Drexel University

Operating Systems

CPU Scheduling

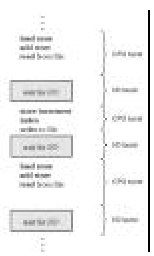
- Basic Concepts
- Scheduling Criteria
- Scheduling Algorithms
- Multiple-Procesor Scheduling
- Real-Time Scheduling
- Algorithm Evaluation

Slides derived from material in "Operating System Concepts," by Silberschatz, Galvin, and Gagne

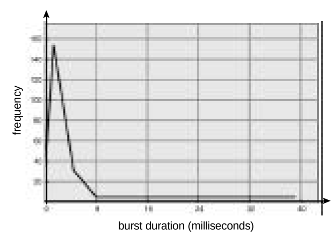
Basic Concepts

- 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 distribution

Alternating Sequence of CPU and I/O Bursts



Histogram of CPU-burst Times



CPU Scheduler

- Selects from among the processes in memory that are ready to execute, and allocates the CPU to one of them.
- CPU scheduling decisions may take place when a process:
  - ❶ Switches from running to waiting state.
  - ❷ Switches from running to ready state.
  - ❸ Switches from waiting to ready.
  - ❹ Terminates.
- Scheduling under 1 and 4 is *nonpreemptive*.
- All other scheduling is *preemptive*.

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 - # 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)

7

Optimization Criteria

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

8

First-Come, First-Served (FCFS) Scheduling

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:

P_1	P_2	P_3	
0	24	27	30

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

9

FCFS Scheduling (Cont.)

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

P_2	P_3	P_1	
0	3	6	30

- 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

10

Shortest-Job-First (SJR) Scheduling

- Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time.
- Two schemes:
  - nonpreemptive - once CPU given to the process it cannot be preempted until completes its CPU burst.
  - preemptive - if a new process arrives with CPU burst length less than remaining time of current executing process, preempt. 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.

11

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)

P_1	P_3	P_2	P_4	
0	7	8	12	16

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

12

Example of 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 (preemptive)

P_1	P_2	P_3	P_2	P_4	P_1

0 2 4 5 7 11 16

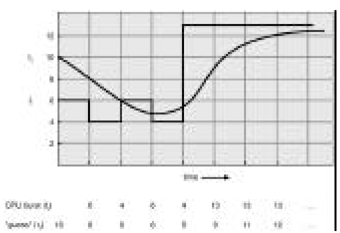
- Average waiting time = (9 + 1 + 0 +2)/4 = 3

Determining Length of Next CPU Burst

- Can only estimate the length.
- Can be done by using the length of previous CPU bursts, using exponential averaging.
  ❶ t_n = actual length of n^{th} CPU burst
  ❷ t_{n+1} = predicted value of the next CPU burst.
  ❸ a, where $0 \le a \le 1$
  ❹ Define:

$$t_{n+1} = a\ t_n + (1 - a)\ t_n$$

Prediction of the Length of the Next CPU Burst



Examples of Exponential Averaging

- When $a = 0$
  - $t_{n+1} = t_n$
  - Recent history does not count.
- When $a = 1$
  - $t_{n+1} = t_n$
  - Only the actual last CPU burst counts.
- If we expand the formula, we get:

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

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

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 unit 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.
- 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 ⇒ FIFO
  - q small ⇒ q must be large with respect to context switch, otherwise overhead is too high.

Example of RR with Time Quantum = 20

Process	Burst Time
P_1	53
P_2	17
P_3	68
P_4	24

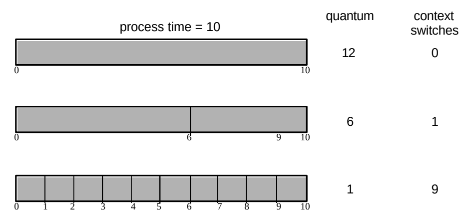
- The Gantt chart is:

P_1	P_2	P_3	P_4	P_1	P_3	P_4	P_1	P_3	P_3

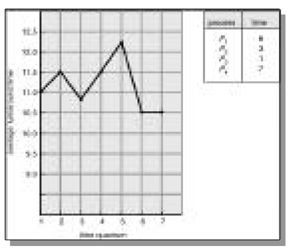
0 20 37 57 77 97 117 121 134 154 162

- Typically, higher average turnaround than SJF, but better response.

Time Quantum and Context Switch Time



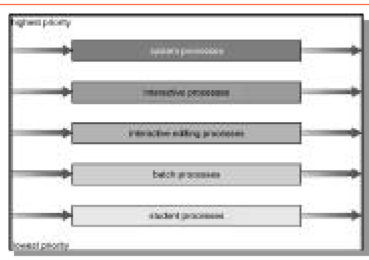
Turnaround Time Varies With The Time Quantum



Multilevel Queue

- Ready queue is partitioned into separate queues:
  - foreground (interactive)
  - background (batch)
- 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



Multilevel Feedback Queue

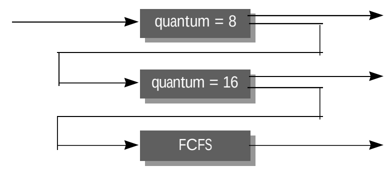
- A process can move between the various queues; aging can be implemented this way.
- Multilevel-feedback-queue scheduler defined by the following parameters:
  - number of queues
  - scheduling algorithms for each queue
  - method used to determine when to upgrade a process
  - method used to determine 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 - time quantum 8 milliseconds
  - Q_1 - 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 .

25

Multilevel Feedback Queues



26

Multiple-Processor Scheduling

- CPU scheduling more complex when multiple CPUs are available.
- *Homogeneous* processors within a multiprocessor.
- *Load sharing*
- *Asymmetric multiprocessing* - only one processor accesses the system data structures, alleviating the need for data sharing.

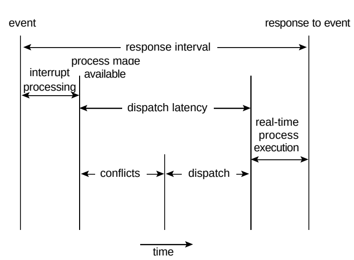
27

Real-Time Scheduling

- *Hard real-time systems* - required to complete a critical task within a guaranteed amount of time.
- *Soft real-time* computing - requires that critical processes receive priority over less fortunate ones.

28

Dispatch Latency



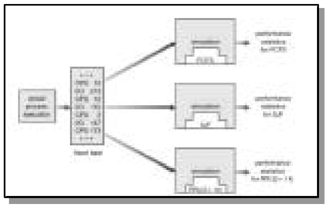
29

Algorithm Evaluation

- Deterministic modeling - takes a particular predetermined workload and defines the performance of each algorithm for that workload.
- Queueing models
- Implementation

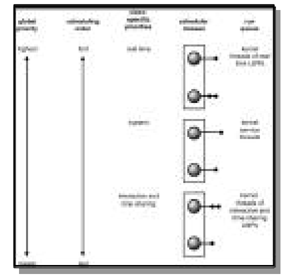
30

Evaluation of CPU Schedulers by Simulation



31

Solaris 2 Scheduling



32