EECS 3221
Operating System Fundamentals

No.4

CPU scheduling

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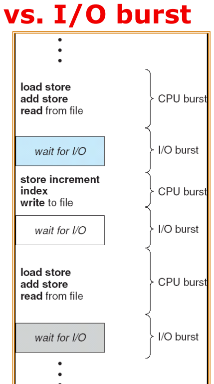
CPU Scheduling

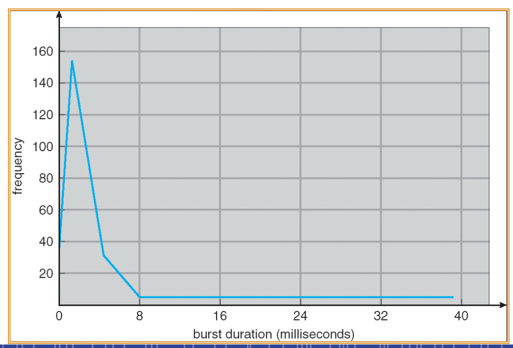
- CPU scheduling is the basis of multiprogramming
- CPU scheduling consists of two components:
  - CPU scheduler: when CPU becomes idle, the CPU scheduler must select from among the processes in ready queue.
  - Dispatcher: the module which gives control of CPU to the process selected by the CPU scheduler.
    - Switching context
    - Switching to user mode
    - Jumping to the proper location in user program to restart
  - Dispatch latency: the time it takes for the dispatcher to stop one process and start another running
    - Dispatcher should be as fast as possible

CPU burst vs. I/O burst

- Process (thread) execution
  = CPU burst + I/O burst
- Process (thread) alternates between these two states.
- Length of these bursts is very different.



Histogram of CPU-burst Times



Non-preemptive vs. Preemptive scheduling

- CPU scheduling decisions may take place when a process:
  1. Switches from running to waiting state.
  2. Switches from running to ready state.
  3. Switches from waiting to ready.
  4. Terminates.
- Non-preemptive scheduling takes place under 1 and 4.
  - Once the CPU has been allocated to a process, the process keeps the CPU until it releases CPU.
- Preemptive scheduling takes place in 1,2,3,4.
  - A running process can be preempted by another process
  - Not easy to make OS kernel to support preemptive scheduling
  - How about if the preempted process is updating some critical data structure?
    - Disable interrupt / Safety points
    - Process synchronization

Scheduling Criteria

- CPU utilization – keep the CPU as busy as possible.
  - Usage percentage (40% -- 90%)
- Throughput – # of processes that complete their execution per time unit.
- Turnaround time – amount of time to execute a particular process.
  - The interval from the time of submission a process to the time of completion.
- Waiting time – amount of time a process has been waiting in the ready queue.
- Response time – amount of time it takes from when a request was submitted until the first response is produced, *not* the final output (for time-sharing environment).

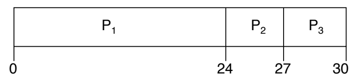
Scheduling Algorithms

- First-come, first-served (FCFS) scheduling
- Shortest-Job-First (SJF) Scheduling
- Priority Scheduling
- Round-Robin (RR) scheduling
- Multi-level Queue Scheduling
- Multilevel Feedback Queue Scheduling

First-Come, First-Served (FCFS) Scheduling

Process	Burst Time
P_1	24
P_2	3
P_3	3

- Suppose that the processes arrive at time 0 in the order: P_1 , P_2 , P_3
The Gantt Chart for the scheduling is:



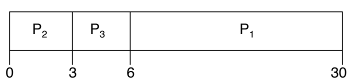
- Waiting time for P_1 = 0; P_2 = 24; P_3 = 27.
- Average waiting time: (0 + 24 + 27)/3 = 17.

FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order:

P_2 , P_3 , P_1 .

- The Gantt chart for the schedule is:



- Waiting time for P_1 = 6; P_2 = 0, P_3 = 3.
- Average waiting time: (6 + 0 + 3)/3 = 3.
- FCFS is easy to implement (as a FIFO sequence).
- FCFS results in long wait in most cases and suffers convoy effect.
  - *Convoy effect* : all the other processes wait for one big process to get off the CPU.

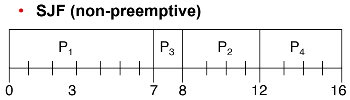
Shortest-Job-First (SJF) Scheduling

- Associate with each process the length of its next CPU burst. Schedule CPU to process with the shortest time.
  - The shortest one is the first.
- Implementation: ready queue → sorted list.
- Two schemes:
  - Non-preemptive – once CPU given to the process it cannot be preempted until it completes its CPU burst.
  - Preemptive – if a new process arrives with CPU burst length less than remaining time of current executing process, it preempts. This scheme is know as the Shortest-Remaining-Time-First (SRTF).
- SJF is optimal – gives minimum average waiting time for a given set of processes.

Example of Non-Preemptive SJF

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

- SJF (non-preemptive)

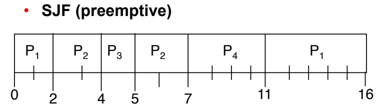


- Average waiting time = (0 + 6 + 3 + 7)/4 = 4

Example of Preemptive SJF (shortest-remaining-time-first)

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

- SJF (preemptive)



- Average waiting time = (9 + 1 + 0 +2)/4 = 3

Determining Length of Next CPU Burst

- Length of next CPU burst is unknown.
- Can only estimate the length.
- Can be done by using the length of previous CPU bursts, using ***exponential averaging***, to predict the next one.

1. $t_n =$ actual lenght of n^{th} CPU burst
2. $\tau_{n+1} =$ predicted value for the next CPU burst
3. $\alpha, 0 \le \alpha \le 1$
4. Define: $\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\tau_n.$

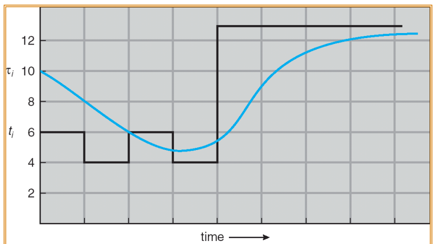
Examples of Exponential Averaging

- **α=0**
  - $\tau_{n+1} = \tau_n = \ldots = \tau_0$
  - Recent history does not count.
- **α=1**
  - $\tau_{n+1} = t_n$
  - Only the actual last CPU burst counts.
- If we expand the formula, we get:

$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\, t_{n-1} + \ldots + (1 - \alpha)^j\, t_{n-j} + \ldots + (1 - \alpha)^{n-1}\, t_0$$

- Since both α and (1 - α) are less than or equal to 1, each successive term has less weight than its predecessor.

Prediction of the Length of the Next CPU Burst



CPU burst (t_i)		6	4	6	4	13	13	13 …
"guess" (τ_i)	10	8	6	6	5	9	11	12 …

Priority Scheduling

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority (smallest integer ➔ highest priority).
  - Preemptive
  - Nonpreemptive
- SJF is a priority scheduling where priority is the predicted next CPU burst time.
- Problem ➔ Starvation – low priority processes may never execute.
- Solution ➔ Aging – as time progresses increase the priority of the process.

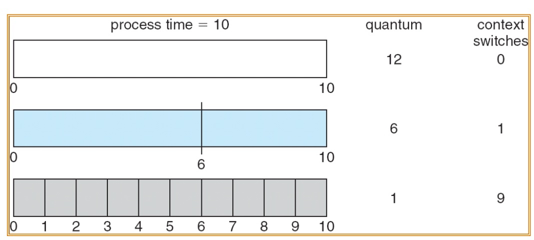
Round Robin (RR)

- Each process gets a small slice of CPU time (***time quantum***), usually 10-100 milliseconds. After this time has elapsed, the process is preempted and added to the end of the ready queue.
  - Ready queue is a circular queue or FIFO queue.

- **Fairness**: If there are ***n*** processes in the ready queue and the time quantum is ***q***, then each process gets 1/***n*** of the CPU time in chunks of at most ***q*** time units at once. No process waits more than (***n***-1)***q*** time units.

- Performance:
  - ***q*** large ➔ FCFS
  - ***q*** small ➔ too many context switches, so overhead is high.
  - ***q*** must be large with respect to most CPU bursts' lengths.

Time Quantum and Context Switch Time



Example of RR with Time Quantum = 20

Process	Burst Time
P_1	53
P_2	17
P_3	68
P_4	24

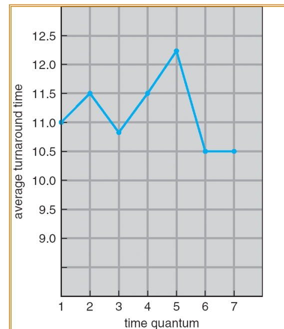
- The Gantt chart is:

P_1	P_2	P_3	P_4	P_1	P_3	P_4	P_1	P_3	P_3

0 20 37 57 77 97 117 121 134 154 162

- Typically, higher average waiting time than SJF, but better *response*.

Turnaround Time Varies With The Time Quantum

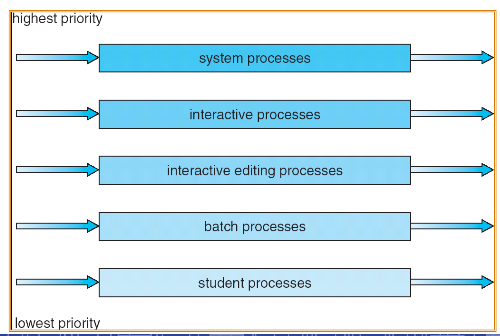


process	time
P_1	6
P_2	3
P_3	1
P_4	7

Multilevel Queue

- Ready queue is partitioned into separate queues:
  - foreground (interactive)
  - background (batch)
- Any process is permanently assigned to one of these queues
- Each queue has its own scheduling algorithm, i.e.,
  - foreground – RR
  - background – FCFS
- Scheduling must be done between the queues.
  - Fixed priority scheduling; (i.e., serve all from foreground then from background). Possibility of starvation.
  - Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its processes; i.e.,
    - 80% to foreground in RR
    - 20% to background in FCFS

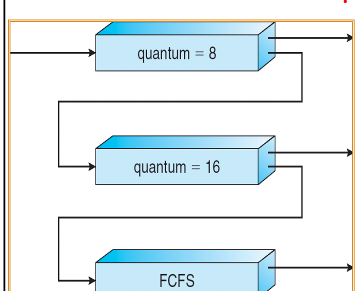
One example of multilevel Queue Scheduling



Multilevel Feedback Queue

- A process can move between the various queues; aging can be implemented this way.
  - If used too much CPU time → lower-priority queue
  - If waited too long → higher-priority queue
- Multilevel-feedback-queue scheduler defined by the following parameters:
  - number of queues
  - scheduling algorithms for each queue
  - method to determine when to upgrade a process
  - method to determine when to demote a process
  - method to determine which queue a process will enter when that process needs service
- It is the most general CPU scheduling algorithm. Can be configured to match a specific system under design.

Example of Multilevel Feedback Queue



- Three queues:
  - Q_0 – time quantum 8 milliseconds
  - Q_1 – time quantum 16 milliseconds
  - Q_2 – FCFS

Scheduling
  - A new job enters queue Q_0. When it gains CPU, job receives 8 milliseconds. If it does not finish in 8 milliseconds, job is moved to queue Q_1.
  - At Q_1 job is again served RR and receives 16 additional milliseconds. If it still does not complete, it is preempted and moved to queue Q_2.
  - Always preemptive.

Scheduling in multi-CPU Era

- Multiple-Processor Scheduling
  - Multi-core scheduling
- Scheduling for multiple systems
  - Load balancer (long-term scheduler)
  - Scheduling for distributed systems

Multiple-Processor Scheduling

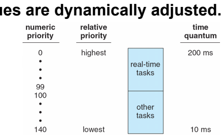
- CPU scheduling more complex when multiple CPUs are available.
- *Homogeneous processors* within a multiprocessor.
  - Any available processor can then be used to run any process in the queue.
- One common ready queue vs. a separate queue for each CPU.
- *Asymmetric multiprocessing* – one processor (master) schedules for all processors
  - only one processor accesses the system data structures
  - alleviating the need for data sharing.
- *Symmetric multiprocessing* – each processor is self-scheduling
  - Each processor select its processes from the queue
  - Process synchronization when accessing common queues

Real-Time Scheduling

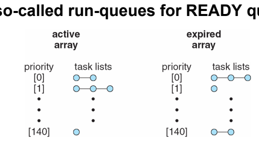
- *Hard real-time* systems – requires to complete a critical task within a guaranteed amount of time.
  - Hard to achieve in a general-purpose computer.
- *Soft real-time* computing – requires that the real-time processes receive priority over others (no aging).
- The dispatch latency must be small → preempt system call (kernel)
  - Adding preemption points (safe points) in system calls
  - Making the entire kernel preemptive by using process synchronization technique to protect all critical region

Linux Scheduling

- Linux scheduling algorithm is preemptive, priority-based, variable-length RR, with complexity O(1).
- Priority values are dynamically adjusted.



- Use two so-called run-queues for READY queue:



Scheduling Algorithm Evaluation

- Analytic evaluation: deterministic modeling
  - Given a pre-determined workload, calculate the performance of each algorithm for that workload.
- Queuing Models
  - No static workload available, so use the probabilistic distribution of CPU and I/O bursts.
  - Use queuing-network analysis.
  - The classes of algorithms and distributions that can be handled in this way are fairly limited.
- Simulation: use a simulator to model a computer system
  - simulator is driven by random-number generator according to certain distributions.
  - Simulator is driven by a trace file, which records actual events happened in a real system.