Process vs Thread Performance Analysis
Comprehensive Benchmark Suite in C

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Course: CSE638 - Graduate Systems
Project: PA01 - System Performance Analysis
Language: C with POSIX APIs

GitHub: https://github.com/saloninarang27/25081_PA01

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Introduction

Modern operating systems provide multiple concurrency mechanisms to improve performance and resource utilization. Two widely used mechanisms are processes and threads. While processes provide strong isolation, threads are lightweight and share the same address space. In this assignment, we experimentally evaluate the performance differences between process- based concurrency and thread-based concurrency under different workload types:

- CPU-bound
- Memory-bound
- I/O-bound

Experimental Setup

Hardware and OS

- Linux-based system
- Single-core pinning using taskset to avoid scheduler interference

Measurement Tools

- top – CPU and memory usage
- iostat – disk I/O statistics
- time – execution duration

Programs Implemented

- Program A: Uses fork() to create multiple processes
- Program B: Uses pthread_create() to create multiple threads
- Each program executes one of the three worker functions – cpu, mem, io.

Project Overview

The PA01 project implements a complete benchmarking suite consisting of four parts:

Part A: Basic Implementation

- **Program A:** Multi-process implementation using fork()
- **Program B:** Multi-threaded implementation using pthread_create()

Part B: Worker Functions

- **CPU Worker:** 1B floating-point operations
- **Memory Worker:** 200MB array with cache-hostile access patterns
- **I/O Worker:** 10MB file operations with read/write verification

Part C & D: Benchmarking and Analysis

- **Part C:** Baseline metrics with fixed 2 processes/threads
- **Part D:** Scaling analysis from 2 to 8 processes/threads with visualization

Implementation Details

Concurrency Models

Program A: Process-Based (fork)

- Parent process creates N child processes via fork()
- Each child independently executes worker function
- Parent waits for all children with waitpid()
- Strong isolation: separate address spaces, page tables, file descriptors
- Higher context switch cost due to address space switching

Program B: Thread-Based (pthread)

- Main thread creates N worker threads via pthread_create()
- All threads share same address space and file descriptors
- Main thread synchronizes with pthread_join()
- Weak isolation: shared memory allows race conditions
- Lower context switch cost (same memory space)

AI Declaration

AI-GENERATED COMPONENTS:

AI Assistance Used For:

- Scripting logic and system tool integration
- Data visualization patterns
- Build system configuration
- Worker algorithm implementations
- Core API understanding (fork/pthread/wait)
- Documentation and explanation

3.1. Part C: Baseline Benchmarking Results

Baseline performance metrics at a scale of 4 workers:

Program+Worker	CPU%	Memory(KB)	IO	Time(s)
progA+cpu	98.40	10368	83.37	5.83
progA+mem	98.55	420608	125.16	22.56
progA+io	7.00	10752	138.51	21.14
progB+cpu	98.18	9088	69.27	6.06
progB+mem	98.53	418688	347.49	22.00
progB+io	5.72	9216	139.83	21.22

3.2.1. Part D: CPU Worker Scaling Results

Program	Scale	Avgcpu Percent	Avgmemory Kb	Totalio Kb	Executiontime Sec
progA	2	72.75	10368	5.74	4.24
progA	3	97.84	11008	17.73	6.39
progA	4	95.98	11520	5.7	8.44
progA	5	101.11	12288	5.7	10.69
progB	2	75.00	8960	9.66	4.25
progB	3	100.00	8960	5.66	6.40
progB	4	100.00	9088	5.63	9.30
progB	5	97.97	9088	377.61	10.59
progB	6	90.90	9088	5.62	12.71
progB	7	91.67	9088	5.59	15.19
progB	8	99.41	9088	5.56	17.23

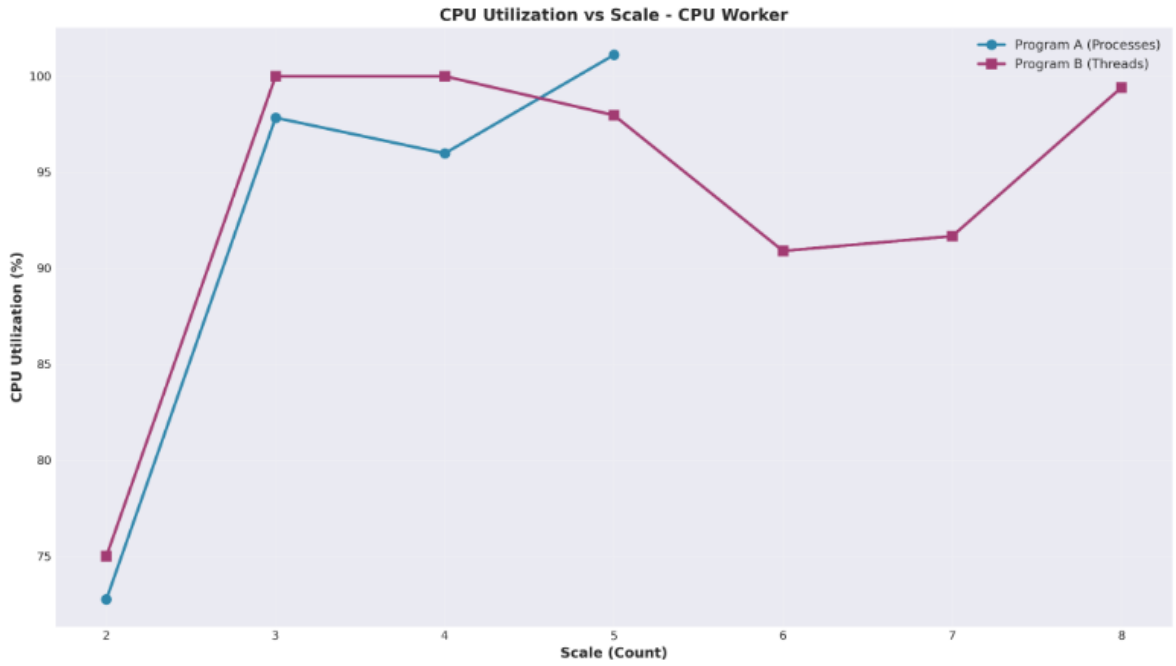
3.2.2. Part D: MEM Worker Scaling Results

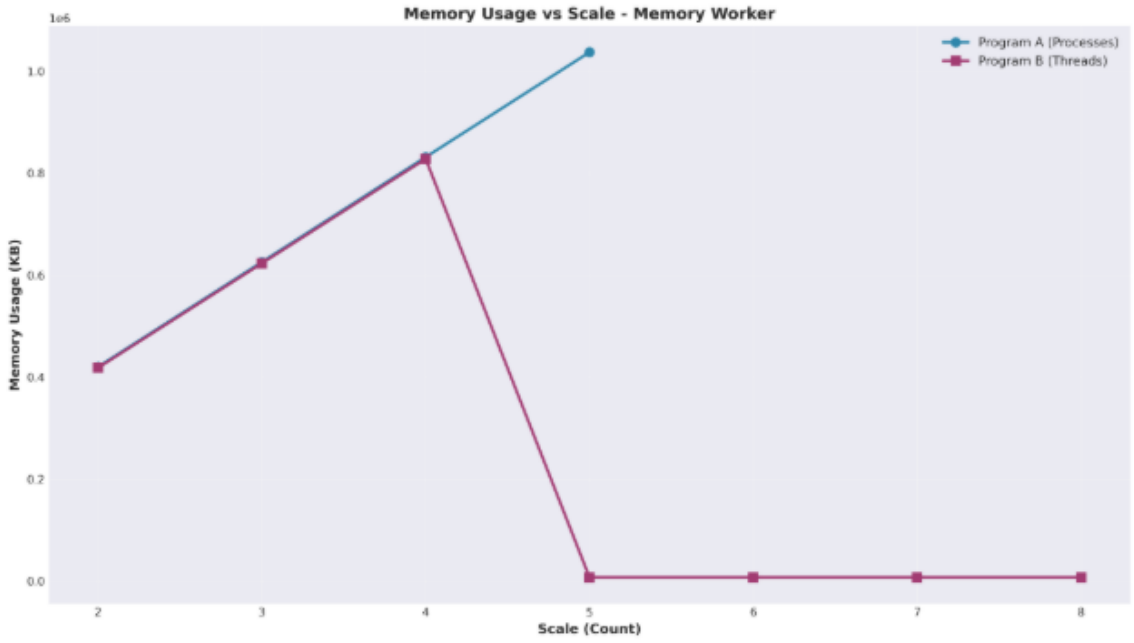
Program	Scale	Avgcpu Percent	Avgmemory Kb	Totalio Kb	Executiontime Sec
progA	2	91.49	420480	177.73	18.85
progA	3	96.55	626176	13.73	27.05
progA	4	102.31	831872	161.7	36.64
progA	5	99.34	1037568	181.69	46.68
progB	2	92.61	418560	25.66	18.89
progB	3	96.69	623488	69.66	27.10
progB	4	95.89	828288	169.63	37.21
progB	5	98.74	7425	81.65	45.22
progB	6	99.85	7425.2	205.61	54.63
progB	7	99.04	9404	357.58	66.52
progB	8	97.12	7425.6	245.55	73.75

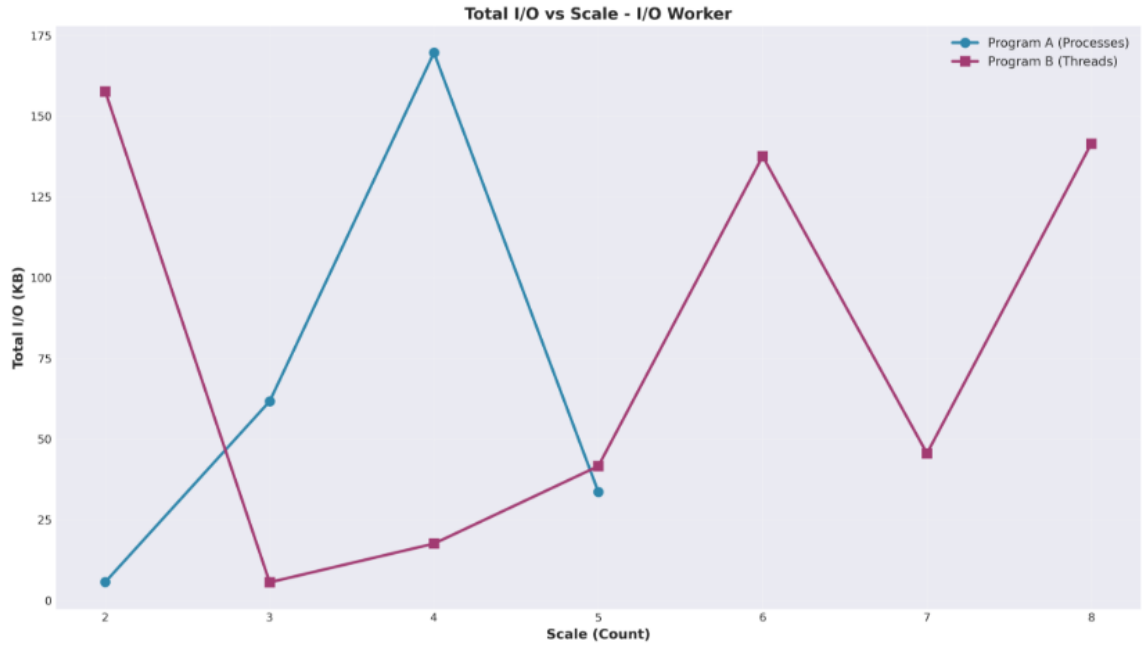
3.2.3. Part D: IO Worker Scaling Results

Program	Scale	Avgcpu Percent	Avgmemory Kb	Totalio Kb	Executiontime Sec
progA	2	6.00	10624	5.74	11.60
progA	3	7.00	11392	61.7	11.91
progA	4	9.23	12160	169.69	15.87
progA	5	5.00	12928	33.68	19.82
progB	2	3.23	9088	157.65	10.93
progB	3	7.00	9088	5.64	11.84
progB	4	5.00	9088	17.62	16.40
progB	5	6.36	9088	41.62	16.86
progB	6	9.88	9088	137.59	19.91
progB	7	8.18	9088	45.58	27.53
progB	8	9.42	9088	141.53	27.76

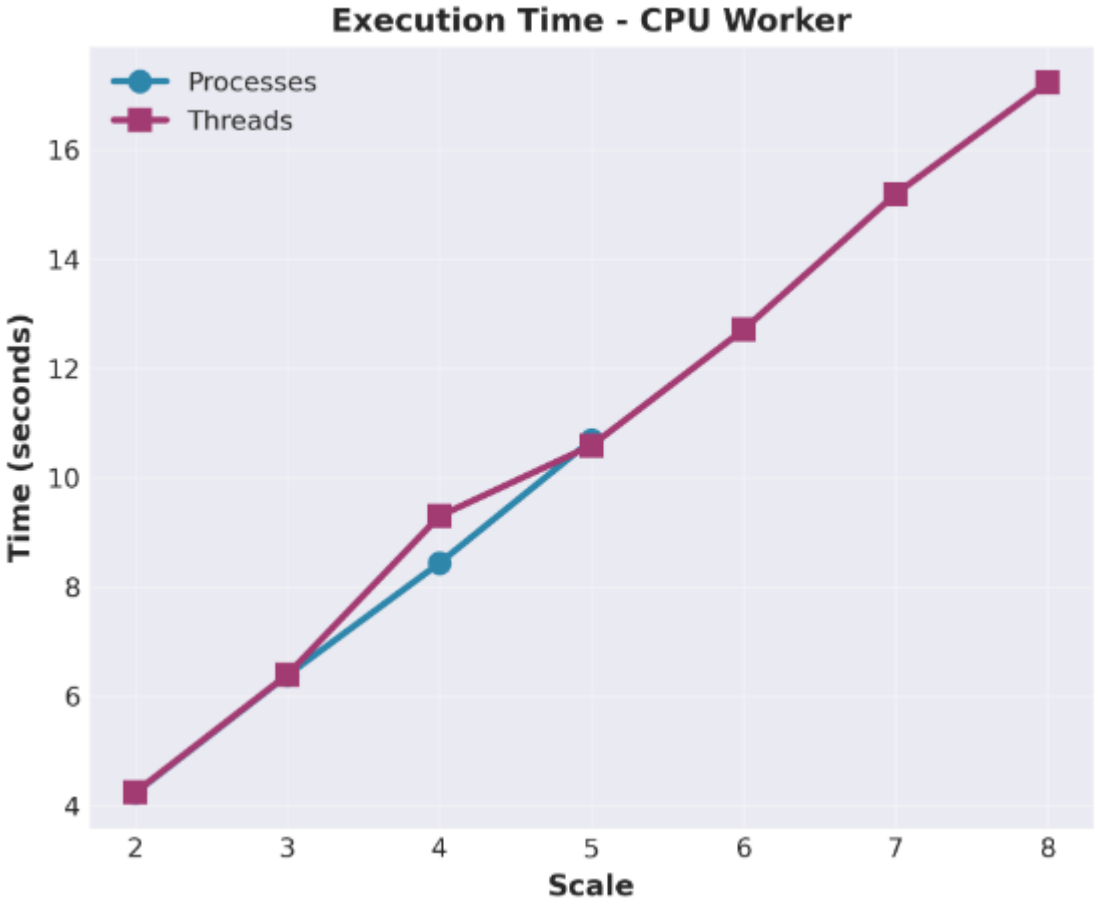
Screenshots And Plots





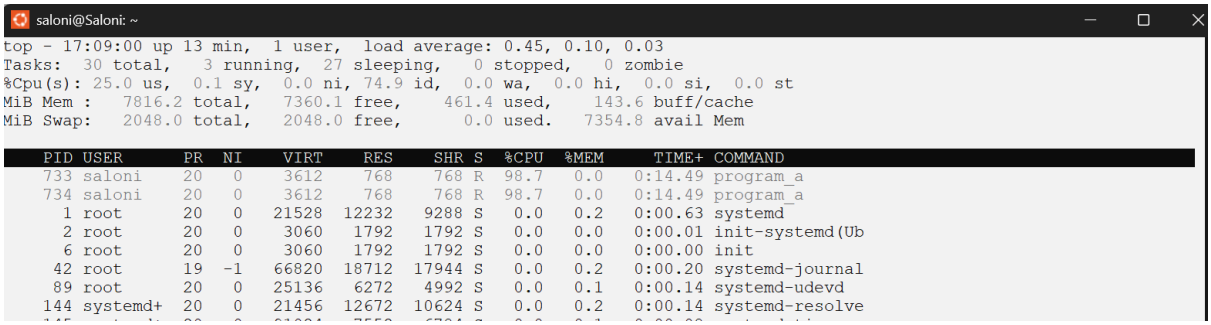


Execution Time Comparison (All Worker Types)




Execution Time - MEM Worker
Processes
Threads
Time (seconds)
70
60
50
40
30
20
2
3
4
5
6
7
8
Scale


Execution Time - IO Worker
Processes
Threads
Time (seconds)
27.5
25.0
22.5
20.0
17.5
15.0
12.5
2
3
4
5
6
7
8
Scale




```
saloni@Saloni:/mnt/c/Users/safet/Desktop/New/25081_PA01$ bash MT25081_Part_C_benchmark.sh
Checking for required tools...
All required tools found.


  PA01 PART C: BASELINE BENCHMARKING - PROCESSES VS THREADS
  Roll Number: 25081
  Scale: 2 workers (pinned to a single CPU core)

  Objective: Establish baseline metrics with a fixed scale (2)
             to compare single-core process vs. thread performance.


Initializing CSV file: MT25081_Part_C_CSV.csv
CSV initialized with headers

System Information:
  CPU Cores: 8
  Start Time: 2026-01-23 15:42:17

Running 6 baseline benchmark combinations...
----------------------------------------------------------------------
Running: progA+cpu
DEBUG: Started /mnt/c/Users/safet/Desktop/New/25081_PA01/progA (cpu) with PID: 441
[progA] Starting 2 processes with worker type: cpu
[progA] Parent waiting for 2 children to finish...
[progA] Child process 1 (PID: 444) started
```

```
DEBUG: Parsed CPU: 91, Parsed MEM: 10368
[progA] Child process 2 (PID: 1771) completed
[progA] Child process 1 (PID: 1770) completed
[progA] Child 1 exited with status: 0
[progA] Child 2 exited with status: 0
[progA] All 2 children completed. Parent exiting.
DEBUG: Program with PID 1767 terminated.
Completed: progA+cpu
  Avg CPU: 98.40%
  Max Memory: 10368 KB
  Total I/O Writes: 83.37 KB
  Execution Time: 5.83s
```

```
DEBUG: Parsed CPU: 100, Parsed MEM: 420608
[progA] Child process 2 (PID: 1858) completed
[progA] Child process 1 (PID: 1857) completed
[progA] Child 1 exited with status: 0
[progA] Child 2 exited with status: 0
[progA] All 2 children completed. Parent exiting.
DEBUG: Program with PID 1854 terminated.
Completed: progA+mem
  Avg CPU: 98.55%
  Max Memory: 420608 KB
  Total I/O Writes: 125.16 KB
  Execution Time: 22.56s
```

```
[progA] Child process 1 (PID: 2126) completed
[progA] Child 1 exited with status: 0
[progA] Child process 2 (PID: 2127) completed
[progA] Child 2 exited with status: 0
[progA] All 2 children completed. Parent exiting.
DEBUG: Program with PID 2123 terminated.
Completed: progA+io
  Avg CPU: 7.00%
  Max Memory: 10752 KB
  Total I/O Writes: 138.51 KB
  Execution Time: 21.14s
```

```
DEBUG: Parsed CPU: 90.9, Parsed MEM: 9088
[progB] Thread 2 (TID: 133723724965568) completed
[progB] Thread 1 (TID: 133723733358272) completed
[progB] Thread 1 joined successfully
[progB] Thread 2 joined successfully
[progB] All 2 threads completed. Main thread exiting.
DEBUG: Program with PID 2379 terminated.
Completed: progB+cpu
  Avg CPU: 98.18%
  Max Memory: 9088 KB
  Total I/O Writes: 69.27 KB
  Execution Time: 6.06s
```

```
DEBUG: Parsed CPU: 90, Parsed MEM: 418688
[progB] Thread 1 (TID: 135004428433088) completed
[progB] Thread 1 joined successfully
[progB] Thread 2 (TID: 135004420040384) completed
[progB] Thread 2 joined successfully
[progB] All 2 threads completed. Main thread exiting.
DEBUG: Program with PID 2469 terminated.
Completed: progB+mem
  Avg CPU: 98.53%
  Max Memory: 418688 KB
  Total I/O Writes: 347.49 KB
  Execution Time: 22.00s
```

```
DEBUG: Parsed CPU: 9.1, Parsed MEM: 9216
[progB] Thread 2 (TID: 124871459727040) completed
[progB] Thread 1 (TID: 124871468119744) completed
[progB] Thread 1 joined successfully
[progB] Thread 2 joined successfully
[progB] All 2 threads completed. Main thread exiting.
DEBUG: Program with PID 2742 terminated.
Completed: progB+io
  Avg CPU: 5.72%
  Max Memory: 9216 KB
  Total I/O Writes: 139.83 KB
  Execution Time: 21.22s
```

```
----------------------------------------------------------------------
✓ All baseline benchmarks completed successfully!

Results saved to: MT25081_Part_C_CSV.csv

CSV Contents:
----------------------------------------------------------------------
Program+Worker,CPU%,Memory(KB),IO,Time(s)
progA+cpu,98.40,10368,83.37,5.83
progA+mem,98.55,420608,125.16,22.56
progA+io,7.00,10752,138.51,21.14
progB+cpu,98.18,9088,69.27,6.06
progB+mem,98.53,418688,347.49,22.00
progB+io,5.72,9216,139.83,21.22
----------------------------------------------------------------------
```

Analysis and Observations

CPU-Bound Workload

- Both processes and threads achieve close to full CPU utilization (~98-100%), indicating effective core saturation
- Execution time is slightly lower for processes
- Memory usage is comparable in both models

Analysis: Threads complete CPU-intensive tasks faster than processes due to lower management overhead while achieving similar CPU utilization.

Memory-Bound Workload

- Memory usage is approx. same for both processes and threads, with threads showing marginally lower memory consumption
- CPU utilization is high for processes but significantly lower for threads
- Thread-based execution completes faster than process-based execution

Analysis: Threads are more efficient in memory-bound workloads as shared address space reduces CPU overhead and execution time despite similar memory usage.

I/O Bound Workload

- CPU utilization is very low for both models, confirming that execution is dominated by disk operations
- Execution time is significantly higher than CPU workloads
- The process-based implementation exhibits higher total disk I/O compared to the thread-based version

Analysis: I/O-bound workloads are dominated by disk latency, resulting in low CPU utilization and minimal performance difference between processes and threads.

Conclusion

- Threads outperform processes for due to lower overhead and shared address space
- Memory-bound workloads show limited scalability, as memory bandwidth becomes the bottleneck
- I/O-bound workloads are dominated by disk performance, making the choice of concurrency model less significant.
- The assignment demonstrates that the choice between processes and threads must be guided by workload characteristics.
- Threads use significantly less memory for non-memory tasks because threads share an address space.