

Scheduling



What is Scheduling?

- On a multi-programmed system
 - We may have more than one *Ready* process
- On a batch system
 - We may have many jobs waiting to be run
- On a multi-user system
 - We may have many users concurrently using the system
- The ***scheduler*** decides who to run next.
 - The process of choosing is called *scheduling*.



Is scheduling important?

- It is not in certain scenarios
 - If you have no choice
 - Early systems
 - Usually batching
 - Scheduling algorithm simple
 - » Run next on tape or next on punch tape
 - Only one thing to run
 - Simple PCs
 - Only ran a word processor, etc....
 - Simple Embedded Systems
 - TV remote control, washing machine, etc....

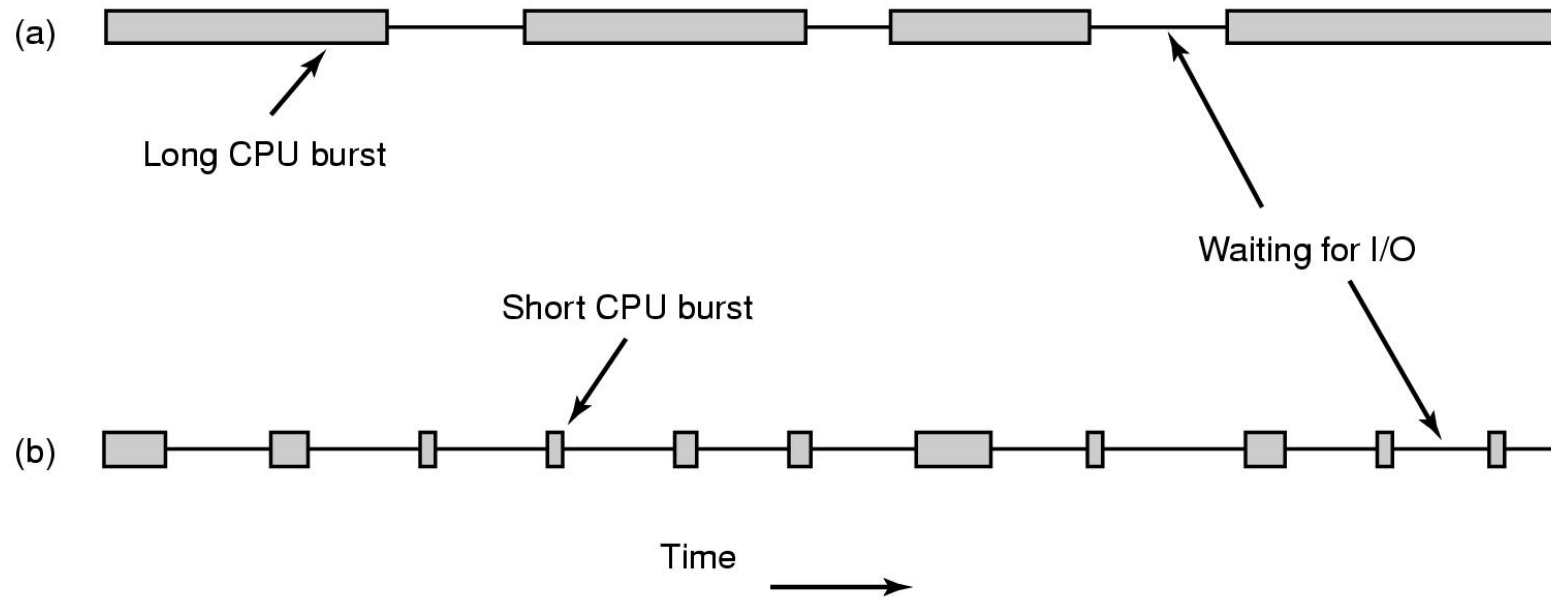


Is scheduling important?

- It is in most realistic scenarios
 - Multitasking/Multi-user System
 - Example
 - Email daemon takes 2 seconds to process an email
 - User clicks button on application.
 - Scenario 1
 - Run daemon, then application
 - » System appears really sluggish to the user
 - Scenario 2
 - Run application, then daemon
 - » Application appears really responsive, small email delay is unnoticed
- Scheduling decisions can have a dramatic effect on the perceived performance of the system
 - Can also affect correctness of a system with deadlines



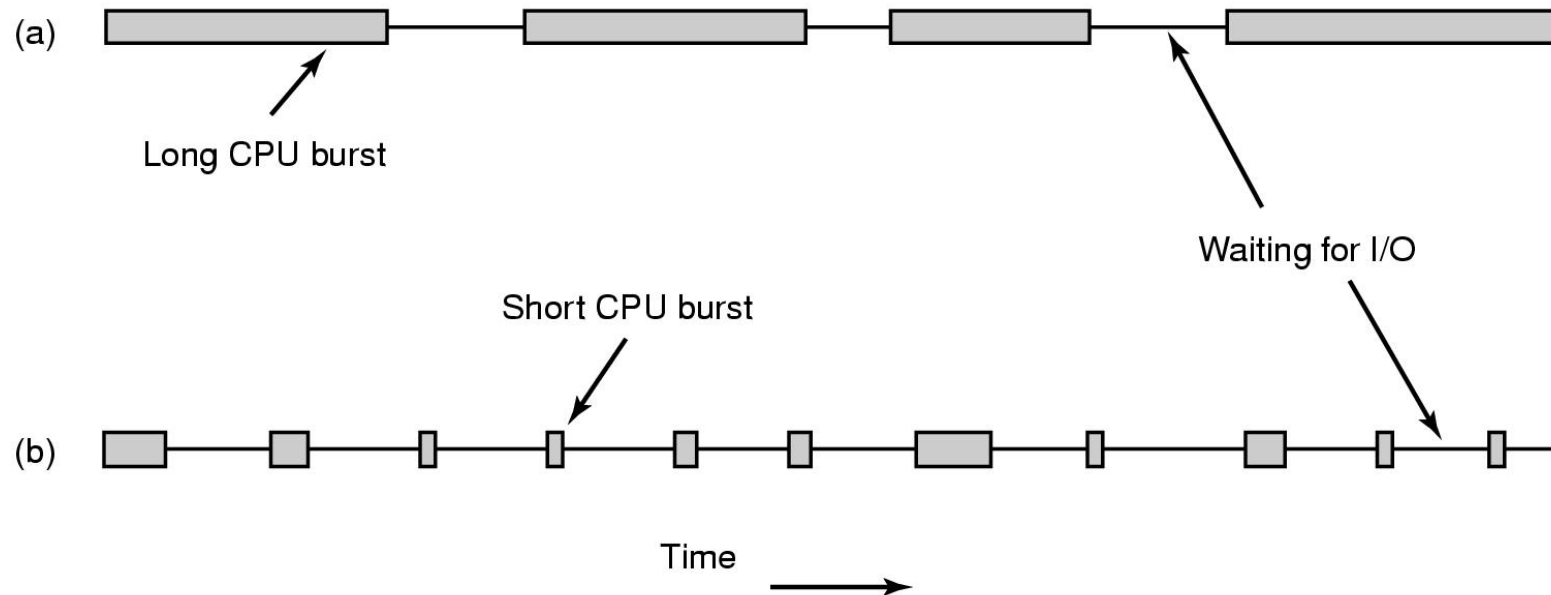
Application Behaviour



- Bursts of CPU usage alternate with periods of I/O wait



Application Behaviour

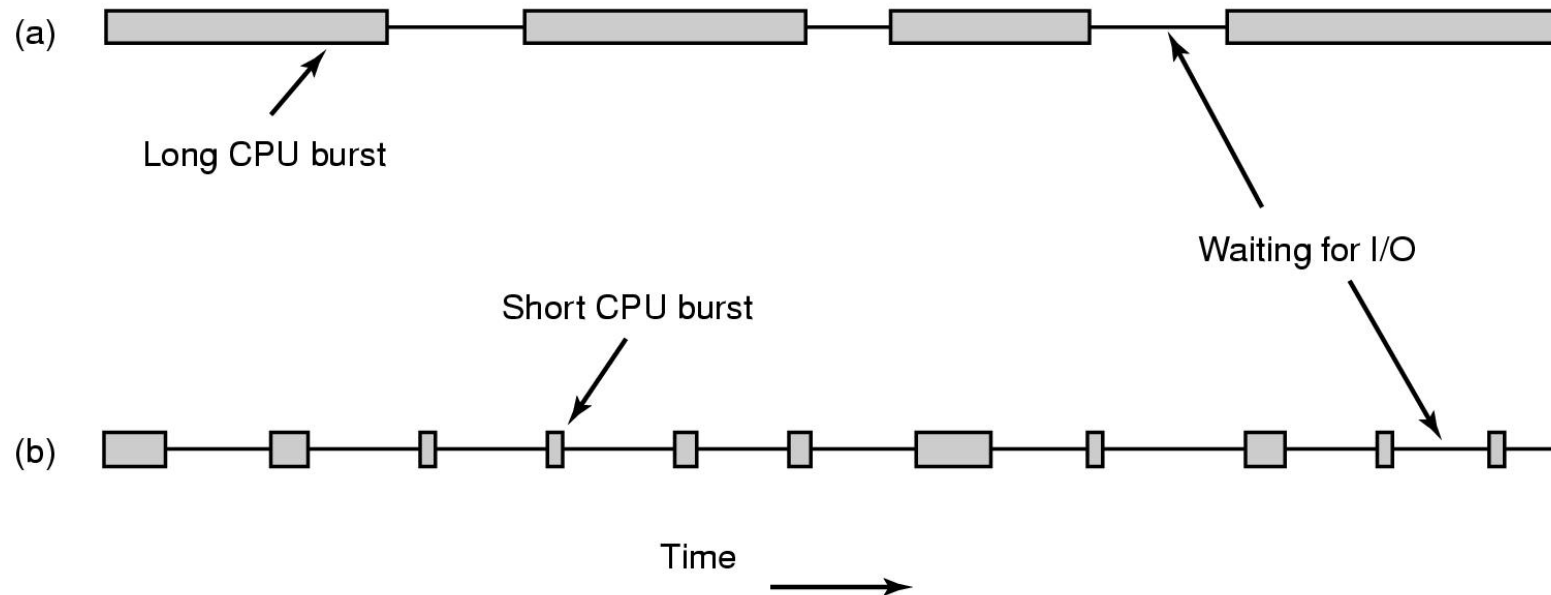


a) CPU-Bound process

- Spends most of its computing
- Time to completion largely determined by received CPU time



Application Behaviour

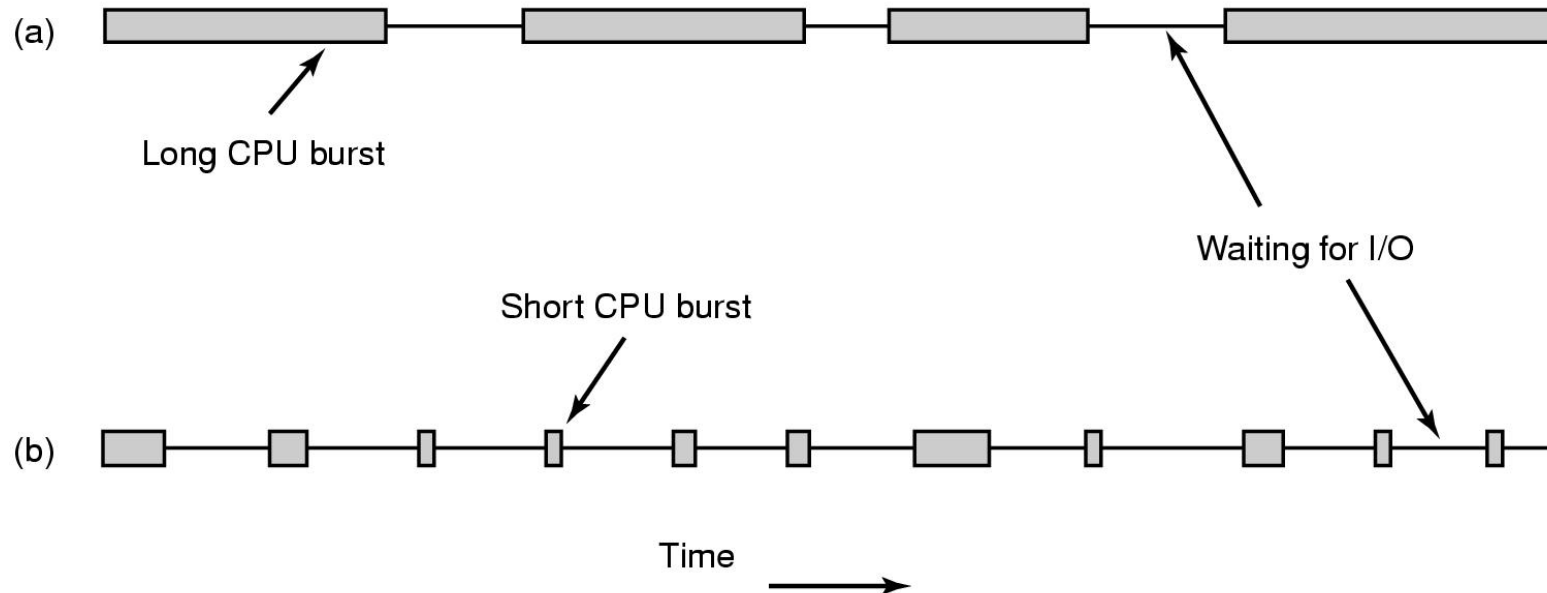


b) I/O-Bound process

- Spend most of its time waiting for I/O to complete
 - Small bursts of CPU to process I/O and request next I/O
- Time to completion largely determined by I/O request time



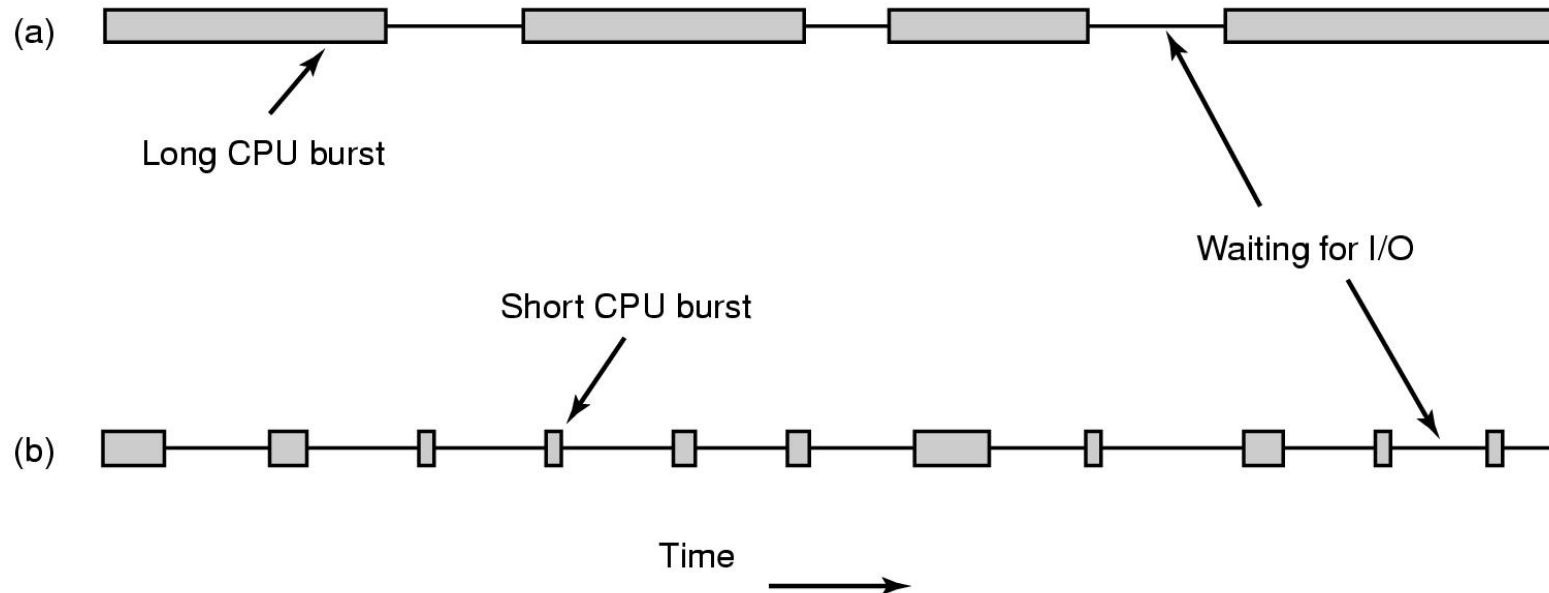
Observations



- Generally, technology is increasing CPU speed much faster than I/O speed
 - ⇒ CPU bursts becoming shorter, I/O waiting is relatively constant
 - ⇒ Processes are becoming more I/O bound



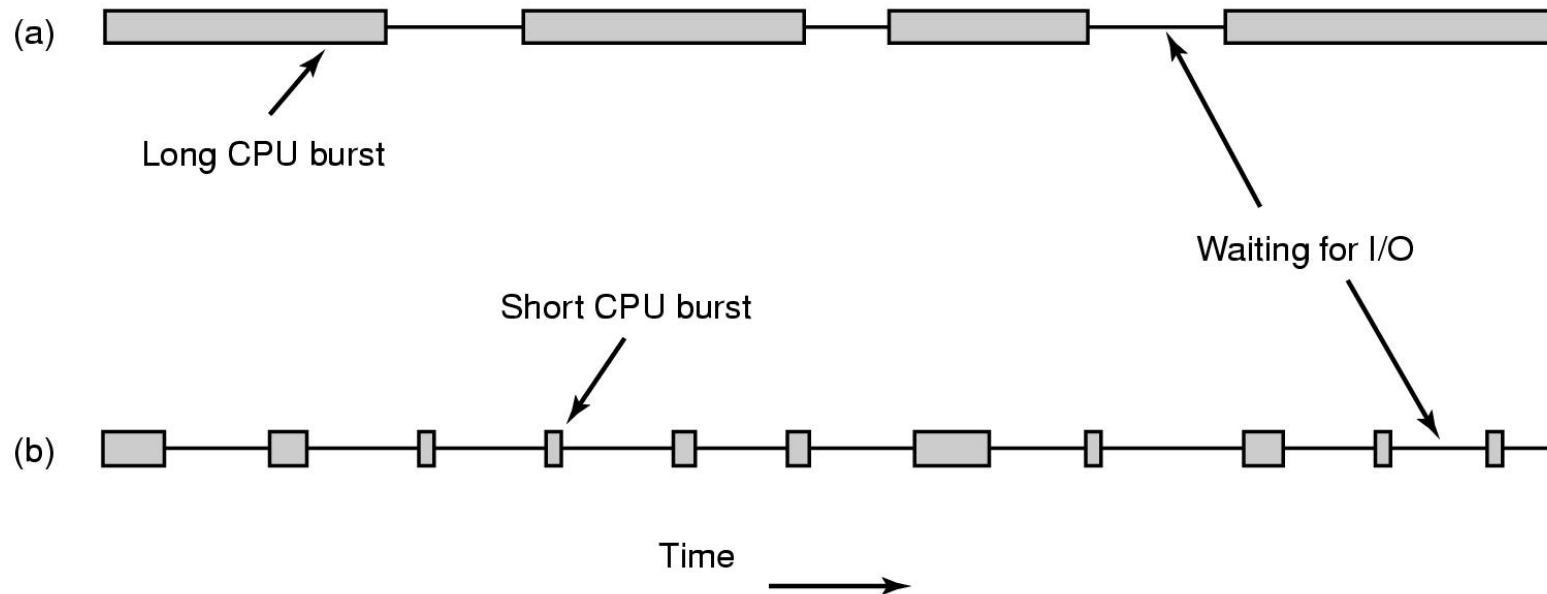
Observations



- We need a mix of CPU-bound and I/O-bound processes to keep both CPU and I/O systems busy
- Process can go from CPU- to I/O-bound (or vice versa) in different phases of execution



Observations



- Choosing to run an I/O-bound process delays a CPU-bound process by very little
 - Choosing to run a CPU-bound process prior to an I/O-bound process delays the next I/O request significantly
 - No overlap of I/O waiting with computation
 - Results in device (disk) not as busy as possible
- ⇒ Generally, favour I/O-bound processes over CPU-bound processes



When is scheduling performed?

- A new process
 - Run the parent or the child?
- A process exits
 - Who runs next?
- A process waits for I/O
 - Who runs next?
- A process blocks on a lock
 - Who runs next? The lock holder?
- An I/O interrupt occurs
 - Who do we resume, the interrupted process or the process that was waiting?
- On a timer interrupt? (See next slide)
- Generally, a scheduling decision is required when a process (or thread) can no longer continue, or when an activity results in more than one ready process.



Preemptive versus Non-preemptive Scheduling

- Non-preemptive
 - Once a thread is in the *running* state, it continues until it completes, blocks on I/O, or voluntarily yields the CPU
 - A single process can monopolised the entire system
- Preemptive Scheduling
 - Current thread can be interrupted by OS and moved to *ready* state.
 - Usually after a timer interrupt and process has exceeded its maximum run time
 - Can also be as a result of higher priority process that has become *ready* (after I/O interrupt).
 - Ensures fairer service as single thread can't monopolise the system
 - Requires a timer interrupt



Categories of Scheduling Algorithms

- The choice of scheduling algorithm depends on the goals of the application (or the operating system)
 - No one algorithm suits all environments
- We can roughly categorise scheduling algorithms as follows
 - Batch Systems
 - No users directly waiting, can optimise for overall machine performance
 - Interactive Systems
 - Users directly waiting for their results, can optimise for users perceived performance
 - Realtime Systems
 - Jobs have deadlines, must schedule such that all jobs (mostly) meet their deadlines.



Goals of Scheduling Algorithms

- All Algorithms
 - Fairness
 - Give each process a *fair* share of the CPU
 - Policy Enforcement
 - What ever policy chosen, the scheduler should ensure it is carried out
 - Balance/Efficiency
 - Try to keep all parts of the system busy



Goals of Scheduling Algorithms

- Batch Algorithms
 - Maximise *throughput*
 - Throughput is measured in jobs per hour (or similar)
 - Minimise *turn-around time*
 - Turn-around time (T_r)
 - difference between time of completion and time of submission
 - Or waiting time (T_w) + execution time (T_e)
 - Maximise *CPU utilisation*
 - Keep the CPU busy
 - Not as good a metric as overall throughput



Goals of Scheduling Algorithms

- Interactive Algorithms
 - Minimise *response time*
 - Response time is the time difference between issuing a command and getting the result
 - E.g selecting a menu, and getting the result of that selection
 - Response time is important to the user's perception of the performance of the system.
 - Provide *Proportionality*
 - Proportionality is the user expectation that short jobs will have a short response time, and long jobs can have a long response time.
 - Generally, favour short jobs



Goals of Scheduling Algorithms

- Real-time Algorithms
 - Must meet deadlines
 - Each job/task has a deadline.
 - A missed deadline can result in data loss or catastrophic failure
 - Aircraft control system missed deadline to apply brakes
 - Provide Predictability
 - For some apps, an occasional missed deadline is okay
 - E.g. DVD decoder
 - Predictable behaviour allows smooth DVD decoding with only rare skips



Scheduling Algorithms

Batch Systems

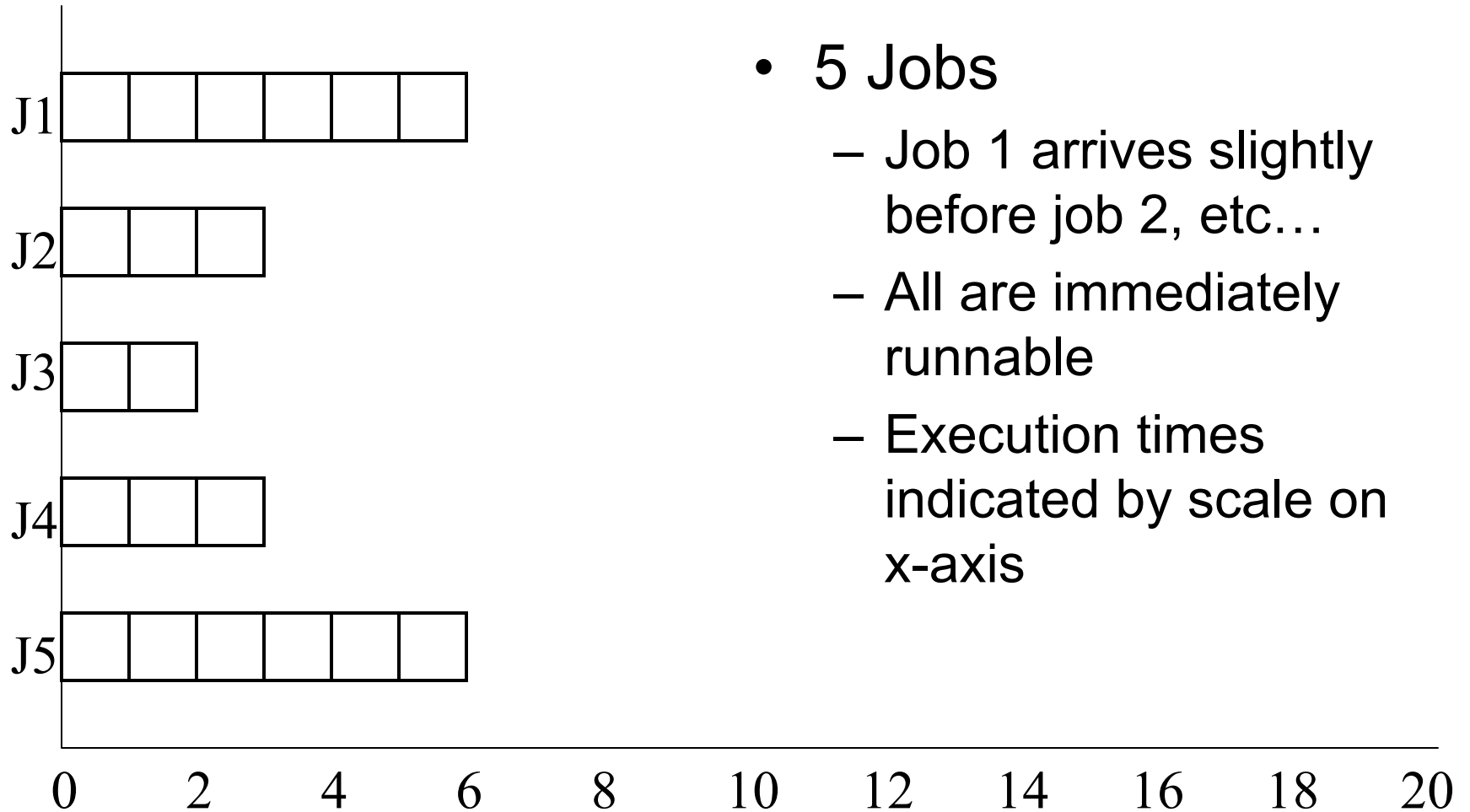


First-Come First-Served (FCFS)

- Algorithm
 - Each job is placed in single queue, the first job in the queue is selected, and allowed to run as long as it wants.
 - If the job blocks, the next job in the queue is selected to run
 - When a blocked jobs becomes ready, it is placed at the end of the queue



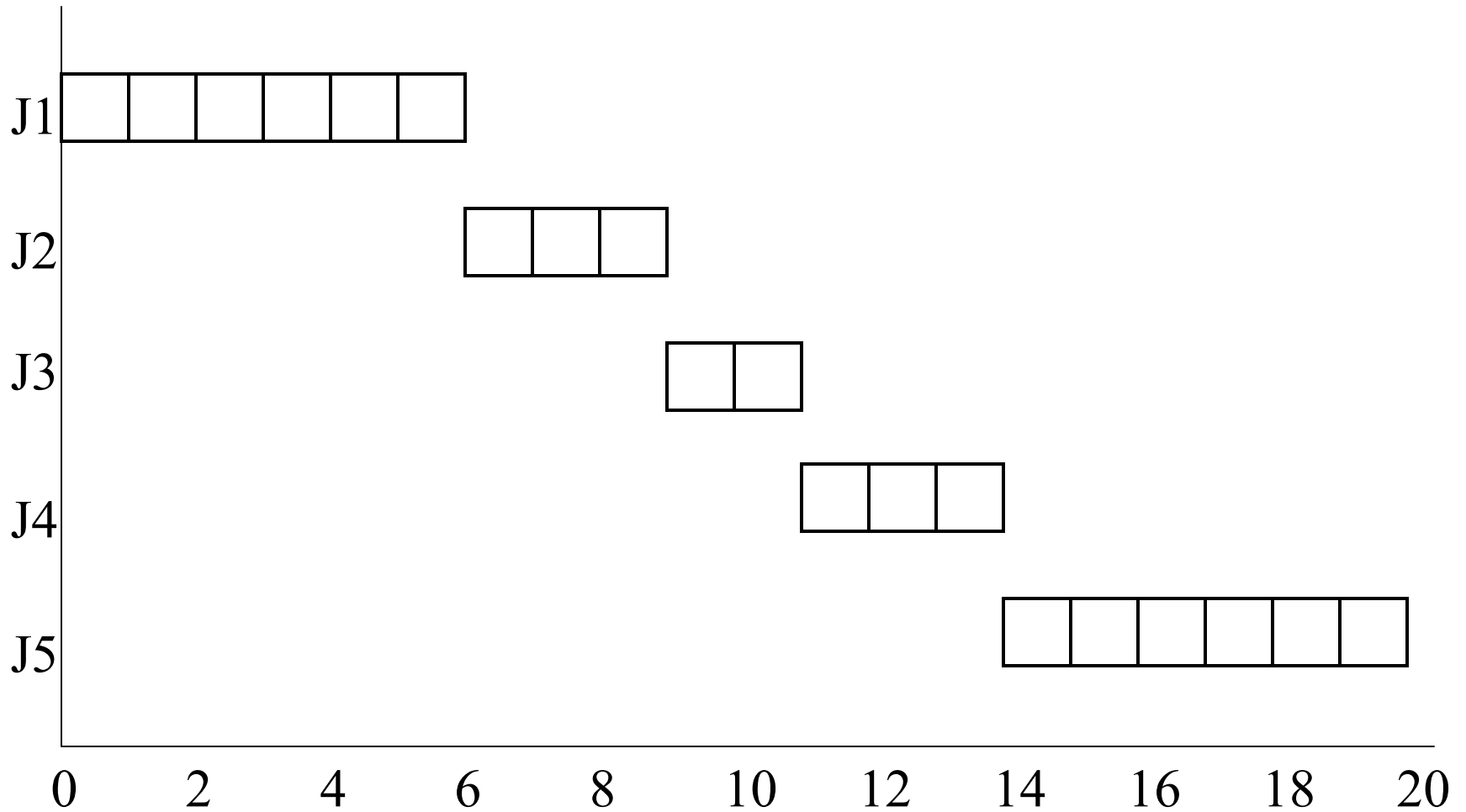
Example



- 5 Jobs
 - Job 1 arrives slightly before job 2, etc...
 - All are immediately runnable
 - Execution times indicated by scale on x-axis



FCFS Schedule



FCFS

- Pros
 - Simple and easy to implement
- Cons
 - I/O-bound jobs wait for CPU-bound jobs
 - ⇒ Favours CPU-bound processes
 - Example:
 - Assume 1 CPU-bound process that computes for 1 second and blocks on a disk request. It arrives first.
 - Assume an I/O bound process that simply issues a 1000 blocking disk requests (very little CPU time)
 - FCFS, the I/O bound process can only issue a disk request per second
 - » the I/O bound process take 1000 seconds to finish
 - Another scheme, that preempts the CPU-bound process when I/O-bound process are ready, could allow I/O-bound process to finish in $1000 \times$ average disk access time.

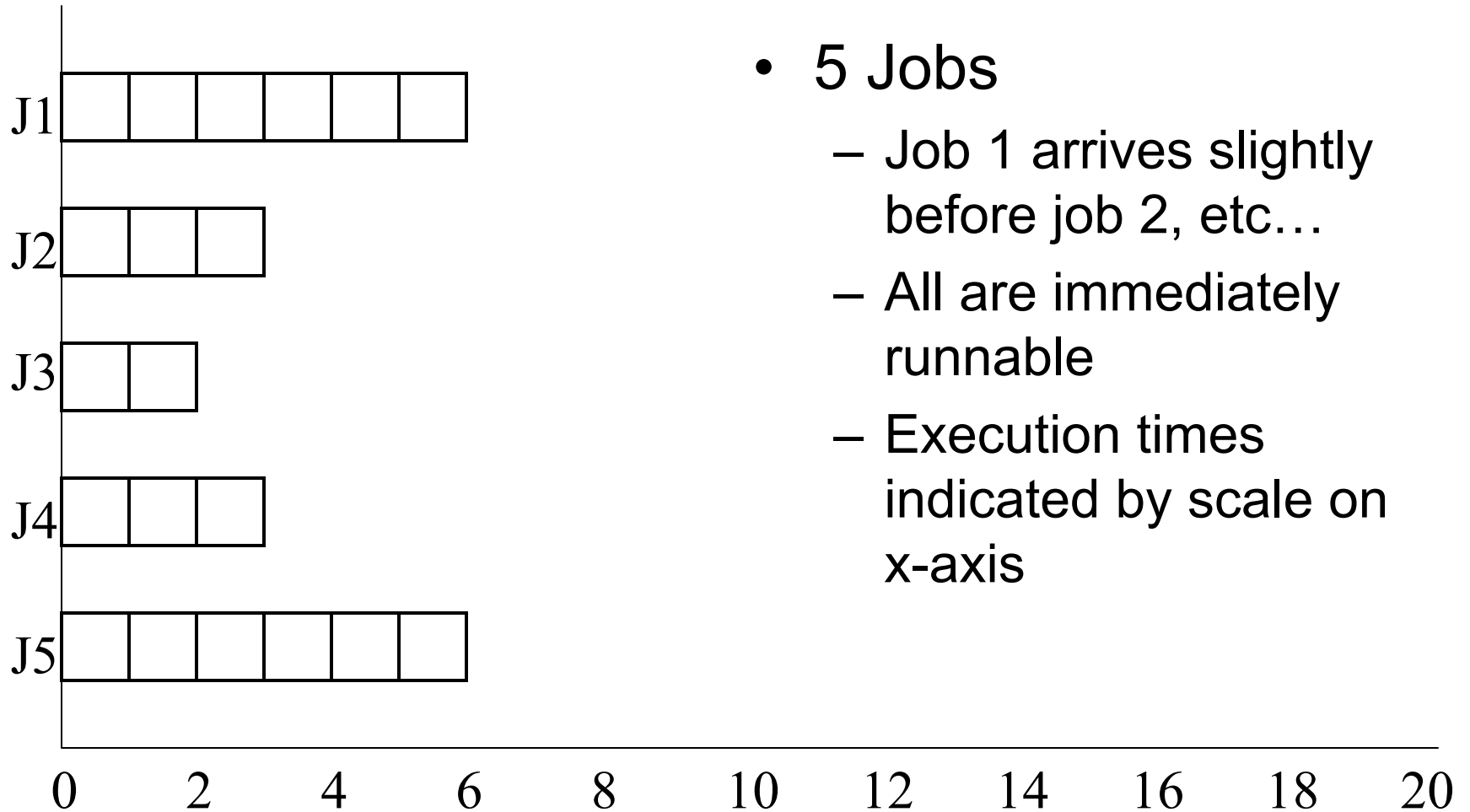


Shortest Job First

- If we know (or can estimate) the execution time *a priori*, we choose the shortest job first.
- Another non-preemptive policy



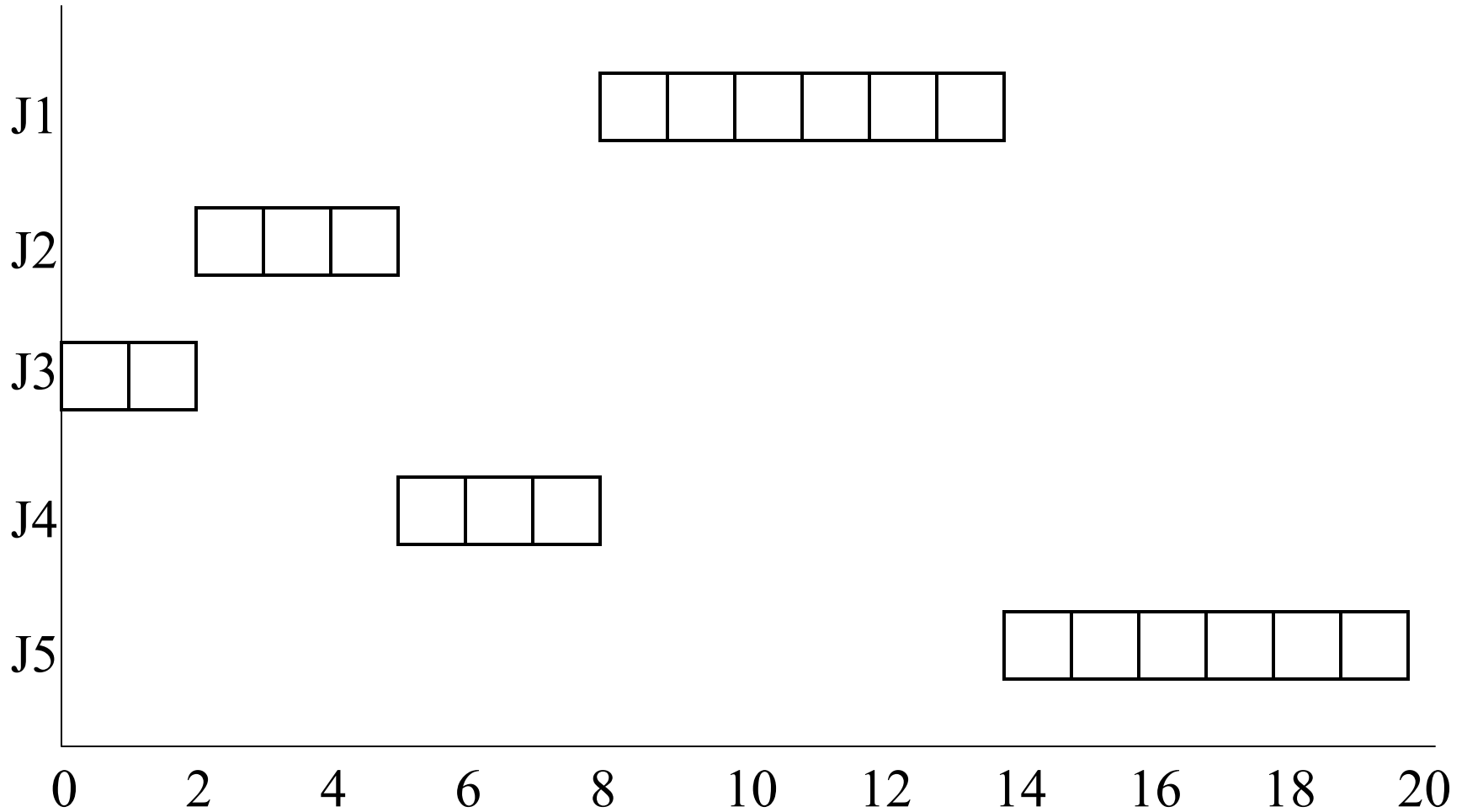
Our Previous Example



- 5 Jobs
 - Job 1 arrives slightly before job 2, etc...
 - All are immediately runnable
 - Execution times indicated by scale on x-axis



Shortest Job First



Shortest Job First

- Con
 - May starve long jobs
 - Needs to predict job length
- Pro
 - Minimises average turnaround time (if, and only if, all jobs are available at the beginning)
 - Example: Assume for processes with execution times of a, b, c, d .
 - a finishes at time a , b finishes at $a + b$, c at $a + b + c$, and so on
 - Average turn-around time is $(4a + 3b + 2c + d)/4$
 - Since a contributes most to average turn-around time, it should be the shortest job.

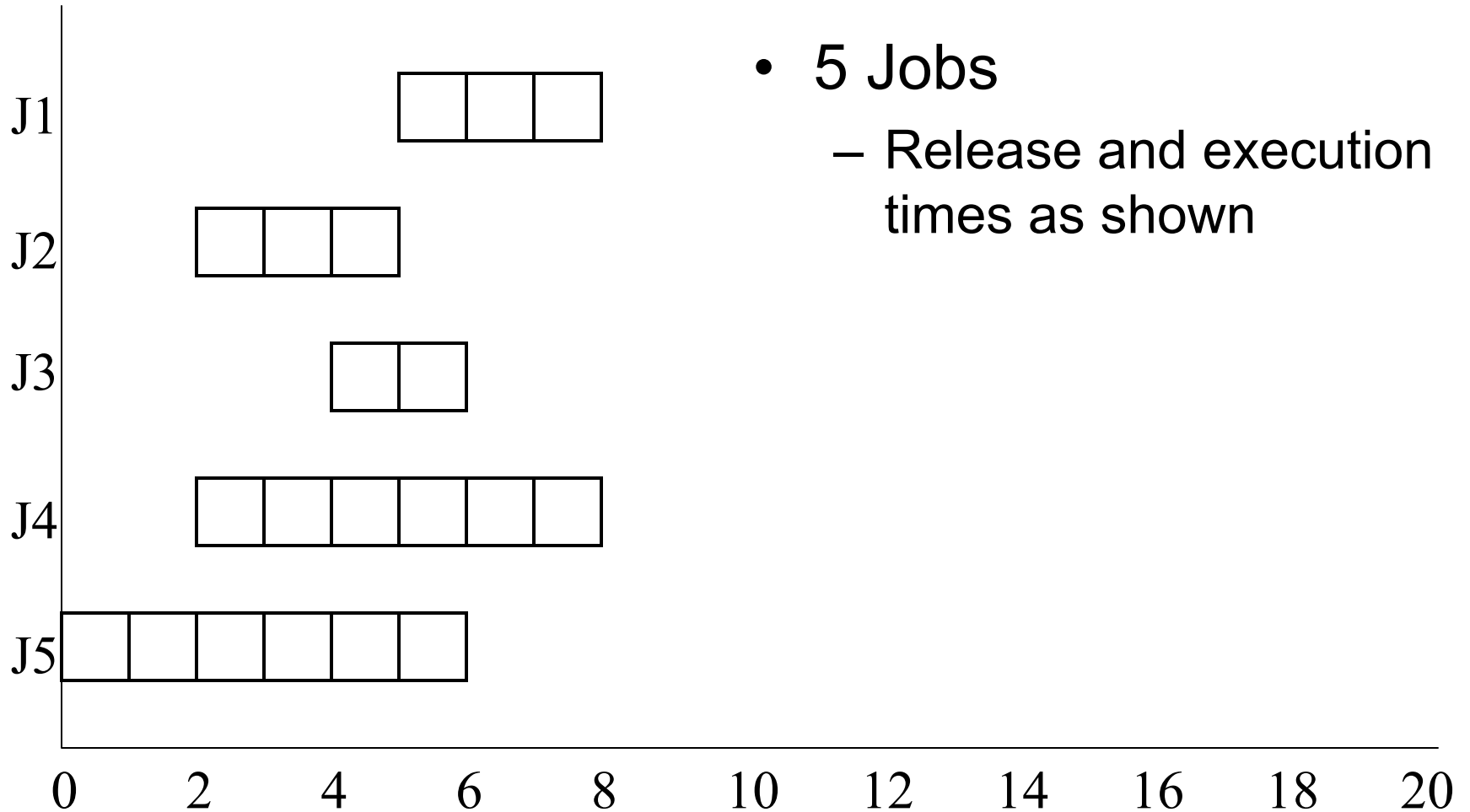


Shortest Remaining Time First

- A preemptive version of shortest job first
- When ever a new jobs arrive, choose the one with the shortest remaining time first
 - New short jobs get good service



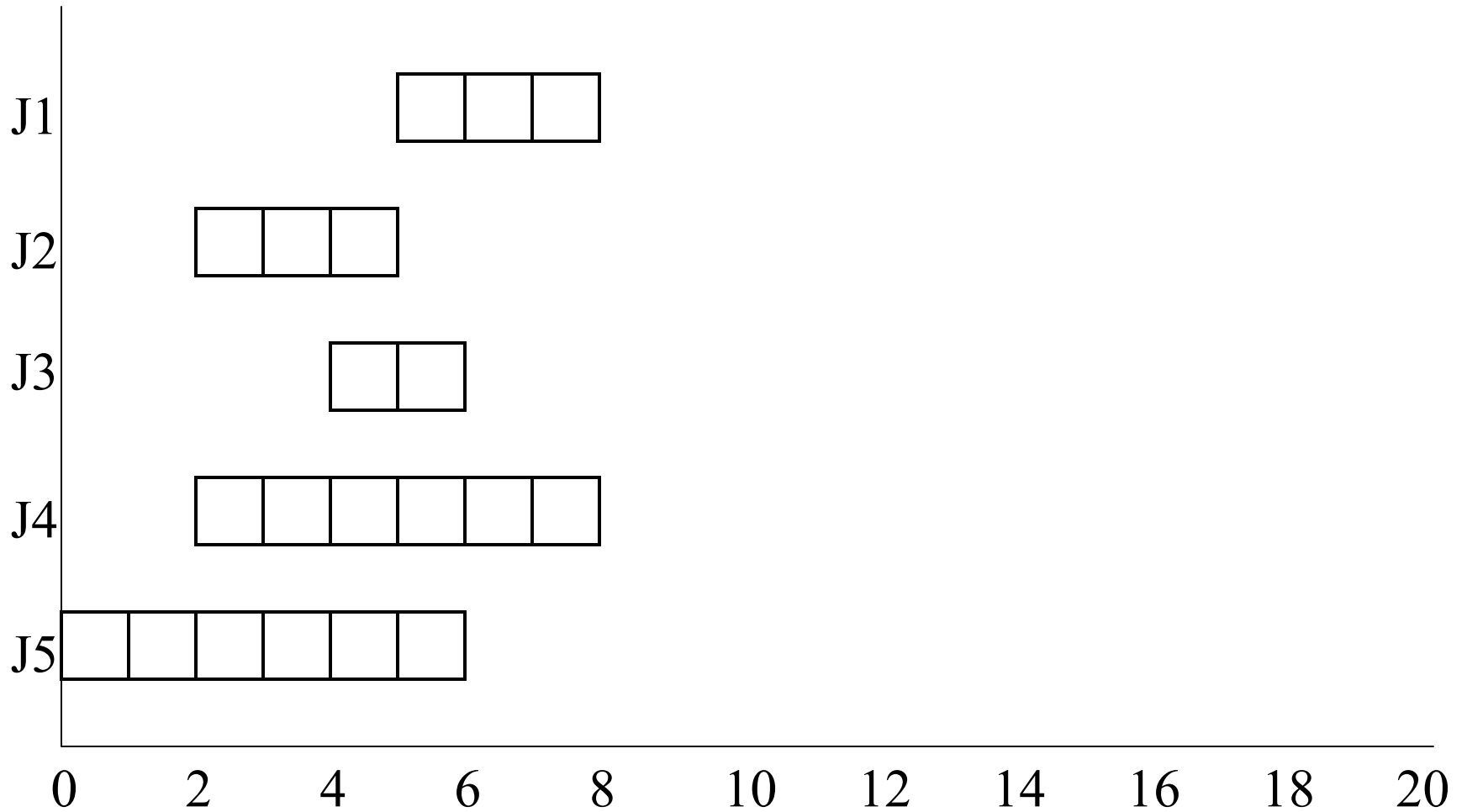
Example



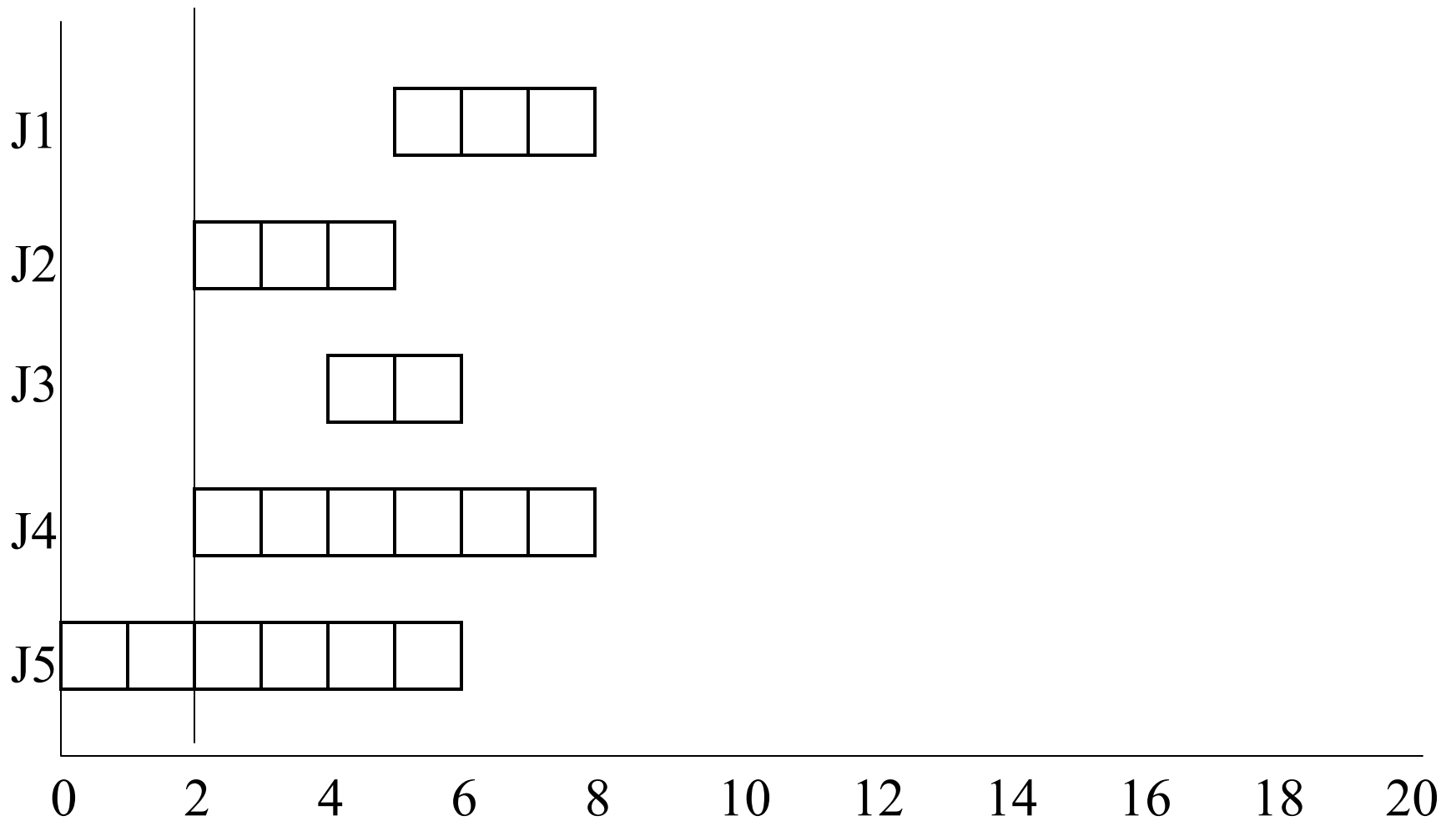
- 5 Jobs
 - Release and execution times as shown



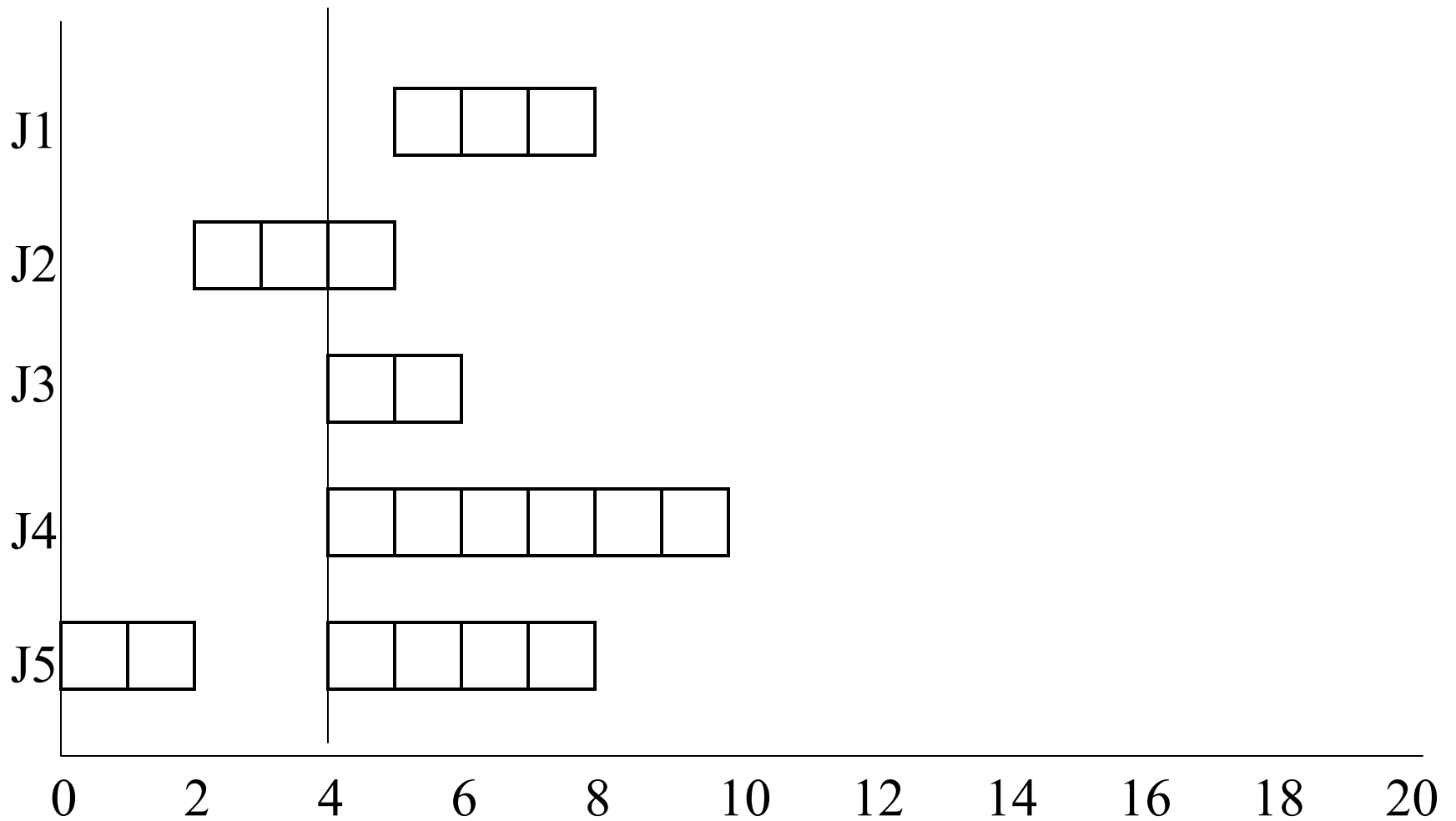
Shortest Remaining Time First



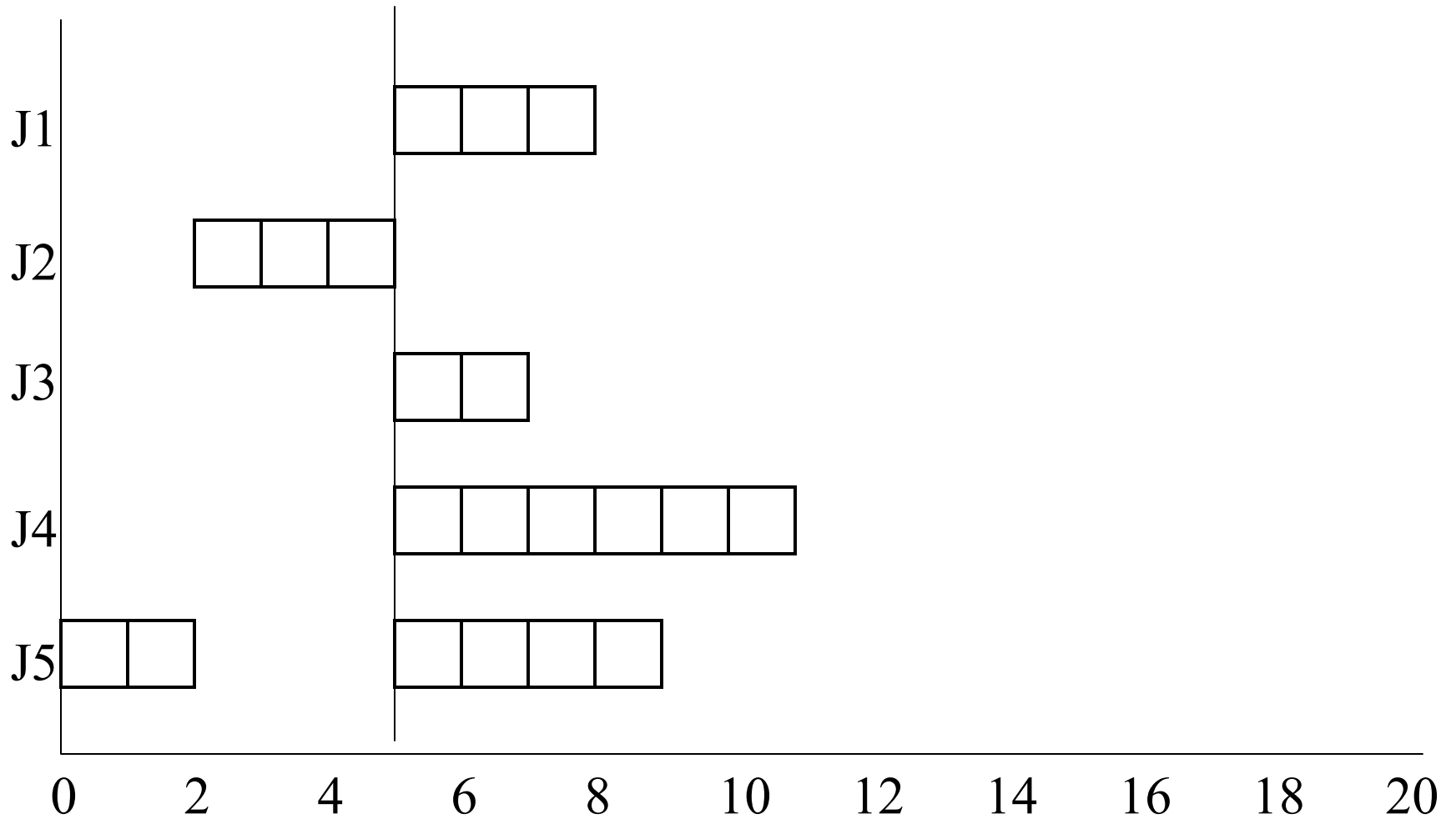
Shortest Remaining Time First



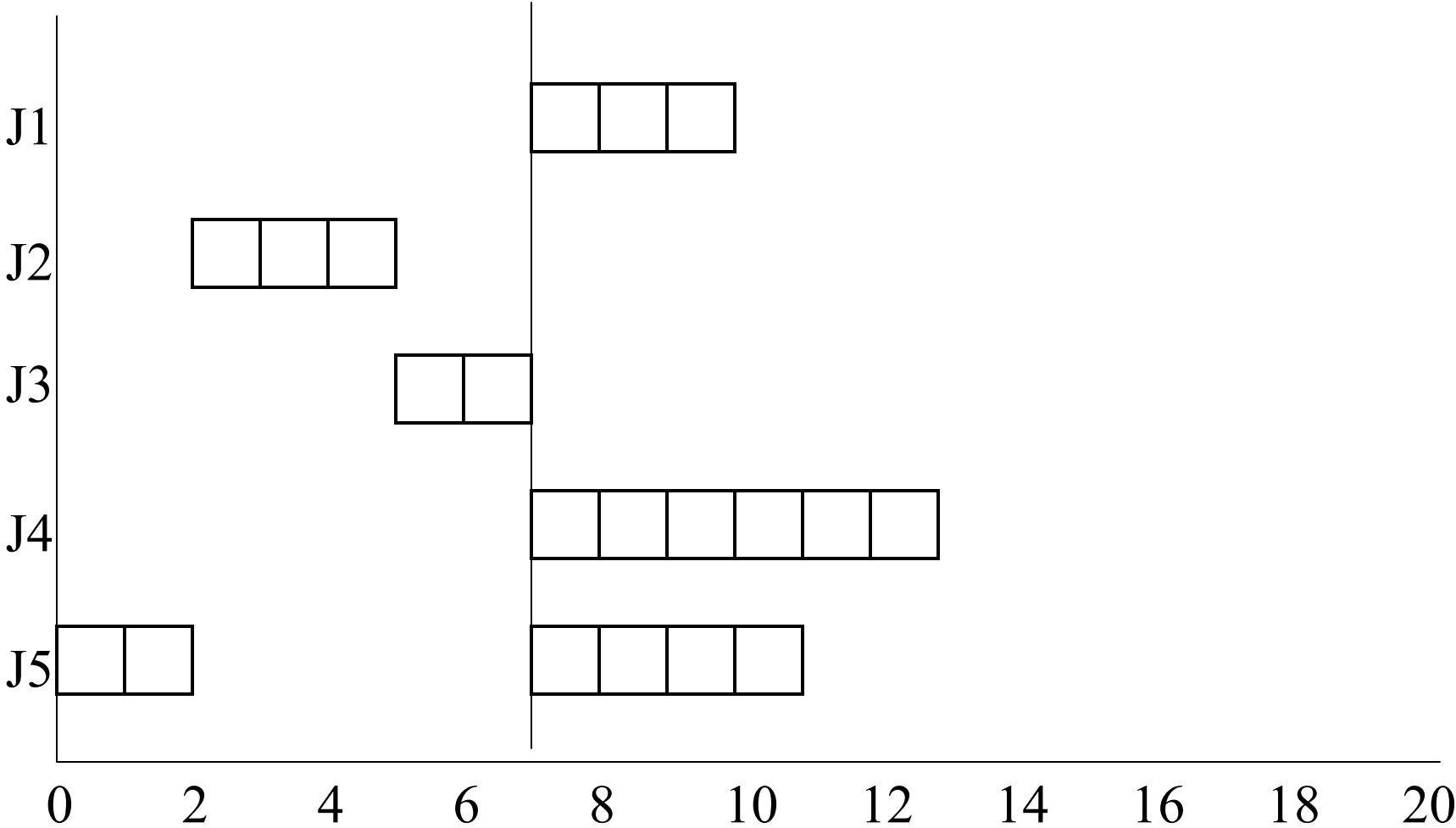
Shortest Remaining Time First



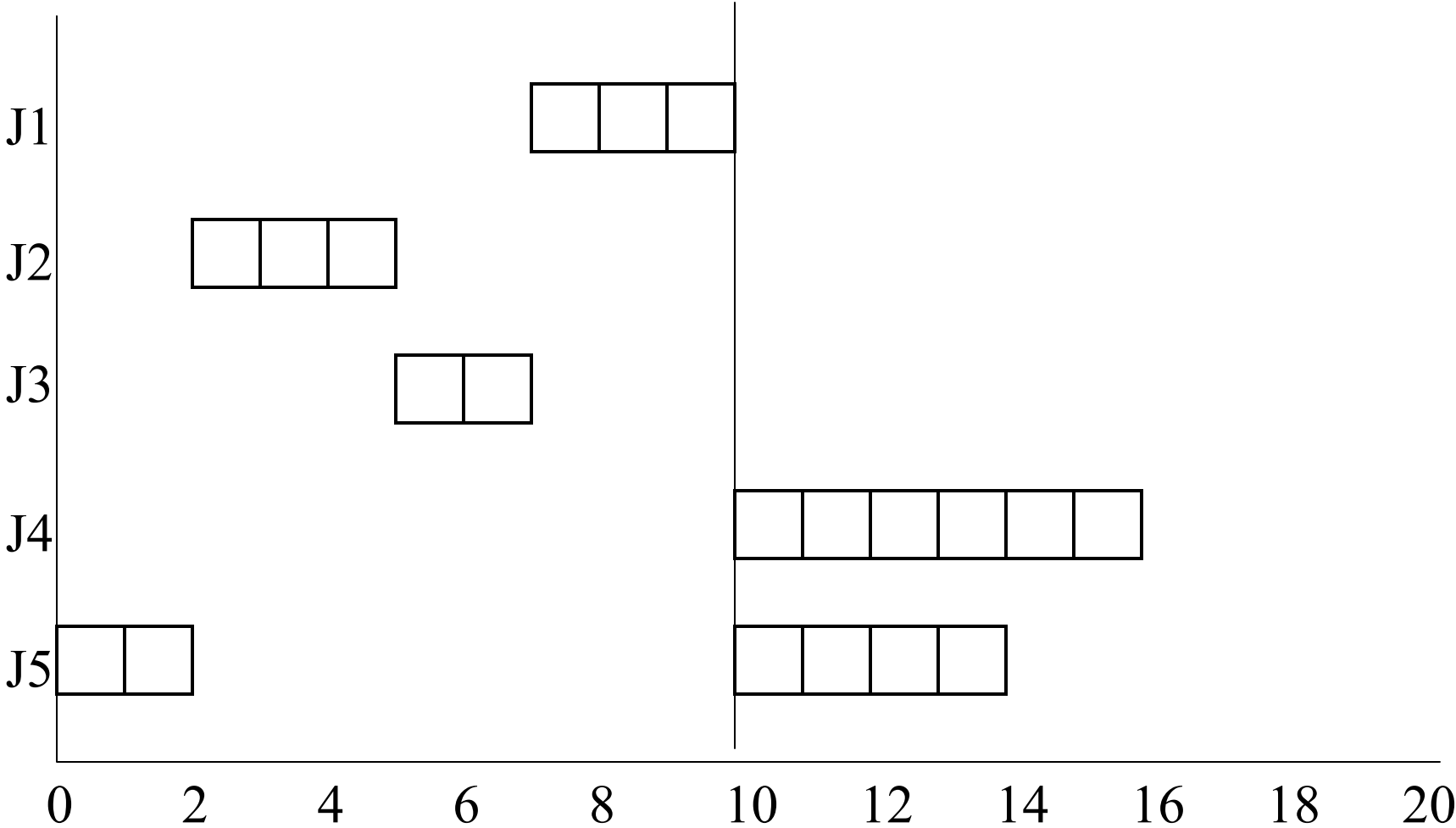
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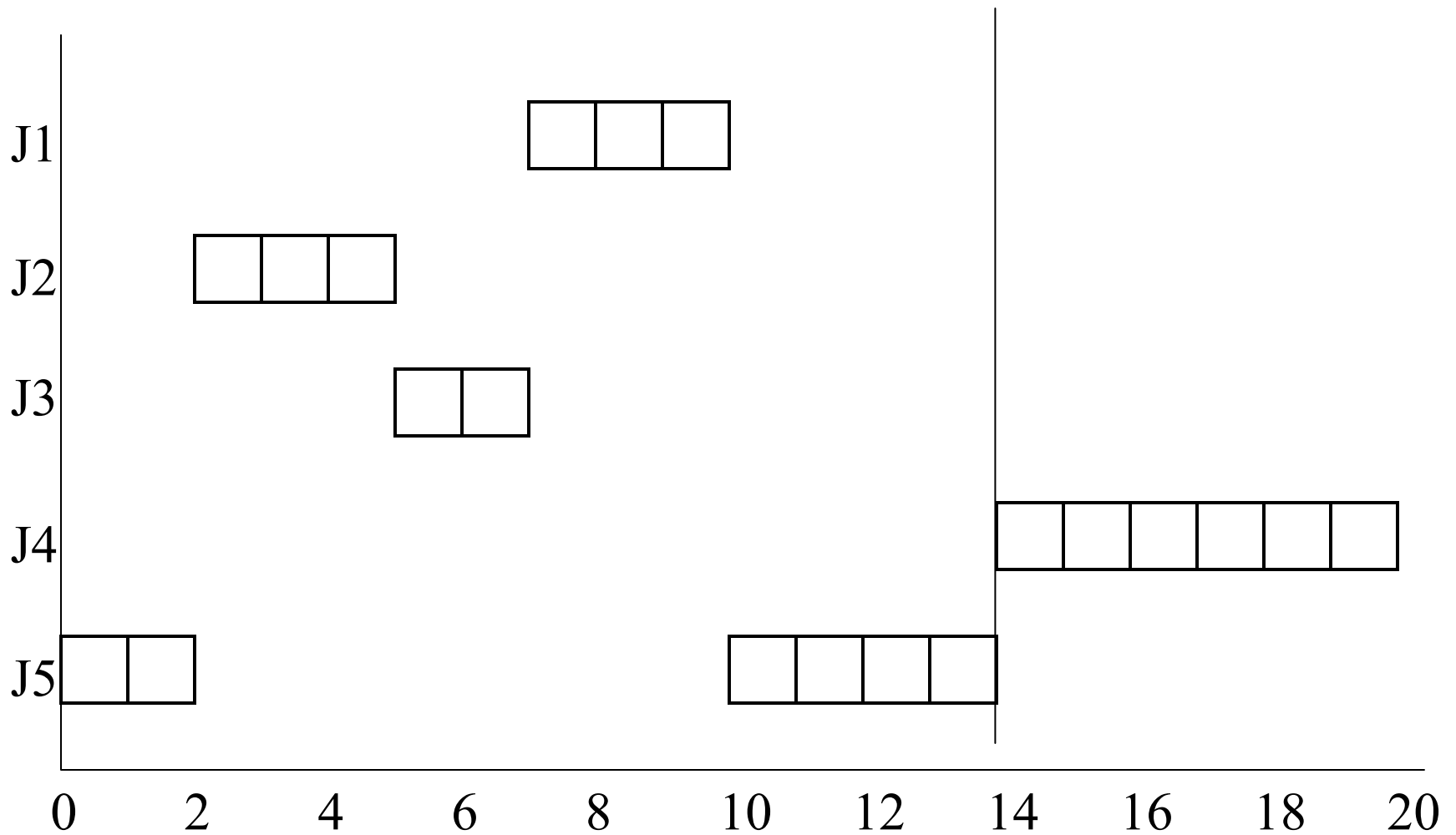
Shortest Remaining Time First



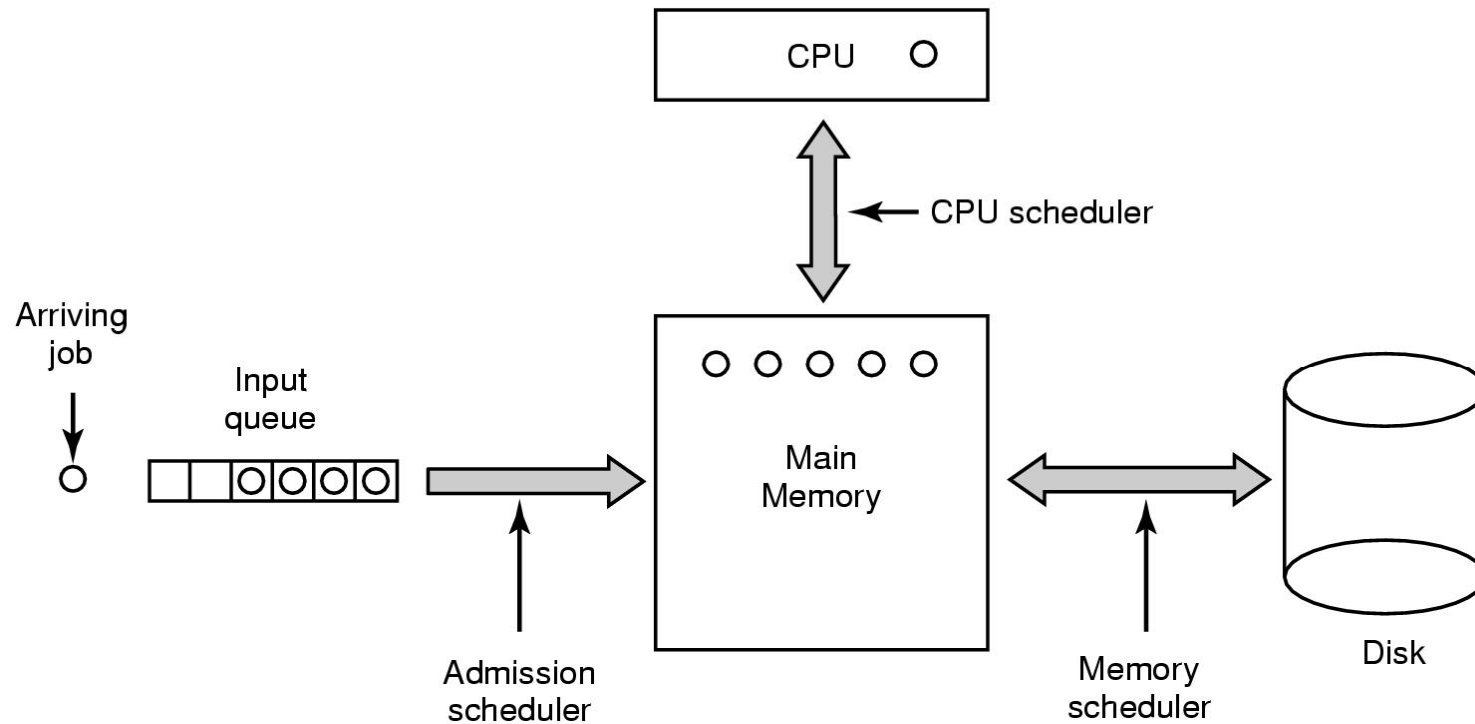
Shortest Remaining Time First



Shortest Remaining Time First



Scheduling in Batch Systems



Three level scheduling



Three Level Scheduling

- Admission Scheduler
 - Also called *long-term* scheduler
 - Determines when jobs are *admitted* into the system for processing
 - Controls degree of multiprogramming
 - More processes \Rightarrow less CPU available per process



Three Level Scheduling

- CPU scheduler
 - Also called *short-term* scheduler
 - Invoked when ever a process blocks or is released, clock interrupts (if preemptive scheduling), I/O interrupts.
 - Usually, this scheduler is what we are referring to if we talk about a *scheduler*.



Three Level Scheduling

- Memory Scheduler
 - Also called *medium-term* scheduler
 - Adjusts the degree of multiprogramming via suspending processes and swapping them out

