CPU Scheduler Program: FCFS, SJF and MLFQ

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Introduction

The goal of this programming assignment is to gain hands-on experience and a deeper insight into common CPU schedulers: First come first serve, shortest job first and multi-level feedback queue. First come first serve (FCFS) is a common technique used by programmers where the first process to arrive in the ready queue will be the first process to be dispatched onto the processor. This is a non-preemptive approach, meaning the processes on the processor will not be interrupted from completing their CPU burst. Shortest job first (SJF) is also a non-preemptive scheduling algorithm where the process with the shortest CPU burst, among the ready queue, is selected for dispatch. In multi-level feedback queue, processes are given priority queues that determine which type of algorithm it will be adhering to (FCFS, SJF, round robin, etc.). This is a preemptive technique and processes can migrate to lesser queue levels, for example, if a process with a current round robin queue level reaches its designated time quantum.

The three algorithms were designed in a C++ simulation code where the wait time, turnaround time, response time and CPU utilization is measured so the algorithms can be compared and contrasted with one another. It is expected that each of the algorithms will have their own strengths and weakness when it comes to wait time, turnaround time, response time and CPU utilization.

Implementation Plan

The initial implementation plan remained intact throughout the writing of both the FCFS and MLFQ algorithms. As previously described, each process was represented by a node of a singly linked list containing the following information:

1. The process number (1-9)
2. An array of CPU bursts
3. An array of IO times
4. An integer representing the accumulated wait time
5. An integer representing the accumulated I/O time
6. An integer representing the accumulated CPU time
7. A pointer to the next node in the list
8. An integer representing queue priority (MLFQ only)

Four linked lists were declared: Executing, Ready, I/O and Complete (Three ready queues for MLFQ). Process nodes were moved from list to list as they would move from processor to I/O to ready. When each node had completed all of its I/O time and CPU bursts, it was moved to the complete list.

The preliminary plan for the FCFS algorithm did not change, as can be seen below.

* 1. Load and initialize all process data, insert nodes into ready queue
  2. If process in executing list has completed CPU burst, move process to IO list
  3. Check each node in IO list for remaining IO time
  4. If IO time is zero, move process node to end of ready queue
  5. If executing list is now empty, dispatch front node of ready queue to executing list
  6. Decrement time from CPU burst on the executing list, increment its time on processor
  7. Decrement time from remaining IO time for all process nodes in IO list, increment each of their times while in IO
  8. Increment the waiting time and response time (for processes not yet on processor) for each process node in the ready queue
  9. If context switch occurred (process node left and/or came into the executing list) print current information
  10. Repeat until the executing, ready and IO lists are all empty
  11. Calculate and print WT, TT and RT from the nodes in the complete list

For the MLFQ algorithm, the preliminary plan only changed with the order of operations where the time quantum and preemption maintenance now come before dispatching a new process node into the executing list.

1. Load and initialize all process data, insert nodes into first ready queue
2. If process in executing list has completed CPU burst, move process to IO list
3. Check each node in IO list for remaining IO time
4. If IO time is zero, move process node to end of designated ready queue (determined by priority queue)
5. Checks process node in executing list for time quantum and preemption from higher priority ready queues.
6. If executing list is now empty, dispatch front node of priority 1 ready queue (if priority 1 empty, move to priority, if priority 2 empty move to priority 3) to executing list
7. Decrement time from CPU burst on the executing list, increment its time on processor
8. Decrement time from remaining IO time for all process nodes in IO list, increment each of their times while in IO
9. Increment the waiting time for each process node in the ready queues
10. If contest switch occurred (process node left and/or came into the executing list) print current information
11. Repeat until the executing, ready and IO lists are all empty
12. Calculate and print WT, TT and RT from the nodes in the complete list

Discussion

Comparing the FCFS, SJF and MLFQ algorithms, the simulation results give a mixed view in that each of the algorithms have their own strengths and weaknesses. When it comes to CPU utilization, which is the amount of time the processor is in use as opposed to sitting idle (Silberschatz, Galvin and Gagne, 2013), FCFS was the strongest with a utilization of 94.66%. MLFQ was the next most efficient with CPU utilization at 89.75% and SJF was the most inefficient with only 77.84% CPU utilization. CPU utilization is an important factor when choosing a CPU scheduler algorithm so a programmer can ensure that the CPU is doing the maximum amount of processing in a given time, rather than sitting idle while there are processes to process.

Another factor to consider is wait time, which is the amount of time that a process must spend in the ready queue waiting to be dispatched onto the processor (Silberschatz, Galvin and Gagne, 2013). SJF averaged the shortest wait time of 205.667 time units for its nine processes. MLFQ averaged a waiting time of 260 time units while FCFS averaged a wait time of 312.778 time units. Generally speaking, the less time processes have to sit in the ready queue waiting to be dispatched onto the process, the more efficient the scheduling algorithm is. It is desired that processes get dispatched onto the processer and complete their CPU bursts in as timely a fashion as possible so the program can continue functioning. The longer a process must wait in the ready queue, the larger the delay for the process to move on. In this case, SJF was the most efficient of the three algorithms as its processes spent the least amount of idle time while waiting for their turn on the processor.

Response time is the time it takes for a process to make it onto the processor for the first time measured from the time of admittance to the ready queue (Silberschatz, Galvin and Gagne, 2013). In this simulation, MLFQ had the shortest average response time of 25.556 time units. FCFS had an average response time of 53.222 time units while SJF had the longest response time of 122.333 time units. MLFQ is clearly the most efficient of the algorithms when it comes to dispatching the processes onto the processor for the first time as quickly as possible. This is most likely due to the nature of MLFQ. Its top queue priority was a round robin design with a time quantum of 7. This means that when all the processes entered the ready queue at the same time, all process only received a maximum of 7 time units on the processor before they were removed from the processor. This allowed other processes to move onto the processor without having to wait for a long time (a maximum of 63 time units or less, depending on the length of CPU bursts). In this case, MLFQ is quite efficient in getting processes onto the processor for their first CPU burst.

Finally, turnaround time, which is the time it takes from admittance into the ready queue to time of completion, is another important measurement programmers must consider when choosing a CPU scheduler algorithm (Silberschatz, Galvin and Gagne, 2013). In this simulation, SJF had the most efficient turnaround time, as it, on average, took 542.444 time units for a process to complete all of its CPU bursts and I/O times. Comparatively, MLFQ had an average turnaround time of 596.778 time units and FCFS had an average turnaround time of 649.556 time units. SJF was most likely able to have such a short turnaround time because it allowed the processes with the shortest CPU bursts to take priority with the processor, thus being able to complete their CPU bursts in a minimum amount of time. The down side to SJF is that processes with longer CPU bursts can spend long periods waiting in the ready queue causing starvation (Silberschatz, Galvin and Gagne, 2013). Evidence of this can be seen in the variance of turnaround times in SJF, where Process 9 had the shortest turnaround time at 346 time units and Process 8 had the largest with 889 time units. Neither FCFS nor MLFQ had this large a difference between their min and max turnaround times.

In conclusion, it is difficult to say which CPU scheduling algorithm is the best because that depends on the needs of the programmer and the user. Different situations may call for different algorithms. However, MLFQ stands out as being unique because priorities can be assigned to processes, making it possible to implement any scheduling algorithms (SCF, FCFS, etc.) into the overall MLFQ scheduling algorithm. This offers a great deal of flexibility allowing a programmer to not just choose 1 scheduling algorithm but a multitude of algorithms of varying conditions (RR with tq3, SJF, RR with tq8, FCFS, etc.) to suit his or her needs.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | First Come First Serve (FCFS) | | | | Shortest Job First (SJF) | | | | Multi-Level Feedback Queue (MLFQ) | | | |
|  | WT | TT | RT | CPU (%) | WT | TT | RT | CPU (%) | WT | TT | RT | CPU (%) |
| **P1** | 232 | 577 | 0 | 94.66% | 109 | 454 | 19 | 77.84% | 341 | 686 | 0 | 89.75% |
| **P2** | 267 | 629 | 12 | 238 | 600 | 31 | 359 | 721 | 7 |
| **P3** | 274 | 566 | 30 | 233 | 525 | 130 | 412 | 704 | 14 |
| **P4** | 302 | 691 | 51 | 70 | 459 | 7 | 124 | 513 | 21 |
| **P5** | 326 | 652 | 56 | 166 | 492 | 3 | 138 | 464 | 26 |
| **P6** | 361 | 657 | 60 | 65 | 361 | 12 | 36 | 332 | 30 |
| **P7** | 330 | 662 | 67 | 424 | 756 | 407 | 318 | 650 | 37 |
| **P8** | 343 | 731 | 89 | 501 | 889 | 492 | 383 | 771 | 44 |
| **P9** | 380 | 681 | 114 | 45 | 346 | 0 | 229 | 530 | 51 |
| **Average** | 312.778 | 649.556 | 53.222 |  | 205.667 | 542.444 | 122.333 |  | 260 | 596.778 | 25.556 |  |

Figure 1: Scheduling Algorithms Chart

Figure 2: CPU Scheduler Comparison

**Program Output**

**FCFS**

Current Time: 0

Now running: P1

......................................................

Ready Queue: Process Burst

P2 18

P3 21

P4 5

P5 4

P6 7

P7 22

P8 25

P9 3

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

......................................................

......................................................

Current Time:12

Now running: P2

......................................................

Ready Queue: Process Burst

P3 21

P4 5

P5 4

P6 7

P7 22

P8 25

P9 3

......................................................

Now in I/O: Process Remaining I/O time

P1 44

......................................................

......................................................

......................................................

Current Time:30

Now running: P3

......................................................

Ready Queue: Process Burst

P4 5

P5 4

P6 7

P7 22

P8 25

P9 3

......................................................

Now in I/O: Process Remaining I/O time

P1 26

P2 32

......................................................

......................................................

......................................................

Current Time:51

Now running: P4

......................................................

Ready Queue: Process Burst

P5 4

P6 7

P7 22

P8 25

P9 3

......................................................

Now in I/O: Process Remaining I/O time

P1 5

P2 11

P3 24

......................................................

......................................................

......................................................

Current Time:56

Now running: P5

......................................................

Ready Queue: Process Burst

P6 7

P7 22

P8 25

P9 3

P1 10

......................................................

Now in I/O: Process Remaining I/O time

P2 6

P3 19

P4 35

......................................................

......................................................

......................................................

Current Time:60

Now running: P6

......................................................

Ready Queue: Process Burst

P7 22

P8 25

P9 3

P1 10

......................................................

Now in I/O: Process Remaining I/O time

P2 2

P3 15

P4 31

P5 41

......................................................

......................................................

......................................................

Current Time:67

Now running: P7

......................................................

Ready Queue: Process Burst

P8 25

P9 3

P1 10

P2 17

......................................................

Now in I/O: Process Remaining I/O time

P3 8

P4 24

P5 34

P6 33

......................................................

......................................................

......................................................

Current Time:89

Now running: P8

......................................................

Ready Queue: Process Burst

P9 3

P1 10

P2 17

P3 15

......................................................

Now in I/O: Process Remaining I/O time

P4 2

P5 12

P6 11

P7 38

......................................................

......................................................

......................................................

Current Time:114

Now running: P9

......................................................

Ready Queue: Process Burst

P1 10

P2 17

P3 15

P4 4

P6 5

P5 6

......................................................

Now in I/O: Process Remaining I/O time

P7 13

P8 21

......................................................

......................................................

......................................................

Current Time:117

Now running: P1

......................................................

Ready Queue: Process Burst

P2 17

P3 15

P4 4

P6 5

P5 6

......................................................

Now in I/O: Process Remaining I/O time

P7 10

P8 18

P9 37

......................................................

......................................................

......................................................

Current Time:127

Now running: P2

......................................................

Ready Queue: Process Burst

P3 15

P4 4

P6 5

P5 6

P7 7

......................................................

Now in I/O: Process Remaining I/O time

P1 52

P8 8

P9 27

......................................................

......................................................

......................................................

Current Time:144

Now running: P3

......................................................

Ready Queue: Process Burst

P4 4

P6 5

P5 6

P7 7

P8 20

......................................................

Now in I/O: Process Remaining I/O time

P1 35

P2 42

P9 10

......................................................

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......................................................

Current Time:159

Now running: P4

......................................................

Ready Queue: Process Burst

P6 5

P5 6

P7 7

P8 20

P9 14

......................................................

Now in I/O: Process Remaining I/O time

P1 20

P2 27

P3 27

......................................................

......................................................

......................................................

Current Time:163

Now running: P6

......................................................

Ready Queue: Process Burst

P5 6

P7 7

P8 20

P9 14

......................................................

Now in I/O: Process Remaining I/O time

P1 16

P2 23

P3 23

P4 41

......................................................

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......................................................

Current Time:168

Now running: P5

......................................................

Ready Queue: Process Burst

P7 7

P8 20

P9 14

......................................................

Now in I/O: Process Remaining I/O time

P1 11

P2 18

P3 18

P4 36

P6 31

......................................................

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......................................................

Current Time:174

Now running: P7

......................................................

Ready Queue: Process Burst

P8 20

P9 14

......................................................

Now in I/O: Process Remaining I/O time

P1 5

P2 12

P3 12

P4 30

P5 26

P6 25

......................................................

......................................................

......................................................

Current Time:181

Now running: P8

......................................................

Ready Queue: Process Burst

P9 14

P1 15

......................................................

Now in I/O: Process Remaining I/O time

P2 5

P3 5

P4 23

P5 19

P6 18

P7 41

......................................................

......................................................

......................................................

Current Time:201

Now running: P9

......................................................

Ready Queue: Process Burst

P1 15

P2 16

P3 5

P6 6

P5 5

......................................................

Now in I/O: Process Remaining I/O time

P4 3

P7 21

P8 33

......................................................

......................................................

......................................................

Current Time:215

Now running: P1

......................................................

Ready Queue: Process Burst

P2 16

P3 5

P6 6

P5 5

P4 6

......................................................

Now in I/O: Process Remaining I/O time

P7 7

P8 19

P9 41

......................................................

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......................................................

Current Time:230

Now running: P2

......................................................

Ready Queue: Process Burst

P3 5

P6 6

P5 5

P4 6

P7 5

......................................................

Now in I/O: Process Remaining I/O time

P1 21

P8 4

P9 26

......................................................

......................................................

......................................................

Current Time:246

Now running: P3

......................................................

Ready Queue: Process Burst

P6 6

P5 5

P4 6

P7 5

P8 16

......................................................

Now in I/O: Process Remaining I/O time

P1 5

P2 27

P9 10

......................................................

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......................................................

Current Time:251

Now running: P6

......................................................

Ready Queue: Process Burst

P5 5

P4 6

P7 5

P8 16

P1 11

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Now in I/O: Process Remaining I/O time

P2 22

P3 28

P9 5

......................................................

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......................................................

Current Time:257

Now running: P5

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Ready Queue: Process Burst

P4 6

P7 5

P8 16

P1 11

P9 8

......................................................

Now in I/O: Process Remaining I/O time

P2 16

P3 22

P6 32

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......................................................

Current Time:262

Now running: P4

......................................................

Ready Queue: Process Burst

P7 5

P8 16

P1 11

P9 8

......................................................

Now in I/O: Process Remaining I/O time

P2 11

P3 17

P5 38

P6 27

......................................................

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......................................................

Current Time:268

Now running: P7

......................................................

Ready Queue: Process Burst

P8 16

P1 11

P9 8

......................................................

Now in I/O: Process Remaining I/O time

P2 5

P3 11

P4 45

P5 32

P6 21

......................................................

......................................................

......................................................

Current Time:273

Now running: P8

......................................................

Ready Queue: Process Burst

P1 11

P9 8

P2 7

......................................................

Now in I/O: Process Remaining I/O time

P3 6

P4 40

P5 27

P6 16

P7 29

......................................................

......................................................

......................................................

Current Time:289

Now running: P1

......................................................

Ready Queue: Process Burst

P9 8

P2 7

P3 9

P6 5

......................................................

Now in I/O: Process Remaining I/O time

P4 24

P5 11

P7 13

P8 41

......................................................

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......................................................

Current Time:300

Now running: P9

......................................................

Ready Queue: Process Burst

P2 7

P3 9

P6 5

P5 4

......................................................

Now in I/O: Process Remaining I/O time

P1 42

P4 13

P7 2

P8 30

......................................................

......................................................

......................................................

Current Time:308

Now running: P2

......................................................

Ready Queue: Process Burst

P3 9

P6 5

P5 4

P7 24

......................................................

Now in I/O: Process Remaining I/O time

P1 34

P4 5

P8 22

P9 30

......................................................

......................................................

......................................................

Current Time:315

Now running: P3

......................................................

Ready Queue: Process Burst

P6 5

P5 4

P7 24

P4 8

......................................................

Now in I/O: Process Remaining I/O time

P1 27

P2 41

P8 15

P9 23

......................................................

......................................................

......................................................

Current Time:324

Now running: P6

......................................................

Ready Queue: Process Burst

P5 4

P7 24

P4 8

......................................................

Now in I/O: Process Remaining I/O time

P1 18

P2 32

P3 26

P8 6

P9 14

......................................................

......................................................

......................................................

Current Time:329

Now running: P5

......................................................

Ready Queue: Process Burst

P7 24

P4 8

......................................................

Now in I/O: Process Remaining I/O time

P1 13

P2 27

P3 21

P6 41

P8 1

P9 9

......................................................

......................................................

......................................................

Current Time:333

Now running: P7

......................................................

Ready Queue: Process Burst

P4 8

P8 7

......................................................

Now in I/O: Process Remaining I/O time

P1 9

P2 23

P3 17

P5 33

P6 37

P9 5

......................................................

......................................................

......................................................

Current Time:357

Now running: P4

......................................................

Ready Queue: Process Burst

P8 7

P9 4

P1 9

P3 11

P2 17

......................................................

Now in I/O: Process Remaining I/O time

P5 9

P6 13

P7 26

......................................................

......................................................

......................................................

Current Time:365

Now running: P8

......................................................

Ready Queue: Process Burst

P9 4

P1 9

P3 11

P2 17

......................................................

Now in I/O: Process Remaining I/O time

P4 51

P5 1

P6 5

P7 18

......................................................

......................................................

......................................................

Current Time:372

Now running: P9

......................................................

Ready Queue: Process Burst

P1 9

P3 11

P2 17

P5 5

P6 4

......................................................

Now in I/O: Process Remaining I/O time

P4 44

P7 11

P8 21

......................................................

......................................................

......................................................

Current Time:376

Now running: P1

......................................................

Ready Queue: Process Burst

P3 11

P2 17

P5 5

P6 4

......................................................

Now in I/O: Process Remaining I/O time

P4 40

P7 7

P8 17

P9 19

......................................................

......................................................

......................................................

Current Time:385

Now running: P3

......................................................

Ready Queue: Process Burst

P2 17

P5 5

P6 4

P7 4

......................................................

Now in I/O: Process Remaining I/O time

P1 31

P4 31

P8 8

P9 10

......................................................

......................................................

......................................................

Current Time:396

Now running: P2

......................................................

Ready Queue: Process Burst

P5 5

P6 4

P7 4

P8 14

P9 7

......................................................

Now in I/O: Process Remaining I/O time

P1 20

P3 49

P4 20

......................................................

......................................................

......................................................

Current Time:413

Now running: P5

......................................................

Ready Queue: Process Burst

P6 4

P7 4

P8 14

P9 7

......................................................

Now in I/O: Process Remaining I/O time

P1 3

P2 33

P3 32

P4 3

......................................................

......................................................

......................................................

Current Time:418

Now running: P6

......................................................

Ready Queue: Process Burst

P7 4

P8 14

P9 7

P1 10

P4 4

......................................................

Now in I/O: Process Remaining I/O time

P2 28

P3 27

P5 37

......................................................

......................................................

......................................................

Current Time:422

Now running: P7

......................................................

Ready Queue: Process Burst

P8 14

P9 7

P1 10

P4 4

......................................................

Now in I/O: Process Remaining I/O time

P2 24

P3 23

P5 33

P6 42

......................................................

......................................................

......................................................

Current Time:426

Now running: P8

......................................................

Ready Queue: Process Burst

P9 7

P1 10

P4 4

......................................................

Now in I/O: Process Remaining I/O time

P2 20

P3 19

P5 29

P6 38

P7 32

......................................................

......................................................

......................................................

Current Time:440

Now running: P9

......................................................

Ready Queue: Process Burst

P1 10

P4 4

......................................................

Now in I/O: Process Remaining I/O time

P2 6

P3 5

P5 15

P6 24

P7 18

P8 23

......................................................

......................................................

......................................................

Current Time:447

Now running: P1

......................................................

Ready Queue: Process Burst

P4 4

P3 14

P2 11

......................................................

Now in I/O: Process Remaining I/O time

P5 8

P6 17

P7 11

P8 16

P9 33

......................................................

......................................................

......................................................

Current Time:457

Now running: P4

......................................................

Ready Queue: Process Burst

P3 14

P2 11

P5 14

......................................................

Now in I/O: Process Remaining I/O time

P1 77

P6 7

P7 1

P8 6

P9 23

......................................................

......................................................

......................................................

Current Time:461

Now running: P3

......................................................

Ready Queue: Process Burst

P2 11

P5 14

P7 3

......................................................

Now in I/O: Process Remaining I/O time

P1 73

P4 61

P6 3

P8 2

P9 19

......................................................

......................................................

......................................................

Current Time:475

Now running: P2

......................................................

Ready Queue: Process Burst

P5 14

P7 3

P8 15

P6 7

......................................................

Now in I/O: Process Remaining I/O time

P1 59

P3 55

P4 47

P9 5

......................................................

......................................................

......................................................

Current Time:486

Now running: P5

......................................................

Ready Queue: Process Burst

P7 3

P8 15

P6 7

P9 5

......................................................

Now in I/O: Process Remaining I/O time

P1 48

P2 43

P3 44

P4 36

......................................................

......................................................

......................................................

Current Time:500

Now running: P7

......................................................

Ready Queue: Process Burst

P8 15

P6 7

P9 5

......................................................

Now in I/O: Process Remaining I/O time

P1 34

P2 29

P3 30

P4 22

P5 28

......................................................

......................................................

......................................................

Current Time:503

Now running: P8

......................................................

Ready Queue: Process Burst

P6 7

P9 5

......................................................

Now in I/O: Process Remaining I/O time

P1 31

P2 26

P3 27

P4 19

P5 25

P7 22

......................................................

......................................................

......................................................

Current Time:518

Now running: P6

......................................................

Ready Queue: Process Burst

P9 5

......................................................

Now in I/O: Process Remaining I/O time

P1 16

P2 11

P3 12

P4 4

P5 10

P7 7

P8 31

......................................................

......................................................

......................................................

Current Time:525

Now running: P9

......................................................

Ready Queue: Process Burst

P4 3

P7 6

......................................................

Now in I/O: Process Remaining I/O time

P1 9

P2 4

P3 5

P5 3

P6 39

P8 24

......................................................

......................................................

......................................................

Current Time:530

Now running: P4

......................................................

Ready Queue: Process Burst

P7 6

P5 7

P2 12

P3 8

......................................................

Now in I/O: Process Remaining I/O time

P1 4

P6 34

P8 19

P9 18

......................................................

......................................................

......................................................

Current Time:533

Now running: P7

......................................................

Ready Queue: Process Burst

P5 7

P2 12

P3 8

......................................................

Now in I/O: Process Remaining I/O time

P1 1

P4 54

P6 31

P8 16

P9 15

......................................................

......................................................

......................................................

Current Time:539

Now running: P5

......................................................

Ready Queue: Process Burst

P2 12

P3 8

P1 11

......................................................

Now in I/O: Process Remaining I/O time

P4 48

P6 25

P7 26

P8 10

P9 9

......................................................

......................................................

......................................................

Current Time:546

Now running: P2

......................................................

Ready Queue: Process Burst

P3 8

P1 11

......................................................

Now in I/O: Process Remaining I/O time

P4 41

P5 18

P6 18

P7 19

P8 3

P9 2

......................................................

......................................................

......................................................

Current Time:558

Now running: P3

......................................................

Ready Queue: Process Burst

P1 11

P9 4

P8 4

......................................................

Now in I/O: Process Remaining I/O time

P2 32

P4 29

P5 6

P6 6

P7 7

......................................................

......................................................

......................................................

Current Time:566

Now running: P1

......................................................

Ready Queue: Process Burst

P9 4

P8 4

P5 12

P6 6

P7 6

......................................................

Now in I/O: Process Remaining I/O time

P2 24

P4 21

......................................................

Completed: P3

......................................................

......................................................

Current Time:577

Now running: P9

......................................................

Ready Queue: Process Burst

P8 4

P5 12

P6 6

P7 6

......................................................

Now in I/O: Process Remaining I/O time

P2 13

P4 10

......................................................

Completed: P1, P3

......................................................

......................................................

Current Time:581

Now running: P8

......................................................

Ready Queue: Process Burst

P5 12

P6 6

P7 6

......................................................

Now in I/O: Process Remaining I/O time

P2 9

P4 6

P9 26

......................................................

Completed: P1, P3

......................................................

......................................................

Current Time:585

Now running: P5

......................................................

Ready Queue: Process Burst

P6 6

P7 6

......................................................

Now in I/O: Process Remaining I/O time

P2 5

P4 2

P8 32

P9 22

......................................................

Completed: P1, P3

......................................................

......................................................

Current Time:597

Now running: P6

......................................................

Ready Queue: Process Burst

P7 6

P4 6

P2 14

......................................................

Now in I/O: Process Remaining I/O time

P5 33

P8 20

P9 10

......................................................

Completed: P1, P3

......................................................

......................................................

Current Time:603

Now running: P7

......................................................

Ready Queue: Process Burst

P4 6

P2 14

......................................................

Now in I/O: Process Remaining I/O time

P5 27

P6 33

P8 14

P9 4

......................................................

Completed: P1, P3

......................................................

......................................................

Current Time:609

Now running: P4

......................................................

Ready Queue: Process Burst

P2 14

P9 5

......................................................

Now in I/O: Process Remaining I/O time

P5 21

P6 27

P7 36

P8 8

......................................................

Completed: P1, P3

......................................................

......................................................

Current Time:615

Now running: P2

......................................................

Ready Queue: Process Burst

P9 5

......................................................

Now in I/O: Process Remaining I/O time

P4 61

P5 15

P6 21

P7 30

P8 2

......................................................

Completed: P1, P3

......................................................

......................................................

Current Time:629

Now running: P9

......................................................

Ready Queue: Process Burst

P8 3

......................................................

Now in I/O: Process Remaining I/O time

P4 47

P5 1

P6 7

P7 16

......................................................

Completed: P1, P2, P3

......................................................

......................................................

Current Time:634

Now running: P8

......................................................

Ready Queue: Process Burst

P5 15

......................................................

Now in I/O: Process Remaining I/O time

P4 42

P6 2

P7 11

P9 31

......................................................

Completed: P1, P2, P3

......................................................

......................................................

Current Time:637

Now running: P5

......................................................

Ready Queue: Process Burst

P6 5

......................................................

Now in I/O: Process Remaining I/O time

P4 39

P7 8

P8 32

P9 28

......................................................

Completed: P1, P2, P3

......................................................

......................................................

Current Time:652

Now running: P6

......................................................

Ready Queue: Process Burst

P7 5

......................................................

Now in I/O: Process Remaining I/O time

P4 24

P8 17

P9 13

......................................................

Completed: P1, P2, P3, P5

......................................................

......................................................

Current Time:657

Now running: P7

......................................................

Ready Queue: Process Burst

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P4 19

P8 12

P9 8

......................................................

Completed: P1, P2, P3, P5, P6

......................................................

......................................................

Current Time:662

Now running:CPU Idle

......................................................

Ready Queue: Process Burst

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P4 14

P8 7

P9 3

......................................................

Completed: P1, P2, P3, P5, P6, P7

......................................................

......................................................

Current Time:665

Now running: P9

......................................................

Ready Queue: Process Burst

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P4 11

P8 4

......................................................

Completed: P1, P2, P3, P5, P6, P7

......................................................

......................................................

Current Time:681

Now running: P8

......................................................

Ready Queue: Process Burst

P4 5

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

Completed: P1, P2, P3, P5, P6, P7, P9

......................................................

......................................................

Current Time:686

Now running: P4

......................................................

Ready Queue: Process Burst

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P8 41

......................................................

Completed: P1, P2, P3, P5, P6, P7, P9

......................................................

......................................................

Current Time:691

Now running:CPU Idle

......................................................

Ready Queue: Process Burst

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P8 36

......................................................

Completed: P1, P2, P3, P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:727

Now running: P8

......................................................

Ready Queue: Process Burst

[empty]

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

Completed: P1, P2, P3, P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:731

Now running:CPU Idle

......................................................

Ready Queue: Process Burst

[empty]

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

Completed: P1, P2, P3, P4, P5, P6, P7, P8, P9

......................................................

......................................................

Finished

Total Time: 731

CPU Utilization: 94.6648%

Waiting Times P1 P2 P3 P4 P5 P6 P7 P8 P9

232 267 274 302 326 361 330 343 380

Average Wait: 312.778

Turnaround Times P1 P2 P3 P4 P5 P6 P7 P8 P9

577 629 566 691 652 657 662 731 681

Average Turnaround:649.556

Response Times P1 P2 P3 P4 P5 P6 P7 P8 P9

0 12 30 51 56 60 67 89 114

Average Response: 53.222

**Program Output**

**MLFQ**

Current Time: 0

Now running: P1

......................................................

Ready Queue: Process Burst Queue

P2 18 1

P3 21 1

P4 5 1

P5 4 1

P6 7 1

P7 22 1

P8 25 1

P9 3 1

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

......................................................

......................................................

Current Time: 7

Now running: P2

......................................................

Ready Queue: Process Burst Queue

P3 21 1

P4 5 1

P5 4 1

P6 7 1

P7 22 1

P8 25 1

P9 3 1

P1 5 2

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

......................................................

......................................................

Current Time:14

Now running: P3

......................................................

Ready Queue: Process Burst Queue

P4 5 1

P5 4 1

P6 7 1

P7 22 1

P8 25 1

P9 3 1

P1 5 2

P2 11 2

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

......................................................

......................................................

Current Time:21

Now running: P4

......................................................

Ready Queue: Process Burst Queue

P5 4 1

P6 7 1

P7 22 1

P8 25 1

P9 3 1

P1 5 2

P2 11 2

P3 14 2

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

......................................................

......................................................

Current Time:26

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P6 7 1

P7 22 1

P8 25 1

P9 3 1

P1 5 2

P2 11 2

P3 14 2

......................................................

Now in I/O: Process Remaining I/O time

P4 35

......................................................

......................................................

......................................................

Current Time:30

Now running: P6

......................................................

Ready Queue: Process Burst Queue

P7 22 1

P8 25 1

P9 3 1

P1 5 2

P2 11 2

P3 14 2

......................................................

Now in I/O: Process Remaining I/O time

P4 31

P5 41

......................................................

......................................................

......................................................

Current Time:37

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P8 25 1

P9 3 1

P1 5 2

P2 11 2

P3 14 2

......................................................

Now in I/O: Process Remaining I/O time

P4 24

P5 34

P6 33

......................................................

......................................................

......................................................

Current Time:44

Now running: P8

......................................................

Ready Queue: Process Burst Queue

P9 3 1

P1 5 2

P2 11 2

P3 14 2

P7 15 2

......................................................

Now in I/O: Process Remaining I/O time

P4 17

P5 27

P6 26

......................................................

......................................................

......................................................

Current Time:51

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P1 5 2

P2 11 2

P3 14 2

P7 15 2

P8 18 2

......................................................

Now in I/O: Process Remaining I/O time

P4 10

P5 20

P6 19

......................................................

......................................................

......................................................

Current Time:54

Now running: P1

......................................................

Ready Queue: Process Burst Queue

P2 11 2

P3 14 2

P7 15 2

P8 18 2

......................................................

Now in I/O: Process Remaining I/O time

P4 7

P5 17

P6 16

P9 37

......................................................

......................................................

......................................................

Current Time:59

Now running: P2

......................................................

Ready Queue: Process Burst Queue

P3 14 2

P7 15 2

P8 18 2

......................................................

Now in I/O: Process Remaining I/O time

P1 44

P4 2

P5 12

P6 11

P9 32

......................................................

......................................................

......................................................

Current Time:61

Now running: P4

......................................................

Ready Queue: Process Burst Queue

P3 14 2

P7 15 2

P8 18 2

P2 9 2

......................................................

Now in I/O: Process Remaining I/O time

P1 42

P5 10

P6 9

P9 30

......................................................

......................................................

......................................................

Current Time:65

Now running: P3

......................................................

Ready Queue: Process Burst Queue

P7 15 2

P8 18 2

P2 9 2

......................................................

Now in I/O: Process Remaining I/O time

P1 38

P4 41

P5 6

P6 5

P9 26

......................................................

......................................................

......................................................

Current Time:70

Now running: P6

......................................................

Ready Queue: Process Burst Queue

P7 15 2

P8 18 2

P2 9 2

P3 9 2

......................................................

Now in I/O: Process Remaining I/O time

P1 33

P4 36

P5 1

P9 21

......................................................

......................................................

......................................................

Current Time:75

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P7 15 2

P8 18 2

P2 9 2

P3 9 2

......................................................

Now in I/O: Process Remaining I/O time

P1 28

P4 31

P6 31

P9 16

......................................................

......................................................

......................................................

Current Time:81

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P8 18 2

P2 9 2

P3 9 2

......................................................

Now in I/O: Process Remaining I/O time

P1 22

P4 25

P5 26

P6 25

P9 10

......................................................

......................................................

......................................................

Current Time:91

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P8 18 2

P2 9 2

P3 9 2

P7 5 2

......................................................

Now in I/O: Process Remaining I/O time

P1 12

P4 15

P5 16

P6 15

......................................................

......................................................

......................................................

Current Time:98

Now running: P8

......................................................

Ready Queue: Process Burst Queue

P2 9 2

P3 9 2

P7 5 2

P9 7 2

......................................................

Now in I/O: Process Remaining I/O time

P1 5

P4 8

P5 9

P6 8

......................................................

......................................................

......................................................

Current Time:106

Now running: P4

......................................................

Ready Queue: Process Burst Queue

P6 6 1

P2 9 2

P3 9 2

P7 5 2

P9 7 2

P1 10 2

P8 10 2

......................................................

Now in I/O: Process Remaining I/O time

P5 1

......................................................

......................................................

......................................................

Current Time:112

Now running: P6

......................................................

Ready Queue: Process Burst Queue

P5 5 1

P2 9 2

P3 9 2

P7 5 2

P9 7 2

P1 10 2

P8 10 2

......................................................

Now in I/O: Process Remaining I/O time

P4 45

......................................................

......................................................

......................................................

Current Time:118

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P2 9 2

P3 9 2

P7 5 2

P9 7 2

P1 10 2

P8 10 2

......................................................

Now in I/O: Process Remaining I/O time

P4 39

P6 32

......................................................

......................................................

......................................................

Current Time:123

Now running: P2

......................................................

Ready Queue: Process Burst Queue

P3 9 2

P7 5 2

P9 7 2

P1 10 2

P8 10 2

......................................................

Now in I/O: Process Remaining I/O time

P4 34

P5 38

P6 27

......................................................

......................................................

......................................................

Current Time:132

Now running: P3

......................................................

Ready Queue: Process Burst Queue

P7 5 2

P9 7 2

P1 10 2

P8 10 2

......................................................

Now in I/O: Process Remaining I/O time

P2 32

P4 25

P5 29

P6 18

......................................................

......................................................

......................................................

Current Time:141

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P9 7 2

P1 10 2

P8 10 2

......................................................

Now in I/O: Process Remaining I/O time

P2 23

P3 24

P4 16

P5 20

P6 9

......................................................

......................................................

......................................................

Current Time:146

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P1 10 2

P8 10 2

......................................................

Now in I/O: Process Remaining I/O time

P2 18

P3 19

P4 11

P5 15

P6 4

P7 38

......................................................

......................................................

......................................................

Current Time:150

Now running: P6

......................................................

Ready Queue: Process Burst Queue

P1 10 2

P8 10 2

P9 3 2

......................................................

Now in I/O: Process Remaining I/O time

P2 14

P3 15

P4 7

P5 11

P7 34

......................................................

......................................................

......................................................

Current Time:155

Now running: P1

......................................................

Ready Queue: Process Burst Queue

P8 10 2

P9 3 2

......................................................

Now in I/O: Process Remaining I/O time

P2 9

P3 10

P4 2

P5 6

P6 41

P7 29

......................................................

......................................................

......................................................

Current Time:157

Now running: P4

......................................................

Ready Queue: Process Burst Queue

P8 10 2

P9 3 2

P1 8 2

......................................................

Now in I/O: Process Remaining I/O time

P2 7

P3 8

P5 4

P6 39

P7 27

......................................................

......................................................

......................................................

Current Time:164

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P8 10 2

P9 3 2

P1 8 2

P2 17 2

P4 1 2

......................................................

Now in I/O: Process Remaining I/O time

P3 1

P6 32

P7 20

......................................................

......................................................

......................................................

Current Time:168

Now running: P8

......................................................

Ready Queue: Process Burst Queue

P9 3 2

P1 8 2

P2 17 2

P4 1 2

P3 15 2

......................................................

Now in I/O: Process Remaining I/O time

P5 33

P6 28

P7 16

......................................................

......................................................

......................................................

Current Time:178

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P1 8 2

P2 17 2

P4 1 2

P3 15 2

......................................................

Now in I/O: Process Remaining I/O time

P5 23

P6 18

P7 6

P8 21

......................................................

......................................................

......................................................

Current Time:181

Now running: P1

......................................................

Ready Queue: Process Burst Queue

P2 17 2

P4 1 2

P3 15 2

......................................................

Now in I/O: Process Remaining I/O time

P5 20

P6 15

P7 3

P8 18

P9 41

......................................................

......................................................

......................................................

Current Time:189

Now running: P2

......................................................

Ready Queue: Process Burst Queue

P4 1 2

P3 15 2

P7 7 2

......................................................

Now in I/O: Process Remaining I/O time

P1 52

P5 12

P6 7

P8 10

P9 33

......................................................

......................................................

......................................................

Current Time:196

Now running: P6

......................................................

Ready Queue: Process Burst Queue

P4 1 2

P3 15 2

P7 7 2

P2 10 2

......................................................

Now in I/O: Process Remaining I/O time

P1 45

P5 5

P8 3

P9 26

......................................................

......................................................

......................................................

Current Time:200

Now running: P4

......................................................

Ready Queue: Process Burst Queue

P3 15 2

P7 7 2

P2 10 2

P8 20 2

......................................................

Now in I/O: Process Remaining I/O time

P1 41

P5 1

P6 42

P9 22

......................................................

......................................................

......................................................

Current Time:201

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P3 15 2

P7 7 2

P2 10 2

P8 20 2

......................................................

Now in I/O: Process Remaining I/O time

P1 40

P4 51

P6 41

P9 21

......................................................

......................................................

......................................................

Current Time:206

Now running: P3

......................................................

Ready Queue: Process Burst Queue

P7 7 2

P2 10 2

P8 20 2

......................................................

Now in I/O: Process Remaining I/O time

P1 35

P4 46

P5 37

P6 36

P9 16

......................................................

......................................................

......................................................

Current Time:220

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P2 10 2

P8 20 2

P3 1 3

......................................................

Now in I/O: Process Remaining I/O time

P1 21

P4 32

P5 23

P6 22

P9 2

......................................................

......................................................

......................................................

Current Time:227

Now running: P2

......................................................

Ready Queue: Process Burst Queue

P8 20 2

P9 8 2

P3 1 3

......................................................

Now in I/O: Process Remaining I/O time

P1 14

P4 25

P5 16

P6 15

P7 41

......................................................

......................................................

......................................................

Current Time:237

Now running: P8

......................................................

Ready Queue: Process Burst Queue

P9 8 2

P3 1 3

......................................................

Now in I/O: Process Remaining I/O time

P1 4

P2 42

P4 15

P5 6

P6 5

P7 31

......................................................

......................................................

......................................................

Current Time:242

Now running: P6

......................................................

Ready Queue: Process Burst Queue

P9 8 2

P1 15 2

P8 15 2

P3 1 3

......................................................

Now in I/O: Process Remaining I/O time

P2 37

P4 10

P5 1

P7 26

......................................................

......................................................

......................................................

Current Time:249

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P9 8 2

P1 15 2

P8 15 2

P3 1 3

......................................................

Now in I/O: Process Remaining I/O time

P2 30

P4 3

P6 39

P7 19

......................................................

......................................................

......................................................

Current Time:256

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P1 15 2

P8 15 2

P4 4 2

P5 7 2

P3 1 3

......................................................

Now in I/O: Process Remaining I/O time

P2 23

P6 32

P7 12

......................................................

......................................................

......................................................

Current Time:264

Now running: P1

......................................................

Ready Queue: Process Burst Queue

P8 15 2

P4 4 2

P5 7 2

P3 1 3

......................................................

Now in I/O: Process Remaining I/O time

P2 15

P6 24

P7 4

P9 30

......................................................

......................................................

......................................................

Current Time:278

Now running: P8

......................................................

Ready Queue: Process Burst Queue

P4 4 2

P5 7 2

P7 5 2

P3 1 3

P1 1 3

......................................................

Now in I/O: Process Remaining I/O time

P2 1

P6 10

P9 16

......................................................

......................................................

......................................................

Current Time:288

Now running: P6

......................................................

Ready Queue: Process Burst Queue

P4 4 2

P5 7 2

P7 5 2

P2 16 2

P8 5 2

P3 1 3

P1 1 3

......................................................

Now in I/O: Process Remaining I/O time

P9 6

......................................................

......................................................

......................................................

Current Time:294

Now running: P4

......................................................

Ready Queue: Process Burst Queue

P5 7 2

P7 5 2

P2 16 2

P8 5 2

P9 4 2

P3 1 3

P1 1 3

......................................................

Now in I/O: Process Remaining I/O time

P6 33

......................................................

......................................................

......................................................

Current Time:298

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P7 5 2

P2 16 2

P8 5 2

P9 4 2

P3 1 3

P1 1 3

......................................................

Now in I/O: Process Remaining I/O time

P4 61

P6 29

......................................................

......................................................

......................................................

Current Time:305

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P2 16 2

P8 5 2

P9 4 2

P3 1 3

P1 1 3

......................................................

Now in I/O: Process Remaining I/O time

P4 54

P5 28

P6 22

......................................................

......................................................

......................................................

Current Time:310

Now running: P2

......................................................

Ready Queue: Process Burst Queue

P8 5 2

P9 4 2

P3 1 3

P1 1 3

......................................................

Now in I/O: Process Remaining I/O time

P4 49

P5 23

P6 17

P7 29

......................................................

......................................................

......................................................

Current Time:324

Now running: P8

......................................................

Ready Queue: Process Burst Queue

P9 4 2

P3 1 3

P1 1 3

P2 2 3

......................................................

Now in I/O: Process Remaining I/O time

P4 35

P5 9

P6 3

P7 15

......................................................

......................................................

......................................................

Current Time:327

Now running: P6

......................................................

Ready Queue: Process Burst Queue

P9 4 2

P8 2 2

P3 1 3

P1 1 3

P2 2 3

......................................................

Now in I/O: Process Remaining I/O time

P4 32

P5 6

P7 12

......................................................

......................................................

......................................................

Current Time:332

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P8 2 2

P3 1 3

P1 1 3

P2 2 3

......................................................

Now in I/O: Process Remaining I/O time

P4 27

P5 1

P7 7

......................................................

Completed: P6

......................................................

......................................................

Current Time:336

Now running: P8

......................................................

Ready Queue: Process Burst Queue

P5 7 2

P3 1 3

P1 1 3

P2 2 3

......................................................

Now in I/O: Process Remaining I/O time

P4 23

P7 3

P9 19

......................................................

Completed: P6

......................................................

......................................................

Current Time:338

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P3 1 3

P1 1 3

P2 2 3

......................................................

Now in I/O: Process Remaining I/O time

P4 21

P7 1

P8 33

P9 17

......................................................

Completed: P6

......................................................

......................................................

Current Time:345

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P3 1 3

P1 1 3

P2 2 3

......................................................

Now in I/O: Process Remaining I/O time

P4 14

P5 18

P8 26

P9 10

......................................................

Completed: P6

......................................................

......................................................

Current Time:359

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P4 3 2

P3 1 3

P1 1 3

P2 2 3

P7 10 3

......................................................

Now in I/O: Process Remaining I/O time

P5 4

P8 12

......................................................

Completed: P6

......................................................

......................................................

Current Time:366

Now running: P4

......................................................

Ready Queue: Process Burst Queue

P5 12 2

P3 1 3

P1 1 3

P2 2 3

P7 10 3

......................................................

Now in I/O: Process Remaining I/O time

P8 5

P9 33

......................................................

Completed: P6

......................................................

......................................................

Current Time:369

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P3 1 3

P1 1 3

P2 2 3

P7 10 3

......................................................

Now in I/O: Process Remaining I/O time

P4 54

P8 2

P9 30

......................................................

Completed: P6

......................................................

......................................................

Current Time:381

Now running: P8

......................................................

Ready Queue: Process Burst Queue

P3 1 3

P1 1 3

P2 2 3

P7 10 3

......................................................

Now in I/O: Process Remaining I/O time

P4 42

P5 33

P9 18

......................................................

Completed: P6

......................................................

......................................................

Current Time:395

Now running: P3

......................................................

Ready Queue: Process Burst Queue

P1 1 3

P2 2 3

P7 10 3

P8 2 3

......................................................

Now in I/O: Process Remaining I/O time

P4 28

P5 19

P9 4

......................................................

Completed: P6

......................................................

......................................................

Current Time:396

Now running: P1

......................................................

Ready Queue: Process Burst Queue

P2 2 3

P7 10 3

P8 2 3

......................................................

Now in I/O: Process Remaining I/O time

P3 27

P4 27

P5 18

P9 3

......................................................

Completed: P6

......................................................

......................................................

Current Time:397

Now running: P2

......................................................

Ready Queue: Process Burst Queue

P7 10 3

P8 2 3

......................................................

Now in I/O: Process Remaining I/O time

P1 21

P3 26

P4 26

P5 17

P9 2

......................................................

Completed: P6

......................................................

......................................................

Current Time:399

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P7 10 3

P8 2 3

......................................................

Now in I/O: Process Remaining I/O time

P1 19

P2 27

P3 24

P4 24

P5 15

......................................................

Completed: P6

......................................................

......................................................

Current Time:404

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P8 2 3

......................................................

Now in I/O: Process Remaining I/O time

P1 14

P2 22

P3 19

P4 19

P5 10

P9 18

......................................................

Completed: P6

......................................................

......................................................

Current Time:414

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P8 2 3

......................................................

Now in I/O: Process Remaining I/O time

P1 4

P2 12

P3 9

P4 9

P7 26

P9 8

......................................................

Completed: P6

......................................................

......................................................

Current Time:428

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P4 6 2

P8 2 3

P1 11 3

P3 5 3

P2 7 3

P5 1 3

......................................................

Now in I/O: Process Remaining I/O time

P7 12

......................................................

Completed: P6

......................................................

......................................................

Current Time:432

Now running: P4

......................................................

Ready Queue: Process Burst Queue

P8 2 3

P1 11 3

P3 5 3

P2 7 3

P5 1 3

......................................................

Now in I/O: Process Remaining I/O time

P7 8

P9 26

......................................................

Completed: P6

......................................................

......................................................

Current Time:438

Now running: P8

......................................................

Ready Queue: Process Burst Queue

P1 11 3

P3 5 3

P2 7 3

P5 1 3

......................................................

Now in I/O: Process Remaining I/O time

P4 61

P7 2

P9 20

......................................................

Completed: P6

......................................................

......................................................

Current Time:440

Now running: P1

......................................................

Ready Queue: Process Burst Queue

P3 5 3

P2 7 3

P5 1 3

P7 4 3

......................................................

Now in I/O: Process Remaining I/O time

P4 59

P8 41

P9 18

......................................................

Completed: P6

......................................................

......................................................

Current Time:451

Now running: P3

......................................................

Ready Queue: Process Burst Queue

P2 7 3

P5 1 3

P7 4 3

......................................................

Now in I/O: Process Remaining I/O time

P1 42

P4 48

P8 30

P9 7

......................................................

Completed: P6

......................................................

......................................................

Current Time:456

Now running: P2

......................................................

Ready Queue: Process Burst Queue

P5 1 3

P7 4 3

......................................................

Now in I/O: Process Remaining I/O time

P1 37

P3 28

P4 43

P8 25

P9 2

......................................................

Completed: P6

......................................................

......................................................

Current Time:458

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P5 1 3

P7 4 3

P2 5 3

......................................................

Now in I/O: Process Remaining I/O time

P1 35

P3 26

P4 41

P8 23

......................................................

Completed: P6

......................................................

......................................................

Current Time:463

Now running: P5

......................................................

Ready Queue: Process Burst Queue

P7 4 3

P2 5 3

......................................................

Now in I/O: Process Remaining I/O time

P1 30

P3 21

P4 36

P8 18

P9 31

......................................................

Completed: P6

......................................................

......................................................

Current Time:464

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P2 5 3

......................................................

Now in I/O: Process Remaining I/O time

P1 29

P3 20

P4 35

P8 17

P9 30

......................................................

Completed: P5, P6

......................................................

......................................................

Current Time:468

Now running: P2

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 25

P3 16

P4 31

P7 32

P8 13

P9 26

......................................................

Completed: P5, P6

......................................................

......................................................

Current Time:473

Now running:CPU Idle

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 20

P2 41

P3 11

P4 26

P7 27

P8 8

P9 21

......................................................

Completed: P5, P6

......................................................

......................................................

Current Time:481

Now running: P8

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 12

P2 33

P3 3

P4 18

P7 19

P9 13

......................................................

Completed: P5, P6

......................................................

......................................................

Current Time:488

Now running: P3

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 5

P2 26

P4 11

P7 12

P8 21

P9 6

......................................................

Completed: P5, P6

......................................................

......................................................

Current Time:494

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P1 9 3

P3 3 3

......................................................

Now in I/O: Process Remaining I/O time

P2 20

P4 5

P7 6

P8 15

......................................................

Completed: P5, P6

......................................................

......................................................

Current Time:508

Now running: P4

......................................................

Ready Queue: Process Burst Queue

P1 9 3

P3 3 3

P7 3 3

P9 2 3

......................................................

Now in I/O: Process Remaining I/O time

P2 6

P8 1

......................................................

Completed: P5, P6

......................................................

......................................................

Current Time:513

Now running: P1

......................................................

Ready Queue: Process Burst Queue

P3 3 3

P7 3 3

P9 2 3

P8 14 3

......................................................

Now in I/O: Process Remaining I/O time

P2 1

......................................................

Completed: P4, P5, P6

......................................................

......................................................

Current Time:522

Now running: P3

......................................................

Ready Queue: Process Burst Queue

P7 3 3

P9 2 3

P8 14 3

P2 17 3

......................................................

Now in I/O: Process Remaining I/O time

P1 31

......................................................

Completed: P4, P5, P6

......................................................

......................................................

Current Time:525

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P9 2 3

P8 14 3

P2 17 3

......................................................

Now in I/O: Process Remaining I/O time

P1 28

P3 26

......................................................

Completed: P4, P5, P6

......................................................

......................................................

Current Time:528

Now running: P9

......................................................

Ready Queue: Process Burst Queue

P8 14 3

P2 17 3

......................................................

Now in I/O: Process Remaining I/O time

P1 25

P3 23

P7 22

......................................................

Completed: P4, P5, P6

......................................................

......................................................

Current Time:530

Now running: P8

......................................................

Ready Queue: Process Burst Queue

P2 17 3

......................................................

Now in I/O: Process Remaining I/O time

P1 23

P3 21

P7 20

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:544

Now running: P2

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 9

P3 7

P7 6

P8 23

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:561

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P3 11 3

P1 10 3

......................................................

Now in I/O: Process Remaining I/O time

P2 33

P8 6

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:567

Now running: P3

......................................................

Ready Queue: Process Burst Queue

P1 10 3

P8 15 3

......................................................

Now in I/O: Process Remaining I/O time

P2 27

P7 26

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:578

Now running: P1

......................................................

Ready Queue: Process Burst Queue

P8 15 3

......................................................

Now in I/O: Process Remaining I/O time

P2 16

P3 49

P7 15

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:588

Now running: P8

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 77

P2 6

P3 39

P7 5

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:603

Now running: P7

......................................................

Ready Queue: Process Burst Queue

P2 11 3

......................................................

Now in I/O: Process Remaining I/O time

P1 62

P3 24

P8 31

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:609

Now running: P2

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 56

P3 18

P7 36

P8 25

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:620

Now running:CPU Idle

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 45

P2 43

P3 7

P7 25

P8 14

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:627

Now running: P3

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 38

P2 36

P7 18

P8 7

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:641

Now running: P8

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 24

P2 22

P3 55

P7 4

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:645

Now running: P7

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 20

P2 18

P3 51

P8 32

......................................................

Completed: P4, P5, P6, P9

......................................................

......................................................

Current Time:650

Now running:CPU Idle

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 15

P2 13

P3 46

P8 27

......................................................

Completed: P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:663

Now running: P2

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P1 2

P3 33

P8 14

......................................................

Completed: P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:675

Now running: P1

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P2 32

P3 21

P8 2

......................................................

Completed: P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:686

Now running: P8

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P2 21

P3 10

......................................................

Completed: P1, P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:689

Now running:CPU Idle

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P2 18

P3 7

P8 32

......................................................

Completed: P1, P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:696

Now running: P3

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P2 11

P8 25

......................................................

Completed: P1, P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:704

Now running:CPU Idle

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P2 3

P8 17

......................................................

Completed: P1, P3, P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:707

Now running: P2

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P8 14

......................................................

Completed: P1, P3, P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:721

Now running: P8

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

Completed: P1, P2, P3, P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:726

Now running:CPU Idle

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

P8 41

......................................................

Completed: P1, P2, P3, P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:767

Now running: P8

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

Completed: P1, P2, P3, P4, P5, P6, P7, P9

......................................................

......................................................

Current Time:771

Now running:CPU Idle

......................................................

Ready Queue: Process Burst Queue

[empty]

......................................................

Now in I/O: Process Remaining I/O time

[empty]

......................................................

Completed: P1, P2, P3, P4, P5, P6, P7, P8, P9

......................................................

......................................................

Finished

Total Time: 771

CPU Utilization: 89.7536%

Waiting Times P1 P2 P3 P4 P5 P6 P7 P8 P9

341 359 412 124 138 36 318 383 229

Average Wait: 260.000

Turnaround Times P1 P2 P3 P4 P5 P6 P7 P8 P9

686 721 704 513 464 332 650 771 530

Average Turnaround:596.778

Response Times P1 P2 P3 P4 P5 P6 P7 P8 P9

0 7 14 21 26 30 37 44 51

Average Response: 25.556

**Source Code**

**FCFS**

#include <iostream>

#include <string>

#include <array>

#include <fstream>

#include <iomanip>

using namespace std;

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//Class: single linked list of process nodes

class PROCESS\_NODE

{

public:

int ProcessNum;

int CPU[20]; //data element

int IO[20];

int WaitTime;

int IOtime;

int CPUtime;

int RT;

int ResponseTime;

PROCESS\_NODE \*next; //pointer element

};

class PROCESS\_LIST\_CLASS

{

public:

PROCESS\_LIST\_CLASS();//default constructor

PROCESS\_LIST\_CLASS::~PROCESS\_LIST\_CLASS();

void Insert(int vProcessNum, int vCPU[], int vIO[], int vWaitTime, int vIOtime, int vCPUtime, int vRT, int vResponseTime );

void InsertSort(int vProcessNum, int vCPU[], int vIO[],int vWaitTime, int vIOtime, int vCPUtime, int vRT, int vResponseTime);

void Remove();

void Remove(PROCESS\_NODE \*p);

void Print();

PROCESS\_NODE \*front, \*back;

};

//Default Contructor

PROCESS\_LIST\_CLASS::PROCESS\_LIST\_CLASS()

{

//cout << "Inside the default constructor\n";

front = back = 0;

}

//Destructor

PROCESS\_LIST\_CLASS::~PROCESS\_LIST\_CLASS()

{

//cout << "Destructor has been called\n";

while (front != 0)

{

PROCESS\_NODE \*p = front;

front = front->next;

delete p;

}

}

//Insert Node at back of list

void PROCESS\_LIST\_CLASS::Insert(int vProcessNum, int vCPU[], int vIO[], int vWaitTime, int vIOtime, int vCPUtime, int vRT, int vResponseTime)

{

if (front == 0)

{

front = new PROCESS\_NODE;

front->ProcessNum = vProcessNum;

int i = 0;

while (i <= 19)

{

front->CPU[i] = vCPU[i];

i++;

}

i = 0;

while (i <= 19)

{

front->IO[i] = vIO[i];

i++;

}

front->WaitTime = vWaitTime;

front->IOtime = vIOtime;

front->CPUtime = vCPUtime;

front->RT = vRT;

front->ResponseTime = vResponseTime;

front->next = 0;

back = front;

}

else

{

PROCESS\_NODE \*p = new PROCESS\_NODE;

p->ProcessNum = vProcessNum;

int i = 0;

while (i <= 19)

{

p->CPU[i] = vCPU[i];

i++;

}

i = 0;

while (i <= 19)

{

p->IO[i] = vIO[i];

i++;

}

p->WaitTime = vWaitTime;

p->IOtime = vIOtime;

p->CPUtime = vCPUtime;

p->RT = vRT;

p->ResponseTime = vResponseTime;

p->next = 0;

back->next = p;

back = back->next;

}

}

void PROCESS\_LIST\_CLASS::InsertSort(int vProcessNum, int vCPU[], int vIO[], int vWaitTime, int vIOtime, int vCPUtime, int vRT, int vResponseTime)

{

PROCESS\_NODE \*p = new PROCESS\_NODE;

p->ProcessNum = vProcessNum;

int i = 0;

while (i <= 19)

{

p->CPU[i] = vCPU[i];

i++;

}

i = 0;

while (i <= 19)

{

p->IO[i] = vIO[i];

i++;

}

p->WaitTime = vWaitTime;

p->IOtime = vIOtime;

p->CPUtime = vCPUtime;

p->RT = vRT;

p->ResponseTime = vResponseTime;

p->next = 0;

if (front == 0)

{

front = back = p;

}

else if (vProcessNum < front->ProcessNum)

{

p->next = front;

front = p;

}

else if (vProcessNum > back->ProcessNum)

{

back->next = p;

back = p;

}

else

{

PROCESS\_NODE \*curr, \*prev;

curr = prev = front;

while (curr != 0 && vProcessNum > curr->ProcessNum)

{

prev = curr;

curr = curr->next;

}

p->next = curr;

prev->next = p;

}

}

//Removes process from front of list

void PROCESS\_LIST\_CLASS::Remove()

{

if (front != 0)

{

PROCESS\_NODE \*p = front;

front = front->next;

delete p;

}

else

{

cout << "ERROR: List Empty\n";

"ERROR: List Empty\n";

}

}

//Removes the process at pointer p

void PROCESS\_LIST\_CLASS::Remove(PROCESS\_NODE \*p)

{

if (p == front && front == back)

{

delete p;

front = back = 0;

}

else if (p == front)

{

front = front->next;

delete p;

}

else

{

PROCESS\_NODE \*backptr = front;

while (backptr != 0 && backptr->next != p)

{

backptr = backptr->next;

}

if (p == back)

{

back = backptr;

}

backptr->next = p->next;

delete p;

}

}

void PROCESS\_LIST\_CLASS::Print()

{

if (front == 0)

{

cout << "List Empty\n";

}

PROCESS\_NODE \*p = front;

while (p != 0)

{

cout << "Process " << p->ProcessNum << endl;

int i = 0;

while (p->CPU[i] != -1)

{

cout << p->CPU[i] << " ";

i++;

}

cout << endl;

i = 0;

while (p->IO[i] != -1)

{

cout << p->IO[i] << " ";

i++;

}

cout << endl;

//cout << p->CPU[0] << " " << p->CPU[1] << " " << p->CPU[2] << " " << p->CPU[3] << " " << p->CPU[4] << " " << p->CPU[5] << " " << p->CPU[6] << " " << p->CPU[7] << endl;

cout << "Wait Time: " << p->WaitTime << endl;

cout << "IO Time: " << p->IOtime << endl;

cout << "CPU Time: " << p->CPUtime << endl;

p = p->next;

cout << endl << endl;

}

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//The program is a FCFS simulation using a singly linked list of process nodes.

//All porcesses inputed into ready queue. When the processor is free the first node from ready queue is

//moved to executing. When it is finished in executing it moves to IO/ WHen its current IO time has expired,

//it moves back to the end of the ready queue.

int main ()

{

PROCESS\_LIST\_CLASS Ready;

PROCESS\_LIST\_CLASS IO;

PROCESS\_LIST\_CLASS Executing;

PROCESS\_LIST\_CLASS COMPLETE;

ofstream outputfile;

outputfile.open("FCFSoutput.txt");

int i = 0;

int ContextSwitch = 0;

int CurrentTime = 0;

//Input data, builds the ready queue

int A1[20] = { 12, 10, 15, 11, 9, 10, 11, -1};

int B1[20] = { 44, 52, 21, 42, 31, 77, -1};

Ready.Insert(1, A1, B1, 0, 0, 0, 1, 0);

int A2[20] = { 18, 17, 16, 7, 17, 11, 12, 14, -1 };

int B2[20] = { 32, 42, 27, 41, 33, 43, 32, -1 };

Ready.Insert(2, A2, B2, 0, 0, 0, 1, 0);

int A3[20] = { 21, 15, 5, 9, 11, 14, 8, -1 };

int B3[20] = { 24, 27, 28, 26, 49, 55, -1 };

Ready.Insert(3, A3, B3, 0, 0, 0, 1, 0);

int A4[20] = { 5, 4, 6, 8, 4, 3, 6, 5, -1 };

int B4[20] = { 35, 41, 45, 51, 61, 54, 61, -1 };

Ready.Insert(4, A4, B4, 0, 0, 0, 1, 0);

int A5[20] = { 4, 6, 5, 4, 5, 14, 7, 12, 15, -1 };

int B5[20] = { 41, 26, 38, 33, 37, 28, 18, 33, -1 };

Ready.Insert(5, A5, B5, 0, 0, 0, 1, 0);

int A6[20] = { 7, 5, 6, 5, 4, 7, 6, 5, -1 };

int B6[20] = { 33, 31, 32, 41, 42, 39, 33, -1 };

Ready.Insert(6, A6, B6, 0, 0, 0, 1,0);

int A7[20] = { 22, 7, 5, 24, 4, 3, 6, 6, 5, -1 };

int B7[20] = { 38, 41, 29, 26, 32, 22, 26, 36, -1 };

Ready.Insert(7, A7, B7, 0, 0, 0, 1, 0);

int A8[20] = { 25, 20, 16, 7, 14, 15, 4, 3, 5, 4, -1 };

int B8[20] = { 21, 33, 41, 21, 23, 31, 32, 32, 41, -1 };

Ready.Insert(8, A8, B8, 0, 0, 0, 1, 0);

int A9[20] = { 3, 14, 8, 4, 7, 5, 4, 5, 16, -1 };

int B9[20] = { 37, 41, 30, 19, 33, 18, 26, 31, -1 };

Ready.Insert(9, A9, B9, 0, 0, 0, 1, 0);

//while loop, processes continue moving and current time increasing until all three lists

//(executing, ready and IO) are empty and all processes are complete

while (Executing.front != 0 || Ready.front != 0 || IO.front != 0)

{

//\*\*\*\*\*\*If process in executing is finished, move process to IO list\*\*\*\*\*\*\*\*\*\*

if (Executing.front != 0 && Executing.front->CPU[0] == 0)

{

//Copies CPU array from front node of executing into array c minue the zero value leading the CPU array

int c[20] = { 0 };

i = 0;

while (Executing.front->CPU[i] != -1)

{

c[i] = Executing.front->CPU[i + 1];

i++;

}

//Copies IO array from front node of executing into array d

int d[20] = { 0 };

i = 0;

while (Executing.front->IO[i] != -1)

{

d[i] = Executing.front->IO[i];

i++;

}

d[i] = -1;

//If all CPU bursts have been completed for this process, moves to COMPLETE list. Otherwise, back to IO

if (c[0] == -1)

{

COMPLETE.InsertSort(Executing.front->ProcessNum, c, d, Executing.front->WaitTime, Executing.front->IOtime,

Executing.front->CPUtime, Executing.front->RT, Executing.front->ResponseTime);

}

else

{

IO.InsertSort(Executing.front->ProcessNum, c, d, Executing.front->WaitTime, Executing.front->IOtime,

Executing.front->CPUtime, Executing.front->RT, Executing.front->ResponseTime);

}

Executing.Remove();

ContextSwitch = 1;

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*Checks for IO completion, returns process to back of queue\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

PROCESS\_NODE \*p = IO.front;

while (p != 0)

{

//if the IO is complete for a process, process moved to ready queue

if (p->IO[0] == 0)

{

//Copies CPU array from p node of IO into array c

int c[20] = { 0 };

i = 0;

while (p->CPU[i] != -1)

{

c[i] = p->CPU[i];

i++;

}

c[i] = -1;

//Copies IO array from p node of IO list into array d, removes first array (zero)

int d[20] = { 0 };

i = 0;

while (p->IO[i] != -1)

{

d[i] = p->IO[i + 1];

i++;

}

Ready.Insert(p->ProcessNum, c, d, p->WaitTime, p->IOtime, p->CPUtime, p->RT, p->ResponseTime);

IO.Remove(p);

if (IO.front == 0)

{

p = 0;

}

else

{

p = IO.front;

}

}

else

{

p = p->next;

}

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*If the processor is empty, moves first node in ready to executing list\*\*\*\*\*

if (Executing.front == 0 && Ready.front != 0)

{

//Copies CPU aarray from front node of ready into array c

int c[20] = { 0 };

i = 0;

while (Ready.front->CPU[i] != -1)

{

c[i] = Ready.front->CPU[i];

i++;

}

c[i] = -1;

//Copies IO array from front node of ready into array d

int d[20] = { 0 };

i = 0;

while (Ready.front->IO[i] != -1)

{

d[i] = Ready.front->IO[i];

i++;

}

d[i] = -1;

//Insert front of ready list into executing list

Executing.Insert(Ready.front->ProcessNum, c, d, Ready.front->WaitTime, Ready.front->IOtime,

Ready.front->CPUtime, Ready.front->RT, Ready.front->ResponseTime);

Ready.Remove();

ContextSwitch = 1;

Executing.front->RT = 0;

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*decrements cpu burst in processor (executing list) and increases process' CPUtime\*\*\*\*\*\*\*\*\*\*\*\*

if (Executing.front != 0)

{

Executing.front->CPU[0] = Executing.front->CPU[0] - 1;

Executing.front->CPUtime = Executing.front->CPUtime + 1;

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*increments waiting time and ResponseTime (if not been on processor) in ready queue\*\*\*\*\*\*\*

if (Ready.front != 0)

{

PROCESS\_NODE \*p = Ready.front;

while (p != 0)

{

p->WaitTime = p->WaitTime + 1;

if (p->RT == 1)

{

p->ResponseTime = p->ResponseTime + 1;

}

p = p->next;

}

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*display info at context switch\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

if (ContextSwitch == 1)

{

cout << "Current Time:" << setw(2) << CurrentTime << endl << endl;

outputfile << "Current Time:" << setw(2) << CurrentTime << endl << endl;

//prints executing

if (Executing.front != 0)

{

cout << "Now running:" << setw(3) << "P" << Executing.front->ProcessNum << endl;

outputfile << "Now running:" << setw(3) << "P" << Executing.front->ProcessNum << endl;

}

else

{

cout << "Now running:" << setw(4) << "CPU Idle\n";

outputfile << "Now running:" << setw(4) << "CPU Idle\n";

}

cout << "......................................................\n";

outputfile << "......................................................\n";

//prints Ready

if (Ready.front != 0)

{

cout << "/nReady Queue:" << setw(10) << "Process " << setw(8) << "Burst\n";

outputfile << "/nReady Queue:" << setw(10) << "Process " << setw(8) << "Burst\n";

PROCESS\_NODE \*p = Ready.front;

while (p != 0)

{

cout << setw(15) << "P" << p->ProcessNum << setw(10) << p->CPU[0] << endl;

outputfile << setw(15) << "P" << p->ProcessNum << setw(10) << p->CPU[0] << endl;

p = p->next;

}

}

else

{

cout << "\nReady Queue:" << setw(10) << "Process " << setw(8) << "Burst\n";

cout << setw(22) << "[empty]\n";

outputfile << "\nReady Queue:" << setw(10) << "Process " << setw(8) << "Burst\n";

outputfile << setw(22) << "[empty]\n";

}

cout << "......................................................\n";

outputfile << "......................................................\n";

//prints IO

if (IO.front != 0)

{

cout << "\nNow in I/O: " << setw(10) << "Process " << setw(8) << "Remaining I/O time\n";

outputfile << "\nNow in I/O: " << setw(10) << "Process " << setw(8) << "Remaining I/O time\n";

PROCESS\_NODE \*p = IO.front;

while (p != 0)

{

cout << setw(15) << "P" << p->ProcessNum << setw(10) << " " << p->IO[0] << endl;

outputfile << setw(15) << "P" << p->ProcessNum << setw(10) << " " << p->IO[0] << endl;

p = p->next;

}

}

else

{

cout << "\nNow in I/O: " << setw(10) << "Process " << setw(21) << "Remaining I/O time\n";

cout << setw(22) << "[empty]\n";

outputfile << "\nNow in I/O: " << setw(10) << "Process " << setw(21) << "Remaining I/O time\n";

outputfile << setw(22) << "[empty]\n";

}

cout << "......................................................\n";

outputfile << "......................................................\n";

//prints completed processes

if (COMPLETE.front != 0)

{

cout << "\nCompleted: " << setw(4);

outputfile << "\nCompleted: " << setw(4);

PROCESS\_NODE \*p = COMPLETE.front;

while (p != 0)

{

cout << "P" << p->ProcessNum;

outputfile << "P" << p->ProcessNum;

if (p ->next != 0)

{

cout << ", ";

outputfile << ", ";

}

p = p->next;

}

cout << endl;

outputfile << endl;

}

cout << "......................................................\n";

cout << "......................................................\n\n\n\n";

outputfile << "......................................................\n";

outputfile << "......................................................\n\n\n\n";

ContextSwitch = 0;

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*decrements IO in IO list and increases IOtime\*\*\*\*\*\*\*\*\*\*

if (IO.front != 0)

{

PROCESS\_NODE \*p = IO.front;

while (p != 0)

{

p->IO[0] = p->IO[0] - 1;

p->IOtime = p->IOtime + 1;

p = p->next;

}

}

CurrentTime = CurrentTime + 1;

}

CurrentTime = CurrentTime - 1;

//\*\*\*\*\*\*\*\*\*\*\*calculates CPU utilization\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

double TotalCPU = 0;

PROCESS\_NODE \*c = COMPLETE.front;

while (c != 0)

{

TotalCPU = TotalCPU + c->CPUtime;

c = c->next;

}

double CPUutilization = (TotalCPU / CurrentTime) \* 100;

//\*\*\*\*\*\*\*\*\*\*\*\*calculates average response, waiting an tunraround time

double avgRT = 0;

double avgWT = 0;

double avgTT = 0;

c = COMPLETE.front;

while (c != 0)

{

avgRT = avgRT + c->ResponseTime;

avgWT = avgWT + c->WaitTime;

avgTT = avgTT + (c->WaitTime + c->IOtime + c->CPUtime);

c = c->next;

}

avgRT = avgRT / 9;

avgWT = avgWT / 9;

avgTT = avgTT / 9;

//\*\*\*\*\*\*\*\*\*\*\*prints total time, CPU utilization, response, wait and turnaround times\*\*\*\*\*\*\*\*\*\*

cout << "Finished\n\n";

outputfile << "Finished\n\n";

cout << "Total Time:" << setw(11) << CurrentTime << endl;

cout << "CPU Utilization:" << setw(10) << CPUutilization << "%\n\n";

outputfile << "Total Time:" << setw(11) << CurrentTime << endl;

outputfile << "CPU Utilization:" << setw(10) << CPUutilization << "%\n\n";

//prints wait time

cout << "Waiting Times" << setw(8) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

outputfile << "Waiting Times" << setw(8) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

cout << setw(22);

outputfile << setw(22);

c = COMPLETE.front;

while (c != 0)

{

cout << c->WaitTime << setw(5);

outputfile << c->WaitTime << setw(5);

c = c->next;

}

cout << "\nAverage Wait:" << setw(13) << avgWT << endl << endl;

outputfile << "\nAverage Wait:" << setw(13) << avgWT << endl << endl;

//prints turnaround time

cout << "Turnaround Times" << setw(5) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

outputfile << "Turnaround Times" << setw(5) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

cout << setw(22);

outputfile << setw(22);

c = COMPLETE.front;

while (c != 0)

{

cout << (c->WaitTime + c->IOtime + c->CPUtime) << setw(5);

outputfile << (c->WaitTime + c->IOtime + c->CPUtime) << setw(5);

c = c->next;

}

cout << "\nAverage Turnaround:" << avgTT << endl << endl;

outputfile << "\nAverage Turnaround:" << avgTT << endl << endl;

//prints response time

cout << "Response Times" << setw(7) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

outputfile << "Response Times" << setw(7) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

cout << setw(21);

outputfile << setw(21);

c = COMPLETE.front;

while (c != 0)

{

cout << c->ResponseTime << setw(5);

outputfile << c->ResponseTime << setw(5);

c = c->next;

}

cout << "\nAverage Response:" << setprecision(5) << setw(8) << avgRT << endl << endl;

outputfile << "\nAverage Response:" << setprecision(5) << setw(8) << avgRT << endl << endl;

outputfile.close();

return 0;

}

**Source Code**

**MLFQ**

#include <iostream>

#include <string>

#include <array>

#include <fstream>

#include <iomanip>

using namespace std;

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//Class: single linked list of process nodes

class PROCESS\_NODE

{

public:

int ProcessNum;

int CPU[20]; //data element

int IO[20];

int WaitTime;

int IOtime;

int CPUtime;

int RT;

int ResponseTime;

int Queue;

PROCESS\_NODE \*next; //pointer element

};

class PROCESS\_LIST\_CLASS

{

public:

PROCESS\_LIST\_CLASS();//default constructor

PROCESS\_LIST\_CLASS::~PROCESS\_LIST\_CLASS();

void Insert(int vProcessNum, int vCPU[], int vIO[], int vWaitTime, int vIOtime, int vCPUtime, int vRT, int vResponseTime, int vQueue);

void InsertSort(int vProcessNum, int vCPU[], int vIO[], int vWaitTime, int vIOtime, int vCPUtime, int vRT, int vResponseTime, int vQueue);

void Remove();

void Remove(PROCESS\_NODE \*p);

void Print();

PROCESS\_NODE \*front, \*back;

};

//Default Contructor

PROCESS\_LIST\_CLASS::PROCESS\_LIST\_CLASS()

{

//cout << "Inside the default constructor\n";

front = back = 0;

}

//Destructor

PROCESS\_LIST\_CLASS::~PROCESS\_LIST\_CLASS()

{

//cout << "Destructor has been called\n";

while (front != 0)

{

PROCESS\_NODE \*p = front;

front = front->next;

delete p;

}

}

//Insert Node at back of list

void PROCESS\_LIST\_CLASS::Insert(int vProcessNum, int vCPU[], int vIO[], int vWaitTime, int vIOtime, int vCPUtime, int vRT, int vResponseTime, int vQueue)

{

if (front == 0)

{

front = new PROCESS\_NODE;

front->ProcessNum = vProcessNum;

int i = 0;

while (i <= 19)

{

front->CPU[i] = vCPU[i];

i++;

}

i = 0;

while (i <= 19)

{

front->IO[i] = vIO[i];

i++;

}

front->WaitTime = vWaitTime;

front->IOtime = vIOtime;

front->CPUtime = vCPUtime;

front->RT = vRT;

front->ResponseTime = vResponseTime;

front->Queue = vQueue;

front->next = 0;

back = front;

}

else

{

PROCESS\_NODE \*p = new PROCESS\_NODE;

p->ProcessNum = vProcessNum;

int i = 0;

while (i <= 19)

{

p->CPU[i] = vCPU[i];

i++;

}

i = 0;

while (i <= 19)

{

p->IO[i] = vIO[i];

i++;

}

p->WaitTime = vWaitTime;

p->IOtime = vIOtime;

p->CPUtime = vCPUtime;

p->RT = vRT;

p->ResponseTime = vResponseTime;

p->Queue = vQueue;

p->next = 0;

back->next = p;

back = back->next;

}

}

void PROCESS\_LIST\_CLASS::InsertSort(int vProcessNum, int vCPU[], int vIO[], int vWaitTime, int vIOtime, int vCPUtime, int vRT, int vResponseTime, int vQueue)

{

PROCESS\_NODE \*p = new PROCESS\_NODE;

p->ProcessNum = vProcessNum;

int i = 0;

while (i <= 19)

{

p->CPU[i] = vCPU[i];

i++;

}

i = 0;

while (i <= 19)

{

p->IO[i] = vIO[i];

i++;

}

p->WaitTime = vWaitTime;

p->IOtime = vIOtime;

p->CPUtime = vCPUtime;

p->RT = vRT;

p->ResponseTime = vResponseTime;

p->Queue = vQueue;

p->next = 0;

if (front == 0)

{

front = back = p;

}

else if (vProcessNum < front->ProcessNum)

{

p->next = front;

front = p;

}

else if (vProcessNum > back->ProcessNum)

{

back->next = p;

back = p;

}

else

{

PROCESS\_NODE \*curr, \*prev;

curr = prev = front;

while (curr != 0 && vProcessNum > curr->ProcessNum)

{

prev = curr;

curr = curr->next;

}

p->next = curr;

prev->next = p;

}

}

//Removes process from front of list

void PROCESS\_LIST\_CLASS::Remove()

{

if (front != 0)

{

PROCESS\_NODE \*p = front;

front = front->next;

delete p;

}

else

{

cout << "ERROR: List Empty\n";

"ERROR: List Empty\n";

}

}

//Removes the process at pointer p

void PROCESS\_LIST\_CLASS::Remove(PROCESS\_NODE \*p)

{

if (p == front && front == back)

{

delete p;

front = back = 0;

}

else if (p == front)

{

front = front->next;

delete p;

}

else

{

PROCESS\_NODE \*backptr = front;

while (backptr != 0 && backptr->next != p)

{

backptr = backptr->next;

}

if (p == back)

{

back = backptr;

}

backptr->next = p->next;

delete p;

}

}

void PROCESS\_LIST\_CLASS::Print()

{

if (front == 0)

{

cout << "List Empty\n";

}

PROCESS\_NODE \*p = front;

while (p != 0)

{

cout << "Process " << p->ProcessNum << endl;

int i = 0;

while (p->CPU[i] != -1)

{

cout << p->CPU[i] << " ";

i++;

}

cout << endl;

i = 0;

while (p->IO[i] != -1)

{

cout << p->IO[i] << " ";

i++;

}

cout << endl;

cout << "Wait Time: " << p->WaitTime << endl;

cout << "IO Time: " << p->IOtime << endl;

cout << "CPU Time: " << p->CPUtime << endl;

cout << "Queue: " << p->Queue << endl;

p = p->next;

cout << endl << endl;

}

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//The program is a MLFQ simulation using a singly linked list of process nodes.

//All processes inputted into ready queue 1 (corresponding to their queue level).

//When the processor is free the first node from the highest ready queue is

//moved to executing. When it is finished in executing it moves to IO/ When its current IO time has expired,

//it moves back to the end of its specified ready queue.

int main()

{

PROCESS\_LIST\_CLASS ReadyQ1;

PROCESS\_LIST\_CLASS ReadyQ2;

PROCESS\_LIST\_CLASS ReadyQ3;

PROCESS\_LIST\_CLASS IO;

PROCESS\_LIST\_CLASS Executing;

PROCESS\_LIST\_CLASS COMPLETE;

ofstream outputfile;

outputfile.open("MLFQoutput.txt");

int i = 0;

int ContextSwitch = 0;

int CurrentTime = 0;

int tq = 0; //time quantum counter for RR queues

//Input data, builds the ready queue

int A1[20] = { 12, 10, 15, 11, 9, 10, 11, -1 };

int B1[20] = { 44, 52, 21, 42, 31, 77, -1 };

ReadyQ1.Insert(1, A1, B1, 0, 0, 0, 1, 0, 1);

int A2[20] = { 18, 17, 16, 7, 17, 11, 12, 14, -1 };

int B2[20] = { 32, 42, 27, 41, 33, 43, 32, -1 };

ReadyQ1.Insert(2, A2, B2, 0, 0, 0, 1, 0, 1);

int A3[20] = { 21, 15, 5, 9, 11, 14, 8, -1 };

int B3[20] = { 24, 27, 28, 26, 49, 55, -1 };

ReadyQ1.Insert(3, A3, B3, 0, 0, 0, 1, 0, 1);

int A4[20] = { 5, 4, 6, 8, 4, 3, 6, 5, -1 };

int B4[20] = { 35, 41, 45, 51, 61, 54, 61, -1 };

ReadyQ1.Insert(4, A4, B4, 0, 0, 0, 1, 0, 1);

int A5[20] = { 4, 6, 5, 4, 5, 14, 7, 12, 15, -1 };

int B5[20] = { 41, 26, 38, 33, 37, 28, 18, 33, -1 };

ReadyQ1.Insert(5, A5, B5, 0, 0, 0, 1, 0, 1);

int A6[20] = { 7, 5, 6, 5, 4, 7, 6, 5, -1 };

int B6[20] = { 33, 31, 32, 41, 42, 39, 33, -1 };

ReadyQ1.Insert(6, A6, B6, 0, 0, 0, 1, 0, 1);

int A7[20] = { 22, 7, 5, 24, 4, 3, 6, 6, 5, -1 };

int B7[20] = { 38, 41, 29, 26, 32, 22, 26, 36, -1 };

ReadyQ1.Insert(7, A7, B7, 0, 0, 0, 1, 0, 1);

int A8[20] = { 25, 20, 16, 7, 14, 15, 4, 3, 5, 4, -1 };

int B8[20] = { 21, 33, 41, 21, 23, 31, 32, 32, 41, -1 };

ReadyQ1.Insert(8, A8, B8, 0, 0, 0, 1, 0, 1);

int A9[20] = { 3, 14, 8, 4, 7, 5, 4, 5, 16, -1 };

int B9[20] = { 37, 41, 30, 19, 33, 18, 26, 31, -1 };

ReadyQ1.Insert(9, A9, B9, 0, 0, 0, 1, 0, 1);

//while loop, processes continue moving and current time increasing until all three lists

//(executing, ready and IO) are empty and all processes are complete

while (Executing.front != 0 || ReadyQ1.front != 0 || ReadyQ2.front != 0 || ReadyQ3.front != 0 || IO.front != 0)

{

//\*\*\*\*\*\*If process in executing is finished, move process to IO list\*\*\*\*\*\*\*\*\*\*

if (Executing.front != 0 && Executing.front->CPU[0] == 0)

{

//Copies CPU array from front node of executing into array c minue the zero value leading the CPU array

int c[20] = { 0 };

i = 0;

while (Executing.front->CPU[i] != -1)

{

c[i] = Executing.front->CPU[i + 1];

i++;

}

//Copies IO array from front node of executing into array d

int d[20] = { 0 };

i = 0;

while (Executing.front->IO[i] != -1)

{

d[i] = Executing.front->IO[i];

i++;

}

d[i] = -1;

//If all CPU bursts have been completed for this process, moves to COMPLETE list. Otherwise, back to IO

if (c[0] == -1)

{

COMPLETE.InsertSort(Executing.front->ProcessNum, c, d, Executing.front->WaitTime, Executing.front->IOtime,

Executing.front->CPUtime, Executing.front->RT, Executing.front->ResponseTime, Executing.front->Queue);

}

else

{

IO.InsertSort(Executing.front->ProcessNum, c, d, Executing.front->WaitTime, Executing.front->IOtime,

Executing.front->CPUtime, Executing.front->RT, Executing.front->ResponseTime, Executing.front->Queue);

}

Executing.Remove();

ContextSwitch = 1;

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*Checks for IO completion, returns process to back of specified ready queue\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

PROCESS\_NODE \*p = IO.front;

while (p != 0)

{

//if the IO is complete for a process, process moved to ready queue

if (p->IO[0] == 0)

{

//Copies CPU array from p node of IO into array c

int c[20] = { 0 };

i = 0;

while (p->CPU[i] != -1)

{

c[i] = p->CPU[i];

i++;

}

c[i] = -1;

//Copies IO array from p node of IO list into array d, removes first array item for IO (zero)

int d[20] = { 0 };

i = 0;

while (p->IO[i] != -1)

{

d[i] = p->IO[i + 1];

i++;

}

if (p->Queue == 1)

{

ReadyQ1.Insert(p->ProcessNum, c, d, p->WaitTime, p->IOtime, p->CPUtime, p->RT, p->ResponseTime, p->Queue);

}

else if (p->Queue == 2)

{

ReadyQ2.Insert(p->ProcessNum, c, d, p->WaitTime, p->IOtime, p->CPUtime, p->RT, p->ResponseTime, p->Queue);

}

else if (p->Queue == 3)

{

ReadyQ3.Insert(p->ProcessNum, c, d, p->WaitTime, p->IOtime, p->CPUtime, p->RT, p->ResponseTime, p->Queue);

}

else

{

cout << "\n\nERROR QUEUE NOT 1,2,3!!!!\n\n";

}

IO.Remove(p);

if (IO.front == 0)

{

p = 0;

}

else

{

p = IO.front;

}

}

else

{

p = p->next;

}

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*Checks for tq and preemption\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//if Q1 in executing and its tq is over move to next ready queue

if (Executing.front != 0 && Executing.front->Queue == 1 && tq >= 7)

{

Executing.front->Queue = 2;

//Copies CPU array from front node of executing into array c

int c[20] = { 0 };

i = 0;

while (Executing.front->CPU[i] != -1)

{

c[i] = Executing.front->CPU[i];

i++;

}

c[i] = -1;

//Copies IO array from front node of executing into array d

int d[20] = { 0 };

i = 0;

while (Executing.front->IO[i] != -1)

{

d[i] = Executing.front->IO[i];

i++;

}

d[i] = -1;

ReadyQ2.Insert(Executing.front->ProcessNum, c, d, Executing.front->WaitTime, Executing.front->IOtime,

Executing.front->CPUtime, Executing.front->RT, Executing.front->ResponseTime, Executing.front->Queue);

Executing.Remove();

ContextSwitch = 1;

}

//if Q2 in executing and its tq is over, moves to next ready queue

else if (Executing.front != 0 && Executing.front->Queue == 2 && tq >= 14)

{

Executing.front->Queue = 3;

//Copies CPU array from front node of executing into array c

int c[20] = { 0 };

i = 0;

while (Executing.front->CPU[i] != -1)

{

c[i] = Executing.front->CPU[i];

i++;

}

c[i] = -1;

//Copies IO array from front node of executing into array d

int d[20] = { 0 };

i = 0;

while (Executing.front->IO[i] != -1)

{

d[i] = Executing.front->IO[i];

i++;

}

d[i] = -1;

ReadyQ3.Insert(Executing.front->ProcessNum, c, d, Executing.front->WaitTime, Executing.front->IOtime,

Executing.front->CPUtime, Executing.front->RT, Executing.front->ResponseTime, Executing.front->Queue);

Executing.Remove();

ContextSwitch = 1;

}

//if Q2 in executing and a Q1 preempts it, moves back to ready ueue

else if (Executing.front != 0 && Executing.front->Queue == 2 && ReadyQ1.front != 0)

{

//Copies CPU array from front node of executing into array c

int c[20] = { 0 };

i = 0;

while (Executing.front->CPU[i] != -1)

{

c[i] = Executing.front->CPU[i];

i++;

}

c[i] = -1;

//Copies IO array from front node of executing into array d

int d[20] = { 0 };

i = 0;

while (Executing.front->IO[i] != -1)

{

d[i] = Executing.front->IO[i];

i++;

}

d[i] = -1;

ReadyQ2.Insert(Executing.front->ProcessNum, c, d, Executing.front->WaitTime, Executing.front->IOtime,

Executing.front->CPUtime, Executing.front->RT, Executing.front->ResponseTime, Executing.front->Queue);

Executing.Remove();

ContextSwitch = 1;

}

//Q3 is executing and its preempted by either a Q1 or Q2

else if (Executing.front != 0 && Executing.front->Queue == 3 && (ReadyQ1.front != 0 || ReadyQ2.front != 0))

{

//Copies CPU array from front node of executing into array c

int c[20] = { 0 };

i = 0;

while (Executing.front->CPU[i] != -1)

{

c[i] = Executing.front->CPU[i];

i++;

}

c[i] = -1;

//Copies IO array from front node of executing into array d

int d[20] = { 0 };

i = 0;

while (Executing.front->IO[i] != -1)

{

d[i] = Executing.front->IO[i];

i++;

}

d[i] = -1;

ReadyQ3.Insert(Executing.front->ProcessNum, c, d, Executing.front->WaitTime, Executing.front->IOtime,

Executing.front->CPUtime, Executing.front->RT, Executing.front->ResponseTime, Executing.front->Queue);

Executing.Remove();

ContextSwitch = 1;

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*If the processor is empty, moves first node in ready to executing list\*\*\*\*\*

if (Executing.front == 0 && (ReadyQ1.front != 0 || ReadyQ2.front != 0 || ReadyQ3.front != 0))

{

//If Q1 is not empty, take from this queue first

if (ReadyQ1.front != 0)

{

//Copies CPU array from front node of ready into array c

int c[20] = { 0 };

i = 0;

while (ReadyQ1.front->CPU[i] != -1)

{

c[i] = ReadyQ1.front->CPU[i];

i++;

}

c[i] = -1;

//Copies IO array from front node of ready into array d

int d[20] = { 0 };

i = 0;

while (ReadyQ1.front->IO[i] != -1)

{

d[i] = ReadyQ1.front->IO[i];

i++;

}

d[i] = -1;

//Insert front of ready list into executing list

Executing.Insert(ReadyQ1.front->ProcessNum, c, d, ReadyQ1.front->WaitTime, ReadyQ1.front->IOtime,

ReadyQ1.front->CPUtime, ReadyQ1.front->RT, ReadyQ1.front->ResponseTime, ReadyQ1.front->Queue);

tq = 0;

ReadyQ1.Remove();

ContextSwitch = 1;

Executing.front->RT = 0;

}

//if Q1 is empty and Q2 isn't, then inserts node from Q2 into executing

else if (ReadyQ2.front != 0)

{

//Copies CPU aarray from front node of ready into array c

int c[20] = { 0 };

i = 0;

while (ReadyQ2.front->CPU[i] != -1)

{

c[i] = ReadyQ2.front->CPU[i];

i++;

}

c[i] = -1;

//Copies IO array from front node of ready into array d

int d[20] = { 0 };

i = 0;

while (ReadyQ2.front->IO[i] != -1)

{

d[i] = ReadyQ2.front->IO[i];

i++;

}

d[i] = -1;

//Insert front of ready list into executing list

Executing.Insert(ReadyQ2.front->ProcessNum, c, d, ReadyQ2.front->WaitTime, ReadyQ2.front->IOtime,

ReadyQ2.front->CPUtime, ReadyQ2.front->RT, ReadyQ2.front->ResponseTime, ReadyQ2.front->Queue);

tq = 0;

ReadyQ2.Remove();

ContextSwitch = 1;

Executing.front->RT = 0;

}

//if both Q1 nad Q2 are empty, remove node from Q3 and inserts into executing

else if (ReadyQ3.front != 0)

{

//Copies CPU aarray from front node of ready into array c

int c[20] = { 0 };

i = 0;

while (ReadyQ3.front->CPU[i] != -1)

{

c[i] = ReadyQ3.front->CPU[i];

i++;

}

c[i] = -1;

//Copies IO array from front node of ready into array d

int d[20] = { 0 };

i = 0;

while (ReadyQ3.front->IO[i] != -1)

{

d[i] = ReadyQ3.front->IO[i];

i++;

}

d[i] = -1;

//Insert front of ready list into executing list

Executing.Insert(ReadyQ3.front->ProcessNum, c, d, ReadyQ3.front->WaitTime, ReadyQ3.front->IOtime,

ReadyQ3.front->CPUtime, ReadyQ3.front->RT, ReadyQ3.front->ResponseTime, ReadyQ3.front->Queue);

ReadyQ3.Remove();

ContextSwitch = 1;

Executing.front->RT = 0;

}

else

{

cout << "\n\nERROR ALL QUEUES EMPTY!!!!\n\n";

}

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

//\*\*\*\*\*\*\*\*\*\*\*\*\*decrements cpu burst in processor (executing list) and increases process' CPUtime\*\*\*\*\*\*\*\*\*\*\*\*

if (Executing.front != 0)

{

Executing.front->CPU[0] = Executing.front->CPU[0] - 1;

Executing.front->CPUtime = Executing.front->CPUtime + 1;

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*increments waiting time and ResponseTime (if not been on processor) in ready queue\*\*\*\*\*\*\*

//for ready queue 1

if (ReadyQ1.front != 0)

{

PROCESS\_NODE \*p = ReadyQ1.front;

while (p != 0)

{

p->WaitTime = p->WaitTime + 1;

//increments RT if not yet on processor

if (p->RT == 1)

{

p->ResponseTime = p->ResponseTime + 1;

}

p = p->next;

}

}

//for ready queue 2

if (ReadyQ2.front != 0)

{

PROCESS\_NODE \*p = ReadyQ2.front;

while (p != 0)

{

p->WaitTime = p->WaitTime + 1;

//increments RT if not yet on processor

if (p->RT == 1)

{

p->ResponseTime = p->ResponseTime + 1;

}

p = p->next;

}

}

//for ready queue 2

if (ReadyQ3.front != 0)

{

PROCESS\_NODE \*p = ReadyQ3.front;

while (p != 0)

{

p->WaitTime = p->WaitTime + 1;

//increments RT if not yet on processor

if (p->RT == 1)

{

p->ResponseTime = p->ResponseTime + 1;

}

p = p->next;

}

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*display info at context switch\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

if (ContextSwitch == 1)

{

cout << "Current Time:" << setw(2) << CurrentTime << endl << endl;

outputfile << "Current Time:" << setw(2) << CurrentTime << endl << endl;

//prints executing

if (Executing.front != 0)

{

cout << "Now running:" << setw(3) << "P" << Executing.front->ProcessNum << endl;

outputfile << "Now running:" << setw(3) << "P" << Executing.front->ProcessNum << endl;

}

else

{

cout << "Now running:" << setw(4) << "CPU Idle\n";

outputfile << "Now running:" << setw(4) << "CPU Idle\n";

}

cout << "......................................................\n";

outputfile << "......................................................\n";

//prints Ready

cout << "\nReady Queue:" << setw(10) << "Process " << setw(8) << "Burst" << setw(8) << "Queue\n";

outputfile << "\nReady Queue:" << setw(10) << "Process " << setw(8) << "Burst" << setw(8) << "Queue\n";

//readyqueue 1

if (ReadyQ1.front != 0)

{

PROCESS\_NODE \*p = ReadyQ1.front;

while (p != 0)

{

cout << setw(15) << "P" << p->ProcessNum << setw(10) << p->CPU[0] << setw(10) << p->Queue << endl;

outputfile << setw(15) << "P" << p->ProcessNum << setw(10) << p->CPU[0] << setw(10) << p->Queue << endl;

p = p->next;

}

}

//ready queue 2

if (ReadyQ2.front != 0)

{

PROCESS\_NODE \*p = ReadyQ2.front;

while (p != 0)

{

cout << setw(15) << "P" << p->ProcessNum << setw(10) << p->CPU[0] << setw(10) << p->Queue << endl;

outputfile << setw(15) << "P" << p->ProcessNum << setw(10) << p->CPU[0] << setw(10) << p->Queue << endl;

p = p->next;

}

}

//ready queue 3

if (ReadyQ3.front != 0)

{

PROCESS\_NODE \*p = ReadyQ3.front;

while (p != 0)

{

cout << setw(15) << "P" << p->ProcessNum << setw(10) << p->CPU[0] << setw(10) << p->Queue << endl;

outputfile << setw(15) << "P" << p->ProcessNum << setw(10) << p->CPU[0] << setw(10) << p->Queue << endl;

p = p->next;

}

}

//all ready queues empty

if (ReadyQ1.front == 0 && ReadyQ2.front == 0 && ReadyQ3.front == 0)

{

cout << setw(22) << "[empty]\n";

outputfile << setw(22) << "[empty]\n";

}

cout << "......................................................\n";

outputfile << "......................................................\n";

//prints IO

if (IO.front != 0)

{

cout << "\nNow in I/O: " << setw(10) << "Process " << setw(8) << "Remaining I/O time\n";

outputfile << "\nNow in I/O: " << setw(10) << "Process " << setw(8) << "Remaining I/O time\n";

PROCESS\_NODE \*p = IO.front;

while (p != 0)

{

cout << setw(15) << "P" << p->ProcessNum << setw(10) << " " << p->IO[0] << endl;

outputfile << setw(15) << "P" << p->ProcessNum << setw(10) << " " << p->IO[0] << endl;

p = p->next;

}

}

else

{

cout << "\nNow in I/O: " << setw(10) << "Process " << setw(21) << "Remaining I/O time\n";

cout << setw(22) << "[empty]\n";

outputfile << "\nNow in I/O: " << setw(10) << "Process " << setw(21) << "Remaining I/O time\n";

outputfile << setw(22) << "[empty]\n";

}

cout << "......................................................\n";

outputfile << "......................................................\n";

//prints completed processes

if (COMPLETE.front != 0)

{

cout << "\nCompleted: " << setw(4);

outputfile << "\nCompleted: " << setw(4);

PROCESS\_NODE \*p = COMPLETE.front;

while (p != 0)

{

cout << "P" << p->ProcessNum;

outputfile << "P" << p->ProcessNum;

if (p->next != 0)

{

cout << ", ";

outputfile << ", ";

}

p = p->next;

}

cout << endl;

outputfile << endl;

}

cout << "......................................................\n";

cout << "......................................................\n\n\n\n";

outputfile << "......................................................\n";

outputfile << "......................................................\n\n\n\n";

ContextSwitch = 0;

}

//\*\*\*\*\*\*\*\*\*\*\*\*\*\*decrements IO in IO list and increases IOtime\*\*\*\*\*\*\*\*\*\*

if (IO.front != 0)

{

PROCESS\_NODE \*p = IO.front;

while (p != 0)

{

p->IO[0] = p->IO[0] - 1;

p->IOtime = p->IOtime + 1;

p = p->next;

}

}

tq = tq + 1;

CurrentTime = CurrentTime + 1;

}

CurrentTime = CurrentTime - 1;

//\*\*\*\*\*\*\*\*\*\*\*calculates CPU utilization\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

double TotalCPU = 0;

PROCESS\_NODE \*c = COMPLETE.front;

while (c != 0)

{

TotalCPU = TotalCPU + c->CPUtime;

c = c->next;

}

double CPUutilization = (TotalCPU / CurrentTime) \* 100;

//\*\*\*\*\*\*\*\*\*\*\*\*calculates average response, waiting an tunraround time

double avgRT = 0;

double avgWT = 0;

double avgTT = 0;

c = COMPLETE.front;

while (c != 0)

{

avgRT = avgRT + c->ResponseTime;

avgWT = avgWT + c->WaitTime;

avgTT = avgTT + (c->WaitTime + c->IOtime + c->CPUtime);

c = c->next;

}

avgRT = avgRT / 9;

avgWT = avgWT / 9;

avgTT = avgTT / 9;

//\*\*\*\*\*\*\*\*\*\*\*prints total time, CPU utilization, response, wait and turnaround times\*\*\*\*\*\*\*\*\*\*

cout << "Finished\n\n";

outputfile << "Finished\n\n";

cout << "Total Time:" << setw(11) << CurrentTime << endl;

cout << "CPU Utilization:" << setw(10) << CPUutilization << "%\n\n";

outputfile << "Total Time:" << setw(11) << CurrentTime << endl;

outputfile << "CPU Utilization:" << setw(10) << CPUutilization << "%\n\n";

//prints wait time

cout << "Waiting Times" << setw(8) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

outputfile << "Waiting Times" << setw(8) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

cout << setw(22);

outputfile << setw(22);

c = COMPLETE.front;

while (c != 0)

{

cout << c->WaitTime << setw(5);

outputfile << c->WaitTime << setw(5);

c = c->next;

}

cout << "\nAverage Wait:" << setw(13) << fixed << setprecision(3) <<avgWT << endl << endl;

outputfile << "\nAverage Wait:" << setw(13) << fixed << setprecision(3) << avgWT << endl << endl;

//prints turnaround time

cout << "Turnaround Times" << setw(5) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

outputfile << "Turnaround Times" << setw(5) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

cout << setw(22);

outputfile << setw(22);

c = COMPLETE.front;

while (c != 0)

{

cout << (c->WaitTime + c->IOtime + c->CPUtime) << setw(5);

outputfile << (c->WaitTime + c->IOtime + c->CPUtime) << setw(5);

c = c->next;

}

cout << "\nAverage Turnaround:" << avgTT << endl << endl;

outputfile << "\nAverage Turnaround:" << avgTT << endl << endl;

//prints response time

cout << "Response Times" << setw(7) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

outputfile << "Response Times" << setw(7) << "P1" << setw(5) << "P2" << setw(5) << "P3" << setw(5) << "P4" << setw(5) << "P5"

<< setw(5) << "P6" << setw(5) << "P7" << setw(5) << "P8" << setw(6) << "P9\n";

cout << setw(21);

outputfile << setw(21);

c = COMPLETE.front;

while (c != 0)

{

cout << c->ResponseTime << setw(5);

outputfile << c->ResponseTime << setw(5);

c = c->next;

}

cout << "\nAverage Response:" << setprecision(3) << setw(8) << avgRT << endl << endl;

outputfile << "\nAverage Response:" << setw(8) << setprecision(3) << avgRT << endl << endl;

outputfile.close();

return 0;

}

References

Silberschatz, A., Galvin, P.B., & Gagne, G. 2013. *Operating System Concepts* (9th ed). John Wiley & Sons.