Graduate Systems (CSE638)

PA01: Processes and Threads

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GitHub Repo URL: https://github.com/rahul25035/GRS_PA01

AI Usage Declaration

I used AI tools to help me while doing this assignment. I mainly used them for:

1. Writing and improving the I/O parts in the C codes (Part B, Part C, and Part D)
2. Getting help with awk commands to calculate stats inside the shell script loops (Part C and Part D)
3. Deciding how the output of the stats should look
4. Writing the plotting script for Part D
5. Improving the format and wording of the report and README
6. Debugging help - finding errors and fixing issues

I checked and tested everything myself before submitting. The final work and responsibility is mine.

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Date: 22nd January, 2026

1. Problem Statement

This assignment compares **process-based parallelism (fork)** and **thread-based parallelism (pthread)** by running three worker functions (**cpu**, **mem**, **io**) and measuring CPU usage, memory impact, I/O activity, and execution time.

2. System & Experimental Setup

2.1 Machine Details

- **OS:** Linux
- **No. of CPU cores:** 2
- **RAM:** 8 GB

2.2 Tools Used

- gcc (compilation)
- make
- top (CPU%)
- taskset (CPU pinning)
- iostat (disk stats)
- time (execution time)

2.3 Fixed Parameters Used

- **Last digit of roll number:** 5
- **Loop count (N):** (last digit × 10^3) = 5000
  (If last digit is 0, used 9 → N = 9000)

3. Part A : Program Implementations

3.1 Program A (Processes using fork())

File: MT25035_Part_A_Program_A.c

Goal: Create **2 child processes** using fork().

Implementation Summary:

- The parent process calls fork() twice.
- Each child prints its PID and exits.
- The parent waits for both child processes using wait().

Observed Output:

```
None
Child 1: pid=<pid>

Child 2: pid=<pid>
```

3.2 Program B (Threads using pthread)

File: MT25035_Part_A_Program_B.c

Goal: Create **2 threads** using pthread.

Implementation Summary:

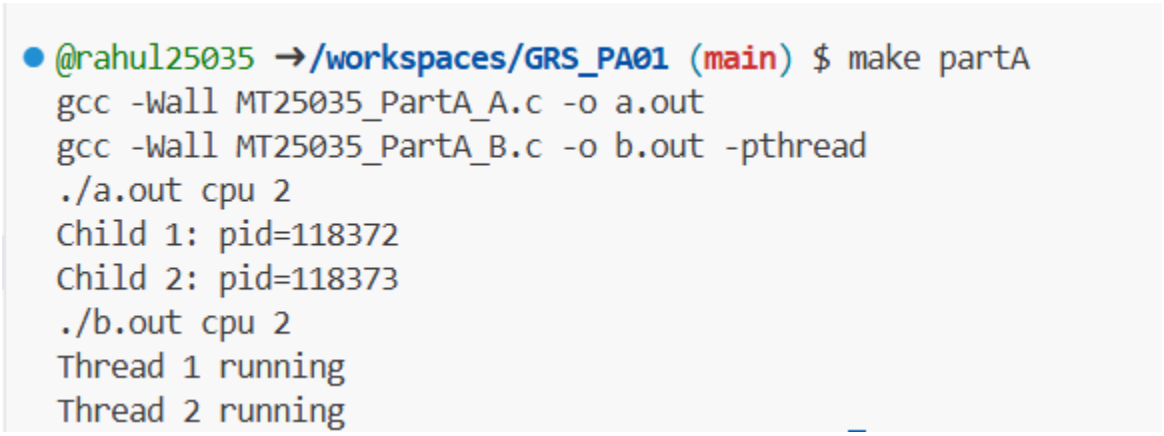
- Two threads are created using pthread_create().
- Each thread prints its thread ID.
- The main thread waits using pthread_join().

Observed Output:

```
None
Thread 1 running

Thread 2 running
```

3.3 Images



4. Part B : Worker Functions

Files:

- MT25035_Part_B_Program_A.c (process-based workers)
- MT25035_Part_B_Program_B.c (thread-based workers)

All worker functions execute a loop with **ITER = 5000**, derived from the last digit of the roll number (5×10^3).

4.1 Worker: cpu (CPU-Intensive)

Work Done:

- Performs deeply nested loops with arithmetic operations.
- No I/O or large memory allocation involved.

Expected Behavior:

- High CPU usage
- Minimal memory and I/O usage

4.2 Worker: mem (Memory-Intensive)

Work Done:

- Allocates a 256 MB buffer using malloc().

- Repeatedly accesses memory pages to stress RAM.

Expected Behavior:

- High memory usage
- Moderate CPU usage

4.3 Worker: io (I/O-Intensive)

Work Done:

- Repeatedly writes 4 KB buffers to a file using write().
- Forces disk writes using fsync().

Expected Behavior:

- High disk I/O activity
- Lower CPU and memory utilization due to I/O wait

5. Part C : Experiments (2 processes/threads)

Files:

- Script: MT25035_Part_C_main.sh
- Data CSV: MT25035_Part_C_results.csv

5.1 Measurement Method

For each variant (A/B + cpu/mem/io):

- Used taskset to pin execution to 0 and 1 CPU cores.
- Sampled CPU% using top at regular intervals.
- Observed disk behavior using iostat.
- Measured elapsed time using time.

5.2 Results Table (Part C)

The following results summarize the automated measurements recorded in MT25035_Part_C_results.csv. CPU usage is reported relative to the two CPU cores to which the program was pinned using taskset.

Program + Function	CPU Usage	Memory Usage	I/O Activity
A + cpu	Very High (~185%)	Low (~1.2 MB)	Low
A + mem	High (~136%)	High (~411 MB)	Low
A + io	Low (~7%)	Low (~1.7 MB)	High (~8k KB/s)
B + cpu	High (~155%)	Low (~1.4 MB)	Low
B + mem	Very High (~165%)	High (~513 MB)	Low
B + io	Low (~7%)	Low (~1.4 MB)	Very High (~25k KB/s)

5.3 Screenshots

```
@rahul25035 →/workspaces/GRS_PA01 (main) $ make partC
chmod +x MT25035_PartC_main.sh
./MT25035_PartC_main.sh
Compiling programs...
Compilation done
================================

components=2
Prog       CPU%     Mem        IO       Time(s)
------------------------------------------------------------
A+cpu      175.84   1.82MB     97.53    7.00
B+cpu      184.30   1.40MB     29.60    6.91
A+mem      169.92   411.31MB   40.00    6.84
B+mem      145.98   410.80MB   19.06    6.60
A+io       9.12     1.41MB     8237.00  5.15
B+io       9.10     0.94MB     26642.00 5.29

Results saved to MT25035_PartC_results.csv
```

5.4 Analysis (Part C)

- **CPU Workload:**
  Both process-based (A) and thread-based (B) CPU workloads almost fully utilize the two pinned cores (~175–185%). This is expected because the CPU worker performs continuous computations with minimal memory access or I/O, allowing the scheduler to keep both cores busy. The slight variation between A and B is due to scheduling and context-switch overhead.
- **Memory Workload:**
  The memory-intensive workload shows high memory usage (~411–513 MB) and slightly lower CPU utilization compared to the pure CPU task. This happens because frequent memory accesses introduce latency (cache misses and main memory access), causing the CPU to stall occasionally instead of executing instructions continuously.
- **I/O Workload:**
  For I/O-heavy workloads, CPU usage drops sharply (~7–9%) while disk activity increases. Most of the execution time is spent waiting for disk writes to complete, so the CPU remains mostly idle. This clearly indicates an I/O-bound workload rather than a compute-bound one.
- **Process vs. Thread Comparison:**
  Thread-based execution (Program B) achieves noticeably higher I/O throughput (~25 KB/s) compared to process-based execution (~8 KB/s). This suggests lower overhead in threads due to shared address space and cheaper context switching, making threads more efficient for I/O-heavy tasks in this setup.

6. Part D : Automation and Plots (vary processes/threads)

Files:

- MT25035_Part_D_main.sh
- MT25035_Part_D_plots.sh
- MT25035_Part_D_Program_A.c
- MT25035_Part_D_Program_B.c
- Data CSV: MT25035_Part_D_results.csv

6.1 Experiment Plan

- **Program A (Processes):** {2, 3, 4, 5, 6, 7 , 8}
- **Program B (Threads):** {2, 3, 4, 5, 6, 7, 8}

All experiments use **ITER = 5000** and the same worker logic as Part C.

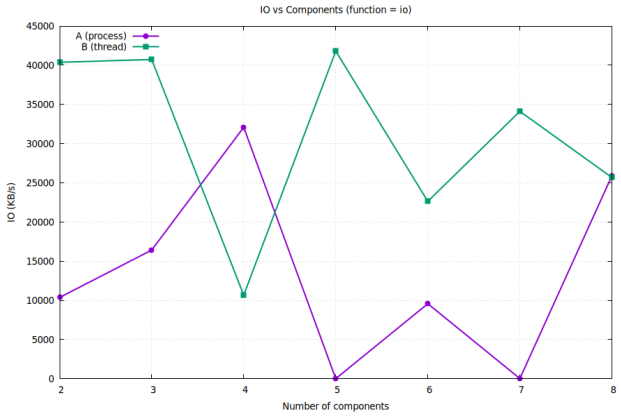
6.2 Collected Metrics

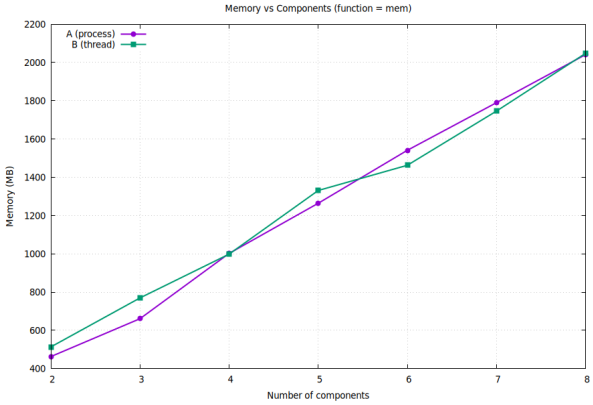
For each run, the following were recorded using the automated script:

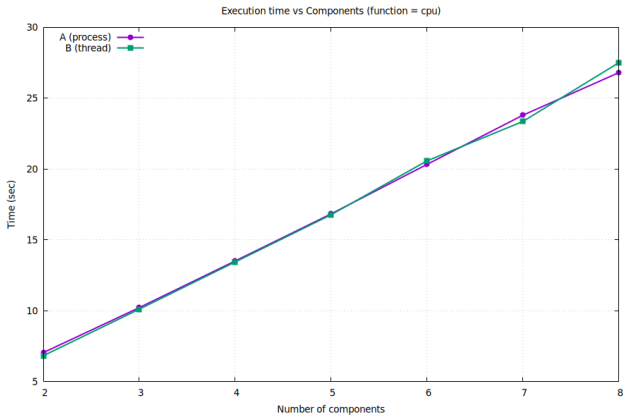
- Average CPU utilization (top)
- Execution time (time)
- Memory usage (RSS from top)
- Disk I/O activity (iostat, write rate / utilization)

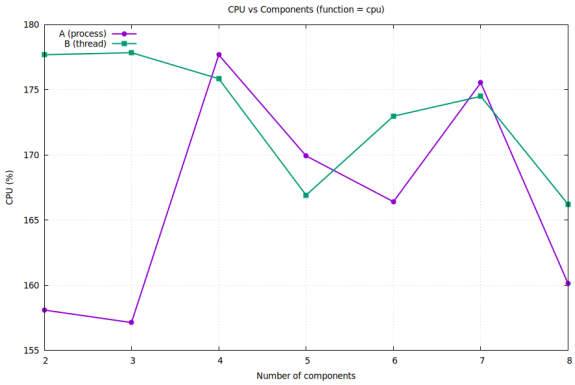
All raw values are available in MT25035_Part_D_results.csv.

6.3 Plots and Images (Part D)










```
@rahul25035 →/workspaces/GRS_PA01 (main) $ make partD
```

components=2

Prog	CPU%	Mem	IO	Time(s)
A+cpu	158.10	1.88MB	34.37	7.050
B+cpu	177.68	1.00MB	50.40	6.830
A+mem	173.14	463.05MB	8.80	7.090
B+mem	171.76	513.51MB	67.79	7.100
A+io	9.10	1.59MB	10377.00	5.230
B+io	9.55	1.03MB	40374.00	5.230

components=3

Prog	CPU%	Mem	IO	Time(s)
A+cpu	157.14	1.96MB	17.64	10.220
B+cpu	177.84	1.27MB	36.57	10.110
A+mem	141.47	661.00MB	61.84	9.670
B+mem	183.46	769.64MB	23.43	10.340
A+io	16.18	2.50MB	16419.00	5.940
B+io	5.46	1.10MB	40731.20	6.370

components=4

Prog	CPU%	Mem	IO	Time(s)
A+cpu	177.67	2.38MB	2877.67	13.510
B+cpu	175.84	1.38MB	78.64	13.440
A+mem	178.17	1002.28MB	55.56	15.200
B+mem	188.72	998.55MB	37.60	15.300
A+io	15.10	2.88MB	32086.40	6.830
B+io	15.46	1.20MB	10668.00	6.750

components=5

Prog	CPU%	Mem	IO	Time(s)
A+cpu	169.92	2.60MB	9314.18	16.830
B+cpu	166.91	1.38MB	90.46	16.770
A+mem	181.48	1264.40MB	21.53	20.110
B+mem	192.39	1331.20MB	87.61	20.250
A+io	11.90	2.19MB	21.33	7.930
B+io	18.80	1.15MB	41805.33	8.040

components=6

Prog	CPU%	Mem	IO	Time(s)
A+cpu	166.41	3.60MB	10514.77	20.320
B+cpu	172.97	1.51MB	58.15	20.570
A+mem	179.59	1541.27MB	43.70	25.870
B+mem	175.21	1462.97MB	51.37	24.490
A+io	19.73	3.62MB	9578.00	8.780
B+io	11.46	1.50MB	22636.00	7.720

components=7

Prog	CPU%	Mem	IO	Time(s)
A+cpu	175.53	4.00MB	5457.05	23.790
B+cpu	174.49	1.39MB	36.49	23.350
A+mem	180.10	1790.11MB	22.28	30.720
B+mem	177.32	1746.19MB	68.82	29.670
A+io	15.62	3.33MB	32.67	8.180
B+io	16.30	1.50MB	34113.33	8.370

```
components=8
Prog   CPU%     Mem       IO         Time(s)
------------------------------------------------------
A+cpu  160.12   3.18MB    4862.41    26.790
B+cpu  166.21   1.38MB    47.89      27.490
A+mem  179.61   2041.34MB 62.11      34.190
B+mem  169.43   2048.00MB 69.80      34.460
A+io   18.20    4.00MB    25892.67   9.150
B+io   15.35    1.50MB    25678.67   8.700

Results saved to MT25035_PartD_results.csv
Making Plots...
Plots created: cpu_vs_components.png, mem_vs_components.png, io_vs_components.png, time_vs_components.png
```

6.4 Observations & Discussion (Part D)

- **Execution Time Scaling:**
  For both CPU-bound and memory-bound workloads, execution time increases almost linearly as the number of components grows from 2 to 8. This is expected because each additional component adds a similar amount of work, and the total workload scales proportionally.
- **Memory Scaling:**
  Memory usage increases steadily with the number of components, by roughly 256 MB per component, reaching about 2 GB at 8 components. This indicates that each component allocates a fixed memory block, and there is little memory reuse across components.
- **CPU Utilization:**
  CPU usage remains consistently high (around 160–180%) across all component counts. Since the programs are pinned to two cores, these cores stay fully utilized regardless of how many components are added, explaining why CPU usage does not scale further.
- **I/O Behavior:**
  I/O throughput shows significant fluctuations across different component counts. This “noisy” behavior is mainly due to operating system effects such as disk buffering, write caching, and background I/O activity, which can hide or batch actual disk writes.
- **Process vs. Thread Efficiency:**
  For non-memory workloads, Program B (threads) consistently uses less memory than Program A (processes). This is because threads share the same address space, while processes require separate memory regions, making threads more resource-efficient in this scenario.