[05] SCHEDULING ALGORITHMS

OUTLINE

- First-Come First-Served
- Shortest Job First
- Shortest Response Time First
- Predicting Burst Length
- Round Robin
- Static vs Dynamic Priority

FIRST-COME FIRST-SERVED (FCFS)

Simplest possible scheduling algorithm, depending only on the order in which processes arrive

E.g. given the following demand:

Process	Burst Time
P_1	25
P_2	4
P_3	7

EXAMPLE: FCFS

Consider the average waiting time under different arrival orders

$\mathbf{P_1, P_2, P_3}$:

- Waiting time $P_1 = 0, P_2 = 25, P_3 = 29$
- Average waiting time: $\frac{(0+25+29)}{3} = 18$

$\mathbf{P_3, P_2, P_1}$:

- Waiting time $P_1 = 11, P_2 = 7, P_3 = 0$
- Average waiting time: $\frac{(11+7+0)}{3} = 6$

Arriving in reverse order is *three times as good*!

- The first case is poor due to the **convoy effect**: later processes are held up behind a long-running first process
- FCFS is simple but not terribly robust to different arrival processes

SHORTEST JOB FIRST (SJF)

Intuition from FCFS leads us to *shortest job first* (SJF) scheduling

- Associate with each process the length of its next CPU burst
- Use these lengths to schedule the process with the shortest time
- Use, e.g., FCFS to break ties

EXAMPLE: SJF

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

Waiting time for $P_1 = 0, P_2 = 6, P_3 = 3, P_4 = 7$. Average waiting time: $\frac{(0+6+3+7)}{4} = 4$

SJF is optimal with respect to average waiting time:

- It minimises average waiting time for a given set of processes
- What might go wrong?

SHORTEST REMAINING-TIME FIRST (SRTF)

Simply a preemptive version of SJF: preempt the running process if a new process arrives with a CPU burst length less than the remaining time of the current executing process

EXAMPLE: SRTF

As before:

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

Waiting time for $P_1 = 9, P_2 = 1, P_3 = 0, P_4 = 2$

Average waiting time: $\frac{(9+1+0+2)}{4} = 3$

EXAMPLE: SRTF

Surely this is optimal in the face of new runnable processes arriving? Not necessarily – why?

- Context switches are not free: many very short burst length processes may thrash the CPU, preventing useful work being done
- More fundamentally, we can't generally know what the **future** burst length is!

PREDICTING BURST LENGTHS

- For both SJF and SRTF require the next "burst length" for each process means we must estimate it
- Can be done by using the length of previous CPU bursts, using exponential averaging:

  1. t_n = actual length of n^{th} CPU burst.
  2. τ_{n+1} = predicted value for next CPU burst.
  3. For $\alpha, 0 \leq \alpha \leq 1$ define:

$$\tau_{n+1} = \alpha t_n + (1 - \alpha)\tau_n$$

PREDICTING BURST LENGTHS

- If we expand the formula we get:

$$\tau_{n+1} = \alpha t_n + \ldots + (1-\alpha)^j \alpha t_{n-j} + \ldots + (1-\alpha)^{n+1} \tau_0$$

where τ_0 is some constant

- Choose value of α according to our belief about the system, e.g., if we believe history irrelevant, choose $\alpha \approx 1$ and then get $\tau_{n+1} \approx t_n$
- In general an exponential averaging scheme is a good predictor if the variance is small
- Since both α and $(1-\alpha)$ are less than or equal to one, each successive term has less weight than its predecessor
- NB. Need some consideration of load, else get (counter-intuitively) increased priorities when increased load

ROUND ROBIN

A preemptive scheduling scheme for time-sharing systems.

- Define a small fixed unit of time called a quantum (or time-slice), typically 10 – 100 milliseconds
- Process at the front of the ready queue is allocated the CPU for (up to) one quantum
- When the time has elapsed, the process is preempted and appended to the ready queue

ROUND ROBIN: PROPERTIES

Round robin has some nice properties:

- Fair: given n processes in the ready queue and time quantum q, each process gets $1/n^{th}$ of the CPU
- Live: no process waits more than $(n-1)q$ time units before receiving a CPU allocation
- Typically get higher average turnaround time than SRTF, but better average response time

But tricky to choose the correct size quantum, q:

- q too large becomes FCFS/FIFO
- q too small becomes context switch overhead too high

PRIORITY SCHEDULING

Associate an (integer) priority with each process, e.g.,

Prio	**Process type**
0	system internal processes
1	interactive processes (staff)
2	interactive processes (students)
3	batch processes

Simplest form might be just system vs user tasks

PRIORITY SCHEDULING

- Then allocate CPU to the highest priority process: "highest priority" typically means smallest integer
    - Get preemptive and non-preemptive variants
    - E.g., SJF is a priority scheduling algorithm where priority is the predicted next CPU burst time

TIE-BREAKING

What do with ties?

- Round robin with time-slicing, allocating quantum to each process in turn
- Problem: biases towards CPU intensive jobs (Why?)
- Solution?
  - Per-process quantum based on usage?
  - Just ignore the problem?

STARVATION

Urban legend about IBM 7074 at MIT: when shut down in 1973, low-priority processes were found which had been submitted in 1967 and had not yet been run...

This is the biggest problem with static priority systems: a low priority process is not guaranteed to run – ever!

DYNAMIC PRIORITY SCHEDULING

Prevent the starvation problem: use same scheduling algorithm, but allow priorities to change over time

- Processes have a (static) base priority and a dynamic effective priority
    - If process starved for k seconds, increment effective priority
    - Once process runs, reset effective priority

EXAMPLE: COMPUTED PRIORITY

First used in Dijkstra's THE

- Timeslots: $\ldots, t, t+1, \ldots$
- In each time slot t, measure the CPU usage of process $j : u^j$
- Priority for process j in slot $t+1$:

$$p^j_{t+1} = f(u^j_t, p^j_t, u^j_{t-1}, p^j_{t-1}, \ldots)$$

- E.g., $p^j_{t+1} = \frac{p^j_t}{2} + ku^j_t$
- Penalises CPU bound but supports IO bound

Once considered impractical but now such computation considered acceptable

SUMMARY

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- Shortest Response Time First
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- Static vs Dynamic Priority