# 15-410

***"...Everything old is new again..."***

## Scheduling
## Oct. 28, 2005

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# Synchronization

## Project 3 suggestions

- Three regular meeting times per week
  - Two hours or more at each meeting
  - Begin by asking questions about each other's code
    - » Requires having read code before meeting
    - » Requires “quiet time” between check-ins and meeting
- Source control
  - Frequent merges, not a single “big bang” at end
- Leave time at end for those multi-day bugs

# Synchronization

## Checkpoint 3

- **Monday, “end of third week”**
- **No cluster meeting – regular lecture**
- **Expect: code drop, milestone-estimation form**
  - **Bboard post today/tomorrow**
  - **Spending the time to really *plan* is worthwhile**

# Outline

**Chapter 5: Scheduling**

# CPU-I/O Cycle

***Process*** **view: 2 states**

- Running
- Waiting for I/O
- Life Cycle
  - I/O (loading executable), CPU, I/O, CPU, .., CPU (`exit()`)

***System*** **view**

- Running, Waiting
- Runnable – not enough processors for you right now

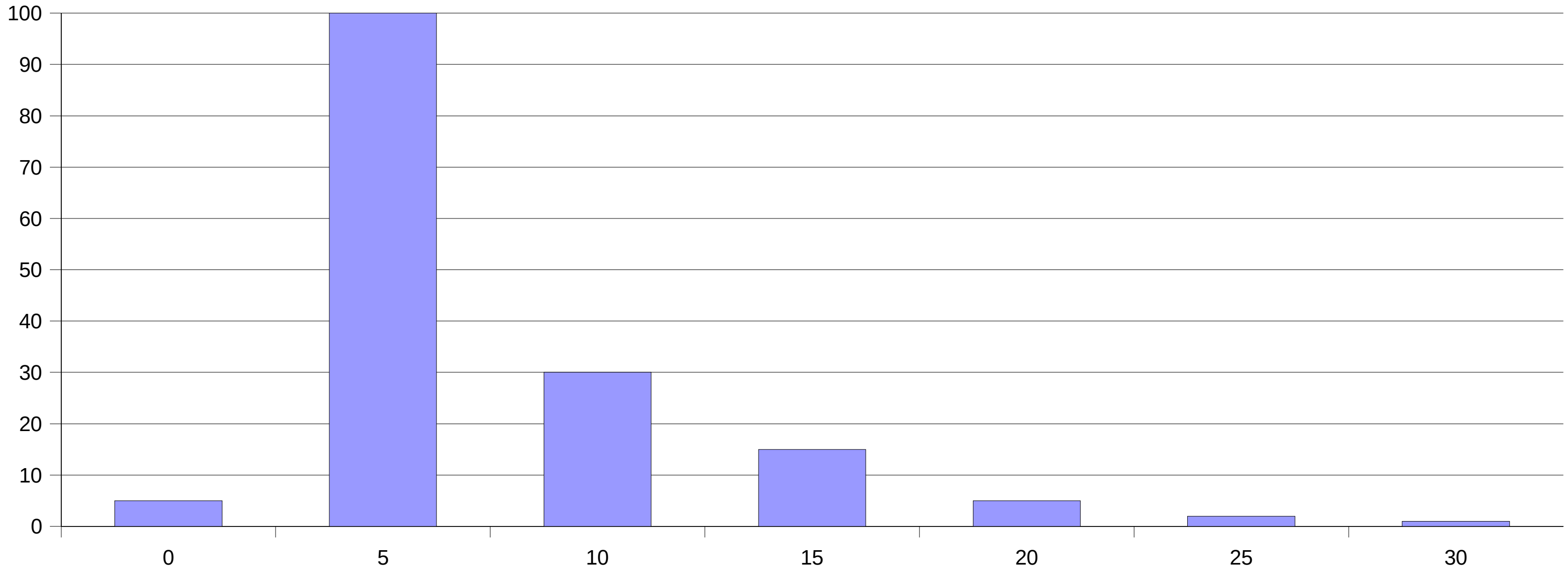
**Running ⇒ waiting is mostly voluntary**

- How long do processes choose to run before waiting?

# CPU Burst Lengths

## Overall

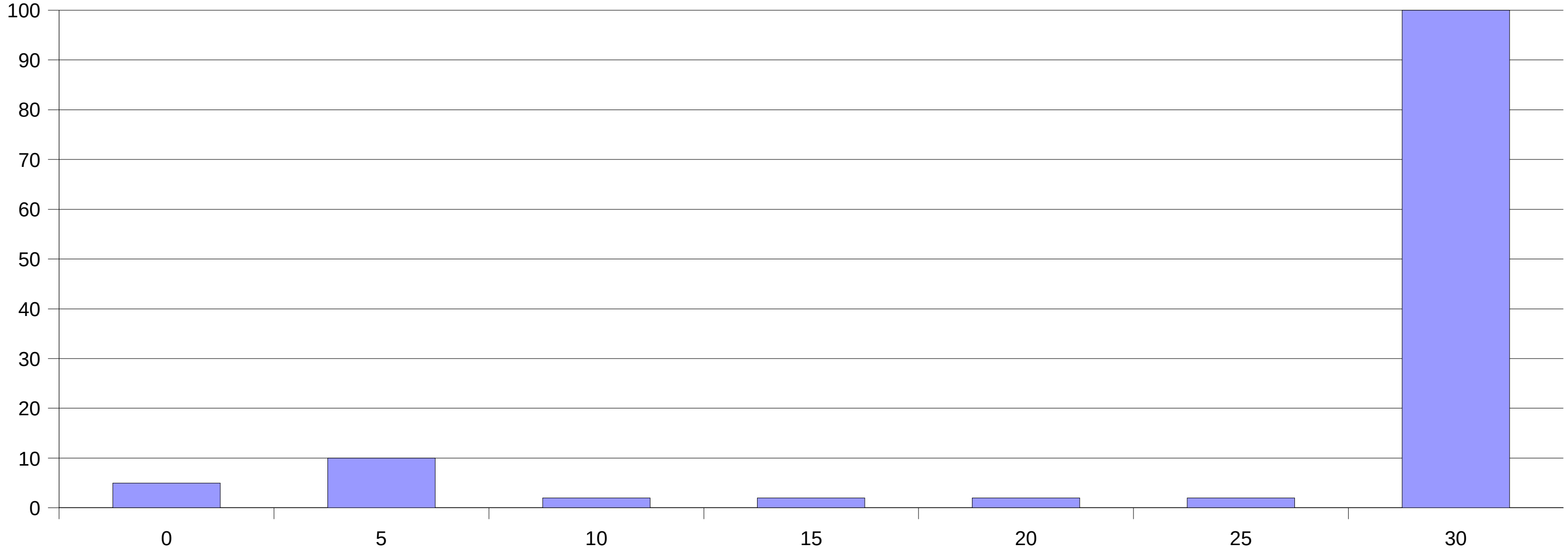
- **Exponential fall-off in CPU burst length**



# CPU Burst Lengths

## “CPU-bound” program

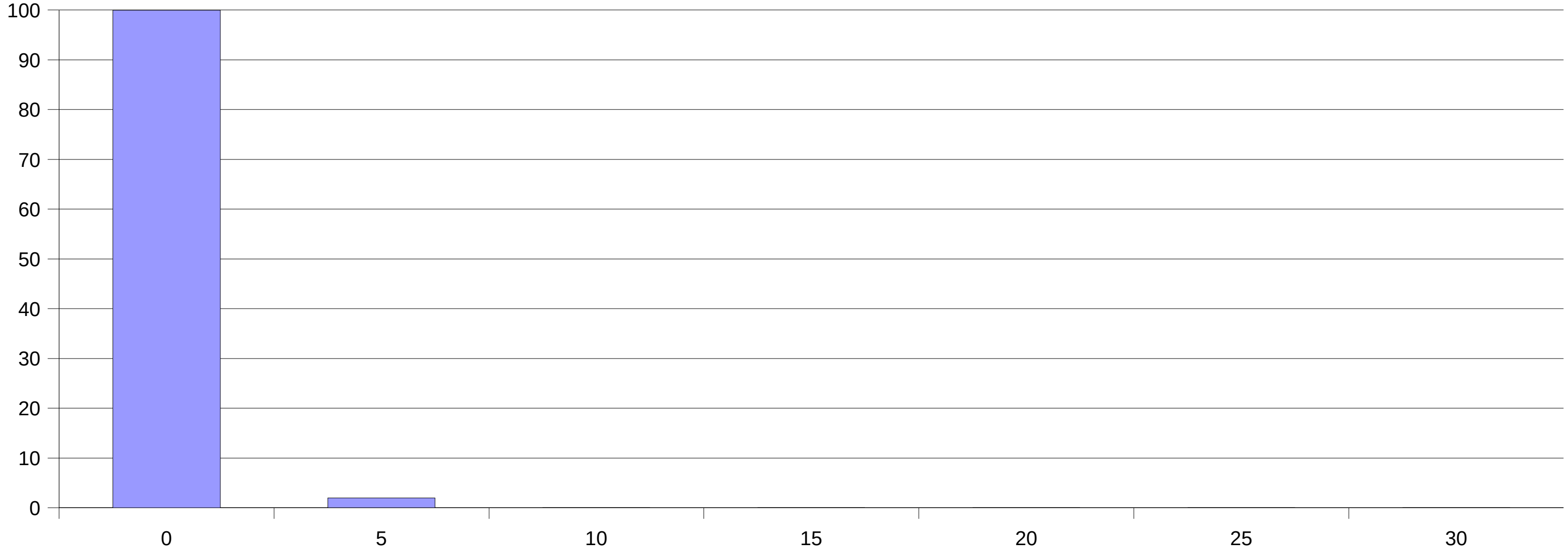
- Batch job
- Long CPU bursts



# CPU Burst Lengths

## "I/O-bound" program

- **Copy, Data acquisition, ...**
- ***Tiny* CPU bursts between system calls**



# Preemptive?

## Four opportunities to schedule

- A running process waits (I/O, child, ...)
- A running process exits
- A waiting process becomes runnable (I/O done)
- Other interrupt (clock, page fault)

## Multitasking types

- Fully Preemptive: ***All four cause scheduling***
- “Cooperative”: only first two

# Preemptive *kernel*?

## Preemptive multitasking

- All four cases cause context switch

## Preemptive *kernel*

- All four cases cause context switch *in kernel mode*
- This is a goal of Project 3
  - System calls: interrupt disabling only when really necessary
  - Clock interrupts should suspend system call execution
    - » So fork() should *appear* atomic, but not *execute* that way

# CPU Scheduler

## Invoked when CPU becomes idle

- Current task blocks
- Clock interrupt

## Select next task

- *Quickly*
- PCB's in: FIFO, priority queue, tree, ...

## Switch (using “dispatcher”)

- Your term may vary

# Dispatcher

## Set down running task

- Save register state
- Update CPU usage information
- Store PCB in “run queue”

## Pick up designated task

- Activate new task's memory
  - Protection, mapping
- Restore register state
- Transfer to user mode

# Scheduling Criteria

## System administrator view

- Maximize/trade off
  - CPU utilization (“busy-ness”)
  - Throughput (“jobs per second”)

## Process view

- Minimize
  - Turnaround time (everything)
  - Waiting time (runnable but not running)

## User view (interactive processes)

- Minimize response time (input/output latency)

# Algorithms

## Don't try these at home

- FCFS
- SJF
- Priority

## Reasonable

- Round-Robin
- Multi-level (plus feedback)

## Multiprocessor, real-time

# FCFS- First Come, First Served

**Basic idea**

- Run task until it relinquishes CPU
- When runnable, place at end of FIFO queue

**Waiting time *very* dependent on mix**

**"Convoy effect"**

- N tasks each make 1 I/O request, stall
- 1 task executes very long CPU burst
- Lather, rinse, repeat
- N "I/O-bound tasks" can't keep I/O device busy!

# SJF- Shortest Job First

## Basic idea

- Choose task with shortest *next* CPU burst
- Will give up CPU soonest, be “nicest” to other tasks
- Provably “optimal”
  - Minimizes average waiting time across tasks
- *Practically impossible* (oh, well)
  - Could *predict* next burst length...
    - » Text presents exponential average
    - » Does not present evaluation (Why not?  Hmm...)

# Priority

## Basic idea

- Choose "most important" waiting task
  - (Nomenclature: does "high priority" mean `p=0` or `p=255`?)

## Priority assignment

- Static: fixed property (engineered?)
- Dynamic: function of task behavior

## Big problem: *Starvation*

- "Most important" task gets to run often
- "Least important " task may *never* run
- Possible hack: priority "aging"

# Round-Robin

## Basic idea

- Run each task for a fixed "time quantum"
- When quantum expires, append to FIFO queue

## "Fair"

- But not "provably optimal"

## Choosing quantum length

- Infinite (until process does I/O) = FCFS
- Infinitesimal (1 instruction) = "Processor sharing"
  - A technical term used by theory folks
- Balance "fairness" vs. context-switch costs

# *True* "Processor Sharing"

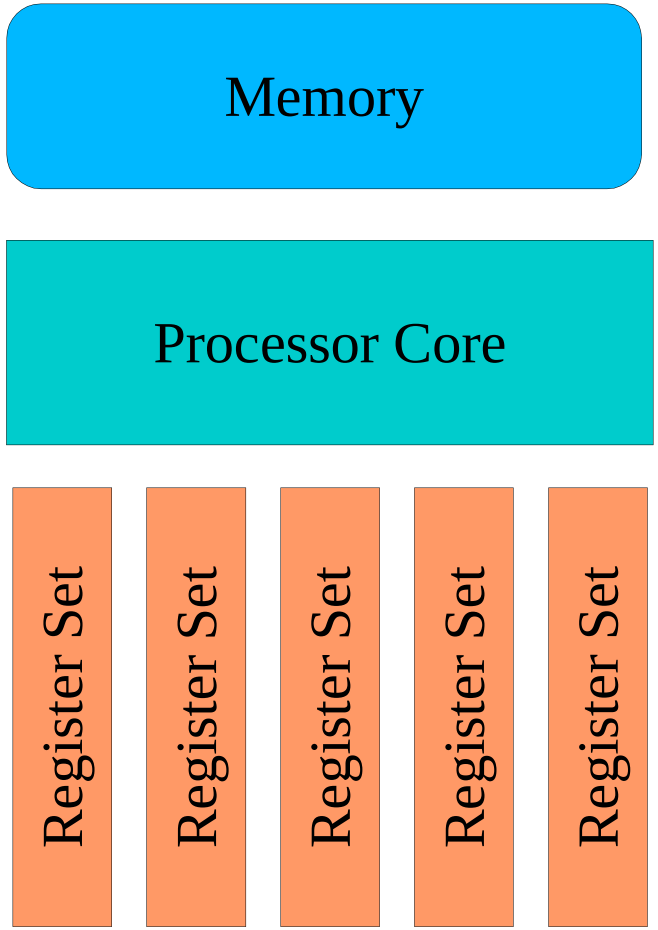
## CDC Peripheral Processors

## Memory latency

- *Long*, fixed constant
- Every instruction has a memory operand

## Solution: round robin

- Quantum = 1 instruction



# *True* "Processor Sharing"

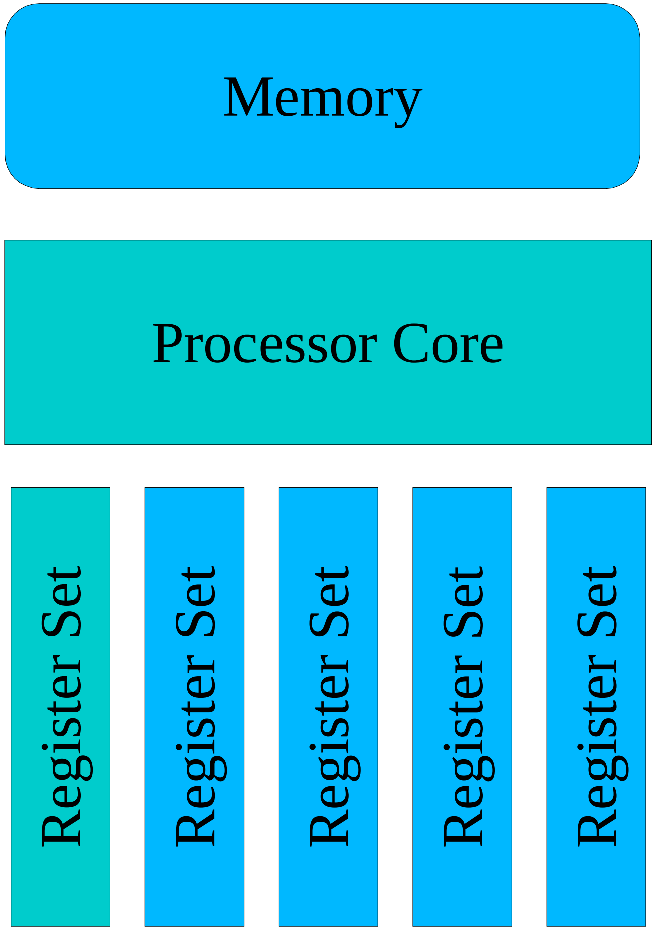
## CDC Peripheral Processors

## Memory latency

- *Long*, fixed constant
- Every instruction has a memory operand

## Solution: round robin

- Quantum = 1 instruction
- One "process" running
- N-1 "processes" waiting



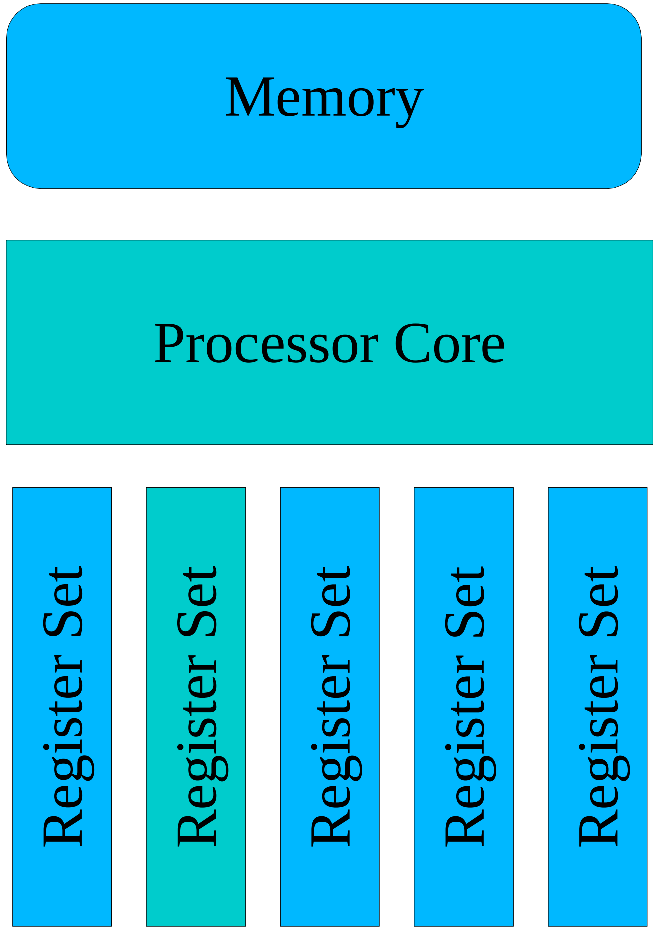
# *True* "Processor Sharing"

## Each instruction

- "Brief" computation
- One load xor one store
  - Sleeps process N cycles

## Steady state

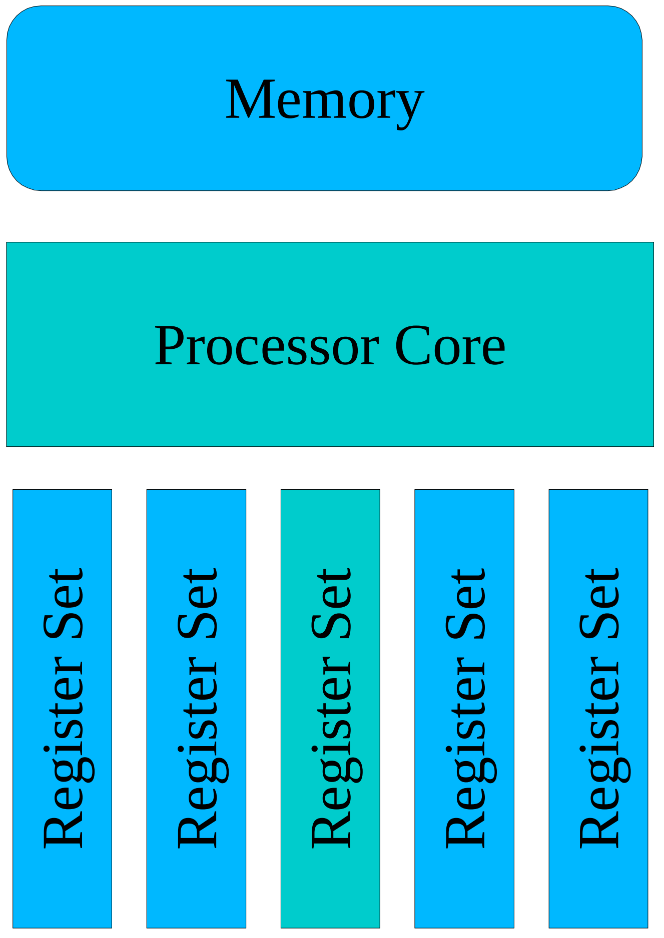
- Run when ready
- Ready when it's your turn



# Everything Old Is New Again

## Intel "hyperthreading"

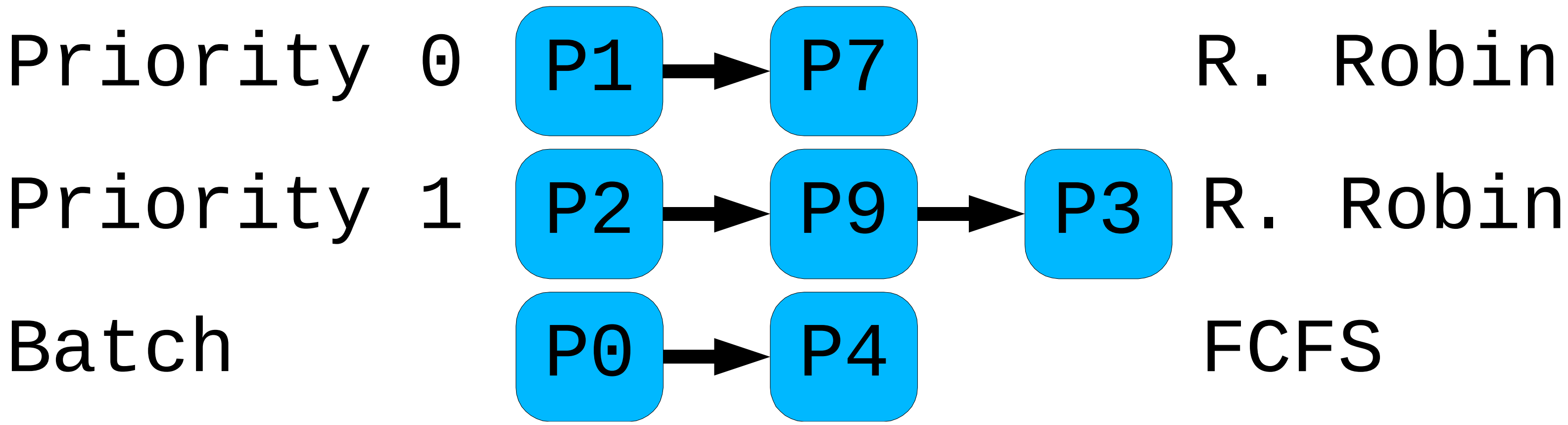
- N register sets
- M functional units
- Switch on long-running operations
- Sharing less regular
- Sharing illusion more lumpy
  - Good for some application *mixes*



# Multi-level Queue

## N independent process queues

- One per priority
- Algorithm per-queue



# Multi-level Queue

## Inter-queue scheduling

- **Strict priority**
  - **Pri 0 runs before Pri 1, Pri 1 runs before batch – *every time***
- **Time slicing (e.g., weighted round-robin)**
  - **Pri 0 gets 2 slices**
  - **Pri 1 gets 1 slice**
  - **Batch gets 1 slice**

# Multi-level *Feedback* Queue

**N queues, different quanta**

**Block/sleep before quantum expires?**

- **Added to end of your queue**

**Exhaust your quantum?**

- **Demoted to slower queue**
  - **Lower priority, typically longer quantum**

**Can you be promoted back up?**

- **Maybe I/O promotes you**
- **Maybe you “age” upward**

**Popular “time-sharing” scheduler**

# Multiprocessor Scheduling

## Common assumptions

- Homogeneous processors (same speed)
- Uniform memory access (UMA)

## Load sharing / Load balancing

- Single global ready queue – no false idleness

## Processor Affinity

- Some processor may be more desirable or necessary
  - » Special I/O device
  - » Fast thread switch

# Multiprocessor Scheduling - “SMP”

## Asymmetric multiprocessing

- One processor is “special”
  - Executes all kernel-mode instructions
  - Schedules other processors
- “Special” aka “bottleneck”

## Symmetric multiprocessing - “SMP”

- “Gold standard”
- Tricky

# Real-time Scheduling

***Hard*** **real-time**

- **System must *always* meet performance goals**
  - **Or it's *broken* (think: avionics)**
- **Designers must describe task requirements**
  - **Worst-case execution time of instruction sequences**
- **“Prove” system response time**
  - **Argument or automatic verifier**
- **Cannot use indeterminate-time technologies**
  - **Disks!**

# Real-time Scheduling

## Soft real-time

- "Occasional" deadline failures tolerable
  - CNN video clip on PC
  - DVD playback on PC
- *Much* cheaper than hard real-time
  - Real-time extension to timesharing OS
    - » POSIX real-time extensions for Unix
  - Can estimate (vs. prove) task needs
- Priority scheduler
- Preemptible kernel implementation

# Scheduler Evaluation Approaches

## "Deterministic modeling"

- aka "hand execution"

## Queueing theory

- Math gets big fast
- Math sensitive to assumptions
  - May be unrealistic (aka "wrong")

## Simulation

- Workload model or trace-driven
- GIGO hazard (either way)

# Summary

## Round-robin is ok for simple cases

- **Certainly 80% of the conceptual weight**
- ***Certainly* good enough for P3**
  - **Speaking of P3...**
    - » **Understand preemption, don't evade it**

## "Real" systems

- **Some multi-level feedback**
- **Probably some soft real-time**