MT25042 — PA01 Report: Processes and Threads

Roll Number: MT25042
Course: Graduate Systems (CSE638)
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Table of Contents

Part A — Program Implementations

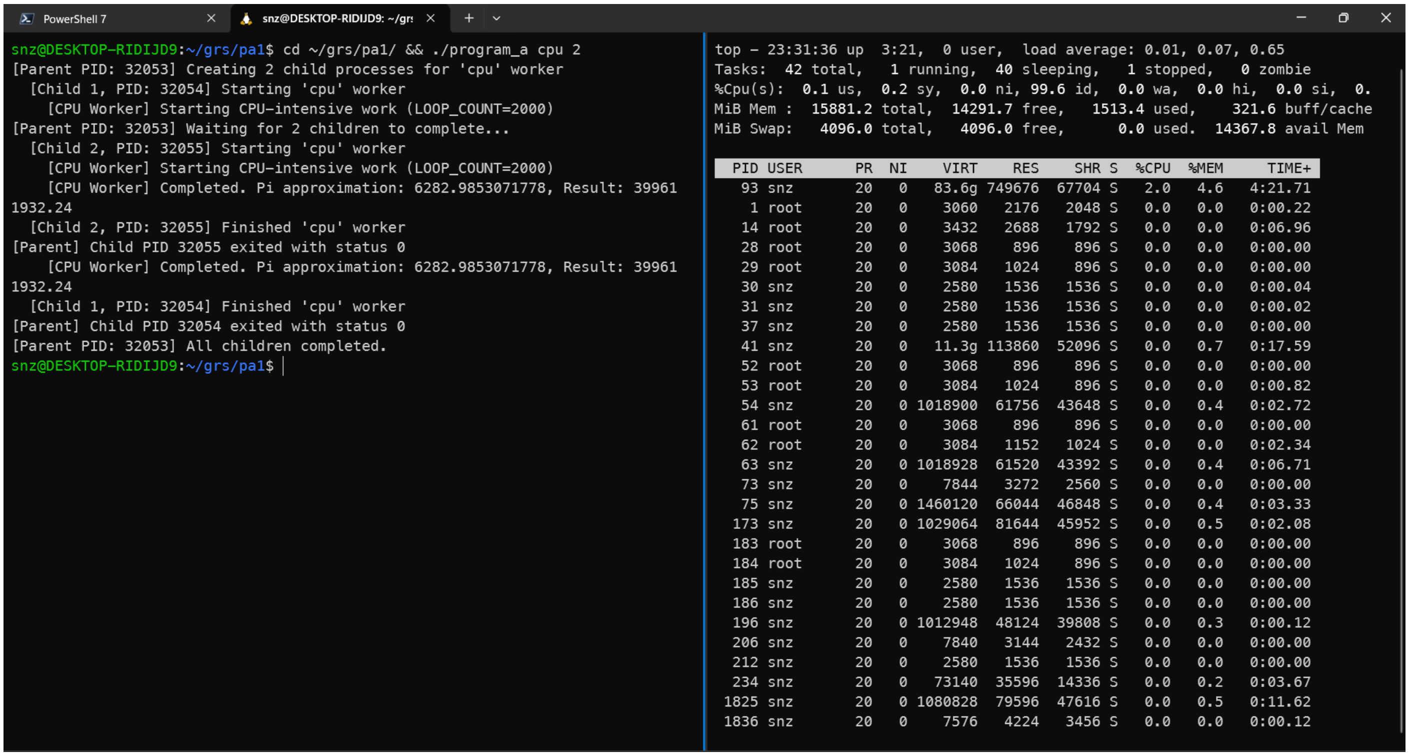
Program A: Process-based (fork)

File: `MT25042_Part_A_Program_A.c`

Description:
Program A creates 2 child processes using `fork()` system call. Each child process executes the specified worker function (cpu, mem, or io). The parent process waits for all children to complete using `waitpid()`.

Key Implementation Details: - Uses `fork()` to create separate address spaces for each process - Each child process runs independently with its own memory - Parent tracks all child PIDs and waits for completion

Screenshot: Program A execution with `top` monitoring



```
snz@DESKTOP-RIDIJD9:~/grs/pa1$ cd ~/grs/pa1/ && ./program_a cpu 2
[Parent PID: 32053] Creating 2 child processes for 'cpu' worker
  [Child 1, PID: 32054] Starting 'cpu' worker
    [CPU Worker] Starting CPU-intensive work (LOOP_COUNT=2000)
[Parent PID: 32053] Waiting for 2 children to complete...
  [Child 2, PID: 32055] Starting 'cpu' worker
    [CPU Worker] Starting CPU-intensive work (LOOP_COUNT=2000)
    [CPU Worker] Completed. Pi approximation: 6282.9853071778, Result: 39961
1932.24
  [Child 2, PID: 32055] Finished 'cpu' worker
[Parent] Child PID 32055 exited with status 0
    [CPU Worker] Completed. Pi approximation: 6282.9853071778, Result: 39961
1932.24
  [Child 1, PID: 32054] Finished 'cpu' worker
[Parent] Child PID 32054 exited with status 0
[Parent PID: 32053] All children completed.
snz@DESKTOP-RIDIJD9:~/grs/pa1$ 
```

```
top - 23:31:36 up  3:21,  0 user,  load average: 0.01, 0.07, 0.65
Tasks:  42 total,   1 running,  40 sleeping,   1 stopped,   0 zombie
%Cpu(s):  0.1 us,  0.2 sy,  0.0 ni, 99.6 id,  0.0 wa,  0.0 hi,  0.0 si,  0.
MiB Mem :  15881.2 total,  14291.7 free,   1513.4 used,    321.6 buff/cache
MiB Swap:   4096.0 total,   4096.0 free,      0.0 used.  14367.8 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+
   93 snz       20   0   83.6g 749676  67704 S   2.0   4.6   4:21.71
    1 root      20   0    3060   2176   2048 S   0.0   0.0   0:00.22
   14 root      20   0    3432   2688   1792 S   0.0   0.0   0:06.96
   28 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
   29 root      20   0    3084   1024    896 S   0.0   0.0   0:00.00
   30 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.04
   31 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.02
   37 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
   41 snz       20   0   11.3g 113860  52096 S   0.0   0.7   0:17.59
   52 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
   53 root      20   0    3084   1024    896 S   0.0   0.0   0:00.82
   54 snz       20   0 1018900  61756  43648 S   0.0   0.4   0:02.72
   61 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
   62 root      20   0    3084   1152   1024 S   0.0   0.0   0:02.34
   63 snz       20   0 1018928  61520  43392 S   0.0   0.4   0:06.71
   73 snz       20   0    7844   3272   2560 S   0.0   0.0   0:00.00
   75 snz       20   0 1460120  66044  46848 S   0.0   0.4   0:03.33
  173 snz       20   0 1029064  81644  45952 S   0.0   0.5   0:02.08
  183 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
  184 root      20   0    3084   1024    896 S   0.0   0.0   0:00.00
  185 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
  186 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
  196 snz       20   0 1012948  48124  39808 S   0.0   0.3   0:00.12
  206 snz       20   0    7840   3144   2432 S   0.0   0.0   0:00.00
  212 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
  234 snz       20   0   73140  35596  14336 S   0.0   0.2   0:03.67
 1825 snz       20   0 1080828  79596  47616 S   0.0   0.5   0:11.62
 1836 snz       20   0    7576   4224   3456 S   0.0   0.0   0:00.12
```

Figure 1: Program A - top output

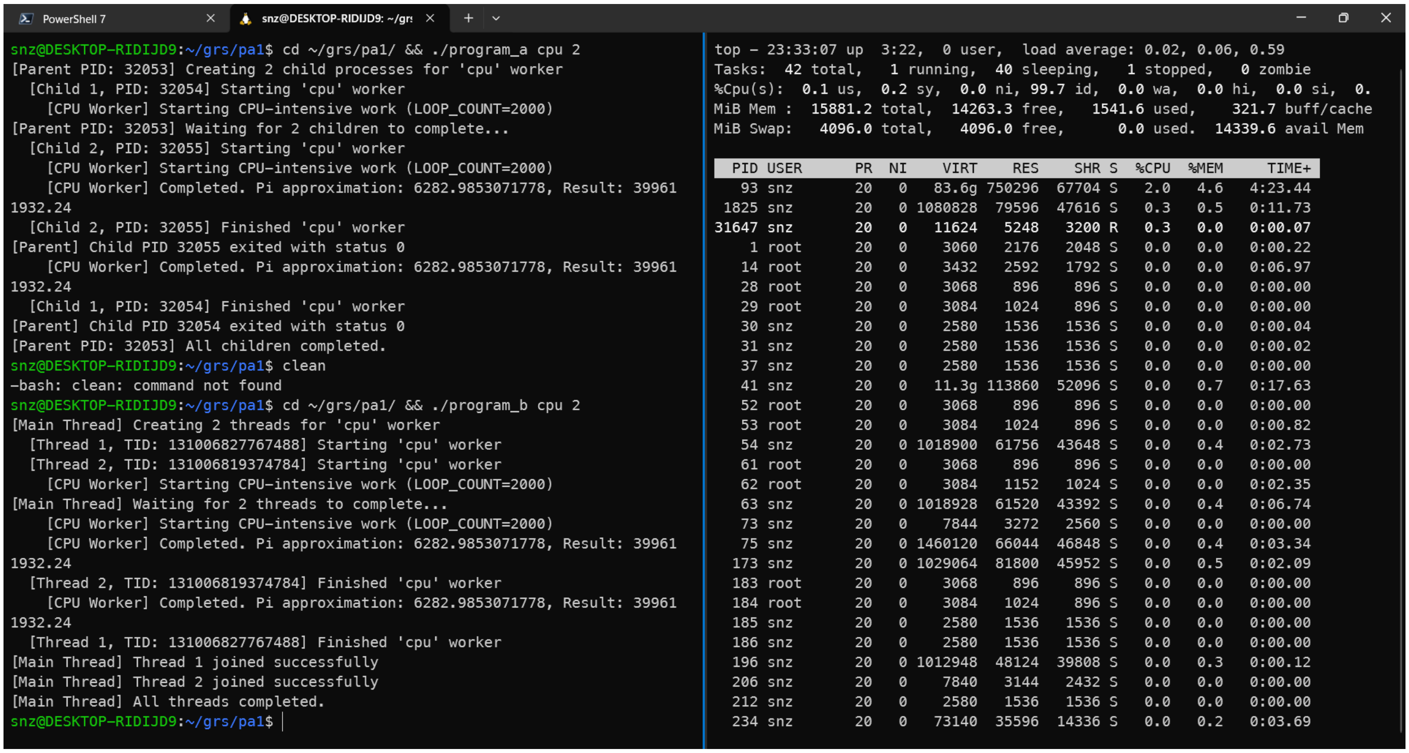
Program B: Thread-based (pthread)

File: `MT25042_Part_A_Program_B.c`

Description:
Program B creates 2 threads using POSIX pthread library. All threads share the same address space and execute the specified worker function concurrently. The main thread joins all worker threads before exiting.

Key Implementation Details: - Uses `pthread_create()` to spawn threads within same process - Threads share memory space (more efficient for shared data) - Uses `pthread_join()` for synchronization

Screenshot: Program B execution with `top` monitoring



```
snz@DESKTOP-RIDIJD9:~/grs/pa1$ cd ~/grs/pa1/ && ./program_a cpu 2
[Parent PID: 32053] Creating 2 child processes for 'cpu' worker
  [Child 1, PID: 32054] Starting 'cpu' worker
    [CPU Worker] Starting CPU-intensive work (LOOP_COUNT=2000)
[Parent PID: 32053] Waiting for 2 children to complete...
  [Child 2, PID: 32055] Starting 'cpu' worker
    [CPU Worker] Starting CPU-intensive work (LOOP_COUNT=2000)
    [CPU Worker] Completed. Pi approximation: 6282.9853071778, Result: 39961
1932.24
  [Child 2, PID: 32055] Finished 'cpu' worker
[Parent] Child PID 32055 exited with status 0
    [CPU Worker] Completed. Pi approximation: 6282.9853071778, Result: 39961
1932.24
  [Child 1, PID: 32054] Finished 'cpu' worker
[Parent] Child PID 32054 exited with status 0
[Parent PID: 32053] All children completed.
snz@DESKTOP-RIDIJD9:~/grs/pa1$ clean
-bash: clean: command not found
snz@DESKTOP-RIDIJD9:~/grs/pa1$ cd ~/grs/pa1/ && ./program_b cpu 2
[Main Thread] Creating 2 threads for 'cpu' worker
  [Thread 1, TID: 131006827767488] Starting 'cpu' worker
  [Thread 2, TID: 131006819374784] Starting 'cpu' worker
    [CPU Worker] Starting CPU-intensive work (LOOP_COUNT=2000)
[Main Thread] Waiting for 2 threads to complete...
    [CPU Worker] Starting CPU-intensive work (LOOP_COUNT=2000)
    [CPU Worker] Completed. Pi approximation: 6282.9853071778, Result: 39961
1932.24
  [Thread 2, TID: 131006819374784] Finished 'cpu' worker
    [CPU Worker] Completed. Pi approximation: 6282.9853071778, Result: 39961
1932.24
  [Thread 1, TID: 131006827767488] Finished 'cpu' worker
[Main Thread] Thread 1 joined successfully
[Main Thread] Thread 2 joined successfully
[Main Thread] All threads completed.
snz@DESKTOP-RIDIJD9:~/grs/pa1$
```

```
top - 23:33:07 up  3:22,  0 user,  load average: 0.02, 0.06, 0.59
Tasks:  42 total,   1 running,  40 sleeping,   1 stopped,   0 zombie
%Cpu(s):  0.1 us,  0.2 sy,  0.0 ni, 99.7 id,  0.0 wa,  0.0 hi,  0.0 si,  0.
MiB Mem :  15881.2 total,  14263.3 free,   1541.6 used,    321.7 buff/cache
MiB Swap:   4096.0 total,   4096.0 free,      0.0 used.  14339.6 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+
   93 snz       20   0   83.6g 750296  67704 S   2.0   4.6   4:23.44
 1825 snz       20   0 1080828  79596  47616 S   0.3   0.5   0:11.73
31647 snz       20   0   11624   5248   3200 R   0.3   0.0   0:00.07
    1 root      20   0    3060   2176   2048 S   0.0   0.0   0:00.22
   14 root      20   0    3432   2592   1792 S   0.0   0.0   0:06.97
   28 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
   29 root      20   0    3084   1024    896 S   0.0   0.0   0:00.00
   30 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.04
   31 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.02
   37 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
   41 snz       20   0   11.3g 113860  52096 S   0.0   0.7   0:17.63
   52 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
   53 root      20   0    3084   1024    896 S   0.0   0.0   0:00.82
   54 snz       20   0 1018900  61756  43648 S   0.0   0.4   0:02.73
   61 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
   62 root      20   0    3084   1152   1024 S   0.0   0.0   0:02.35
   63 snz       20   0 1018928  61520  43392 S   0.0   0.4   0:06.74
   73 snz       20   0    7844   3272   2560 S   0.0   0.0   0:00.00
   75 snz       20   0 1460120  66044  46848 S   0.0   0.4   0:03.34
  173 snz       20   0 1029064  81800  45952 S   0.0   0.5   0:02.09
  183 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
  184 root      20   0    3084   1024    896 S   0.0   0.0   0:00.00
  185 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
  186 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
  196 snz       20   0 1012948  48124  39808 S   0.0   0.3   0:00.12
  206 snz       20   0    7840   3144   2432 S   0.0   0.0   0:00.00
  212 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
  234 snz       20   0   73140  35596  14336 S   0.0   0.2   0:03.69
```

Figure 2: Program B - top output

Part B — Worker Functions

Files: `MT25042_Part_B_workers.c`, `MT25042_Part_B_workers.h`

LOOP_COUNT Configuration

```
#define LOOP_COUNT 2000  // Last digit of MT25042 is 2, so 2 × 1000 = 2000
```

Worker Function: `cpu` (CPU-intensive)

Implementation: - Computes Pi using Leibniz series (slow convergence, many iterations) - Performs trigonometric calculations (sin, cos, tan) - Executes nested loop multiplications (matrix-like operations)

Expected Behavior: High CPU%, minimal memory usage, negligible I/O

Observed Results (from CSV):

Program	CPU%	Memory (KB)	I/O Write (KB)
Program_A	195%	1,792	4

Program	CPU%	Memory (KB)	I/O Write (KB)
Program_B	195%	2,304	4

Analysis: Both programs achieve ~195% CPU utilization (indicating both cores/processes active). Thread-based Program B shows slightly higher memory due to thread stack overhead.

Worker Function: `mem` (Memory-intensive)

Implementation: - Allocates two 16MB arrays (larger than typical L3 cache) - Performs `memcpy` operations (memory bandwidth test) - Random access patterns to cause cache misses - Sequential access with modifications

Expected Behavior: Moderate CPU%, high memory usage, minimal I/O

Observed Results (from CSV):

Program	CPU%	Memory (KB)	I/O Write (KB)
Program_A	199%	33,920	4
Program_B	199%	67,200	4

Analysis: Program B (threads) shows ~2x memory because threads share address space but each allocates its own arrays. Program A processes have copy-on-write initially but diverge.

Worker Function: `io` (I/O-intensive)

Implementation: - Creates temporary files per process/thread - Writes 1MB blocks to disk repeatedly - Uses `fsync()` to force disk writes (bypass OS cache) - Reads data back from disk

Expected Behavior: Low CPU%, moderate memory, very high I/O

Observed Results (from CSV):

Program	CPU%	Memory (KB)	I/O Write (KB)	Time (s)
Program_A	42%	2,048	4,096,004	24.92
Program_B	41%	3,712	4,096,004	24.97

Analysis: Low CPU% confirms I/O bound nature. High system time indicates kernel involvement in I/O operations. Both programs show similar I/O patterns.

Part C — Measurements and Analysis

Raw Data: `MT25042_Part_C_CSV.csv`

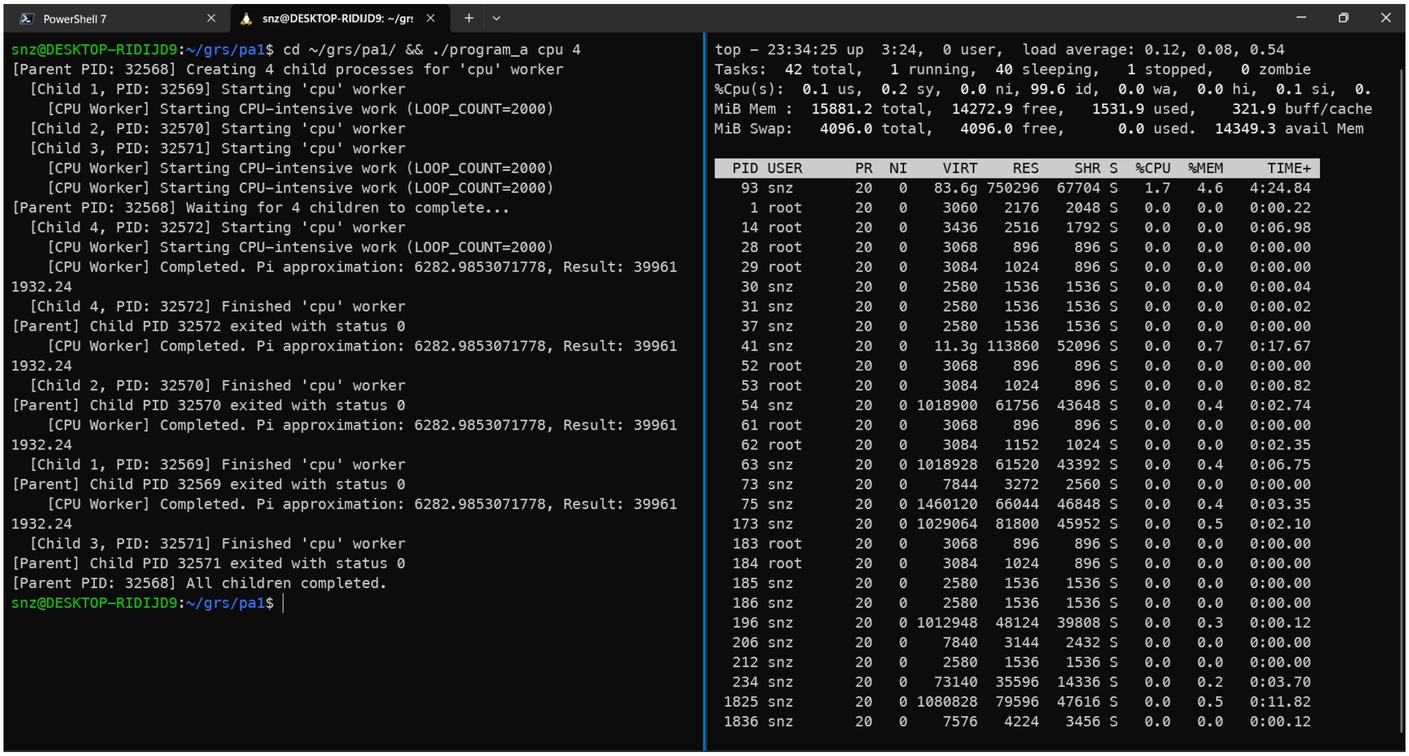
Measurement Methodology

- **CPU Affinity:** Programs pinned to CPUs 0,1 using `taskset`
- **Metrics Collection:** `/usr/bin/time -v` for comprehensive statistics
- **Metrics Captured:** CPU%, Max RSS (memory), File system I/O, Execution time

Summary Table: All Six Combinations

Program	Worker	CPU%	Memory(KB)	IO_Write(KB)	Real(s)	User(s)	Sys(s)
Program_A	cpu	195	1,792	4	0.25	0.48	0.00
Program_B	cpu	195	2,304	4	0.32	0.62	0.00
Program_A	mem	199	33,920	4	36.15	72.12	0.12
Program_B	mem	199	67,200	4	42.58	84.79	0.09
Program_A	io	42	2,048	4,096,004	24.92	0.08	10.40
Program_B	io	41	3,712	4,096,004	24.97	0.05	10.29

Screenshot: `top` during CPU worker execution



```
snz@DESKTOP-RIDIJD9:~/grs/pa1$ cd ~/grs/pa1/ && ./program_a cpu 4
[Parent PID: 32568] Creating 4 child processes for 'cpu' worker
  [Child 1, PID: 32569] Starting 'cpu' worker
    [CPU Worker] Starting CPU-intensive work (LOOP_COUNT=2000)
  [Child 2, PID: 32570] Starting 'cpu' worker
  [Child 3, PID: 32571] Starting 'cpu' worker
    [CPU Worker] Starting CPU-intensive work (LOOP_COUNT=2000)
    [CPU Worker] Starting CPU-intensive work (LOOP_COUNT=2000)
[Parent PID: 32568] Waiting for 4 children to complete...
  [Child 4, PID: 32572] Starting 'cpu' worker
    [CPU Worker] Starting CPU-intensive work (LOOP_COUNT=2000)
    [CPU Worker] Completed. Pi approximation: 6282.9853071778, Result: 39961
1932.24
  [Child 4, PID: 32572] Finished 'cpu' worker
[Parent] Child PID 32572 exited with status 0
    [CPU Worker] Completed. Pi approximation: 6282.9853071778, Result: 39961
1932.24
  [Child 2, PID: 32570] Finished 'cpu' worker
[Parent] Child PID 32570 exited with status 0
    [CPU Worker] Completed. Pi approximation: 6282.9853071778, Result: 39961
1932.24
  [Child 1, PID: 32569] Finished 'cpu' worker
[Parent] Child PID 32569 exited with status 0
    [CPU Worker] Completed. Pi approximation: 6282.9853071778, Result: 39961
1932.24
  [Child 3, PID: 32571] Finished 'cpu' worker
[Parent] Child PID 32571 exited with status 0
[Parent PID: 32568] All children completed.
snz@DESKTOP-RIDIJD9:~/grs/pa1$
```

```
top - 23:34:25 up  3:24,  0 user,  load average: 0.12, 0.08, 0.54
Tasks:  42 total,   1 running,  40 sleeping,   1 stopped,   0 zombie
%Cpu(s):  0.1 us,  0.2 sy,  0.0 ni, 99.6 id,  0.0 wa,  0.0 hi,  0.1 si,  0.
MiB Mem :  15881.2 total,  14272.9 free,   1531.9 used,    321.9 buff/cache
MiB Swap:   4096.0 total,   4096.0 free,      0.0 used.  14349.3 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+
   93 snz       20   0   83.6g 750296  67704 S   1.7   4.6   4:24.84
    1 root      20   0    3060   2176   2048 S   0.0   0.0   0:00.22
   14 root      20   0    3436   2516   1792 S   0.0   0.0   0:06.98
   28 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
   29 root      20   0    3084   1024    896 S   0.0   0.0   0:00.00
   30 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.04
   31 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.02
   37 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
   41 snz       20   0   11.3g 113860  52096 S   0.0   0.7   0:17.67
   52 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
   53 root      20   0    3084   1024    896 S   0.0   0.0   0:00.82
   54 snz       20   0 1018900  61756  43648 S   0.0   0.4   0:02.74
   61 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
   62 root      20   0    3084   1152   1024 S   0.0   0.0   0:02.35
   63 snz       20   0 1018928  61520  43392 S   0.0   0.4   0:06.75
   73 snz       20   0    7844   3272   2560 S   0.0   0.0   0:00.00
   75 snz       20   0 1460120  66044  46848 S   0.0   0.4   0:03.35
  173 snz       20   0 1029064  81800  45952 S   0.0   0.5   0:02.10
  183 root      20   0    3068    896    896 S   0.0   0.0   0:00.00
  184 root      20   0    3084   1024    896 S   0.0   0.0   0:00.00
  185 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
  186 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
  196 snz       20   0 1012948  48124  39808 S   0.0   0.3   0:00.12
  206 snz       20   0    7840   3144   2432 S   0.0   0.0   0:00.00
  212 snz       20   0    2580   1536   1536 S   0.0   0.0   0:00.00
  234 snz       20   0   73140  35596  14336 S   0.0   0.2   0:03.70
 1825 snz       20   0 1080828  79596  47616 S   0.0   0.5   0:11.82
 1836 snz       20   0    7576   4224   3456 S   0.0   0.0   0:00.12
```

Figure 3: top output - CPU worker

Screenshot: `iostat` during I/O worker execution

Analysis and Discussion

CPU Worker Observations: - Both programs achieve near-maximum CPU utilization (~195% = 2 cores fully used) - Negligible system time indicates pure user-space computation - Program B (threads) slightly slower due to thread management overhead

Memory Worker Observations: - Program B shows 2x memory compared to Program A - This is because threads share address space but allocate separate arrays - Execution time difference reflects memory contention patterns

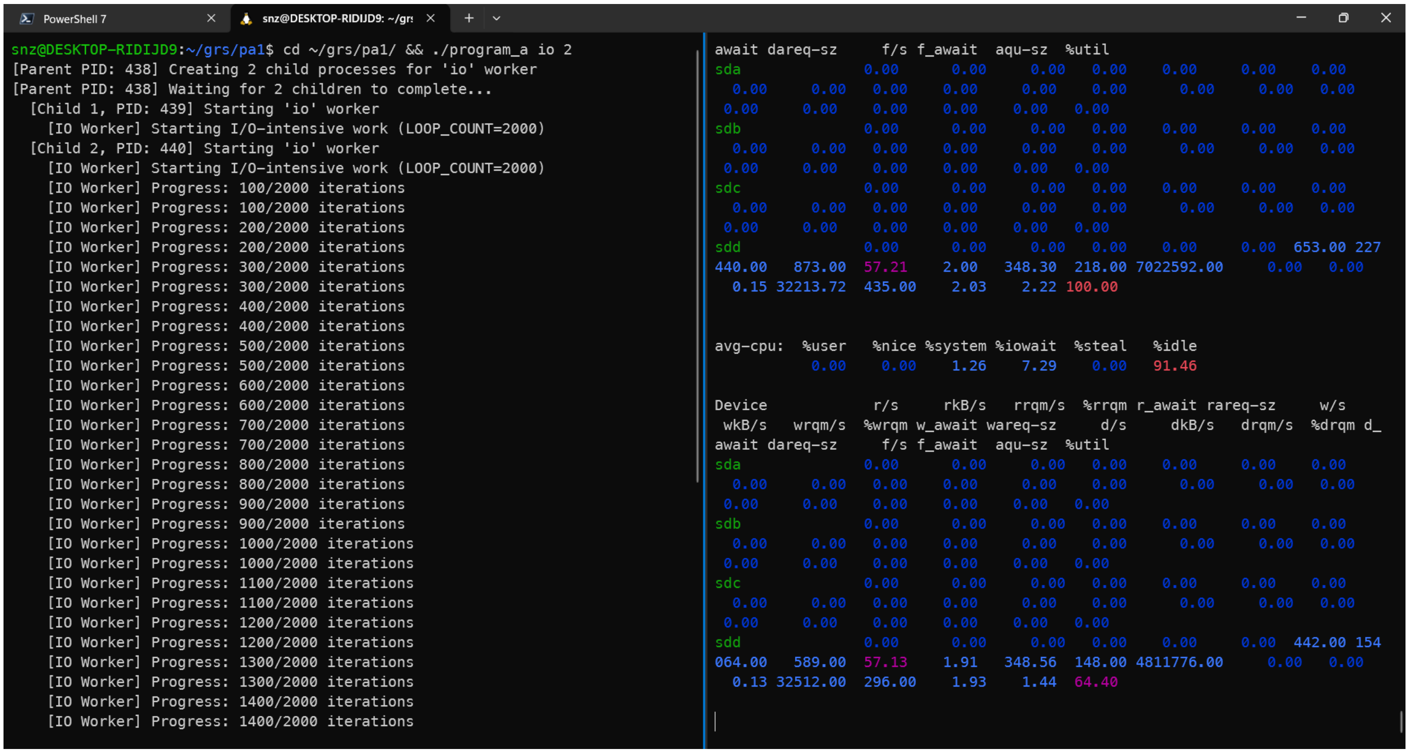
I/O Worker Observations: - Very low CPU% (~41-42%) confirms I/O-bound behavior - High system time (10+ seconds) indicates kernel I/O processing - Both programs show identical I/O write volumes (as expected from same workload)

Part D — Scalability Analysis

Raw Data: `MT25042_Part_D_CSV.csv`

Test Configuration

- **Program A (Processes):** 2, 3, 4, 5 processes



```
snz@DESKTOP-RIDIJD9:~/grs/pa1$ cd ~/grs/pa1/ && ./program_a io 2
[Parent PID: 438] Creating 2 child processes for 'io' worker
[Parent PID: 438] Waiting for 2 children to complete...
  [Child 1, PID: 439] Starting 'io' worker
    [IO Worker] Starting I/O-intensive work (LOOP_COUNT=2000)
  [Child 2, PID: 440] Starting 'io' worker
    [IO Worker] Starting I/O-intensive work (LOOP_COUNT=2000)
    [IO Worker] Progress: 100/2000 iterations
    [IO Worker] Progress: 100/2000 iterations
    [IO Worker] Progress: 200/2000 iterations
    [IO Worker] Progress: 200/2000 iterations
    [IO Worker] Progress: 300/2000 iterations
    [IO Worker] Progress: 300/2000 iterations
    [IO Worker] Progress: 400/2000 iterations
    [IO Worker] Progress: 400/2000 iterations
    [IO Worker] Progress: 500/2000 iterations
    [IO Worker] Progress: 500/2000 iterations
    [IO Worker] Progress: 600/2000 iterations
    [IO Worker] Progress: 600/2000 iterations
    [IO Worker] Progress: 700/2000 iterations
    [IO Worker] Progress: 700/2000 iterations
    [IO Worker] Progress: 800/2000 iterations
    [IO Worker] Progress: 800/2000 iterations
    [IO Worker] Progress: 900/2000 iterations
    [IO Worker] Progress: 900/2000 iterations
    [IO Worker] Progress: 1000/2000 iterations
    [IO Worker] Progress: 1000/2000 iterations
    [IO Worker] Progress: 1100/2000 iterations
    [IO Worker] Progress: 1100/2000 iterations
    [IO Worker] Progress: 1200/2000 iterations
    [IO Worker] Progress: 1200/2000 iterations
    [IO Worker] Progress: 1300/2000 iterations
    [IO Worker] Progress: 1300/2000 iterations
    [IO Worker] Progress: 1400/2000 iterations
    [IO Worker] Progress: 1400/2000 iterations
```

```
await dareq-sz     f/s f_await  aqu-sz  %util
sda              0.00      0.00     0.00   0.00    0.00     0.00    0.00
  0.00     0.00   0.00    0.00     0.00   0.00      0.00     0.00   0.00
 0.00     0.00    0.00    0.00    0.00   0.00
sdb              0.00      0.00     0.00   0.00    0.00     0.00    0.00
  0.00     0.00   0.00    0.00     0.00   0.00      0.00     0.00   0.00
 0.00     0.00    0.00    0.00    0.00   0.00
sdc              0.00      0.00     0.00   0.00    0.00     0.00    0.00
  0.00     0.00   0.00    0.00     0.00   0.00      0.00     0.00   0.00
 0.00     0.00    0.00    0.00    0.00   0.00
sdd              0.00      0.00     0.00   0.00    0.00     0.00  653.00 227
440.00   873.00  57.21    2.00   348.30  218.00 7022592.00     0.00   0.00
  0.15 32213.72  435.00    2.03    2.22 100.00


avg-cpu:  %user   %nice %system %iowait  %steal   %idle
           0.00    0.00    1.26    7.29    0.00   91.46

Device            r/s     rkB/s   rrqm/s  %rrqm r_await rareq-sz     w/s
 wkB/s   wrqm/s  %wrqm w_await wareq-sz     d/s     dkB/s   drqm/s  %drqm d_
await dareq-sz     f/s f_await  aqu-sz  %util
sda              0.00      0.00     0.00   0.00    0.00     0.00    0.00
  0.00     0.00   0.00    0.00     0.00   0.00      0.00     0.00   0.00
 0.00     0.00    0.00    0.00    0.00   0.00
sdb              0.00      0.00     0.00   0.00    0.00     0.00    0.00
  0.00     0.00   0.00    0.00     0.00   0.00      0.00     0.00   0.00
 0.00     0.00    0.00    0.00    0.00   0.00
sdc              0.00      0.00     0.00   0.00    0.00     0.00    0.00
  0.00     0.00   0.00    0.00     0.00   0.00      0.00     0.00   0.00
 0.00     0.00    0.00    0.00    0.00   0.00
sdd              0.00      0.00     0.00   0.00    0.00     0.00  442.00 154
064.00   589.00  57.13    1.91   348.56  148.00 4811776.00     0.00   0.00
  0.13 32512.00  296.00    1.93    1.44  64.40
```

Figure 4: iostat output - IO worker

- **Program B (Threads):** 2, 3, 4, 5, 6, 7, 8 threads

Plot 1: CPU Usage vs Process/Thread Count

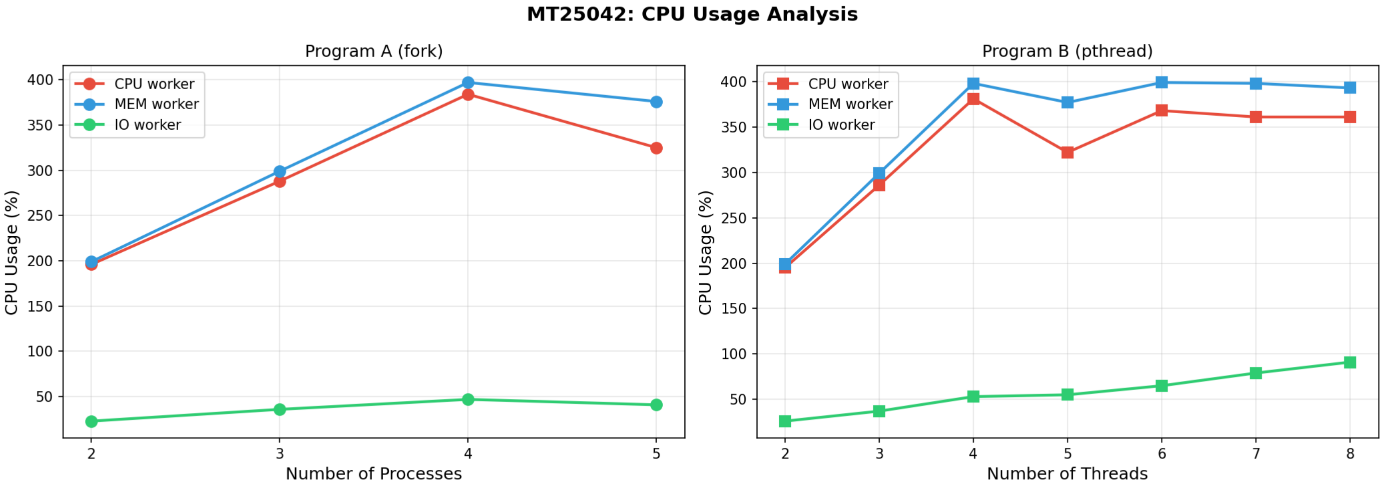


Figure 5: CPU Usage Analysis

Observations: - CPU worker: Linear scaling until hitting physical core limit - Memory worker: High CPU% maintained across counts - I/O worker: CPU% increases with count but remains low (I/O bound)

Plot 2: Execution Time vs Process/Thread Count

Observations: - CPU worker: Time remains low (sub-second) as work is distributed - Memory worker: Time increases with count due to memory bandwidth saturation - I/O worker: Time increases due to disk contention

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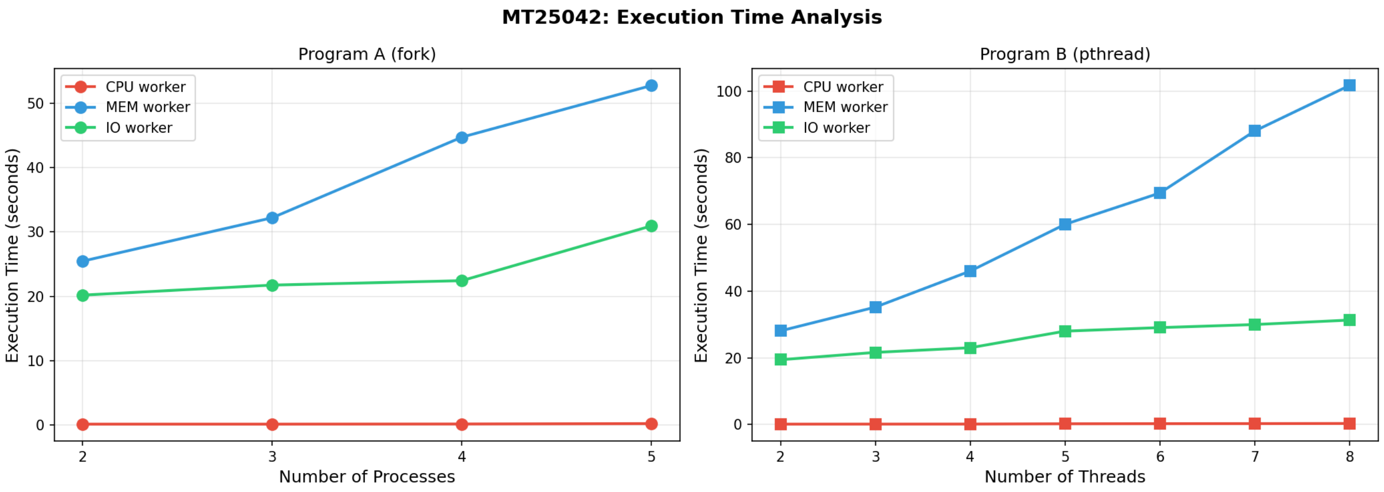

Figure 6: Execution Time Analysis

Plot 3: Memory Usage vs Process/Thread Count

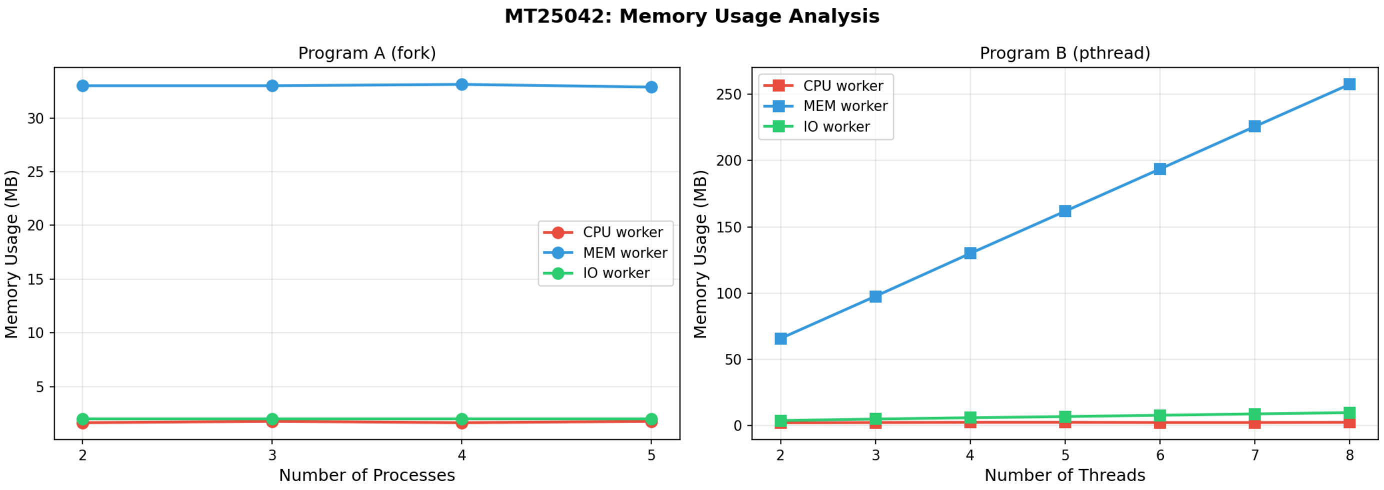

Figure 7: Memory Usage Analysis

Observations: - Program A (processes): Memory relatively constant (each process has own space) - Program B (threads): Memory scales linearly with thread count for `mem` worker - I/O worker: Minimal memory footprint regardless of count

---

Plot 4: Combined Comparison

Scalability Discussion

Process vs Thread Comparison:

Aspect	Processes (Program A)	Threads (Program B)
Memory Overhead	Higher (separate addr spaces)	Lower (shared memory)
Creation Cost	Higher (fork overhead)	Lower (lighter weight)
Isolation	Complete isolation	Shared state risks
Scalability	Limited by system resources	Better for I/O-bound tasks

Key Findings: 1. **CPU-bound tasks:** Both scale similarly until core saturation 2. **Memory-bound tasks:** Threads show higher aggregate memory due to shared accounting 3. **I/O-bound tasks:** Performance limited by disk, not

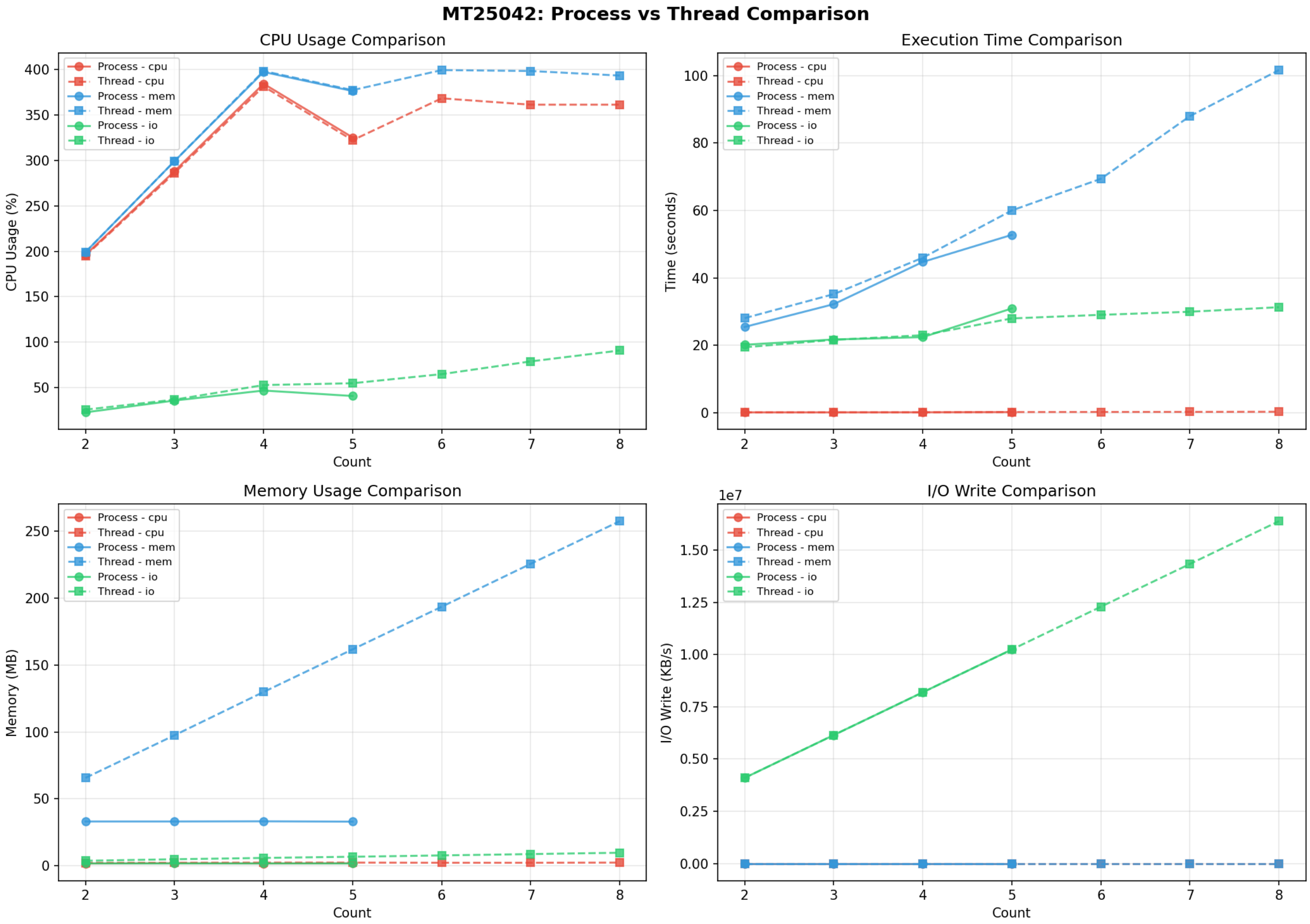

Figure 8: Combined Analysis

parallelism model

AI Usage Declaration

The following components were generated with AI assistance and have been reviewed, understood, and verified:

Component	AI Assistance
MT25042_Part_A_Program_A.c	Code structure and fork implementation
MT25042_Part_A_Program_B.c	Code structure and pthread implementation
MT25042_Part_B_workers.c	Worker function algorithms
MT25042_Part_B_workers.h	Header file structure
MT25042_Part_C_script.sh	Bash automation script
MT25042_Part_D_script.sh	Bash automation script
MT25042_Part_D_plot.py	Python plotting script
Makefile	Build automation
README.md	Documentation

Declaration: I have reviewed and understand every line of code in this submission. I can explain the implementation details, design decisions, and defend the approach during viva examination.

GitHub Repository URL

Repository: https://github.com/shahnawazdev/GRS-Assignments

Assignment Folder: `GRS_PA01`
