15-410

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

Scheduling
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Roger Dannenberg

Dave Eckhardt

Synchronization

Checkpoint 3

- "End of third week"
- No cluster meeting – regular lecture
- Expect: code drop, milestone-estimation form
  - Spending the time to really *plan* is worthwhile

Outline

Chapter 5: Scheduling

- Scheduling-people/textbook terminology note
  - "Waiting time" means "time spent runnable but stuck in a scheduler queue"
    - » Not "time waiting for an event to awaken you"
  - "Task" means "something a scheduler schedules" (we say "thread" or sometimes "runnable")

CPU-I/O Cycle

Process view: 2 states

- Running
- Blocked on I/O

Life Cycle:

- I/O (loading executable), CPU, I/O, CPU, .., CPU (`exit()`)

System view

- Running
- Blocked on I/O
- Runnable (i.e. Waiting) – not enough processors right now

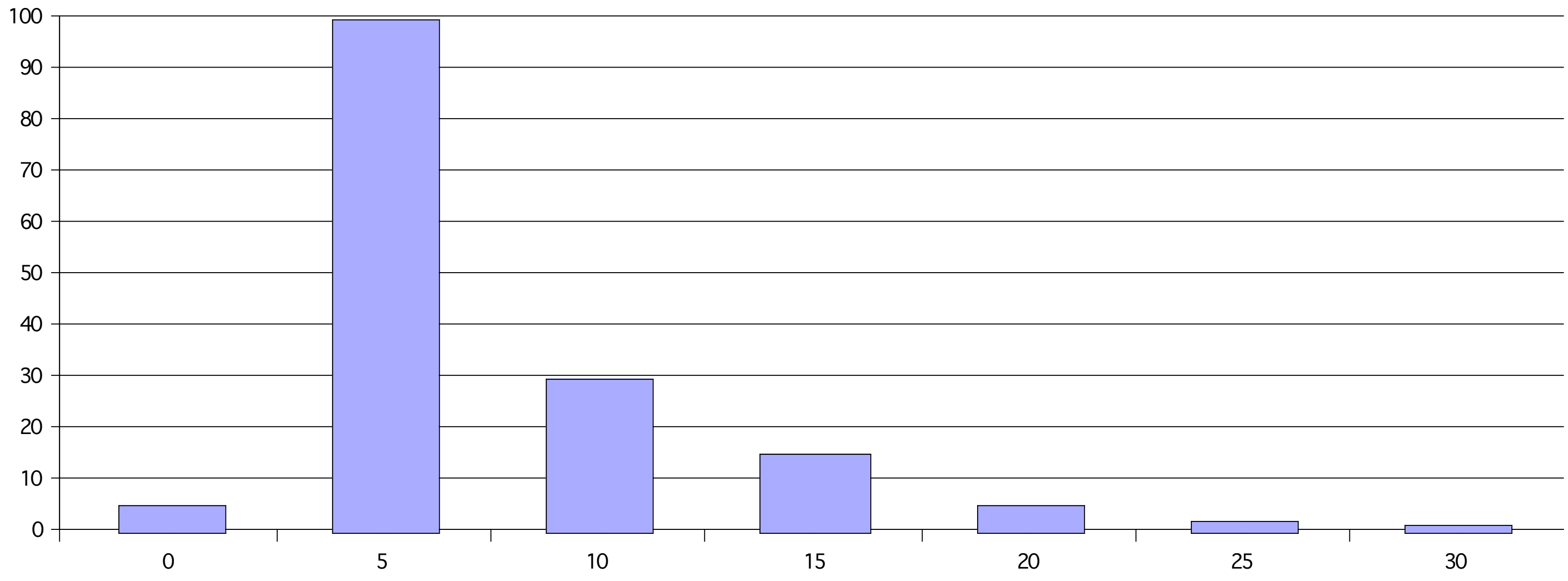
Running ⇒ blocked mostly depends on program

- How long do processes run before blocking?

CPU Burst Lengths

Overall

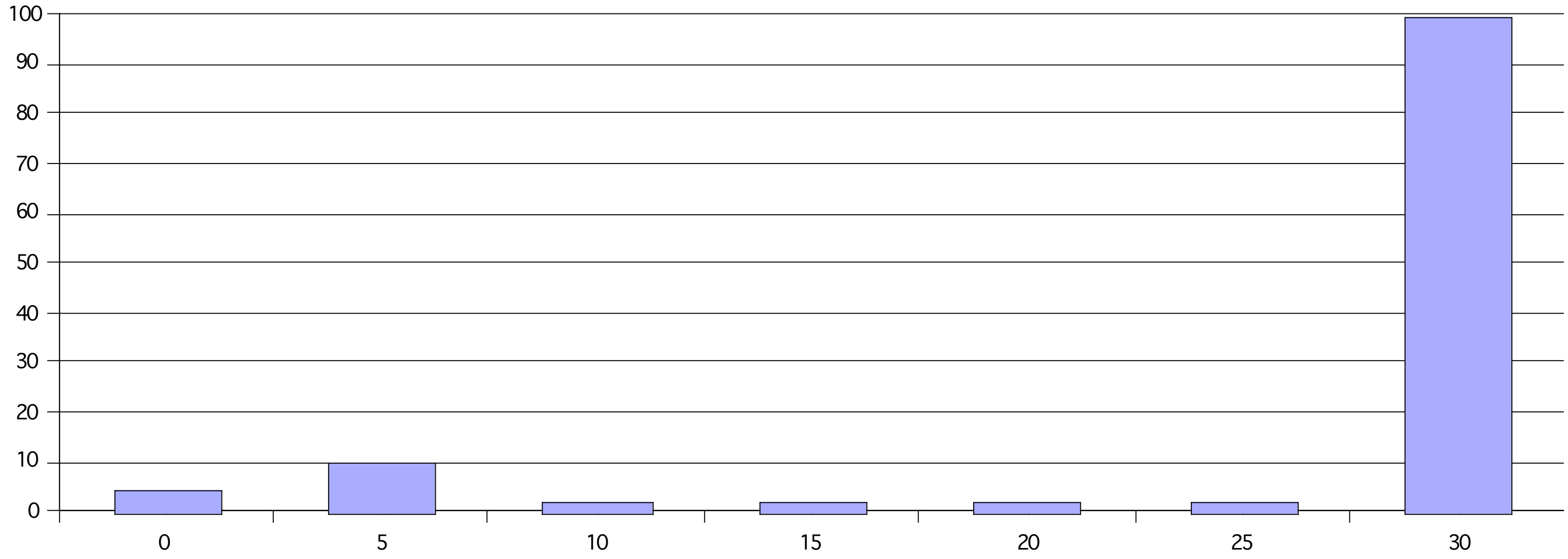
- Exponential fall-off in CPU burst length



CPU Burst Lengths

"CPU-bound" program

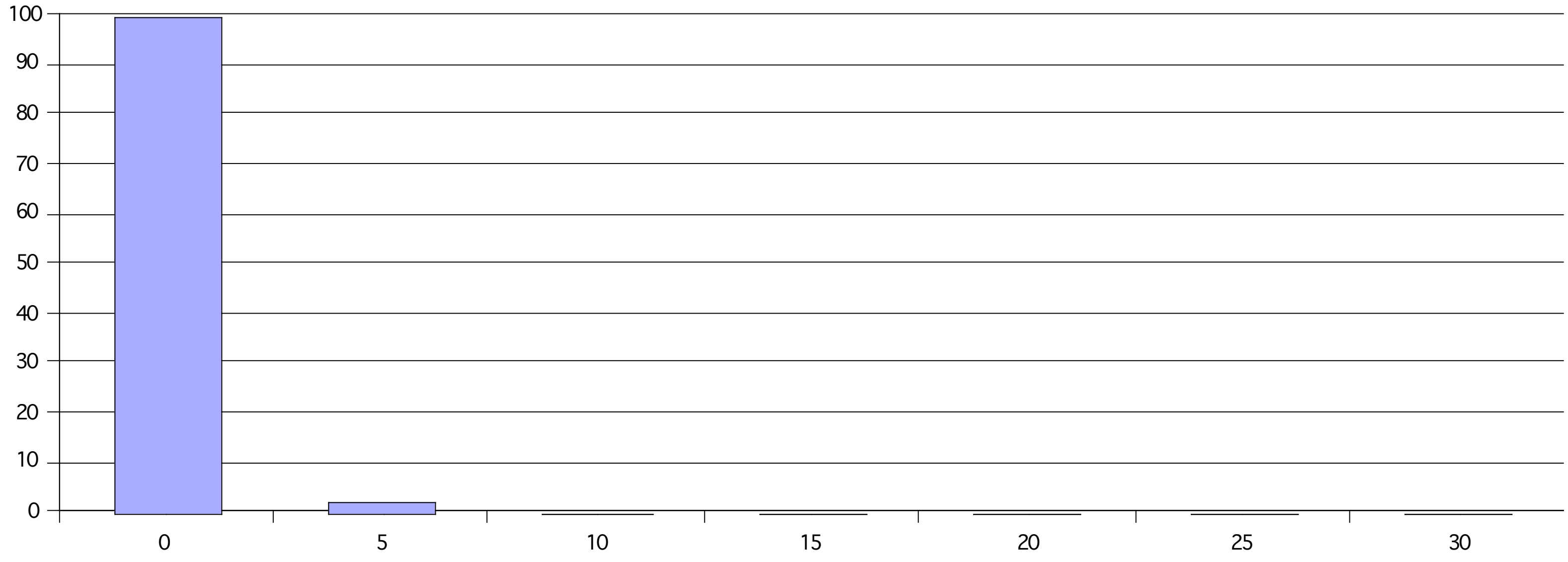
- Batch job
- Long CPU bursts



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 blocked 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 and/or time passes

- Current task blocks
- Clock interrupt

Select next task

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

Switch (using “dispatcher”)

- Your term may vary

Dispatcher

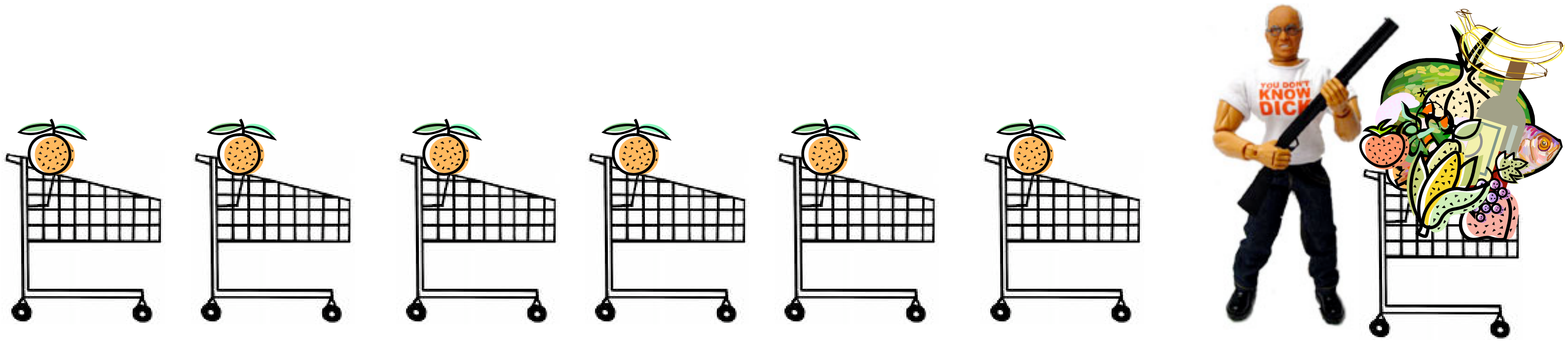
Set down running task

- 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
- “Return” to whatever the task was previously doing

Consider…



Who goes first? Last?

Now who goes first? Last?

Does this change things?

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

- Some processes run briefly, some much longer

“Convoy effect”

- N tasks each make 1 I/O request, stall (e.g., file copy)
- 1 task executes very long CPU burst
  - All I/O tasks become runnable during this time
- Lather, rinse, repeat
  - Result: N “I/O-bound tasks” can't keep I/O devices 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 suggests averaging recent burst lengths
    - » 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"

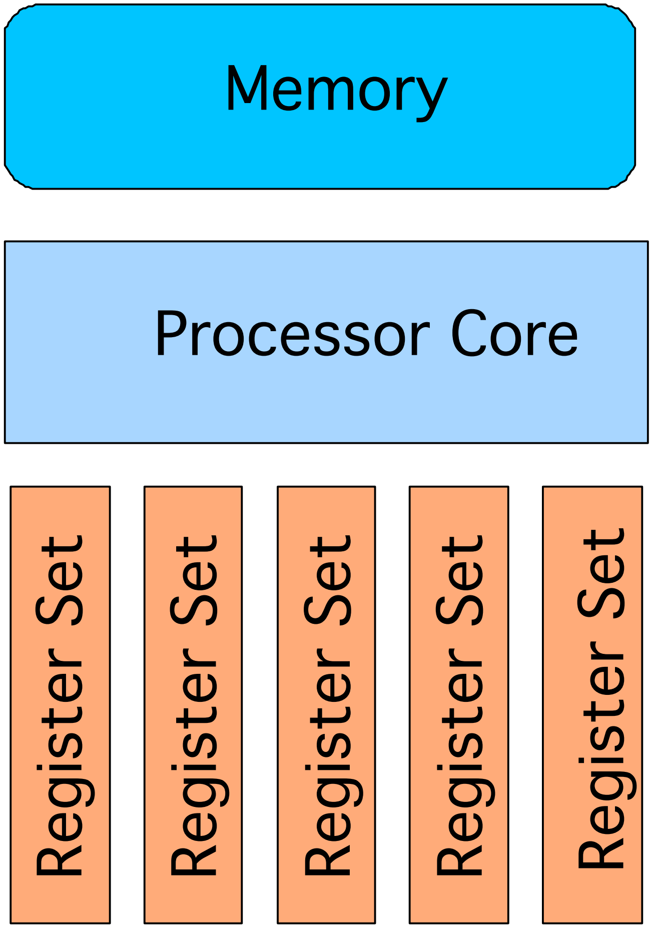
CDC Peripheral Processors

Memory latency

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

Solution: round robin

- Quantum = 1 instruction



True "Processor Sharing"

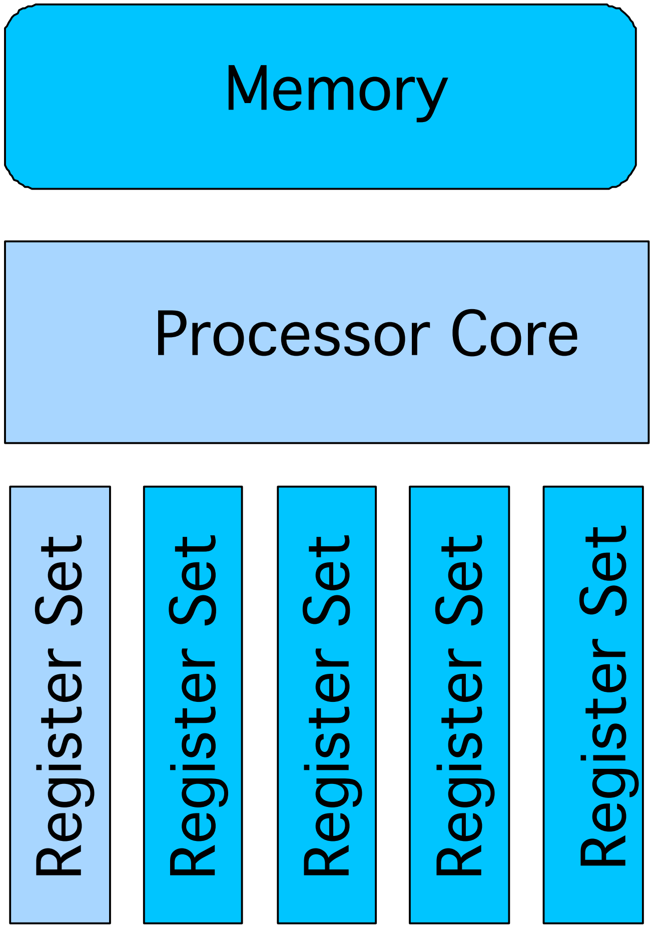
CDC Peripheral Processors

Memory latency

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

Solution: round robin

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



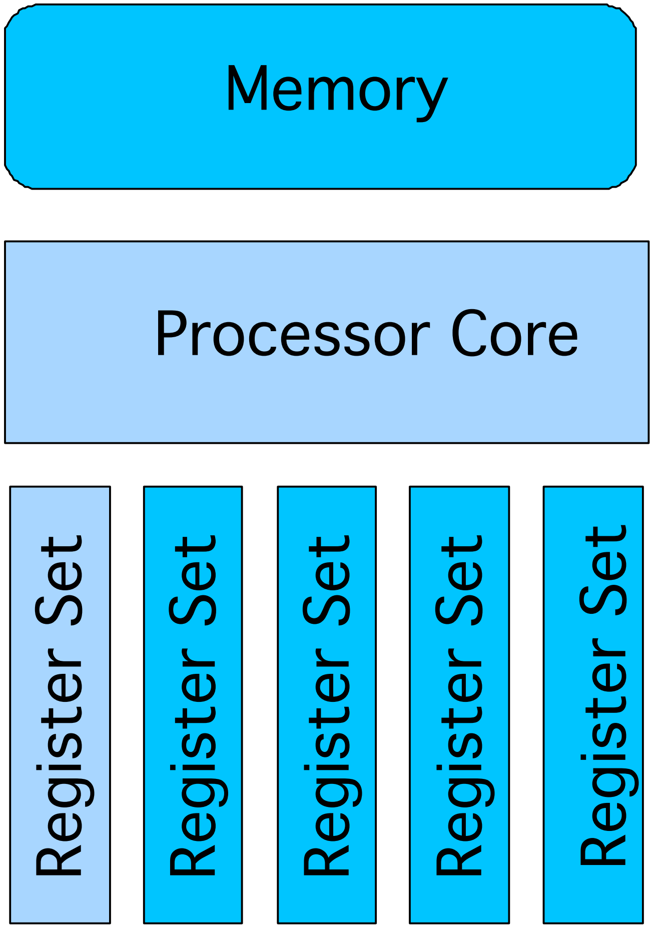
True "Processor Sharing"

Each instruction

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

Steady state

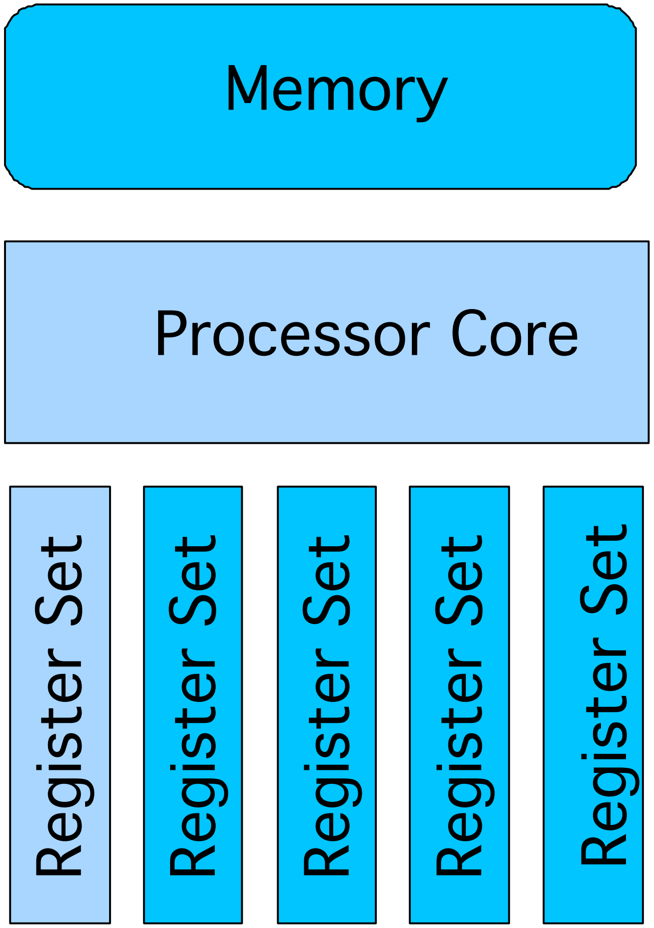
- Run when you're ready
- Ready when it's your turn



Everything Old Is New Again

Intel “hyperthreading”

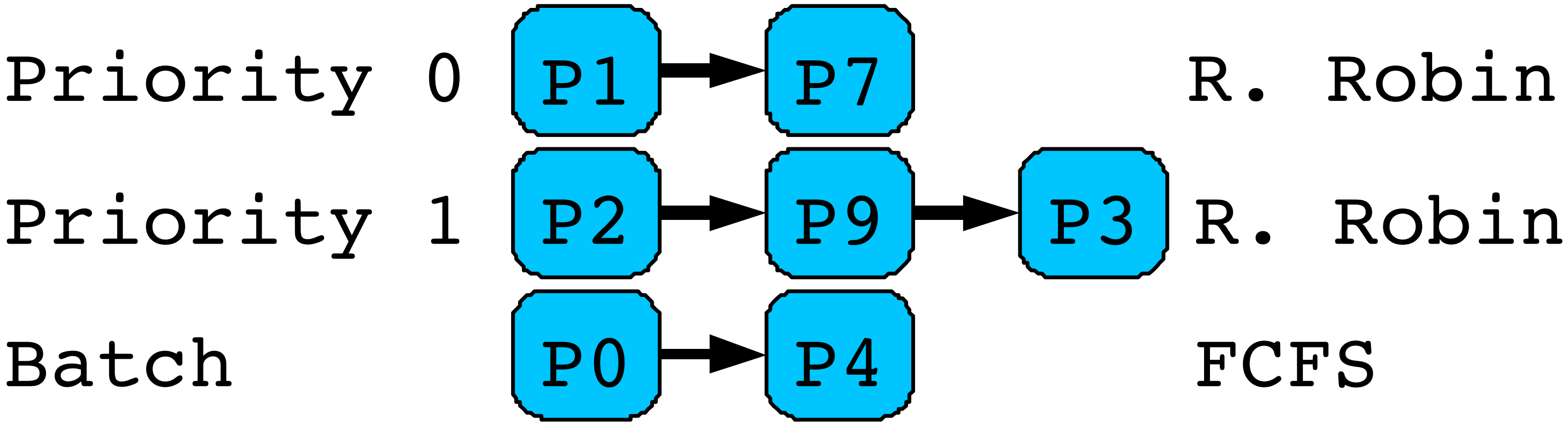
- N register sets
- M functional units
- Switch on long-running operations
- Sharing less regular
- Sharing illusion more lumpy
  - Good for some application *mixes*
  - *Awful* for others
  - “Hyperthreading Hurts Server Performance, Say Developers”



Multi-level Queue

N independent process queues

- One per priority
- Algorithm per-queue



Priority 0 P1 → P7 R. Robin

Priority 1 P2 → P9 → P3 R. Robin

Batch P0 → P4 FCFS

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 ("good runnable")

Exhaust your quantum?

- Demoted to slower queue ("bad runnable!")
  - 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)

Goal: Load sharing / Load balancing

- “Easy”: single global ready queue – no false idleness

But: “Processor Affinity”

- Some processor may be more desirable or necessary
    - » Special I/O device
    - » Fast thread switch
    - » 1/Nth of memory may be faster

Multiprocessor Scheduling

Asymmetric multiprocessing

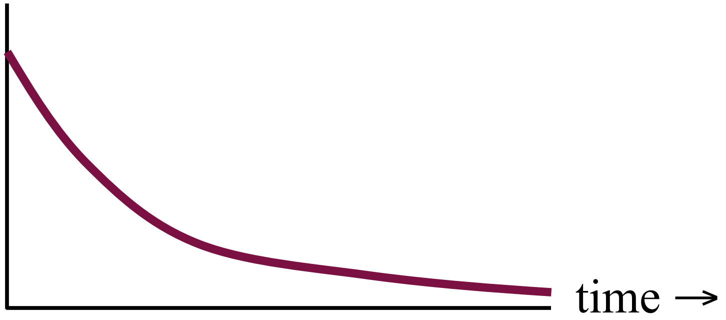
- Also known as “master/slave”
- One processor is “special”
  - Executes all kernel-mode instructions
  - Schedules other processors
- “Special” aka “bottleneck”

Symmetric multiprocessing - “SMP”

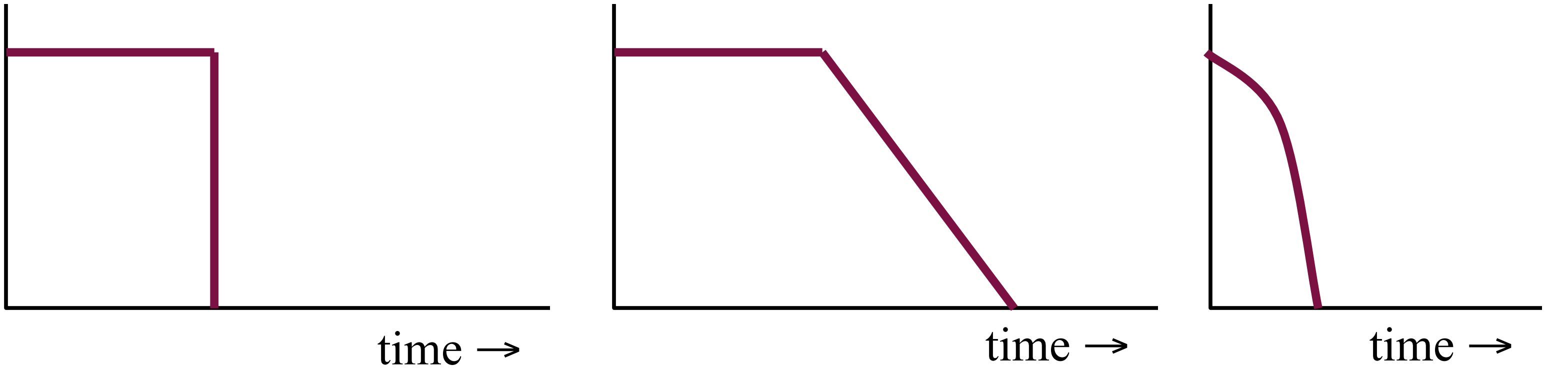
- “Gold standard”
- Tricky

Real-Time Scheduling

What’s a computation worth?



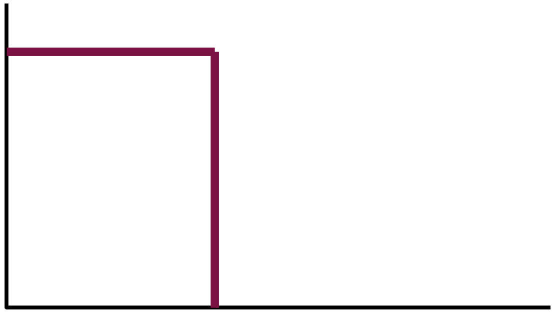
Real Time: No (extra) value if early (or in some cases, curve just falls off fast)



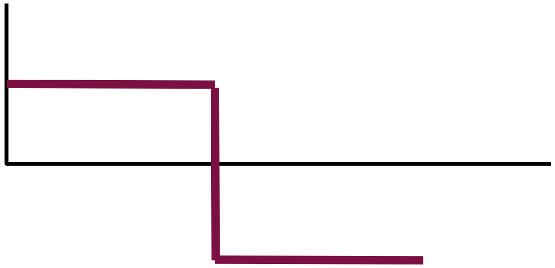
“Hard Real Time”: Many Definitions

Very fast response time -- 10s of *μ*s

No value if results are late:



Very costly if late:



Never late

Note: literature is unclear about the “real” definition.

Hard Real-Time Scheduling

- 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?
  - Networks?
- Solutions often involve
  - Simplified designs
  - Over-engineered systems
  - Dedicated hardware
  - Specialized OS

More Definitions: “Soft Real Time”

Computation is still has value after deadline

- Think User Interface
- Many control systems

Performance is not critical (no one will die)

- YouTube video
- Skype

It’s acceptable for system to be late sometimes

- User Interfaces
- CD-R writing software

Soft Real-Time Scheduling

Now commonly supported in generic OS

- POSIX real-time extensions for Unix

Priority-based Scheduler

Preemptible kernel implementation

Scheduler Evaluation Approaches

“Deterministic modeling”

- aka “hand execution”

Queueing theory

- Often gives fast and useful *approximations*
- 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