Scheduling in Linux (2.6)

Don Porter

Last time

- We went through the high-level theory of scheduling algorithms
  - One approach was a multi-level feedback queue
- Today: View into how Linux makes its scheduling decisions
  - Note: a bit dated – this is from v2.6, but I think still pedagogically useful and more accessible than the new approach

Lecture goals

- Understand low-level building blocks of a scheduler
- Understand competing policy goals
- Understand the O(1) scheduler

(Linux) Terminology Map

- task – a Linux PCB
  - Really represents a thread in the kernel
    - (more on threads next lecture)
- Quantum – CPU timeslice
  - "Quanta" is plural, for those whose Latin is dusty

Outline

- Policy goals (review)
- O(1) Scheduler

Policy goals

- Fairness – everything gets a fair share of the CPU
- Real-time deadlines
  - CPU time before a deadline more valuable than time after
- Latency vs. Throughput: Timeslice length matters!
  - GUI programs should feel responsive
  - CPU-bound jobs want long timeslices, better throughput
- User priorities
  - Virus scanning is nice, but I don't want it slowing things down

No perfect solution

- Optimizing multiple variables
- Like memory allocation, this is best-effort
  - Some workloads prefer some scheduling strategies
- Nonetheless, some solutions are generally better than others

Outline

- Policy goals
- O(1) Scheduler

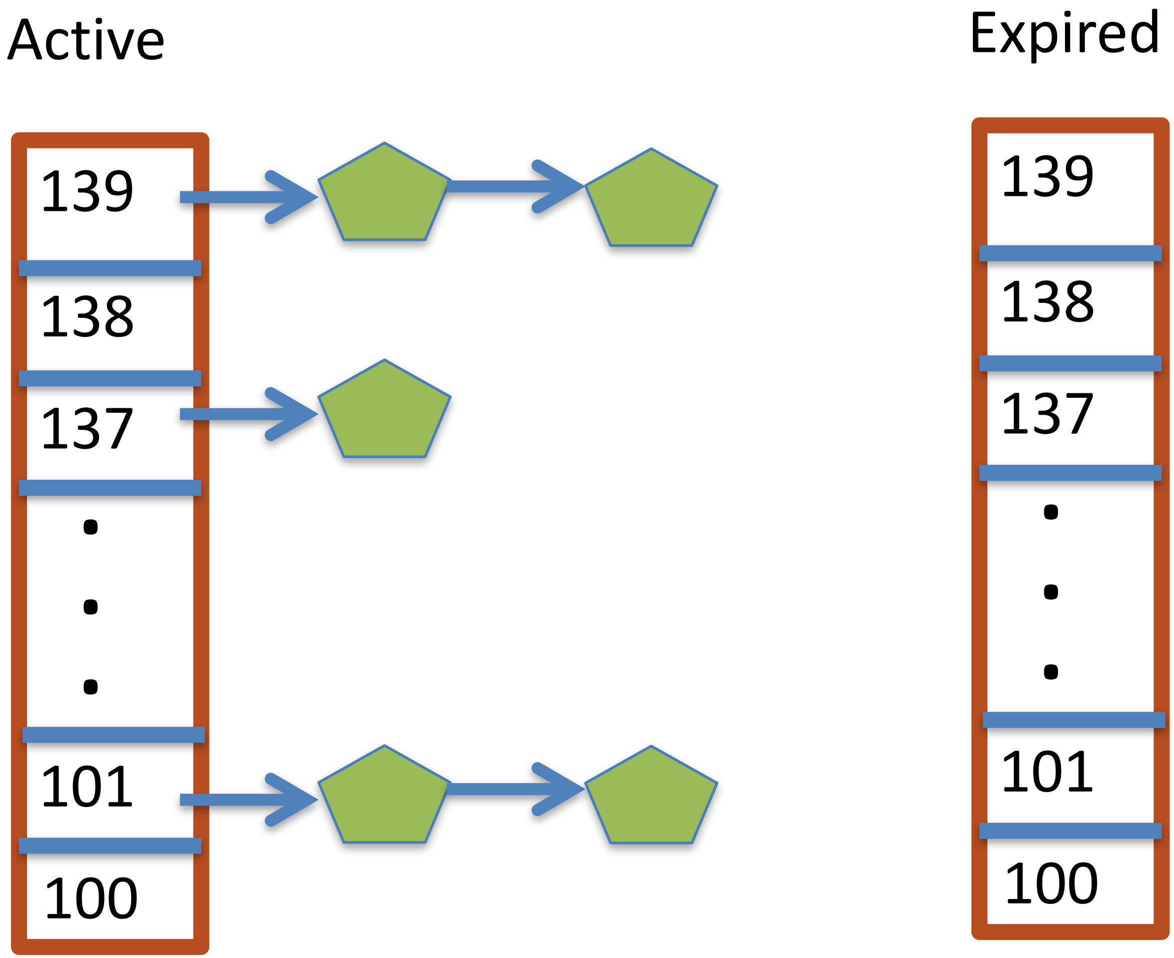
O(1) scheduler

- Goal: decide who to run next, independent of number of processes in system
  - Still maintain ability to prioritize tasks, handle partially unused quanta, etc

O(1) Bookkeeping

- runqueue: a list of runnable tasks
  - Blocked processes are not on any runqueue
  - A runqueue belongs to a specific CPU
  - Each task is on exactly one runqueue
    - Task only scheduled on runqueue's CPU unless migrated
- 2 *40 * #CPUs runqueues
  - 40 dynamic priority levels (more later)
  - 2 sets of runqueues – one active and one expired

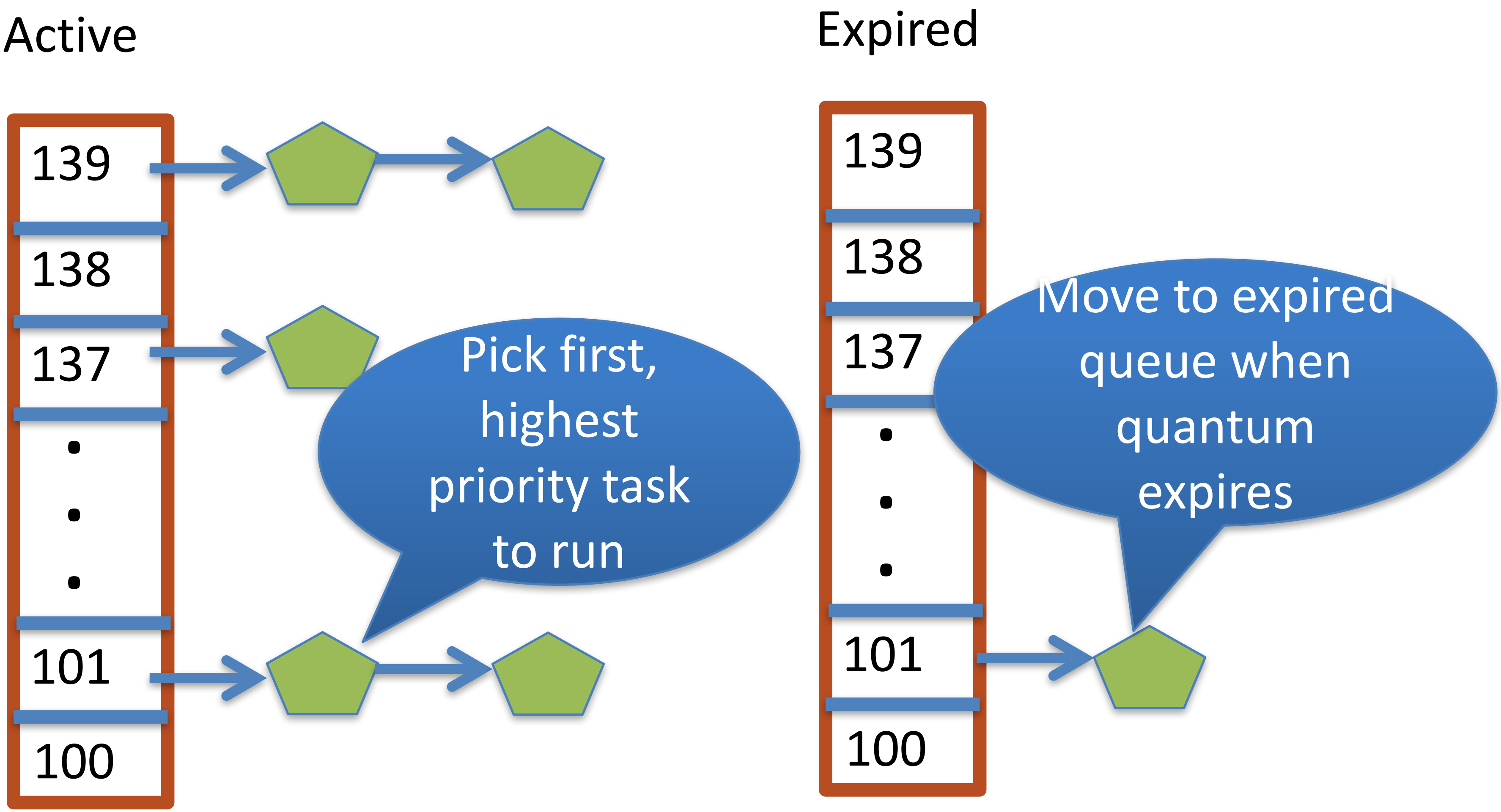
O(1) Data Structures



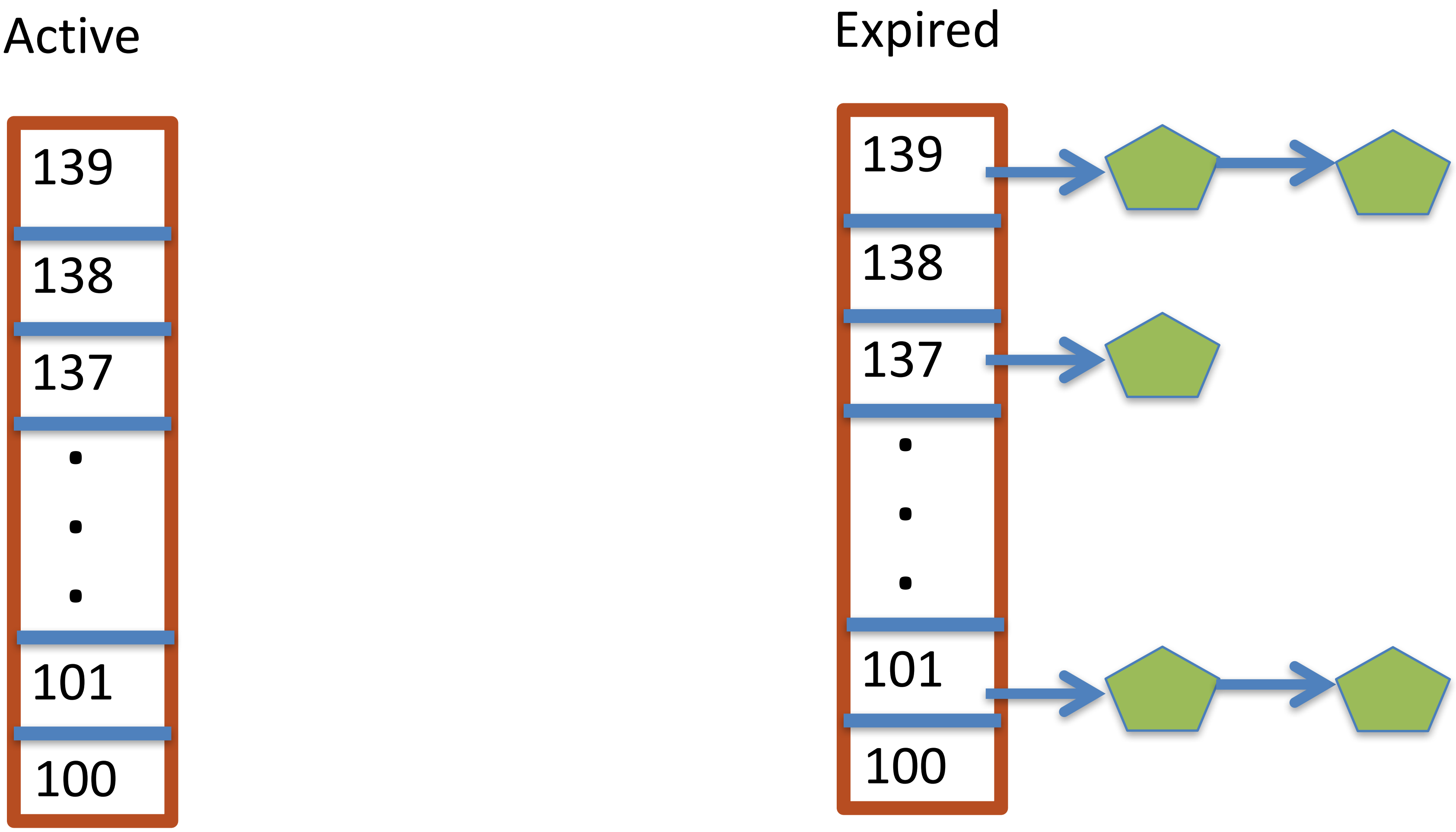
O(1) Intuition

- Take the first task off the lowest-numbered runqueue on active set
  - Confusingly: a lower priority value means higher priority
- When done, put it on appropriate runqueue on expired set
- Once active is completely empty, swap which set of runqueues is active and expired
- “Constant time”, since fixed number of queues to check; only take first item from non-empty queue

O(1) Example


Active
139
138
137
101
100
Pick first, highest priority task to run
Expired
139
138
137
101
100
Move to expired queue when quantum expires

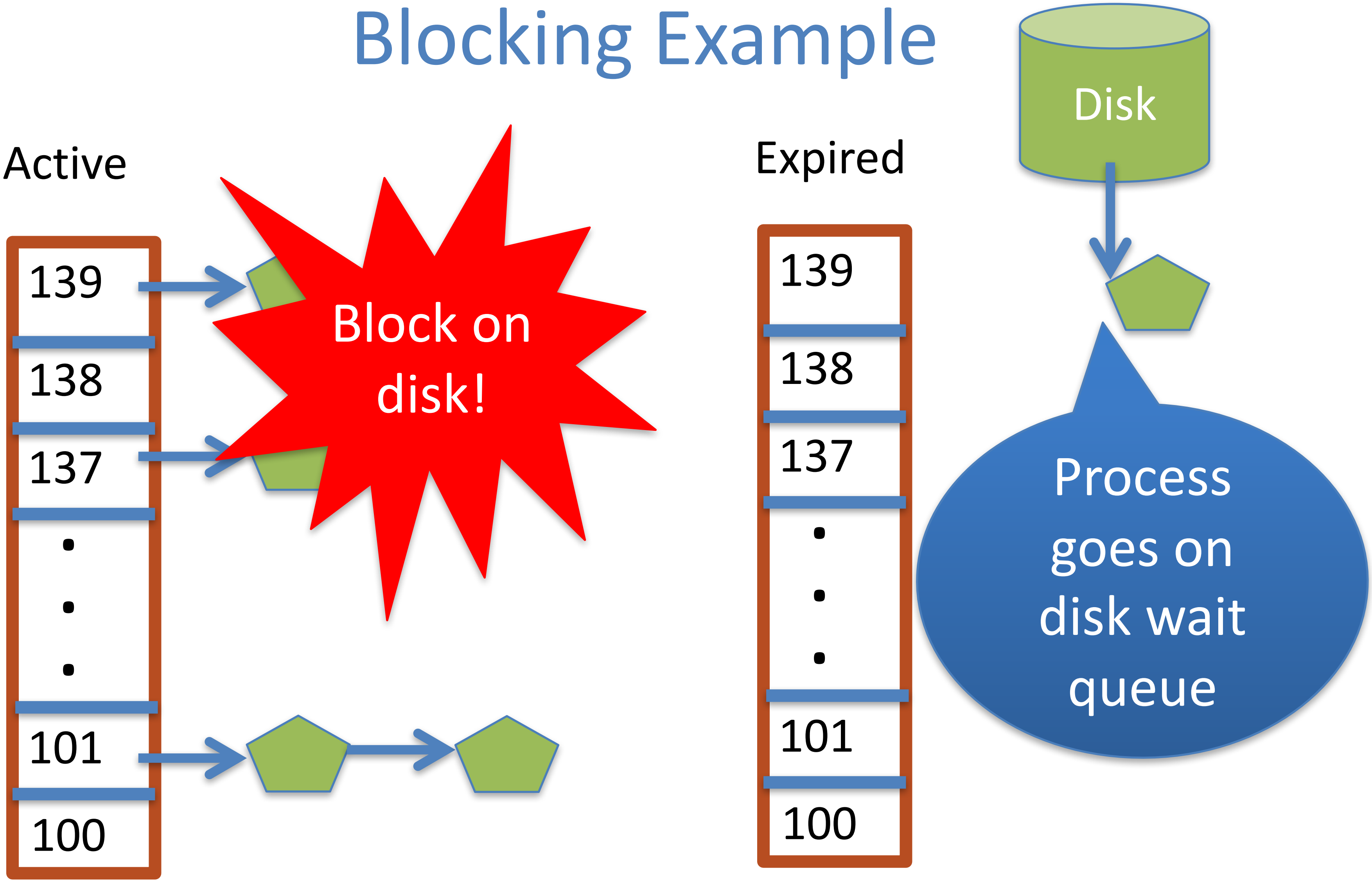
What now?



Blocked Tasks

- What if a program blocks on I/O, say for the disk?
  - It still has part of its quantum left
  - Not runnable, so don't waste time putting it on the active or expired runqueues
- We need a "wait queue" associated with each blockable event
  - Disk, lock, pipe, network socket, etc.

Blocking Example



Blocked Tasks, cont.

- A blocked task is moved to a wait queue until the expected event happens
  - **No longer on any active or expired queue!**
- Disk example:
  - After I/O completes, interrupt handler moves task back to active runqueue

Time slice tracking

- If a process blocks and then becomes runnable, how do we know how much time it had left?
- Each task tracks ticks left in 'time_slice' field
  - On each clock tick: `current->time_slice--`
  - If time slice goes to zero, move to expired queue
    - Refill time slice
    - Schedule someone else
  - An unblocked task can use balance of time slice
  - Forking halves time slice with child

More on priorities

- 100 = highest priority
- 139 = lowest priority
- 120 = base priority
  - "nice" value: user-specified adjustment to base priority
  - Selfish (not nice) = -20 (I want to go first)
  - Really nice = +19 (I will go last)

Base time slice

$$time = \begin{cases} (140 - prio) * 20ms & prio < 120 \\ (140 - prio) * 5ms & prio \geq 120 \end{cases}$$

- "Higher" priority tasks get longer time slices
  - And run first

Don't worry about memorizing these formulae

Goal: Responsive UIs

- Most GUI programs are I/O bound on the user
  - Unlikely to use entire time slice
- Users get annoyed when they type a key and it takes a long time to appear
- Idea: give UI programs a priority boost
  - Go to front of line, run briefly, block on I/O again
- Which ones are the UI programs?

Idea: Infer from sleep time

- By definition, I/O bound applications spend most of their time waiting on I/O
- We can monitor I/O wait time and infer which programs are GUI (and disk intensive)
- Give these applications a priority boost
- Note that this behavior can be dynamic
  - Ex: GUI configures DVD ripping, then it is CPU-bound
  - Scheduling should match program phases

Dynamic priority

dynamic priority = max (100, min (*static priority* – *bonus* + 5, 139))

- Bonus is calculated based on sleep time
- Dynamic priority determines a tasks' runqueue
- This is a heuristic to balance competing goals of CPU throughput and latency in dealing with infrequent I/O
  – May not be optimal

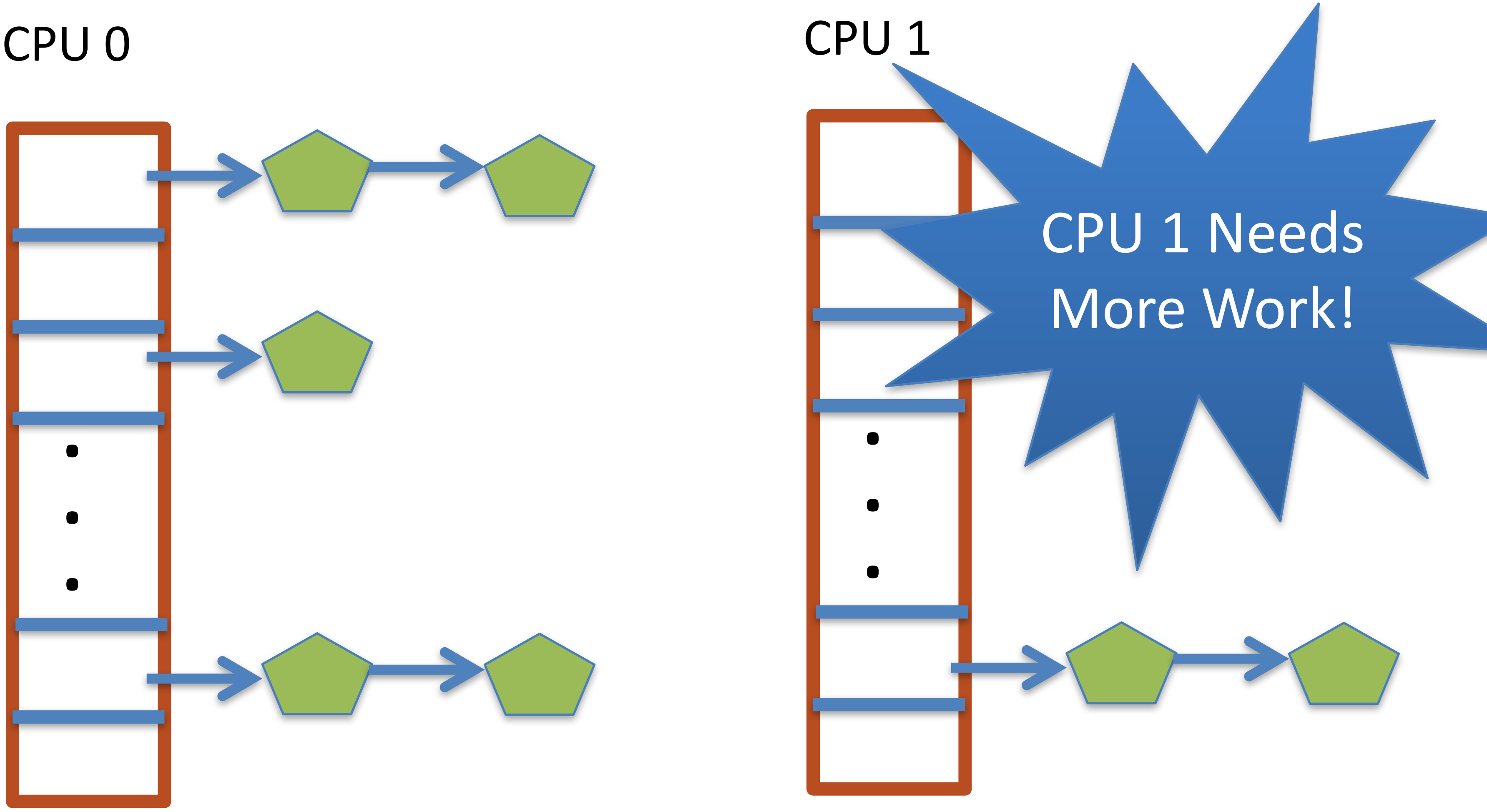
Dynamic Priority in O(1) Scheduler

- Important: The runqueue a process goes in is determined by the **dynamic** priority, not the static priority
  - Dynamic priority is mostly determined by time spent waiting, to boost UI responsiveness
- Nice values influence **static** priority
  - No matter how “nice” you are (or aren’t), you can’t boost your dynamic priority without blocking on a wait queue!

Rebalancing tasks

- As described, once a task ends up in one CPU's runqueue, it stays on that CPU forever

Rebalancing



Rebalancing tasks

- As described, once a task ends up in one CPU's runqueue, it stays on that CPU forever
- What if all the processes on CPU 0 exit, and all of the processes on CPU 1 fork more children?
- We need to periodically rebalance
- Balance overheads against benefits
  - Figuring out where to move tasks isn't free

Idea: Idle CPUs rebalance

- If a CPU is out of runnable tasks, it should take load from busy CPUs
  - Busy CPUs shouldn't lose time finding idle CPUs to take their work if possible
- There may not be any idle CPUs
  - Overhead to figure out whether other idle CPUs exist
  - Just have busy CPUs rebalance much less frequently

Average load

- How do we measure how busy a CPU is?
- Average number of runnable tasks over time
- Available in /proc/loadavg

Rebalancing strategy

- Read the loadavg of each CPU
- Find the one with the highest loadavg
- (Hand waving) Figure out how many tasks we could take
  - If worth it, lock the CPU’s runqueues and take them
  - If not, try again later

Editorial Note

- O(1) scheduler is not constant time if you consider rebalancing costs
  - But whatevs: Execution time to pick next process is one of only several criteria for selecting a scheduling algorithm
  - O(1) was later replaced by a logarithmic time algorithm (Completely Fair Scheduler), that was much simpler
    - More elegantly captured these policy goals
    - Amusingly, not “completely fair” in practice

Summary

- Understand competing scheduling goals
- Understand O(1) scheduler + rebalancing