**Programming Assignment**

**CPU Scheduler**

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COP 4610

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**Introduction**

The objective of this project is to experience hands-on simulation programming in order to learn more about OS scheduling. In particular, three CPU scheduling algorithms are implemented: first-come, first-served (FCFS), shortest-job-first (SJF), and multilevel feedback queue (MLFQ). Each of these CPU scheduling algorithms are simulated and evaluated with the following set of eight processes:

P1 {5, 27, 3, 31, 5, 43, 4, 18, 6, 22, 4, 26, 3, 24, 4}

P2 {4, 48, 5, 44, 7, 42, 12, 37, 9, 76, 4, 41, 9, 31, 7, 43, 8}

P3 {8, 33, 12, 41, 18, 65, 14, 21, 4, 61, 15, 18, 14, 26, 5, 31, 6}

P4 {3, 35, 4, 41, 5, 45, 3, 51, 4, 61, 5, 54, 6, 82, 5, 77, 3}

P5 {16, 24, 17, 21, 5, 36, 16, 26, 7, 31, 13, 28, 11, 21, 6, 13, 3, 11, 4}

P6 {11, 22, 4, 8, 5, 10, 6, 12, 7, 14, 9, 18, 12, 24, 15, 30, 8}

P7 {14, 46, 17, 41, 11, 42, 15, 21, 4, 32, 7, 19, 16, 33, 10}

P8 {4, 14, 5, 33, 6, 51, 14, 73, 16, 87, 6}

Moreover, the FCFS scheduling algorithm is non-preemptive, the SJF scheduling algorithm is non-preemptive, and the MLFQ scheduling algorithm includes absolute priority in higher queues. The MLFQ scheduling algorithm contains a total of three queues: Queue 1, Queue2, and Queue 3. Queue 1 applies the round-robin (RR) scheduling algorithm with a time quantum (Tq) of 5, Queue 2 applies the RR scheduling algorithm with a Tq of 10, and Queue 3 applies the FCFS scheduling algorithm.

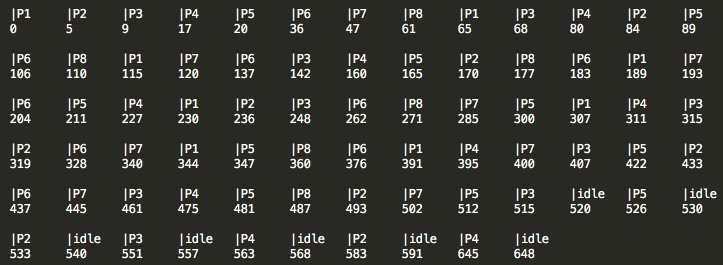
In addition, for the MLFQ scheduling algorithm, all processes first arrive at Queue 1. The process is demoted to the next lower priority queue if the Tq expires before the CPU burst finishes. However, when processes are preempted by a higher queue level process, the processes are not demoted to the next lower priority queue. Also, a process will not be upgraded after the process has been downgraded.

Furthermore, the assumptions made for this project include that a process is moved to the ready queue after finishing an I/O event, processes do not wait on I/O devices, and all processes are activated at time 0.

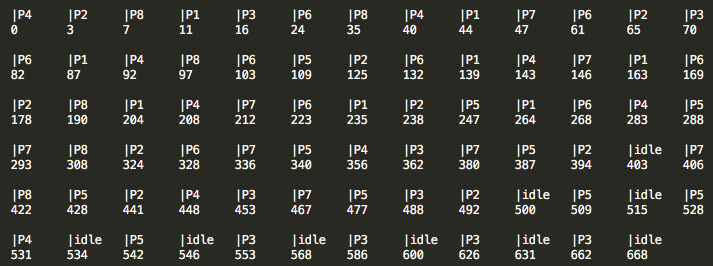
The programming language utilized for the implementation of the CPU scheduling algorithms is Python. The program listing is included at the end of the report. The report also contains the GANTT charts for all three of the CPU scheduling algorithms, the tables of results comparison between the three CPU scheduling algorithms, a final discussion, a sample of the dynamic execution for each context switch, and the results printed at the end of each simulation.

**GANTT Charts**

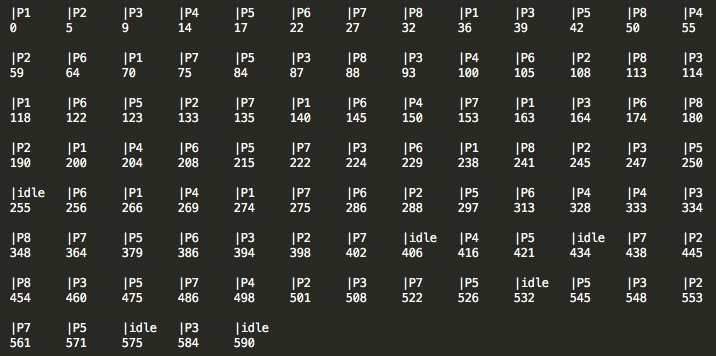
FCFS



SJF



MLFQ



**Final Results**

Table of results comparison (SJF, FCFS, MLFQ)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **SJF** | **FCFS** | **MLFQ** |
| CPU utilization | 82.78% | 85.34% | 93.73% |
| Avg Waiting time (Tw) | 133.5 | 185.25 | 154.75 |
| Avg Turnaround time (Ttr) | 469.625 | 521.37 | 490.875 |
| Avg Response time (Tr) | 27.125 | 24.37 | 15.75 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **SJF CPU utilization:** 82.78% | | | | **FCFS CPU utilization:**  85.34% | | | | **MLFQ CPU utilization:** 93.73% | | | |
|  | ***Tw*** | ***Ttr*** | ***Tr*** |  | ***Tw*** | ***Ttr*** | ***Tr*** |  | ***Tw*** | ***Ttr*** | ***Tr*** |  |
| P1 | 43 | 268 | 11 | 170 | 395 | 0 | 50 | 275 | 0 |
| P2 | 73 | 500 | 3 | 164 | 591 | 5 | 134 | 561 | 5 |
| P3 | 276 | 668 | 16 | 165 | 557 | 9 | 198 | 590 | 9 |
| P4 | 50 | 534 | 0 | 164 | 648 | 17 | 17 | 501 | 14 |
| P5 | 237 | 546 | 109 | 221 | 530 | 20 | 266 | 575 | 17 |
| P6 | 121 | 336 | 24 | 230 | 445 | 36 | 179 | 394 | 22 |
| P7 | 149 | 477 | 47 | 184 | 512 | 47 | 243 | 571 | 27 |
| P8 | 119 | 428 | 7 | 184 | 493 | 61 | 151 | 460 | 32 |
| **Avg** | ***133.5*** | ***469.625*** | ***27.125*** | ***185.25*** | ***521.37*** | ***24.37*** | ***154.75*** | ***490.875*** | ***15.75*** |

**Discussion**

In terms of CPU utilization, SJF has the lowest result with a CPU utilization of 82.78%, while MLFQ has the highest result with a CPU utilization of 93.73%. MLFQ has the highest CPU utilization because most of the queues, specifically Queue 1 and Queue2, employ the RR scheduling algorithm. The smaller time quantum of these queues allows for more context switches to occur and, thus, increasing the CPU utilization. Nonetheless, SJF has the lowest CPU utilization because when a new process arrives at the ready queue with a shorter next CPU burst than what is remaining of the currently running process, the non-preemptive SJF will allow the currently executing process to complete its CPU burst. This can cause more idle time in the CPU, which decreases the CPU utilization.

In terms of average waiting time (Tw), SJF also has the lowest result with a Tw of 133.5, while FCFS has highest result with a Tw of 185.25. SJF has the lowest average waiting time because short jobs go first and do not wait a long time for longer jobs to complete. Contrastingly, FCFS has the highest average waiting time because short jobs can wait a long time for longer jobs to finish.

In terms of average turnaround time (Ttr), SJF also has the lowest result with a Ttr of 469.625, while FCFS has the highest result with a Ttr of 521.37. SJF has the lowest average turnaround time because the jobs with the shortest CPU burst go first, which enables the short jobs to complete quickly and have a low turnaround time. On the other hand, FCFS has the highest average turnaround time because short jobs can wait longer for long jobs to complete, which increases the turnaround time.

In terms of average response time, MLFQ has the lowest result with a Tr of 15.75, while SJF has the highest result with a Tr of 27.125. MLFQ has the lowest average response time because most of the queues, specifically Queue 1 and Queue2, employ the RR scheduling algorithm. The smaller time quantum of these queues allows for more context switches to occur and, thus, decreasing the response time. In contrast, SJF has the highest average response time because longer jobs have to wait for shorter jobs to complete and cannot preempt shorter jobs, which increases the response time.

To summarize, although the MLFQ scheduling algorithm has the highest CPU utilization and the lowest average response time, while the SJF scheduling algorithm has the lowest average waiting time as well as the lowest average turnaround time. Consequently, SJF is the most optimal scheduling algorithm.

**Sample of Dynamic Execution and Simulation Results**

FCFS

Current Time: 0 fcfs

Next process on the CPU: P1, Burst: 5

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

List of processes in the ready queue:

Process Burst

P2 4

P3 8

P4 3

P5 16

P6 11

P7 14

P8 4

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 5

Next process on the CPU: P2, Burst: 4

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

List of processes in the ready queue:

Process Burst

P3 8

P4 3

P5 16

P6 11

P7 14

P8 4

List of processes in I/O:

Process Remaining I/O Time

P1 27

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 9

Next process on the CPU: P3, Burst: 8

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

List of processes in the ready queue:

Process Burst

P4 3

P5 16

P6 11

P7 14

P8 4

List of processes in I/O:

Process Remaining I/O Time

P1 23

P2 48

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 17

Next process on the CPU: P4, Burst: 3

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

List of processes in the ready queue:

Process Burst

P5 16

P6 11

P7 14

P8 4

List of processes in I/O:

Process Remaining I/O Time

P1 15

P2 40

P3 33

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 20

Next process on the CPU: P5, Burst: 16

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

List of processes in the ready queue:

Process Burst

P6 11

P7 14

P8 4

List of processes in I/O:

Process Remaining I/O Time

P1 12

P2 37

P3 30

P4 35

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 36

Next process on the CPU: P6, Burst: 11

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

List of processes in the ready queue:

Process Burst

P7 14

P8 4

P1 3

List of processes in I/O:

Process Remaining I/O Time

P2 21

P3 14

P4 19

P5 24

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 47

Next process on the CPU: P7, Burst: 14

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

List of processes in the ready queue:

Process Burst

P8 4

P1 3

List of processes in I/O:

Process Remaining I/O Time

P2 10

P3 3

P4 8

P5 13

P6 22

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 502

Next process on the CPU: P7, Burst: 10

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

List of processes in the ready queue:

Process Burst

P5 3

P3 5

List of processes in I/O:

Process Remaining I/O Time

P4 61

P2 31

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

Completed: P1, P6, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 512

Next process on the CPU: P5, Burst: 3

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

List of processes in the ready queue:

Process Burst

P3 5

List of processes in I/O:

Process Remaining I/O Time

P4 51

P2 21

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

Completed: P1, P6, P7, P8,

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Current Time: 515

Next process on the CPU: P3, Burst: 5

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P4 48

P2 18

P5 11

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

Completed: P1, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 526

Next process on the CPU: P5, Burst: 4

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P4 37

P2 7

P3 25

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

Completed: P1, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 533

Next process on the CPU: P2, Burst: 7

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P4 30

P3 18

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

Completed: P1, P5, P6, P7, P8,

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Current Time: 551

Next process on the CPU: P3, Burst: 6

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P4 12

P2 32

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

Completed: P1, P5, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 563

Next process on the CPU: P4, Burst: 5

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P2 20

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

Completed: P1, P3, P5, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 583

Next process on the CPU: P2, Burst: 8

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P4 62

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

Completed: P1, P3, P5, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 645

Next process on the CPU: P4, Burst: 3

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

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

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 648

Next process on the CPU: [idle]

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

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

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Finished

total\_time: 648

CPU utilization: 85.3395061728395%

Wait times: P1 P2 P3 P4 P5 P6 P7 P8

170 164 165 164 221 230 184 184

Ave Wait: 185.25

T-around times: P1 P2 P3 P4 P5 P6 P7 P8

395 591 557 648 530 445 512 493

Ave T-around: 521.375

Response times: P1 P2 P3 P4 P5 P6 P7 P8

0 5 9 17 20 36 47 61

Ave Response: 24.375

SJF

Current Time: 0 sjf

Next process on the CPU: P4, Burst: 3

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

List of processes in the ready queue:

Process Burst

P2 4

P8 4

P1 5

P3 8

P6 11

P7 14

P5 16

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

Completed: [empty]

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Current Time: 3

Next process on the CPU: P2, Burst: 4

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

List of processes in the ready queue:

Process Burst

P8 4

P1 5

P3 8

P6 11

P7 14

P5 16

List of processes in I/O:

Process Remaining I/O Time

P4 35

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 7

Next process on the CPU: P8, Burst: 4

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

List of processes in the ready queue:

Process Burst

P1 5

P3 8

P6 11

P7 14

P5 16

List of processes in I/O:

Process Remaining I/O Time

P4 31

P2 48

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 11

Next process on the CPU: P1, Burst: 5

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

List of processes in the ready queue:

Process Burst

P3 8

P6 11

P7 14

P5 16

List of processes in I/O:

Process Remaining I/O Time

P4 27

P2 44

P8 14

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 16

Next process on the CPU: P3, Burst: 8

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

List of processes in the ready queue:

Process Burst

P6 11

P7 14

P5 16

List of processes in I/O:

Process Remaining I/O Time

P4 22

P2 39

P8 9

P1 27

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 24

Next process on the CPU: P6, Burst: 11

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

List of processes in the ready queue:

Process Burst

P7 14

P5 16

List of processes in I/O:

Process Remaining I/O Time

P4 14

P2 31

P8 1

P1 19

P3 33

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 35

Next process on the CPU: P8, Burst: 5

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

List of processes in the ready queue:

Process Burst

P7 14

P5 16

List of processes in I/O:

Process Remaining I/O Time

P4 3

P2 20

P1 8

P3 22

P6 22

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 492

Next process on the CPU: P2, Burst: 8

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P4 38

P5 17

P3 61

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

Completed: P1, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 509

Next process on the CPU: P5, Burst: 6

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P4 21

P3 44

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

Completed: P1, P2, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 528

Next process on the CPU: P5, Burst: 3

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P4 2

P3 25

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

Completed: P1, P2, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 531

Next process on the CPU: P4, Burst: 3

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P3 22

P5 11

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

Completed: P1, P2, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 542

Next process on the CPU: P5, Burst: 4

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

P3 11

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

Completed: P1, P2, P4, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 553

Next process on the CPU: P3, Burst: 15

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

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

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 586

Next process on the CPU: P3, Burst: 14

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

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

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 626

Next process on the CPU: P3, Burst: 5

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

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

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 662

Next process on the CPU: P3, Burst: 6

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

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

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 668

Next process on the CPU: [idle]

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

List of processes in the ready queue:

Process Burst

[empty]

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

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

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Finished

total\_time: 668

CPU utilization: 82.78443113772454%

Wait times: P1 P2 P3 P4 P5 P6 P7 P8

43 73 276 50 237 121 149 119

Ave Wait: 133.5

T-around times: P1 P2 P3 P4 P5 P6 P7 P8

268 500 668 534 546 336 477 428

Ave T-around: 469.625

Response times: P1 P2 P3 P4 P5 P6 P7 P8

11 3 16 0 109 24 47 7

Ave Response: 27.125

MLFQ

Current Time: 0 mlfq

Next process on the CPU: P1, Burst: 5

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

List of processes in the ready queue:

Process Burst Queue

P2 4 Q1

P3 8 Q1

P4 3 Q1

P5 16 Q1

P6 11 Q1

P7 14 Q1

P8 4 Q1

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 5

Next process on the CPU: P2, Burst: 4

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

List of processes in the ready queue:

Process Burst Queue

P3 8 Q1

P4 3 Q1

P5 16 Q1

P6 11 Q1

P7 14 Q1

P8 4 Q1

List of processes in I/O:

Process Remaining I/O Time

P1 27

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 9

Next process on the CPU: P3, Burst: 8

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

List of processes in the ready queue:

Process Burst Queue

P4 3 Q1

P5 16 Q1

P6 11 Q1

P7 14 Q1

P8 4 Q1

List of processes in I/O:

Process Remaining I/O Time

P1 23

P2 48

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 14

Next process on the CPU: P4, Burst: 3

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

List of processes in the ready queue:

Process Burst Queue

P5 16 Q1

P6 11 Q1

P7 14 Q1

P8 4 Q1

P3 3 Q2

List of processes in I/O:

Process Remaining I/O Time

P1 18

P2 43

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

Completed: [empty]

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 498

Next process on the CPU: P4, Burst: 3

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

List of processes in the ready queue:

Process Burst Queue

P2 7 Q3

P3 14 Q3

P7 4 Q3

List of processes in I/O:

Process Remaining I/O Time

P5 9

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

Completed: P1, P6, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 501

Next process on the CPU: P2, Burst: 7

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

List of processes in the ready queue:

Process Burst Queue

P3 14 Q3

P7 4 Q3

List of processes in I/O:

Process Remaining I/O Time

P5 6

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

Completed: P1, P4, P6, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 508

Next process on the CPU: P3, Burst: 14

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

List of processes in the ready queue:

Process Burst Queue

P7 4 Q3

P5 6 Q3

List of processes in I/O:

Process Remaining I/O Time

P2 43

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

Completed: P1, P4, P6, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 522

Next process on the CPU: P7, Burst: 4

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

List of processes in the ready queue:

Process Burst Queue

P5 6 Q3

List of processes in I/O:

Process Remaining I/O Time

P2 29

P3 26

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

Completed: P1, P4, P6, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 526

Next process on the CPU: P5, Burst: 6

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

List of processes in the ready queue:

Process Burst Queue

[empty]

List of processes in I/O:

Process Remaining I/O Time

P2 25

P3 22

P7 33

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

Completed: P1, P4, P6, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 545

Next process on the CPU: P5, Burst: 3

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

List of processes in the ready queue:

Process Burst Queue

[empty]

List of processes in I/O:

Process Remaining I/O Time

P2 6

P3 3

P7 14

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

Completed: P1, P4, P6, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 548

Next process on the CPU: P3, Burst: 5

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

List of processes in the ready queue:

Process Burst Queue

[empty]

List of processes in I/O:

Process Remaining I/O Time

P2 3

P7 11

P5 11

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

Completed: P1, P4, P6, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 553

Next process on the CPU: P2, Burst: 8

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

List of processes in the ready queue:

Process Burst Queue

[empty]

List of processes in I/O:

Process Remaining I/O Time

P7 6

P5 6

P3 31

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

Completed: P1, P4, P6, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 561

Next process on the CPU: P7, Burst: 10

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

List of processes in the ready queue:

Process Burst Queue

P5 4 Q3

List of processes in I/O:

Process Remaining I/O Time

P3 23

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

Completed: P1, P2, P4, P6, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 571

Next process on the CPU: P5, Burst: 4

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

List of processes in the ready queue:

Process Burst Queue

[empty]

List of processes in I/O:

Process Remaining I/O Time

P3 13

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

Completed: P1, P2, P4, P6, P7, P8,

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 584

Next process on the CPU: P3, Burst: 6

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

List of processes in the ready queue:

Process Burst Queue

[empty]

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

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

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Current Time: 590

Next process on the CPU: [idle]

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

List of processes in the ready queue:

Process Burst Queue

[empty]

List of processes in I/O:

Process Remaining I/O Time

[empty]

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

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

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

Finished

total\_time: 590

CPU utilization: 93.72881355932203%

Wait times: P1 P2 P3 P4 P5 P6 P7 P8

50 134 198 17 266 179 243 151

Ave Wait: 154.75

T-around times: P1 P2 P3 P4 P5 P6 P7 P8

275 561 590 501 575 394 571 460

Ave T-around: 490.875

Response times: P1 P2 P3 P4 P5 P6 P7 P8

0 5 9 14 17 22 27 32

Ave Response: 15.75

**Source Code**

**class** **CPU**():

**def** **\_\_init\_\_**(self):

self.process = []

self.occupied = False

self.cpu\_time = **0**

**def** **add**(self, process):

self.process = process

self.occupied = True

**def** **execute**(self):

self.process[**1**][**0**] -= **1**

**if** self.process[**1**][**0**] == **0**:

**del** self.process[**1**][**0**]

self.occupied = False

self.cpu\_time += **1**

**class** **IO**():

**def** **\_\_init\_\_**(self):

self.io\_list = []

**def** **add**(self, process):

self.io\_list.append(process)

**def** **execute**(self):

**for** p **in** self.io\_list:

p[**1**][**0**] -= **1**

**class** **Data**():

**def** **\_\_init\_\_**(self):

self.ready\_queue = []

self.cpu = CPU()

self.io = IO()

self.completed = []

self.total\_time = **0**

self.cpu\_time = **0**

self.wait = dict()

self.turn\_around = dict()

self.response = dict()

self.mlfq = [[], [], []]

self.qcounter = [**0**, **0**]

self.gantt = []

# Information printed at each context switch for FCFS and SJF

**def** **print\_context\_switch**(data):

**print**(f"""

Current Time: {data.total\_time}

Next process on the CPU: {data.cpu.process[0] + ", Burst: " + str(data.cpu.process[1][0]) if data.cpu.process else "[idle]"}

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

List of processes in the ready queue:

**\t**Process**\t\t**Burst""")

**for** p **in** data.ready\_queue:

**print**(f"**\t**{p[0]}**\t\t**{p[1][0]}")

**if** **not** data.ready\_queue:

**print**("**\t**[empty]")

**print**(f"""

List of processes in I/O:

**\t**Process**\t\t**Remaining I/O Time""")

**for** p **in** data.io.io\_list:

**print**(f"**\t**{p[0]}**\t\t**{p[1][0]}")

**if** **not** data.io.io\_list:

**print**("**\t**[empty]")

**print**("..................................................................")

**print**("Completed: ", end='')

**if** data.completed:

**for** c **in** sorted(data.completed):

**print**(c, end=', ')

**print**('**\n**')

**else**:

**print**("[empty]")

**print**("::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::")

# Printing the details of the final results

**def** **print\_detail**(data\_dict, title):

**print**(f"{title} times:", end='**\t\t**')

**for** k **in** sorted(data\_dict.keys()):

**print**(f"{k}", end='**\t**')

**print**("**\n\t\t\t**", end='')

**for** k **in** sorted(data\_dict.keys()):

**print**(f"{data\_dict[k]}", end='**\t**')

**print**(f"**\n**Ave {title}:**\t\t**{sum(list(data\_dict.values())) / len(data\_dict)}**\n**")

# Information printed at the end of simulation

**def** **print\_finished**(data):

**print**("Finished**\n**")

**print**(f"total\_time:**\t\t**{data.total\_time}")

**print**(f"CPU utilization:**\t**{data.cpu.cpu\_time / data.total\_time \* 100}%**\n**")

print\_detail(data.wait, "Wait")

print\_detail(data.turn\_around, "T-around")

print\_detail(data.response, "Response")

# Print out raw gantt chart

**def** **print\_gantt\_chart**(data):

**for** p **in** data.gantt:

**if** p[**0**] == 'idle':

**print**('|' + p[**0**], end='**\t**')

**else**:

**print**('|' + p[**0**], end='**\t\t**' )

**print**('|idle')

**for** t **in** data.gantt:

**print**(t[**1**], end='**\t\t**')

**print**(data.total\_time)

# FCFS scheduling algorithm

**def** **fcfs**(data):

context\_switch = True

idle = False

**while** data.ready\_queue **or** data.cpu.process **or** data.io.io\_list:

# check CPU first

**if** **not** data.cpu.occupied **and** data.ready\_queue:

data.cpu.add(data.ready\_queue.pop(**0**))

**if** data.response[data.cpu.process[**0**]] < **0**: # record response time

data.response[data.cpu.process[**0**]] = data.total\_time

context\_switch = True

idle = False

**else**:

context\_switch = False

**if** context\_switch:

print\_context\_switch(data)

data.gantt.append((data.cpu.process[**0**], data.total\_time))

**if** **not** data.cpu.occupied **and** **not** data.ready\_queue **and** **not** idle:

data.gantt.append(('idle', data.total\_time))

idle = True

data.total\_time += **1** # time tick

# execute current process on CPU

**if** data.cpu.occupied:

data.cpu.execute()

# execute process on IO

data.io.execute()

# everyone else on ready\_queue waits

**for** p **in** list(data.ready\_queue):

data.wait[p[**0**]] += **1**

**if** **not** data.cpu.occupied **and** data.cpu.process: # move process to IO, trigger context switch

**if** data.cpu.process[**1**]: # there are still CPU or IO left

data.io.add(data.cpu.process)

**else**:

data.completed.append(data.cpu.process[**0**])

data.turn\_around[data.cpu.process[**0**]] = data.total\_time # record turn around time

data.cpu.process = []

# check IO, push completed process to ready\_queue

temp = data.io.io\_list[:]

data.io.io\_list = []

**for** p **in** temp:

**if** p[**1**][**0**] == **0**: # completed IO process

**del** p[**1**][**0**]

data.ready\_queue.append(p)

**else**:

data.io.io\_list.append(p)

print\_context\_switch(data)

# SJF scheduling algorithm

**def** **sjf**(data):

context\_switch = True

idle = False

**while** data.ready\_queue **or** data.cpu.process **or** data.io.io\_list:

data.ready\_queue.sort(key=**lambda** x: x[**1**][**0**]) # put shortest job at front

# check CPU first

**if** **not** data.cpu.occupied **and** data.ready\_queue:

data.cpu.add(data.ready\_queue.pop(**0**))

**if** data.response[data.cpu.process[**0**]] < **0**: # record response time

data.response[data.cpu.process[**0**]] = data.total\_time

context\_switch = True

idle = False

**else**:

context\_switch = False

**if** context\_switch:

print\_context\_switch(data)

data.gantt.append((data.cpu.process[**0**], data.total\_time))

**if** **not** data.cpu.occupied **and** **not** data.ready\_queue **and** **not** idle:

data.gantt.append(('idle', data.total\_time))

idle = True

data.total\_time += **1** # time tick

# execute current process on CPU

**if** data.cpu.occupied:

data.cpu.execute()

# execute process on IO

data.io.execute()

# everyone else on ready\_queue waits

**for** p **in** list(data.ready\_queue):

data.wait[p[**0**]] += **1**

**if** **not** data.cpu.occupied **and** data.cpu.process: # move process to IO, trigger context switch

**if** data.cpu.process[**1**]: # there are still CPU or IO left

data.io.add(data.cpu.process)

**else**:

data.completed.append(data.cpu.process[**0**])

data.turn\_around[data.cpu.process[**0**]] = data.total\_time # record turn around time

data.cpu.process = []

# check IO, push completed process to ready\_queue

temp = data.io.io\_list[:]

data.io.io\_list = []

**for** p **in** temp:

**if** p[**1**][**0**] == **0**: # completed IO process

**del** p[**1**][**0**]

data.ready\_queue.append(p)

**else**:

data.io.io\_list.append(p)

print\_context\_switch(data)

# Information printed at each context switch for MLFQ

**def** **print\_context\_switch\_mlfq**(data):

mlfq\_names = ['Q1', 'Q2', 'Q3']

**print**(f"""

Current Time: {data.total\_time}

Next process on the CPU: {data.cpu.process[0] + ", Burst: " + str(data.cpu.process[1][0]) if data.cpu.process else "[idle]"}

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

List of processes in the ready queue:

**\t**Process**\t\t**Burst**\t\t**Queue""")

**for** q **in** data.mlfq:

**for** p **in** q:

**print**(f"**\t**{p[0]}**\t\t**{p[1][0]}**\t\t**{mlfq\_names[p[2]]}")

**if** **not** any(data.mlfq):

**print**("**\t**[empty]")

**print**(f"""

List of processes in I/O:

**\t**Process**\t\t**Remaining I/O Time""")

**for** p **in** data.io.io\_list:

**print**(f"**\t**{p[0]}**\t\t**{p[1][0]}")

**if** **not** data.io.io\_list:

**print**("**\t**[empty]")

**print**("..................................................................")

**print**("Completed: ", end='')

**if** data.completed:

**for** c **in** sorted(data.completed):

**print**(c, end=', ')

**print**('**\n**')

**else**:

**print**("[empty]")

**print**("::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::")

# MLFQ scheduling algorithm

**def** **mlfq**(data):

context\_switch = True

idle = False

**while** any(data.mlfq) **or** data.io.io\_list **or** data.cpu.process:

# check CPU first

**if** **not** data.cpu.occupied **or** **not** data.cpu.process:

**for** i, q **in** enumerate(data.mlfq):

**if** q:

data.cpu.add(q.pop(**0**))

**if** i < **2**:

data.qcounter[i] = **0**

**if** data.response[data.cpu.process[**0**]] < **0**: # record response time

data.response[data.cpu.process[**0**]] = data.total\_time

context\_switch = True

idle = False

**break**

**else**:

context\_switch = False

**else**:

curr\_process\_priority = data.cpu.process[**2**]

**for** i, q **in** enumerate(data.mlfq):

**if** i < curr\_process\_priority **and** q:

# preemption

data.mlfq[curr\_process\_priority].append(data.cpu.process)

**if** curr\_process\_priority < **2**:

data.qcounter[curr\_process\_priority] = **0**

data.cpu.add(q.pop(**0**))

data.qcounter[i] = **0**

**if** data.response[data.cpu.process[**0**]] < **0**: # record response time

data.response[data.cpu.process[**0**]] = data.total\_time

context\_switch = True

idle = False

**break**

**else**:

context\_switch = False

**if** context\_switch:

print\_context\_switch\_mlfq(data)

data.gantt.append((data.cpu.process[**0**], data.total\_time))

**if** **not** data.cpu.occupied **and** **not** any(data.mlfq) **and** **not** idle:

data.gantt.append(('idle', data.total\_time))

idle = True

data.total\_time += **1** # time tick

# execute current process on CPU

**if** data.cpu.occupied:

data.cpu.execute()

**if** data.cpu.process[**2**] < **2**:

data.qcounter[data.cpu.process[**2**]] += **1**

# execute process on IO

data.io.execute()

# everyone else on ready\_queue waits

**for** q **in** data.mlfq:

**for** p **in** q:

data.wait[p[**0**]] += **1**

**if** **not** data.cpu.occupied **and** data.cpu.process: # move process to other queue or io, trigger context switch

**if** data.cpu.process[**1**]: # there are still CPU or IO left

data.io.add(data.cpu.process)

**else**:

data.completed.append(data.cpu.process[**0**])

data.turn\_around[data.cpu.process[**0**]] = data.total\_time # record turn around time

**if** data.cpu.process[**2**] < **2**:

data.qcounter[data.cpu.process[**2**]] = **0**

data.cpu.process = []

**if** data.qcounter[**0**] == **5** **and** data.cpu.occupied **and** data.cpu.process[**2**] == **0**:

# time quantum used up, downgrade

data.cpu.process[**2**] = **1**

data.mlfq[**1**].append(data.cpu.process)

data.cpu.process = []

data.qcounter[**0**] = **0**

**if** data.qcounter[**1**] == **10** **and** data.cpu.occupied **and** data.cpu.process[**2**] == **1**:

# time quantum used up, downgrade

data.cpu.process[**2**] = **2**

data.mlfq[**2**].append(data.cpu.process)

data.cpu.process = []

data.qcounter[**1**] = **0**

# check IO, push completed process to ready\_queue

temp = data.io.io\_list[:]

data.io.io\_list = []

**for** p **in** temp:

**if** p[**1**][**0**] == **0**: # completed IO process

**del** p[**1**][**0**]

data.mlfq[p[**2**]].append(p)

**else**:

data.io.add(p)

print\_context\_switch\_mlfq(data)

# Main driver for program

**def** **main**():

# Original

bursts = [

['P1', [**5**, **27**, **3**, **31**, **5**, **43**, **4**, **18**, **6**, **22**, **4**, **26**, **3**, **24**, **4**]],

['P2', [**4**, **48**, **5**, **44**, **7**, **42**, **12**, **37**, **9**, **76**, **4**, **41**, **9**, **31**, **7**, **43**, **8**]],

['P3', [**8**, **33**, **12**, **41**, **18**, **65**, **14**, **21**, **4**, **61**, **15**, **18**, **14**, **26**, **5**, **31**, **6**]],

['P4', [**3**, **35**, **4**, **41**, **5**, **45**, **3**, **51**, **4**, **61**, **5**, **54**, **6**, **82**, **5**, **77**, **3**]],

['P5', [**16**, **24**, **17**, **21**, **5**, **36**, **16**, **26**, **7**, **31**, **13**, **28**, **11**, **21**, **6**, **13**, **3**, **11**, **4**]],

['P6', [**11**, **22**, **4**, **8**, **5**, **10**, **6**, **12**, **7**, **14**, **9**, **18**, **12**, **24**, **15**, **30**, **8**]],

['P7', [**14**, **46**, **17**, **41**, **11**, **42**, **15**, **21**, **4**, **32**, **7**, **19**, **16**, **33**, **10**]],

['P8', [**4**, **14**, **5**, **33**, **6**, **51**, **14**, **73**, **16**, **87**, **6**]]]

data = Data()

# initialize ready\_queue and wait

**for** p **in** bursts:

data.mlfq[**0**].append(p + [**0**])

data.ready\_queue.append(p)

data.wait[p[**0**]] = **0**

data.turn\_around[p[**0**]] = **0**

data.response[p[**0**]] = -**1**

# Choose which algorithm to perform

fcfs(data)

# sjf(data)

# mlfq(data)

print\_finished(data)

print\_gantt\_chart(data)

**if** \_\_name\_\_ == "\_\_main\_\_":

main()