# CS 370: OPERATING SYSTEMS

# [CPU SCHEDULING]

**CPU Scheduling Algorithms**
A surfeit of choices
Each imbued with shades of Achilles
And the lurking, hobbled heel

FIFO simple
Plagued with poor response times

SJF response-time optimal yet
pessimal for variance

Round robin just, objective
Snared by the tangled context switch trade-off

Have it all
with an armored heel
to boot
The imperfectly, flawless MFQ

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## Frequently asked questions from the previous class survey

- Can you force an OS to fail by flooding it with a several small jobs and a few large jobs?
- Batch vs Interactive systems: what are they?
- Why are I/O devices so slow?
- How does the CPU know how long a process will run?
- CPU scheduling
  - Does the CPU ever make scheduling decisions?
  - Does preemptive scheduling require a preemptive kernel?
  - Do CPUs slow down over time?
  - How does the kernel know when to go back to the ready queue?
  - Do schedulers harvest data every clock cycle to make decisions?

## Topics covered in this lecture

- Scheduling Algorithms
  - SJF
  - Priority Scheduling
  - Round robin scheduling
- Multilevel feedback queues
- Lottery scheduling

## SJF IN SCHEDULERS

# Use of SJF in long term schedulers

- Length of the process time limit
  - Used as CPU burst estimate
- Motivate users to accurately estimate time limit
  - Lower value will give faster response times
  - Too low a value?
    - Time limit exceeded error
    - Requires resubmission!

# The SJF algorithm and short term schedulers

- **No way to know** the length of the next CPU burst
- So, try to **predict** it
- Processes scheduled *based on predicted* CPU bursts

## Prediction of CPU bursts: Make estimates based on past behavior

- $t_n$ : Length of the nth CPU burst
- $\tau_n$ : Estimate for the nth CPU burst
- $\alpha$ : Controls weight of recent and past history
- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\tau_n$
- Burst is predicted as an **exponential average** of the measured lengths of previous CPU bursts

## $\alpha$ controls the relative weight of recent and past history

- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\tau_n$
- Value of $t_n$ contains our most recent information, while **$\tau_n$ stores the past history**
- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\alpha t_{n-1} + \ldots + (1-\alpha)^j\,\alpha t_{n-j} + \ldots + (1-\alpha)^{n+1}\,\alpha\tau_0$
- $\alpha$ is less than 1, $(1-\alpha)$ is also less than one
  - **Each successive term has less weight than its predecessor**

# The choice of α in our predictive equation

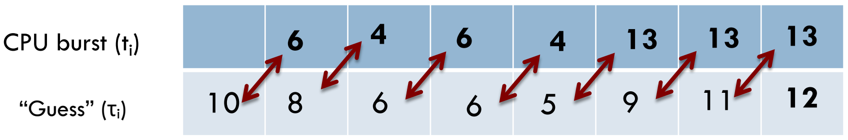
- If $\alpha=1/2$
  - Recent history and past history are **equally weighted**

- With $\alpha = ½$; successive estimates of $\tau$

$t_0/2 \qquad t_0/4 + t_1/2 \qquad t_0/8 + t_1/4 + t_2/2 \qquad t_0/16 + t_1/8 + t_2/4 + t_3/2$

  - By the 3rd estimate, weight of what was observed at $t_0$ has dropped to 1/8.

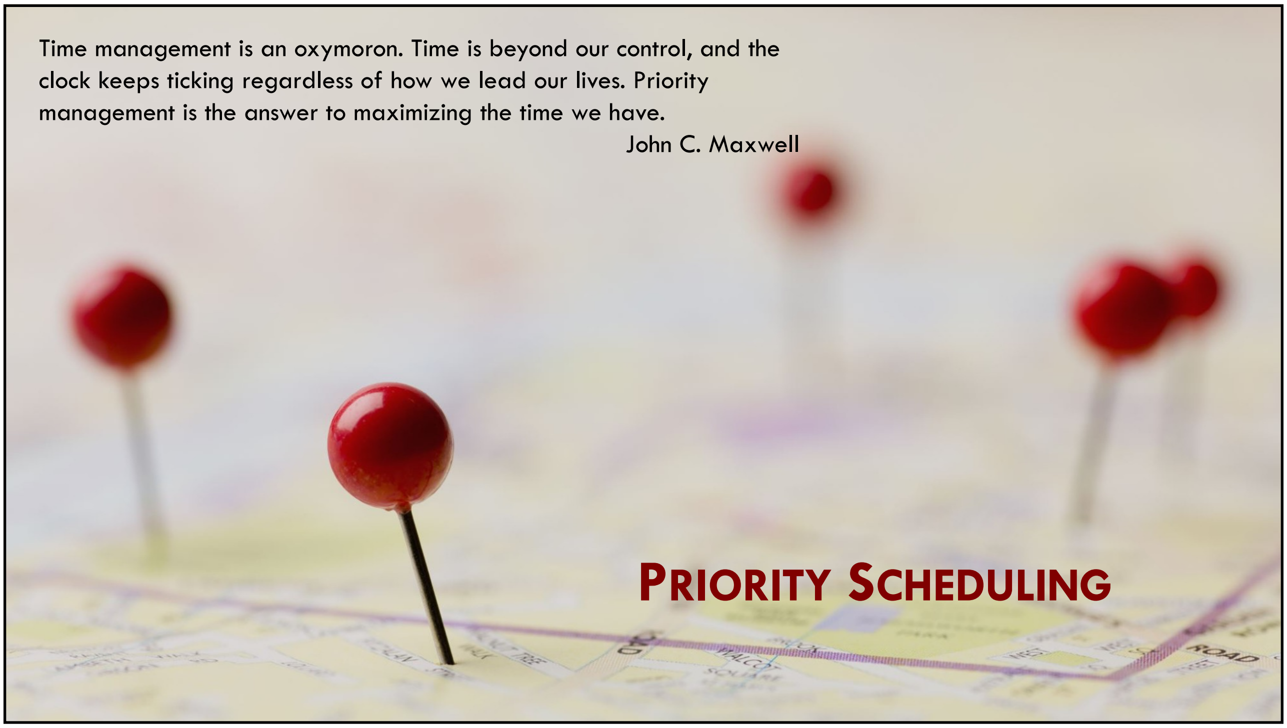
# An example: Predicting the length of the next CPU burst



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CPU burst ($t_i$) | | **6** | **4** | **6** | **4** | **13** | **13** | **13** |
| "Guess" ($\tau_i$) | 10 | 8 | 6 | 6 | 5 | 9 | 11 | **12** |

## The choice of α in our predictive equation

- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\tau_n$
- If $\alpha \rightarrow 0$, $\tau_{n+1} = \tau_n$
  - Current conditions are transient
- If $\alpha = 1$, $\tau_{n+1} = t_n$
  - Only most recent bursts matter
  - History is assumed to be old and irrelevant



Time management is an oxymoron. Time is beyond our control, and the clock keeps ticking regardless of how we lead our lives. Priority management is the answer to maximizing the time we have.
John C. Maxwell

## PRIORITY SCHEDULING

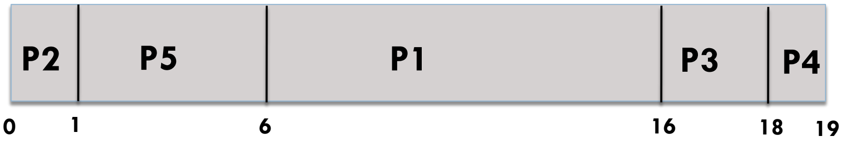
# Priority Scheduling

- **Priority** associated with each process
- CPU allocated to process with **highest** priority
- Can be preemptive or nonpreemptive
  - If preemptive: Preempt CPU from a lower priority process when a higher one is ready

# Depiction of priority scheduling in action

| Process | Burst Time | Priority |
|---|---|---|
| P1 | 10 | 3 |
| P2 | 1 | 1 |
| P3 | 2 | 4 |
| P4 | 1 | 5 |
| P5 | 5 | 2 |

Here: Lower number means higher priority



```
Wait time = (6 + 0 + 16 + 18 + 1)/5 = 8.2
```

## How priorities are set

- Internally defined priorities based on:
  - **Measured** quantities
  - Time limits, memory requirements, # of open files, ratio (averages) of I/O to CPU burst
- External priorities
  - Criteria outside the purview of the OS
  - Importance of process, $ paid for usage, politics, etc.

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## Issue with priority scheduling

- Can leave lower priority processes waiting indefinitely
- Perhaps apocryphal tale:
  - MIT's IBM 7094 shutdown (1973) found processes from 1967!

## Coping with issues in priority scheduling: Aging

- **Gradually increase priority** of processes that wait for a long time
- Example:
  - Process starts with a priority of 127 and decrements every 15 minutes
  - Process priority becomes 0 in no more than 32 hours

## Can SJF be thought of as a priority algorithm?

- Priority is **inverse** of CPU burst
- The larger the burst, the lower the priority
  - *Note*: The number we assign to represent priority levels may vary from system to system

## ROUND ROBIN SCHEDULING

## Round-Robin Scheduling

- Similar to FCFS scheduling
  - **Preemption** to enable switch between processes
- Ready queue is implemented as **FIFO**
  - Process Entry: PCB at *tail* of queue
  - Process chosen: From *head* of the queue
- CPU scheduler goes around ready queue
  - Allocates CPU to each process *one after the other*
    - CPU-bound up to a maximum of 1 **quantum**

# A round-robin analogy

- Hyperkinetic student studying for multiple exams simultaneously
  - If you switch between paragraphs of different textbooks? [Quantum is too short]
    - You won't get much done
  - If you never switch? [Quantum is too long]
    - You never get around to studying for some of the courses

# Round Robin: Choosing the quantum

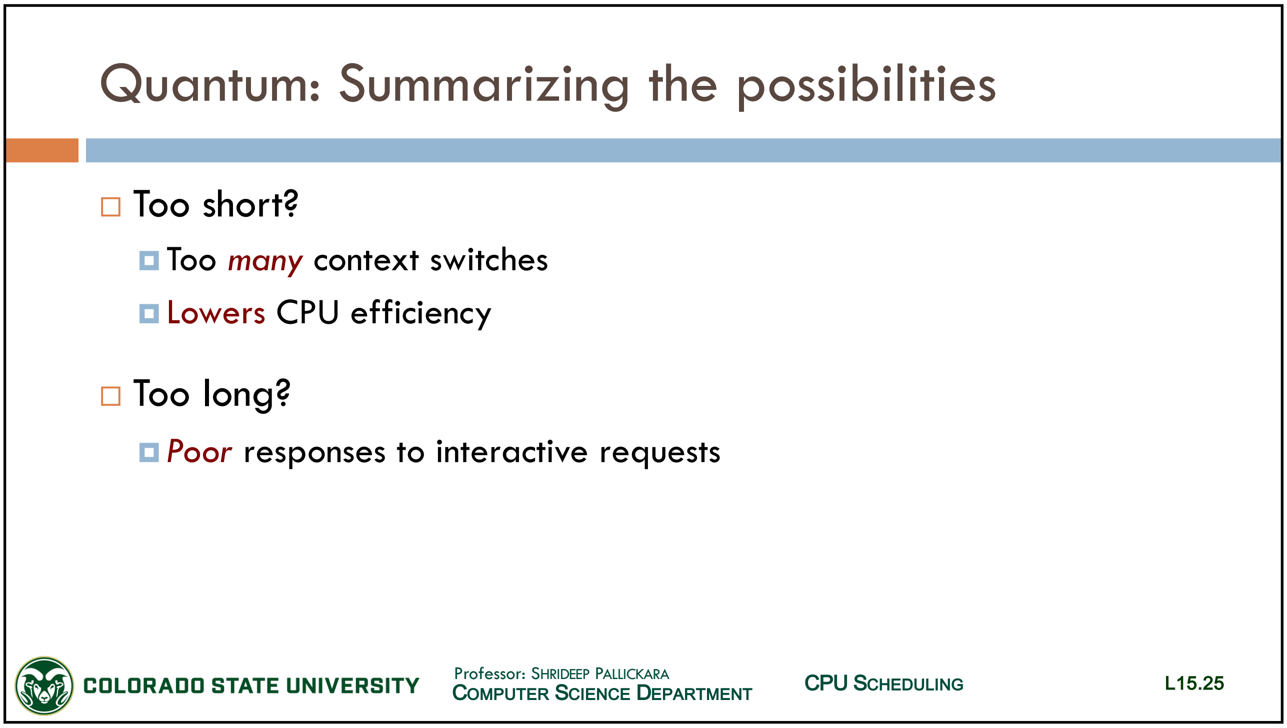
- Context switch is **time consuming**
  - Saving and loading registers and memory maps
  - Updating tables
  - Flushing and reloading memory cache
- What if quantum is 4 ms and context switch overhead is 1 ms?
  - 20% of CPU time thrown away in administrative overhead

## Round Robin: Improving efficiency by increasing quantum

- Let’s say quantum is 100 ms and context-switch is 1ms
  - Now wasted time is only 1%
- But what if 50 concurrent requests come in?
  - Each with widely varying CPU requirements
  - 1st one starts immediately, 2nd one 100 ms later, …
  - The last one may have to wait for 5 seconds!
  - A shorter quantum would have given them better service

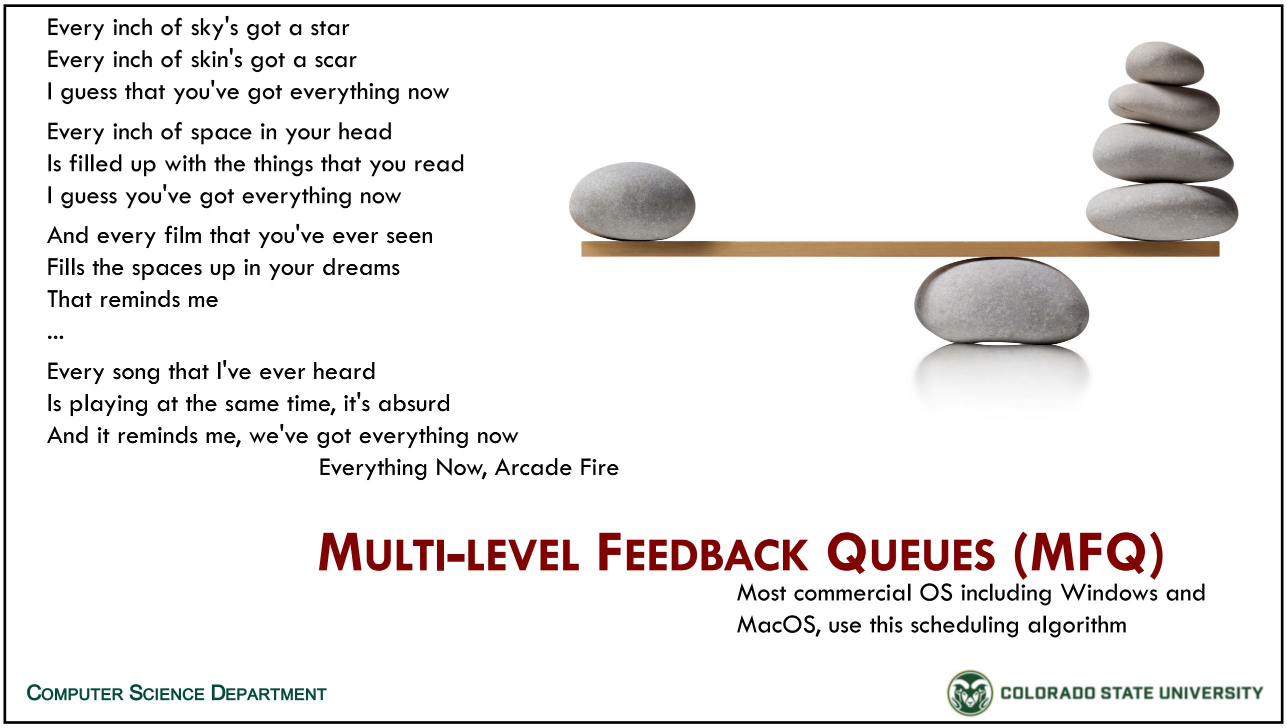
## If quantum is set longer than mean CPU burst?

- **Preemption will not happen very often**
- Most processes will perform a blocking operation before quantum runs out
- Switches happens only when process blocks and cannot continue



## Quantum: Summarizing the possibilities

- Too short?
  - Too *many* context switches
  - Lowers CPU efficiency
- Too long?
  - *Poor* responses to interactive requests



Every inch of sky's got a star
Every inch of skin's got a scar
I guess that you've got everything now

Every inch of space in your head
Is filled up with the things that you read
I guess you've got everything now

And every film that you've ever seen
Fills the spaces up in your dreams
That reminds me

...

Every song that I've ever heard
Is playing at the same time, it's absurd
And it reminds me, we've got everything now

Everything Now, Arcade Fire

## MULTI-LEVEL FEEDBACK QUEUES (MFQ)

Most commercial OS including Windows and MacOS, use this scheduling algorithm

## MFQ is designed to achieve several simultaneous goals

- **Responsiveness**: Run short tasks quickly as in SJF
- **Low Overhead**: Minimize number of preemptions, as in FIFO
    - Minimize time spent making scheduling decisions
- **Starvation-Freedom**
    - All tasks should make progress, as in Round Robin
- **Background tasks**
    - Defer system maintenance tasks, such as defragmentation, so they do not interfere with user work
- **Fairness**

## Does MFQ achieve all of these?

- As with any real system that must ***balance*** several, conflicting goals …
    - MFQ does not perfectly achieve these goals simultaneously
- MFQ is intended to be a **reasonable compromise** in most real-world cases

## MFQ

- Extension of round robin
- Instead of only a single queue, MFQ has **multiple round robin queues**
  - Each queue has a **different** *priority level* and *time quanta*

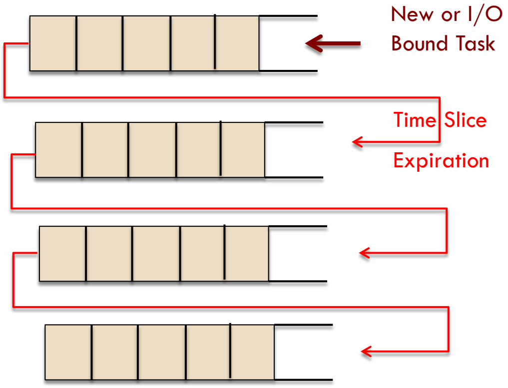
## Tasks and priorities

- Tasks at a higher priority **preempt** lower priority tasks
- Tasks at the same priority level are scheduled in a **round robin** fashion
- Higher priority tasks have **shorter** time quanta than lower priority tasks

## MFQ: Example with 4 priority levels

| **Priority** | **Time Slice (ms)** |
|---|---|
| 1 | 10 |
| 2 | 20 |
| 3 | 40 |
| 4 | 60 |

**Round Robin Queues**



## Task movements and priority

- Tasks are moved between priority levels to **favor short tasks** over long ones
- Every time a task uses up its time quantum?
  - It **drops** a priority level
- Every time task yields the processor because it is waiting on I/O?
  - It **stays** at the same level, or is **bumped up** a level
- If the task completes … it leaves

## Impact on CPU and I/O bound processes

- A **new** CPU bound process will start as *high priority*
  - But it will quickly exhaust its time quantum and fall to the next lower priority, and then the next …
- An I/O bound process with a modest amount of computing
  - Will always be **scheduled quickly**
    - Also, keeps the disk busy
- Compute bound tasks run with a long time quantum to minimize switching overhead while sharing processor

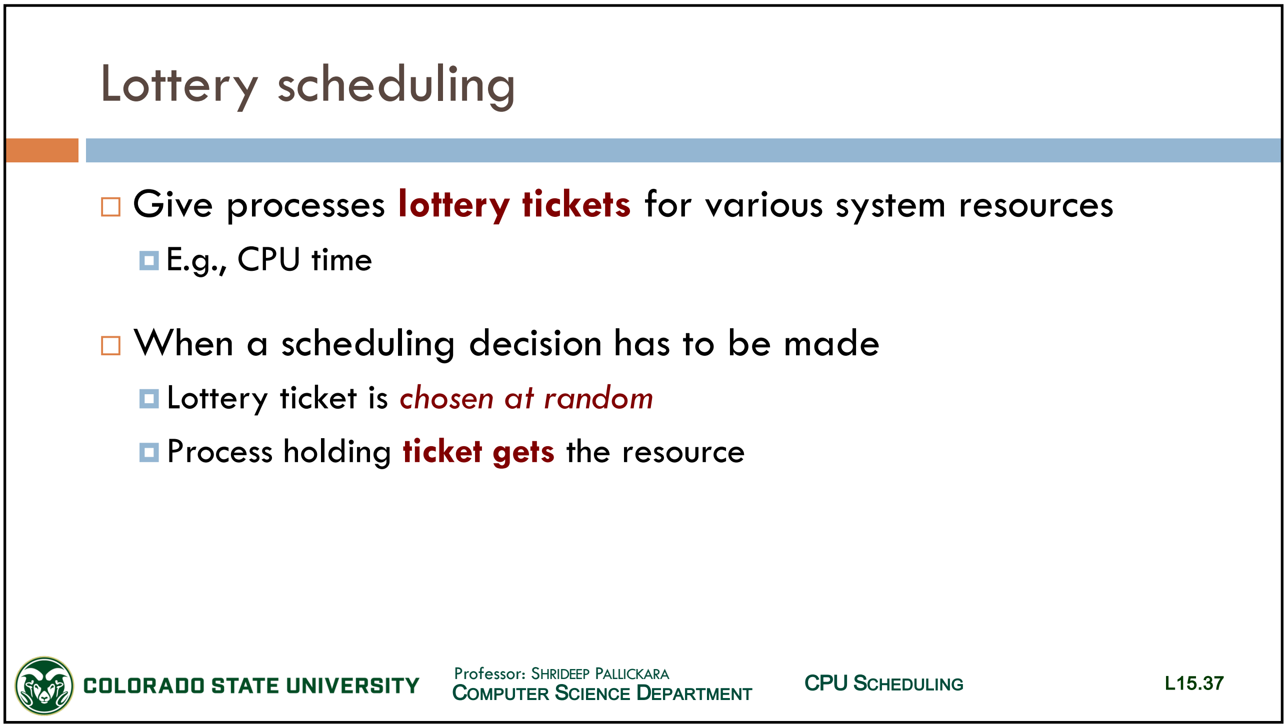
## What about starvation and fairness?

- If there are too many I/O bound tasks, the compute bound tasks may receive no time on the processor
- MFQ scheduler **monitors every process** to ensure that it is receiving its fair share
  - For e.g., at each level, maintain two queues
    - Tasks whose processes have already reached their fair share are only scheduled if other processes at the same level have also received their fair share
- Periodically, processes not receiving their fair share have their tasks increased in priority
  - Tasks that receive more than their fair share have their priority reduced

## Adjusting priority addresses strategic behavior

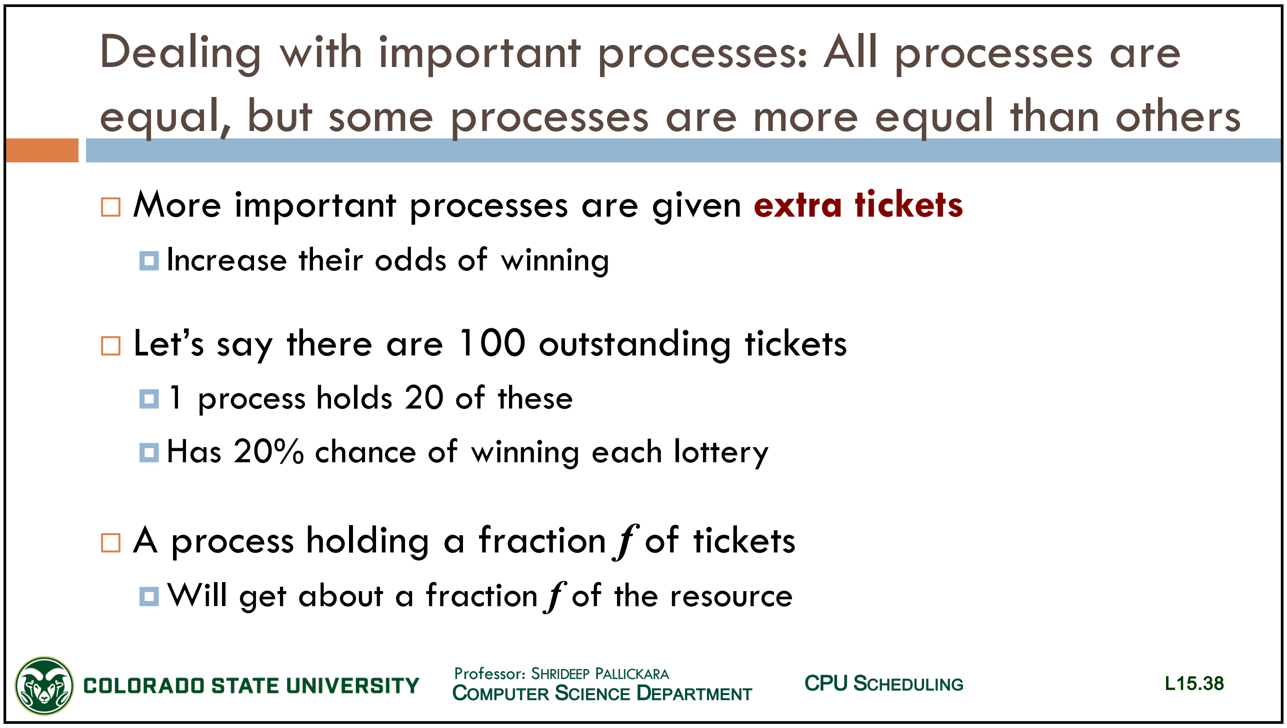
- From a selfish point of view, a task can keep its priority high by doing a short I/O request just before its quantum expires
  - With MFQ this will be detected, and its priority reduced to its fair level

## LOTTERY SCHEDULING



## Lottery scheduling

- Give processes **lottery tickets** for various system resources
  - E.g., CPU time
- When a scheduling decision has to be made
  - Lottery ticket is *chosen at random*
  - Process holding **ticket gets** the resource



## Dealing with important processes: All processes are equal, but some processes are more equal than others

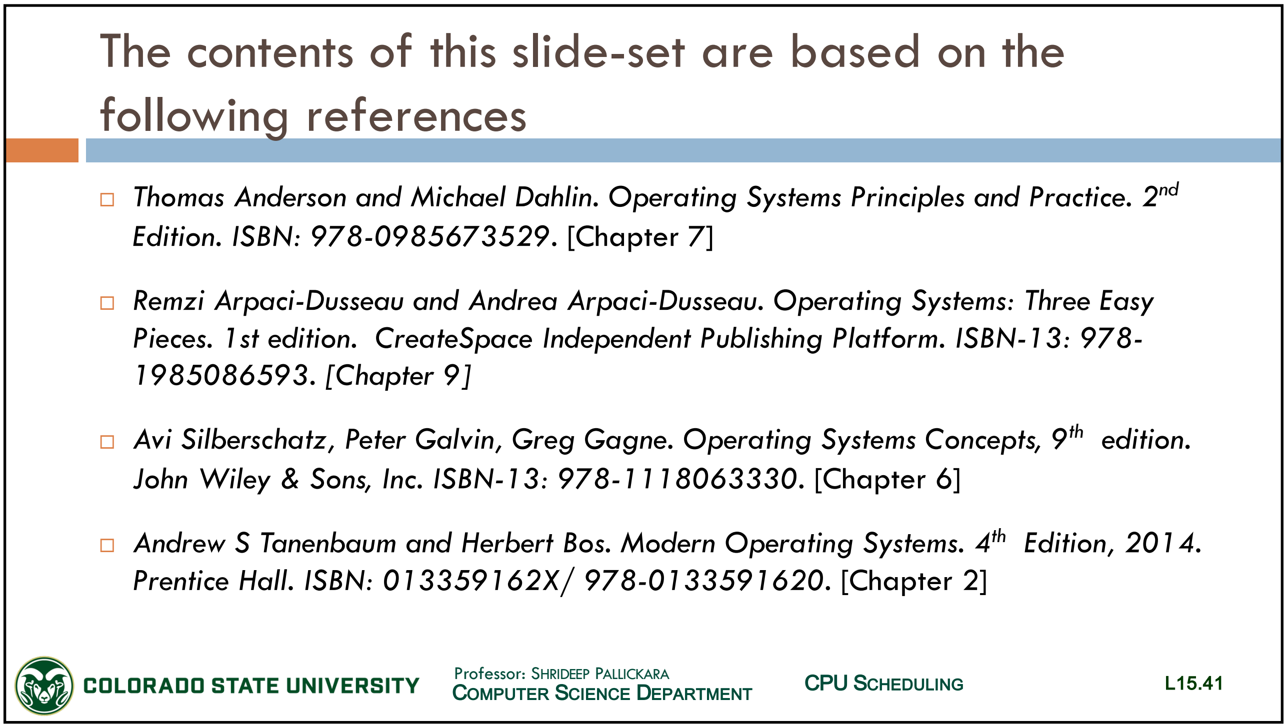
- More important processes are given **extra tickets**
  - Increase their odds of winning
- Let's say there are 100 outstanding tickets
  - 1 process holds 20 of these
  - Has 20% chance of winning each lottery
- A process holding a fraction $f$ of tickets
  - Will get about a fraction $f$ of the resource

## Lottery Scheduling: Properties [1/2]

- Highly **responsive**
  - Chance of winning is proportional to tickets
- Cooperating processes may **exchange** tickets
  - Process **A** sends request to **B**, and then hands **B** all its tickets for a faster response
- Avoids starvation
  - Each process holds at least one ticket …. Is guaranteed to have a non-zero probability of being scheduled

## Lottery Scheduling: Properties [2/2]

- Solves problems that are *difficult to handle* in other scheduling algorithms
- E.g., video server that is managing processes that feed video frames to clients
  - Clients need frames at 10, 20, and 25 frames/sec
  - Allocate processes 10, 20 and 25 tickets
    - CPU divided into approximately 10:20:25



## The contents of this slide-set are based on the following references

- *Thomas Anderson and Michael Dahlin. Operating Systems Principles and Practice. 2nd Edition. ISBN: 978-0985673529.* [Chapter 7]
- *Remzi Arpaci-Dusseau and Andrea Arpaci-Dusseau. Operating Systems: Three Easy Pieces. 1st edition. CreateSpace Independent Publishing Platform. ISBN-13: 978-1985086593. [Chapter 9]*
- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 6]
- *Andrew S Tanenbaum and Herbert Bos. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620.* [Chapter 2]