

## The Nature of Program Executions

- A running thread can be modeled as alternating series of *CPU bursts* and *I/O bursts*
  - during a CPU burst, a thread is executing instructions
  - during an I/O burst, a thread is waiting for an I/O operation to be performed and is not executing instructions

## Preemptive vs. Non-Preemptive

- A *non-preemptive* scheduler runs only when the running thread gives up the processor through its own actions, e.g.,
  - the thread terminates
  - the thread blocks because of an I/O or synchronization operation
  - the thread performs a Yield system call (if one is provided by the operating system)
- A *preemptive* scheduler may, in addition, force a running thread to stop running
  - typically, a preemptive scheduler will be invoked periodically by a timer interrupt handler, as well as in the circumstances listed above
  - a running thread that is preempted is moved to the ready state

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## FCFS and Round-Robin Scheduling

### First-Come, First-Served (FCFS):

- non-preemptive - each thread runs until it blocks or terminates
- FIFO ready queue

### Round-Robin:

- preemptive version of FCFS
- running thread is preempted after a fixed time quantum, if it has not already blocked
- preempted thread goes to the end of the FIFO ready queue

## Shortest Job First (SJF) Scheduling

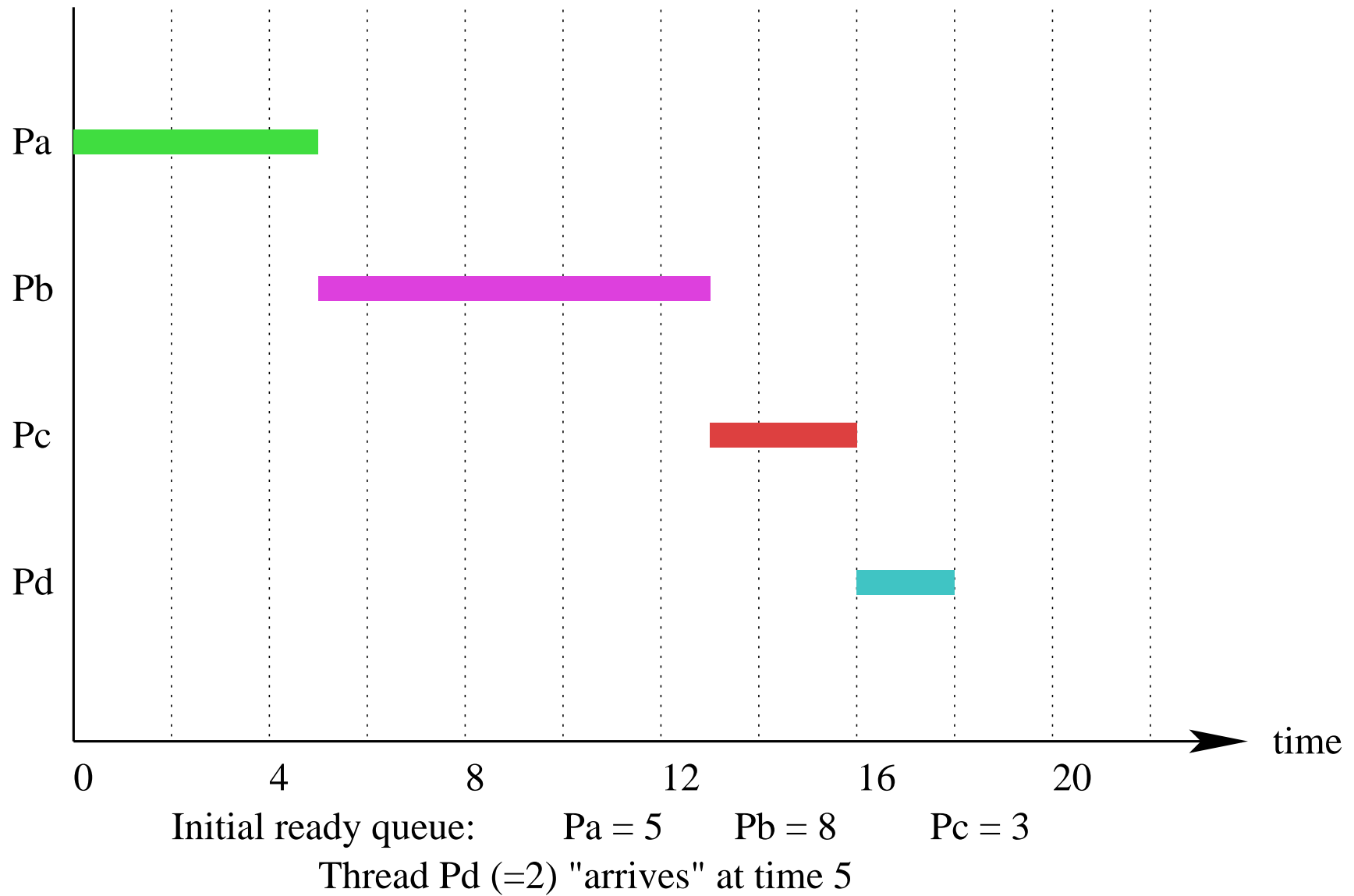
- non-preemptive
- ready threads are scheduled according to the length of their next CPU burst - thread with the shortest burst goes first
- SJF minimizes average waiting time, but can lead to starvation
- SJF requires knowledge of CPU burst lengths
  - Simplest approach is to estimate next burst length of each thread based on previous burst length(s). For example, exponential average considers all previous burst lengths, but weights recent ones most heavily:

$$B_{i+1} = \alpha b_i + (1 - \alpha)B_i$$

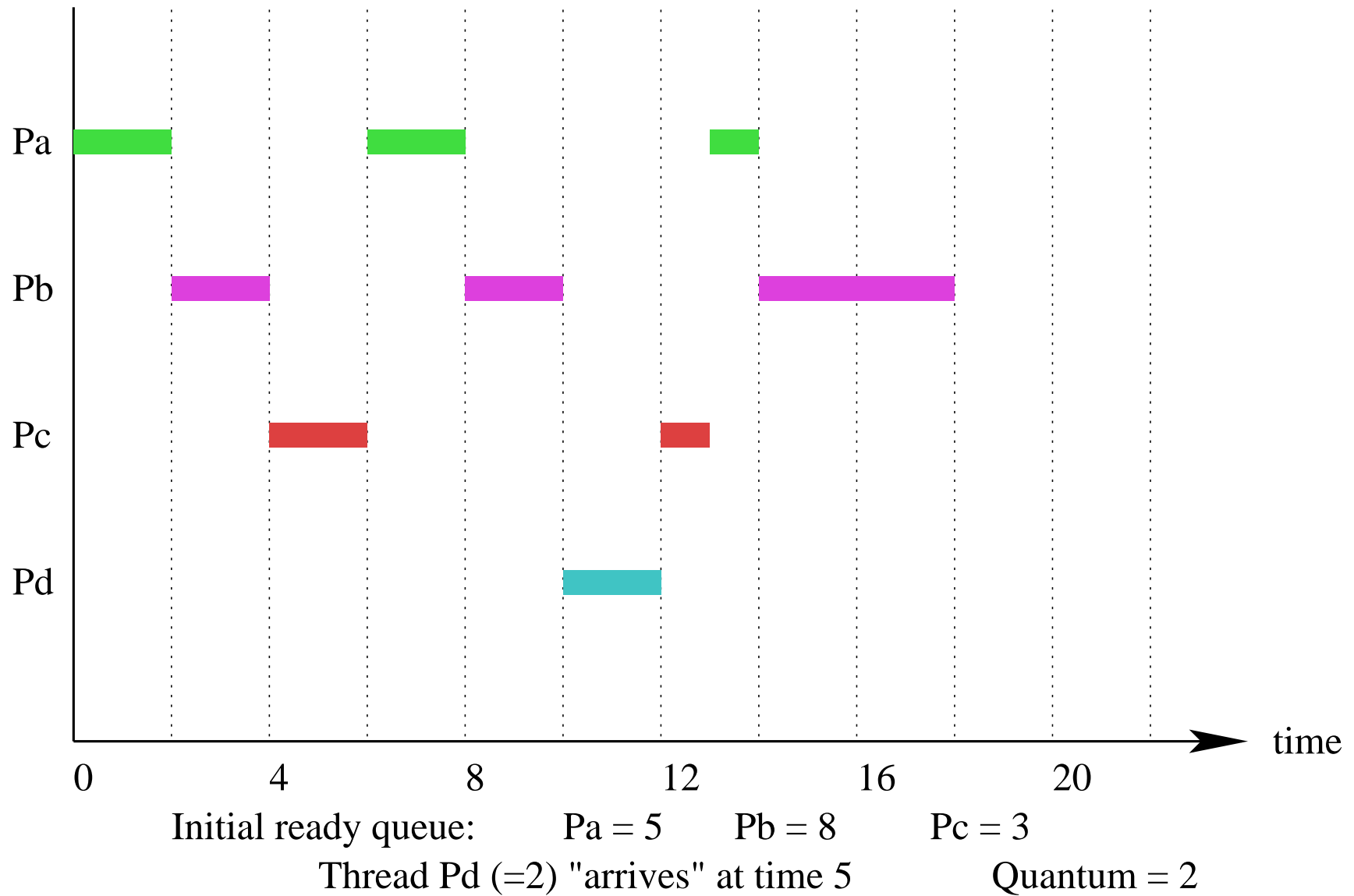
where  $B_i$  is the predicted length of the  $i$ th CPU burst, and  $b_i$  is its actual length, and  $0 \leq \alpha \leq 1$ .

- Shortest Remaining Time First is a preemptive variant of SJF. Preemption may occur when a new thread enters the ready queue.

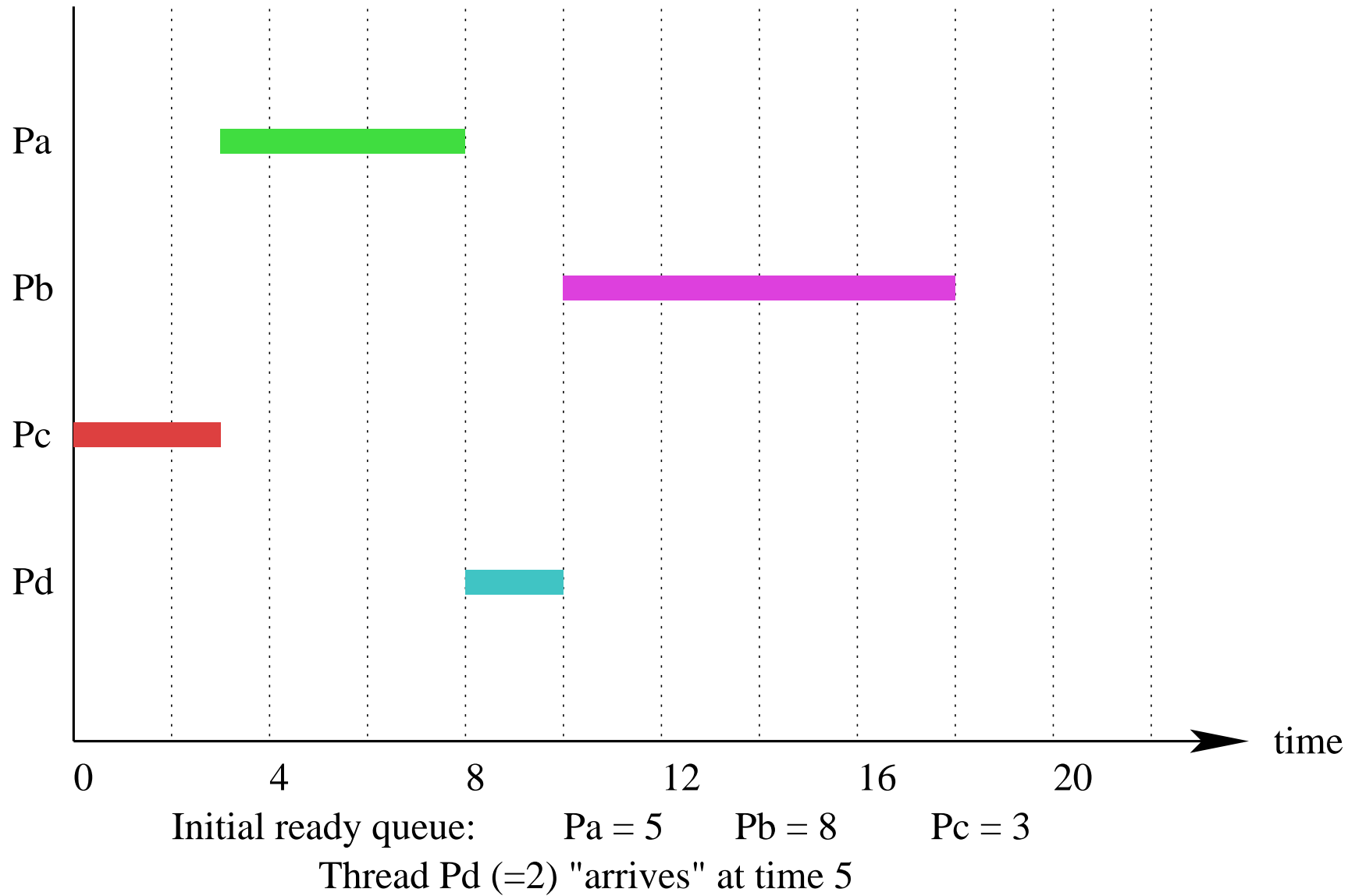
## FCFS Gantt Chart Example



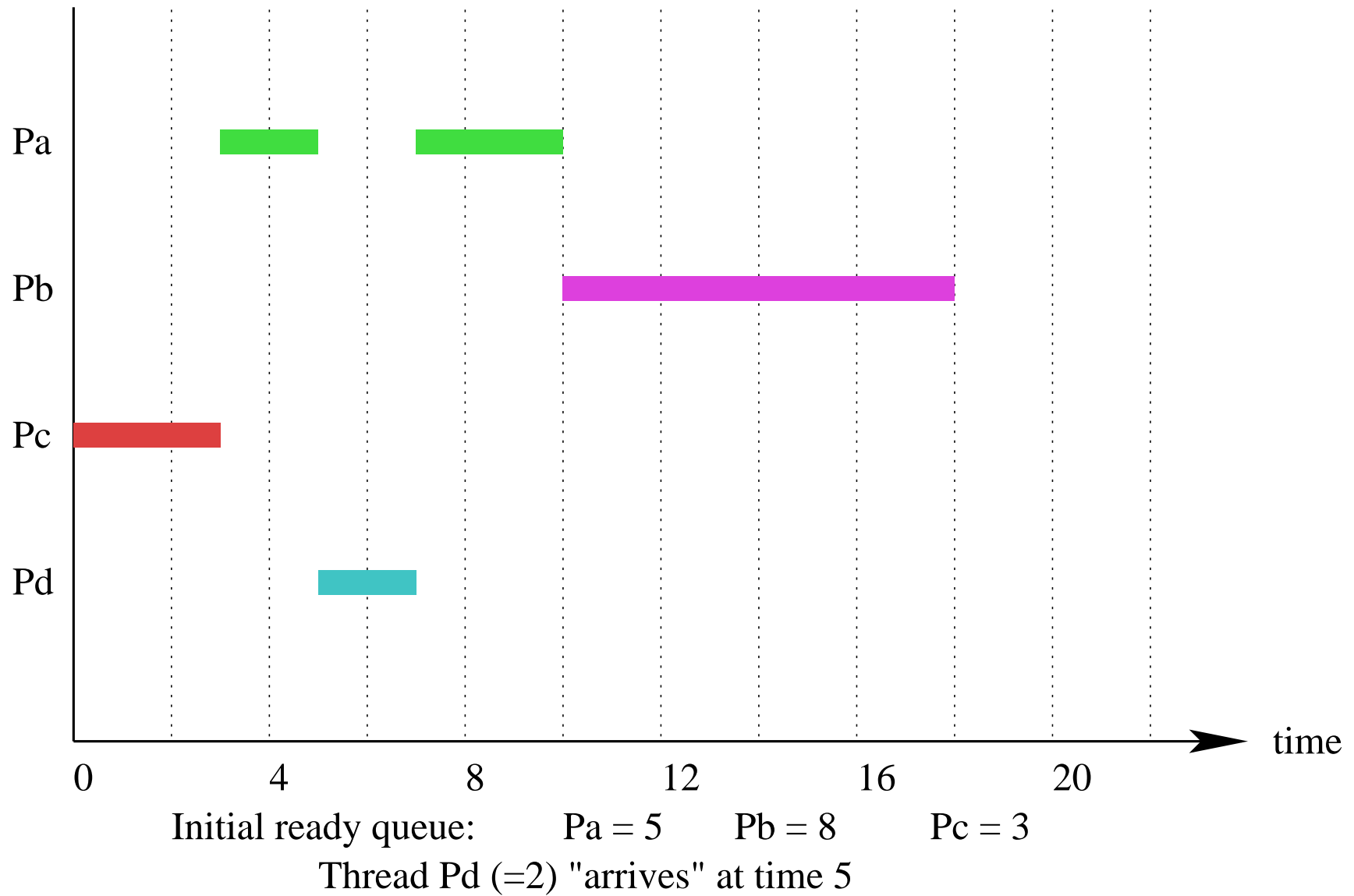
## Round Robin Example



## SJF Example



## SRTF Example





## Highest Response Ratio Next

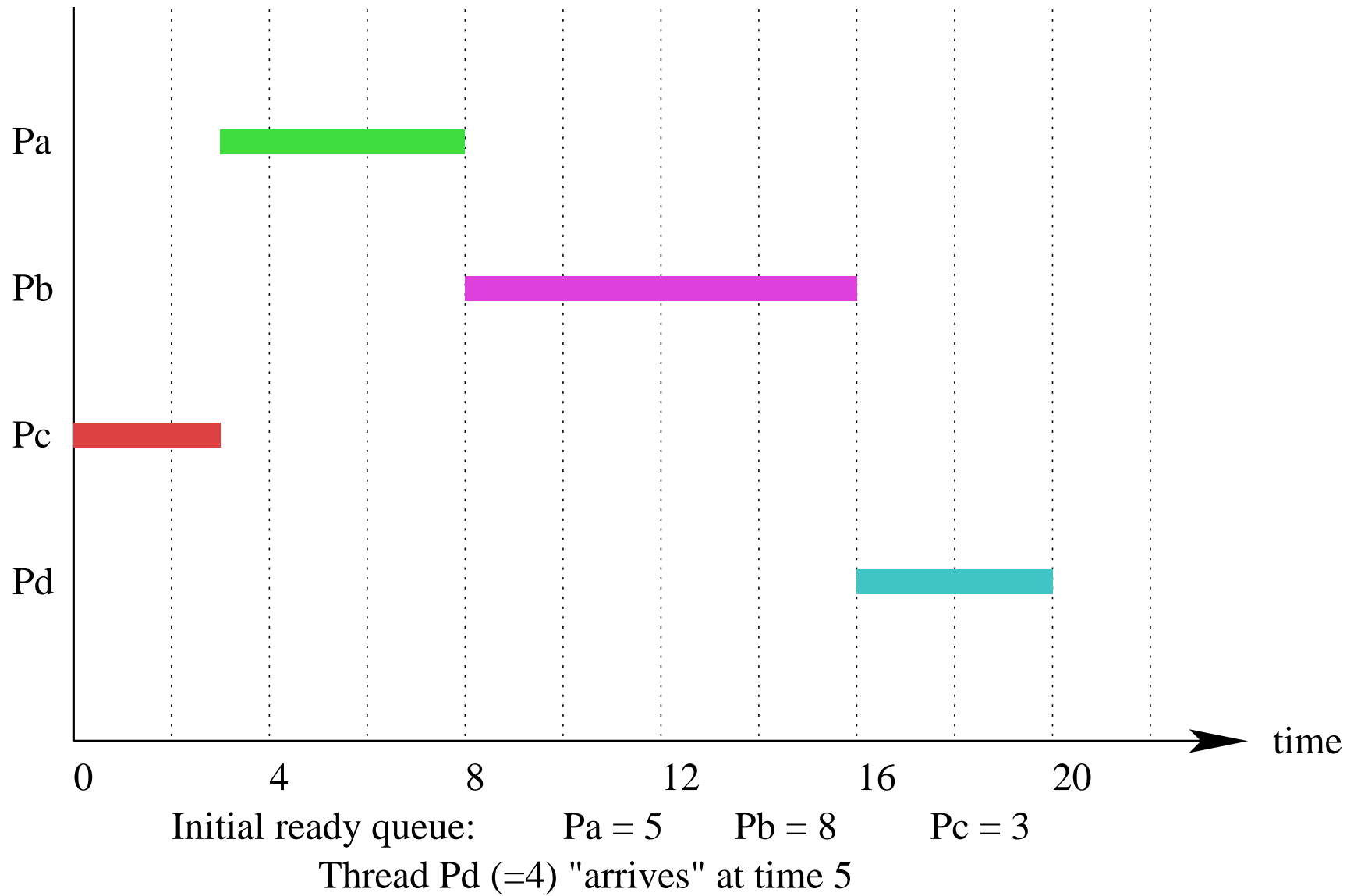
- non-preemptive
- response ratio is defined for each ready thread as:

$$\frac{w + b}{b}$$

where  $b$  is the estimated CPU burst time and  $w$  is the actual waiting time

- scheduler chooses the thread with the highest response ratio (choose smallest  $b$  in case of a tie)
- HRRN is an example of a heuristic that blends SJF and FCFS

## HRRN Example



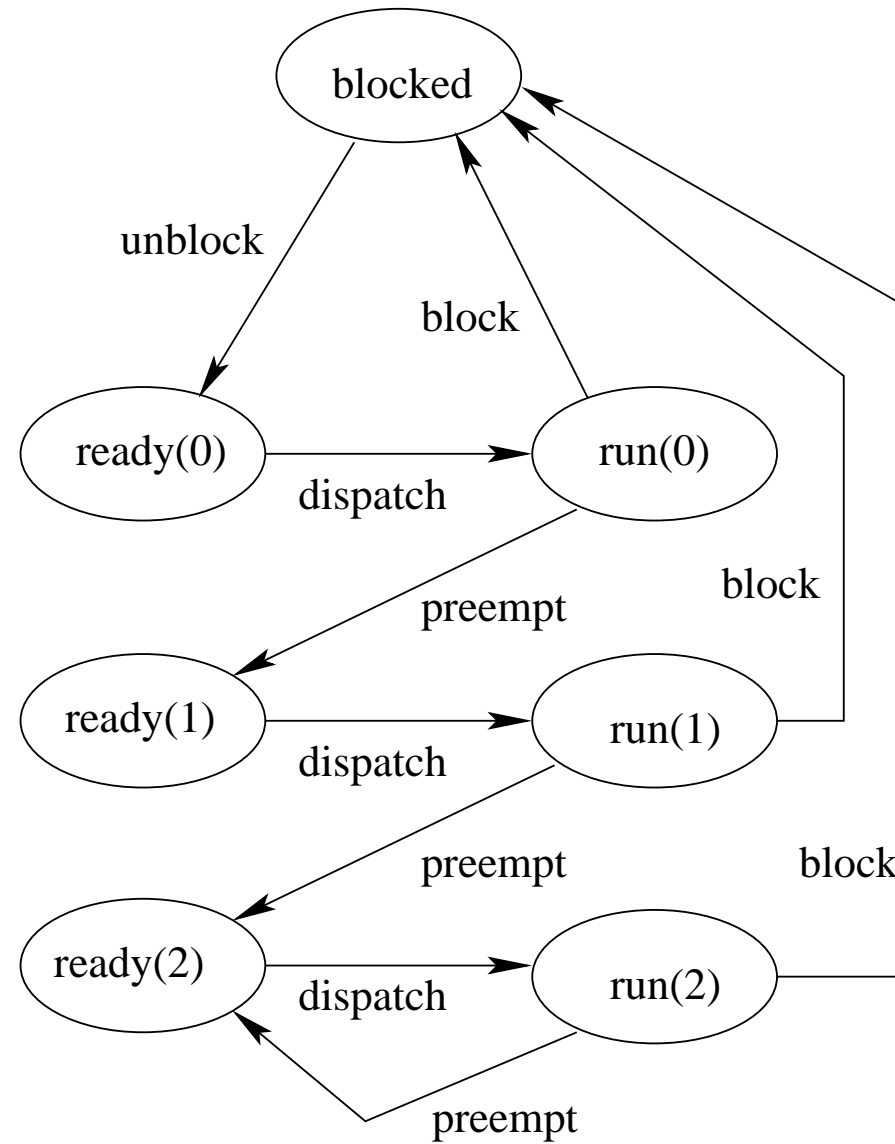
## Prioritization

- a scheduler may be asked to take process or thread priorities into account
- for example, priorities could be based on
  - user classification
  - application classification
  - application specification  
(e.g., Linux `setpriority/sched_setscheduler`)
- scheduler can:
  - always choose higher priority threads over lower priority thread
  - use any scheduling heuristic to schedule threads of equal priority
- low priority threads risk starvation. If this is not desired, scheduler must have a mechanism for elevating the priority of low priority threads that have waited a long time

## Multilevel Feedback Queues

- gives priority to interactive threads (those with short CPU bursts)
- scheduler maintains several ready queues
- scheduler never chooses a thread in queue  $i$  if there are threads in any queue  $j < i$ .
- threads in queue  $i$  use quantum  $q_i$ , and  $q_i < q_j$  if  $i < j$
- newly ready threads go in to queue 0
- a level  $i$  thread that is preempted goes into the level  $i + 1$  ready queue

### 3 Level Feedback Queue State Diagram



## Lottery Scheduling

- randomized proportional share resource allocation
- resource rights represented by lottery tickets, allocation determined by lottery
  - resource granted to holder of winning ticket
- probabilistically fair with  $p = t/T$ 
  - $p$  = probability of allocation,  $t$  = tickets held,  $T$  = total tickets
  - avoid starvation by ensuring  $t > 0$
- uniformly-distributed pseudo-random number generator (10 lines on MIPS)
- can proportionally assign other resources (e.g., memory, bandwidth)
- “Lottery Scheduling: Flexible Proportional-Share Resource Management”, Waldspurger and Weihl, Operating System Design and Implementation, 1994.

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## Other Scheduling Issues

**short term scheduling:** what has been covered so far

**medium term scheduling:** suspension/resumption of partially executed processes

- usually because a resource, especially memory, is overloaded
- suspended process releases resources
- operating system may also provide mechanisms for applications or users to request suspension/resumption of processes

**long term scheduling:** process admission control to limit the degree of multiprogramming

## Scheduling States Including Suspend/Resume

