CPU Scheduling Simulation Project
CS 3502: Operating Systems
Kennesaw State University

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Abstract

This project involved the implementation of new, and possibly more efficient CPU scheduling algorithms into an existing CPU scheduling simulator in order to evaluate their various efficiencies and weaknesses. The goal was to each algorithm strategy based on metrics such as Average Waiting Time (AWT), Average Turnaround Time (ATT), CPU Utilization, and Throughput. Both pre-existing algorithms (FCFS, SJF, Priority, Round Robin) and self-implemented advanced algorithms (SRTF, HRRN) were implemented, tested, and analyzed across different workloads. Results were gathered through both small-scale, controlled experiments and random large-scale tests, to determine the optimal scheduling strategy based on empirical performance data.

1 Introduction

CPU scheduling is a fundamental component of operating system design as it is responsible for determining the order in which processes access the CPU for execution. Effective scheduling improves system responsiveness, throughput, and resource utilization, directly impacting overall system performance in various ways.

This project involved integrating new, more advanced scheduling algorithms to an existing CPU scheduling simulator capable of measuring algorithm performance. The simulator was developed to evaluate these scheduling strategies across a variety of workloads. Algorithms implemented include First Come First Serve (FCFS), Shortest Job First (SJF), Priority Scheduling, Round Robin (RR), Shortest Remaining Time First (SRTF), and Highest Response Ratio Next (HRRN).

The primary objectives of the simulator were to measure and compare key performance metrics such as: Average Waiting Time (AWT), Average Turnaround Time (ATT), CPU Utilization, and Throughput across different algorithms. By running controlled small-scale tests, edge case scenarios, and larger randomized workloads; Meaningful, empirical insights into the efficiency and weaknesses of each strategy could be extracted.

2 Implementation Details

The CPU scheduling simulator was implemented using C# with a Windows Forms graphical interface. The simulator models processes and scheduling operations using basic array-based data structures for simplicity and efficiency. Each process is represented using the following attributes:

- **Arrival Time:** A double array storing the time each process arrives in the system.
- **Burst Time:** A double array representing the total CPU execution time required by each process.
- **Priority:** An integer array assigning a priority level to each process (lower values indicate higher priority).
- **Waiting Time:** A double array storing the computed waiting time for each process.
- **Turnaround Time:** A double array storing the total time from arrival to completion for each process.
- **Response Time:** A double array recording the time between process arrival and first CPU allocation.
- **Remaining Time:** A double array (used in SRTF and Round Robin algorithms) tracking how much CPU time a process still needs.
- **Completion Flags:** A boolean array used to indicate whether each process has completed execution.

The scheduling algorithms operate by manipulating these arrays based on specific scheduling rules:

- **First Come First Serve (FCFS):** Processes are sorted and executed based on arrival order.
- **Shortest Job First (SJF):** Processes with the shortest burst time are selected first.
- **Priority Scheduling:** Processes are selected based on the highest priority (lowest numerical value).
- **Round Robin (RR):** Processes share CPU time slices (quantum) in a cyclic order with preemption.

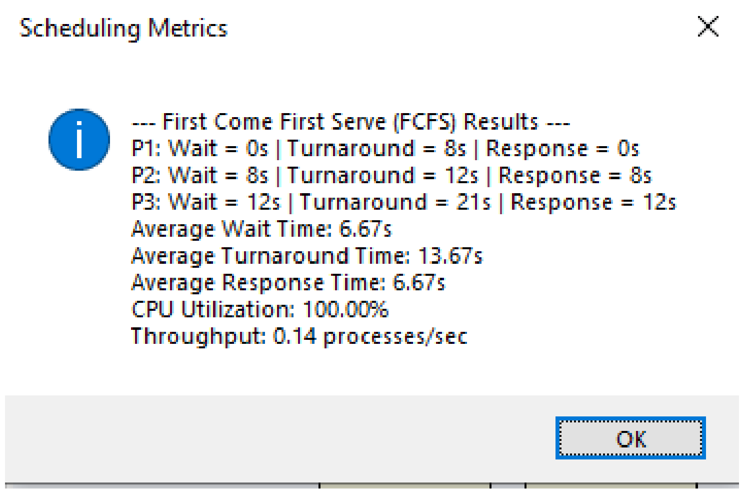
- **Shortest Remaining Time First (SRTF):** Preemptive version of SJF where processes with the least remaining CPU time are scheduled next.
- **Highest Response Ratio Next (HRRN):** Non-preemptive scheduling where processes with the highest response ratio (waiting time plus service time divided by service time) are selected.

Randomized workload generation was incorporated to automate testing across larger scenarios. Functions were temporarily modified to dynamically generate 20 random arrival times, burst times, and priorities for each test run, enabling repeatable and scalable evaluations without manual input.

3 Testing and Results

3.1 Basic Functionality Tests (3 Processes)

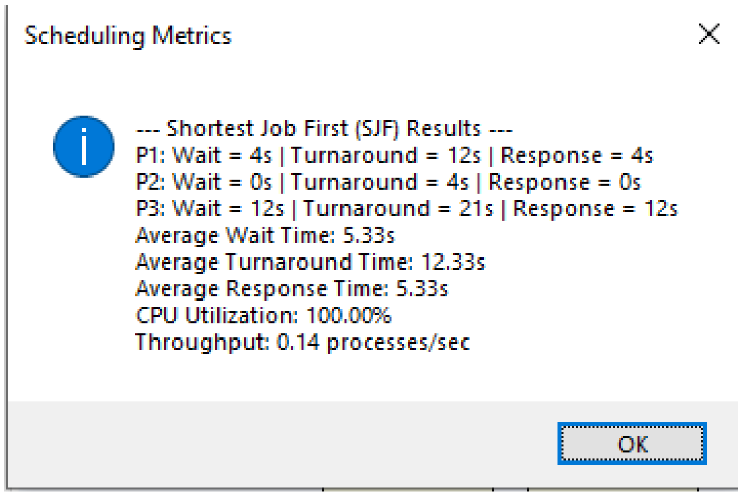
First Come First Serve (FCFS)



```
--- First Come First Serve (FCFS) Results ---
P1: Wait = 0s | Turnaround = 8s | Response = 0s
P2: Wait = 8s | Turnaround = 12s | Response = 8s
P3: Wait = 12s | Turnaround = 21s | Response = 12s
Average Wait Time: 6.67s
Average Turnaround Time: 13.67s
Average Response Time: 6.67s
CPU Utilization: 100.00%
Throughput: 0.14 processes/sec
```

Figure 1: First Come First Serve (FCFS) - Basic Test

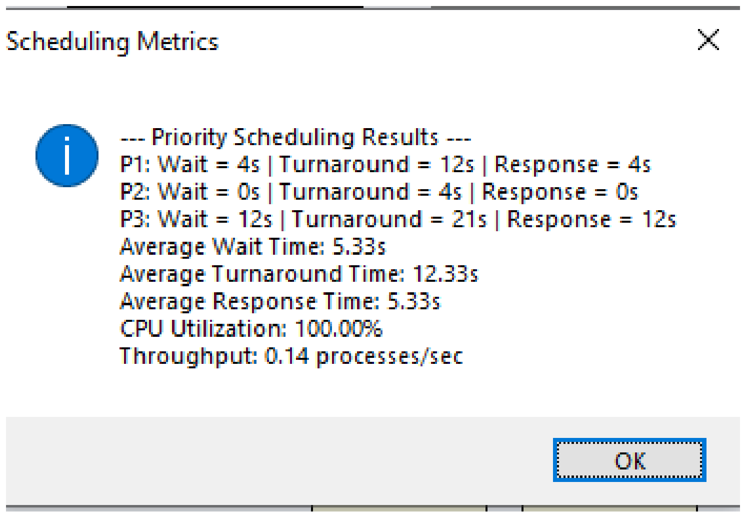
Shortest Job First (SJF)



```
--- Shortest Job First (SJF) Results ---
P1: Wait = 4s | Turnaround = 12s | Response = 4s
P2: Wait = 0s | Turnaround = 4s | Response = 0s
P3: Wait = 12s | Turnaround = 21s | Response = 12s
Average Wait Time: 5.33s
Average Turnaround Time: 12.33s
Average Response Time: 5.33s
CPU Utilization: 100.00%
Throughput: 0.14 processes/sec
```

Figure 2: Shortest Job First (SJF) - Basic Test

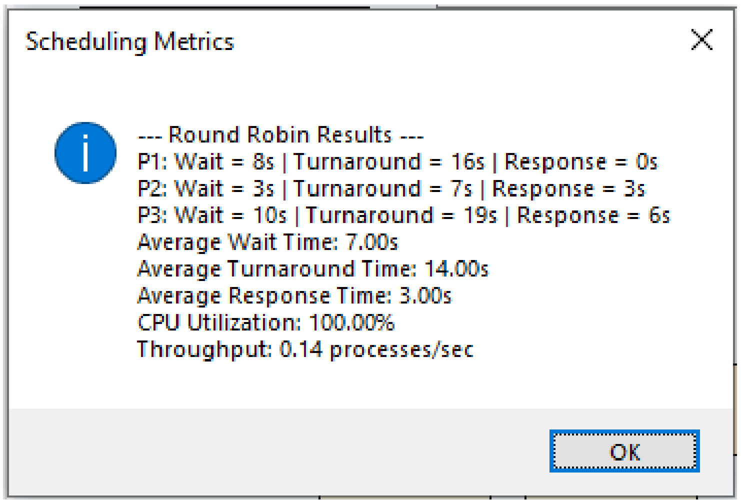
Priority Scheduling



```
--- Priority Scheduling Results ---
P1: Wait = 4s | Turnaround = 12s | Response = 4s
P2: Wait = 0s | Turnaround = 4s | Response = 0s
P3: Wait = 12s | Turnaround = 21s | Response = 12s
Average Wait Time: 5.33s
Average Turnaround Time: 12.33s
Average Response Time: 5.33s
CPU Utilization: 100.00%
Throughput: 0.14 processes/sec
```

Figure 3: Priority Scheduling - Basic Test

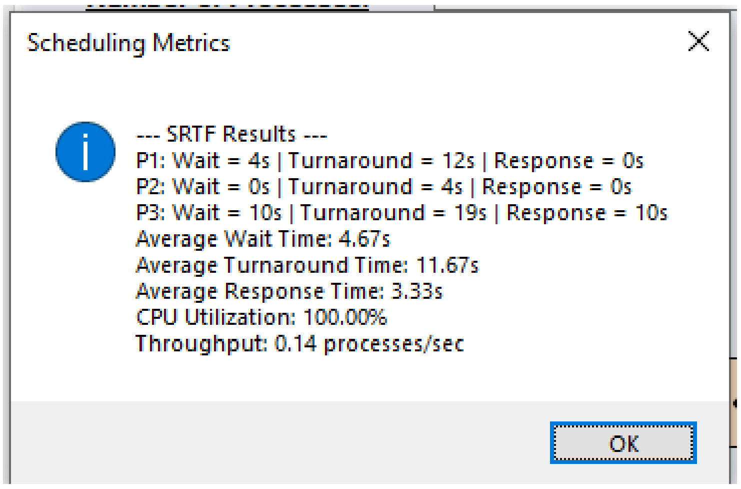
Round Robin (RR)



```
--- Round Robin Results ---
P1: Wait = 8s | Turnaround = 16s | Response = 0s
P2: Wait = 3s | Turnaround = 7s | Response = 3s
P3: Wait = 10s | Turnaround = 19s | Response = 6s
Average Wait Time: 7.00s
Average Turnaround Time: 14.00s
Average Response Time: 3.00s
CPU Utilization: 100.00%
Throughput: 0.14 processes/sec
```

Figure 4: Round Robin (RR) - Basic Test

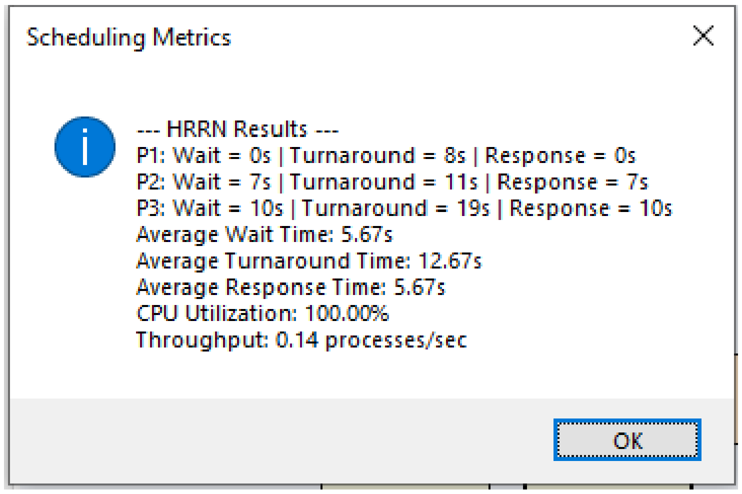
Shortest Remaining Time First (SRTF)



```
--- SRTF Results ---
P1: Wait = 4s | Turnaround = 12s | Response = 0s
P2: Wait = 0s | Turnaround = 4s | Response = 0s
P3: Wait = 10s | Turnaround = 19s | Response = 10s
Average Wait Time: 4.67s
Average Turnaround Time: 11.67s
Average Response Time: 3.33s
CPU Utilization: 100.00%
Throughput: 0.14 processes/sec
```

Figure 5: Shortest Remaining Time First (SRTF) - Basic Test

Highest Response Ratio Next (HRRN)

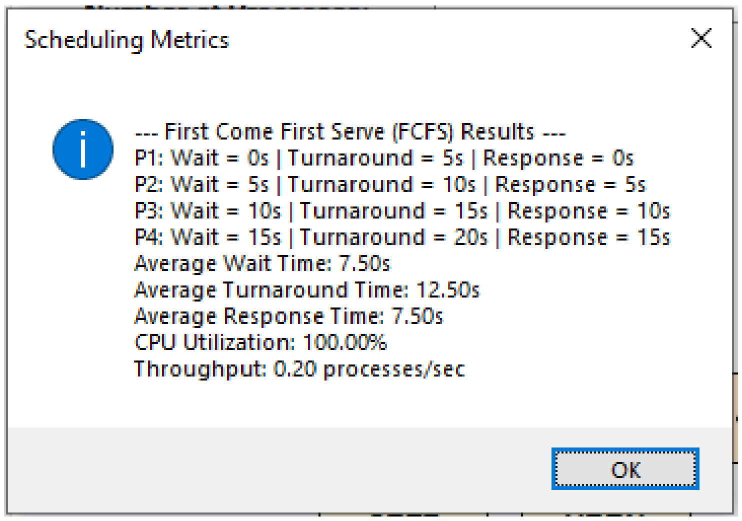


```
--- HRRN Results ---
P1: Wait = 0s | Turnaround = 8s | Response = 0s
P2: Wait = 7s | Turnaround = 11s | Response = 7s
P3: Wait = 10s | Turnaround = 19s | Response = 10s
Average Wait Time: 5.67s
Average Turnaround Time: 12.67s
Average Response Time: 5.67s
CPU Utilization: 100.00%
Throughput: 0.14 processes/sec
```

Figure 6: Highest Response Ratio Next (HRRN) - Basic Test

3.2 Edge Case Tests (4 Processes)

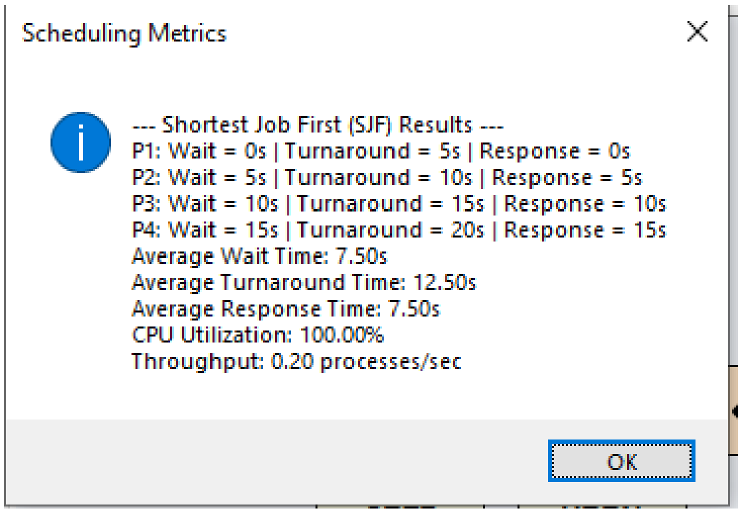
Case: Identical Burst Times Per Process
First Come First Serve (FCFS)



```
--- First Come First Serve (FCFS) Results ---
P1: Wait = 0s | Turnaround = 5s | Response = 0s
P2: Wait = 5s | Turnaround = 10s | Response = 5s
P3: Wait = 10s | Turnaround = 15s | Response = 10s
P4: Wait = 15s | Turnaround = 20s | Response = 15s
Average Wait Time: 7.50s
Average Turnaround Time: 12.50s
Average Response Time: 7.50s
CPU Utilization: 100.00%
Throughput: 0.20 processes/sec
```

Figure 7: First Come First Serve (FCFS) - Edge Case Test

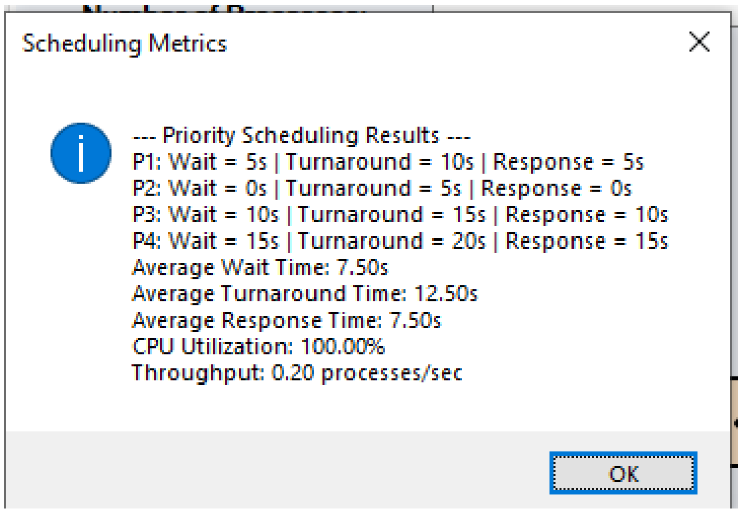
Shortest Job First (SJF)



```
--- Shortest Job First (SJF) Results ---
P1: Wait = 0s | Turnaround = 5s | Response = 0s
P2: Wait = 5s | Turnaround = 10s | Response = 5s
P3: Wait = 10s | Turnaround = 15s | Response = 10s
P4: Wait = 15s | Turnaround = 20s | Response = 15s
Average Wait Time: 7.50s
Average Turnaround Time: 12.50s
Average Response Time: 7.50s
CPU Utilization: 100.00%
Throughput: 0.20 processes/sec
```

Figure 8: Shortest Job First (SJF) - Edge Case Test

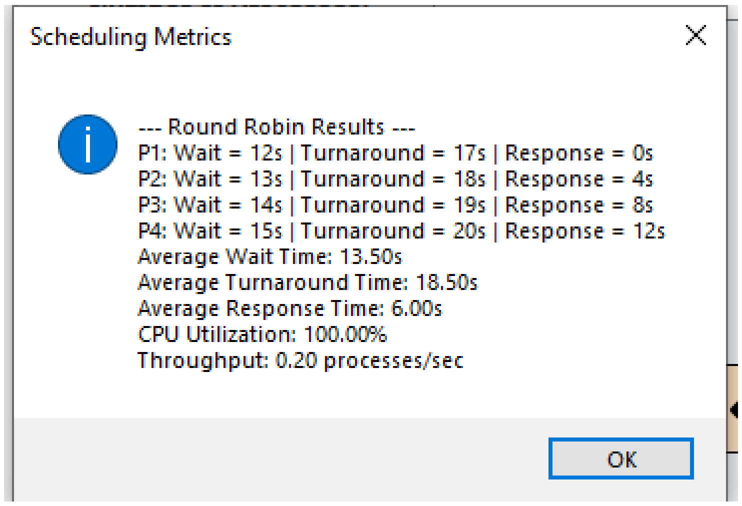
Priority Scheduling



```
--- Priority Scheduling Results ---
P1: Wait = 5s | Turnaround = 10s | Response = 5s
P2: Wait = 0s | Turnaround = 5s | Response = 0s
P3: Wait = 10s | Turnaround = 15s | Response = 10s
P4: Wait = 15s | Turnaround = 20s | Response = 15s
Average Wait Time: 7.50s
Average Turnaround Time: 12.50s
Average Response Time: 7.50s
CPU Utilization: 100.00%
Throughput: 0.20 processes/sec
```

Figure 9: Priority Scheduling - Edge Case Test

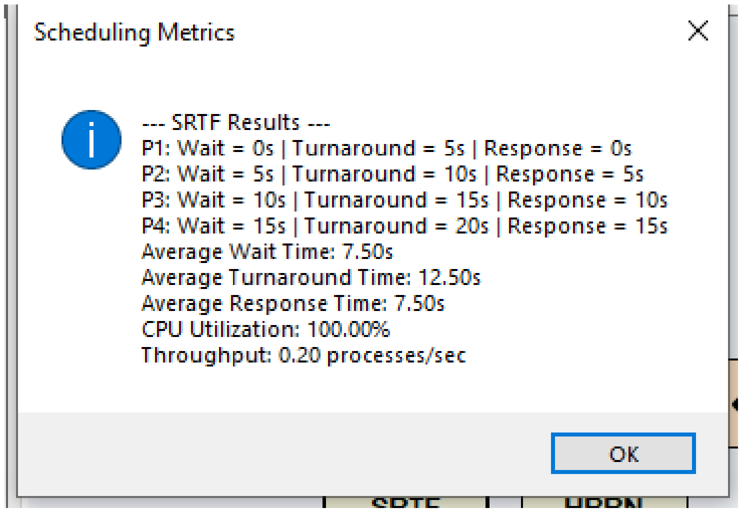
Round Robin (RR)



```
--- Round Robin Results ---
P1: Wait = 12s | Turnaround = 17s | Response = 0s
P2: Wait = 13s | Turnaround = 18s | Response = 4s
P3: Wait = 14s | Turnaround = 19s | Response = 8s
P4: Wait = 15s | Turnaround = 20s | Response = 12s
Average Wait Time: 13.50s
Average Turnaround Time: 18.50s
Average Response Time: 6.00s
CPU Utilization: 100.00%
Throughput: 0.20 processes/sec
```

Figure 10: Round Robin (RR) - Edge Case Test

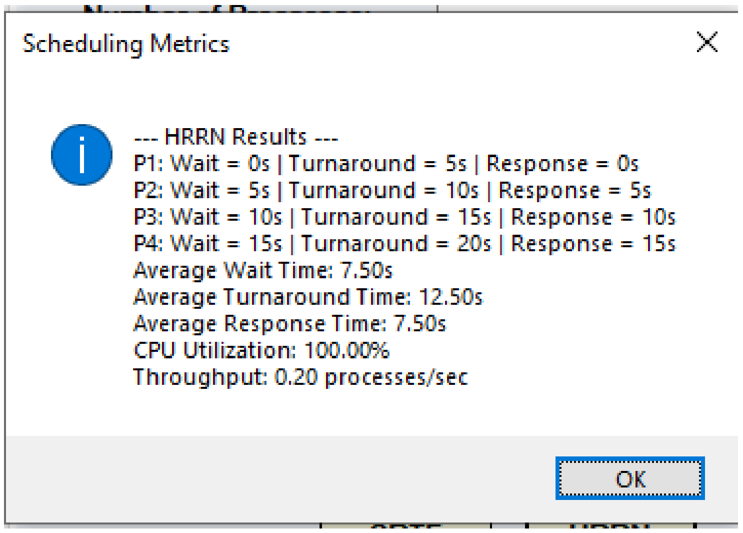
Shortest Remaining Time First (SRTF)



```
--- SRTF Results ---
P1: Wait = 0s | Turnaround = 5s | Response = 0s
P2: Wait = 5s | Turnaround = 10s | Response = 5s
P3: Wait = 10s | Turnaround = 15s | Response = 10s
P4: Wait = 15s | Turnaround = 20s | Response = 15s
Average Wait Time: 7.50s
Average Turnaround Time: 12.50s
Average Response Time: 7.50s
CPU Utilization: 100.00%
Throughput: 0.20 processes/sec
```

Figure 11: Shortest Remaining Time First (SRTF) - Edge Case Test

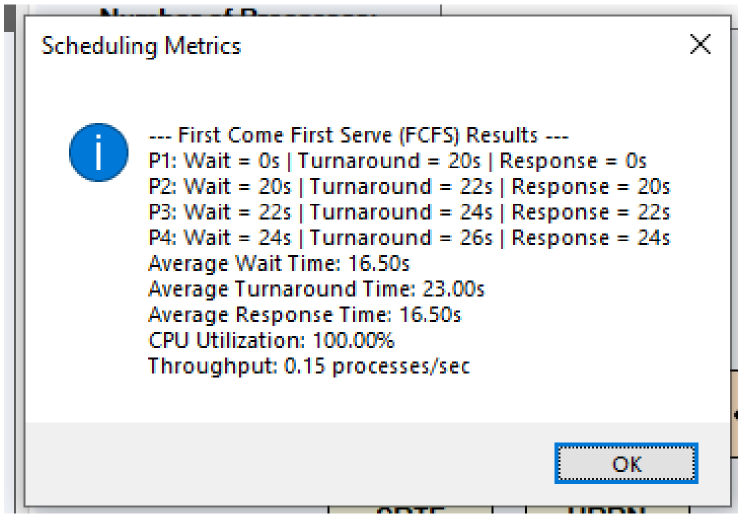
Highest Response Ratio Next (HRRN)



```
--- HRRN Results ---
P1: Wait = 0s | Turnaround = 5s | Response = 0s
P2: Wait = 5s | Turnaround = 10s | Response = 5s
P3: Wait = 10s | Turnaround = 15s | Response = 10s
P4: Wait = 15s | Turnaround = 20s | Response = 15s
Average Wait Time: 7.50s
Average Turnaround Time: 12.50s
Average Response Time: 7.50s
CPU Utilization: 100.00%
Throughput: 0.20 processes/sec
```

Figure 12: Highest Response Ratio Next (HRRN) - Edge Case Test

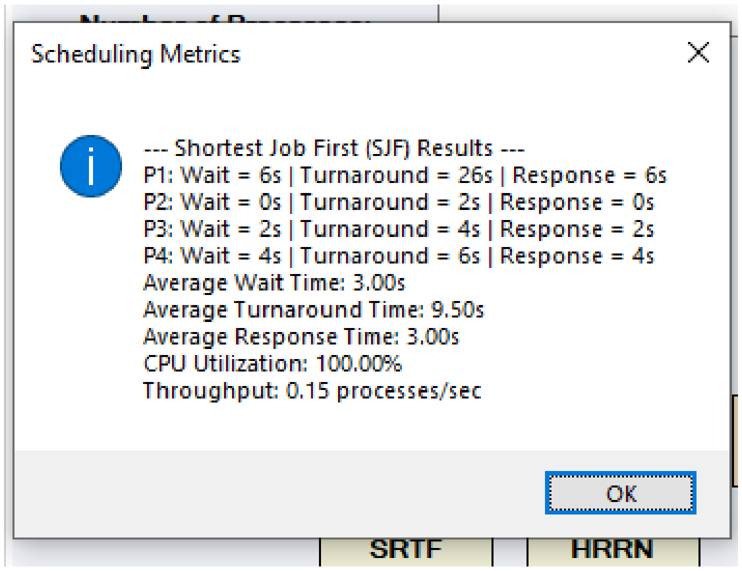
Case: Mixture of Long and Short Bursts
First Come First Serve (FCFS)



```
--- First Come First Serve (FCFS) Results ---
P1: Wait = 0s | Turnaround = 20s | Response = 0s
P2: Wait = 20s | Turnaround = 22s | Response = 20s
P3: Wait = 22s | Turnaround = 24s | Response = 22s
P4: Wait = 24s | Turnaround = 26s | Response = 24s
Average Wait Time: 16.50s
Average Turnaround Time: 23.00s
Average Response Time: 16.50s
CPU Utilization: 100.00%
Throughput: 0.15 processes/sec
```

Figure 13: First Come First Serve (FCFS) - Edge Case Test

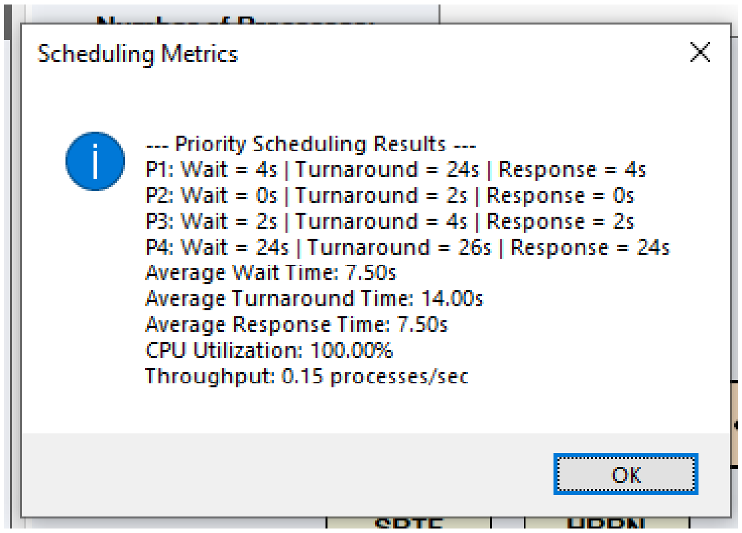
Shortest Job First (SJF)



```
--- Shortest Job First (SJF) Results ---
P1: Wait = 6s | Turnaround = 26s | Response = 6s
P2: Wait = 0s | Turnaround = 2s | Response = 0s
P3: Wait = 2s | Turnaround = 4s | Response = 2s
P4: Wait = 4s | Turnaround = 6s | Response = 4s
Average Wait Time: 3.00s
Average Turnaround Time: 9.50s
Average Response Time: 3.00s
CPU Utilization: 100.00%
Throughput: 0.15 processes/sec
```

Figure 14: Shortest Job First (SJF) - Edge Case Test

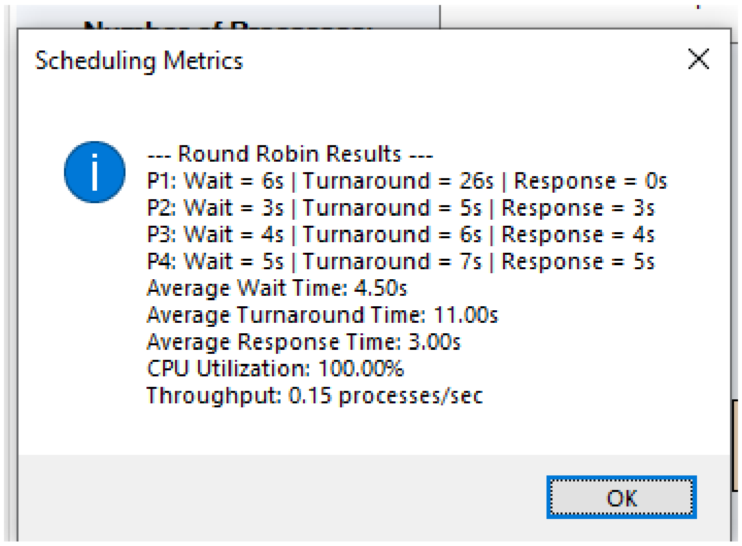
Priority Scheduling



```
--- Priority Scheduling Results ---
P1: Wait = 4s | Turnaround = 24s | Response = 4s
P2: Wait = 0s | Turnaround = 2s | Response = 0s
P3: Wait = 2s | Turnaround = 4s | Response = 2s
P4: Wait = 24s | Turnaround = 26s | Response = 24s
Average Wait Time: 7.50s
Average Turnaround Time: 14.00s
Average Response Time: 7.50s
CPU Utilization: 100.00%
Throughput: 0.15 processes/sec
```

Figure 15: Priority Scheduling - Edge Case Test

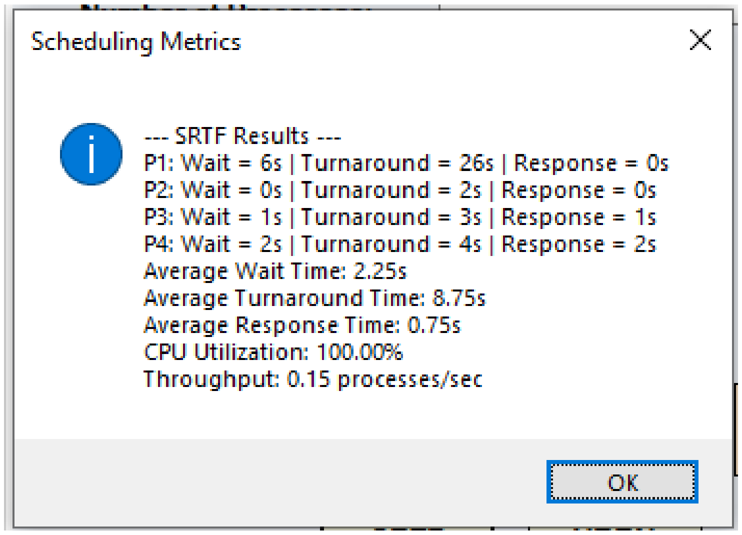
Round Robin (RR)



```
--- Round Robin Results ---
P1: Wait = 6s | Turnaround = 26s | Response = 0s
P2: Wait = 3s | Turnaround = 5s | Response = 3s
P3: Wait = 4s | Turnaround = 6s | Response = 4s
P4: Wait = 5s | Turnaround = 7s | Response = 5s
Average Wait Time: 4.50s
Average Turnaround Time: 11.00s
Average Response Time: 3.00s
CPU Utilization: 100.00%
Throughput: 0.15 processes/sec
```

Figure 16: Round Robin (RR) - Edge Case Test

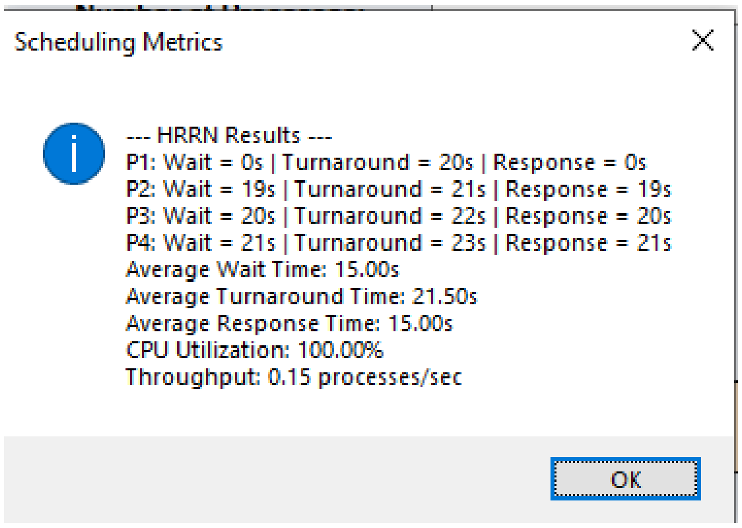
Shortest Remaining Time First (SRTF)



```
--- SRTF Results ---
P1: Wait = 6s | Turnaround = 26s | Response = 0s
P2: Wait = 0s | Turnaround = 2s | Response = 0s
P3: Wait = 1s | Turnaround = 3s | Response = 1s
P4: Wait = 2s | Turnaround = 4s | Response = 2s
Average Wait Time: 2.25s
Average Turnaround Time: 8.75s
Average Response Time: 0.75s
CPU Utilization: 100.00%
Throughput: 0.15 processes/sec
```

Figure 17: Shortest Remaining Time First (SRTF) - Edge Case Test

Highest Response Ratio Next (HRRN)

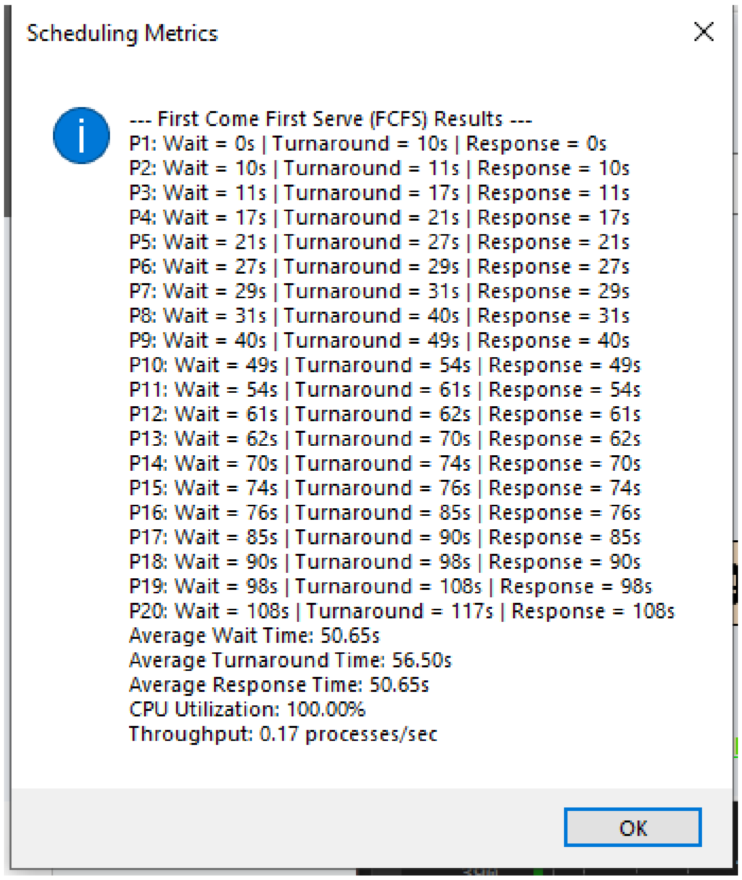


```
--- HRRN Results ---
P1: Wait = 0s | Turnaround = 20s | Response = 0s
P2: Wait = 19s | Turnaround = 21s | Response = 19s
P3: Wait = 20s | Turnaround = 22s | Response = 20s
P4: Wait = 21s | Turnaround = 23s | Response = 21s
Average Wait Time: 15.00s
Average Turnaround Time: 21.50s
Average Response Time: 15.00s
CPU Utilization: 100.00%
Throughput: 0.15 processes/sec
```

Figure 18: Highest Response Ratio Next (HRRN) - Edge Case Test

3.3 Large Scale Random Tests (20 Processes)

First Come First Serve (FCFS)

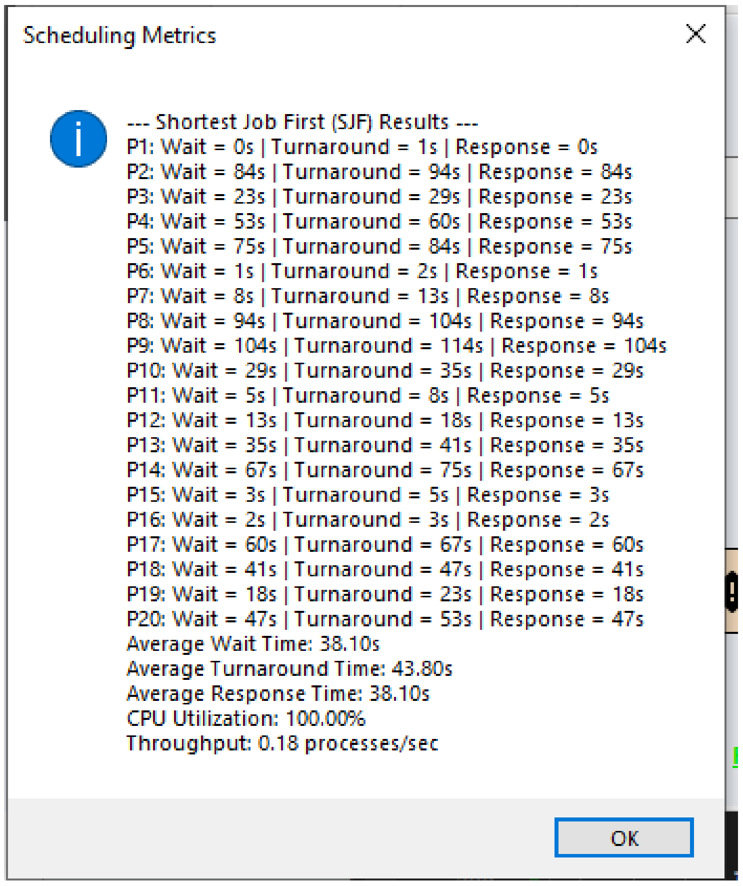


```
Scheduling Metrics

--- First Come First Serve (FCFS) Results ---
P1: Wait = 0s | Turnaround = 10s | Response = 0s
P2: Wait = 10s | Turnaround = 11s | Response = 10s
P3: Wait = 11s | Turnaround = 17s | Response = 11s
P4: Wait = 17s | Turnaround = 21s | Response = 17s
P5: Wait = 21s | Turnaround = 27s | Response = 21s
P6: Wait = 27s | Turnaround = 29s | Response = 27s
P7: Wait = 29s | Turnaround = 31s | Response = 29s
P8: Wait = 31s | Turnaround = 40s | Response = 31s
P9: Wait = 40s | Turnaround = 49s | Response = 40s
P10: Wait = 49s | Turnaround = 54s | Response = 49s
P11: Wait = 54s | Turnaround = 61s | Response = 54s
P12: Wait = 61s | Turnaround = 62s | Response = 61s
P13: Wait = 62s | Turnaround = 70s | Response = 62s
P14: Wait = 70s | Turnaround = 74s | Response = 70s
P15: Wait = 74s | Turnaround = 76s | Response = 74s
P16: Wait = 76s | Turnaround = 85s | Response = 76s
P17: Wait = 85s | Turnaround = 90s | Response = 85s
P18: Wait = 90s | Turnaround = 98s | Response = 90s
P19: Wait = 98s | Turnaround = 108s | Response = 98s
P20: Wait = 108s | Turnaround = 117s | Response = 108s
Average Wait Time: 50.65s
Average Turnaround Time: 56.50s
Average Response Time: 50.65s
CPU Utilization: 100.00%
Throughput: 0.17 processes/sec
```

Figure 19: First Come First Serve (FCFS) - Large Scale Test

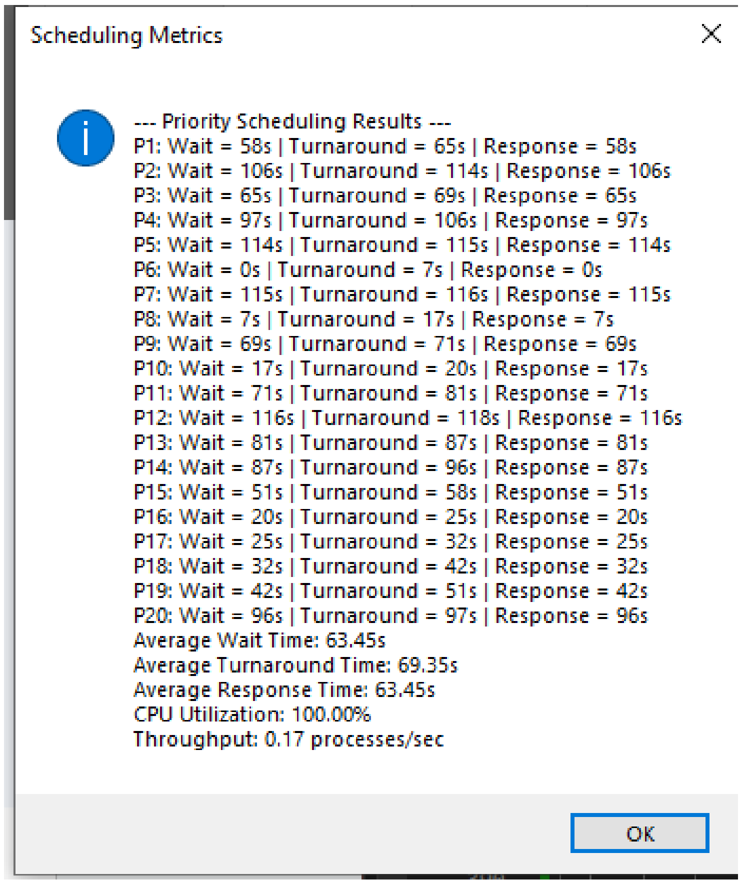
Shortest Job First (SJF)


Scheduling Metrics

```
--- Shortest Job First (SJF) Results ---
P1: Wait = 0s | Turnaround = 1s | Response = 0s
P2: Wait = 84s | Turnaround = 94s | Response = 84s
P3: Wait = 23s | Turnaround = 29s | Response = 23s
P4: Wait = 53s | Turnaround = 60s | Response = 53s
P5: Wait = 75s | Turnaround = 84s | Response = 75s
P6: Wait = 1s | Turnaround = 2s | Response = 1s
P7: Wait = 8s | Turnaround = 13s | Response = 8s
P8: Wait = 94s | Turnaround = 104s | Response = 94s
P9: Wait = 104s | Turnaround = 114s | Response = 104s
P10: Wait = 29s | Turnaround = 35s | Response = 29s
P11: Wait = 5s | Turnaround = 8s | Response = 5s
P12: Wait = 13s | Turnaround = 18s | Response = 13s
P13: Wait = 35s | Turnaround = 41s | Response = 35s
P14: Wait = 67s | Turnaround = 75s | Response = 67s
P15: Wait = 3s | Turnaround = 5s | Response = 3s
P16: Wait = 2s | Turnaround = 3s | Response = 2s
P17: Wait = 60s | Turnaround = 67s | Response = 60s
P18: Wait = 41s | Turnaround = 47s | Response = 41s
P19: Wait = 18s | Turnaround = 23s | Response = 18s
P20: Wait = 47s | Turnaround = 53s | Response = 47s
Average Wait Time: 38.10s
Average Turnaround Time: 43.80s
Average Response Time: 38.10s
CPU Utilization: 100.00%
Throughput: 0.18 processes/sec
```

Figure 20: Shortest Job First (SJF) - Large Scale Test

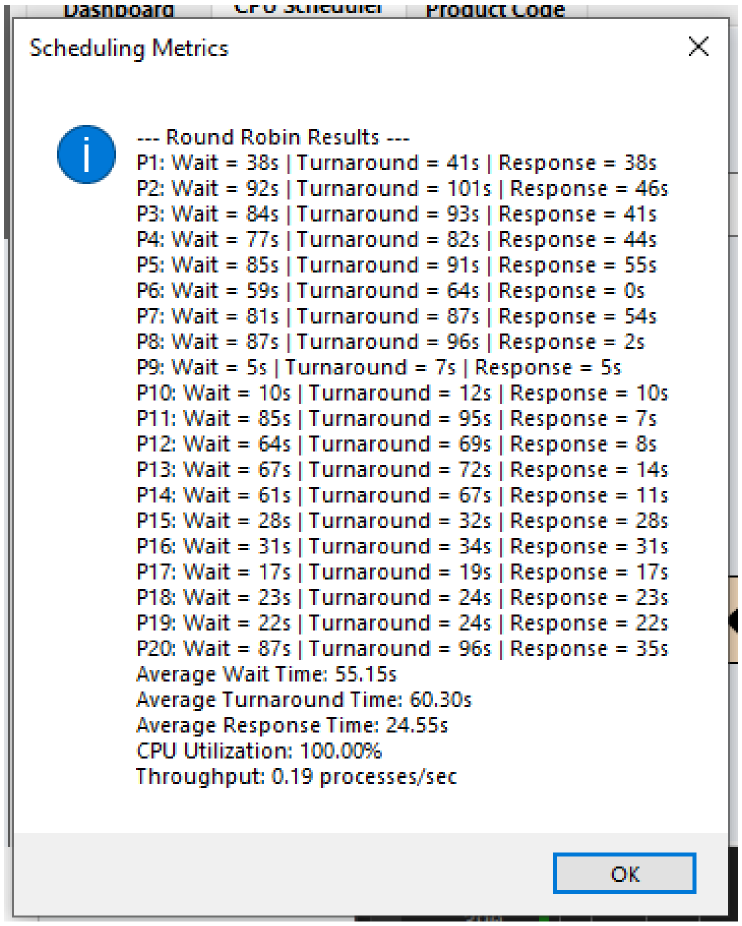
Priority Scheduling



```
--- Priority Scheduling Results ---
P1: Wait = 58s | Turnaround = 65s | Response = 58s
P2: Wait = 106s | Turnaround = 114s | Response = 106s
P3: Wait = 65s | Turnaround = 69s | Response = 65s
P4: Wait = 97s | Turnaround = 106s | Response = 97s
P5: Wait = 114s | Turnaround = 115s | Response = 114s
P6: Wait = 0s | Turnaround = 7s | Response = 0s
P7: Wait = 115s | Turnaround = 116s | Response = 115s
P8: Wait = 7s | Turnaround = 17s | Response = 7s
P9: Wait = 69s | Turnaround = 71s | Response = 69s
P10: Wait = 17s | Turnaround = 20s | Response = 17s
P11: Wait = 71s | Turnaround = 81s | Response = 71s
P12: Wait = 116s | Turnaround = 118s | Response = 116s
P13: Wait = 81s | Turnaround = 87s | Response = 81s
P14: Wait = 87s | Turnaround = 96s | Response = 87s
P15: Wait = 51s | Turnaround = 58s | Response = 51s
P16: Wait = 20s | Turnaround = 25s | Response = 20s
P17: Wait = 25s | Turnaround = 32s | Response = 25s
P18: Wait = 32s | Turnaround = 42s | Response = 32s
P19: Wait = 42s | Turnaround = 51s | Response = 42s
P20: Wait = 96s | Turnaround = 97s | Response = 96s
Average Wait Time: 63.45s
Average Turnaround Time: 69.35s
Average Response Time: 63.45s
CPU Utilization: 100.00%
Throughput: 0.17 processes/sec
```

Figure 21: Priority Scheduling - Large Scale Test

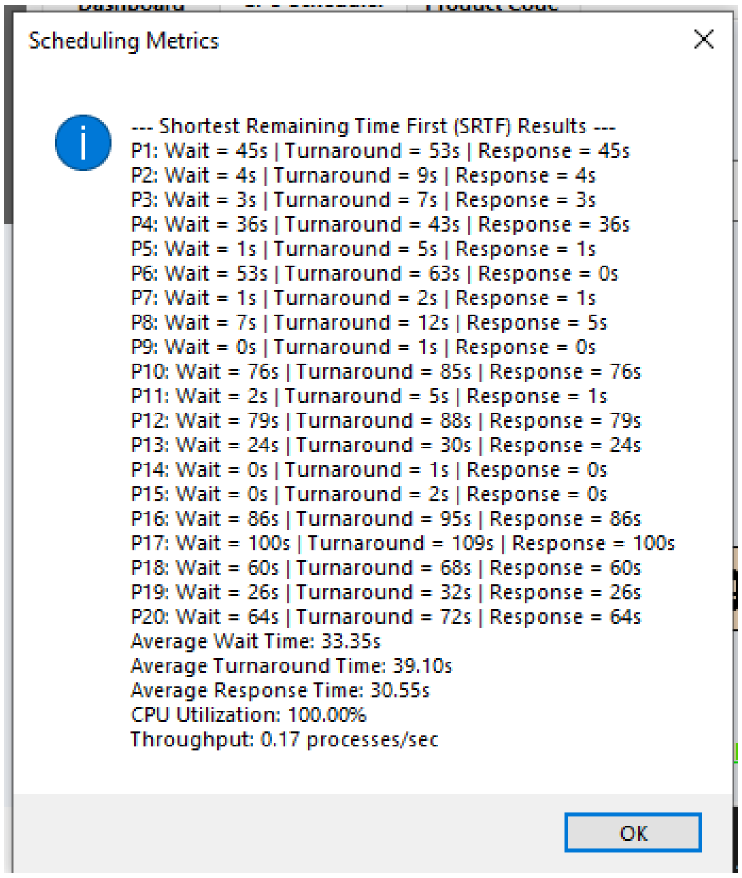
Round Robin (RR)



```
--- Round Robin Results ---
P1: Wait = 38s | Turnaround = 41s | Response = 38s
P2: Wait = 92s | Turnaround = 101s | Response = 46s
P3: Wait = 84s | Turnaround = 93s | Response = 41s
P4: Wait = 77s | Turnaround = 82s | Response = 44s
P5: Wait = 85s | Turnaround = 91s | Response = 55s
P6: Wait = 59s | Turnaround = 64s | Response = 0s
P7: Wait = 81s | Turnaround = 87s | Response = 54s
P8: Wait = 87s | Turnaround = 96s | Response = 2s
P9: Wait = 5s | Turnaround = 7s | Response = 5s
P10: Wait = 10s | Turnaround = 12s | Response = 10s
P11: Wait = 85s | Turnaround = 95s | Response = 7s
P12: Wait = 64s | Turnaround = 69s | Response = 8s
P13: Wait = 67s | Turnaround = 72s | Response = 14s
P14: Wait = 61s | Turnaround = 67s | Response = 11s
P15: Wait = 28s | Turnaround = 32s | Response = 28s
P16: Wait = 31s | Turnaround = 34s | Response = 31s
P17: Wait = 17s | Turnaround = 19s | Response = 17s
P18: Wait = 23s | Turnaround = 24s | Response = 23s
P19: Wait = 22s | Turnaround = 24s | Response = 22s
P20: Wait = 87s | Turnaround = 96s | Response = 35s
Average Wait Time: 55.15s
Average Turnaround Time: 60.30s
Average Response Time: 24.55s
CPU Utilization: 100.00%
Throughput: 0.19 processes/sec
```

Figure 22: Round Robin (RR) - Large Scale Test

Shortest Remaining Time First (SRTF)

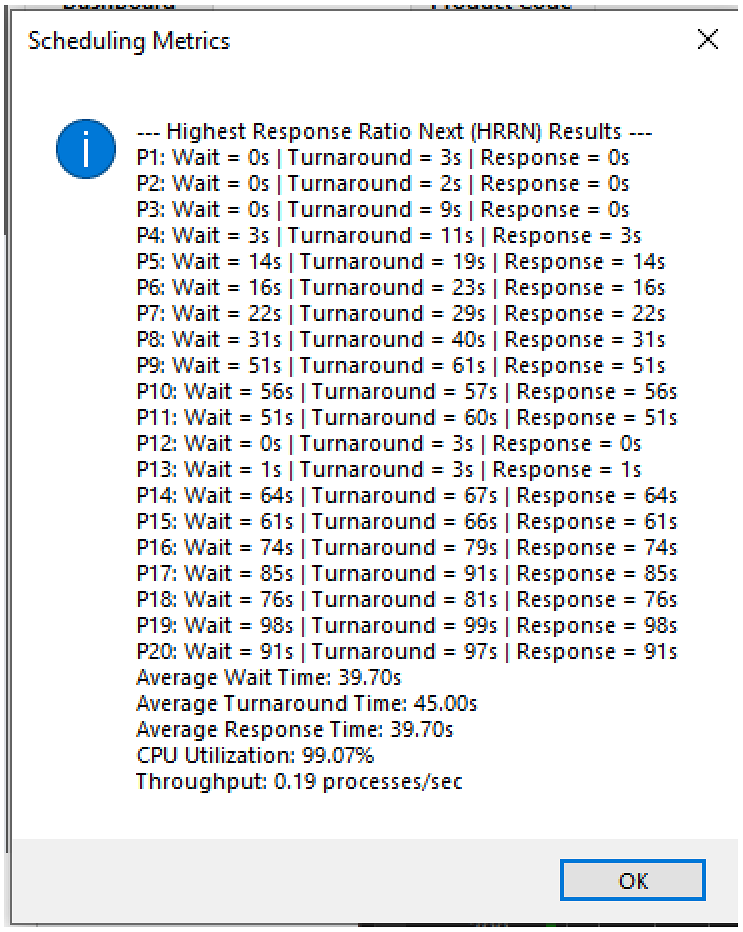


Scheduling Metrics

```
--- Shortest Remaining Time First (SRTF) Results ---
P1: Wait = 45s | Turnaround = 53s | Response = 45s
P2: Wait = 4s | Turnaround = 9s | Response = 4s
P3: Wait = 3s | Turnaround = 7s | Response = 3s
P4: Wait = 36s | Turnaround = 43s | Response = 36s
P5: Wait = 1s | Turnaround = 5s | Response = 1s
P6: Wait = 53s | Turnaround = 63s | Response = 0s
P7: Wait = 1s | Turnaround = 2s | Response = 1s
P8: Wait = 7s | Turnaround = 12s | Response = 5s
P9: Wait = 0s | Turnaround = 1s | Response = 0s
P10: Wait = 76s | Turnaround = 85s | Response = 76s
P11: Wait = 2s | Turnaround = 5s | Response = 1s
P12: Wait = 79s | Turnaround = 88s | Response = 79s
P13: Wait = 24s | Turnaround = 30s | Response = 24s
P14: Wait = 0s | Turnaround = 1s | Response = 0s
P15: Wait = 0s | Turnaround = 2s | Response = 0s
P16: Wait = 86s | Turnaround = 95s | Response = 86s
P17: Wait = 100s | Turnaround = 109s | Response = 100s
P18: Wait = 60s | Turnaround = 68s | Response = 60s
P19: Wait = 26s | Turnaround = 32s | Response = 26s
P20: Wait = 64s | Turnaround = 72s | Response = 64s
Average Wait Time: 33.35s
Average Turnaround Time: 39.10s
Average Response Time: 30.55s
CPU Utilization: 100.00%
Throughput: 0.17 processes/sec
```

Figure 23: Shortest Remaining Time First (SRTF) - Large Scale Test

Highest Response Ratio Next (HRRN)



Scheduling Metrics

```
--- Highest Response Ratio Next (HRRN) Results ---
P1: Wait = 0s | Turnaround = 3s | Response = 0s
P2: Wait = 0s | Turnaround = 2s | Response = 0s
P3: Wait = 0s | Turnaround = 9s | Response = 0s
P4: Wait = 3s | Turnaround = 11s | Response = 3s
P5: Wait = 14s | Turnaround = 19s | Response = 14s
P6: Wait = 16s | Turnaround = 23s | Response = 16s
P7: Wait = 22s | Turnaround = 29s | Response = 22s
P8: Wait = 31s | Turnaround = 40s | Response = 31s
P9: Wait = 51s | Turnaround = 61s | Response = 51s
P10: Wait = 56s | Turnaround = 57s | Response = 56s
P11: Wait = 51s | Turnaround = 60s | Response = 51s
P12: Wait = 0s | Turnaround = 3s | Response = 0s
P13: Wait = 1s | Turnaround = 3s | Response = 1s
P14: Wait = 64s | Turnaround = 67s | Response = 64s
P15: Wait = 61s | Turnaround = 66s | Response = 61s
P16: Wait = 74s | Turnaround = 79s | Response = 74s
P17: Wait = 85s | Turnaround = 91s | Response = 85s
P18: Wait = 76s | Turnaround = 81s | Response = 76s
P19: Wait = 98s | Turnaround = 99s | Response = 98s
P20: Wait = 91s | Turnaround = 97s | Response = 91s
Average Wait Time: 39.70s
Average Turnaround Time: 45.00s
Average Response Time: 39.70s
CPU Utilization: 99.07%
Throughput: 0.19 processes/sec
```

Figure 24: Highest Response Ratio Next (HRRN) - Large Scale Test

4 Analysis and Discussion

4.1 Basic Functionality Analysis (Small Sample Analysis)

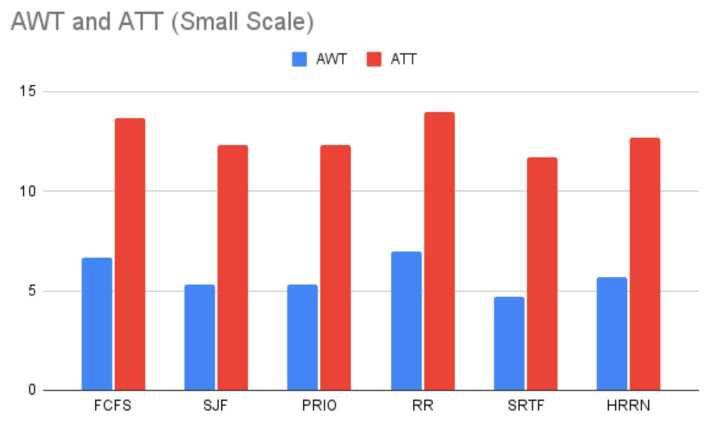


Figure 25: Average Waiting Time (AWT) and Average Turnaround Time (ATT) Comparison for Large-Scale Test

In the small-scale tests involving three processes, our algorithms were fed the exact same burst times, arrival times, etc. and acted as would be predicted. Shortest Remaining Time First (SRTF) consistently produced the lowest Average Waiting Time (4.67s) and Average Turnaround Time (11.67s) because it always selected the process with the least remaining CPU burst time. Highest Response Ratio Next (HRRN) also performed well, balancing waiting time and service time effectively (AWT = 5.67s ATT = 11.67s).

First Come First Serve (FCFS) resulted in higher waiting (6.67s) and turnaround times (13.67s) due to its non-preemptive, strictly arrival-based execution. Priority scheduling acted in a similar fashion, showing varied results depending on how priority levels aligned with burst lengths.

Round Robin (RR), using a quantum of 4, provided moderate waiting times but introduced frequent context switches, slightly inflating turnaround time compared to SJF and SRTF.

Overall, SRTF performed the best in small-scale environments, minimizing both AWT and ATT.

4.2 Large Scale Random Test Analysis (20 Processes)

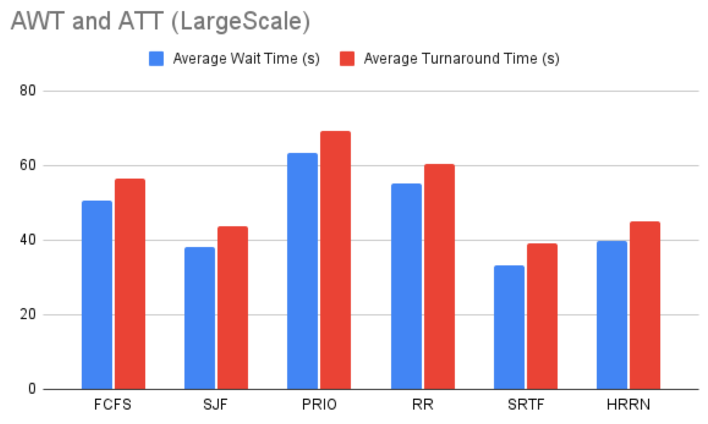


Figure 26: Average Waiting Time (AWT) and Average Turnaround Time (ATT) Comparison for Large-Scale Test

In the large-scale tests involving twenty randomly generated processes, Shortest Remaining Time First (SRTF) again produced the lowest Average Waiting Time (33.35s) and Average Turnaround Time (39.10s). This was expected, as SRTF continuously selects the process with the least remaining work.

Highest Response Ratio Next (HRRN) also performed well (AWT = 39.70s ATT = 45s). Priority Scheduling's results varied significantly, depending on the alignment between process priorities and burst durations.

First Come First Serve (AWT = 50.65s ATT = 56.50) and Round Robin (AWT = 55.15s ATT = 60.30s) generally showed higher waiting and turnaround times in the large-scale setting, as they lack dynamic burst time awareness.

Throughput remained relatively consistent across algorithms, but SRTF and HRRN slightly edged out others due to better CPU utilization efficiency.

Based on overall performance, SRTF remains the most effective scheduling method in both small and large-scale environments.

4.3 Edge Case Test Analysis (4 Processes)

Edge Case 1: Identical Burst Times

In the identical burst time scenario, all processes had the same execution length, eliminating burst-based scheduling advantages. As a result, First Come First Serve (FCFS), Shortest Job First (SJF), and Shortest Remaining Time First (SRTF) produced very similar Average Waiting Time and Average Turnaround Time values. Priority Scheduling slightly improved performance when priorities aligned favorably, while Round Robin (RR) was more inefficient due to context switching. Overall, differences between algorithms were minimal in this case because no process had a clear advantage based on burst length.

Edge Case 2: One Long Burst and Several Small Bursts

In the mixed burst scenario, scheduling algorithms that favored shorter jobs significantly outperformed those that did not. Shortest Job First (SJF) and Shortest Remaining Time First (SRTF) excelled by immediately prioritizing small burst processes, minimizing overall waiting times. First Come First Serve (FCFS) performed poorly, as the initial long burst blocked the CPU and delayed all shorter processes. Priority Scheduling results varied depending on how priorities were assigned. Round Robin (RR) moderately alleviated long waits, but context switching still added inefficiency. This edge case clearly demonstrates the need for preemptive and burst-aware scheduling algorithms.

Edge Case 3: Skewed Priorities

Naturally in the skewed priority scenario, Priority Scheduling showed the greatest variation in performance. Processes with high priority but large burst times could delay lower-priority, shorter jobs, negatively impacting overall efficiency. Algorithms like Shortest Remaining Time First (SRTF) and Highest Response Ratio Next (HRRN), which do not rely on static priority, maintained better Average Waiting Time and Turnaround Time values by dynamically adapting to system conditions. Round Robin (RR) and First Come First Serve (FCFS) offered consistent but suboptimal results, unaffected by priority.

5 Challenges and Lessons Learned

One of the main challenges encountered was implementing the preemptive logic required for Shortest Remaining Time First (SRTF). Correctly tracking remaining burst times, handling frequent process switching, and ensuring that newly arriving processes preempted ongoing ones without introducing timing errors required careful planning and repeated testing.

Another challenge was calculating and managing the Highest Response Ratio Next (HRRN) priorities dynamically based on real-time system states. Correctly updating response ratios as waiting times changed was crucial to avoid errors in scheduling.

Beyond algorithm logic, refactoring the existing system to uniformly display key performance metrics across all algorithms proved challenging. Creating a flexible, reusable metrics module required restructuring how results were gathered.

Lessons I learned via this assignment include a deeper appreciation for the necessity and complexity of preemptive scheduling, the importance of clear time management within simulations, and the value of building modular code to improve future maintainability and testing efficiency.

6 Conclusion

This project provided practical experience in implementing and evaluating CPU scheduling algorithms within a simulated environment. By developing Shortest Remaining Time First (SRTF) and Highest Response Ratio Next (HRRN) scheduling methods, and by enhancing the metrics reporting methods, the simulator was able to produce consistent, useful performance results across a variety of workloads.

Empirical testing demonstrated that preemptive, burst-aware strategies such as SRTF consistently has smaller Average Waiting Time (AWT) and Average Turnaround Time (ATT), while non-preemptive algorithms like First Come First Serve (FCFS) exhibited higher delays under most conditions. Highest Response Ratio Next (HRRN) also performed competitively, particularly in environments with diverse burst times and arrival patterns.

The final recommendation based on testing outcomes is that SRTF should be adopted when minimizing response and turnaround times is the primary system goal. In contrast, HRRN offers a strong alternative when fairness and starvation prevention are critical considerations.

Overall, this project strengthened understanding of scheduling, the workings of the operating system, preemptive system behavior, and the importance of designing simulation tools.

References

[1] CS 3502 - Operating Systems, *Project 2: CPU Scheduling Simulation*, Department of Computer Science, Kennesaw State University, 2025.