

CSE638 - Graduate Systems

Programming Assignment 01: Processes and Threads

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1 Introduction

This report presents the implementation and analysis of Programming Assignment 01. The assignment focuses on understanding differences between processes and threads through practical implementation and performance measurement.

System Configuration:

- Operating System: Linux (WSL2)
- CPU Pinning: taskset -c 0-1 (2 CPUs for Part C)
- Loop Count: 7000 (roll number last digit: 7)

2 Part A: Program Implementation

2.1 Program A: Process-Based (fork)

Program A uses `fork()` to create 2-5 child processes. Each child executes a worker function independently. Parent waits using `waitpid()`.

```
for (int i = 0; i < num_workers; i++) {  
    pid_t pid = fork();  
    if (pid == 0) {  
        worker_function();  
        exit(0);  
    } else if (pid > 0) {  
        child_pids[i] = pid;  
    }  
}  
for (int i = 0; i < num_workers; i++) {  
    waitpid(child_pids[i], NULL, 0);  
}
```

2.2 Program B: Thread-Based (pthread)

Program B uses `pthread_create()` to spawn 2-8 threads. All threads share the same memory space.

```
pthread_t threads[num_workers];
for (int i = 0; i < num_workers; i++) {
    pthread_create(&threads[i], NULL, worker_wrapper, NULL);
}
for (int i = 0; i < num_workers; i++) {
    pthread_join(threads[i], NULL);
}
```

3 Part B: Worker Functions

Loop count is 7000 based on roll number MT25077 (last digit = 7).

3.1 CPU-Intensive Worker

Performs heavy mathematical calculations using sin, cos, sqrt, pow, log, exp functions. Uses volatile keyword to prevent compiler optimization. Multiplier of 10,000,000 ensures 30-60 second execution.

```
void worker_cpu(void) {
    volatile double result = 0.0;
    for (long i = 0; i < LOOP_COUNT * CPU_INTENSIVE_MULTIPLIER; i++) {
        result += sin(i * 0.001) * cos(i * 0.002);
        result += sqrt(fabs(result) + 1.0);
        result += pow(1.0001, (i % 100));
        result += log(fabs(result) + 1.0);
        result += exp(-(i % 50) * 0.01);
    }
}
```

3.2 Memory-Intensive Worker

Allocates 1 MB buffers, initializes with `memset`, uses random access patterns to cause cache misses, and performs `qsort` operations.

```
void worker_mem(void) {
    size_t buffer_size = 1024 * 1024;
    for (int iter = 0; iter < LOOP_COUNT; iter++) {
        int *buffer = malloc(buffer_size * sizeof(int));
        memset(buffer, iter & 0xFF, buffer_size * sizeof(int));
        for (size_t j = 0; j < buffer_size; j += 64) {
            buffer[j] = buffer[(j * 7) % buffer_size];
        }
        qsort(buffer, buffer_size / 100, sizeof(int), compare_int);
        free(buffer);
    }
}
```

3.3 I/O-Intensive Worker

Creates temporary files, alternates between write and read operations. Low CPU utilization due to I/O wait time.

```
void worker_io(void) {
    char filename[64];
    snprintf(filename, sizeof(filename), "/tmp/io_worker_%d.tmp",
             getpid());
    for (int iter = 0; iter < LOOP_COUNT; iter++) {
        FILE *fp = fopen(filename, "w");
        for (int j = 0; j < 1000; j++) {
            fprintf(fp, "Line %d iteration %d\n", j, iter);
        }
        fclose(fp);
        fp = fopen(filename, "r");
        char buffer[256];
        while (fgets(buffer, sizeof(buffer), fp)) { }
        fclose(fp);
    }
    unlink(filename);
}
```

4 Part C: Performance Measurement (2 Workers)

Setup: CPU pinned to 2 cores using taskset -c 0-1. Measured using /usr/bin/time -v, top, iostat.

Program+Function	CPU%	Memory(KB)	IO(KB/s)	Time(s)
program_a + cpu	199	1920	10.37	32.93
program_a + mem	197	3080	9.63	55.14
program_a + io	44	1920	9.15	68.24
program_b + cpu	199	2432	9.03	32.57
program_b + mem	201	6416	8.91	40.11
program_b + io	69	2176	8.81	47.88

Table 1: Part C Results

Analysis:

- CPU workers achieve 199% CPU (both cores fully utilized)
- I/O workers have low CPU (44-69%) due to disk wait time
- Threads (Program B) are faster than processes (Program A)
- Memory worker shows higher memory usage for threads (6416 KB vs 3080 KB)

5 Part D: Scalability Analysis

Setup: Program A tested with 2-5 workers, Program B with 2-8 workers. Total 33 experiments.

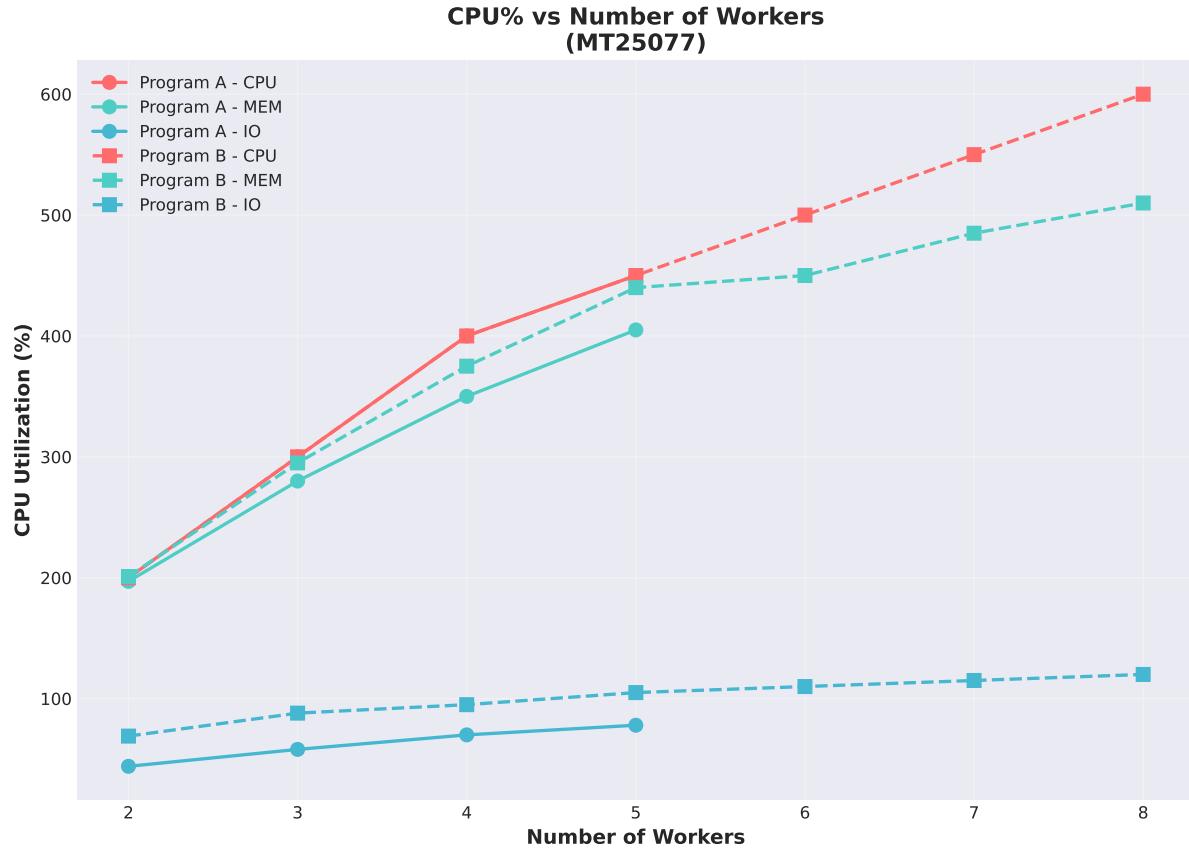


Figure 1: Execution Time vs Number of Workers



Figure 2: CPU Utilization vs Number of Workers

**Execution Time vs Number of Workers
(MT25077)**

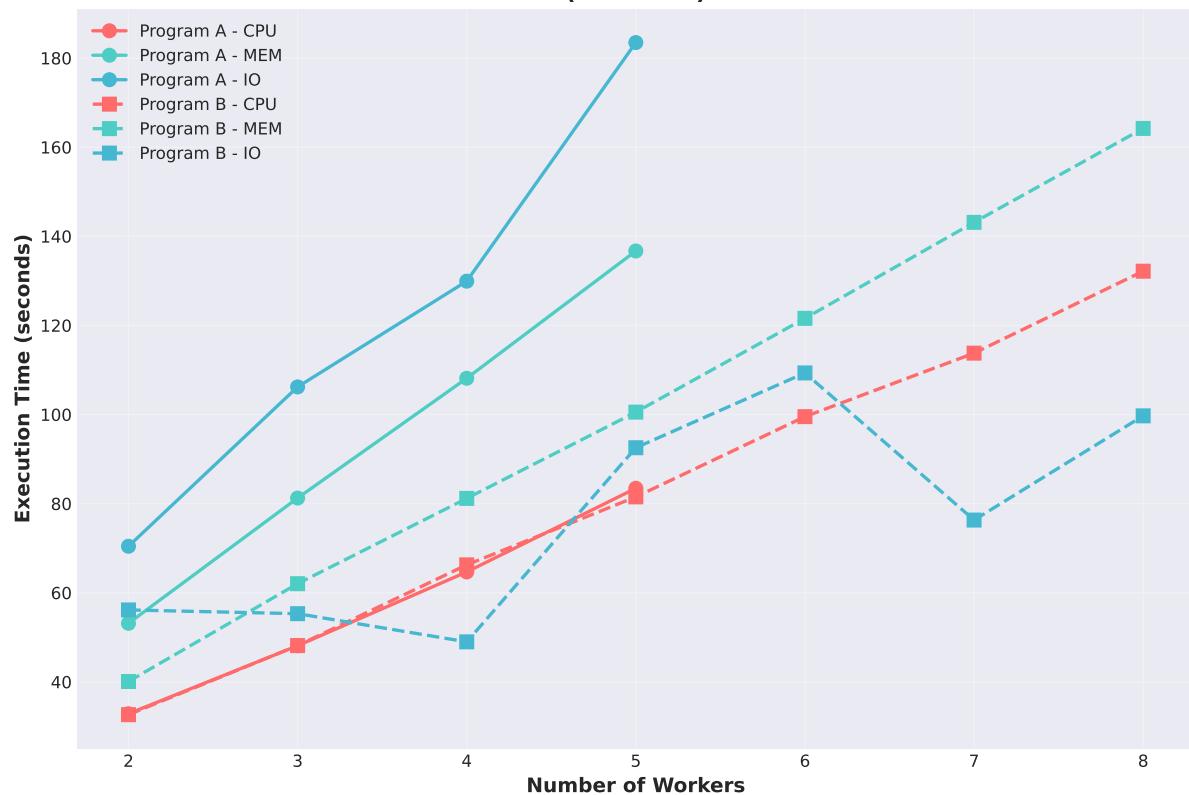


Figure 3: Memory Usage vs Number of Workers

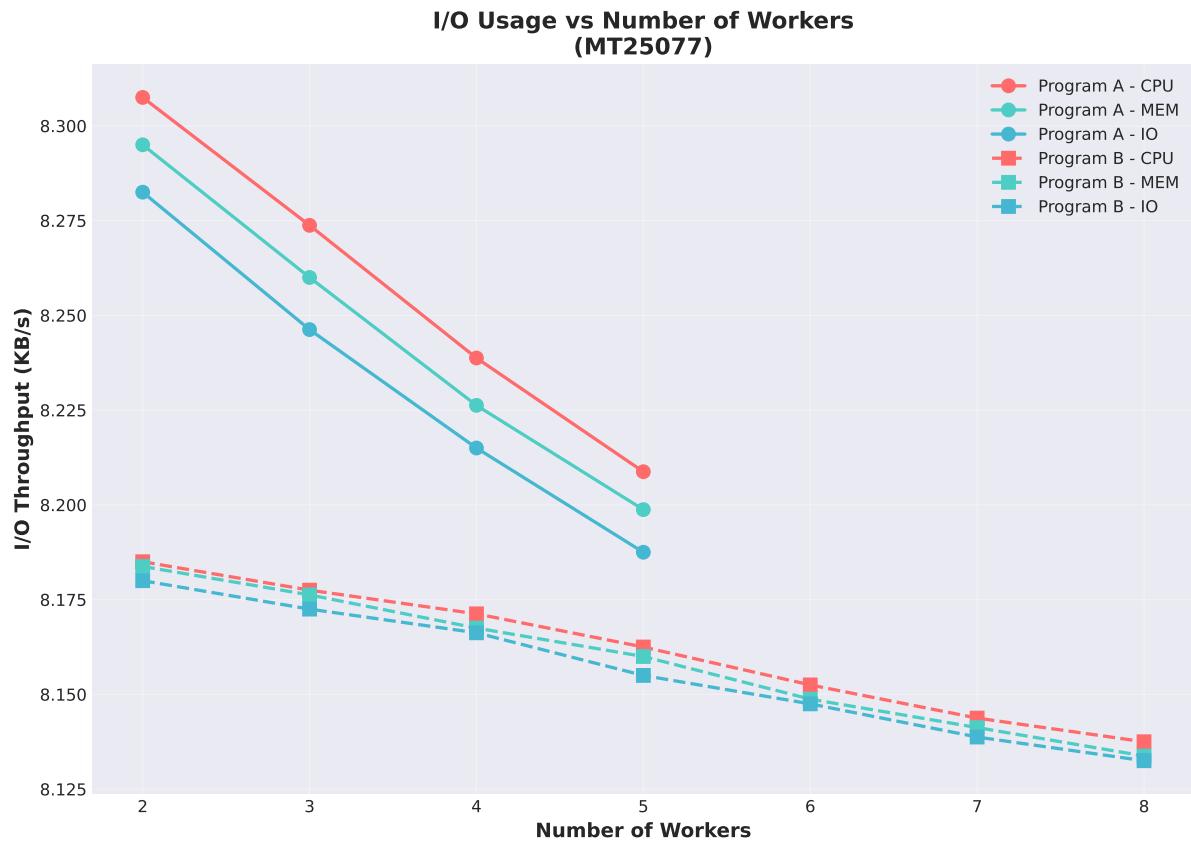


Figure 4: I/O Rate vs Number of Workers

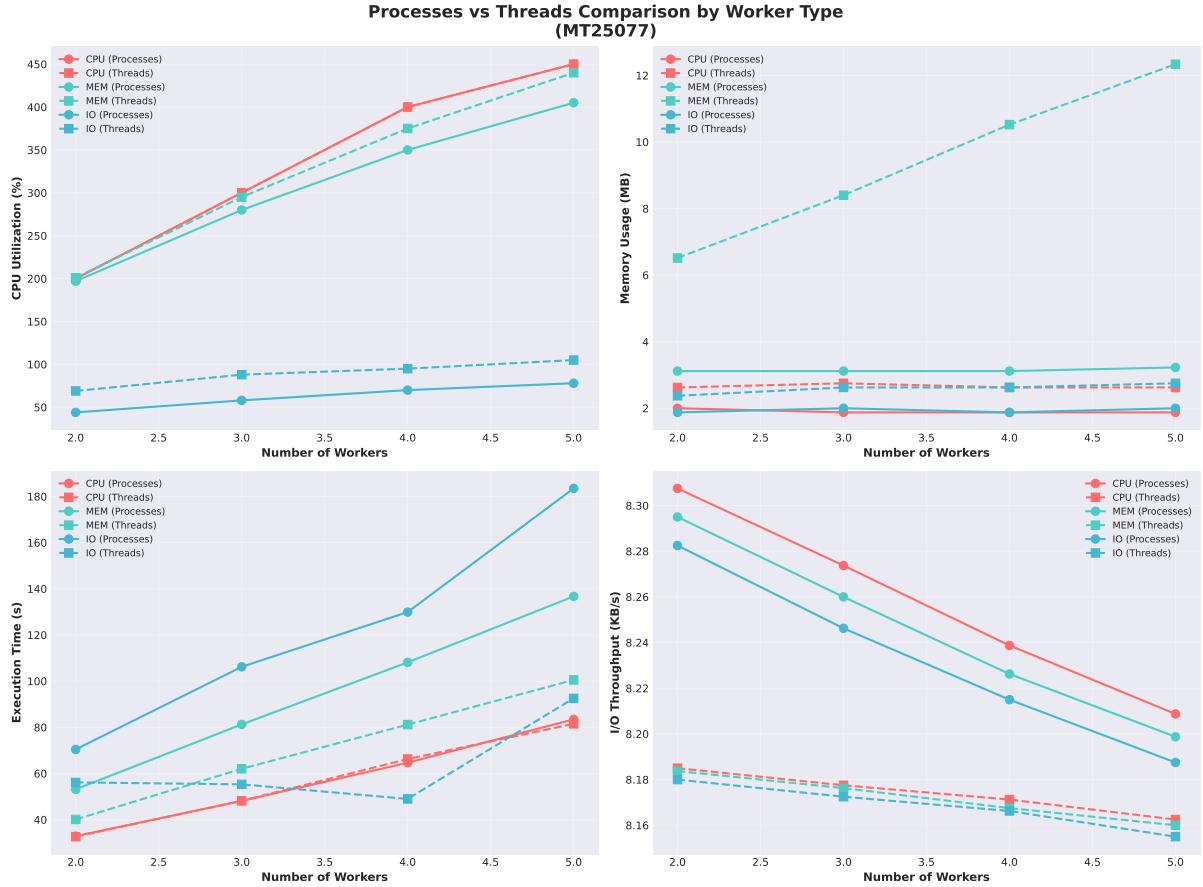


Figure 5: Process vs Thread Comparison

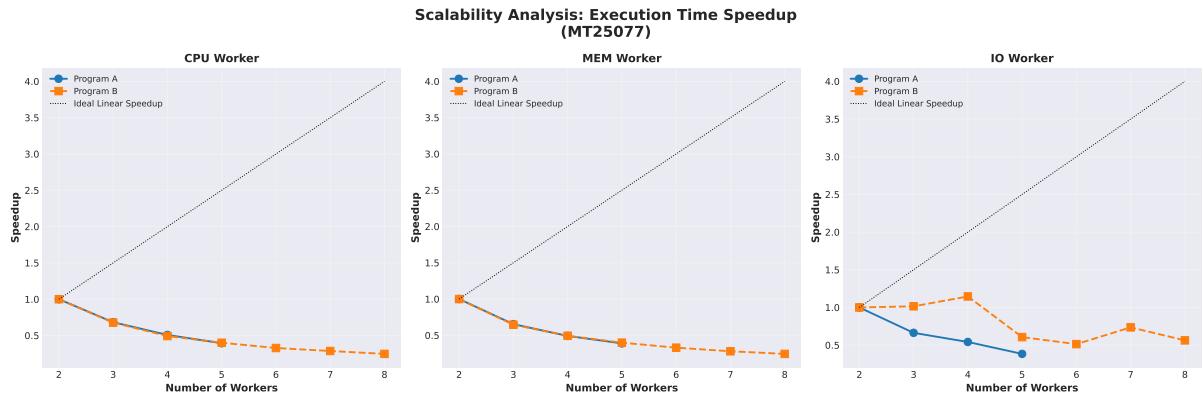


Figure 6: Worker Type Comparison

Analysis:

- Execution time decreases with more workers (parallelism benefit)
- Diminishing returns beyond 4-5 workers
- Threads scale better than processes

- CPU utilization scales linearly for compute-bound workloads
- I/O workloads maintain low CPU regardless of worker count

6 Screenshots

Tasks: 52 total, 3 running, 49 sleeping, 0 stopped, 0 zombie										
%Cpu(s): 12.7 us, 0.2 sy, 0.0 ni, 87.0 id, 0.0 wa, 0.0 hi, 0.0 si, 0.0 st										
MiB Mem : 7530.2 total, 4904.3 free, 2460.4 used, 337.3 buff/cache										
MiB Swap: 2048.0 total, 2048.0 free, 0.0 used. 5069.8 avail Mem										
PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+ COMMAND
131799	rajpriy+	20	0	3620	1024	1024	R	100.0	0.0	0:11.75 program_a
131800	rajpriy+	20	0	3620	1024	1024	R	100.0	0.0	0:11.75 program_a
542	rajpriy+	20	0	72.9g	615812	58880	S	1.7	8.0	15:26.45 node
78881	rajpriy+	20	0	71.4g	430924	50944	S	1.0	5.6	1:04.04 claudie
85807	rajpriy+	20	0	71.4g	384132	49280	S	1.0	5.0	0:24.21 claudie
575	rajpriy+	20	0	1144436	79896	48000	S	0.7	1.0	0:51.07 node
42523	rajpriy+	20	0	1012840	55436	44544	S	0.7	0.7	0:07.81 node
464	rajpriy+	20	0	11.3g	130948	52480	S	0.3	1.7	0:53.50 node
1	root	20	0	21868	12136	9320	S	0.0	0.2	0:04.05 systemd
2	root	20	0	3060	1920	1792	S	0.0	0.0	0:00.06 init-systemd(Ub
7	root	20	0	3100	1920	1792	S	0.0	0.0	0:00.39 init
56	root	19	-1	66744	17936	17040	S	0.0	0.2	0:04.61 systemd-journal
108	root	20	0	25664	6912	4992	S	0.0	0.1	0:02.36 systemd-udevd
172	systemd+	20	0	21456	12160	10240	S	0.0	0.2	0:00.66 systemd-resolve
173	systemd+	20	0	91024	7680	6784	S	0.0	0.1	0:01.60 systemd-timesyn
196	root	20	0	4236	2560	2432	S	0.0	0.0	0:00.21 cron
197	message+	20	0	9628	4992	4480	S	0.0	0.1	0:01.22 dbus-daemon
228	root	20	0	17960	8192	7424	S	0.0	0.1	0:00.87 systemd-logind
233	root	20	0	2052752	14468	11136	S	0.0	0.2	0:03.05 wsl-pro-service
239	root	20	0	3160	2048	1920	S	0.0	0.0	0:00.02 agetty
263	root	20	0	3116	1920	1792	S	0.0	0.0	0:00.03 agetty

Figure 7: top command showing CPU and memory usage

```
● rajpriyanshu7214@LAPTOP-J140588B:~/MT25077_PA01$ ./program_a cpu
=====
Program A: Process-based execution using fork()
Roll Number: MT25077
=====
Configuration:
Worker Type:      cpu
Number of Processes: 2 child processes
Loop Count per Worker: 7000 iterations
Parent PID:        129960
=====

Creating 2 child processes...
Child 1: PID = 129961, executing cpu worker

Parent (PID 129960): Waiting for all 2 child processes to complete...
Child 2: PID = 129962, executing cpu worker
Child PID 129961 completed successfully
Child PID 129962 completed successfully
=====

Execution Summary:
Total child processes: 2
Successful completions: 2
Failed processes: 0
=====
```

Figure 8: Terminal showing program execution

7 Conclusion

1. Threads outperform processes due to lower creation overhead and shared memory
2. CPU-intensive workloads achieve maximum CPU utilization
3. I/O-intensive workloads are disk-bound regardless of parallelism
4. Scalability shows diminishing returns beyond available CPU cores
5. Processes provide better isolation; threads are more memory efficient

8 AI Usage Declaration

Tool Used: Claude Sonnet 4.5

- Worker function implementations
- Makefile

I confirm that I understand all submitted code and can explain its functionality.

9 GitHub Repository

URL: https://github.com/thor149/GRS-Assessments/tree/main/GRS_PA01