Scheduling in Linux (2.6)

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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

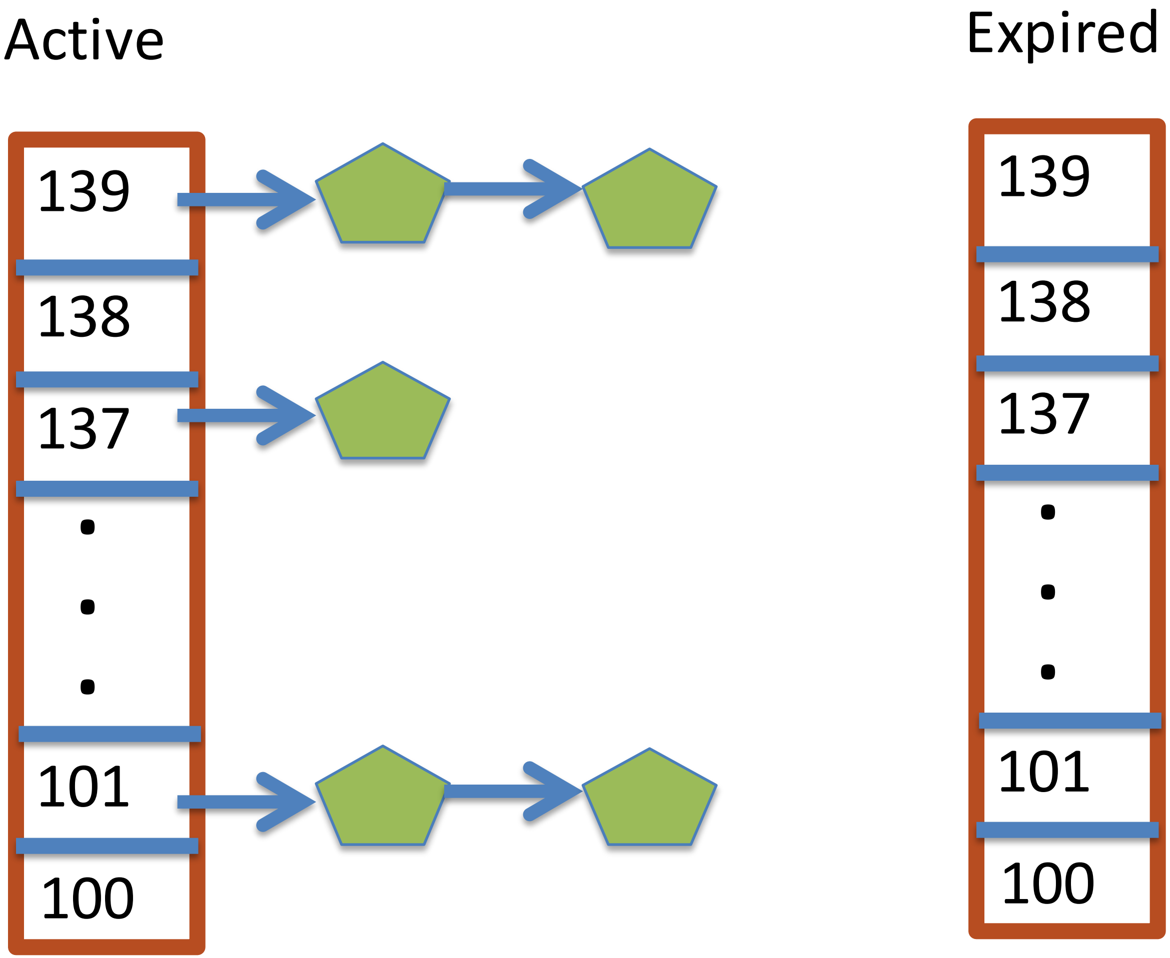
O(1) scheduler

- 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

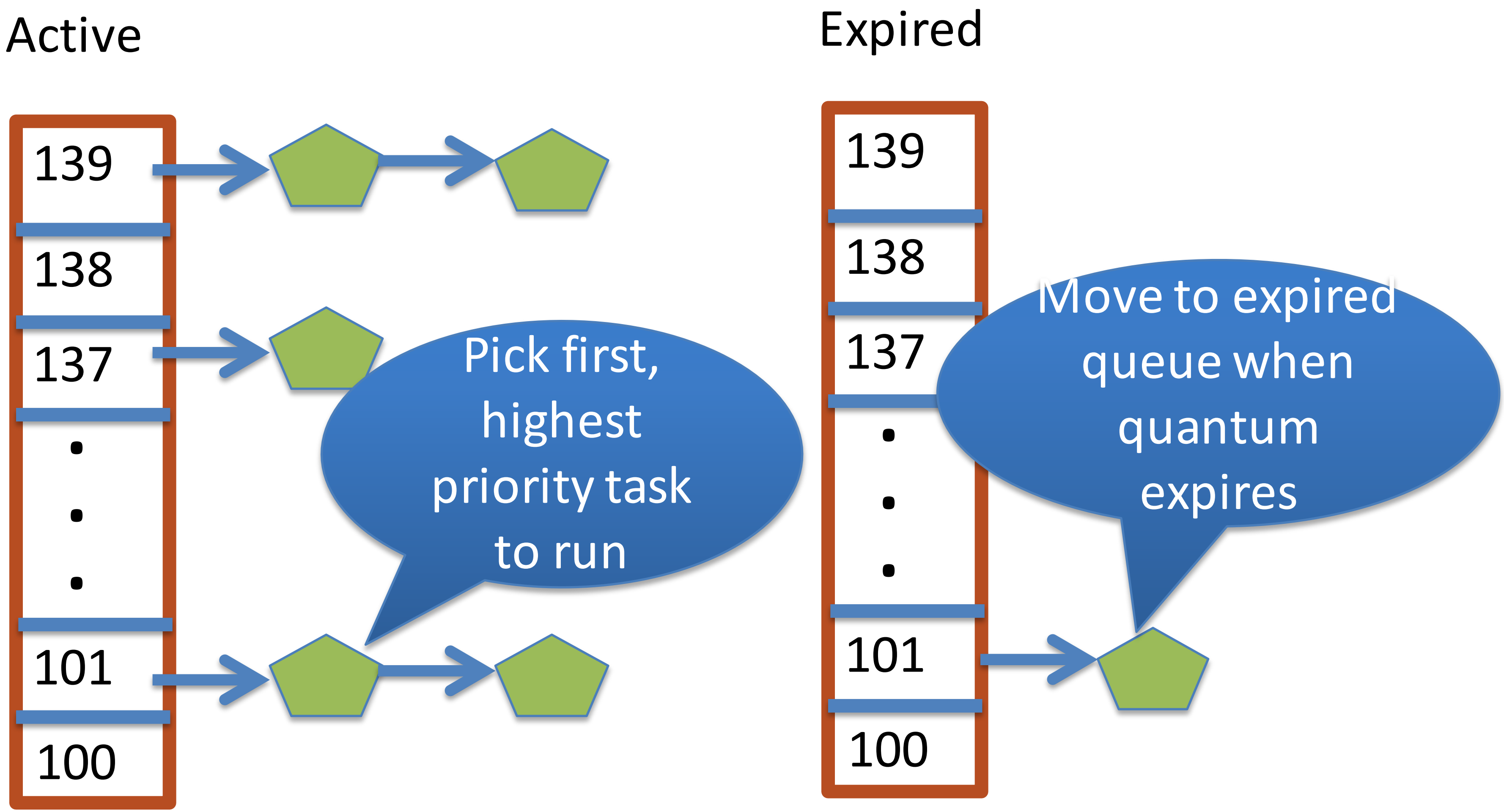
O(1) Data Structures



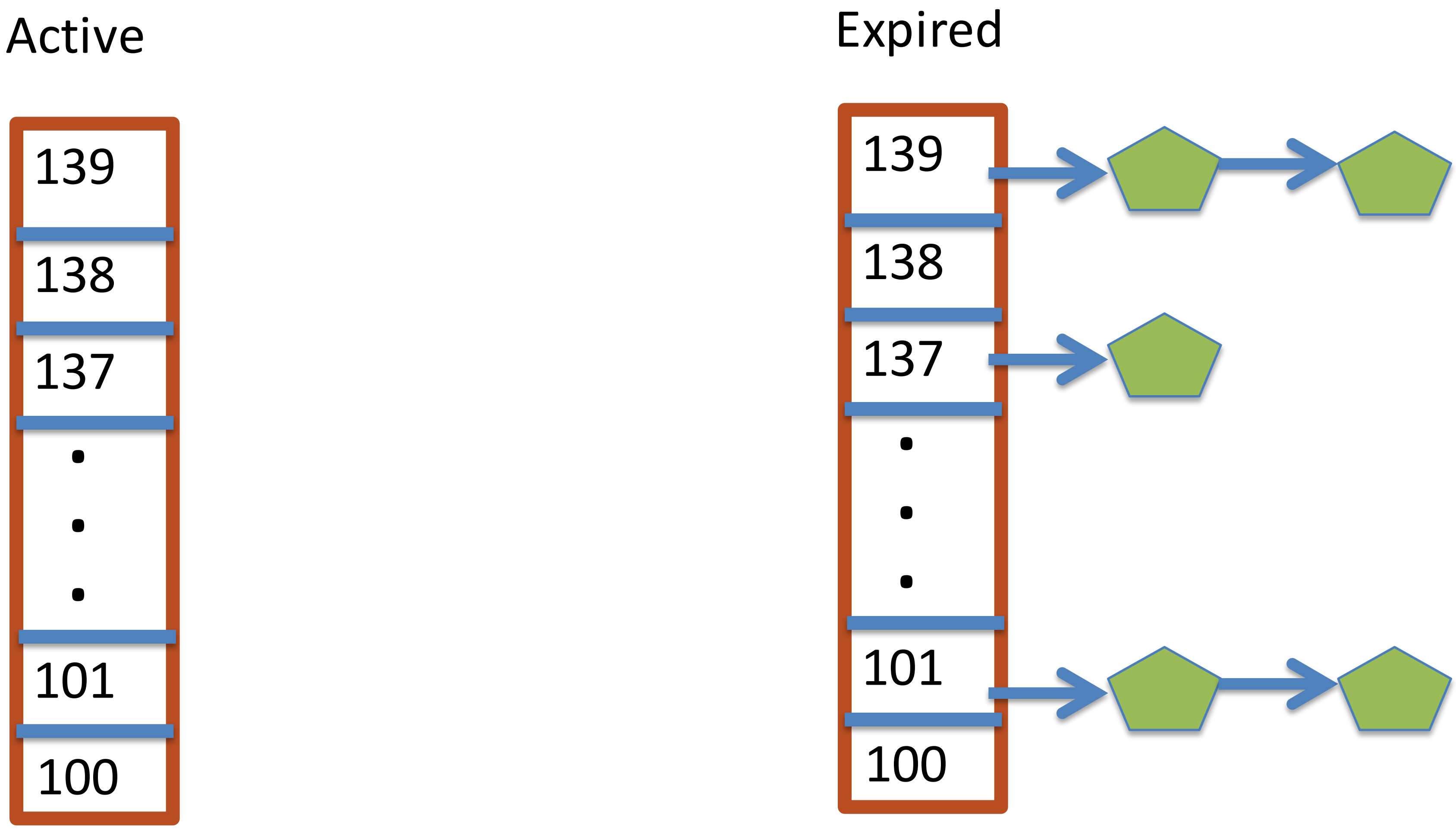
O(1) Intuition

- 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

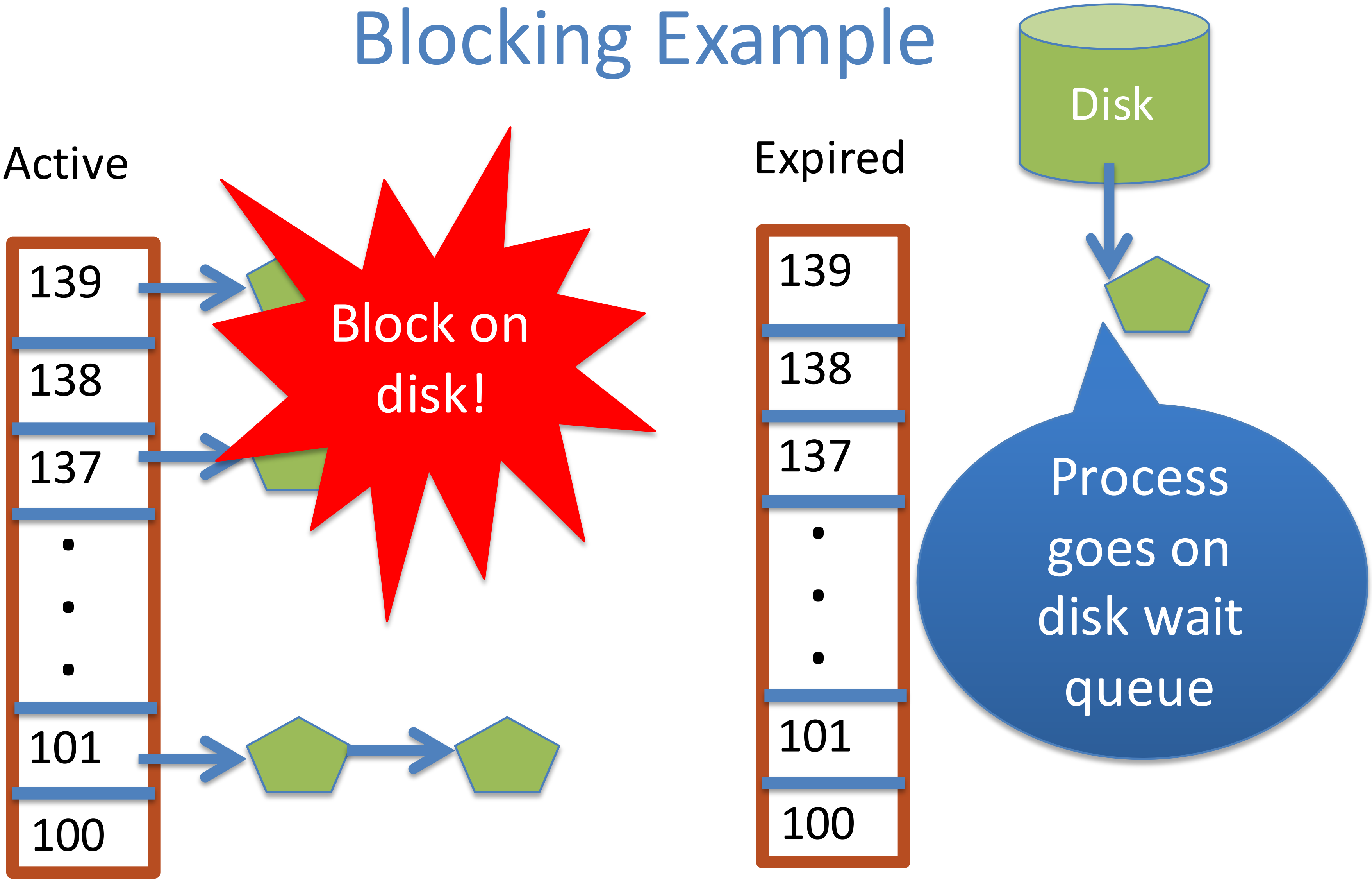
What now?



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

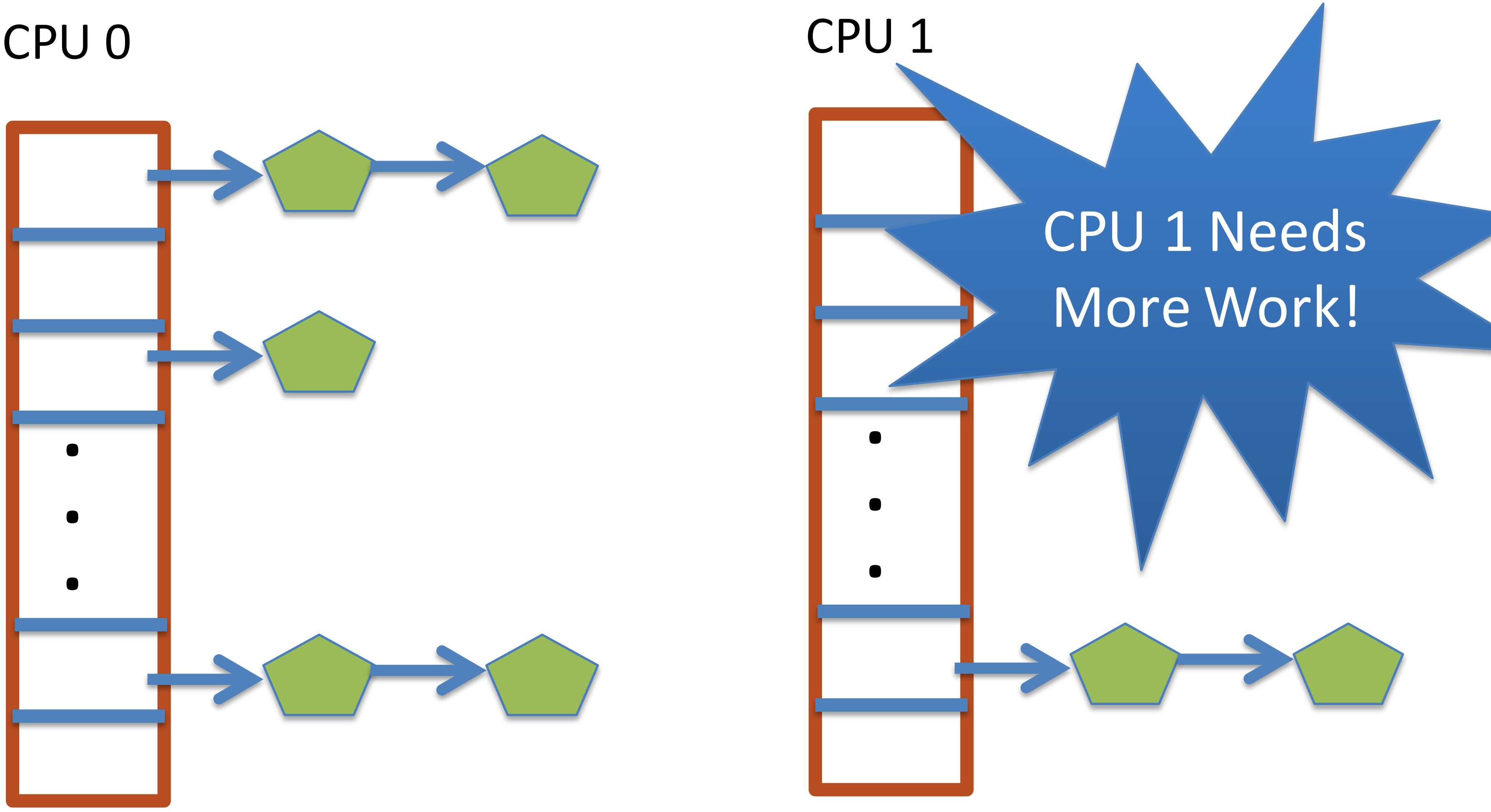
Dynamic Priority in O(1) Scheduler

- 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