# **CPU** Scheduling

#### key concepts

round robin, shortest job first, MLFQ, multi-core scheduling, cache affinity, load balancing

#### reading

Three Easy Pieces: Chapter 7 (CPU Scheduling), Chapter 8 (Multi-level Feedback), Chapter 10 (Multi-CPU Scheduling)

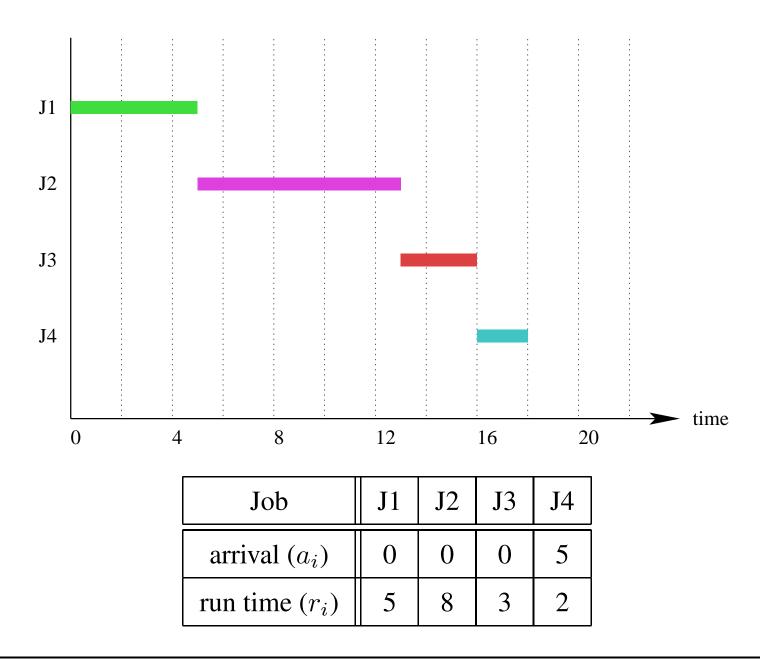
## **Simple Scheduling Model**

- We are given a set of *jobs* to schedule.
- Only one job can run at a time.
- For each job, we are given
  - job arrival time  $(a_i)$
  - job run time  $(r_i)$
- For each job, we define
  - response time: time between the job's arrival and when the job starts to run
  - turnaround time: time between the job's arrival and when the job finishes running.
- We must decide when each job should run, to achieve some goal, e.g., minimize average turnaround time, or minimize average response time.

#### **Basic Non-Preemptive Schedulers: FCFS and SJF**

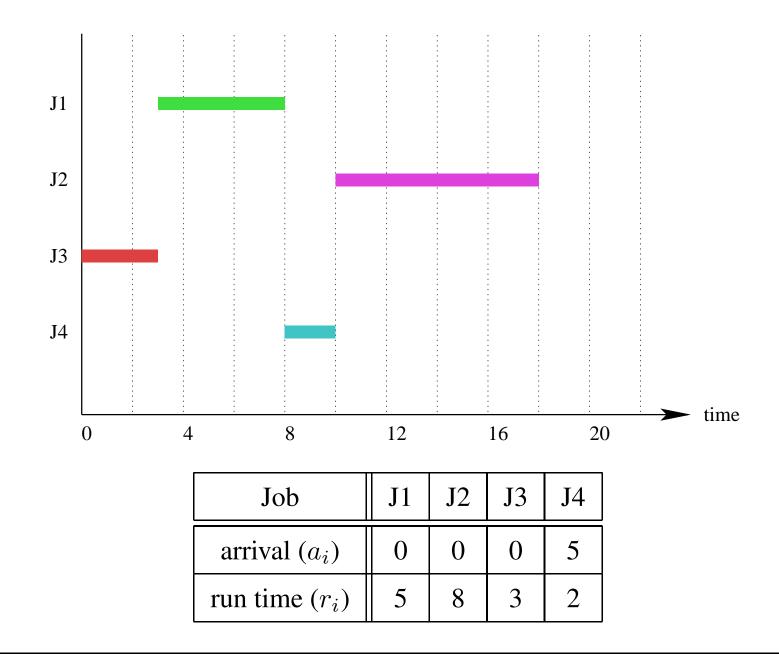
- FCFS: runs jobs in arrival time order.
  - simple, avoids starvation
  - pre-emptive variant: round-robin
- SJF: shortest job first run jobs in increasing order of  $r_i$ 
  - minimizes average *turnaround* time
  - long jobs may starve
  - pre-emptive variant: SRTF (shortest remaining time first)

## **FCFS Gantt Chart Example**

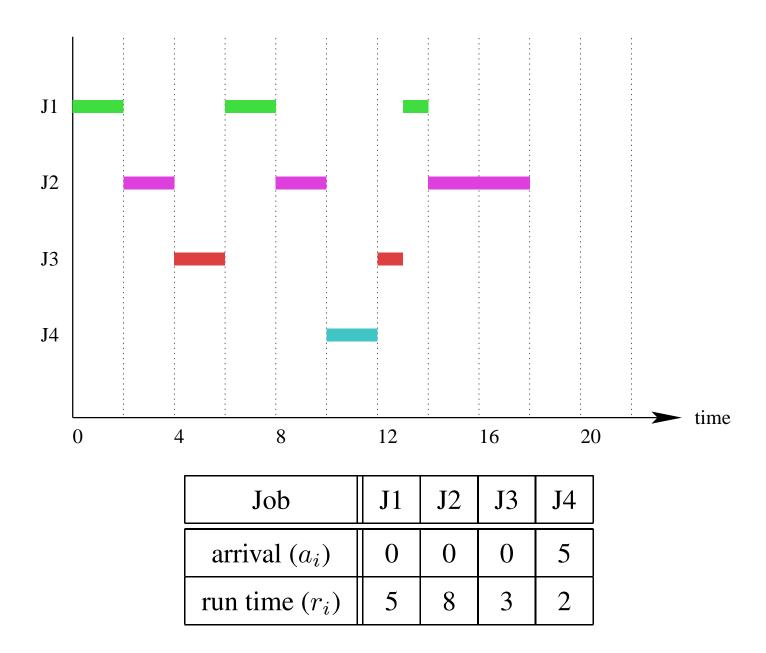


4

**SJF** Example







**J**1 J2 J3 J4 time  $\succ$ 0 8 12 16 20 4 Job **J**1 J2 J3 J4 arrival  $(a_i)$ 

0

5

run time  $(r_i)$ 

0

8

0

3

5

2

## **CPU Scheduling**

- In CPU scheduling, the "jobs" to be scheduled are the threads.
- CPU scheduling typically differs from the simple scheduling model:
  - the run times of threads are normally not known
  - threads are sometimes not runnable: when they are blocked
  - threads may have different priorities
- The objective of the scheduler is normally to achieve a balance between
  - responsiveness (ensure that threads get to run regularly),
  - fairness,
  - efficiency

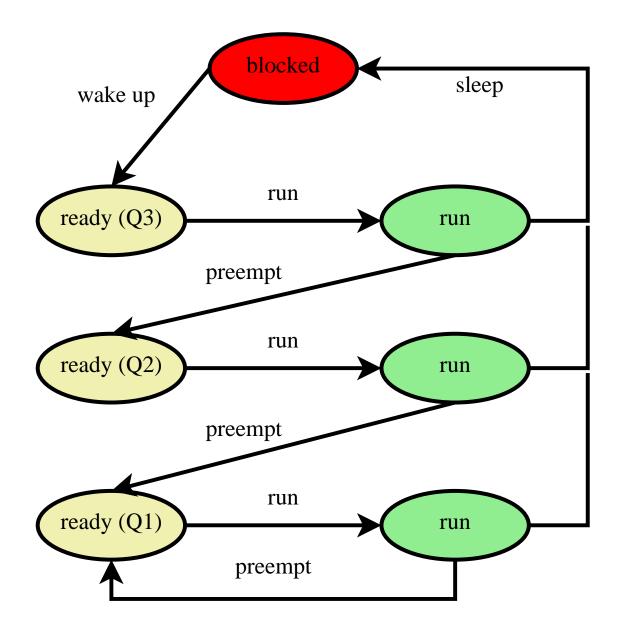
### **Multi-level Feedback Queues**

- objective: good responsiveness for *interactive* threads, non-interactive threads make as much progress as possible
  - key idea: interactive threads are frequently blocked
- approach: given higher priority to interactive threads, so that they run whenever they are ready.
- problem: how to determine which threads are interactive and which are not?

### **Multi-level Feedback Queues (Algorithm)**

- scheduler maintains n round-robin ready queues  $(Q_1 \dots Q_n)$
- scheduler always chooses a thread from  $Q_n$ , unless it is empty
  - if  $Q_n$  is empty, choose a thread from  $Q_{n-1}$ , unless it is empty too
  - and so on, choosing a thread from  $Q_1$  only if all other queues are empty.
- threads in queue  $Q_i$  use quantum  $q_i$ 
  - typically larger quanta for lower-priority threads  $(q_i \ge q_{i+1})$
- if the running thread from Q<sub>i</sub> uses its entire quantum and gets preempted,
  demote it to queue Q<sub>i-1</sub>
- if a thread blocks, put it into  $Q_n$  when it wakes up
- to prevent starvation, periodically move all threads to  $Q_n$



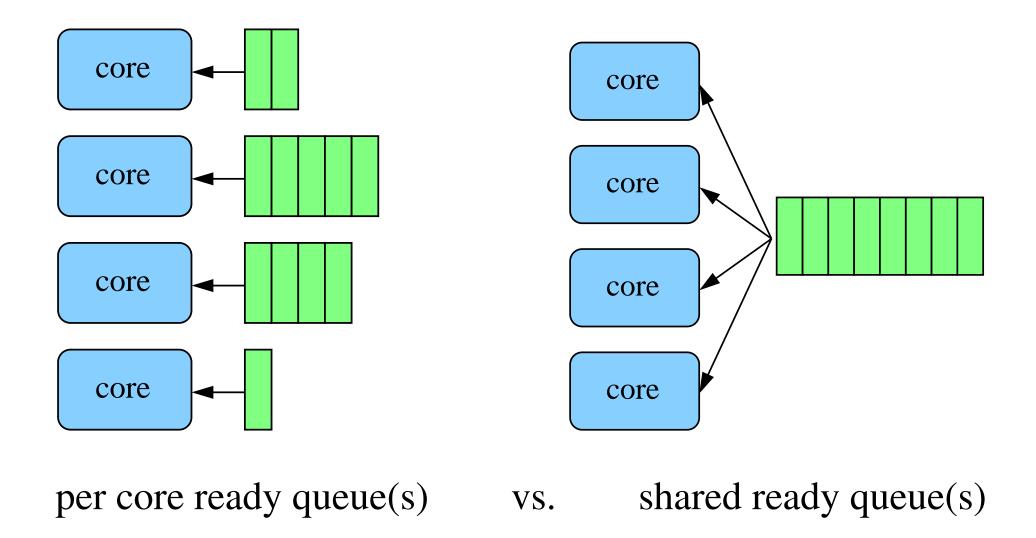


11

## Linux Completely Fair Scheduler (CFS) - Main Ideas

- each thread can be assigned a *weight*
- the goal of the scheduler is to ensure that each thread gets a "share" of the processor in proportion to its weight
- basic operation
  - track the "virtual" runtime of each runnable thread
  - always run the thread with the lowest virtual runtime
- virtual runtime is actual runtime adjusted by the thread weights
  - suppose  $w_i$  is the weight of the *i*th thread
  - actual runtime of *i*th thread is multiplied by  $\frac{\sum_{j} w_{j}}{w_{i}}$
  - virtual runtime advances slowly for threads with high weights, quickly for threads with low weights

### **Scheduling on Multi-Core Processors**



## **Scalability and Cache Affinity**

- Contention and Scalability
  - access to shared ready queue is a critical section, mutual exclusion needed
  - as number of cores grows, contention for ready queue becomes a problem
  - per core design *scales* to a larger number of cores
- CPU cache affinity
  - as thread runs, data it accesses is loaded into CPU cache(s)
  - moving the thread to another core means data must be reloaded into that core's caches
  - as thread runs, it acquires an *affinity* for one core because of the cached data
  - per core design benefits from affinity by keeping threads on the same core
  - shared queue design does not

## **Load Balancing**

- in per-core design, queues may have different lengths
- this results in *load imbalance* across the cores
  - cores may be idle while others are busy
  - threads on lightly loaded cores get more CPU time than threads on heavily loaded cores
- not an issue in shared queue design
- per-core designs typically need some mechanism for *thread migration* to address load imbalances
  - migration means moving threads from heavily loaded cores to lightly loaded cores