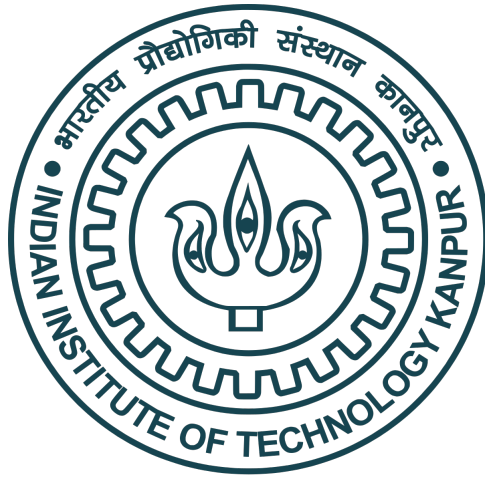


# CS330A: OPERATING SYSTEMS



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## Assignment 2

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# 1 Implementation of the schedulers

**Note:** Variables like minimum burst time, scheduling policy, overall turnaround time and other such required for an entire batch are declared global in *kernel/proc.c*.

## 1.1 SCHED\_NPREEMPT\_SJF

The algorithm finds the job with least estimated CPU burst length by iterating through the process table. In between, if it comes across a process which is not part of the batch (not created using *forkp*), it schedules it immediately and looks out for the next job in the next loop. After finding the job with smallest estimated CPU burst length, it schedules it. In case of interrupt, the estimation is updated. The estimated CPU burst length is stored as a process table entry.

## 1.2 SCHED\_PREEMPT\_UNIX

Being a pre-emptive scheduler, timer interrupts are possible. In the scheduler function in *kernel/proc.c* we first update the priority of all the processes according to the formula given. Then in another iteration, we find the job with minimum priority and schedule it. In cases of interruption, we change the CPU Usage of the process according to the given formula. Priorities and CPU Usage are stored as process table entries.

# 2 Comparison: FCFS and RR

## 2.1 Batch-1

```
$ gcc -o xt -I../lib
$ submitjobs < batch1.txt
$ 6789101112131415678910111213141567891011121314156789101112131415
Total sum: 0
Start time: 25290, End time: 43855, Total time: 18565

Total sum: 0
Start time: 25661, End time: 43857, Total time: 18196

Total sum: 0
Start time: 26053, End time: 43859, Total time: 17806

Total sum: 0
Start time: 26415, End time: 43861, Total time: 17446

Total sum: 0
Start time: 26775, End time: 43863, Total time: 17088

Total sum: 0
Start time: 27135, End time: 43865, Total time: 16730

Total sum: 0
Start time: 27496, End time: 43867, Total time: 16371

Total sum: 0
Start time: 27878, End time: 43869, Total time: 15991

Total sum: 0
Start time: 28277, End time: 43872, Total time: 15595

Total sum: 0
Start time: 28653, End time: 43874, Total time: 15221
Batch execution time: 18589
Average turn-around time: 18577
Average waiting time: 16717
Completion time: avg: 43866, max: 43877, min: 43857
□
```

First Come First Serve

```

$ cat submitjobs.txt
$ submitjobs < batch1.txt
$ 567891011121314567891011121314567891011121314567891011121314
Total sum: 0
Start time: 12134, End time: 34669, Total time: 22535

Total sum: 0
Start time: 12546, End time: 34671, Total time: 22125

Total sum: 0
Start time: 12951, End time: 34674, Total time: 21723

Total sum: 0
Start time: 13353, End time: 34676, Total time: 21323

Total sum: 0
Start time: 13757, End time: 34678, Total time: 20921

Total sum: 0
Start time: 14192, End time: 34680, Total time: 20488

Total sum: 0
Start time: 14643, End time: 34682, Total time: 20039

Total sum: 0
Start time: 15056, End time: 34684, Total time: 19628

Total sum: 0
Start time: 15534, End time: 34686, Total time: 19152

Total sum: 0
Start time: 15977, End time: 34688, Total time: 18711
Batch execution time: 22559
Average turn-around time: 22548
Average waiting time: 20291
Completion time: avg: 34680, max: 34690, min: 34671

```

Round Robin

## 2.2 Batch-2

```

init: starting sh
$ submitjobs < batch2.txt
$ 45678910111213456789101112134567891011121345678910111213
Total sum: 0
Start time: 3239, End time: 24098, Total time: 20859

Total sum: 0
Start time: 3649, End time: 24100, Total time: 20451

Total sum: 0
Start time: 4053, End time: 24102, Total time: 20049

Total sum: 0
Start time: 4458, End time: 24104, Total time: 19646

Total sum: 0
Start time: 4862, End time: 24106, Total time: 19244

Total sum: 0
Start time: 5267, End time: 24108, Total time: 18841

Total sum: 0
Start time: 5676, End time: 24110, Total time: 18434

Total sum: 0
Start time: 6142, End time: 24112, Total time: 17970

Total sum: 0
Start time: 6551, End time: 24114, Total time: 17563

Total sum: 0
Start time: 6954, End time: 24116, Total time: 17162
Batch execution time: 20882
Average turn-around time: 20871
Average waiting time: 18788
Completion time: avg: 24109, max: 24118, min: 24100

```

First Come First Serve

```

$ submitjobs < batch2.txt
$ 576810941312115710896131112479581061311124597108136111241059
Total sum: 0
Start time
Total sum: 0
Start time: 6320
Total sum: 0
Start time: 6338, End time: 26544, Total, End time: 26549, Total time: 20229 En
tim
7e: 20205

Total sum: 0
Start time: 6330, End time: 26575, Total time: 20245

Total sum: 0
Start time: 6331, End time: 26582, Total time: 20
Total sum: 0
Start time: 6349, End time: 26589, Total time: 20240
ime: 26589, Total time: 20240
11
Total sum: 0
Start time: 6348, End time: 26600, Total time: 20252
13
Total sum: 0
Start time: 6350, End time: 26607, Total time: 20257

Total sum: 0
Start time: 6329, End time: 26614, Total time: 20285
4
Total sum: 0
Start time: 6319, End time: 26631, Total time: 20312
Batch execution time: 20317
Average turn-around time: 20260
Average waiting time: 18235
Completion time: avg: 26594, max: 26633, min: 26563

```

## Round Robin

**Explanation of 1(a) and 1(b)** - We receive similar statistics, and the PIDs get printed in the same fashion for both FCFS and RR. This is because, the yield and system calls in testloop programs, interrupt the FCFS and since we did not disable the yield and sleep system call interrupts, FCFS works just like round-robin in these cases. This example demonstrates that *Round-Robin is just a special case of FCFS*, and that FCFS can also behave exactly like Round-Robin.

## 2.3 Batch-7

```

$ submitjobs < batch7.txt
$ 44444
Total sum: 0
Start time: 2654, End time: 4665, Total time: 2011
55555
Total sum: 0
Start time: 4667, End time: 6694, Total time: 2027
66666
Total sum: 0
Start time: 6696, End time: 8721, Total time: 2025
77777
Total sum: 0
Start time: 8724, End time: 10757, Total time: 2033
88888
Total sum: 0
Start time: 10760, End time: 12796, Total time: 2036
99999
Total sum: 0
Start time: 12799, End time: 14819, Total time: 2020
1010101010
Total sum: 0
Start time: 14822, End time: 16834, Total time: 2012
1111111111
Total sum: 0
Start time: 16837, End time: 18869, Total time: 2032
1212121212
Total sum: 0
Start time: 18872, End time: 20889, Total time: 2017
1313131313
Total sum: 0
Start time: 20892, End time: 22918, Total time: 2026
Batch execution time: 20271
Average turn-around time: 11145
Average waiting time: 9123
Completion time: avg: 13798, max: 22921, min: 4667

```

First Come First Serve

```

$ submitjobs < batch7.txt
$ 569478121311105678912413111051269137811104512138910711645
Total sum: 0
Start time: 2115, End time: 20770, Total time: 18655
8
Total sum: 0
Start time: 213
Total sum: 0
Start time: 2123, End time: 2082137, End time: 20832, Total time: Start time: 2128, End
10
Total sum: 0
Start time: 18695
, Total time: 18705
9
Total sum: 0
Start time: 2135, End time: 20847, Total time: 18712
Total sum: 0
Start time: 2124, End time: 20853, Total time: 18712
time: 2122, End time: 20858, Total time: 18729
al time: 18736
6
Total sum: 0
Start time: 2116, End time: 20870, Total time: 1869, Total time: 18734
4
Total sum: 0
Start time: 2114, End time: 20884, Total time: 18770
Batch execution time: 18776
Average turn-around time: 18742
Average waiting time: 16864
Completion time: avg: 20856, max: 20886, min: 20790

```

Round Robin

**Explanation 1(c)** - This example shows the difference between FCFS and Round-Robin. FCFS completes each process, then prints its statistics, and moves on to the next process. Round-Robin executes according to timer interrupts occurring when the time quantum of a process expires. Also shows the unfairness of FCFS scheduler.

## 3 CPU burst estimation error

### 3.1 Batch-2

```
$ submitjobs < batch2.txt
$ 44444
Total sum: 0
Start time: 3400, End time: 5466, Total time: 2066
55555
Total sum: 0
Start time: 5469, End time: 7549, Total time: 2080
66666
Total sum: 0
Start time: 7552, End time: 9718, Total time: 2166
77777
Total sum: 0
Start time: 9720, End time: 11757, Total time: 2037
88888
Total sum: 0
Start time: 11760, End time: 13793, Total time: 2033
99999
Total sum: 0
Start time: 13797, End time: 15823, Total time: 2026
1010101010
Total sum: 0
Start time: 15826, End time: 17851, Total time: 2025
1111111111
Total sum: 0
Start time: 17854, End time: 19877, Total time: 2023
1212121212
Total sum: 0
Start time: 19881, End time: 21896, Total time: 2015
1313131313
Total sum: 0
Start time: 21900, End time: 23918, Total time: 2018
Batch execution time: 20523
Average turn-around time: 11368
Average waiting time: 9320
Completion time: avg: 14766, max: 23920, min: 5468
CPU bursts: count: 69, avg: 789, max: 3399, min: 1
CPU burst estimates: 61, avg: 813, max: 1700, min: 409
CPU burst estimation error: count: 59, avg: 450
$
```

Shortest Job First



### 3.2 Batch-3

[illegible]

## Shortest Job First

**Explanation:** The only difference in batch2 and batch3 is the number of OUTER iterations. Batch3 has a much larger OUTER\_BOUND(20). If we observe carefully, the number of OUTER\_BOUNDS directly relates to the error samples in the SJF algorithms. So, quite trivially the average estimation error per CPU burst length is smaller for a larger sampling i.e. batch3. This is a trivial statistical result, and our output confirms it.

## 4 Comparison: FCFS and SJF

### 4.1 Batch-4

```
init: starting on
$ submitjobs < batch4.txt
$ 45678910111213456789101112134567891011121345678910111213
Total sum: 0
Start time: 1473, End time: 16777, Total time: 15304

Total sum: 0
Start time: 1889, End time: 16779, Total time: 14890

Total sum: 0
Start time: 2096, End time: 16780, Total time: 14684

Total sum: 0
Start time: 2520, End time: 16782, Total time: 14262

Total sum: 0
Start time: 2722, End time: 16785, Total time: 14063

Total sum: 0
Start time: 3130, End time: 16787, Total time: 13657

Total sum: 0
Start time: 3341, End time: 16789, Total time: 13448

Total sum: 0
Start time: 3761, End time: 16791, Total time: 13030

Total sum: 0
Start time: 3975, End time: 16793, Total time: 12818

Total sum: 0
Start time: 4397, End time: 16795, Total time: 12398
Batch execution time: 15327
Average turn-around time: 15316
Average waiting time: 13787
Completion time: avg: 16787, max: 16797, min: 16779
```

First Come First Serve

```
init: starting on
$ submitjobs < batch4.txt
$ 44444
Total sum: 0
Start time: 2232, End time: 4088, Total time: 1856
655555
Total sum: 0
Start time: 4457, End time: 5357, Total time: 900
6666
Total sum: 0
Start time: 4090, End time: 6843, Total time: 2753
77777
Total sum: 0
Start time: 6846, End time: 7758, Total time: 912
88888
Total sum: 0
Start time: 7762, End time: 9605, Total time: 1843
99999
Total sum: 0
Start time: 9609, End time: 10601, Total time: 992
1010101010
Total sum: 0
Start time: 10605, End time: 12592, Total time: 1987
1111111111
Total sum: 0
Start time: 12596, End time: 13514, Total time: 918
1212121212
Total sum: 0
Start time: 13517, End time: 15316, Total time: 1799
1313131313
Total sum: 0
Start time: 15319, End time: 16231, Total time: 912
Batch execution time: 14003
Average turn-around time: 7961
Average waiting time: 6565
Completion time: avg: 10192, max: 16233, min: 4090
CPU bursts: count: 69, avg: 526, max: 2231, min: 1
CPU burst estimates: 63, avg: 525, max: 1116, min: 183
CPU burst estimation error: count: 59, avg: 273
```



## Shortest Job First

**Explanation** - FCFS works like it did in 1(a) and 1(b) as expected. The key observation here is the *large average waiting time difference*. As expected by the nature of the algorithm, FCFS increases the average waiting time of the batch, whereas SJF has less average waiting time, because it keeps updating the estimated burst length after interrupts due to yield, and every process has to wait for a shorter time as compared to FCFS.

## 5 Comparison: RR and UNIX

### 5.1 Batch-5

```
ctrl: starting sh
$ submitjobs < batch5.txt
$ 56781012139114681257910411136810129475111368101247951113610
Total sum: 0
Start time: 842, End time: 13430, Total time: 12588

Total sum: 0
Start time: 846, End time: 13433, Total time: 12587
128
Total sum: 0
Start time: 848, End time: 13440, Total time: 12592

Total sum: 0
Start time: 844, End time: 13444, Total time: 12600
49
Total sum: 0
Start time: 840, End time: 13457, Total time: 12617
7
Total sum: 0
Start time: 845, End time: 13458, Total time: 12613
Total sum: 0
Start time: 843, End time: 13461, Total time: 12618
e: 13458, Total time: 12613

Total sum: 0
Start time: 849, End time: 13462, Total time: 12613
5
Total sum: 0
Start time: 841, End time: 13463, Total time: 12622
11
Total sum: 0
Start time: 847, End time: 13465, Total time: 12618
Batch execution time: 12627
Average turn-around time: 12609
Average waiting time: 11345
Completion time: avg: 13451, max: 13465, min: 13430
```

## Round Robin

```

ctrl. starting sh
$ submitjobs < batch5.txt
$ 13121113121013121113121013
Total sum: 0
Start time: 653, End time: 4456, Total time: 3803
12
Total sum: 0
Start time: 654, End time: 4463, Total time: 3809
111011109811
Total sum: 0
Start time: 655, End time: 6360, Total time: 5705
10
Total sum: 0
Start time: 662, End time: 6365, Total time: 5703
989876989
Total sum: 0
Start time: 4465, End time: 9209, Total time: 4744
8
Total sum: 0
Start time: 4472, End time: 9221, Total time: 4749
767645767
Total sum: 0
Start time: 6364, End time: 11579, Total time: 5215
6
Total sum: 0
Start time: 6374, End time: 11606, Total time: 5232
5454455
Total sum: 0
Start time: 9214, End time: 13340, Total time: 4126
4
Total sum: 0
Start time: 652, End time: 13341, Total time: 12689
Batch execution time: 12692
Average turn-around time: 8343
Average waiting time: 7069
Completion time: avg: 8994, max: 13341, min: 4456

```

## UNIX Scheduling

## 5.2 Batch-6

```
ctrl: starting sh
$ submitjobs < batch6.txt
$ 6581012479111365810127911413658101279111346125791011813465
Total sum: 0
Start time: 875, End time: 13483, Total time: 12608
91112
Total sum: 0
Start time: 874, End time: 13488, Total time: 12614
8
Total sum: 0
Start time: 878, End time: 13490, Total time: 12610
Total sum: 0
Start time: 880, End time: 13490, Total time: 12610
Total sum: 0
Start time: 881, End time: 13497
Total sum: 0
e: 13489, Total time: 12611
Total sum: 0
Start time: 879, End time: 13494, Total time: 12615
0, Total time: 12609
Total sum: 0
Start time: 876, End time: 13496, Total time: 12620
Start time: 877, End time: 13493, Total time: 12616
134
Total sum: 0
Start time:
Total sum: 0
Start time: 873, End time: 13499, Total time: 12626
882, End time: 13498, Total time: 12616
Batch execution time: 12628
Average turn-around time: 12621
Average waiting time: 11358
Completion time: avg: 13493, max: 13499, min: 13483
```

### Round Robin

```
ctrl: starting sh
$ submitjobs < batch6.txt
$ 13121310111213121130121113
Total sum: 0
Start time: 986, End time: 4803, Total time: 3817
12
Total sum: 0
Start time: 987, End time: 4812, Total time: 3825
101110119810
Total sum: 0
Start time: 992, End time: 6726, Total time: 5734
11
Total sum: 0
Start time: 989, End time: 6727, Total time: 5738
989867989
Total sum: 0
Start time: 4808, End time: 9593, Total time: 4785
8
Total sum: 0
Start time: 4821, End time: 9602, Total time: 4781
7667546767
Total sum: 0
Start time: 6732, End time: 11981, Total time: 5249
Total sum: 0
Start time: 6729, End time: 11981, Total time: 5252
5454545
Total sum: 0
Start time: 9598, End time: 13731, Total time: 4133
4
Total sum: 0
Start time: 9611, End time: 13736, Total time: 4125
Batch execution time: 12752
Average turn-around time: 4745
Average waiting time: 7110
Completion time: avg: 9369, max: 13737, min: 4803
```

UNIX scheduling

**Explanation for 4(a) and 4(b)** - In both the cases, again the key observation is the difference in *average waiting time*. Round robin has a larger average waiting time in comparison to priority based scheduler. Priority based is more fair as compared to round-robin. Burst length of the processes is same, so turnaround time will difference will be similar to average waiting time difference which is the observation in both batch2 and batch3.