# Operating Systems - CPU Scheduling

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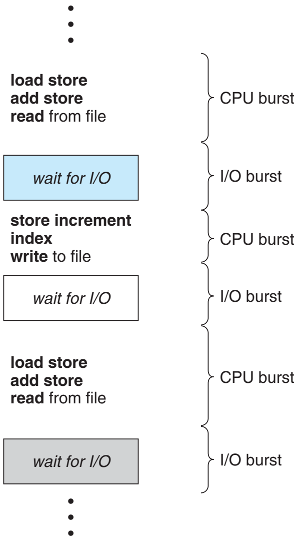
# Slide Credits

- Most of the slides are adapted from the companion lecture slides of the text book by Avi Silberschatz, Peter Baer Galvin, Greg Gagne

# Basic Concepts

- Maximum CPU utilization obtained with multiprogramming
- CPU–I/O Burst Cycle – Process execution consists of a cycle of CPU execution and I/O wait
- CPU burst followed by I/O burst
- CPU burst distribution is of main concern



# CPU Scheduler

- Short-term scheduler selects from among the processes in ready queue, and allocates the CPU to one of them
  - Queue may be ordered in various ways
- 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
- Scheduling under 1 and 4 is nonpreemptive
- All other scheduling is preemptive
  - Consider access to shared data
  - Consider preemption while in kernel mode
  - Consider interrupts occurring during crucial OS activities

# Dispatcher

- Dispatcher module gives control of the CPU to the process selected by the short-term scheduler; this involves:
  - switching context
  - switching to user mode
  - jumping to the proper location in the user program to restart that program
- Dispatch latency – time it takes for the dispatcher to stop one process and start another running

# Scheduling Criteria

- **CPU utilization** – keep the CPU as busy as possible
- **Throughput** – number of processes that complete their execution per time unit
- **Turnaround time** – amount of time to execute a particular process
- **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 output (for time-sharing environment)

# Scheduling Algorithm Optimization Criteria

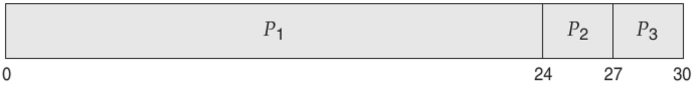
- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time

# First-Come, First-Served (FCFS) Scheduling I

- Process that arrives first is allocated the CPU first
- Example: Consider the three processes with CPU burst times

| Process | Burst Time |
|---|---|
| $P_1$ | 24 |
| $P_2$ | 3 |
| $P_3$ | 3 |

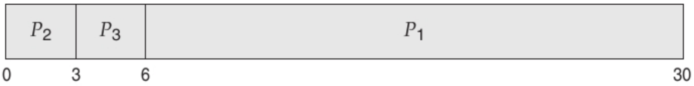
- Suppose that the processes arrive in the order: $P_1$, $P_2$, $P_3$
- The Gantt Chart for the schedule is:




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

# First-Come, First-Served (FCFS) Scheduling II

- 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: $(6 + 0 + 3)/3 = 3$
- Much better than previous case
- Convoy effect - short process behind long process
  - Consider one CPU-bound and many I/O-bound processes

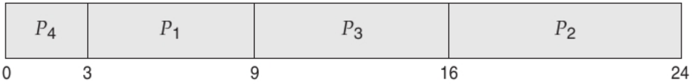
# Shortest-Job-First (SJF) Scheduling

- Associate with each process the length of its next CPU burst
    - Use these lengths to schedule the process with the shortest time
- SJF is optimal – gives minimum average waiting time for a given set of processes
    - The difficulty is knowing the length of the next CPU request
    - Could ask the user

# Example of SJF

| Process | Burst Time |
|---|---|
| $P_1$ | 6 |
| $P_2$ | 8 |
| $P_3$ | 7 |
| $P_4$ | 3 |

- The Gantt Chart for the SJF schedule is:




- Average waiting time: $(3+16 + 9 + 0)/4 = 7$

# Determining Length of Next CPU Burst

- Can only estimate the length – should be similar to the previous one
    - Then pick process with shortest predicted next CPU burst
- 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. $\tau_{n+1}$ = predicted value of next CPU burst
    3. $\alpha, 0 \leq \alpha \leq 1$
    4. Define: $\tau_{n+1} = \alpha t_n + (1 - \alpha)\tau_n$
- Commonly, $\alpha$ is set to $\frac{1}{2}$
- Preemptive version called **shortest-remaining-time-first**

# Examples of Exponential Averaging

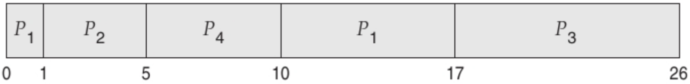
- $\alpha = 0$
  - $\tau_{n+1} = \tau_n$
  - Recent history does not count
- $\alpha = 1$
  - $\tau_{n+1} = t_n$
  - Only the actual last CPU burst counts
- If we expand the formula, we get:
  $\tau_{n+1} = \alpha t_n + (1-\alpha)\tau_n$
  $= \alpha t_n + (1-\alpha)(\alpha t_{n-1} + (1-\alpha)\tau_{n-1})$
  $= \alpha t_n + (1-\alpha)\alpha t_{n-1} + (1-\alpha)^2(\alpha t_{n-2} + (1-\alpha)\tau_{n-2})$
  $= \alpha t_n + (1-\alpha)\alpha t_{n-1} + (1-\alpha)^2\alpha t_{n-2} + (1-\alpha)^3\tau_{n-2}$
  $\ldots$
  $= \alpha t_n + (1-\alpha)\alpha t_{n-1} + \ldots + (1-\alpha)^j\alpha t_{n-j} + \ldots + (1-\alpha)^{n+1}\tau_0$
- Since both $\alpha$ and $(1-\alpha)$ are less than or equal to 1, each successive term has less weight than its predecessor

# Example of Shortest-remaining-time-first

- Now we add the concepts of varying arrival times and preemption to the analysis

| Process | Arrival Time | Burst Time |
|---|---|---|
| $P_1$ | 0 | 8 |
| $P_2$ | 1 | 4 |
| $P_3$ | 2 | 9 |
| $P_4$ | 3 | 5 |

- The Gantt Chart for the Preemptive SJF schedule is:




- Average waiting time: $[(10\text{-}1)+(1\text{-}1)+(17\text{-}2)+(5\text{-}3)]/4 = 6.5$

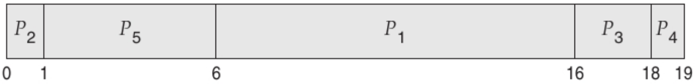
# Priority Scheduling

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

# Example of Priority Scheduling

| Process | Burst Time | Priority |
|---|---|---|
| $P_1$ | 10 | 3 |
| $P_2$ | 1 | 1 |
| $P_3$ | 2 | 4 |
| $P_4$ | 1 | 5 |
| $P_5$ | 5 | 2 |

- The Gantt Chart for Priority scheduling:




- Average waiting time = 8.2

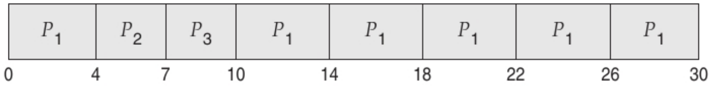
# Round Robin (RR)

- Each process gets a small unit of CPU time (time quantum $q$), usually 10-100 milliseconds. After this time has elapsed, the process is preempted and added to the end of the ready queue.
- If there are $n$ processes in the ready queue and the time quantum is $q$, then each process gets $\frac{1}{n}$ of the CPU time in chunks of at most $q$ time units at once. No process waits more than $(n-1)q$ time units.
- Timer interrupts every quantum to schedule next process
- Performance
    - $q$ large $\Rightarrow$ FIFO
    - $q$ small $\Rightarrow$ $q$ must be large with respect to context switch, otherwise overhead is too high

# Example of RR with Time Quantum $= 4$

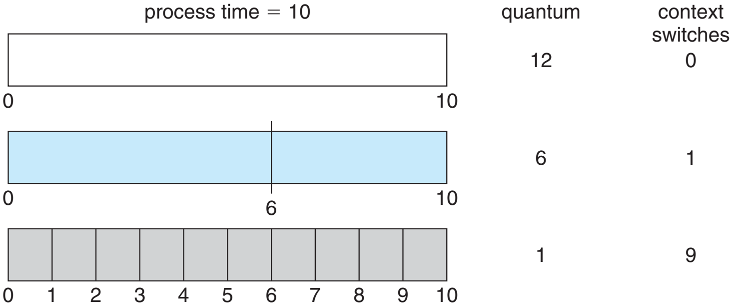
| Process | Burst Time |
|---|---|
| $P_1$ | 24 |
| $P_2$ | 3 |
| $P_3$ | 3 |

- The Gantt Chart for Round Robin scheduling:

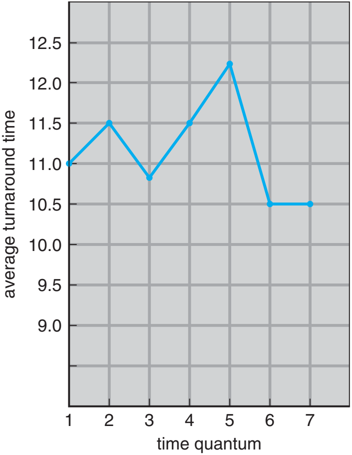



- Typically, higher average turnaround than SJF, but better response
- $q$ should be large compared to context switch time
- $q$ usually 10ms to 100ms, context switch $< 10$

# Time Quantum and Context Switch Time



# Turnaround Time Varies With The Time Quantum

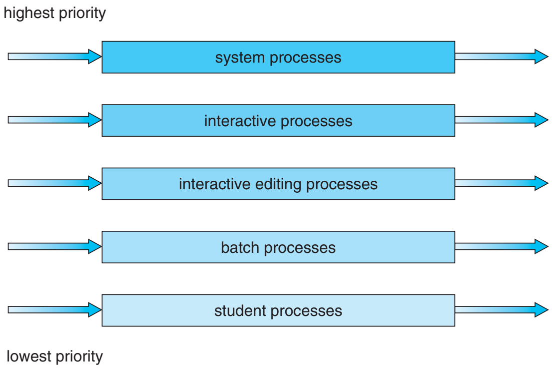



| process | time |
|---|---|
| $P_1$ | 6 |
| $P_2$ | 3 |
| $P_3$ | 1 |
| $P_4$ | 7 |

# Multilevel Queue Scheduling I

- Ready queue is partitioned into separate queues, eg:
  - foreground (interactive)
  - background (batch)
- Process permanently in a given queue
- Each queue has its own scheduling algorithm:
  - 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

# Multilevel Queue Scheduling II



# Multilevel Feedback Queue

- A process can move between the various queues; aging can be implemented this way
- Multilevel-feedback-queue scheduler defined by the following parameters:
  - number of queues
  - scheduling algorithms for each queue
  - method used to determine when to upgrade a process
  - method used to determine when to demote a process
  - method used to determine which queue a process will enter when that process needs service

# Example of Multilevel Feedback Queue

- Three queues:
  - $Q_0$ – RR with time quantum 8 milliseconds
  - $Q_1$ – RR time quantum 16 milliseconds
  - $Q_2$ – FCFS
- Scheduling
  - A new job enters queue $Q_0$ which is served FCFS
    - 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 FCFS and receives 16 additional milliseconds
    - If it still does not complete, it is preempted and moved to queue $Q_2$