Multi-threaded Program Analysis using "perf" Tool

Graduate Systems (CSE638) – PA02

1. Introduction

This project focuses on analyzing multithreaded programs using the Linux `perf` tool to assess performance, detect bottlenecks, and optimize execution. The study involves developing different types of workloads, implementing a producer-consumer pipeline, and evaluating performance metrics such as CPU usage, memory bandwidth, and context switches.

2. Objectives

- Develop four distinct multithreaded programs to simulate CPU-bound, memory-bound, I/O-bound, and mixed workloads.
- Implement a producer-consumer pipeline using synchronization primitives.
- Utilize `perf` to analyze execution efficiency and identify bottlenecks.
- Compare the scalability of different workload types by varying thread counts.

3. Implementation

3.1 Part A: Multithreaded Program Variants

Four separate programs were implemented using the pthread library:

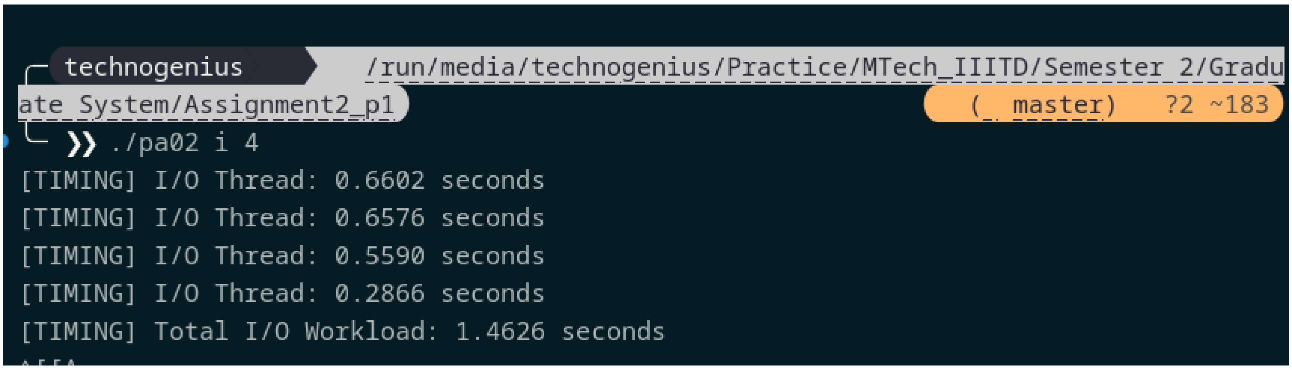
1. **CPU-bound:** Performs intensive computations (e.g., matrix multiplication, prime number calculations).
2. **Memory-bound:** Focuses on operations requiring large memory allocations and accesses.
3. **I/O-bound:** Simulates disk I/O or network operations to assess read/write performance.
4. **Mixed workload:** Combines CPU, memory, and I/O tasks to simulate real-world applications.

Each program was executed with different thread configurations (2, 4, 8, 50, 100) to study the effect of thread scaling on performance.

4. Performance Analysis with `perf`

The following key metrics were analyzed for each program:

- **CPU Usage:** Measures processor load during execution.
- **Memory Bandwidth:** Tracks memory reads/writes per second.
- **Cache Behavior:** Monitors cache references and misses.
- **Context Switches:** Evaluates efficiency in handling multiple threads.
- **Execution Time & Throughput:** Determines overall performance.



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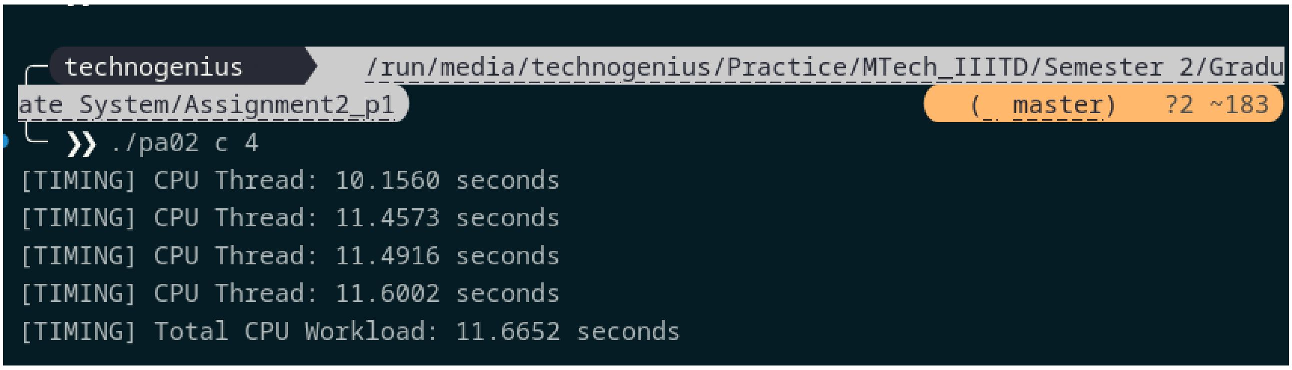
╭─ technogenius   /run/media/technogenius/Practice/MTech_IIITD/Semester 2/Gradu
ate System/Assignment2_p1                                  ( master)   ?2 ~183
╰─ ❯❯ ./pa02 i 4
[TIMING] I/O Thread: 0.6602 seconds
[TIMING] I/O Thread: 0.6576 seconds
[TIMING] I/O Thread: 0.5590 seconds
[TIMING] I/O Thread: 0.2866 seconds
[TIMING] Total I/O Workload: 1.4626 seconds
```



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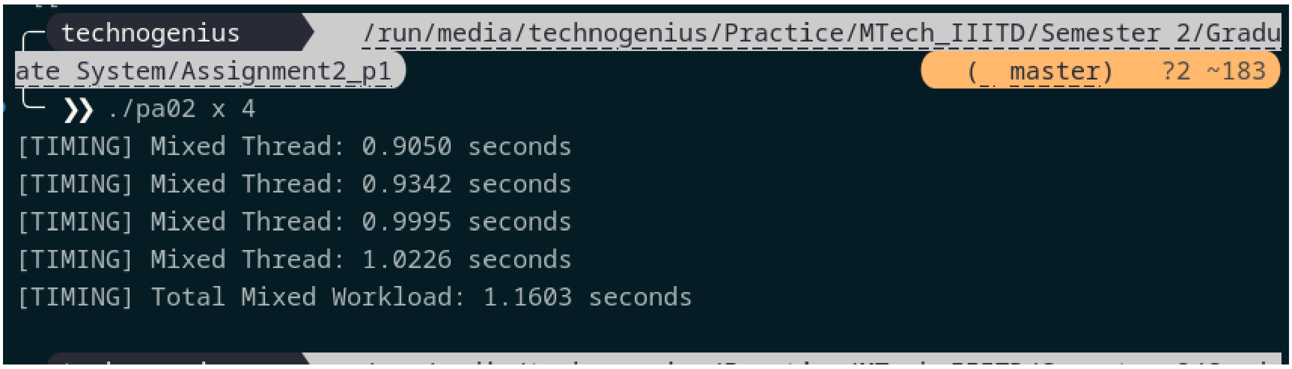
ate System/Assignment2_p1                                  ( master)   ?2 ~183
╰─ ❯❯ ./pa02 c 4
[TIMING] CPU Thread: 10.1560 seconds
[TIMING] CPU Thread: 11.4573 seconds
[TIMING] CPU Thread: 11.4916 seconds
[TIMING] CPU Thread: 11.6002 seconds
[TIMING] Total CPU Workload: 11.6652 seconds
```



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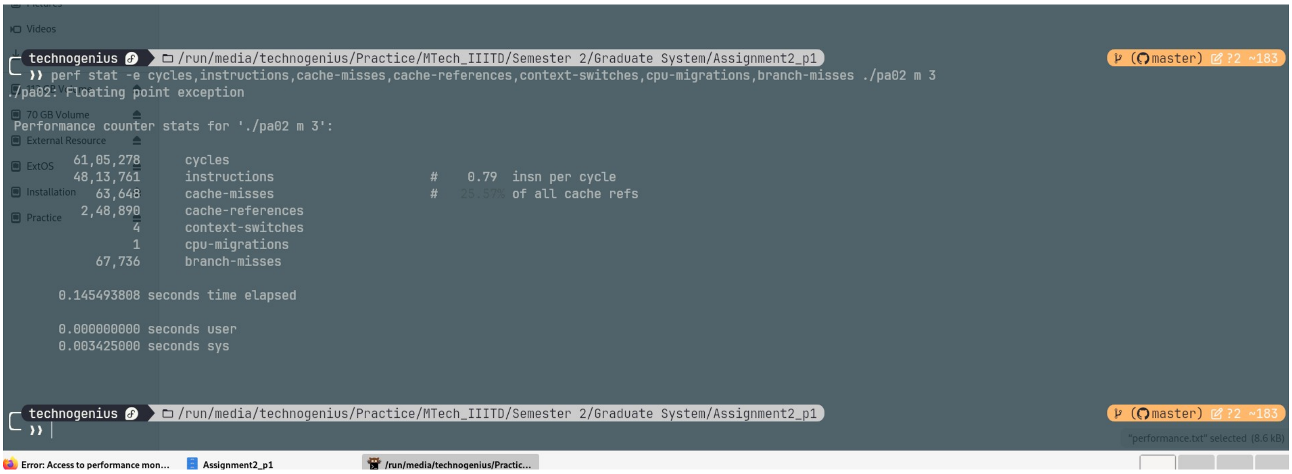
ate System/Assignment2_p1                                  ( master)   ?2 ~183
╰─ ❯❯ ./pa02 x 4
[TIMING] Mixed Thread: 0.9050 seconds
[TIMING] Mixed Thread: 0.9342 seconds
[TIMING] Mixed Thread: 0.9995 seconds
[TIMING] Mixed Thread: 1.0226 seconds
[TIMING] Total Mixed Workload: 1.1603 seconds
```



```
technogenius  /run/media/technogenius/Practice/MTech_IIITD/Semester 2/Graduate System/Assignment2_p1                (master) ?2 ~183
)) perf stat -e cycles,instructions,cache-misses,cache-references,context-switches,cpu-migrations,branch-misses ./pa02 m 3
./pa02: Floating point exception

 Performance counter stats for './pa02 m 3':

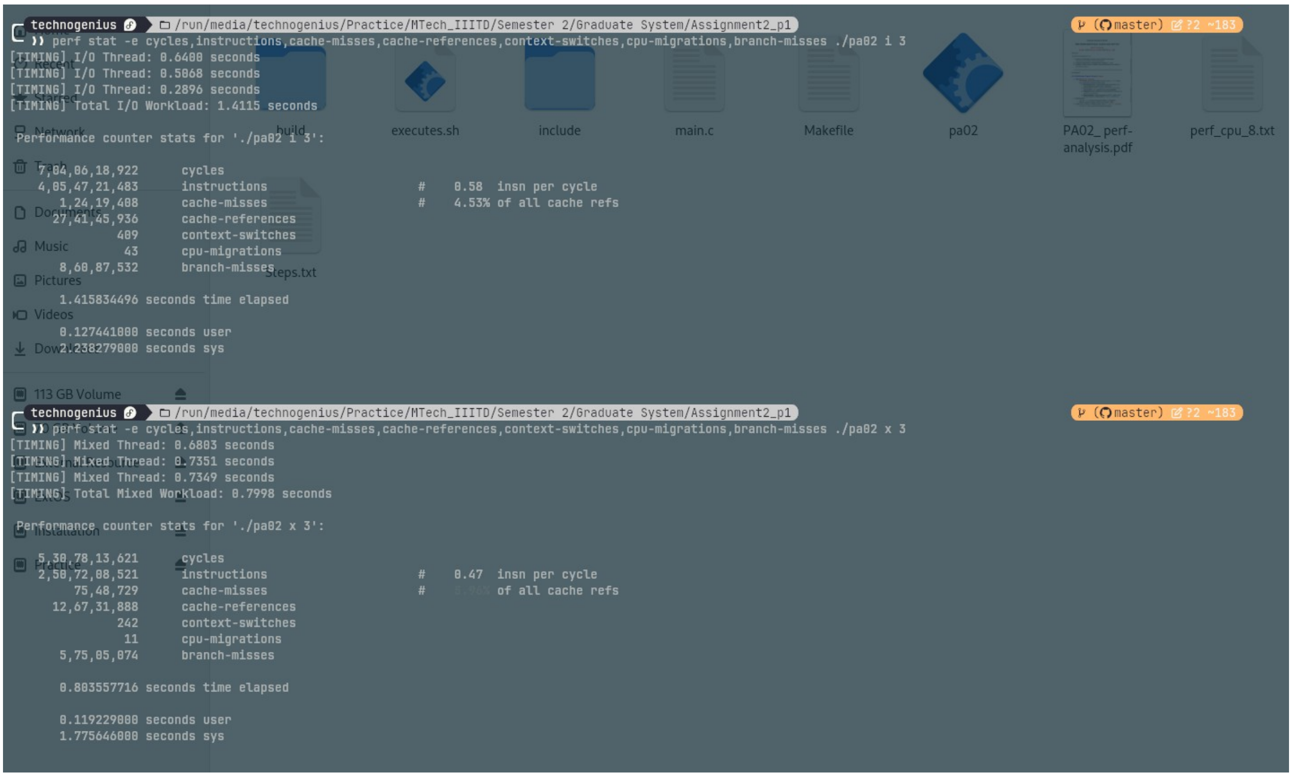
         61,05,278      cycles
         48,13,761      instructions                     #    0.79  insn per cycle
            63,648      cache-misses                     #   25.57% of all cache refs
          2,48,890      cache-references
                 4      context-switches
                 1      cpu-migrations
            67,736      branch-misses

       0.145493808 seconds time elapsed

       0.000000000 seconds user
       0.003425000 seconds sys


technogenius  /run/media/technogenius/Practice/MTech_IIITD/Semester 2/Graduate System/Assignment2_p1                (master) ?2 ~183
))
```

"performance.txt" selected (8.6 kB)
Error: Access to performance mon...
Assignment2_p1
/run/media/technogenius/Practic...



```
technogenius  /run/media/technogenius/Practice/MTech_IIITD/Semester 2/Graduate System/Assignment2_p1                (master) ?2 ~183
)) perf stat -e cycles,instructions,cache-misses,cache-references,context-switches,cpu-migrations,branch-misses ./pa02 i 3
[TIMING] I/O Thread: 0.6400 seconds
[TIMING] I/O Thread: 0.5068 seconds
[TIMING] I/O Thread: 0.2896 seconds
[TIMING] Total I/O Workload: 1.4115 seconds

 Performance counter stats for './pa02 i 3':

    7,04,06,18,922      cycles
    4,05,47,21,483      instructions                     #    0.58  insn per cycle
       1,24,19,408      cache-misses                     #    4.53% of all cache refs
      27,41,45,936      cache-references
               409      context-switches
                43      cpu-migrations
       8,60,87,532      branch-misses

       1.415834496 seconds time elapsed

       0.127441000 seconds user
       2.238279000 seconds sys

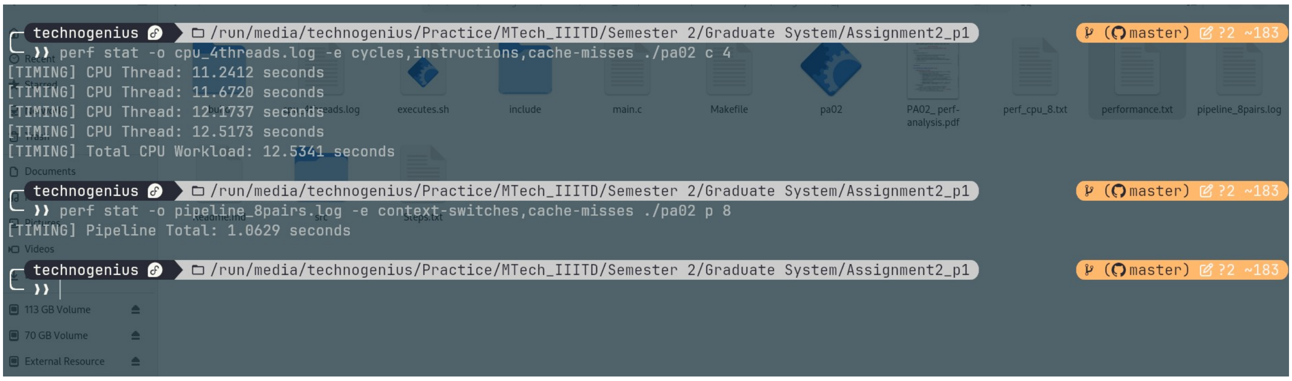
technogenius  /run/media/technogenius/Practice/MTech_IIITD/Semester 2/Graduate System/Assignment2_p1                (master) ?2 ~183
)) perf stat -e cycles,instructions,cache-misses,cache-references,context-switches,cpu-migrations,branch-misses ./pa02 x 3
[TIMING] Mixed Thread: 0.6803 seconds
[TIMING] Mixed Thread: 0.7351 seconds
[TIMING] Mixed Thread: 0.7349 seconds
[TIMING] Total Mixed Workload: 0.7998 seconds

 Performance counter stats for './pa02 x 3':

    5,30,78,13,621      cycles
    2,50,72,08,521      instructions                     #    0.47  insn per cycle
         75,48,729      cache-misses                     #    5.96% of all cache refs
      12,67,31,888      cache-references
               242      context-switches
                11      cpu-migrations
       5,75,05,074      branch-misses

       0.803557716 seconds time elapsed

       0.119229000 seconds user
       1.775646000 seconds sys
```

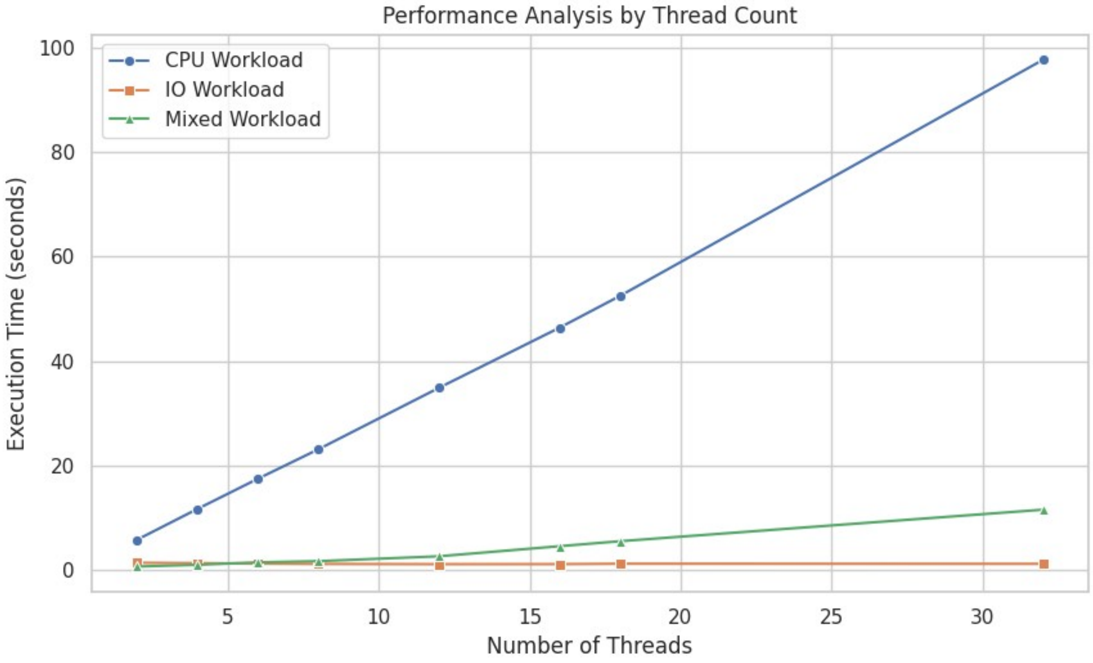


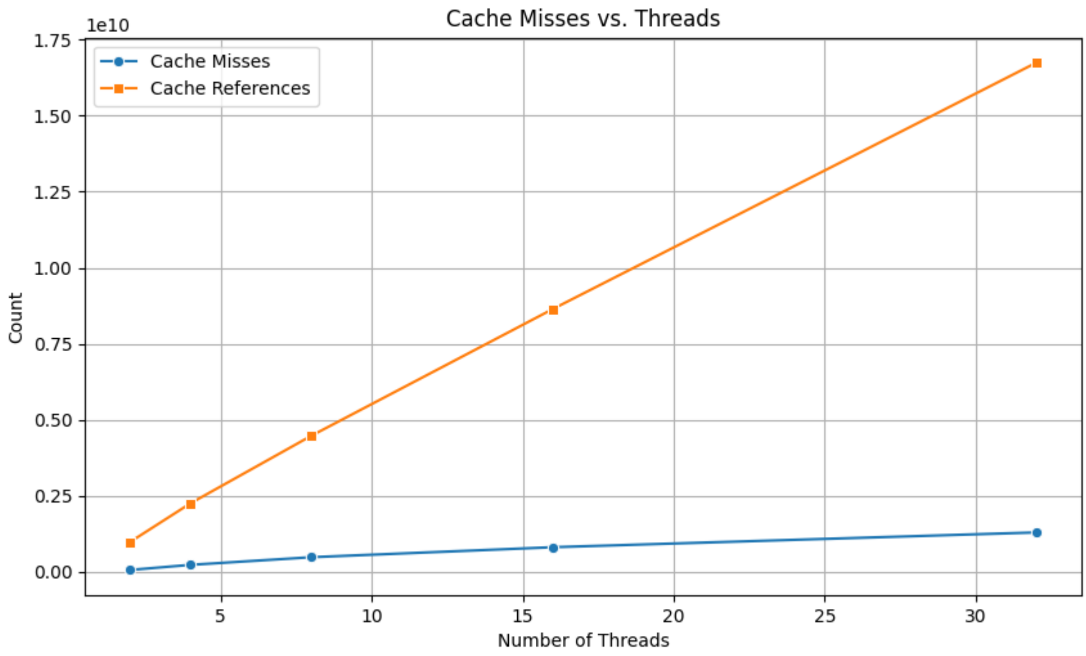
```
technogenius  /run/media/technogenius/Practice/MTech_IIITD/Semester 2/Graduate System/Assignment2_p1     (master) ?2 ~183
)) perf stat -o cpu_4threads.log -e cycles,instructions,cache-misses ./pa02 c 4
[TIMING] CPU Thread: 11.2412 seconds
[TIMING] CPU Thread: 11.6720 seconds
[TIMING] CPU Thread: 12.1737 seconds
[TIMING] CPU Thread: 12.5173 seconds
[TIMING] Total CPU Workload: 12.5341 seconds
technogenius  /run/media/technogenius/Practice/MTech_IIITD/Semester 2/Graduate System/Assignment2_p1     (master) ?2 ~183
)) perf stat -o pipeline_8pairs.log -e context-switches,cache-misses ./pa02 p 8
[TIMING] Pipeline Total: 1.0629 seconds
technogenius  /run/media/technogenius/Practice/MTech_IIITD/Semester 2/Graduate System/Assignment2_p1     (master) ?2 ~183
))
```

5. Scalability Testing

To assess scalability, each program was executed with increasing thread counts. Observations include:

- CPU-bound programs showed diminishing returns beyond a certain thread count.
- Memory-bound workloads suffered from increased cache misses with more threads.
- I/O-bound tasks exhibited bottlenecks due to disk read/write limitations.
- Mixed workloads demonstrated variable performance based on resource contention.





6. Observations and Bottlenecks

- Excessive thread creation led to overhead due to frequent context switching.
- Cache efficiency played a crucial role in memory-bound workloads.
- I/O operations became a limiting factor beyond a certain number of threads.
- The producer-consumer model improved efficiency but required careful synchronization tuning.

7. Conclusion

This project provided insights into multithreaded performance analysis using `perf`. The results highlighted the importance of workload-specific optimizations, proper thread management, and synchronization techniques for improving performance. Future improvements could include exploring alternative scheduling policies and optimizing memory access patterns.

8. References

- Linux `perf` Tool Documentation
- Multithreading with Pthreads
- Performance Optimization Techniques