CS 310 Operating Systems

Lecture 25 Scheduling – Round Robin, Priority Scheduling, Multilevel Queue Scheduling,

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In this lecture we will study

- Last lecture
- Scheduling in Interactive Systems
- Round Robin Scheduling
- Priority Scheduling
- Strict Priority Scheduling Multilevel Queue
- Adaptive Scheduling - Introduction

Acknowledgements !

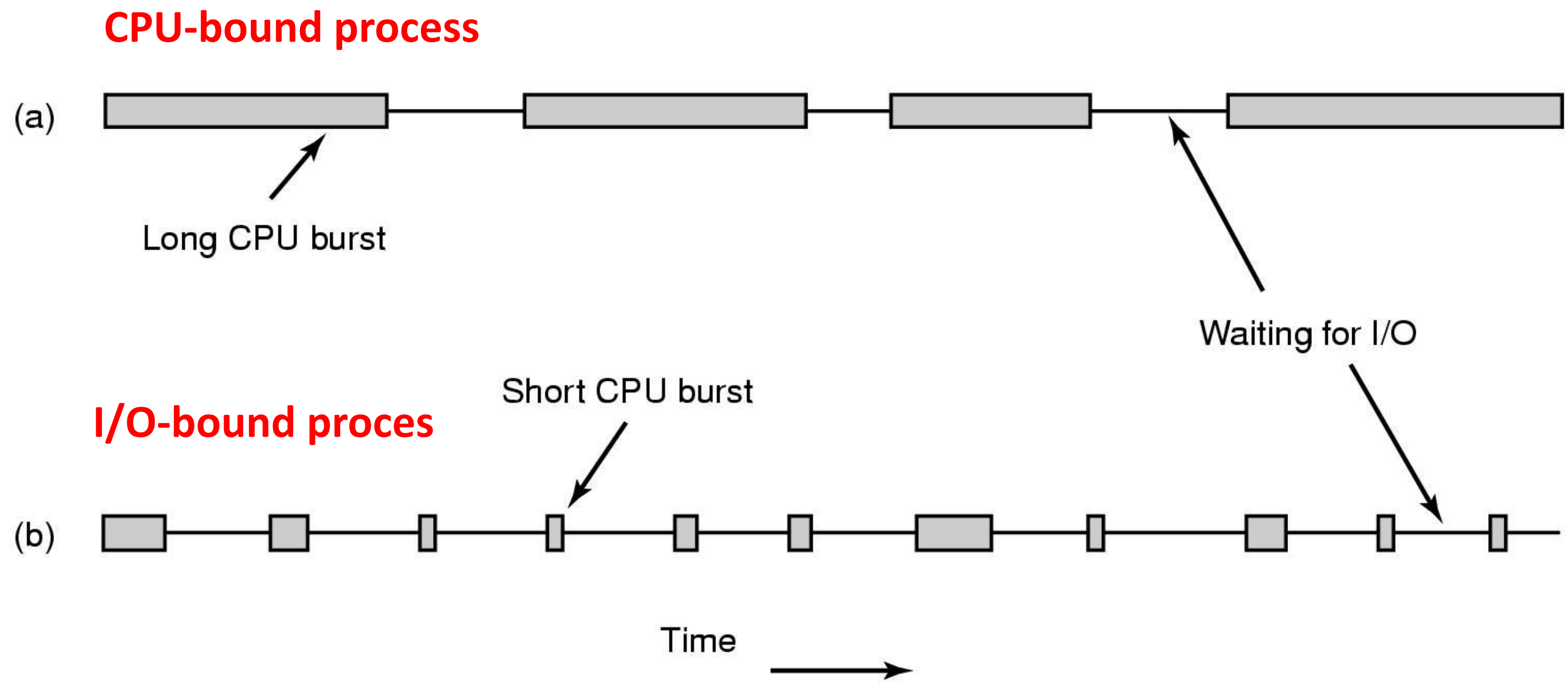
- Contents of this class presentation has been taken from various sources. Thanks are due to the original content creators:
  - CS162, Operating System and Systems Programming, University of California, Berkeley
  - Book: Modern Operating Systems, Andrew Tenenbaum, and Herbert Bos, 4th Edition, Pearson

Reading

- Book: Modern Operating Systems, Andrew Tenenbaum, and Herbert Bos, 4th Edition, Pearson
  - Chapter 2
- CS162, Operating System and Systems Programming, University of California, Berkeley

Last Class

CPU Bursts



- As processors become faster, processes tend to become more I/O bound
  - Why?
  - CPU is becoming faster than the I?O

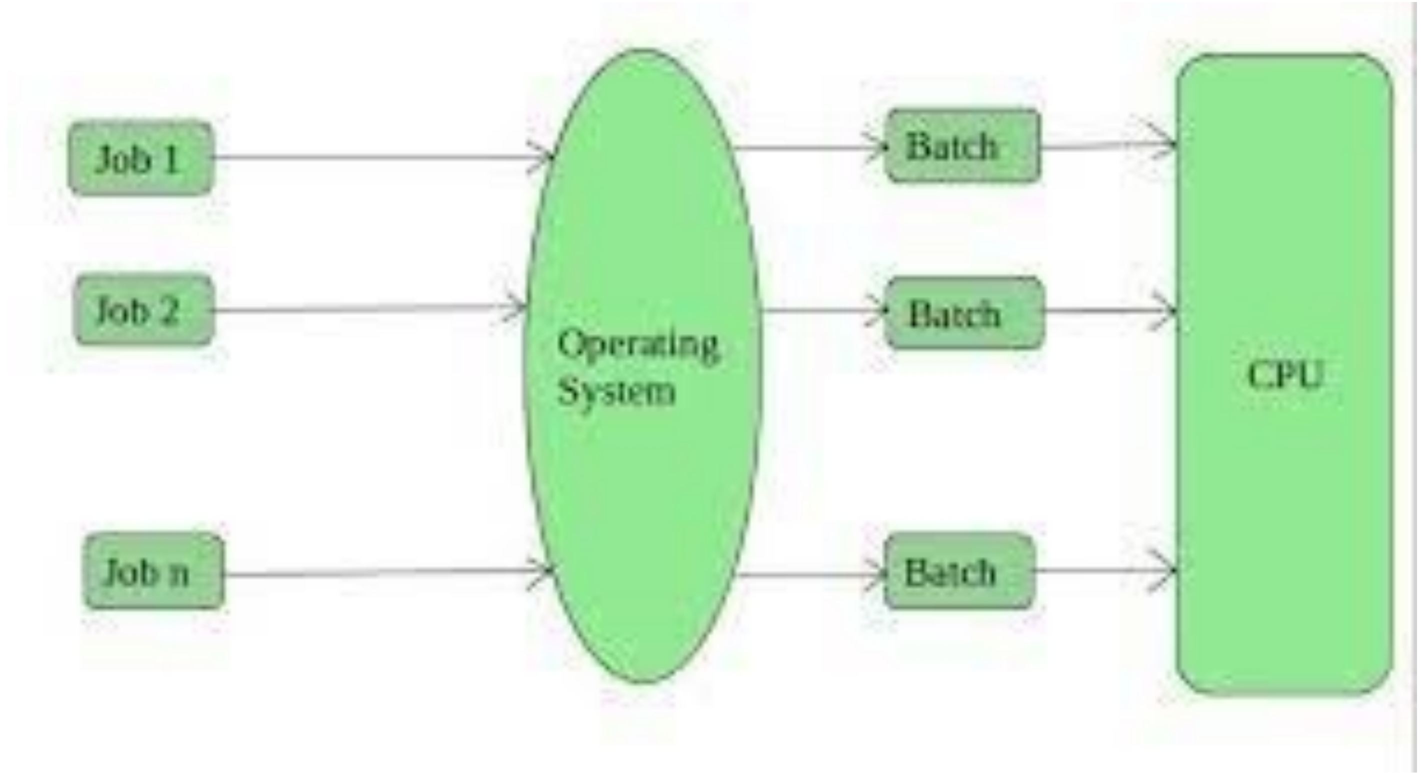
Non-preemptive vs Preemptive scheduling

- Non-preemptive Scheduling Algorithm
  - Picks up a process to run
  - Let the process run until it blocks (for I/O or waiting for another process) or voluntarily releases the CPU
  - A process may run for hours; it will not be forcibly suspended
    - No scheduling decisions are made during clock interrupts
- Preemptive Scheduling
  - Picks up a process to run
  - lets the process run for a maximum of some fixed time
  - At the end of time period, timer interrupt occurs
  - In Kernel mode, scheduler picks up another ready process to run

Scheduling Algorithms - types

- Different environment require different scheduling algorithms
  - Different applications have different goals appropriate scheduling algorithms
- Categories of Scheduling Algorithms
  - Batch
  - Interactive
  - Real time (deadlines)

Batch System



Scheduling Policy Goals/Criteria

- Minimize Response Time
  - Time between issuing a command and getting result
- Maximize Throughput
  - Maximize operations (or jobs) per second
- Minimize Turnaround time
  - Average elapsed time – primarily for batch system
- Fairness
  - Share CPU among users in some equitable way

First-Come, First-Served (FCFS) Scheduling

- First-Come, First-Served (FCFS)
  - Also First In First Out (FIFO) or Run until done
  - In early systems, FCFS meant one program scheduled until done (including I/O)
  - Now, means keep CPU until thread blocks
- Simple Algorithm, Easy to implement (+)
- FCFS Scheme: Potentially bad for short jobs!
  - Depends on submit order
  - If you are first in line at supermarket with milk, you don't care who is behind you, on the other hand…
  - *Convoy effect:* short process stuck behind long process (-)

Shortest Job First (SJF)

- Non-preemptive
- Run whatever job has least amount of computation to do
- Provably optimal
- Need to know run times in advance

Shortest Remaining Time First (SRTF)

- Preemptive version of SJF
- If job arrives and has a shorter time to completion than the remaining time on the current job, immediately preempt CPU
- Sometimes called Shortest Remaining Time to Completion First (SRTCF)
- Both SJF and SRTF:
  - These can be applied to whole program or current CPU burst
    - Idea is to get short jobs out of the system
    - Big effect on short jobs, only small effect on long ones
    - Result is better average response time

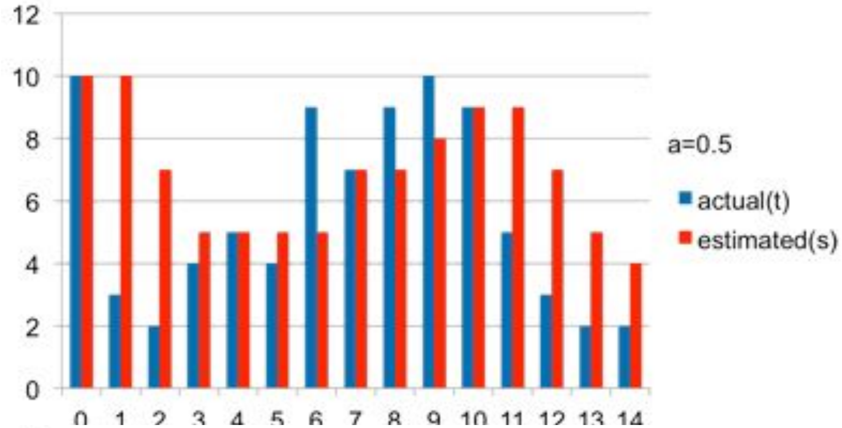
Estimating future CPU Burst time

- The SRTF algorithm can be applied to whole program or current CPU burst
- Sorting based on future burst time?
  - How do we know it ?
- Solution:
  - Predict future burst based on the past history
  - Use an estimator function on previous bursts:
    Let tn-1, tn-2, tn-3, etc. be previous CPU burst lengths.
    Estimate next burst τn = f(tn-1, tn-2, tn-3, …)
  - For example: Exponential Averaging
    - $\tau n = \alpha tn\text{-}1 + (1-\alpha)\tau n\text{-}1$ with $(0<\alpha\leq 1)$, where
      - τn : predicted size of the n^{th} CPU burst
      - tn-1 : the measured time of the $(n\text{-}1)^{th}$ burst
      - α : a weighing factor

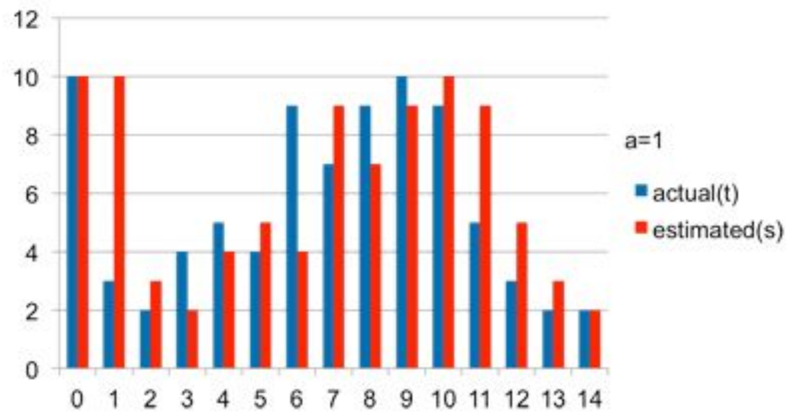
Estimating future CPU Burst time

- Weighing factor α can be adjusted based on how much to weigh past history versus last observation
- If $\alpha = 1$ then only the last observation of the CPU burst period counts
- If $\alpha = ½$ then the last observation has as much weight as the historical weight

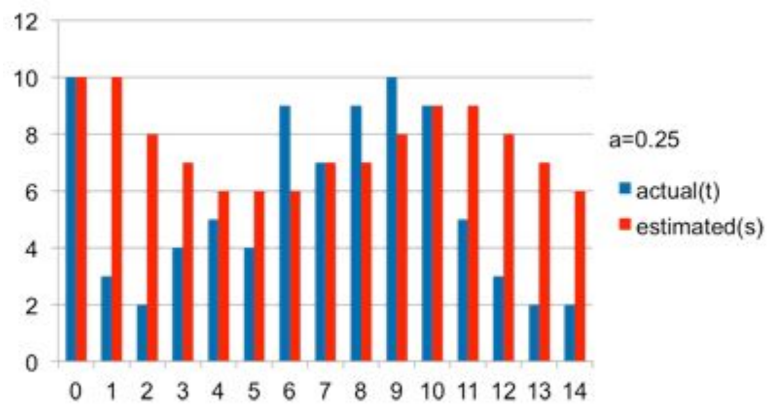
Exponential Average with α = 0.5, 1, 0.25



Exponential Average (α =0.5)



Exponential Average (α = 1)



Exponential Average (α = 0.25)

Advantages and Disadvantages of SRTF

- Advantages
  - This scheduling is optimal in that it always produces the lowest average response time
  - Processes with short CPU bursts are given priority and hence run quickly
- Disadvantages
  - Long-burst (CPU-intensive) processes are hurt with a long average waiting time
  - In fact, if short-burst processes are always available to run, the long-burst ones may never get scheduled
    - Starvation
  - The effectiveness of meeting the scheduling criteria relies on our ability to estimate the length of the next CPU burst

Useful metrics

- Waiting time for process *P:* time before *P* got scheduled
- Average waiting time: Average of all processes’ wait time.
- Completion time (response time): Waiting time + Run time.
- Average completion time (response time): Average of all processes' completion time

Scheduling in Interactive Systems

Scheduling in Interactive Systems

- Round Robin
- Priority

Round Robin

"MY TURN! MY TURN!"

Round Robin (RR) Scheduling

- Uses Preemption!
- Each process gets a small unit of CPU time (time quantum), usually 10-100 milliseconds
- After quantum expires, the process is preempted and added to the end of the ready queue
- n processes in ready queue and time quantum is q
  - Each process gets 1/n of the CPU time
  - In chunks of at most q time units
  - No process waits more than (n-1)q time units

The magic number

- What should q be?
  - *q* large ⇒ FCFS
  - *q* small ⇒ Interleaved
- *q* must be large with respect to context switch, otherwise overhead is too high (all overhead)

Example of RR with Time Quantum q = 20

- Example:

Process	Burst Time
P_1	53
P_2	8
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 28 48 68 88 108 112 125 145 153

- Waiting time for $P_1 = 0 + (68-20)+(112-88)=72$
  $P_2=(20-0)=20$
  $P_3=(28-0)+(88-48)+(125-108) + 0 =85$
  $P_4=(48-0)+(108-68)=88$

- Average waiting time = (72+20+85+88)/4=66¼
- Average completion time = (125+28+153+112)/4 = 104½

Round-Robin Quantum

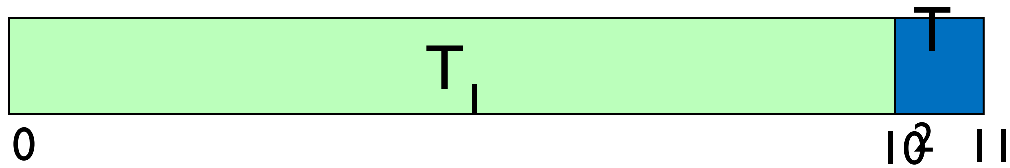
- Assume that context switch overhead is 0
- What happens when we *decrease* *q*?

1. Avg. response time always **decreases** or **stays the same**
2. Avg. response time always **increases** or **stays the same**
3. Avg. response time can **increase**, **decrease**, or **stays the same**

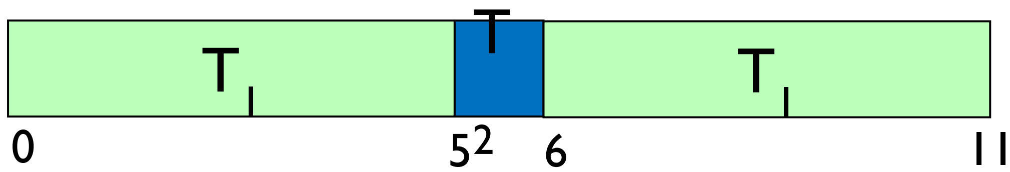
Note: Response time: Time between issuing a command and getting result

Decrease in Response Time

- T_1: Burst Length 10
- T_2: Burst Length 1
- Q = 10



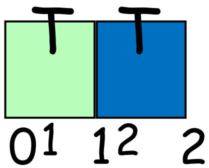
  - Average Response Time = (10 + 11)/2 = 10.5
- Q = 5



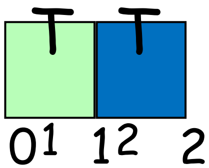
  - Average Response Time = (6 + 11)/2 = 8.5

Same Response Time

- T1: Burst Length 1
- T2: Burst Length 1
- $Q = 10$



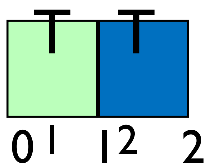
- Average Response Time = (1 + 2)/2 = 1.5
- $Q = 1$



- Average Response Time = (1 + 2)/2 = 1.5

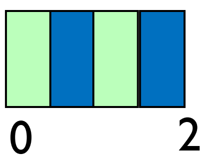
Increase in Response Time

- T1: Burst Length 1
- T2: Burst Length 1
- Q = 1



  - Average Response Time = (1 + 2)/2 = 1.5

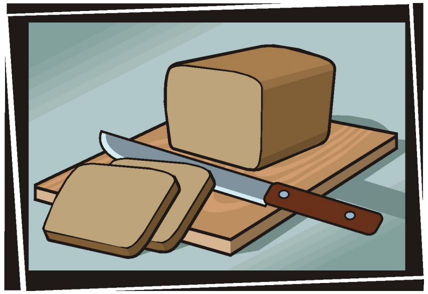
- Q = 0.5



  - Average Response Time = (1.5 + 2)/2 = 1.75

Round-Robin Scheduling: Discussion

- How do you choose time slice?
  - What if too big?
    - Response time suffers
  - What if time slice too small?
    - Throughput suffers!



- Actual choices of timeslice:
  - Initially, UNIX timeslice one second:
    - Worked ok when UNIX was used by one or two people
  - Need to balance short-job performance and long-job throughput:
    - Typical time slice today is between 10ms – 100ms
    - Typical context-switching overhead is 0.1ms – 1ms
    - Roughly 1% overhead due to context-switching

Comparisons between FCFS and Round Robin

- Assuming zero-cost context-switching time, is RR always better than FCFS?
- Simple example: 10 jobs, each take 100s of CPU time
  RR scheduler quantum of 1s
  All jobs start at the same time
- Completion Times:

Job #	FIFO	RR
1	100	991
2	200	992
…	…	…
9	900	999
10	1000	1000

  - Both RR and FCFS finish at the same time
  - Average completion(response) time is much worse under RR!
    - Bad when all jobs same length
- Also: Cache state must be shared between all jobs with RR but can be devoted to each job with FIFO
  - Total time for RR longer even for zero-cost switch!

Earlier Example with Different Time Quantum

Best FCFS:

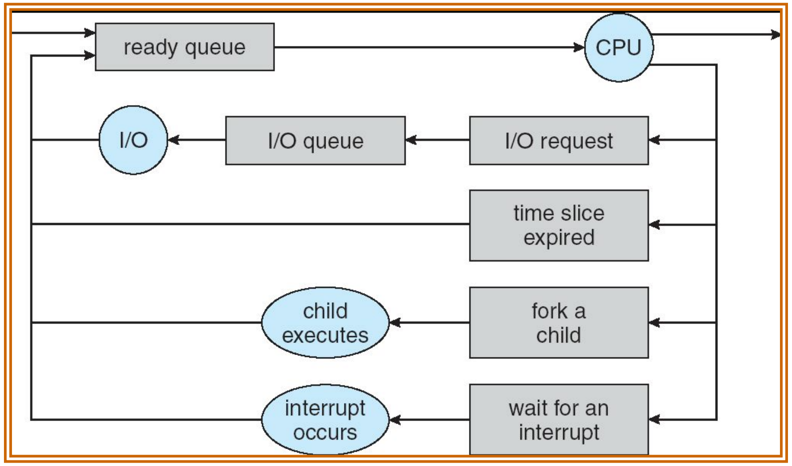
P_2 [8]	P_4 [24]	P_1 [53]	P_3 [68]

0 8 32 85 153

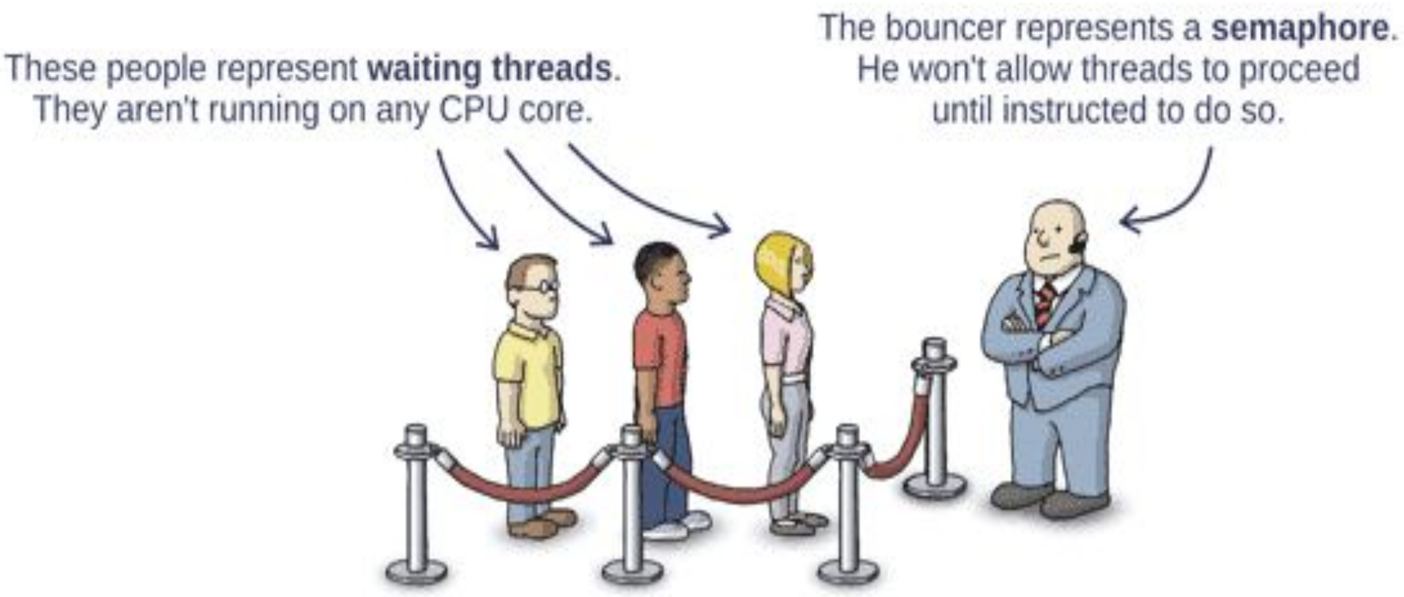
	Quantum	P_1	P_2	P_3	P_4	Average
Wait Time	Best FCFS	32	0	85	8	31¼
	Q = 1	84	22	85	57	62
	Q = 5	82	20	85	58	61¼
	Q = 8	80	8	85	56	57¼
	Q = 10	82	10	85	68	61¼
	Q = 20	72	20	85	88	66¼
	Worst FCFS	68	145	0	121	83½
Completion Time	Best FCFS	85	8	153	32	69½
	Q = 1	137	30	153	81	100½
	Q = 5	135	28	153	82	99½
	Q = 8	133	16	153	80	95½
	Q = 10	135	18	153	92	99½
	Q = 20	125	28	153	112	104½
	Worst FCFS	121	153	68	145	121¾

How to Implement RR in the Kernel?

- FIFO Queue, as in FCFS
- But preempt job after quantum expires, and send it to the back of the queue
  - How? Timer interrupt!



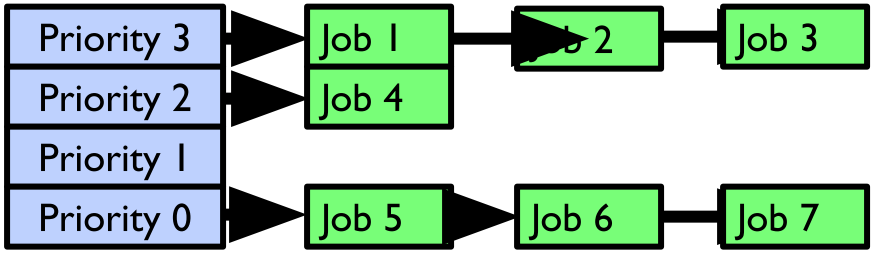
Priority Scheduling



Priority Scheduling

- Run jobs according to their priority
- In RR or other Scheduling there is one queue of jobs
  - Scheduler selects the highest priority process
  - It takes O(n) time
- Solution
  - Separate queue for each distinct priority
  - Schedule the process in the highest priority queue

Multilevel Queue Scheduling – Strict Priority



- Execution Plan
  - Always execute highest-priority runnable jobs to completion
  - Each queue can be processed in RR with some time-quantum
  - A priority is assigned statically to each process, and a process remains in the same queue for the duration of the run time
- Problems
  - Starvation
    - Lower priority jobs don't get to run because higher priority jobs
  - Deadlock: Priority Inversion
    - Happens when low priority task holds a lock needed by high-priority task

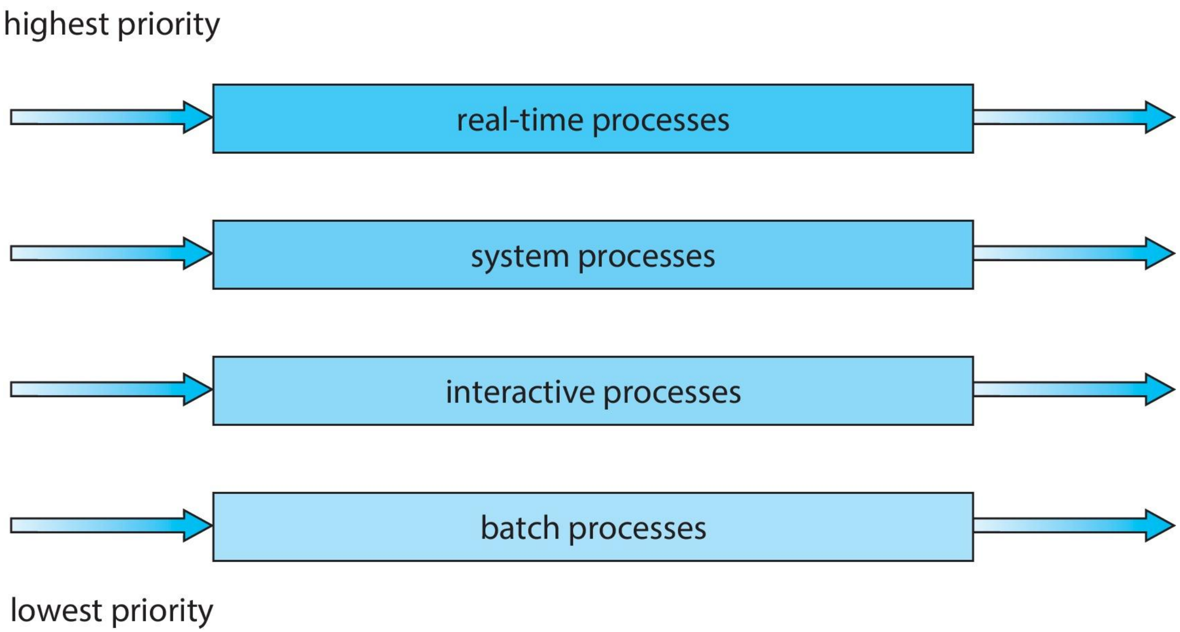
Multi level queue: Strict Priority Scheduling: Fairness Issues

- Strict fixed-priority scheduling between queues is unfair (run highest, then next, etc):
  - Long running low priority jobs may never get CPU
  - When you shut down machine, you may find 10-year-old job still waiting to run ??

- Must give long-running jobs (with low priority) a fraction of the CPU even when there are higher priority jobs to run

Multilevel Queue Scheduling (for different process types)

- Prioritization based upon process type



Adaptive Scheduling

"I purchased this great book on time management, but with my schedule I don't have the time to read it."

Adaptive Scheduling

- How can we adapt the scheduling algorithm based on threads' past behavior?

- Two steps:
  1. Based on past observations, predict what threads will do in the future
  2. Make scheduling decisions based on those predictions

- Now, let's look at the first step. How can we predict future behavior from past behavior?

Predicting Future Behavior

- Consider Round-Robin Scheduling

- If process exhausts quantum, has to be preempted
  - Consuming all of the CPU time it can: “CPU-Bound”
  - Likely to remain CPU-Bound

- If process blocks on I/O before quantum exhausted
  - Short CPU bursts, just to initiate I/O: “I/O-Bound”
  - Often interactive tasks
  - Likely to remain I/O-Bound and/or Interactive

How to implement Fairness?

- Could give each queue some fraction of the CPU?
- Could increase priority of jobs that don't get service
  - What rate should you increase priorities?
  - And, as system gets overloaded, no job gets CPU time, so everyone increases in priority

  $\Rightarrow$ Interactive jobs suffer

$\Rightarrow$ Multilevel Feedback Queue

Lecture Summary

- Interactive systems use scheduling that reduce average response time
- Round Robin is the oldest, simplest, fairest, and widely used scheduling algorithm
- In round robin algorithm, proper choice of time quantum is very important
  - If the time quantum is too short, there will too many context switches □ lower CPU utilization
  - If the time quantum is too big, there will be high values of wait time and response time □ poor response to short interactive requests
- Priority scheduling
  - Multilevel Queue Scheduling – Strict Priority
- Adaptive Scheduling

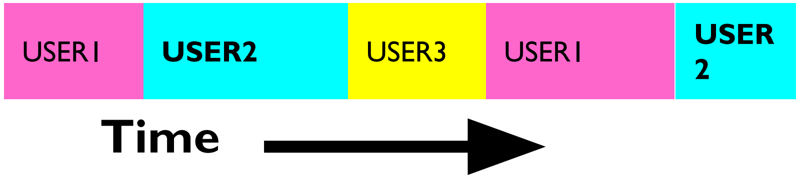
Backup

Types of Resource

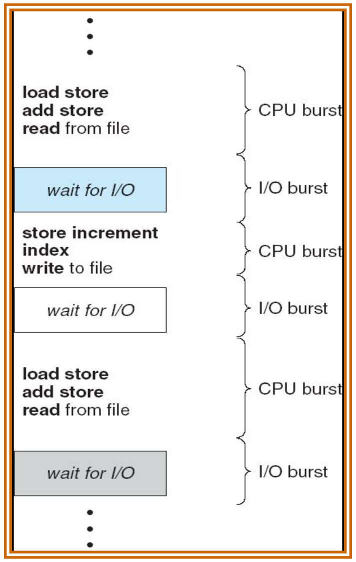
- Preemptible
  - OS can take resource away, use it for something else, and give it back later
    - E.g., CPU
- Non-preemptible
  - Once given resource, it can’t be reused until voluntarily relinquished
    - E.g., disk space
- Given set of resources and set of requests for the resources, types of resource determines how OS manages it

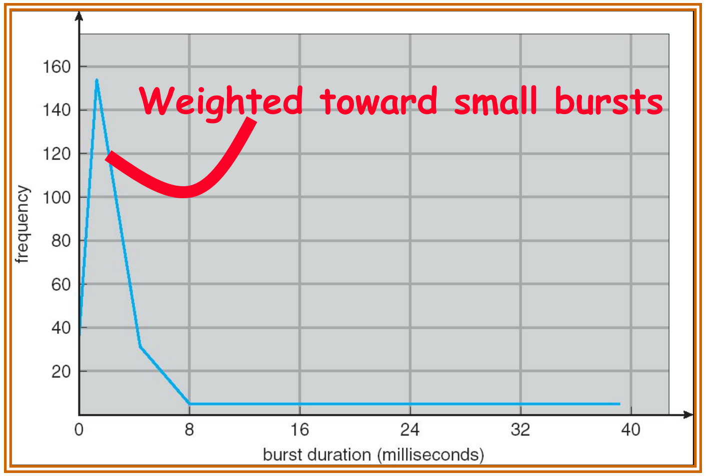
Scheduling Assumptions

- Many implicit assumptions for CPU scheduling:
  - One program per user
  - One thread per program
  - Programs are independent
- Clearly, these are unrealistic but they simplify the problem so it can be solved
  - For instance: is “fair” about fairness among users or programs?
    - If I run one compilation job and you run five, you get five times as much CPU on many operating systems
- The high-level goal: Dole out CPU time to optimize some desired parameters of system



Assumption: CPU Bursts





- Execution model: programs alternate between bursts of CPU and I/O
  - Program typically uses the CPU for some period of time, then does I/O, then uses CPU again
  - Each scheduling decision is about which job to give to the CPU for use in next CPU burst
    - If a process comes back after I/O wait, it counts as a fresh CPU burst
  - With time-slicing, thread may be forced to give up CPU before finishing current CPU burst