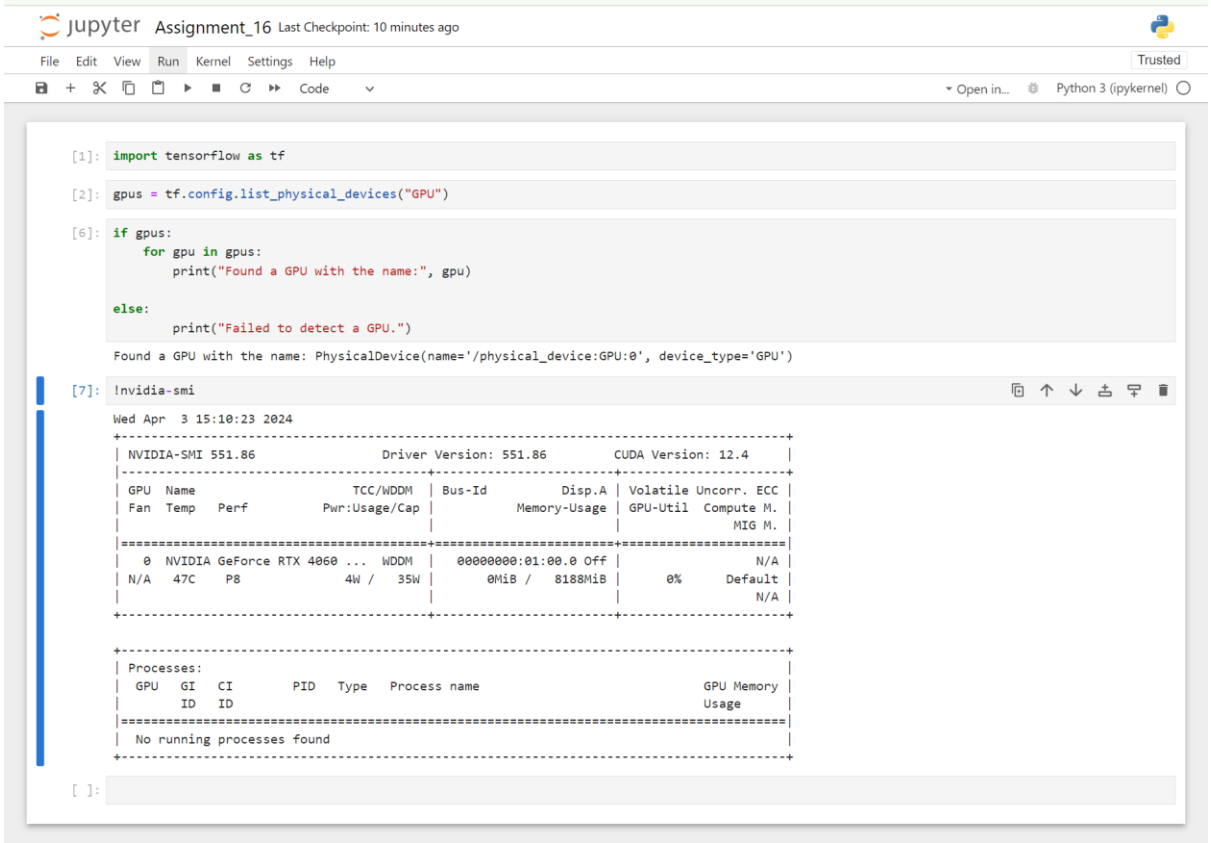
Pre-requisite:

- anaconda
- Python
- Tensorflow
- Jupyter
- CUDA enabled graphic card

To install CUDA run this following command in conda power shell or in its environment.

conda install -c conda-forge cudatoolkit=11.2 cudnn=8.1.0 -y





As shown in above image if CUDA was successfully installed then by running above code it will show available gpu and also by running **nvidia-smi** it will show all detail of gpu and also show CUDA version.

Code example :

```
import numpy as np
from numba import cuda
# Define the CUDA kernel function
@cuda.jit
# @cuda.jit(gridsize=(arr.size // threadsperblock + 1, 1), blocksize=(threadsperblock,))
def add_to_array(arr):
  """
  This kernel adds 1.0 to each element of the input array.
  Each thread processes one element of the array.
  """
  # Get the unique thread index within a block
  idx = cuda.threadIdx.x
  # Check if the thread index is within the array bounds
  if idx < arr.size:
    arr[idx] += 1.0
# Create a sample NumPy array on the CPU (host)
arr = np.array([1.0, 2.0, 3.0])
# Allocate memory for the array on the GPU (device)
d_arr = cuda.to_device(arr)
# Configure the number of threads per block (adjust as needed)
threadsperblock = 512
gridsize = (arr.size // threadsperblock + 1, 1)
add_to_array[gridsize, threadsperblock](d_arr)
# Copy results back from GPU to CPU
host_arr = d_arr.copy_to_host()  # Use copy_to_host instead of to_host
arr = host_arr  # Assign the copied data to the original array
arr
```

Output :

```
array([3., 4., 5.])
```

HPC_assignment_17

April 16, 2024

1 HPC assignment 17

[ ]:
```
!nvidia-smi
```

```
Tue Apr 16 07:06:05 2024
+---------------------------------------------------------------------------------
--------+
| NVIDIA-SMI 535.104.05             Driver Version: 535.104.05   CUDA Version:
12.2     |
|-----------------------------------------+----------------------+-------------
--------+
| GPU  Name                 Persistence-M | Bus-Id        Disp.A | Volatile
Uncorr. ECC |
| Fan  Temp   Perf          Pwr:Usage/Cap |         Memory-Usage | GPU-Util
Compute M. |
|                                         |                      |
MIG M. |
|=========================================+======================+==============
========|
|   0  Tesla T4                       Off | 00000000:00:04.0 Off |
0 |
| N/A   40C    P8              9W /  70W |      0MiB / 15360MiB |      0%
Default |
|                                         |                      |
N/A |
+-----------------------------------------+----------------------+-------------
--------+

+---------------------------------------------------------------------------------
--------+
| Processes:
|
|  GPU   GI   CI        PID   Type   Process name                            GPU
Memory |
|        ID   ID
Usage      |
|=================================================================================
========|
```

```
|  No running processes found                                                 |
|                                                                             |
+-----------------------------------------------------------------------------+
```

1.1 1. To print hello message on the screen using kernal function

[ ]:
```
%%writefile hello_1_1.cu

#include <stdio.h>

__global__ void cuda_hello_1_1() {
    printf("Hello World from GPU with grid dimension (1, 1) and block dimension␣
 ↪(1, 1)!\n");
}

int main() {
    cuda_hello_1_1<<<1,1>>>();
    cudaDeviceSynchronize(); // Make sure all GPU work is done before exiting
    return 0;
}
```

```
Writing hello_1_1.cu
```

[ ]:
```
!nvcc -o hello_1_1 hello_1_1.cu
```

[ ]:
```
!./hello_1_1
```

```
Hello World from GPU with grid dimension (1, 1) and block dimension (1, 1)!
```

1.2 2. To add two vectors of size 100 and 20000 and analyze the performance comparison between cpu and gpu processing

1.2.1 GPU

[ ]:
```
!pip install pycuda
```

```
Collecting pycuda
  Downloading pycuda-2024.1.tar.gz (1.7 MB)
                             1.7/1.7 MB
12.0 MB/s eta 0:00:00
  Installing build dependencies … done
  Getting requirements to build wheel … done
  Preparing metadata (pyproject.toml) … done
Collecting pytools>=2011.2 (from pycuda)
  Downloading pytools-2024.1.1-py2.py3-none-any.whl (85 kB)
                             85.1/85.1 kB
12.0 MB/s eta 0:00:00
Requirement already satisfied: appdirs>=1.4.0 in
```

```
/usr/local/lib/python3.10/dist-packages (from pycuda) (1.4.4)
Collecting mako (from pycuda)
  Downloading Mako-1.3.3-py3-none-any.whl (78 kB)
                             78.8/78.8 kB
10.9 MB/s eta 0:00:00
Requirement already satisfied: platformdirs>=2.2.0 in
/usr/local/lib/python3.10/dist-packages (from pytools>=2011.2->pycuda) (4.2.0)
Requirement already satisfied: typing-extensions>=4.0 in
/usr/local/lib/python3.10/dist-packages (from pytools>=2011.2->pycuda) (4.11.0)
Requirement already satisfied: MarkupSafe>=0.9.2 in
/usr/local/lib/python3.10/dist-packages (from mako->pycuda) (2.1.5)
Building wheels for collected packages: pycuda
  Building wheel for pycuda (pyproject.toml) … done
  Created wheel for pycuda: filename=pycuda-2024.1-cp310-cp310-linux_x86_64.whl
size=661204
sha256=51efb7c5582dd86e48b9404a05e0a366352406f4840bf4dc162fe9a89aa2ad1c
  Stored in directory: /root/.cache/pip/wheels/12/34/d2/9a349255a4eca3a486d82c79
d21e138ce2ccd90f414d9d72b8
Successfully built pycuda
Installing collected packages: pytools, mako, pycuda
Successfully installed mako-1.3.3 pycuda-2024.1 pytools-2024.1
```

[ ]:
```python
import numpy as np
import pycuda.driver as cuda
import pycuda.autoinit
from pycuda.compiler import SourceModule
import time
```

[ ]:
```python
# CUDA kernel function to add two vectors
cuda_kernel_code = """
__global__ void vector_add(float *a, float *b, float *c, int n) {
    int i = blockIdx.x * blockDim.x + threadIdx.x;
    if (i < n) {
        c[i] = a[i] + b[i];
    }
}
"""
```

[ ]:
```python
cuda_module = SourceModule(cuda_kernel_code)
vector_add_cuda = cuda_module.get_function("vector_add")
```

[ ]:
```python
def vector_add_gpu(a, b):
    n = a.size

    a_gpu = cuda.mem_alloc(a.nbytes)
    b_gpu = cuda.mem_alloc(b.nbytes)
    c_gpu = cuda.mem_alloc(b.nbytes)
```

```
    cuda.memcpy_htod(a_gpu, a)
    cuda.memcpy_htod(b_gpu, b)

    block_dim = (256, 1, 1)
    grid_dim = ((n + block_dim[0] - 1) // block_dim[0], 1)

    start_time = time.time()

    vector_add_cuda(a_gpu, b_gpu, c_gpu, np.int32(n), block=block_dim,␣
 ↪grid=grid_dim)

    cuda.Context.synchronize()

    end_time = time.time()

    c = np.empty_like(a)
    cuda.memcpy_dtoh(c, c_gpu)

    return c, end_time - start_time
```

[ ]:
```
vector_size_1 = 100
vector_size_2 = 20000
a = np.random.randn(vector_size_2).astype(np.float32)
b = np.random.randn(vector_size_2).astype(np.float32)

result_gpu1, gpu_time1 = vector_add_gpu(a[:vector_size_1], b[:vector_size_1])
result_gpu2, gpu_time2 = vector_add_gpu(a[:vector_size_2], b[:vector_size_2])
```

[ ]:
```
print("Vector addition of size", vector_size_1, "on GPU took", gpu_time1,␣
 ↪"seconds.")

print("Vector addition of size", vector_size_2, "on GPU took", gpu_time2,␣
 ↪"seconds.")
```

```
Vector addition of size 100 on GPU took 0.0007643699645996094 seconds.
Vector addition of size 20000 on GPU took 6.818771362304688e-05 seconds.
```

1.2.2 CPU

[1]:
```
import numpy as np
import time
```

[10]:
```
def vector_add_cpu(a, b):
    start_time = time.time()
    result = a + b
    end_time = time.time()
    return result, end_time - start_time
```

[11]:
```
vector_size_1 = 100
vector_size_2 = 20000
a = np.random.randn(vector_size_2).astype(np.float32)
b = np.random.randn(vector_size_2).astype(np.float32)

result_cpu1, cpu_time1 = vector_add_cpu(a[:vector_size_1], b[:vector_size_1])
result_cpu2, cpu_time2 = vector_add_cpu(a[:vector_size_2], b[:vector_size_2])
```

[12]:
```
print("Vector addition of size", vector_size_1, "on CPU took", cpu_time1,␣
 ↪"seconds.")
print("Vector addition of size", vector_size_2, "on CPU took", cpu_time2,␣
 ↪"seconds.")
```

```
Vector addition of size 100 on CPU took 0.0 seconds.
Vector addition of size 20000 on CPU took 0.0 seconds.
```

- Vector addition of size 100 on GPU took 0.0007691383361816406 seconds.
- Vector addition of size 20000 on GPU took 7.128715515136719e-05 seconds.

1.3 3. To multply two matrix of size 20 X 20 and 1024 X 1024 analyze the performance comparison between cpu and gpu processing

1.3.1 GPU

[ ]:
```
def matrix_multiply_gpu(a, b):
    cuda_code = """
    __global__ void matrix_multiply(float *a, float *b, float *c, int n) {
        int row = blockIdx.y * blockDim.y + threadIdx.y;
        int col = blockIdx.x * blockDim.x + threadIdx.x;

        if (row < n && col < n) {
            float sum = 0.0;
            for (int i = 0; i < n; ++i) {
                sum += a[row * n + i] * b[i * n + col];
            }
            c[row * n + col] = sum;
        }
    }
    """

    mod = SourceModule(cuda_code)

    matrix_multiply_cuda = mod.get_function("matrix_multiply")

    a_gpu = cuda.mem_alloc(a.nbytes)
    b_gpu = cuda.mem_alloc(b.nbytes)
    c_gpu = cuda.mem_alloc(a.nbytes)

    cuda.memcpy_htod(a_gpu, a)
```

```
    cuda.memcpy_htod(b_gpu, b)

    block_size = (16, 16, 1)
    grid_size = ((a.shape[1] + block_size[0] - 1) // block_size[0], (a.shape[0]␣
 ↪+ block_size[1] - 1) // block_size[1], 1)

    matrix_multiply_cuda(a_gpu, b_gpu, c_gpu, np.int32(a.shape[0]),␣
 ↪block=block_size, grid=grid_size)

    c = np.empty_like(a)
    cuda.memcpy_dtoh(c, c_gpu)

    return c
```

[ ]:
```
def generate_random_matrix(rows, cols):
    return np.random.rand(rows, cols).astype(np.float32)
```

[ ]:
```
def measure_time(matrix_size, func, *args):
    start_time = time.time()
    result = func(*args)
    end_time = time.time()
    return result, end_time - start_time
```

[ ]:
```
matrix_sizes = [(20, 20), (1024, 1024)]
```

[ ]:
```
for size in matrix_sizes:
    print(f"\nMatrix size: {size}")
    a = generate_random_matrix(*size)
    b = generate_random_matrix(*size)

    gpu_result, gpu_time = measure_time(size, matrix_multiply_gpu, a, b)
    print(f"GPU time: {gpu_time:.6f} seconds")
```

```
Matrix size: (20, 20)
GPU time: 0.428407 seconds

Matrix size: (1024, 1024)
GPU time: 0.018636 seconds
```

1.3.2 CPU

[2]:
```
def matrix_multiply_cpu(a, b):
    result = np.zeros((a.shape[0], b.shape[1]), dtype=np.float32)
    for i in range(a.shape[0]):
        for j in range(b.shape[1]):
            for k in range(a.shape[1]):
                result[i, j] += a[i, k] * b[k, j]
```

```
    return result
```

[3]:
```
def generate_random_matrix(rows, cols):
    return np.random.rand(rows, cols).astype(np.float32)
```

[4]:
```
def measure_time(matrix_size, func, *args):
    start_time = time.time()
    result = func(*args)
    end_time = time.time()
    return result, end_time - start_time
```

[5]:
```
matrix_sizes = [(20, 20), (1024, 1024)]
```

[6]:
```
for size in matrix_sizes:
    print(f"\nMatrix size: {size}")
    a = generate_random_matrix(*size)
    b = generate_random_matrix(*size)

    # CPU matrix multiplication
    cpu_result, cpu_time = measure_time(size, matrix_multiply_cpu, a, b)
    print(f"CPU time: {cpu_time:.6f} seconds")
```

```
Matrix size: (20, 20)
CPU time: 0.000000 seconds

Matrix size: (1024, 1024)
CPU time: 533.798448 seconds
```

- Matrix size: (20, 20)
- GPU time: 0.703994 seconds
- Matrix size: (1024, 1024)
- GPU time: 0.014648 seconds

1.4 4. To obtain CUDA device information and print the output

[ ]:
```
import pycuda.driver as cuda

# Initialize PyCUDA
cuda.init()

num_devices = cuda.Device.count()

print("Number of CUDA devices:", num_devices)

for i in range(num_devices):
    device = cuda.Device(i)
```

```
    print("\nCUDA Device:", i)
    print("  Name:", device.name())
    print("  Compute Capability:", device.compute_capability())
    print("  Total Memory:", device.total_memory() / (1024 ** 3), "GB")
    print("  Max Threads per Block:", device.max_threads_per_block)
    print("  Multiprocessor Count:", device.multiprocessor_count)
    print("  Clock Rate:", device.clock_rate / 1e6, "GHz")
```

```
Number of CUDA devices: 1

CUDA Device: 0
  Name: Tesla T4
  Compute Capability: (7, 5)
  Total Memory: 14.74810791015625 GB
  Max Threads per Block: 1024
  Multiprocessor Count: 40
  Clock Rate: 1.59 GHz
```

HPC-Assignment-18

April 25, 2024

1 HPC Assignment 18

1.1 Image Processing CUDA

1.2 Implement the following Image Processing operations in sequential and parallel using CUDA Programming.

1.2.1 Gaussian blur

Describe Gaussian Blur in brief. Gaussian blur is a popular image processing technique used to minimize visual noise and detail, resulting in a smoother look. Gaussian blur convolves each pixel in the image with a Gaussian kernel, a 2D matrix that represents a bell-shaped curve. The size and standard deviation (sigma) of the Gaussian kernel control the amount of blurring applied to the image. A larger kernel size and a higher sigma value cause more noticeable blurring. During convolution, each pixel in the image is replaced by a weighted average of its neighbors, the weights of which are defined by the Gaussian function. This method efficiently decreases the image's high-frequency components, smoothing out sharp transitions and noise.

Where parallelism can be inserted? Parallelism can be inserted in Gaussian blur at key stages:

1. image Copy and Memory Allocation: Transfer input picture data to GPU while allocating memory for the output image in parallel.
2. Convolution: Perform the convolution process with CUDA kernels, with each thread computing the weighted sum for a given output pixel.
3. Border Handling: Process border regions concurrently, allocating various threads to handle different parts of the border.
4. image Copy Back: Transfer processed picture data from the GPU to the host RAM in parallel.

Analyze the performance in serial and parallel model.

Serial

[28]:
```
import os
import cv2
import numpy as np
import time
```

[29]:
```

```

```
def gaussian_kernel(size, sigma=1):
    kernel = np.fromfunction(lambda x, y: (1/(2*np.pi*sigma**2)) * np.
 ↪exp(-((x-(size-1)/2)**2 + (y-(size-1)/2)**2)/(2*sigma**2)), (size, size))
    return kernel / np.sum(kernel)
```

[30]:
```
def gaussian_blur_sequential(image, kernel_size):
    kernel = gaussian_kernel(kernel_size)
    blurred_image = cv2.filter2D(image, -1, kernel)  # Using OpenCV's filter2D␣
 ↪for convolution
    return blurred_image
```

[31]:
```
def process_images_in_folder(folder_path, kernel_size):
    times = {}
    for filename in os.listdir(folder_path):
        if filename.endswith(".jpg") or filename.endswith(".png"):
            image_path = os.path.join(folder_path, filename)
            image = cv2.imread(image_path, cv2.IMREAD_COLOR)
            start_time = time.time()
            blurred_image = gaussian_blur_sequential(image, kernel_size)
            end_time = time.time()
            times[filename] = end_time - start_time
    return times
```

[32]:
```
folder_path = "/content/drive/MyDrive/data_set/minion"
kernel_size = 3
```

[33]:
```
start_time_total = time.time()
times_per_image = process_images_in_folder(folder_path, kernel_size)
end_time_total = time.time()
total_time = end_time_total - start_time_total
```

[34]:
```
print("Time taken for Gaussian blur on each image:")
for filename, time_taken in times_per_image.items():
    print(f"{filename}: {time_taken:.4f} seconds")
```

```
Time taken for Gaussian blur on each image:
1.jpg: 0.0348 seconds
2.jpg: 0.0024 seconds
3.jpg: 0.0618 seconds
4.jpg: 0.0038 seconds
5.jpg: 0.0173 seconds
6.jpg: 0.0064 seconds
7.jpg: 0.0085 seconds
8.jpg: 0.0044 seconds
9.jpg: 0.0034 seconds
10.jpg: 0.0033 seconds
11.jpg: 0.0027 seconds
```

[35]:
```
print(f"\nTotal time taken for all images: {total_time:.4f} seconds")
```

```
Total time taken for all images: 0.6478 seconds
```

Parallel

[36]:
```
import cupy as cp
from PIL import Image
import os
import time

def process_image(image_array):
    def gaussian_kernel(size, sigma=1):
        kernel_1D = cp.linspace(-(size // 2), size // 2, size)
        for i in range(size):
            kernel_1D[i] = cp.exp(-0.5 * (kernel_1D[i] / sigma) ** 2)
        kernel_2D = cp.outer(kernel_1D, kernel_1D)
        kernel_2D /= kernel_2D.sum()
        return kernel_2D

    kernel_size = 5
    gaussian_kernel_array = gaussian_kernel(kernel_size)
    blurred_image = cp.asarray(Image.fromarray(cp.asnumpy(image_array)).
 ↪convert("L"))

    return blurred_image

directory = "/content/drive/MyDrive/data_set/minion"
num_images = 0
start_time = time.time()

image_paths = [os.path.join(directory, filename) for filename in os.
 ↪listdir(directory) if filename.endswith(".jpg")]
image_arrays = [cp.array(Image.open(image_path).convert("L")) for image_path in␣
 ↪image_paths]
processed_images = [process_image(image_array) for image_array in image_arrays]

cp.cuda.Device().synchronize()

total_time_parallel = time.time() - start_time
num_images = len(image_paths)

print("Number of images processed in parallel:", num_images)
print("Time taken for parallel processing:", total_time_parallel, "seconds")
```

```
Number of images processed in parallel: 11
Time taken for parallel processing: 0.41269755363464355 seconds
```

1.2.2 FFT- Fast Fourier Transform

Describe FFT in brief The FFT algorithm decomposes the DFT computation into smaller subproblems, exploiting the periodicity and symmetry properties of complex exponential functions. By iteratively applying these subproblems and integrating the answers, the FFT computes the DFT in much less operations than direct computation.

The FFT output represents the input signal's frequency spectrum, including the magnitude and phase of each frequency component. This information is useful for filtering, noise reduction, spectrum analysis, and feature extraction.

Where parallelism can be inserted? Parallelism in the Fast Fourier Transform (FFT) can be introduced at numerous stages:

1. Data Splitting: Split incoming data into chunks that can be processed independently by several cores or thread
2. Butterfly Operations: Parallelize butterfly operations, particularly on SIMD architectures such as GUs.
3. Twiddle Factor Calculation: Calculate twiddle factors simultaneously across several processor nits.
4. Memory Access: Improve memory access patterns for parallel processing, such as coalesced memory access and preftching.
5. Inverse FFT (IFFT): Use parallelization techniques to improve inverse FFT computation permance.

Analyze the performance in serial and parallel model.

serial

[37]:
```
def fft_sequential(image):
    fft_image = np.fft.fft2(image)
    return fft_image
```

[38]:
```
def process_images_in_folder_fft(folder_path):
    times = {}
    for filename in os.listdir(folder_path):
        if filename.endswith(".jpg") or filename.endswith(".png"):
            image_path = os.path.join(folder_path, filename)
            image = cv2.imread(image_path, cv2.IMREAD_GRAYSCALE)
            start_time = time.time()
            fft_image = fft_sequential(image)
            end_time = time.time()
            times[filename] = end_time - start_time
    return times
```

[39]:
```
folder_path = "/content/drive/MyDrive/data_set/minion"
```

[40]:
```
start_time_total = time.time()
times_per_image_fft = process_images_in_folder_fft(folder_path)
end_time_total = time.time()
total_time_fft = end_time_total - start_time_total
```

[41]:
```
print("Time taken for FFT on each image:")
for filename, time_taken in times_per_image_fft.items():
    print(f"{filename}: {time_taken:.4f} seconds")
```

```
Time taken for FFT on each image:
1.jpg: 0.0262 seconds
2.jpg: 0.0302 seconds
3.jpg: 1.3454 seconds
4.jpg: 0.0321 seconds
5.jpg: 0.2315 seconds
6.jpg: 0.0642 seconds
7.jpg: 0.0505 seconds
8.jpg: 0.0690 seconds
9.jpg: 0.0231 seconds
10.jpg: 0.0405 seconds
11.jpg: 0.0352 seconds
```

[42]:
```
print(f"\nTotal time taken for FFT on all images: {total_time_fft:.4f} seconds")
```

```
Total time taken for FFT on all images: 2.2286 seconds
```

Parallel

[43]:
```
import os
import time
import cupy as cp
from PIL import Image

directory = "/content/drive/MyDrive/data_set/minion"

num_images = 0
start_time = time.time()

def process_image(image_array):
    global num_images
    num_images += 1

    fft_image = cp.fft.fft2(image_array)
    fft_image_shifted = cp.fft.fftshift(fft_image)

    rows, cols = image_array.shape
    center_row, center_col = rows // 2, cols // 2
    radius = 20
```

```
    high_pass_filter = cp.ones((rows, cols))
    mask = cp.zeros((rows, cols))
    mask[center_row - radius:center_row + radius, center_col - radius:
 ↪center_col + radius] = 1
    high_pass_filter -= mask

    filtered_image_fft = fft_image_shifted * high_pass_filter

    filtered_image = cp.abs(cp.fft.ifft2(cp.fft.ifftshift(filtered_image_fft)))
    return filtered_image

image_paths = [os.path.join(directory, filename) for filename in os.
 ↪listdir(directory) if filename.endswith(".jpg")]
image_arrays = [cp.array(Image.open(image_path).convert("L")) for image_path in␣
 ↪image_paths]
processed_images = [process_image(image_array) for image_array in image_arrays]

cp.cuda.Device().synchronize()

total_time_parallel = time.time() - start_time

print("Number of images processed in parallel:", num_images)
print("Time taken for parallel processing:", total_time_parallel, "seconds")
```

```
Number of images processed in parallel: 11
Time taken for parallel processing: 0.7189762592315674 seconds
```