4001 Assignment 3 Part 1 Report
Concurrency, Shared Memory, Virtual Memory, Files

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Github Repo: https://github.com/AC0406/SYSC4001_A3_P1/tree/main

INTRODUCTION

This report presents the results and analysis of a comprehensive scheduler simulation study comparing three scheduling algorithms: External Priority (EP), Round Robin (RR), and a hybrid External Priority with Round Robin (EP_RR). The simulation was executed across 22 distinct test scenarios, encompassing CPU-bound, I/O-bound, and mixed workload characteristics to evaluate scheduler performance under varying conditions.

The key performance metrics evaluated include:
• Throughput: Number of processes completed per unit time
• Average Wait Time: Time processes spend in the ready queue
• Average Turnaround Time: Total time from arrival to completion
• Average Response Time: Time from arrival to first execution

METHODOLOGY

Test Scenario Design:
A total of 22 test scenarios were designed and executed for each scheduler:
• 7 CPU-bound scenarios: High CPU time (200-500ms), minimal I/O operations
• 7 I/O-bound scenarios: Lower CPU time (50-150ms), frequent I/O (every 10-30ms)
• 8 Mixed scenarios: Balanced CPU (100-300ms) and I/O characteristics

Each scenario varied in:
- Number of processes (3-12 processes)
- CPU burst times
- I/O frequency and duration
- Process arrival patterns

Memory Management:
All simulations utilized fixed memory partitions (40MB, 25MB, 15MB, 10MB, 8MB, 2MB) with best-fit allocation strategy. Processes were assigned memory upon arrival and released upon termination.

SIMULATION RESULTS

Summary Statistics by Workload Type and Scheduler:

CPU-BOUND WORKLOADS:

Scheduler	Throughput	Avg Wait (ms)	Avg Turnaround (ms)	Avg Response (ms)
EP	0.0100	115.60	483.98	92.48
EP_RR	0.0100	146.68	520.45	33.00
RR	0.0100	440.49	816.05	120.86

I/O-BOUND WORKLOADS:

Scheduler	Throughput	Avg Wait (ms)	Avg Turnaround (ms)	Avg Response (ms)
EP	0.0100	423.77	721.21	381.39
EP_RR	0.0200	156.40	453.83	18.29
RR	0.0100	206.29	503.72	113.29

MIXED WORKLOADS:

Scheduler	Throughput	Avg Wait (ms)	Avg Turnaround (ms)	Avg Response (ms)
EP	0.0100	351.00	537.06	298.35
EP_RR	0.0200	339.60	527.03	33.62
RR	0.0100	432.44	619.87	123.38

DETAILED ANALYSIS

1. CPU-BOUND PROCESSES

External Priority (EP) Performance:
EP demonstrated the best performance for CPU-bound workloads with the lowest average wait time (115.60ms) and turnaround time (483.98ms). The non-preemptive nature of EP allows CPU-bound processes to run to completion without interruption, minimizing context switching overhead. However, response time was moderate

(92.48ms) as lower-priority processes must wait for higher-priority processes to complete.

Round Robin (RR) Performance:
RR showed significantly worse performance for CPU-bound processes, with average wait time of 440.49ms and turnaround time of 816.05ms - nearly double that of EP. The 100ms time quantum caused excessive context switching for processes with long CPU bursts (200-500ms), resulting in high overhead. Each process experienced multiple quantum expirations before completion, degrading overall efficiency.

EP_RR Hybrid Performance:
The hybrid scheduler balanced both approaches, showing wait times (146.68ms) slightly higher than EP but maintaining excellent response time (33.00ms) due to preemption capabilities. The 100ms quantum was sufficiently large to reduce context switching overhead while still providing responsiveness.

Key Finding: For CPU-bound workloads, non-preemptive priority scheduling (EP) minimizes overhead and provides best throughput, while RR's frequent preemption significantly degrades performance.

2. I/O-BOUND PROCESSES

External Priority (EP) Performance:
EP performed poorly with I/O-bound processes, showing the highest wait time (423.77ms) and response time (381.39ms). Without preemption, lower-priority I/O-bound processes were blocked by higher-priority processes, even when the CPU could be utilized during I/O waits. This led to poor CPU utilization and process starvation.

Round Robin (RR) Performance:
RR showed moderate performance with wait time of 206.29ms and turnaround time of 503.72ms. The time-sharing nature allowed I/O-bound processes to quickly execute their short CPU bursts and initiate I/O operations, improving CPU utilization. However, the fixed 100ms quantum was larger than needed for processes with 50-150ms total CPU time.

EP_RR Hybrid Performance:
EP_RR excelled with I/O-bound workloads, achieving the best throughput (0.02) and dramatically lower wait (156.40ms) and response times (18.29ms). The combination of priority-based scheduling with preemption allowed high-priority I/O-bound processes to preempt CPU-bound processes, maximizing CPU utilization during I/O operations. The scheduler effectively interleaved process execution

around I/O operations.

Key Finding: I/O-bound processes benefit significantly from preemptive scheduling. EP_RR's ability to preempt for higher-priority I/O operations resulted in 2x throughput improvement over other schedulers.

3. MIXED WORKLOADS

External Priority (EP) Performance:
EP showed moderate performance with mixed workloads (wait: 351.00ms, turnaround: 537.06ms). The algorithm handled heterogeneous processes reasonably well when priority assignments aligned with process characteristics, but lacked flexibility to adapt to varying execution patterns.

Round Robin (RR) Performance:
RR exhibited the highest wait time (432.44ms) and turnaround time (619.87ms) for mixed workloads. While providing fairness, the fixed quantum size was suboptimal for both long-running CPU-bound processes (causing excessive context switches) and short I/O-bound processes (causing unnecessary delays).

EP_RR Hybrid Performance:
EP_RR demonstrated superior performance with best throughput (0.02), competitive wait time (339.60ms), lowest turnaround time (527.03ms), and excellent response time (33.62ms). The hybrid approach leveraged priority for process importance while using preemption and time-slicing to maintain responsiveness and fairness.

Key Finding: Mixed workloads benefit most from hybrid scheduling approaches that combine multiple strategies to adapt to varying process characteristics.

COMPARATIVE ANALYSIS

Response Time Comparison:
EP_RR consistently provided the best response times across all workload types (18.29-33.62ms range), making it ideal for interactive systems requiring quick initial response. EP showed high variance in response time depending on priority assignments, while RR maintained moderate but consistent response times.

Wait Time and Turnaround Time:
For CPU-bound workloads, EP minimized both metrics through reduced context switching. For I/O-bound and mixed workloads, EP_RR achieved the best results by intelligently interleaving process execution. RR consistently showed the highest wait and turnaround times due to context switching overhead.

Throughput Analysis:
EP_RR achieved highest throughput (0.02) for I/O-bound and mixed workloads, representing a 2x improvement over EP and RR. For CPU-bound workloads, all schedulers showed similar throughput (0.01), as the bottleneck was CPU time rather than scheduling efficiency.

Context Switching Overhead:
EP incurred minimal context switching overhead, occurring only at process completion or I/O operations. RR experienced maximum overhead with context switches every 100ms regardless of process state. EP_RR balanced overhead by preempting only when higher-priority processes arrived or quantum expired.

SCHEDULER-SPECIFIC OBSERVATIONS

External Priority (EP):
Strengths:
• Minimal overhead for CPU-bound processes
• Predictable behavior based on priorities
• Low context switching frequency
• Best performance for compute-intensive workloads

Weaknesses:
• Poor handling of I/O-bound processes
• Potential for process starvation
• High response time variance
• Inflexible to changing workload patterns

Best Use Cases: Batch processing systems, scientific computing, compilation tasks

Round Robin (RR):
Strengths:
• Fair CPU allocation among processes
• Guaranteed response time bounds
• Good for interactive workloads
• Prevents process starvation

Weaknesses:
• High context switching overhead
• Poor throughput for CPU-bound processes
• Fixed quantum may be suboptimal
• Treats all processes equally regardless of importance

Best Use Cases: Time-sharing systems, interactive applications, general-purpose OS

External Priority + Round Robin (EP_RR):
Strengths:
• Excellent response times across all workloads
• Highest throughput for I/O-bound processes
• Adapts to workload heterogeneity
• Balances efficiency and fairness

Weaknesses:
• More complex implementation
• Requires careful priority assignment
• Moderate context switching overhead
• Priority inversion possible without mitigation

Best Use Cases: Modern multi-user systems, real-time systems with mixed priorities, enterprise servers

CONCLUSIONS

This simulation study demonstrates that scheduler selection significantly impacts system performance, with optimal choice dependent on workload characteristics:

1. CPU-Bound Workloads: External Priority (EP) scheduler provides best performance by minimizing context switching overhead. Non-preemptive execution allows processes to complete CPU bursts efficiently.

2. I/O-Bound Workloads: The hybrid EP_RR scheduler excels by combining priority-based scheduling with preemption, achieving 2x throughput improvement through better CPU utilization during I/O waits.

3. Mixed Workloads: EP_RR offers the best overall performance, providing flexibility to handle varying process types while maintaining low response times and high throughput.

4. Context Switching Impact: Excessive context switching in RR significantly degrades performance for CPU-intensive tasks, with turnaround times nearly double those of EP for CPU-bound workloads.

5. Preemption Benefits: Preemptive scheduling proves crucial for I/O-bound processes, enabling efficient CPU utilization during I/O operations.

6. Response Time vs. Throughput Trade-off: EP_RR successfully balances quick response times with high throughput, while EP optimizes throughput at the expense of response time variance, and RR prioritizes fairness over efficiency.

The simulation results validate theoretical scheduling concepts and demonstrate that modern operating systems benefit from sophisticated hybrid scheduling approaches that adapt to workload diversity. For general-purpose systems handling mixed workloads, the EP_RR hybrid scheduler offers the most balanced and effective performance profile.

RECOMMENDATIONS FOR SCHEDULER SELECTION

- Batch Processing Systems: Use EP for maximum throughput with CPU-bound tasks
- Interactive Systems: Use RR or EP_RR for predictable response times
- Real-Time Systems: Use EP_RR with carefully assigned priorities
- I/O-Intensive Applications: Use EP_RR to maximize CPU utilization
- General-Purpose OS: Use EP_RR for balanced performance across workload types

Future work could explore dynamic priority adjustment, adaptive quantum sizing, and multi-level feedback queue approaches to further optimize scheduler performance across diverse workload conditions.