RAMAIAH UNIVERSITY OF APPLIED SCIENCES

ASSIGNMENT

Course Code	19CSC304A
Course Name	Operating Systems
Programme	B. Tech.
Department	Computer Science and Engineering
Faculty	Faculty of Engineering & Technology

Name of the Student	Subhendu Maji
Reg. No	18ETCS002121
Semester/Year	5^{TH} semester / 2018 batch
Course Leader/s	Ms. Naveeta

Declaration Sheet			
Student Name	Subhendu Maji		
Reg. No	18ETCS002121		
Programme	B. Tech.	Semester/Year	5th sem / 2018 batch
Course Code	19CSC304A		
Course Title	Operating Systems		
Course Date		to	
Course Leader	Ms. Naveeta		

Declaration

The assignment submitted herewith is a result of my own investigations and that I have conformed to the guidelines against plagiarism as laid out in the Student Handbook. All sections of the text and results, which have been obtained from other sources, are fully referenced. I understand that cheating and plagiarism constitute a breach of University regulations and will be dealt with accordingly.

Signature of the Student		Date	
Submission date stamp (by Examination & Assessment Section)			

Signature of the Course Leader and date	Signature of the Reviewer and date

Contents

Assignment						
Register No.	**18ETCS002121**	Name of Student	**SUBHENDU MAJI**			
Sections		**Marking Scheme**	**Max Marks**	**First Examiner Marks**	**Moderator Marks**	
Question 1	Q1.1	Introduction to multi-programming	01			
	Q1.2	Effect of multi-programming on CPU utilisation	04			
		Question 1 Max Marks	**05**			
Question 2	Q2.1	Design and implementation of the application using sequential approach with functions	04			
	Q2.2	Design and implementation of the application using multithreaded approach	04			
	Q2.3	Comparison of the execution time of the above two versions of the program and its analysis	02			
		Question 2 Max Marks	**10**			
Question 3	Q3.1	Schedule of the processes using a Gantt chart	04			
	Q3.2	Average waiting time and average turnaround time experienced	04			
	Q3.3	Scheduling algorithm with better performance and its justification	02			
		Question 3 Max Marks	**10**			
		Total Assignment Marks	**25**			

Course Marks Tabulation				
Component- 1(B) Assignment	**First Examiner**	**Remarks**	**Moderator**	**Remarks**
Q1				
Q2				
Q3				
Marks (out of 25)				

Signature of First Examiner Signature of Second Examiner

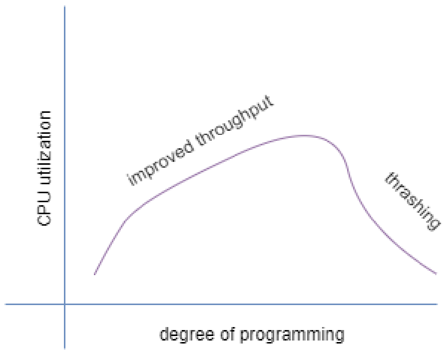
Question No. 1

Solution to Question No. 1:

1.1 Introduction to multi-programming

Early computers ran one process at a time. While the process waited for servicing by another device, the CPU was idle. In an I/O intensive process, the CPU could be idle as much as 80% of the time. Advancements in operating systems led to computers that load several independent processes into memory and switch the CPU from one job to another when the first becomes blocked while waiting for servicing by another device. This idea of **multiprogramming** reduces the idle time of the CPU. Multiprogramming accelerates the throughput of the system by efficiently using the CPU time.

Programs in a multiprogrammed environment appear to run at the same time. Processes running in a multiprogrammed environment are called **concurrent** processes. In actuality, the CPU processes one instruction at a time, but can execute instructions from any active process.



As the illustration shows, CPU utilization of a system can be improved by using multiprogramming.
Let P be the fraction of time that a process spends away from the CPU. If there is one process in memory, the CPU utilization is $(1 - P)$. If there are N processes in memory, the probability of N processes waiting for an I/O is $P * P \ldots * P$ $(N\ times)$. The CPU utilization is $(1 - P^N)$ where N is called the multiprogramming level (MPL) or the degree of multiprogramming. As N increases, the CPU utilization increases. While this equation indicates that a CPU continues to work more efficiently as more and more processes are added, logically, this cannot be true. Once the system passes the point of optimal CPU utilization, it thrashes.

In order to use the multiprogramming concept, processes must be loaded into independent sections or partitions of memory. So, main memory is divided into fixed-sized or variable-sized partitions. Since a partition may not be large enough for the entire process, virtual memory is implemented to keep the processes executing. The answers to several questions are important to implementing an efficient virtual memory system in a multiprogrammed environment.

1.2 Effect of multi-programming on CPU utilization

Back in the days when 1 processor contained 1 core capable of running 1 thread, CPU utilization reported by the operating system indicated actual resource consumption (and resource availability) of the processor. In such environment's CPU utilization grows linearly with increased workload.

Multi-core CPUs: 1 processor = 2 or more cores
In multi-core CPUs, where 1 processor contains 2 or more cores, each processing core has its own arithmetic and logic unit, floating point unit, set of registers, pipeline, as well as some amount of cache. However multi-core CPUs also share some resources between the cores (e.g. L3-Cache, memory controller).

Simultaneous multi-threading CPUs/cores: 1 processor or core = 2 or more threads (aka "Hyper-Threading", "Chip Multi-threading")
The hardware components of one physical core are shared between several threads. Each thread has at least its own set of registers. Most resources of the core (arithmetic and logic unit, floating point unit, cache) are shared between the threads. Naturally those threads compete for processing resources and stall if the desired units are already busy.

benefits of resource sharing.
Resource sharing can increase overall throughput and efficiency by keeping the processing units of a core busy. For instance, hyper-threading can reduce or hide stalls on memory access (cache misses). Instead of wasting many cycles while data is fetched from main memory the current thread is suspended and the next runnable thread is resumed and continues execution.

disadvantages

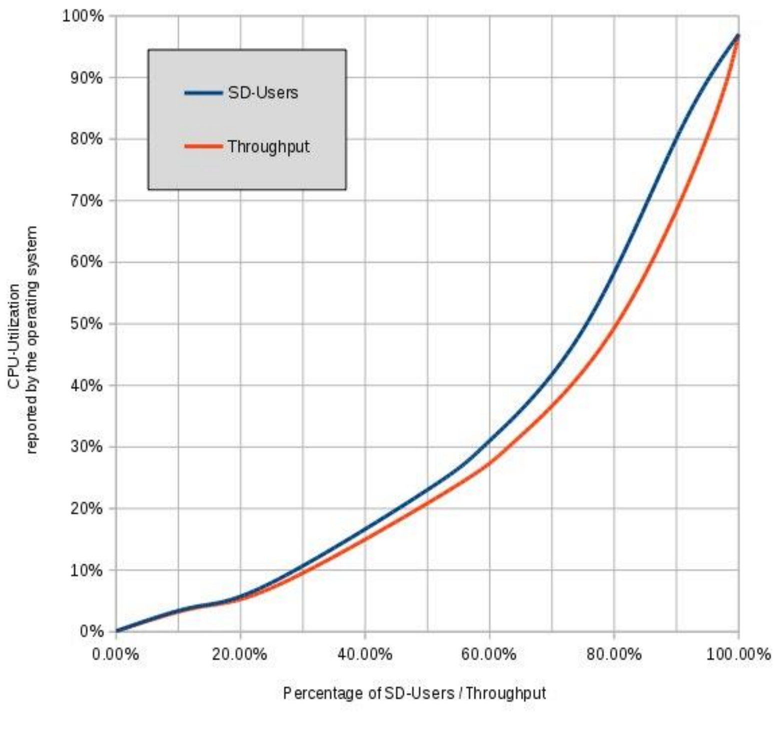
- CPU time accounting measurements (sys/usr/idle) as reported by standard tools do not reflect the side-effects of resource sharing between hardware threads
- It is impossible to correctly measure idle and extrapolate available computing resources

Idle does not indicate how much more work can be accomplished by the CPU

Example:
Assuming 1 CPU core has 4 threads. Currently 2 (single-threaded) processes are scheduled to run on this core and these 2 processes already saturate all available shared compute resources (ALU, FPU, Cache, Memory bandwidth, etc.) of the core. Commonly used performance tools would still report (at least) 50% idle since 2 logical processors (hardware threads) appear completely idle.

In order to correctly estimate how much work can be added until the system approaches full saturation the operating system would need to get detailed utilization information of all shared core processing units (ALU, FPU, Cache, Memory bandwidth, etc.) as well as knowing the characteristics of the workload to be added.

Measurements with SAP ABAP workload
To illustrate our case, let's look at a very specific but very common workload in Enterprise Computing: SAP-SD ABAP. We took these measurements on a SPARC T5 system running the latest Solaris 11 release. Simulated benchmark users logged onto the SAP system and entered SD transactions. The maximum number of SD-Users and SAP transaction throughput the system could handle are represented by the 100% mark on the X-Axis. A series of test runs was carried out in order to measure CPU utilization (Y-Axis) as reported by the operating system at 0%, 12.5%, 25%, 50%, 60%, 75%, 90% and 100% of the maximum number of SD-Users.



Unlike what one could naively assume the diagram does not show a straight diagonal line. Instead we see that at 25% of the SD-User / maximum throughput load, the operating system only reports 8% CPU utilization with 92% idle.
At half of the maximum achievable throughput the system only appears to be 21% busy with 79% idle.

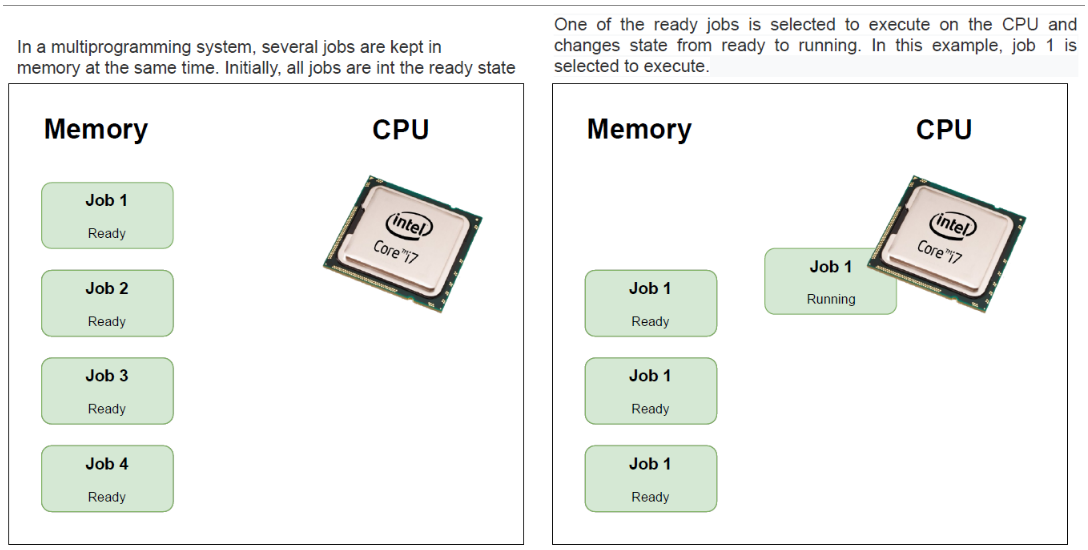
Put it another way, when the OS reports 50% CPU utilization, we are already at 80% of maximum throughput, and cannot assume that adding the same load again would double the throughput with the same response time, yet this is a very common mistake we see reported by customers.

The curve shown on the diagram is highly dependent on the workload (application or application mix) and CPU architecture (number of hardware threads, shared computing resources, etc.). It can be assumed that most applications running on multi-threaded architectures will show this non-linear behavior (more or less pronounced).

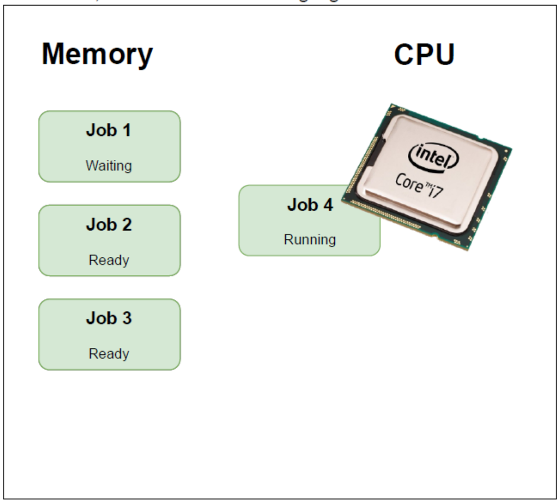
Capacity Planning has become a much more complex affair with the advent of multi-thread/multi-core CPU architectures, and to answer the question of how much more load one can add to an existing system, one has to analyze the workload to be added as well as the current resource consumption.

Multi programmed system's working

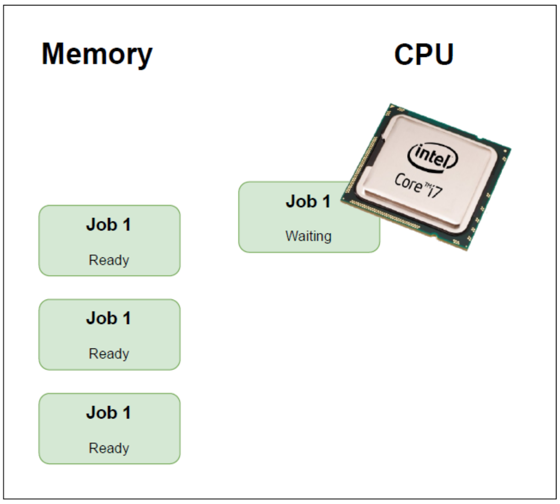
In a multi-programmed system, as soon as one job goes for an I/O task, the Operating System interrupts that job, chooses another job from the job pool (waiting queue), gives CPU to this new job and starts its execution. The previous job keeps doing its I/O operation while this new job does CPU bound tasks. Now say the second job also goes for an I/O task, the CPU chooses a third job and starts executing it. As soon as a job completes its I/O operation and comes back for CPU tasks, the CPU is allocated to it.



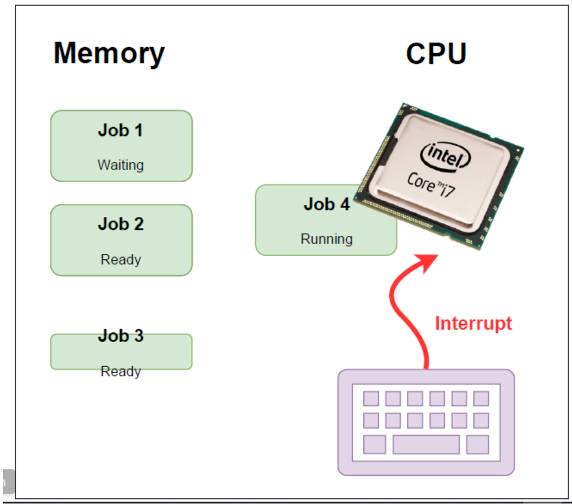
Instead of idle waiting for the I/O request to complete, one of the ready jobs is selected to execute on the CPU and have its state change from ready to running. In this example job 4 is selected to execute, based on the scheduling algorithm



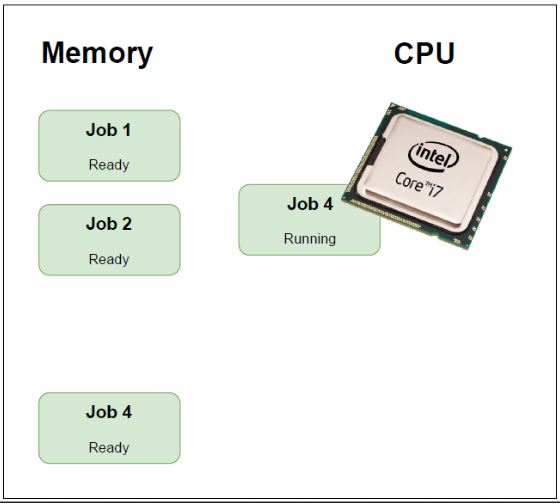
Eventually, the running job makes a request for I/O and the state changes from running to waiting.



Eventually the the I/O request job 1 is waiting for will complete and the CPU will be notified by an interrupt. In this example, job 1 was waiting for a keypress on the keyboard.



The state of the waiting job (job 1) will change from waiting to ready.



In this way, no CPU time is wasted by the system waiting for the I/O task to be completed. Therefore, the ultimate goal of multi programming is to keep the CPU busy as long as there are processes ready to execute. This way, multiple programs can be executed on a single processor by executing a part of a program at one time, a part of another program after this, then a part of another program and so on, hence executing multiple programs. Hence, the CPU never remains idle.

Question No. 2

Solution to Question No. 2:

> **Note:** The sequential approach and the multi-threaded approach are implemented in one program, where command line arguments are used to execute a selected approach.

2.1 Design and implementation of the application using sequential approach with functions

Algorithm for adding two matrices with Sequential Approach:

```
STEP 1: Start
STEP 2: define MAX = 15,000
STEP 3: generate matrixA[MAX][MAX]and matrixB[MAX][MAX]  with random
values
STEP 4: initialize a thread thread_id
STEP 5: Start time using clock_gettime
STEP 6: pthread_create(&thread_id, NULL, &sequential_add, NULL);
STEP 7: join thread
STEP 8: End time
STEP 9: print sum [][]
STEP 10: print difference of start and end time
STEP 11: Stop
```

```
sequential_add(void *arg)
STEP 1: for i = 0 to MAX
     1.1 for j = 0 to MAX
          1.1.1 sum[i][j] = matrixA[i][j] + matrixB[i][j]
STEP 2: pthread_exit
```

Program For adding two matrices with sequential approach

```c
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <string.h>
#include <sys/sysinfo.h>

// function prototypes
void *parallel_addition(void *arg);
void *sequential_addition(void *arg);
void generateMatrix();
void sequential_approach();
void parallel_approach();

// Value depend on System core
#define CORE 12

// Maximum matrix size
#define MAX 15000

// initializing matrix
int mat_A[MAX][MAX], mat_B[MAX][MAX], sum[MAX][MAX];

// Driver Code
int main(int argc, char *argv[])
{
    // chexking how many cores available
    printf("This system has %d processors configured and "
           "%d processors available.\n",
           get_nprocs_conf(), get_nprocs());

    //genearating matrix A and matrix B with random values
    generateMatrix();
    // Displaying mat_A
    printf("\nMatrix A:\n");

    for (size_t i = 0; i < MAX; i++)
    {
        for (size_t j = 0; j < MAX; j++)
        {

            printf("%d ", mat_A[i][j]);
        }

        printf("\n");
    }

    // Displaying mat_B
    printf("\nMatrix B:\n");

    for (size_t i = 0; i < MAX; i++)
    {
        for (size_t j = 0; j < MAX; j++)
        {

            printf("%d ", mat_B[i][j]);
        }

        printf("\n");
    }

    if (strcmp(argv[1], "--sequential") == 0)
    {
        printf("\nRunning in sequential mode.\n");
        sequential_approach();
    }
    else
    {
        printf("\nRunning in parallel mode.\n");
        parallel_approach();
    }

    return 0;
}
```

Figure 1 Driver Code

```c

void generateMatrix()
{
    // Generating random values in mat_A and mat_B
    for (size_t i = 0; i < MAX; i++)
    {
        for (size_t j = 0; j < MAX; j++)
        {
            mat_A[i][j] = rand() % 10;
            mat_B[i][j] = rand() % 10;
        }
    }
}
```

Figure 2 Function to generate random values and store in matrixA and matrixB

```c

void sequential_approach()
{

    // defining variables to calculate time
    struct timespec start, end;

    // intializing thread id
    pthread_t thread_id;

    // storing start time
    clock_gettime(CLOCK_REALTIME, &start);

    pthread_create(&thread_id, NULL, &sequential_addition, NULL);

    // Waiting for join threads after compute
    pthread_join(thread_id, NULL);

    // storing end time
    clock_gettime(CLOCK_REALTIME, &end);

    // Display Addition of mat_A and mat_B
    printf("\nSum of Matrix A and B:\n");
    for (size_t i = 0; i < MAX; i++)
    {
        for (size_t j = 0; j < MAX; j++)
        {
            printf("%d ", sum[i][j]);
        }
        printf("\n");
    }

    // calculating time elapsed
    double time_taken;
    time_taken = (end.tv_sec - start.tv_sec) * 1e9;
    time_taken = (time_taken + (end.tv_nsec - start.tv_nsec)) * 1e-9;

    printf("Time taken : %.10f seconds.\n", time_taken);
}
```

Figure 3 Driver Function to add, print and record time in matrix addition

```c
void *sequential_addition(void *arg)
{
    for (size_t i = 0; i < MAX; i++)
    {
        for (size_t j = 0; j < MAX; j++)
        {
            // Compute Sum Row wise
            sum[i][j] = mat_A[i][j] + mat_B[i][j];
        }
    }
    pthread_exit(NULL);
}
```

Figure 4 function to add two matrices

Output

```makefile
all:
	@gcc -pthread matrix_sum.c

run-parallel:
	@./a.out --parallel -O4

run-sequential:
	@./a.out --sequential -O4

debug:
	@gcc -pthread -g matrix_sum.c

clean:
	@rm -r a.out

.PHONY: clean
```

Figure 5 makefile

Note: This output is to check whether the program is adding two matrices correctly hence running the program with MAX = 3.

```
 subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make
matrix_sum.c: In function 'parallel_addition':
matrix_sum.c:80:16: warning: cast from pointer to integer of different size [-Wpointer-to-int-cast]
   80 |     int core = (int)arg;
      |                ^
matrix_sum.c: In function 'parallel_approach':
matrix_sum.c:172:62: warning: cast to pointer from integer of different size [-Wint-to-pointer-cast]
  172 |         pthread_create(&thread[i], NULL, &parallel_addition, (void *)step);
      |                                                              ^
 subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-sequential
This system has 12 processors configured and 12 processors available.

Matrix A:
3 7 3
6 9 2
0 3 0

Matrix B:
6 5 5
2 1 7
9 6 6

Running in sequential mode.

Sum of Matrix A and B:
9 12 8
8 10 9
9 9 6
Time taken : 0.0006847000 seconds.
 subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment 
```

Figure 6 execution of adding two matrices with sequential approach

2.2 Design and implementation of the application using multithreaded approach

Algorithm for adding two matrices with Parallel/Multithreaded Approach:

```
STEP 1: Start
STEP 2: define MAX = 15000 and CORE = 12
STEP 3: generate matrixA[MAX][MAX]and matrixB[MAX][MAX] with random
values
STEP 4: initialize threads thread_id[CORE]
STEP 5: Start time using clock_gettime
STEP 6: for i = 0 to CORE
          6.1 pthread_create(&thread_id[i], NULL, &parallel_add, step);
STEP 7: for i = 0 to CORE
          7.1join thread[i]
STEP 8: End time
STEP 9: print sum [][]
STEP 10: print difference of start and end time
STEP 11: Stop
```

```
parallel_add(void *arg)
STEP 1: int core = (int)arg
STEP 2: each thread computes 1/COREth of matrix addition
     2.1 for i = (core * MAX / CORE) to ((core + 1) * MAX / CORE)
          2.1.1 for j = 0 to MAX
               2.1.1.1 sum[i][j] = matrixA[i][j] + matrixB[i][j]
STEP 3: pthread_exit
```

Program for adding two matrices with parallel/multithreaded approach

```c
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <string.h>
#include <sys/sysinfo.h>

// function prototypes
void *parallel_addition(void *arg);
void *sequential_addition(void *arg);
void generateMatrix();
void sequential_approach();
void parallel_approach();

// Value depend on System core
#define CORE 12

// Maximum matrix size
#define MAX 15000

// initializing matrix
int mat_A[MAX][MAX], mat_B[MAX][MAX], sum[MAX][MAX];

// Driver Code
int main(int argc, char *argv[])
{
    // chexking how many cores available
    printf("This system has %d processors configured and "
           "%d processors available.\n",
           get_nprocs_conf(), get_nprocs());

    //genearating matrix A and matrix B with random values
    generateMatrix();
    // Displaying mat_A
    printf("\nMatrix A:\n");

    for (size_t i = 0; i < MAX; i++)
    {
        for (size_t j = 0; j < MAX; j++)
        {

            printf("%d ", mat_A[i][j]);
        }

        printf("\n");
    }

    // Displaying mat_B
    printf("\nMatrix B:\n");

    for (size_t i = 0; i < MAX; i++)
    {
        for (size_t j = 0; j < MAX; j++)
        {

            printf("%d ", mat_B[i][j]);
        }

        printf("\n");
    }

    if (strcmp(argv[1], "--sequential") == 0)
    {
        printf("\nRunning in sequential mode.\n");
        sequential_approach();
    }
    else
    {
        printf("\nRunning in parallel mode.\n");
        parallel_approach();
    }

    return 0;
}
```

Figure 7 Driver Code

```c

void generateMatrix()
{
    // Generating random values in mat_A and mat_B
    for (size_t i = 0; i < MAX; i++)
    {
        for (size_t j = 0; j < MAX; j++)
        {
            mat_A[i][j] = rand() % 10;
            mat_B[i][j] = rand() % 10;
        }
    }
}
```

Figure 8 Function to generate random values and store in matrixA and matrixB

```c
void parallel_approach()
{
    // defining variables to calculate time
    struct timespec start, end;

    // Maximum threads is equal to total core of system
    pthread_t thread[CORE];
    // storing start time
    clock_gettime(CLOCK_REALTIME, &start);

    // Creating threads equal
    // to core size and compute matrix row
    int step = 0;
    for (size_t i = 0; i < CORE; i++)
    {
        pthread_create(&thread[i], NULL, &parallel_addition, (void *)step);
        step++;
    }
    for (size_t i = 0; i < CORE; i++)
    {

        // Waiting for join threads after compute
        pthread_join(thread[i], NULL);
    }

    // storing end time
    clock_gettime(CLOCK_REALTIME, &end);

    // Display Addition of mat_A and mat_B
    printf("\nSum of Matrix A and B:\n");

    for (size_t i = 0; i < MAX; i++)
    {

        for (size_t j = 0; j < MAX; j++)
        {

            printf("%d ", sum[i][j]);
        }

        printf("\n");
    }
    // calculating time elapsed
    double time_taken;
    time_taken = (end.tv_sec - start.tv_sec) * 1e9;
    time_taken = (time_taken + (end.tv_nsec - start.tv_nsec)) * 1e-9;

    printf("Time taken : %.10f seconds.\n", time_taken);
}
```

Figure 9 Driver Function to add, print and record time in matrix addition

```c
void *parallel_addition(void *arg)
{

    int core = (int)arg;

    // Each thread computes 1/CORE th of matrix addition
    for (size_t i = core * MAX / CORE; i < (core + 1) * MAX / CORE; i++)
    {
        for (size_t j = 0; j < MAX; j++)
        {
            // Compute Sum Row wise
            sum[i][j] = mat_A[i][j] + mat_B[i][j];
        }
    }
    pthread_exit(NULL);
}
```

Figure 10 function to add two matrices in multithreads

Output

```makefile
makefile
all:
	@gcc -pthread matrix_sum.c

run-parallel:
	@./a.out --parallel -O4

run-sequential:
	@./a.out --sequential -O4

debug:
	@gcc -pthread -g matrix_sum.c

clean:
	@rm -r a.out

.PHONY: clean
```

Figure 11 makefile

Note: This output is to check whether the program is adding two matrices correctly hence running the program with MAX = 3.

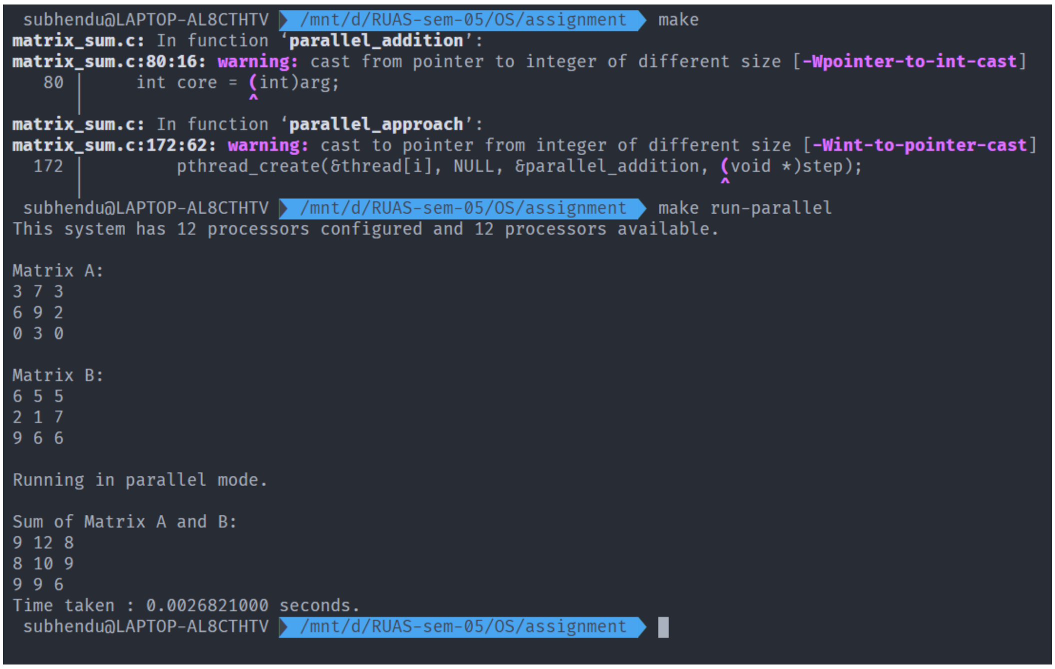


Figure 12 execution of adding two matrices with multithreaded approach

2.3 Comparison of the execution time of the above two versions of the program and its analysis

As I have a system with 12 cores.

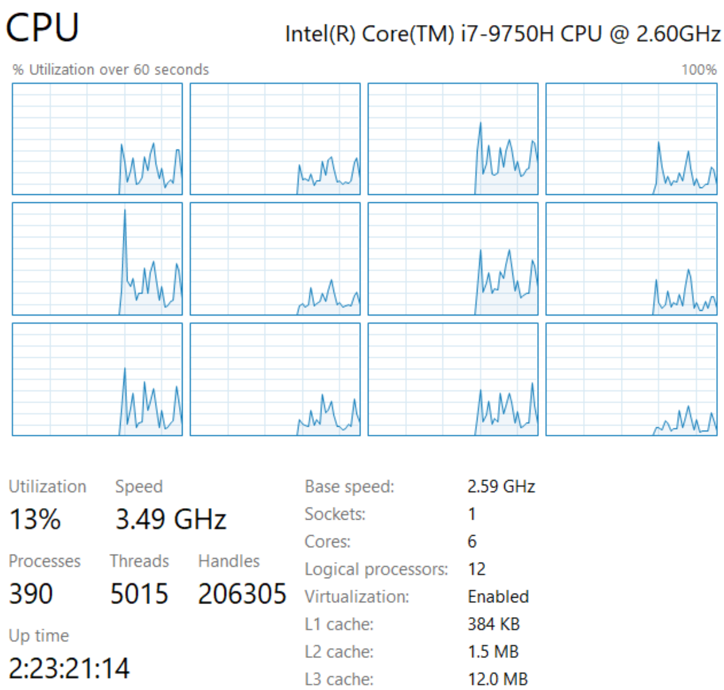


Figure 13 screenshot of CPU config

To get a good comparison of the execution we have to take a larger value of MAX, hence we are taking MAX = 15000 and CORE = 12. This will create 15000 X 15000 matrices and in multithreaded approach each thread will add 1250 row of matrix.

As the matrix size is humungous, it is not possible to display the matrices hence commenting out the code which displaying the matrices and only displaying the time taken in execution.

```
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-sequential
Running in sequential mode.
Time taken : 1.7344959000 seconds.
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-sequential
Running in sequential mode.
Time taken : 1.7639178000 seconds.
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-sequential
Running in sequential mode.
Time taken : 1.8076375000 seconds.
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-sequential
Running in sequential mode.
Time taken : 1.7746254000 seconds.
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-sequential
Running in sequential mode.
Time taken : 1.8804018000 seconds.
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment 
```

Figure 14 execution of sequential matrix addition with matrix size 15000 X 15000

```
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-parallel
Running in parallel mode.
Time taken : 0.3074759000 seconds.
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-parallel
Running in parallel mode.
Time taken : 0.3101453000 seconds.
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-parallel
Running in parallel mode.
Time taken : 0.3038756000 seconds.
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-parallel
Running in parallel mode.
Time taken : 0.3245156000 seconds.
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment  make run-parallel
Running in parallel mode.
Time taken : 0.3244580000 seconds.
subhendu@LAPTOP-AL8CTHTV  /mnt/d/RUAS-sem-05/OS/assignment 
```

Figure 15 execution of multi-threaded matrix addition with matrix size 15000 X 15000

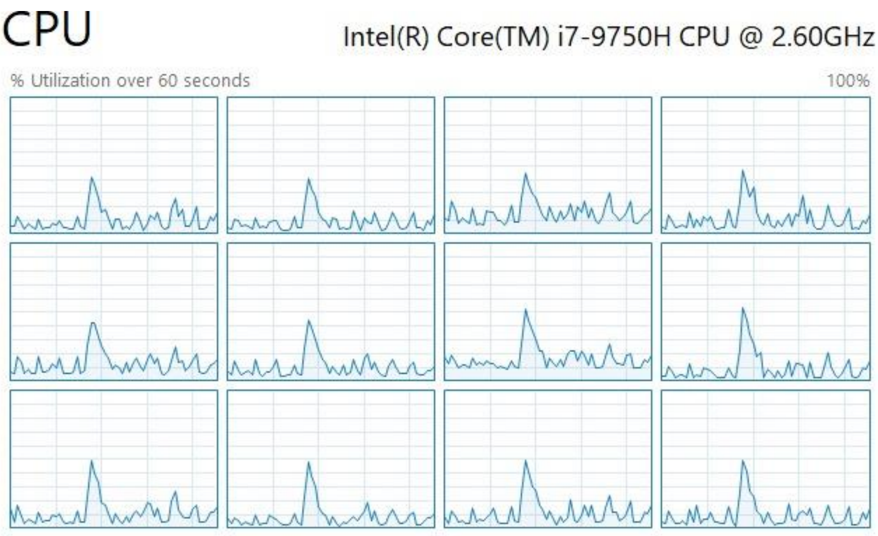


Figure 16 (Hike in all 12 CPU utilization) proof that all the CPU cores are working when executing multithreaded matrix addition

Experiment Number	Sequential Mode Execution Time (seconds)	Parallel Mode Execution Time (seconds)
1	1.734495	0.307475
2	1.763917	0.310145
3	1.807637	0.303875
4	1.774625	0.324515
5	1.880401	0.324458
Average Execution time	**1.792215**	**0.314093**

Therefore,

Average execution time in parallel mode $\approx 0.31409\ sec.$

Average execution time in sequential mode ≈ 1.792215 sec.

Hence, parallel mode is 6 times(approx.) faster than sequential mode.

Thus, the parallel mode execution is faster. This is obvious from the fact that in parallel mode, the addition of 15000 rows divided into 12 threads and processed simultaneously.

In parallel mode, each thread is assigned 1250 rows of matrix to add. But in sequential mode, the main thread processes the whole matrix line by line. Hence, the sequential execution is slower.

Solution to Question No. 3:

3.1 Schedule of the processes using a Gantt chart

Non-Pre-emptive priority scheduling algorithm:

processes	Burst time (ns)	Arrival time (ns)	Priority	Start time	Completion time	Turnaround time	Waiting time	delay
1	10	15	6	37	47	32	22	3.2
2	15	20	8	22	37	17	2	1.134
3	5	25	2	47	52	27	22	5.4
4	12	10	4	10	22	12	0	1

Gantt chart for non-pre-emptive:

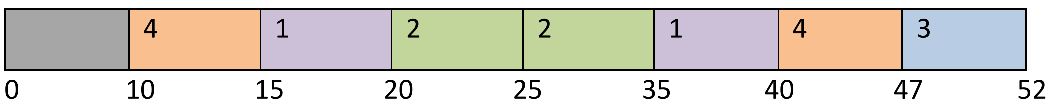
Ready Queue: 4 2 1 3

Number of context switches: 3

Pre-emptive priority scheduling algorithm:

processes	Burst time (ns)	Arrival time (ns)	Priority	Start time	Completion time	Turnaround time	Waiting time	delay
1	10->5->0	15	6	15	40	25	15	2.5
2	15->10->0	20	8	20	35	15	0	1
3	5->0	25	2	47	52	27	22	5.4
4	12->7->0	10	4	10	47	37	25	3.08

Gantt chart for pre-emptive:



Ready Queue: 4 1 3 2

Number of context switches: 5

3.2 Average waiting time and average turnaround time experienced

Formulae for calculating turnaround time, waiting time and delay:

$Turnaround\ time\ = completion\ time - arrival\ time$

$Waiting\ time = \ turnaround\ time\ - service\ time$

$Delay = \ turnaround\ time\ /service\ time$

Non pre-emptive:

- **Average turnaround time experienced in non-pre-emptive scheduling is:**

  Average turnaround time:

$$\frac{(32+17+27+12)}{4} = \frac{88}{4} = 22 \text{ ns}$$

- **Average waiting time experienced in non-pre-emptive scheduling is:**

  Average waiting time:

$$\frac{(22+2+22+0)}{4} = \frac{46}{4} = 11.5\ ns$$

- **Average delay experienced in non-pre-emptive scheduling is:**

  Average delay:

$$\frac{(3.2+1.134+5.4+1)}{4} = 2.683$$

Pre-emptive:

- **Average turnaround time experienced in pre-emptive scheduling is:**

  Average turnaround time:

$$\frac{(25+15+27+37)}{4} = \frac{104}{4} = 26\ ns$$

- **Average waiting time experienced in pre-emptive scheduling is:**

  Average waiting time:

$$\frac{(15+0+22+25)}{4} = \frac{62}{4} = 15.5\ ns$$

- **Average delay experienced in pre-emptive scheduling is:**

  Average delay:

$$\frac{(2.5+1+5.4+3.08)}{4} = 2.995$$

3.3 Scheduling algorithm with better performance and its justification

By looking at the above solved problem we can say that **non pre-emptive** priority-based scheduling algorithm has better performance than pre-emptive scheduling algorithm as it has

- Less average turnaround time
- Less average awaiting time
- Less average delay
- Less contest switches

than pre-emptive scheduling.

1. https://blogs.oracle.com/solaris/cpu-utilization-of-multi-threaded-architectures-explained-v2
2. http://www.it.uu.se/education/course/homepage/os/vt18/module-1/multiprogramming/
3. https://www.geeksforgeeks.org/difference-between-multitasking-multithreading-and-multiprocessing/