

Scheduling



Learning Outcomes

- Understand the role of the scheduler, and how its behaviour influences the performance of the system.
- Know the difference between I/O-bound and CPU-bound tasks, and how they relate to scheduling.
- Understand typical interactive and real time scheduling approaches.



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....

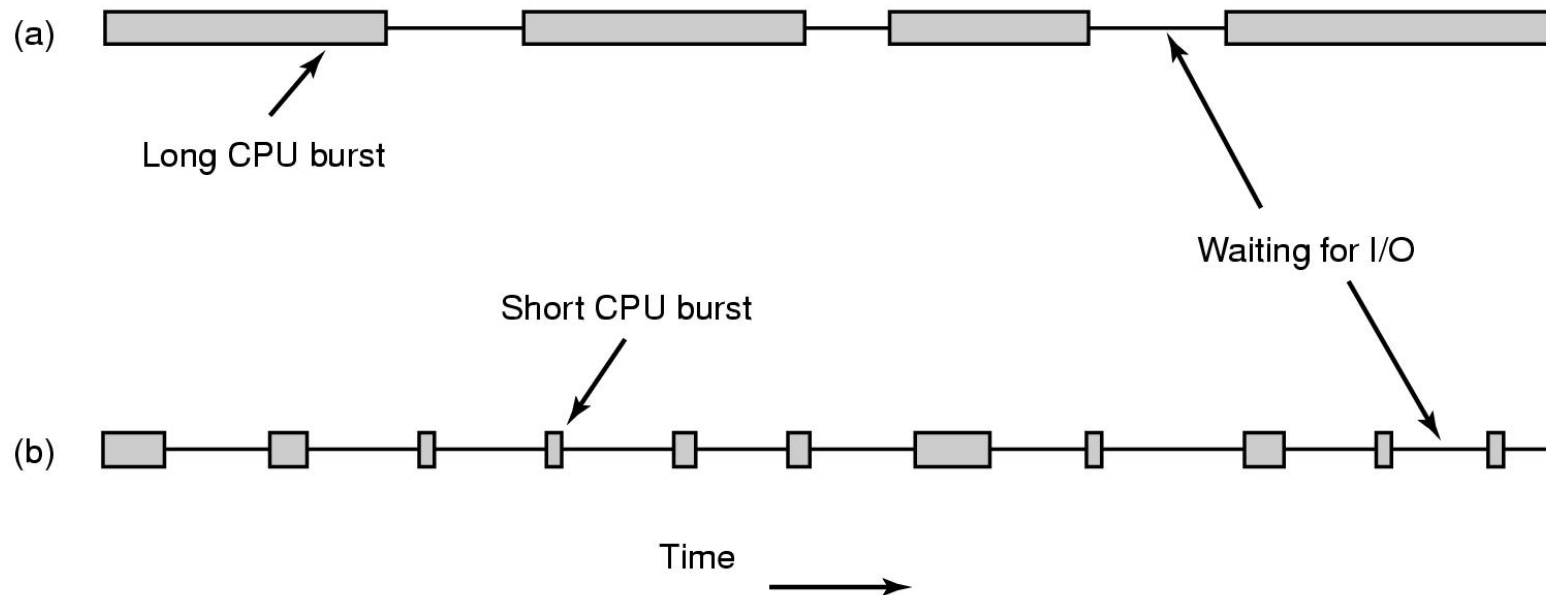


Is scheduling important?

- 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



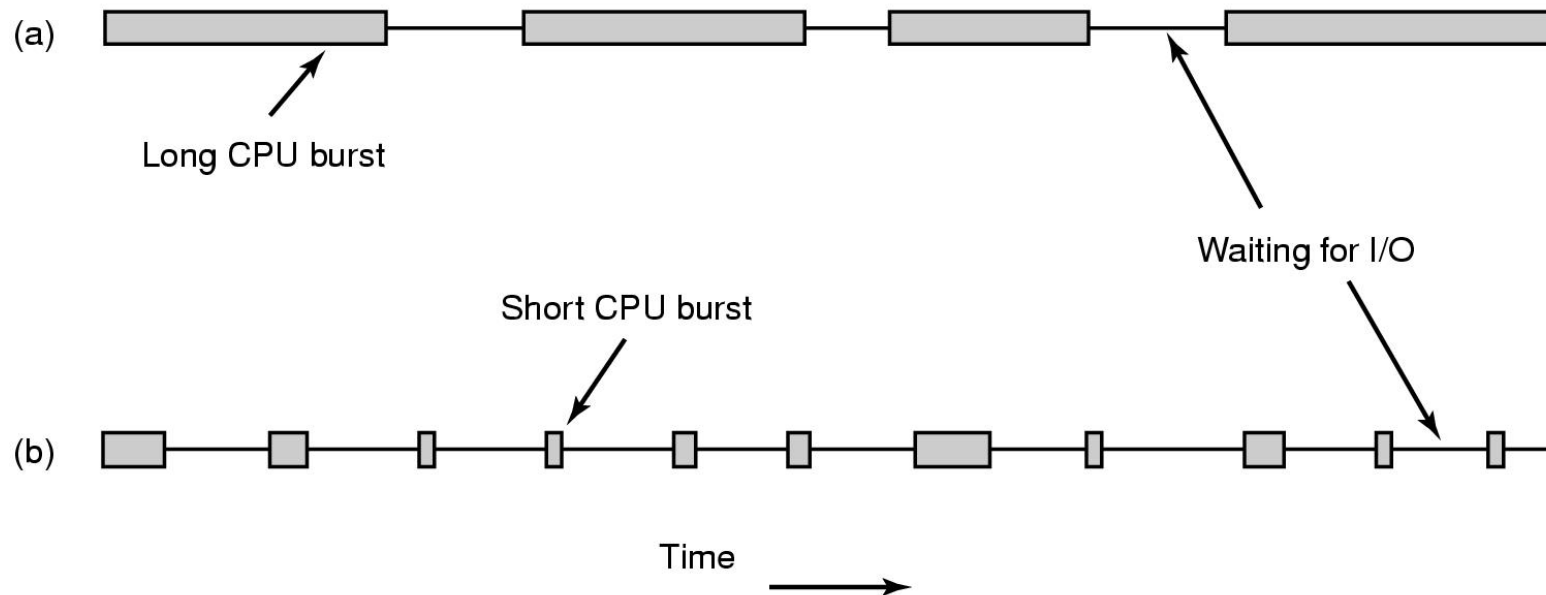
Application Behaviour



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



Application Behaviour

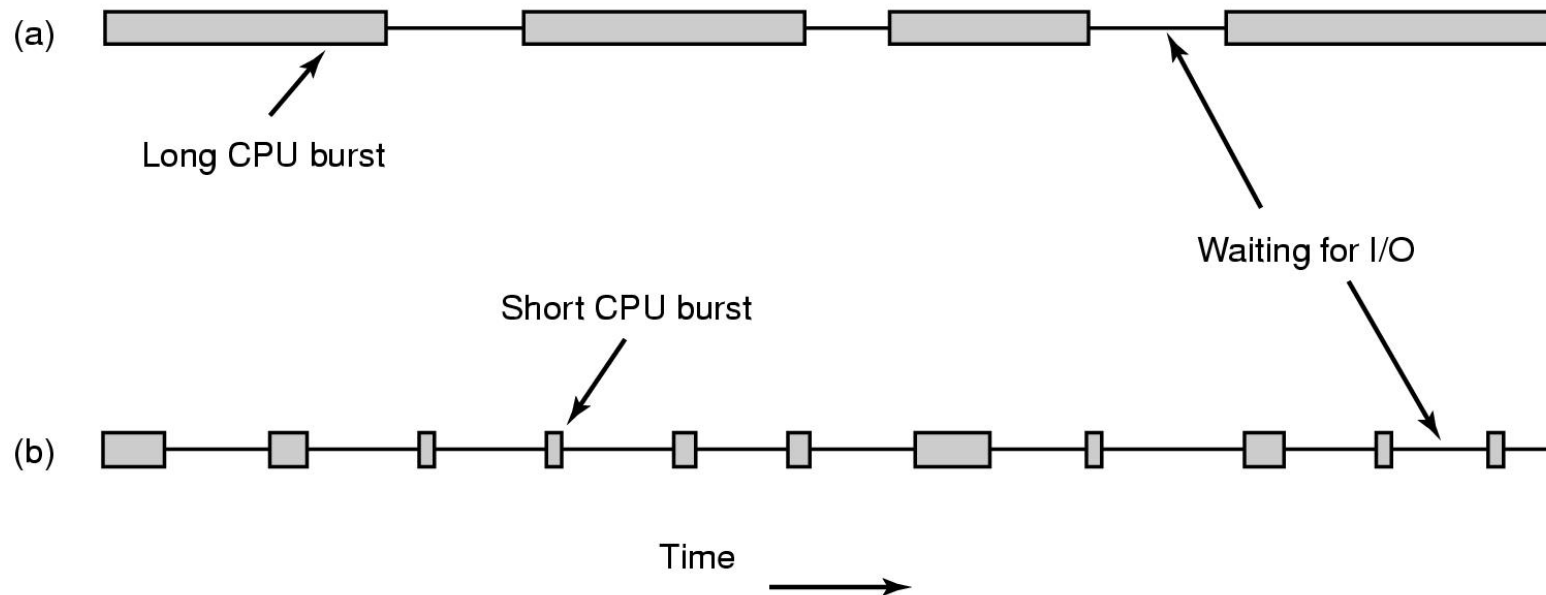


a) CPU-Bound process

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



Application Behaviour

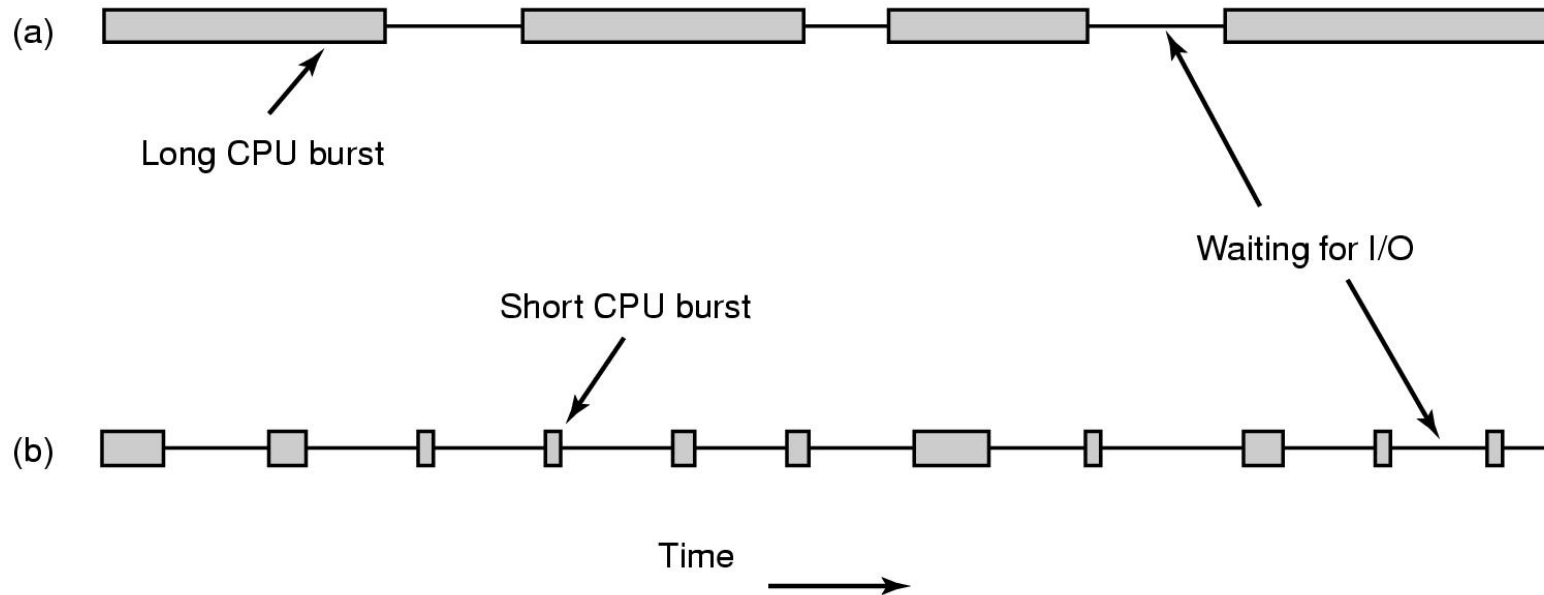


b) I/O-Bound process

- 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



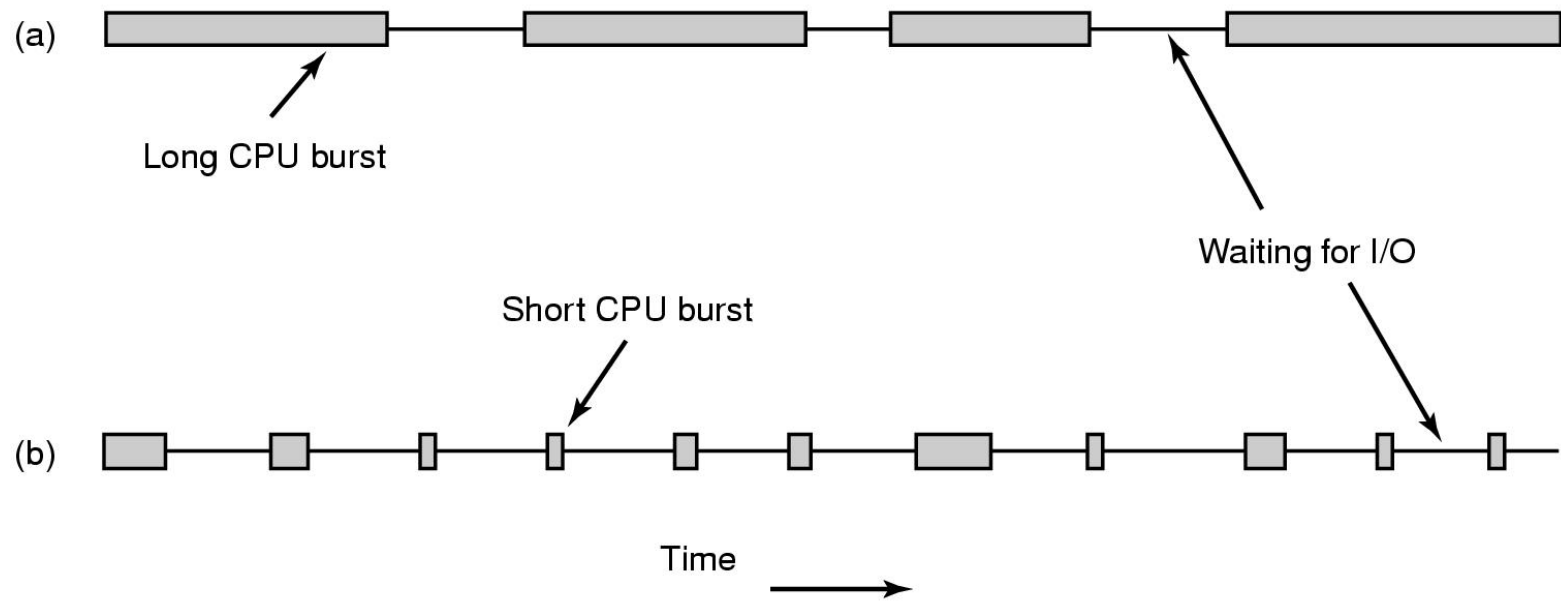
Observations



- 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



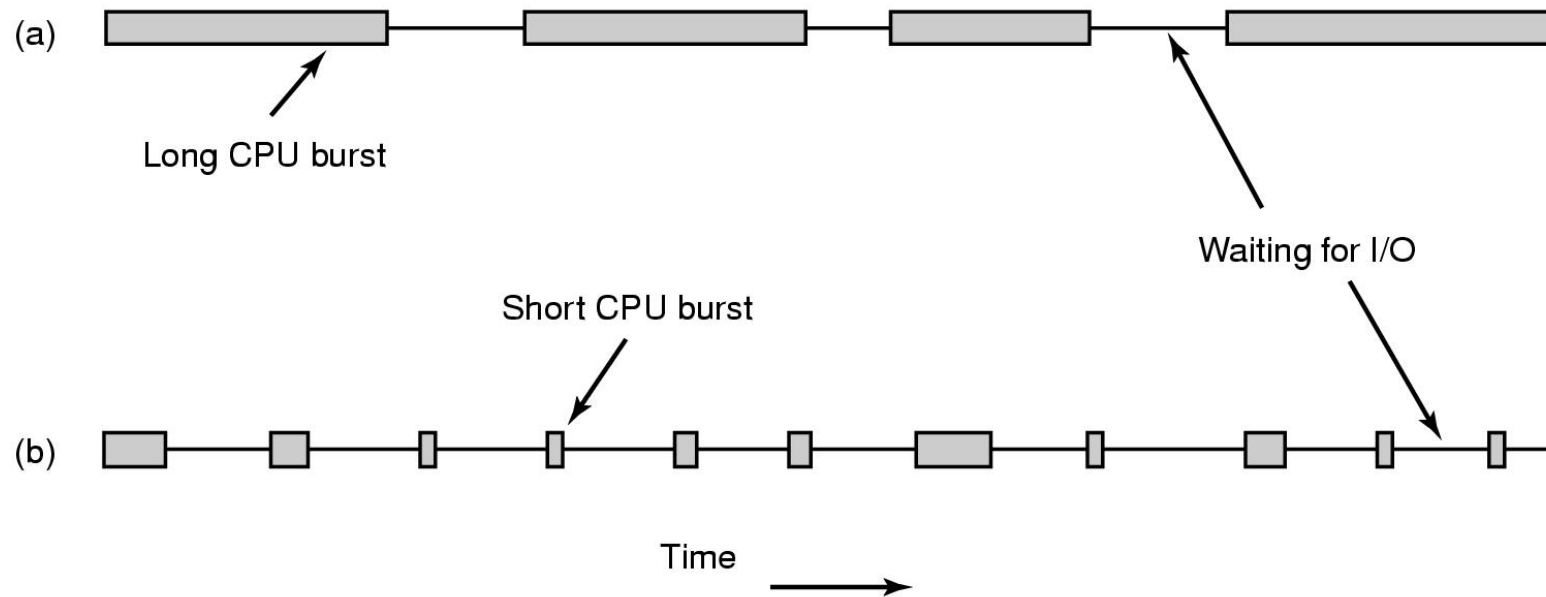
Observations



- 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



Key Insight



- 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

- 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



Interactive Scheduling

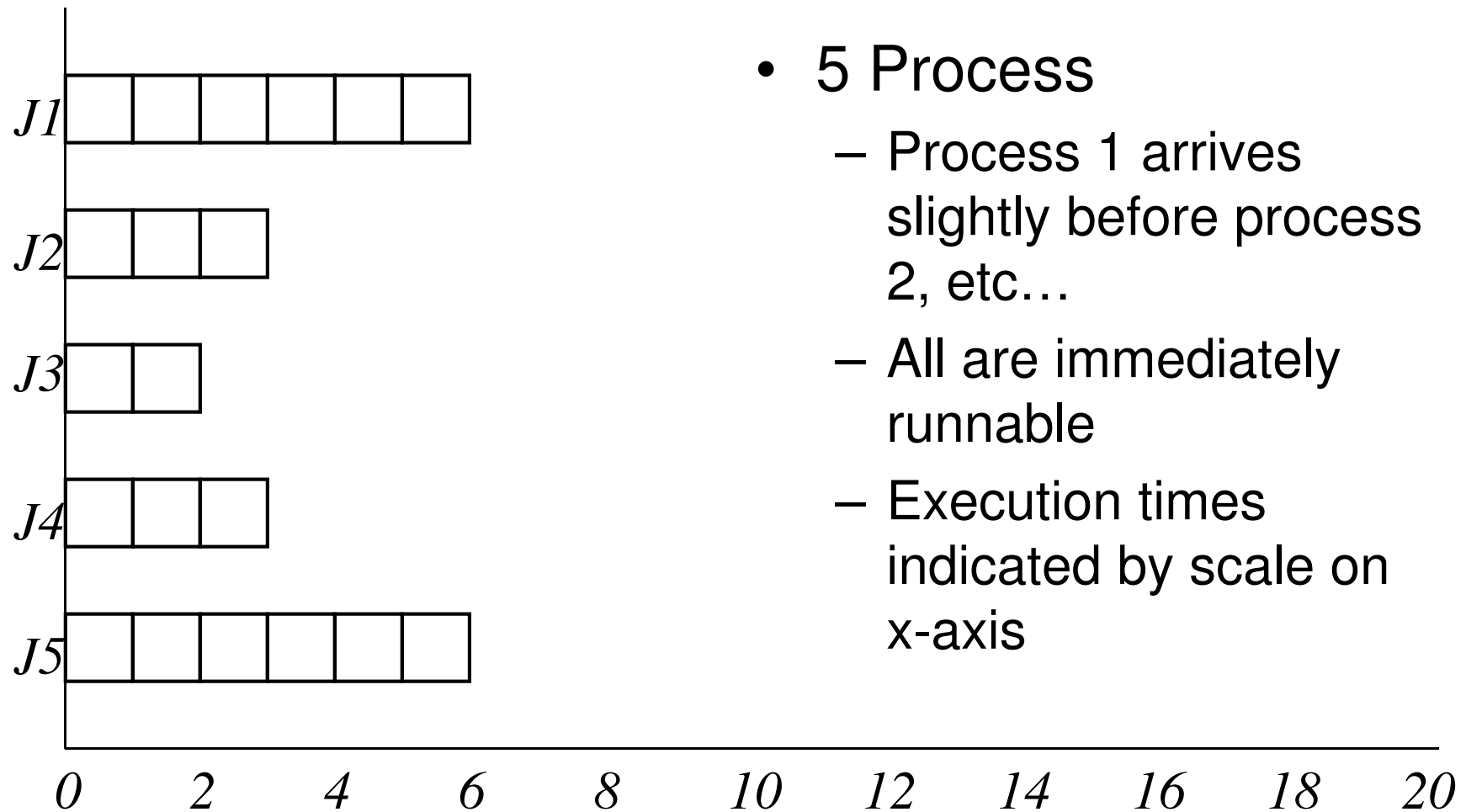


Round Robin Scheduling

- Each process is given a *timeslice* to run in
- When the timeslice expires, the next process preempts the current process, and runs for its timeslice, and so on
 - The preempted process is placed at the end of the queue
- Implemented with
 - A ready queue
 - A regular timer interrupt



Example

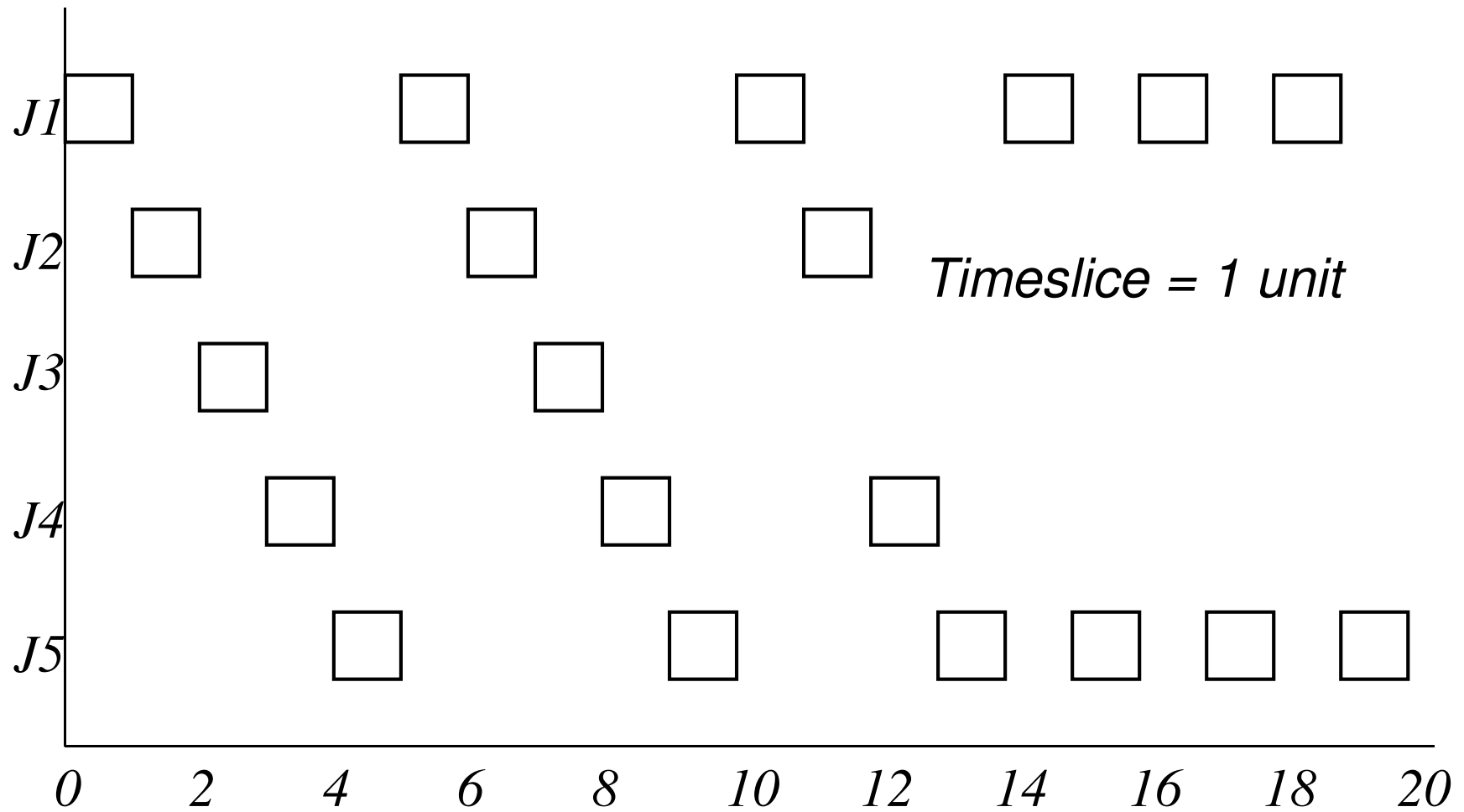


- 5 Process

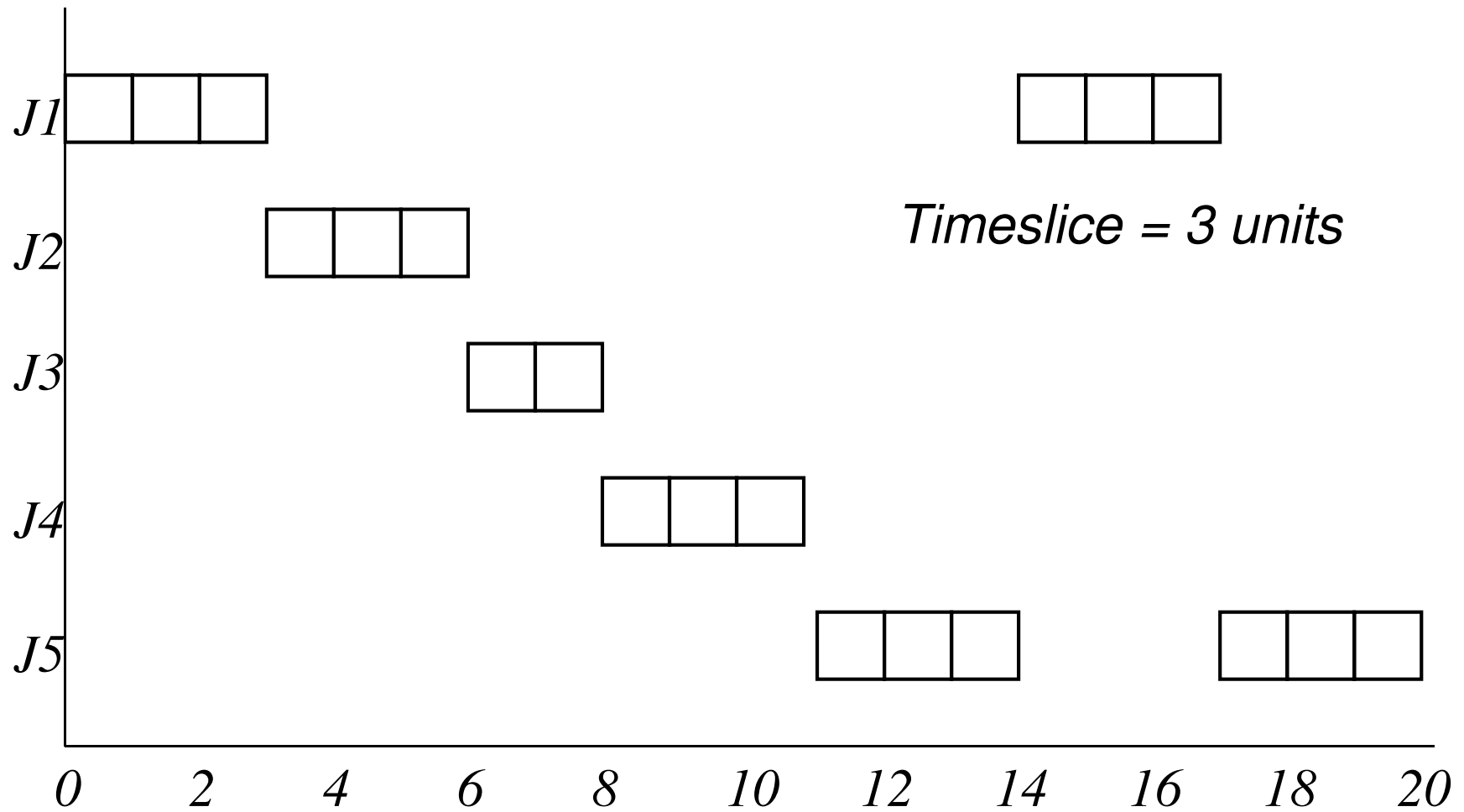
- Process 1 arrives slightly before process 2, etc...
- All are immediately runnable
- Execution times indicated by scale on x-axis



Round Robin Schedule



Round Robin Schedule



Round Robin

- Pros
 - Fair, easy to implement
- Con
 - Assumes everybody is equal
- Issue: What should the timeslice be?
 - Too short
 - Waste a lot of time switching between processes
 - Example: timeslice of 4ms with 1 ms context switch = 20% round robin overhead
 - Too long
 - System is not responsive
 - Example: timeslice of 100ms
 - If 10 people hit “enter” key simultaneously, the last guy to run will only see progress after 1 second.
 - Degenerates into FCFS if timeslice longer than burst length

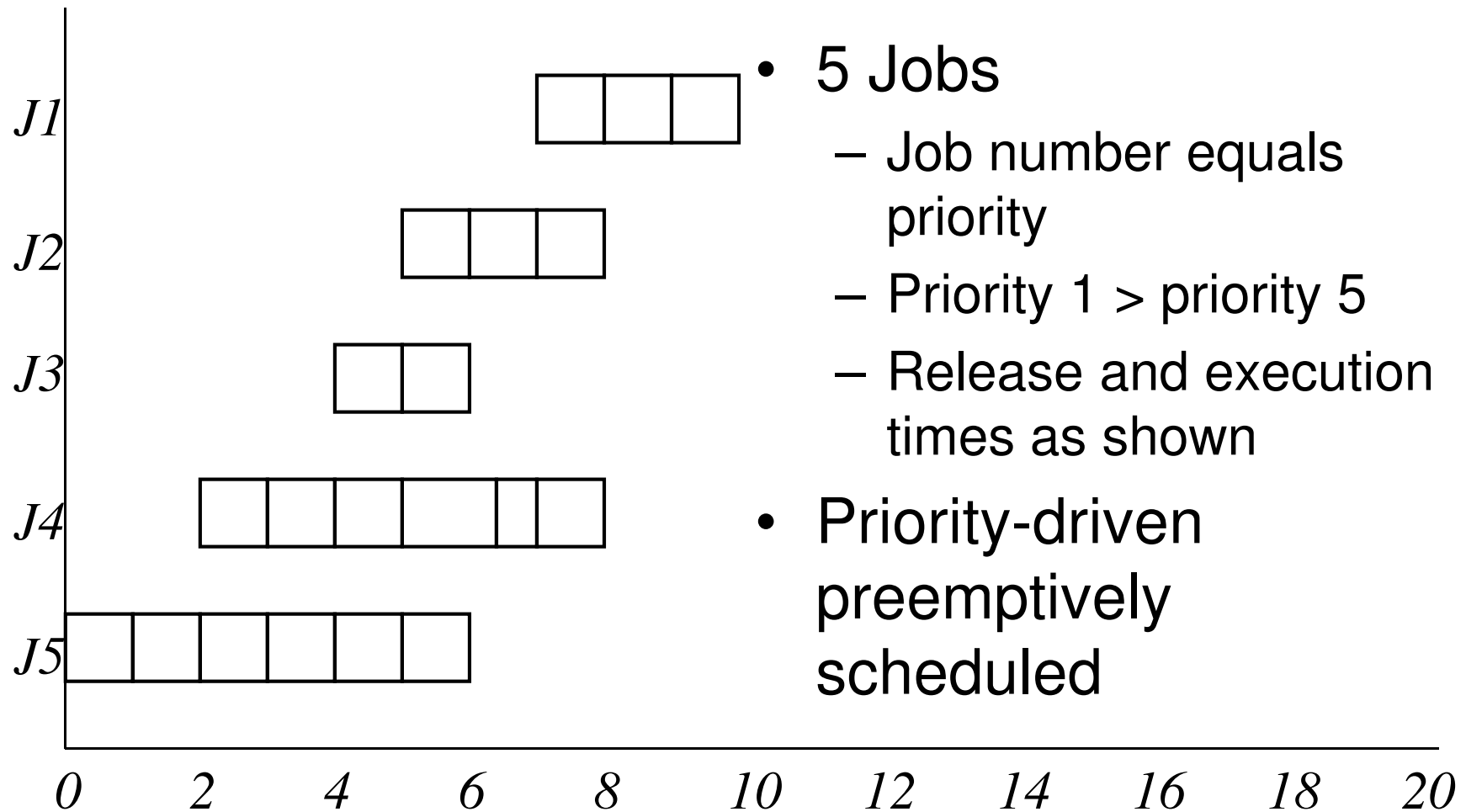


Priorities

- Each Process (or thread) is associated with a priority
- Provides basic mechanism to influence a scheduler decision:
 - Scheduler will always chooses a thread of higher priority over lower priority
- Priorities can be defined internally or externally
 - Internal: e.g. I/O bound or CPU bound
 - External: e.g. based on importance to the user



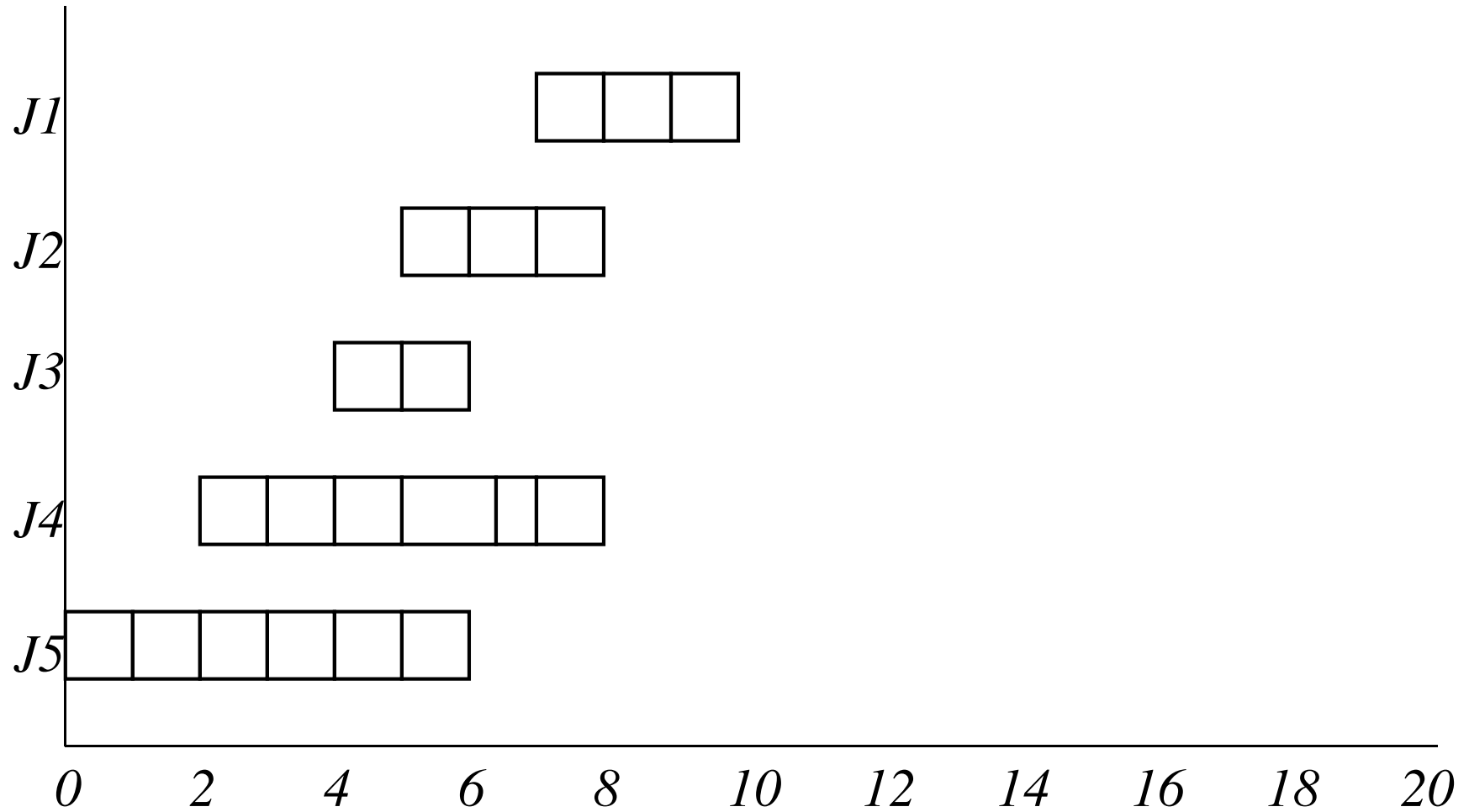
Example



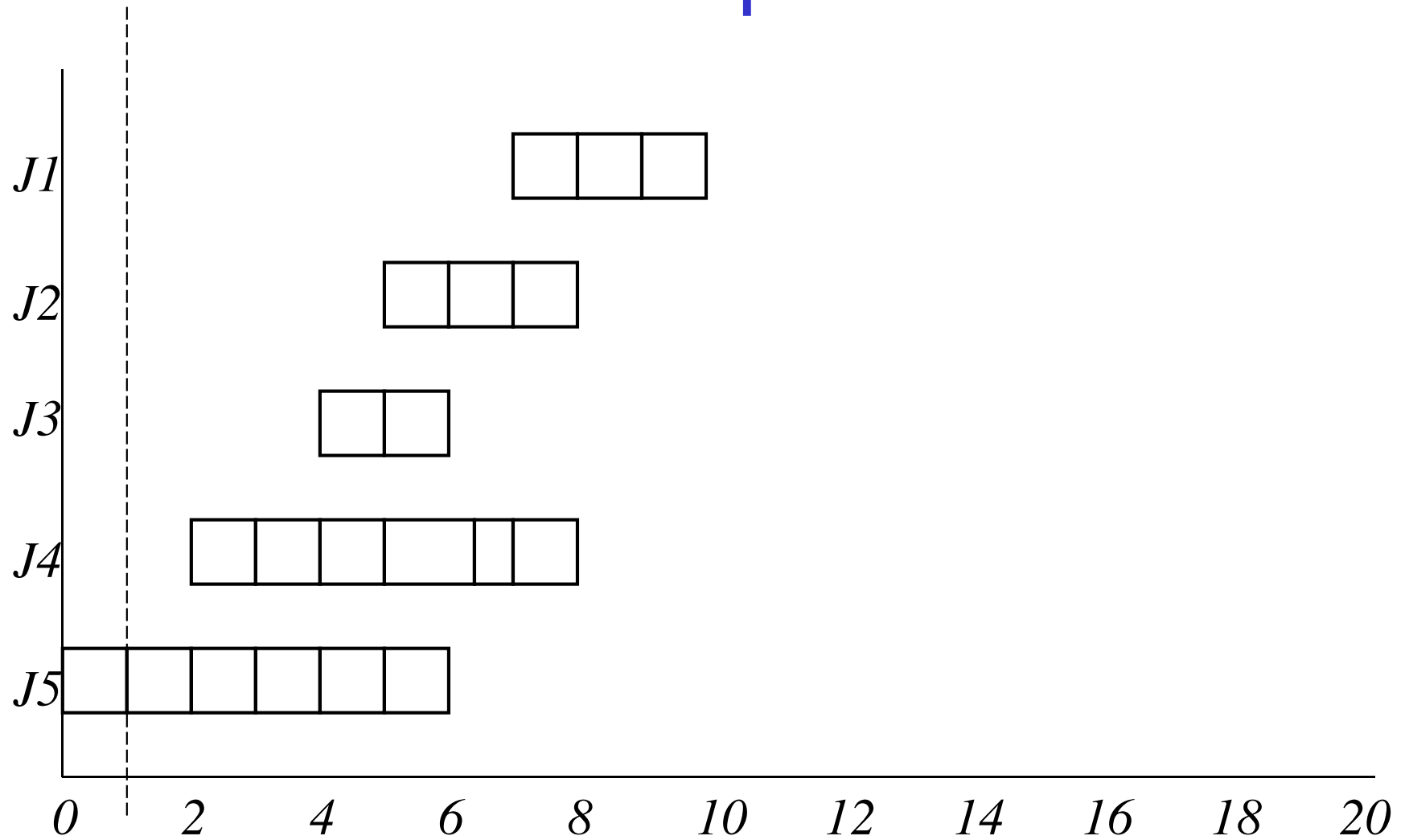
- 5 Jobs
 - Job number equals priority
 - Priority 1 > priority 5
 - Release and execution times as shown
- Priority-driven preemptively scheduled



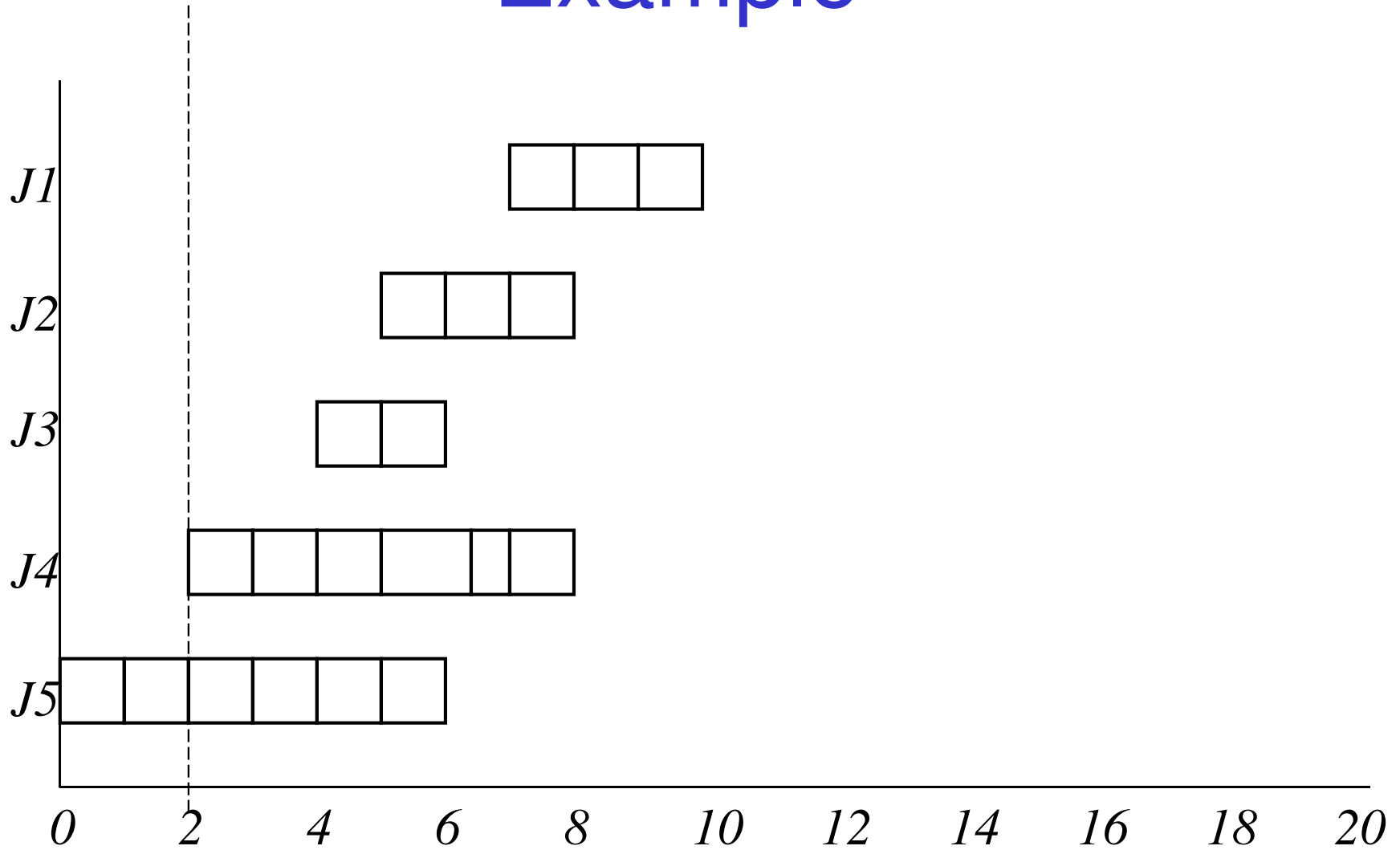
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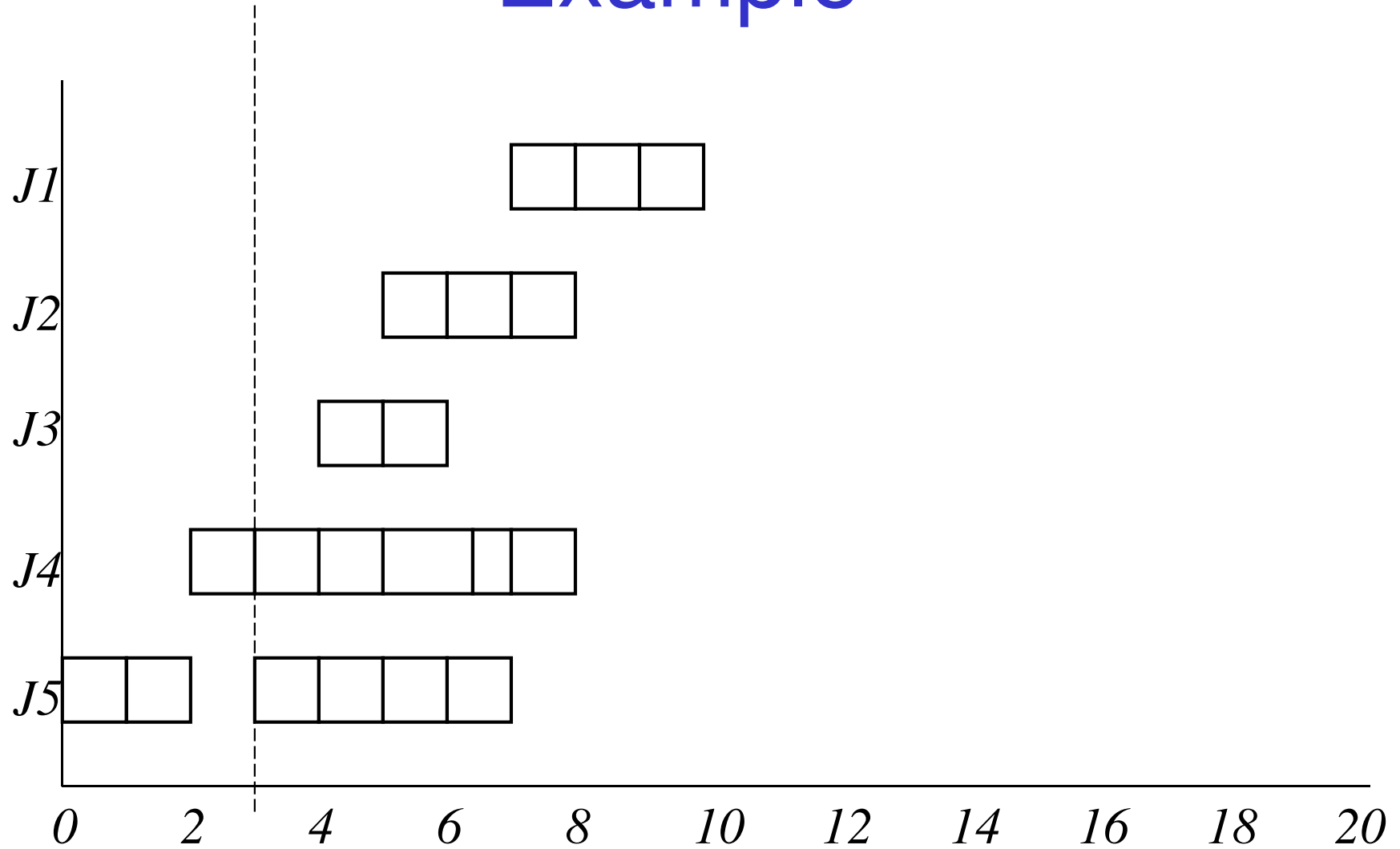
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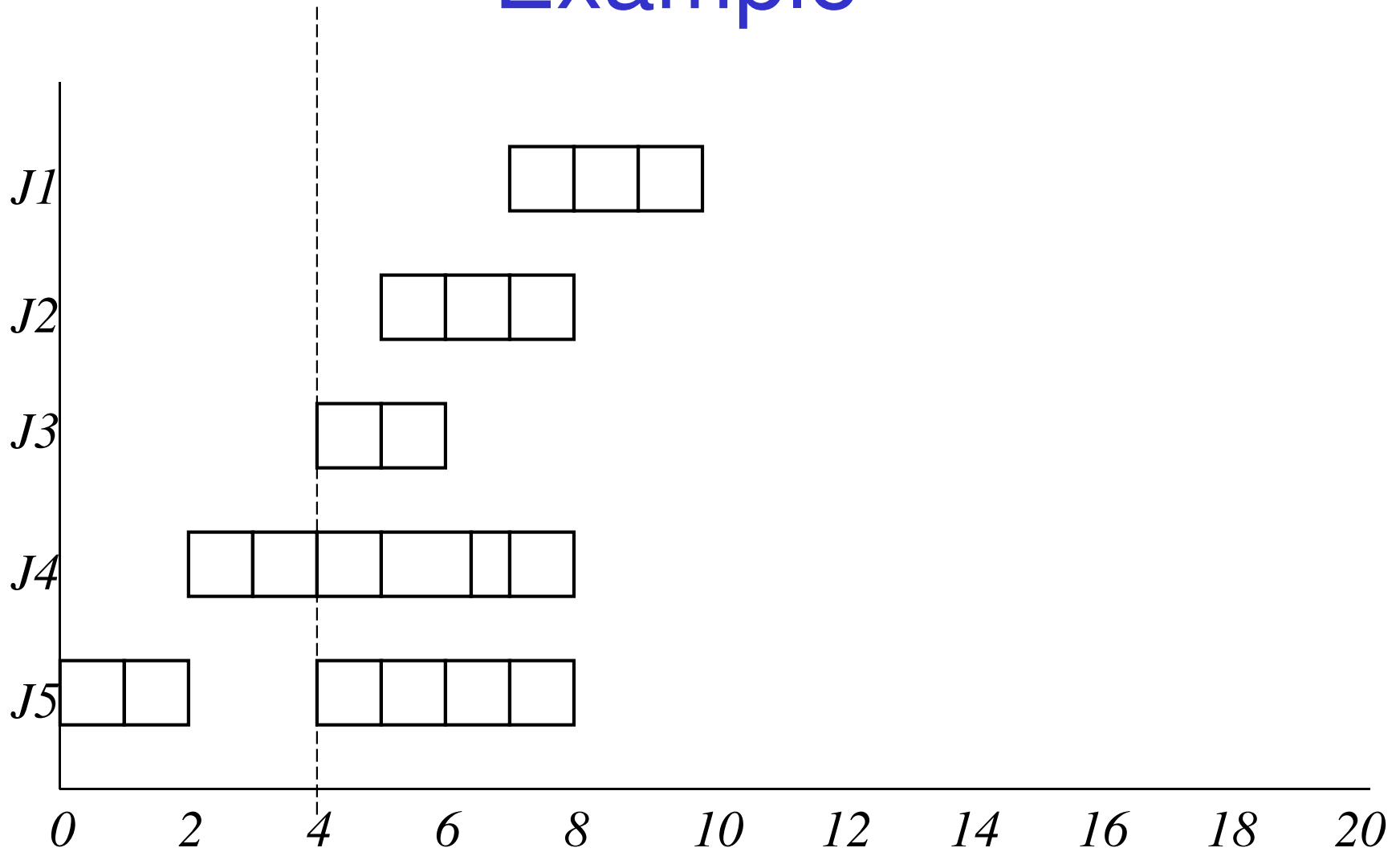
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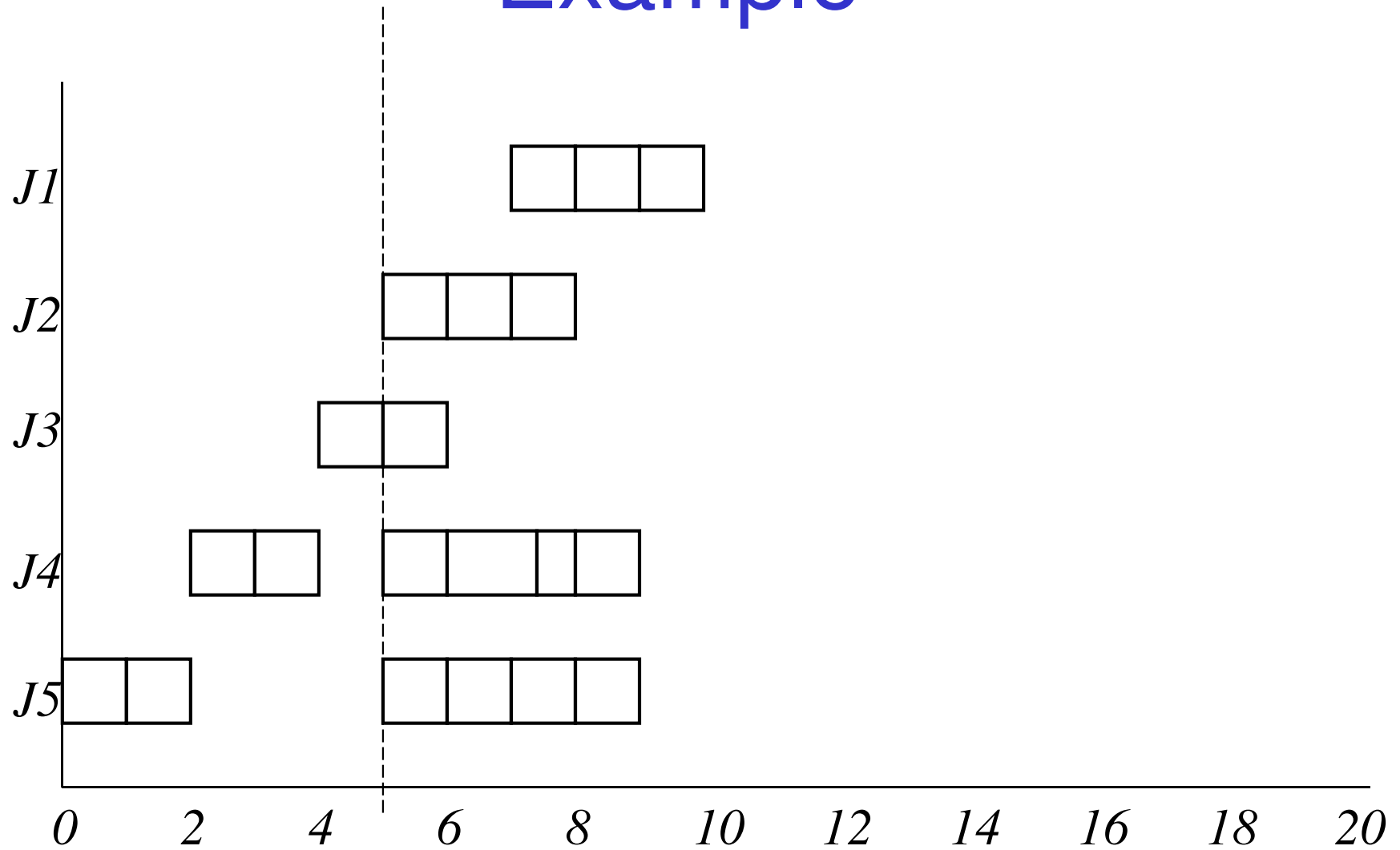
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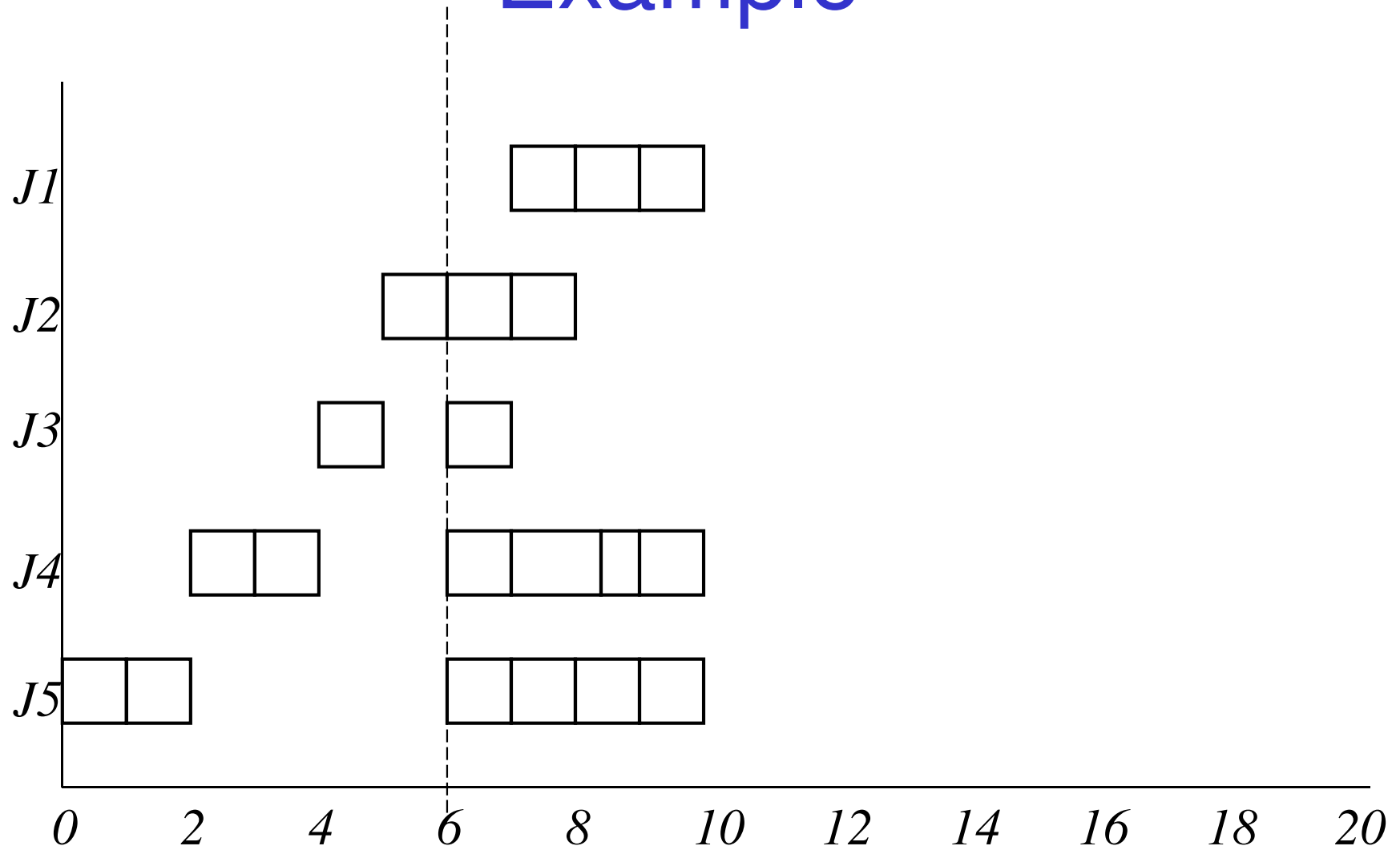
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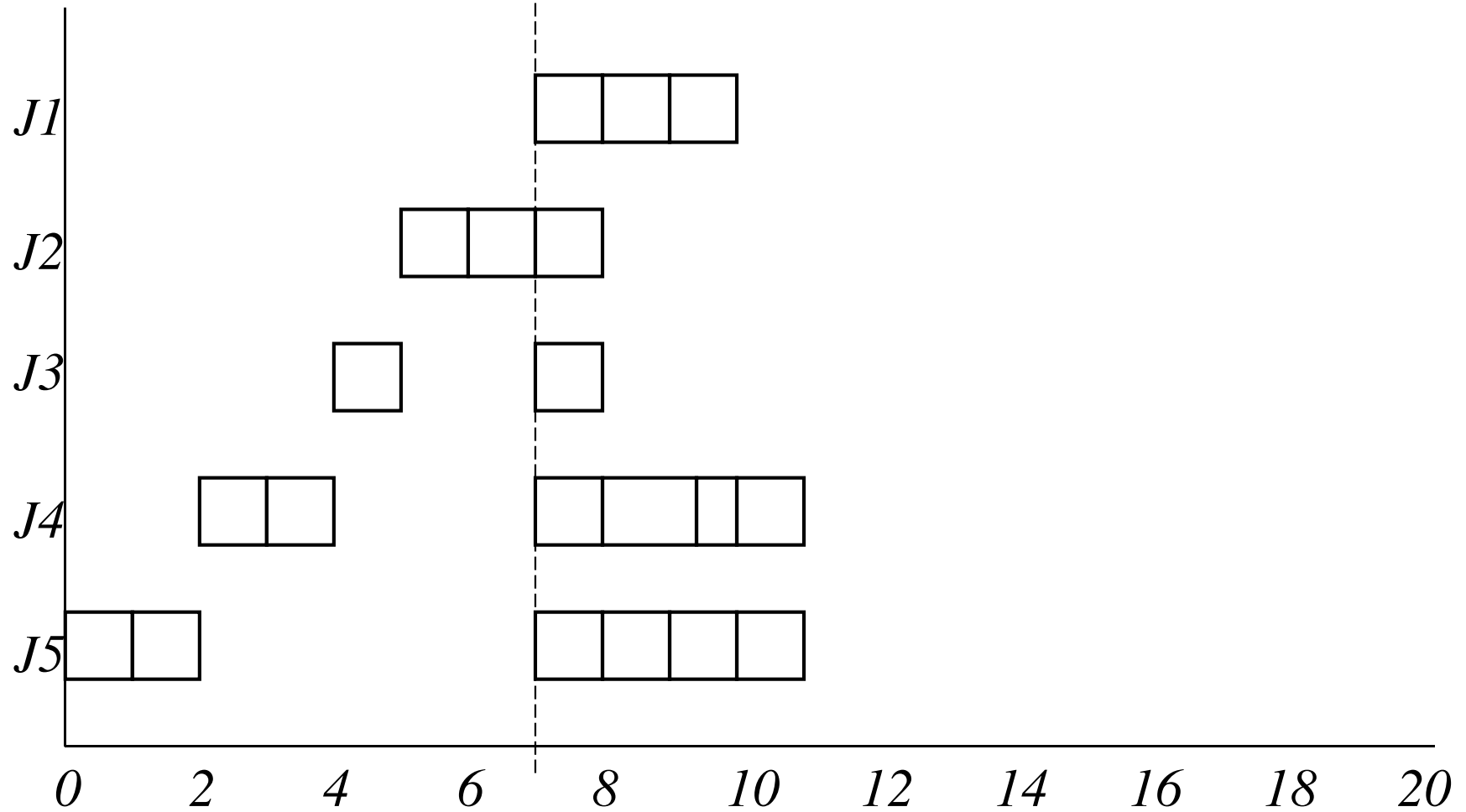
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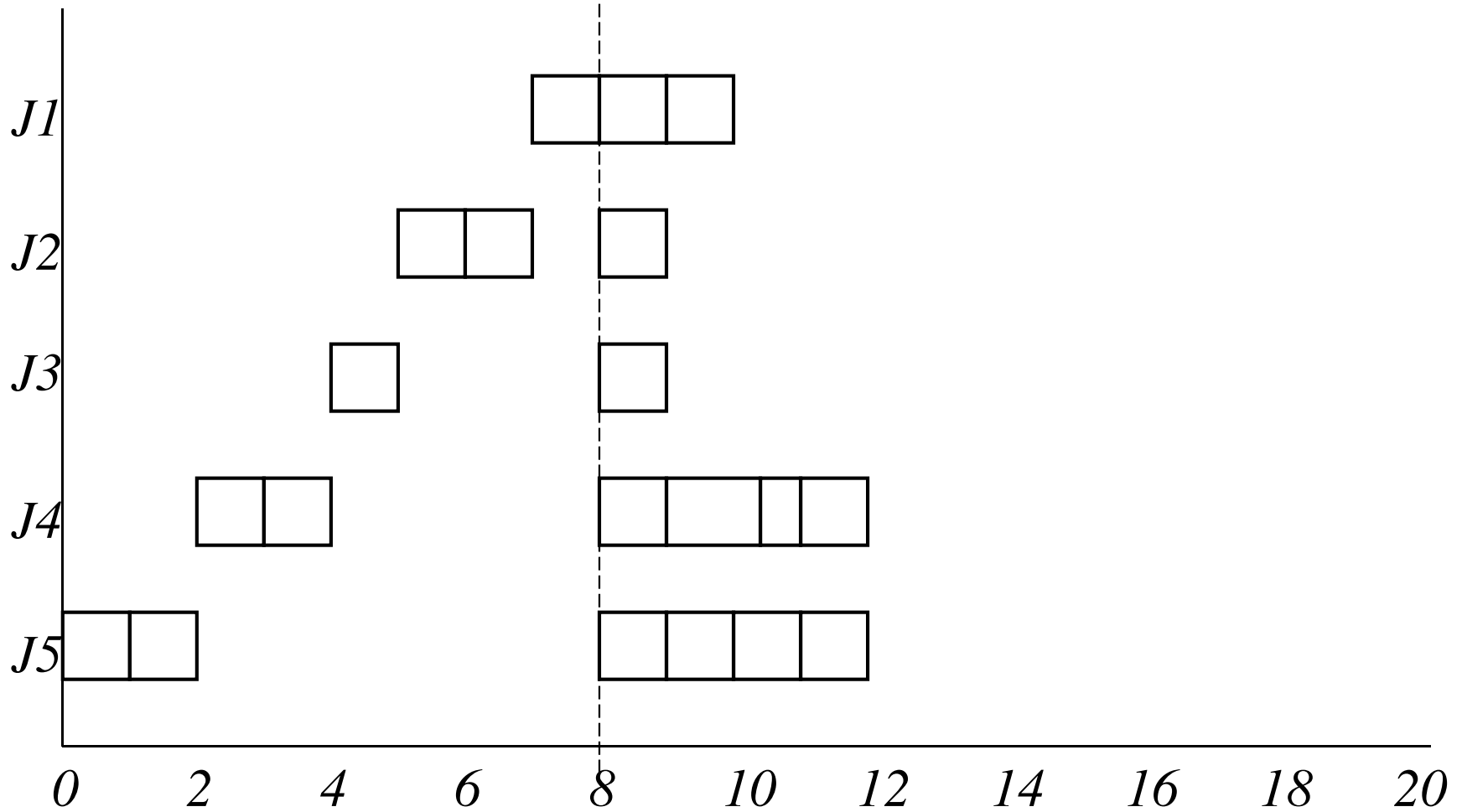
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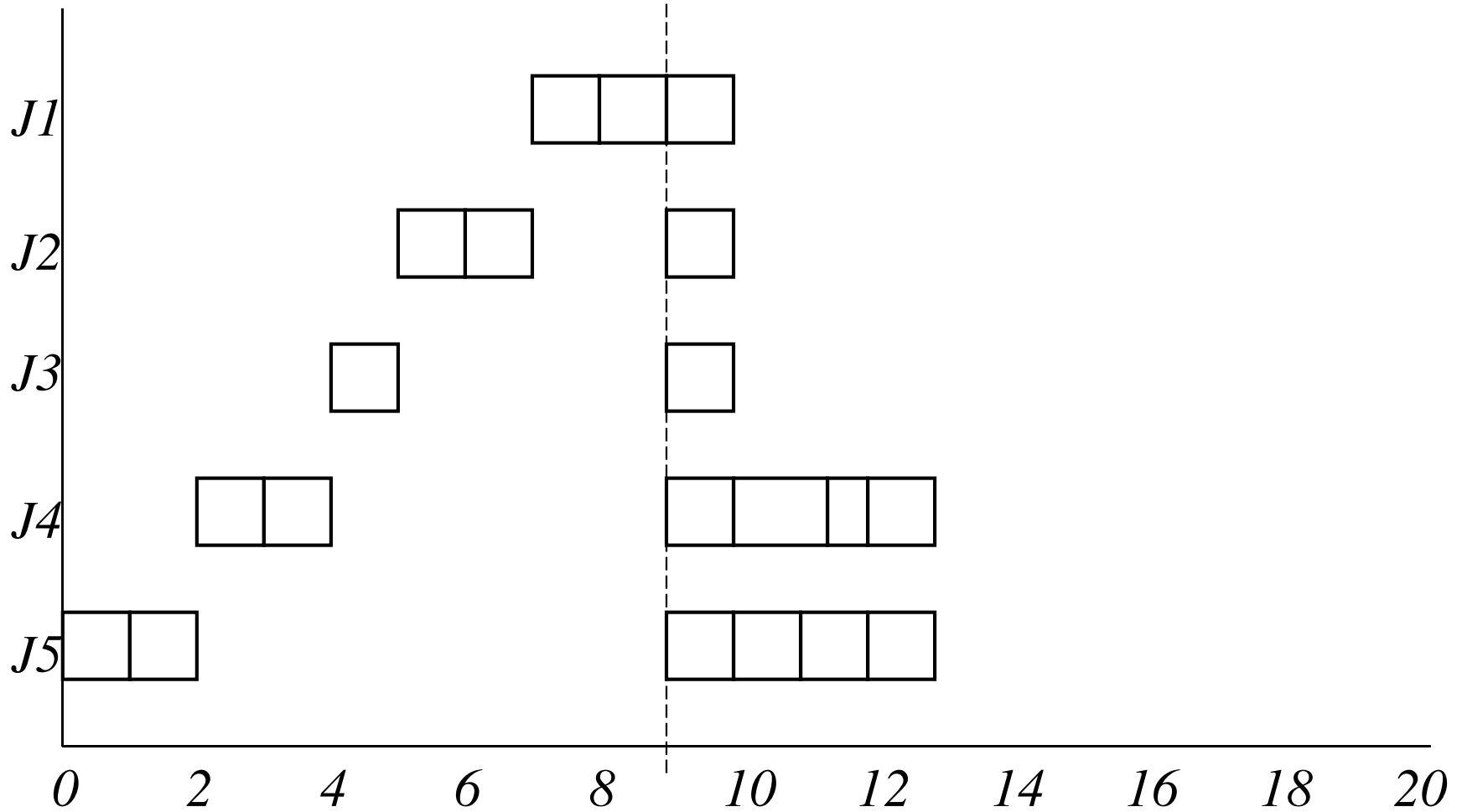
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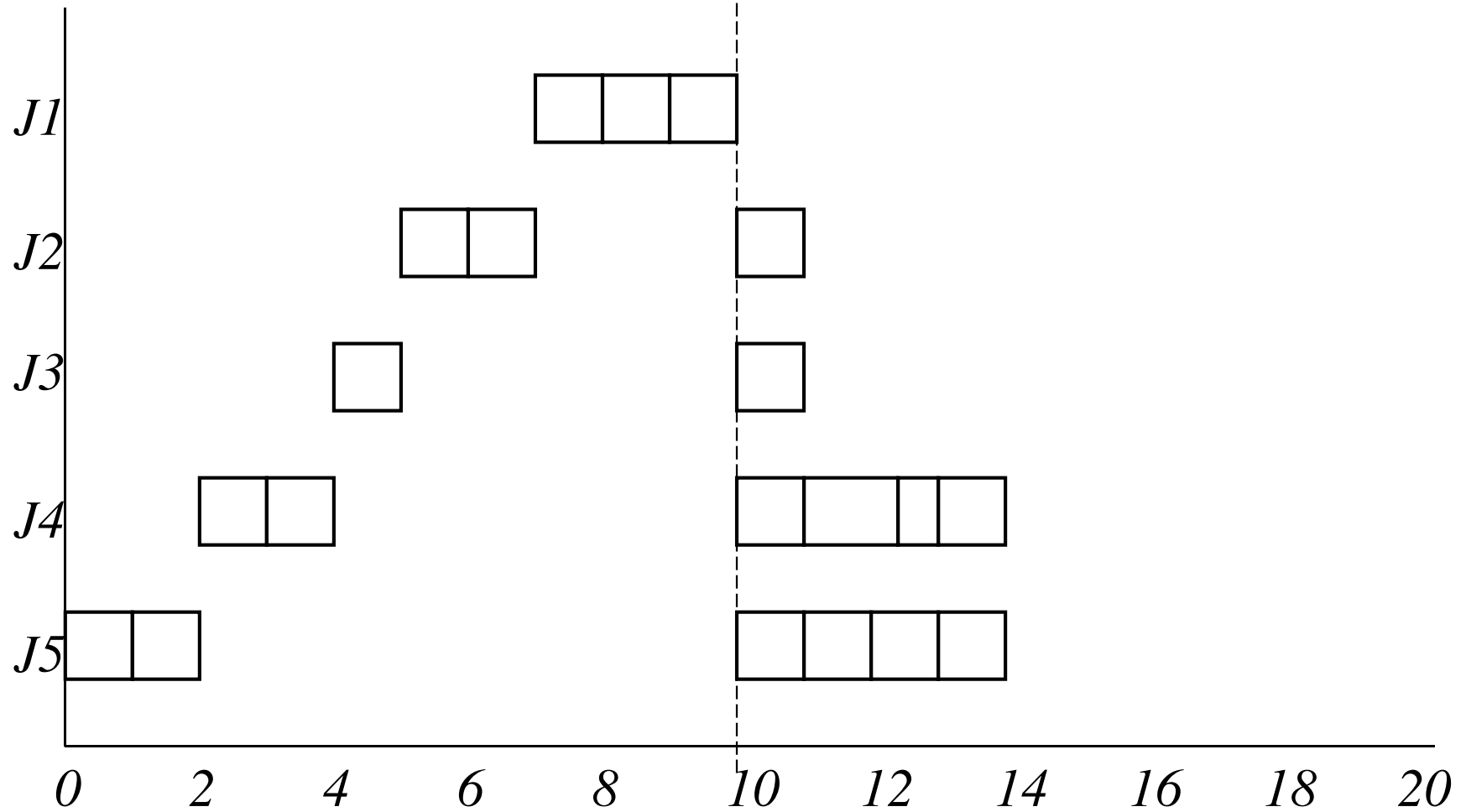
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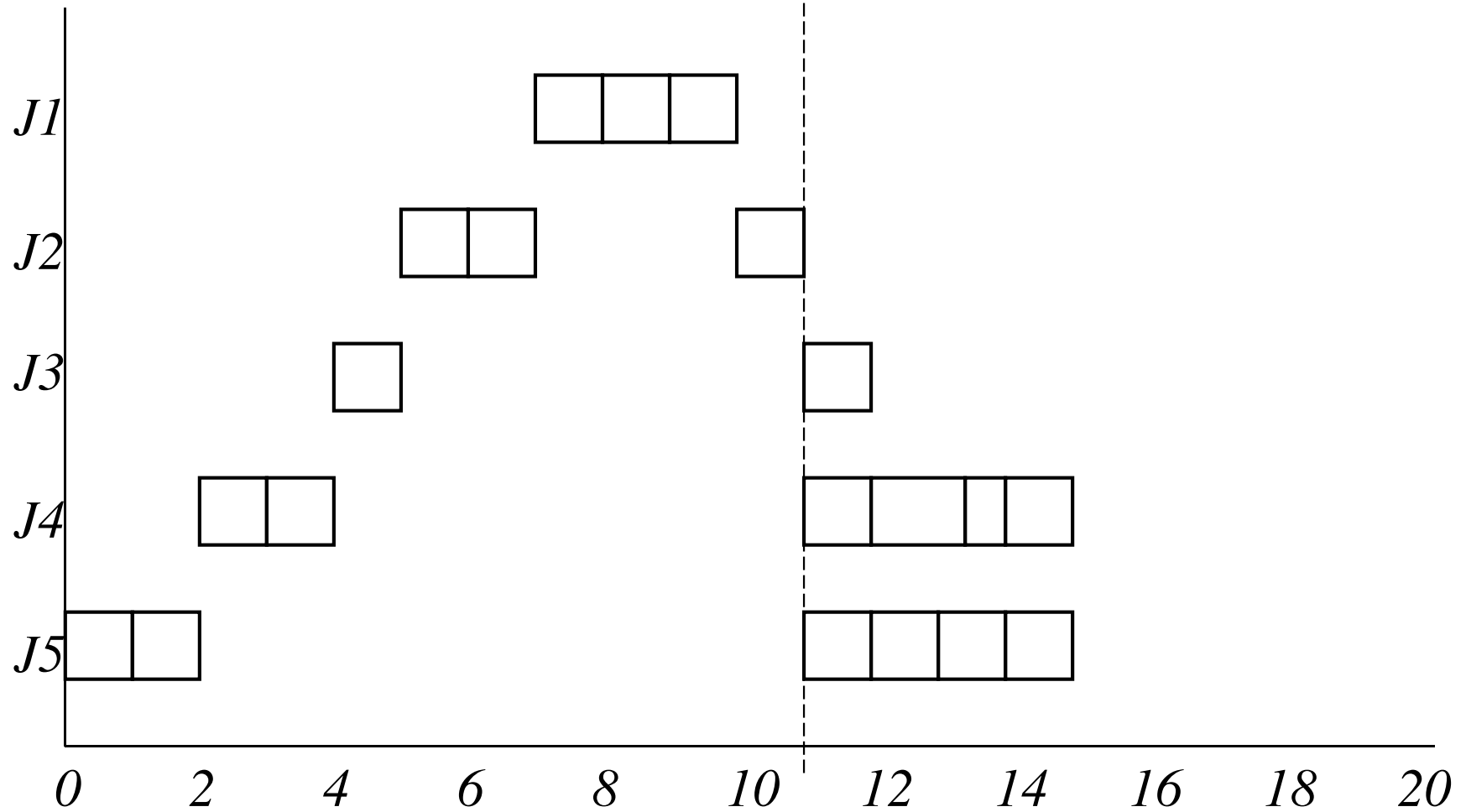
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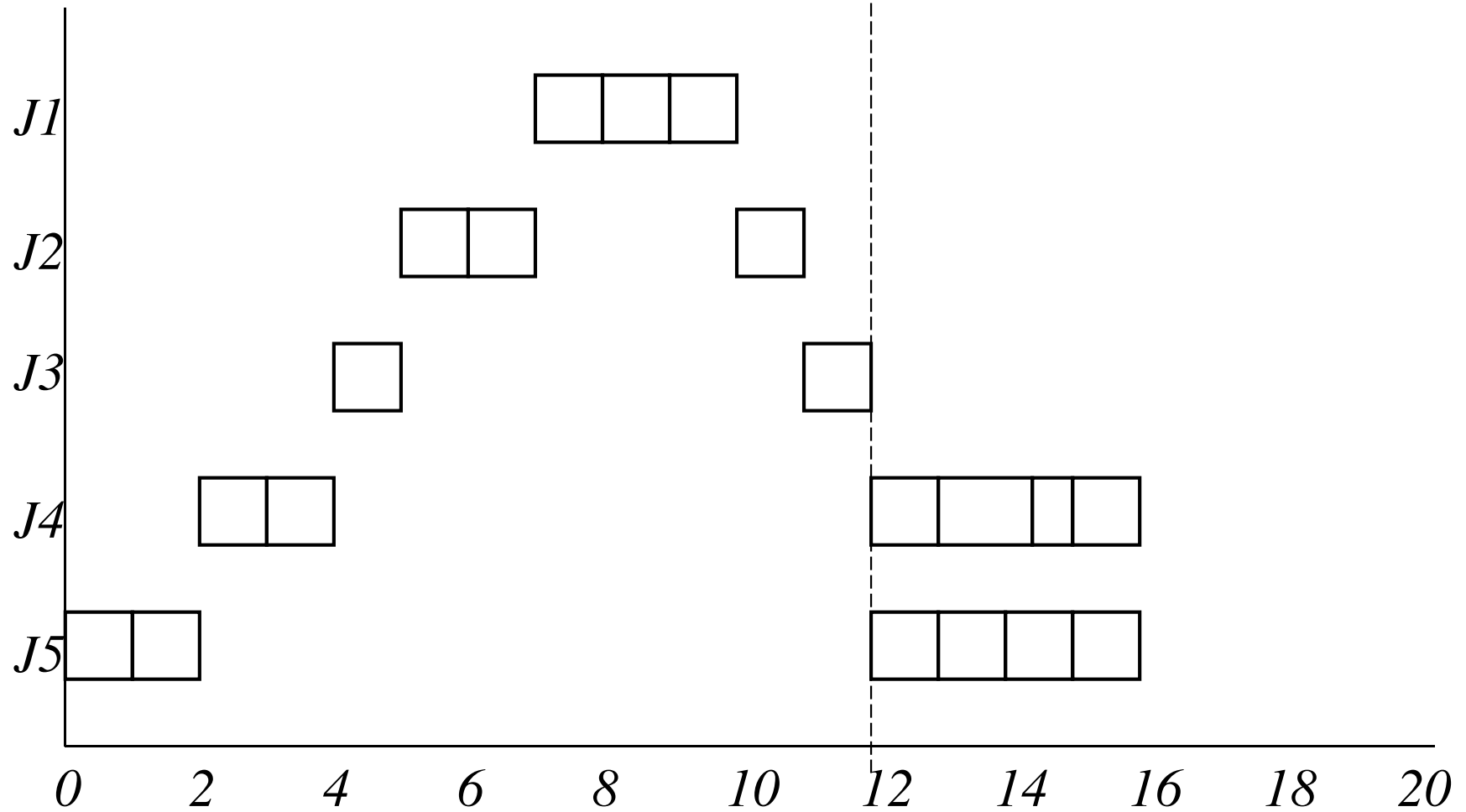
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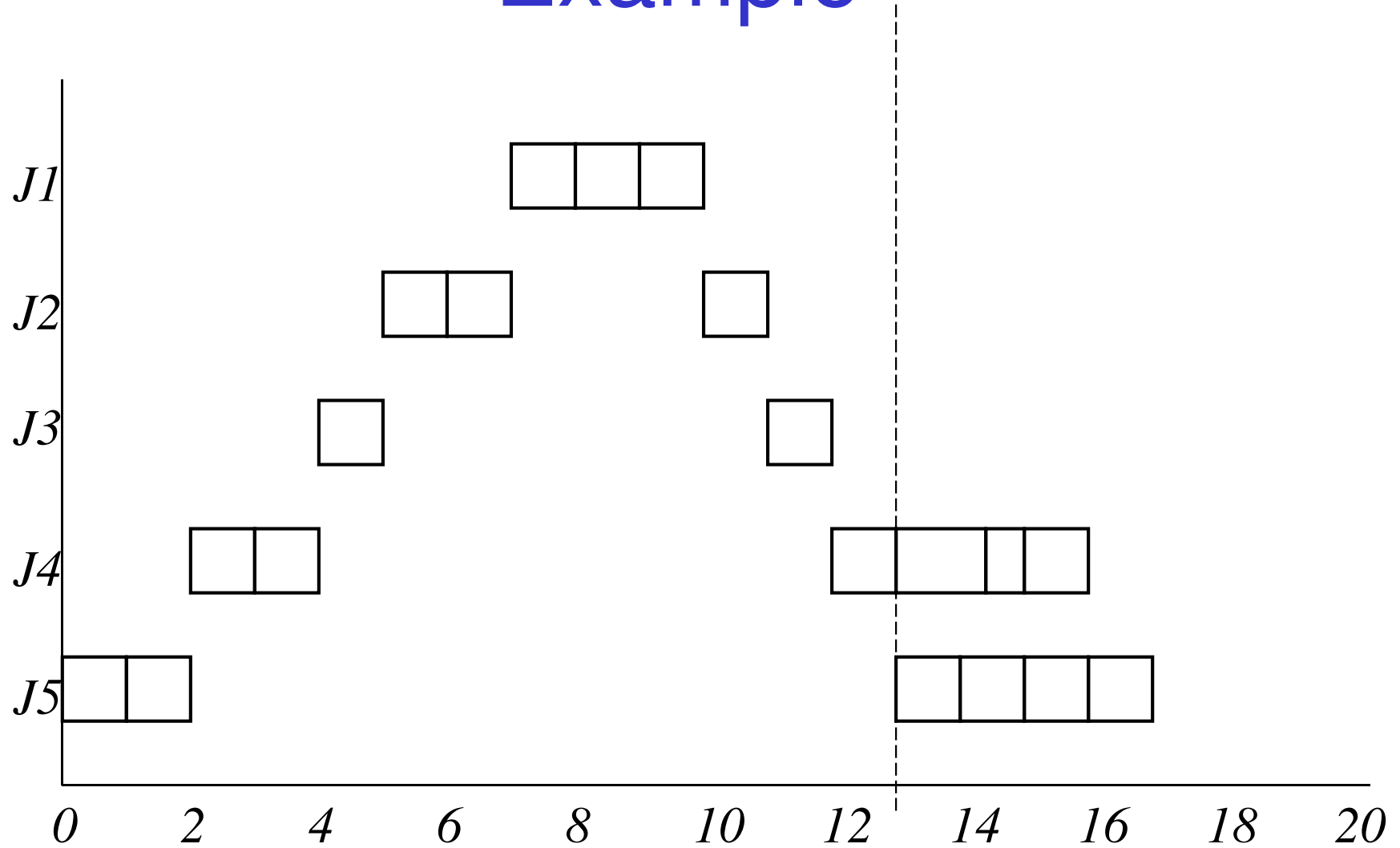
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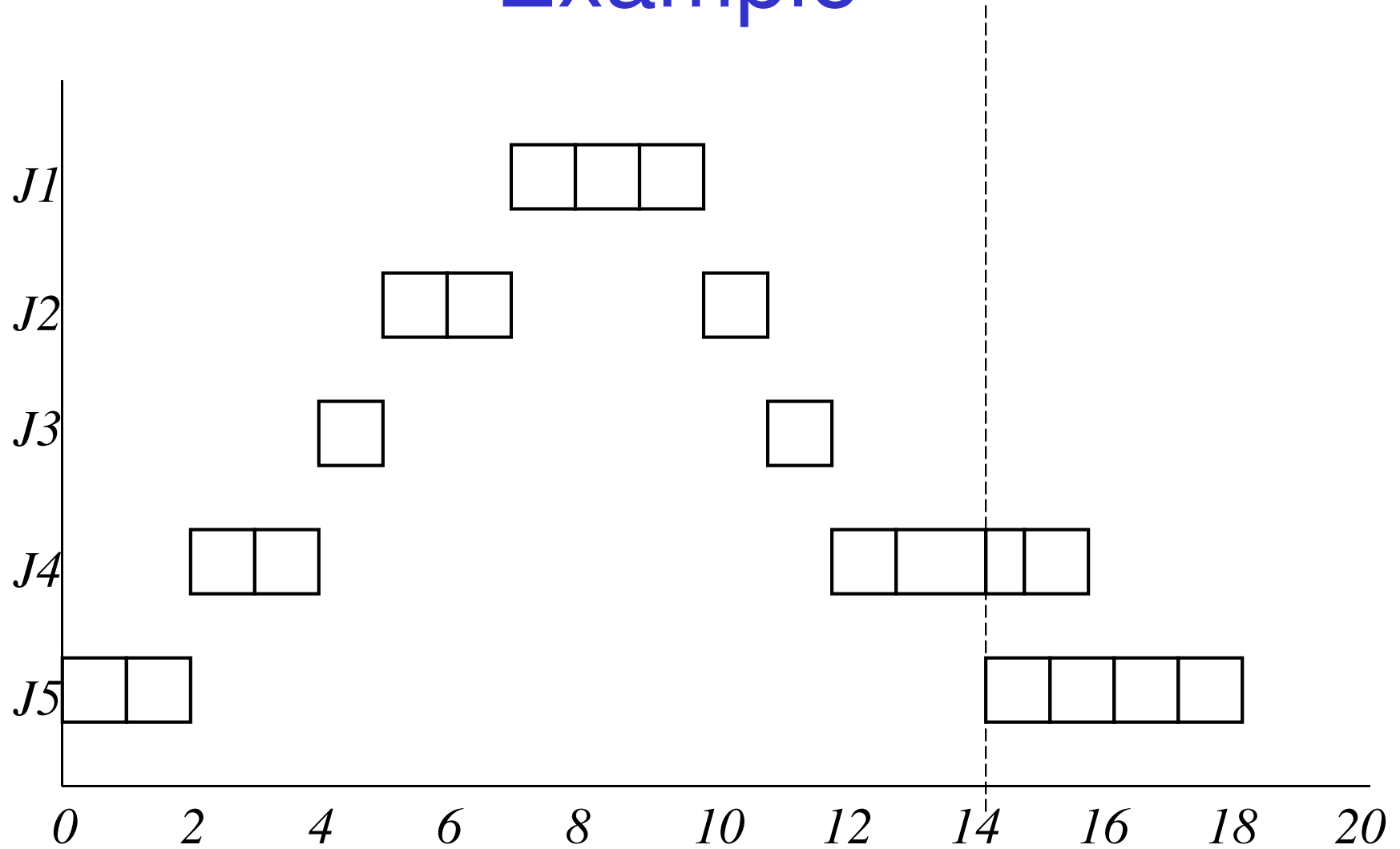
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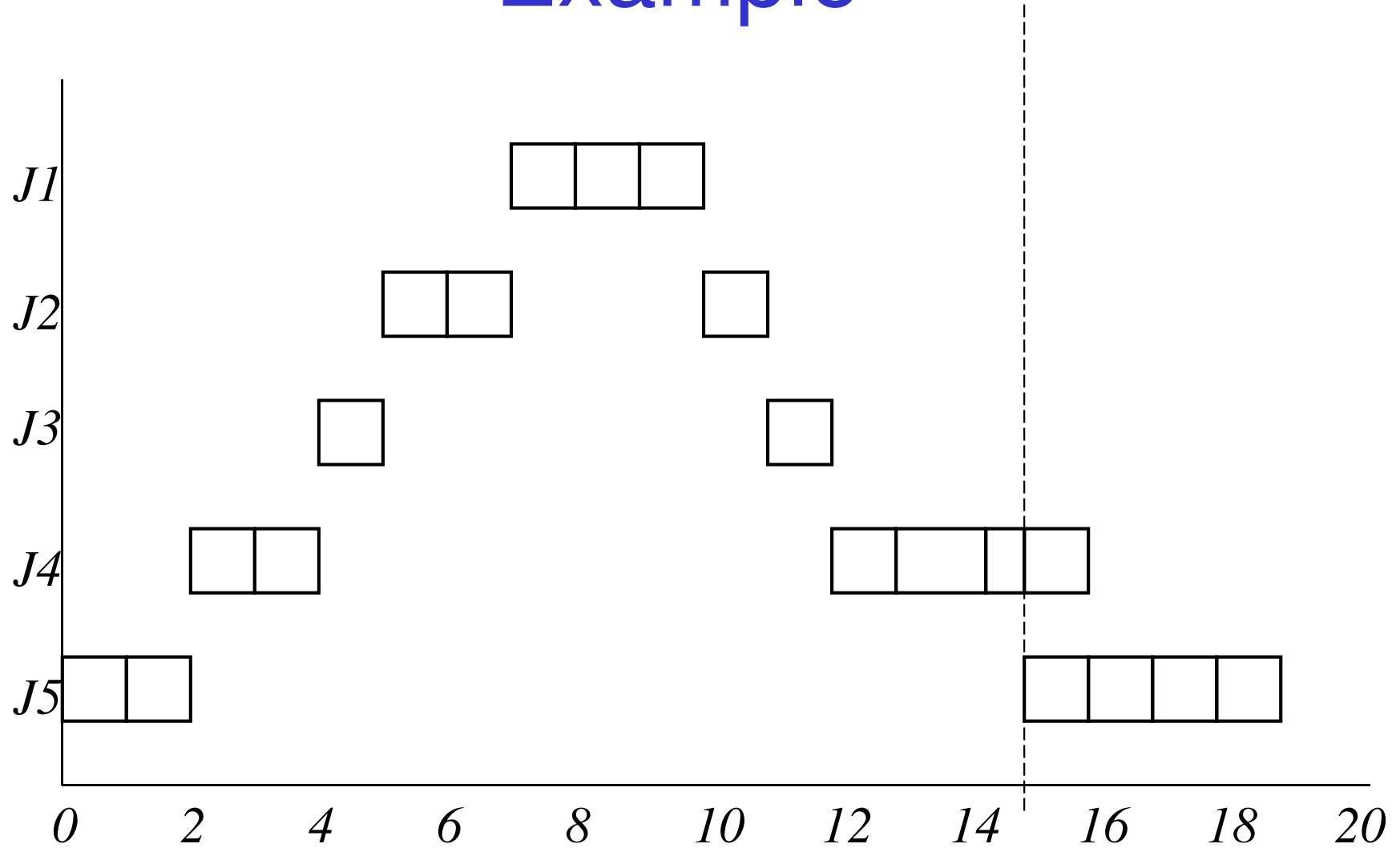
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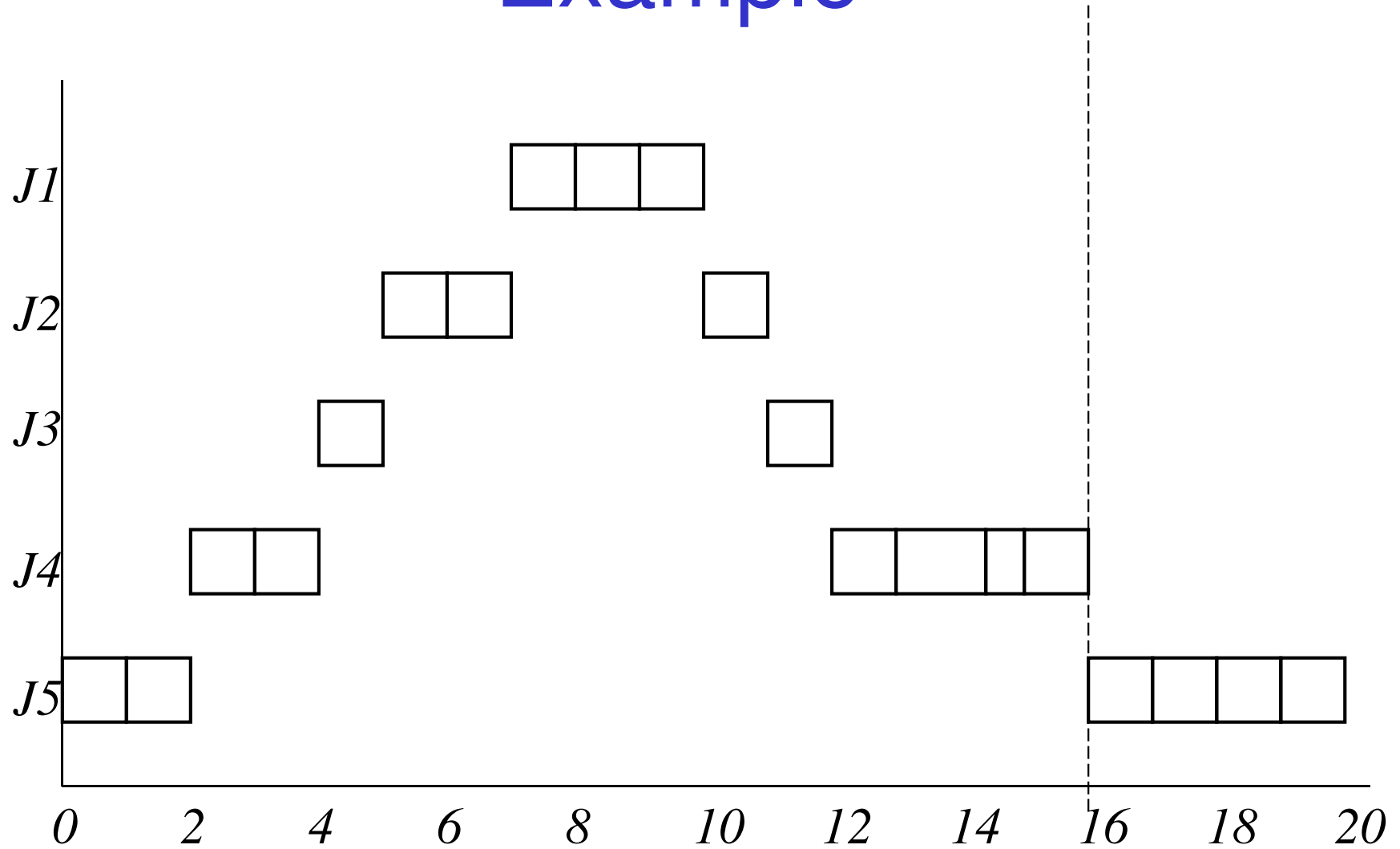
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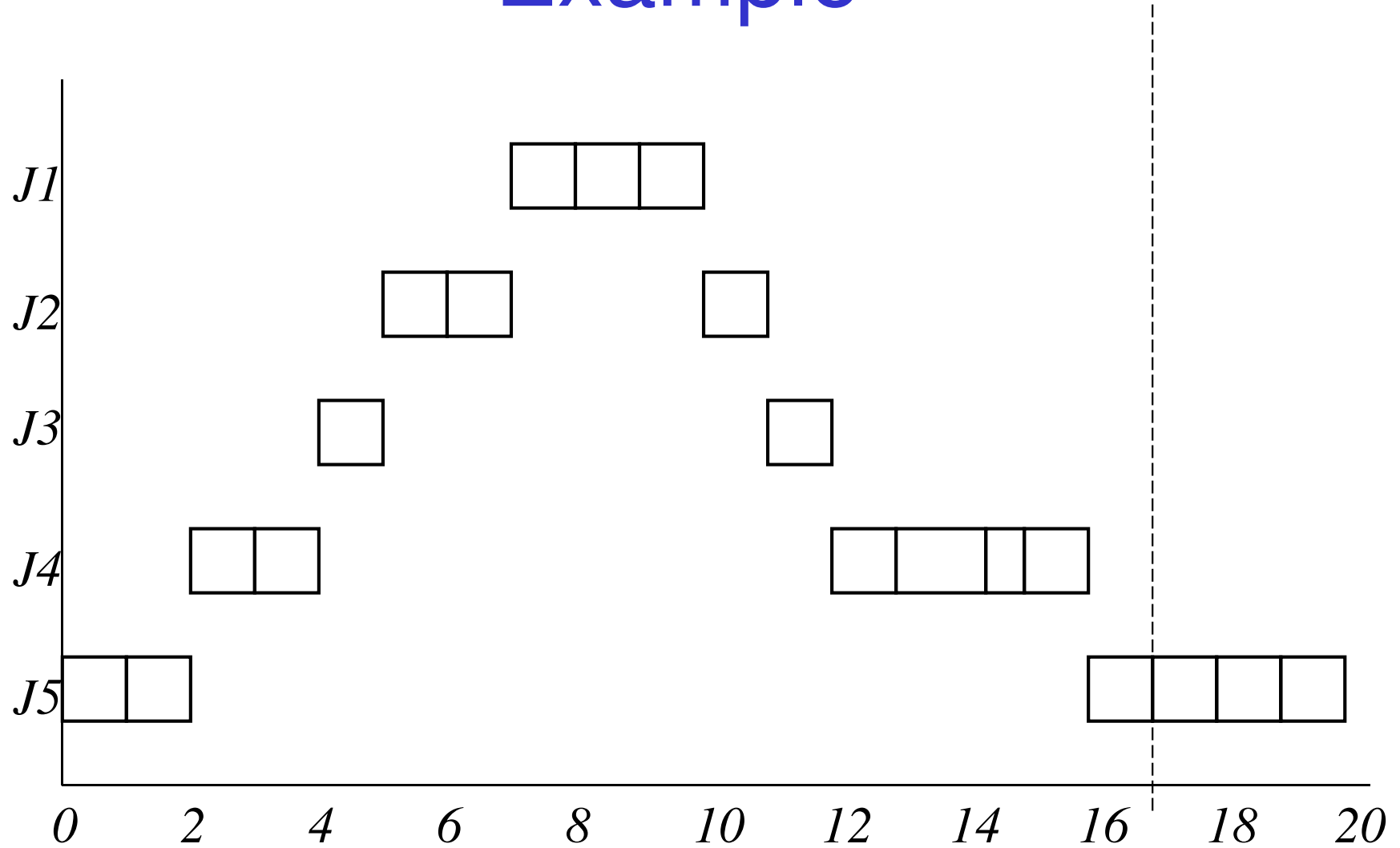
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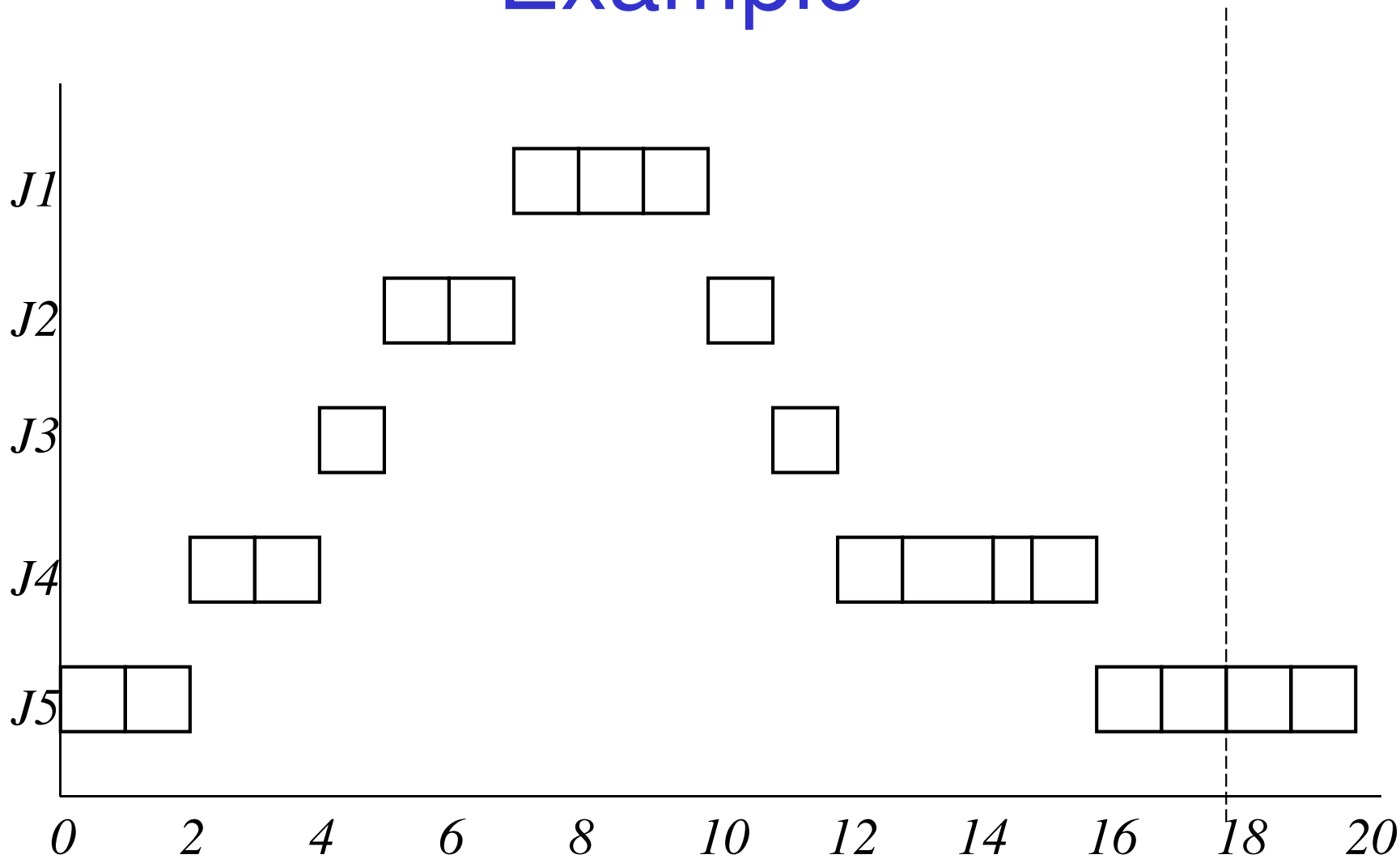
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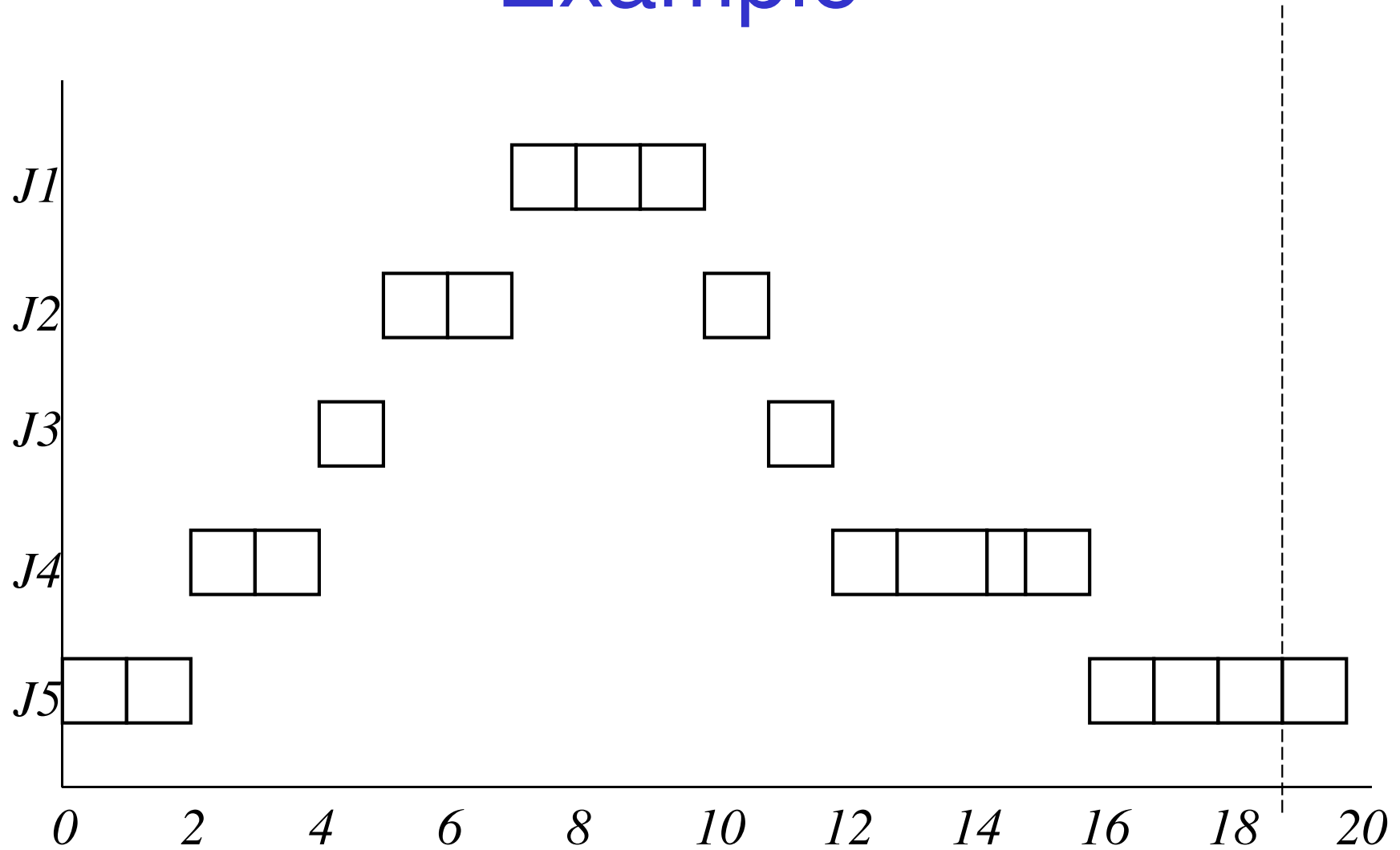
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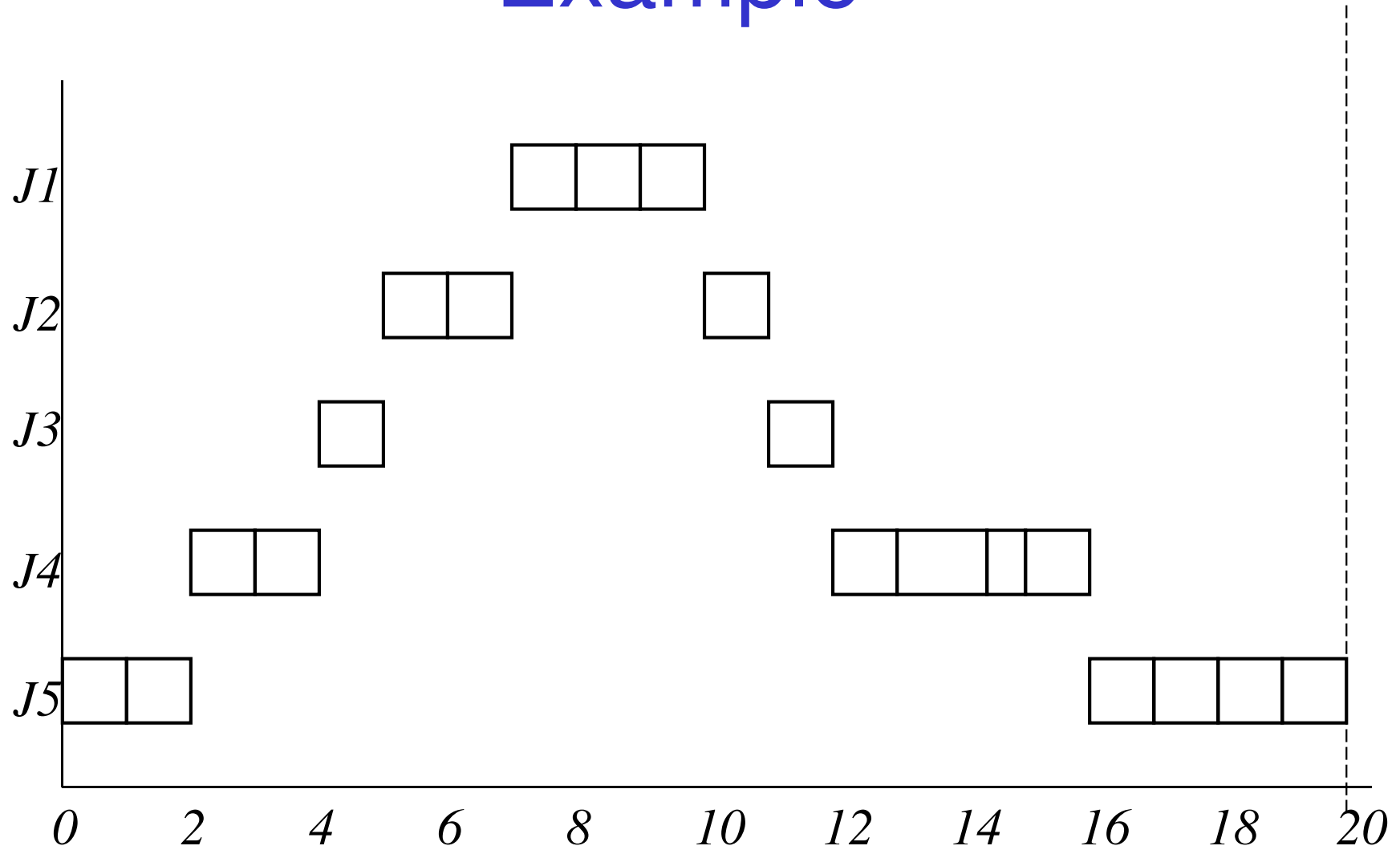
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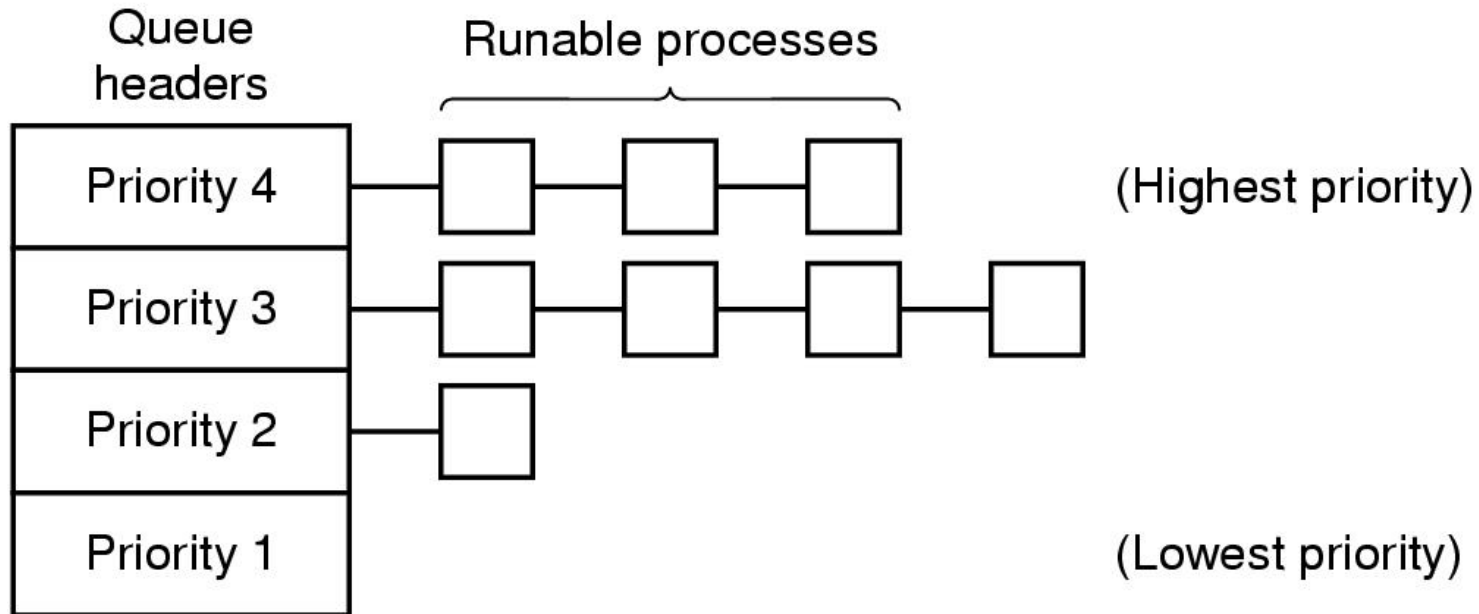
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Example



Priorities

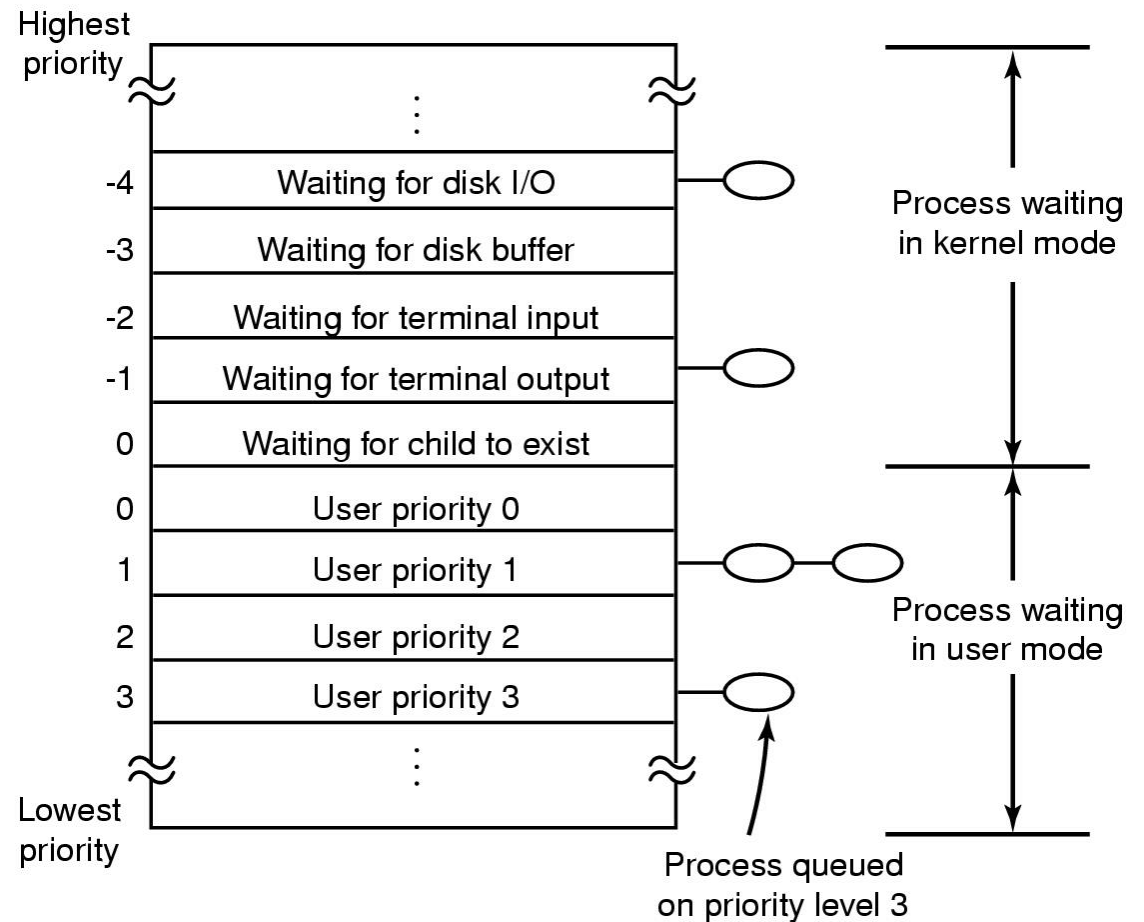


- Usually implemented by multiple priority queues, with round robin on each queue
- Con
 - Low priorities can starve
 - Need to adapt priorities periodically
 - Based on ageing or execution history



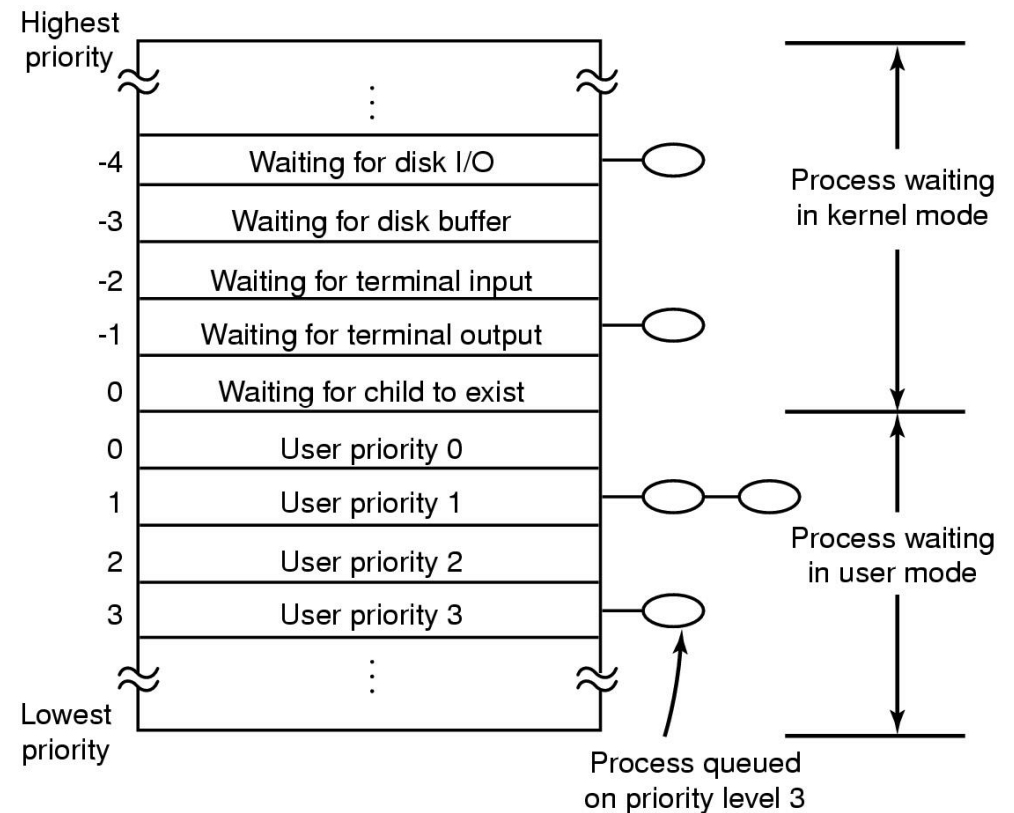
Traditional UNIX Scheduler

- Two-level scheduler
 - High-level scheduler schedules processes between memory and disk
 - Low-level scheduler is CPU scheduler
 - Based on a multi-level queue structure with round robin at each level



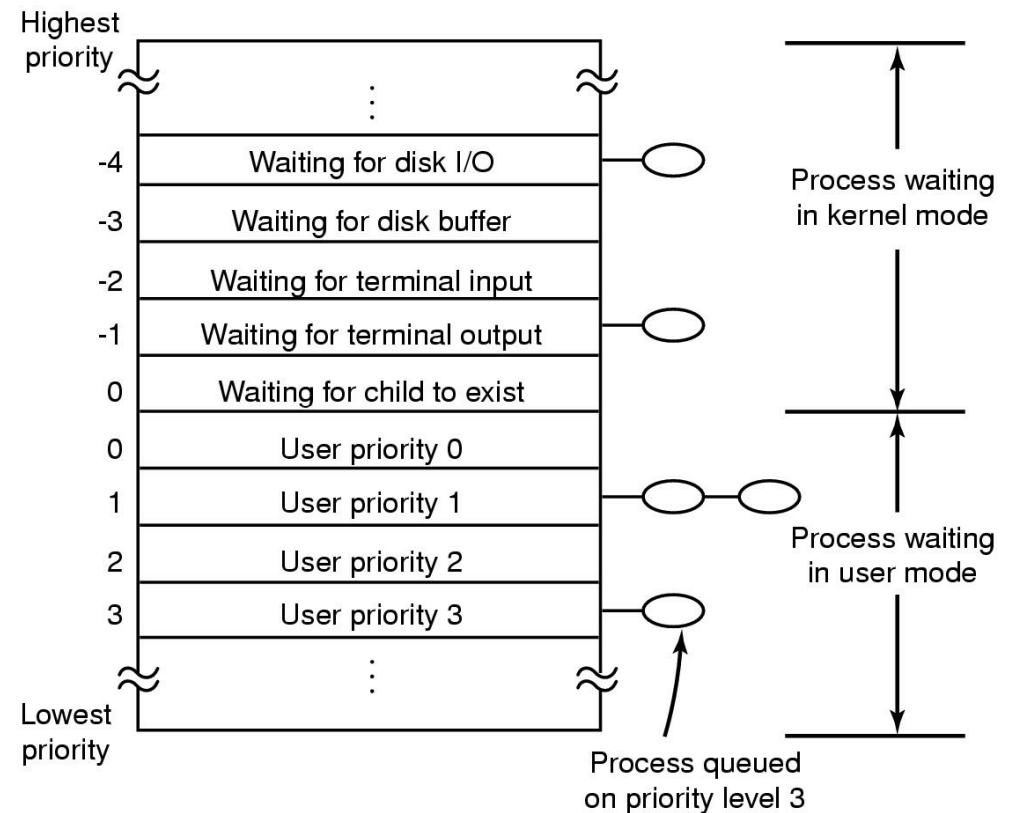
Traditional UNIX Scheduler

- The highest priority (lower number) is scheduled
- Priorities are re-calculated once per second, and re-inserted in appropriate queue
 - Avoid starvation of low priority threads
 - Penalise CPU-bound threads



Traditional UNIX Scheduler

- $Priority = CPU_usage + nice + base$
 - CPU_usage = number of clock ticks
 - Decays over time to avoid permanently penalising the process
 - *Nice* is a value given to the process by a user to permanently boost or reduce its priority
 - Reduce priority of background jobs
 - *Base* is a set of hardwired, negative values used to boost priority of I/O bound system activities
 - Swapper, disk I/O, Character I/O



Real-time Scheduling



Real Time Scheduling

- Correctness of the system may depend not only on the logical result of the computation but also ***on the time when*** these results are produced, e.g.
 - Tasks attempt to control events or to react to events that take place in the outside world
 - These external events occur in *real time* and processing must be able to keep up
 - Processing must happen in a timely fashion,
 - neither too late, nor too early



Real Time System (RTS)

- RTS accepts an activity A and guarantees its requested (timely) behaviour B if and only if
 - RTS finds a *schedule*
 - that includes all already accepted activities A_i and the new activity A ,
 - that guarantees all requested timely behaviour B_i and B , and
 - that can be enforced by the RTS.
- Otherwise, RT system rejects the new activity A .



Typical Real Time Systems

- Control of laboratory experiments
- Robotics
- (Air) Traffic control
- Controlling Cars / Trains/ Planes
- Telecommunications
- Medical support (Remote Surgery, Emergency room)
- Multi-Media
- Remark: Some applications may have only **soft-real time** requirements, but some have really **hard real-time** requirements



Hard-Real Time Systems

- Requirements:
 - **Must *always* meet all deadlines** (time guarantees)
 - You have to guarantee that in any situation these applications are done in time, otherwise dangerous things may happen

Examples:

1. If the landing of a fly-by-wire jet cannot react to sudden side-winds within some milliseconds, an accident might occur.
2. An airbag system or the ABS has to react within milliseconds



Soft-Real Time Systems

Requirements:

Must *mostly* meet all deadlines, e.g. 99.9% of cases

Examples:

1. Multi-media: 100 frames per day might be dropped (late)
2. Car navigation: 5 late announcements per week are acceptable
3. Washing machine: washing 10 sec over time might occur once in 10 runs, 50 sec once in 100 runs.



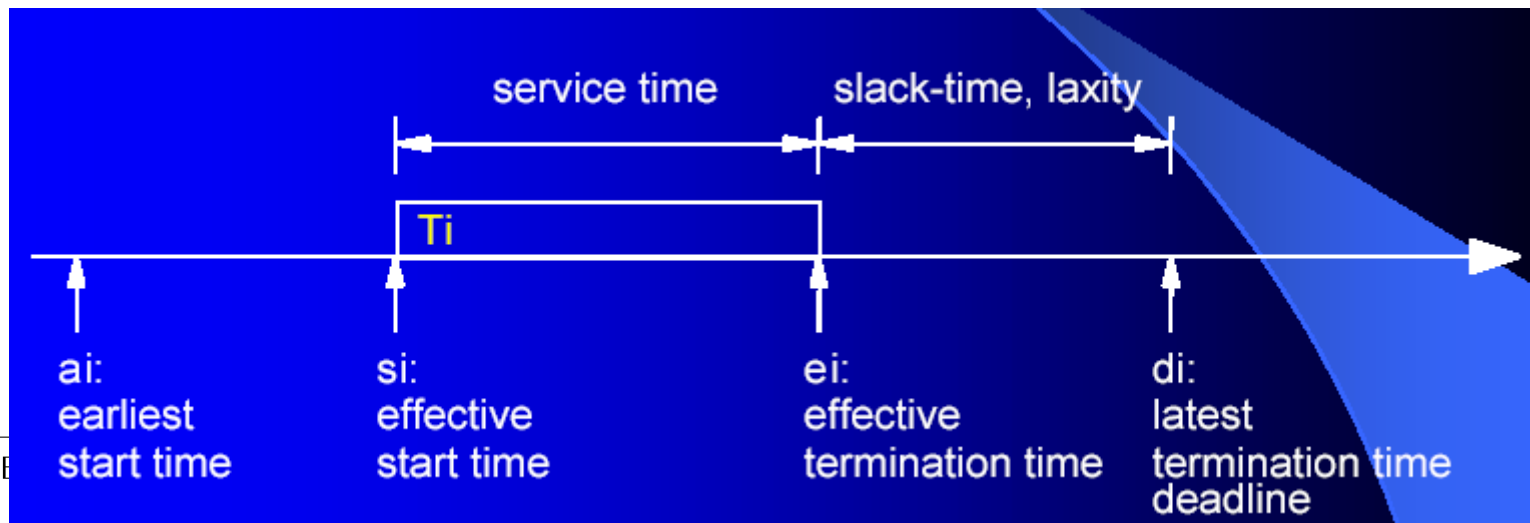
Predictability, not Speed

- Real time systems are NOT necessarily fast
- Real time systems can be slow, as long as they are predictably so.
 - It does not matter how fast they are, as long as they meet their deadlines.



Properties of Real-Time Tasks

- To schedule a real time task, its properties must be known *a priori*
- The most relevant properties are
 - Arrival time (or release time) a_i
 - Maximum execution time (service time)
 - Deadline d_i



Categories of Real time tasks

- Periodic
 - Each task is repeated at a regular interval
 - Max execution time is the same each period
 - Arrival time is usually the start of the period
 - Deadline is usually the end
- Aperiodic (and sporadic)
 - Each task can arrive at any time (may have minimum inter-arrival time)



Real-time scheduling approaches

- Static table-driven scheduling
 - Given a set of tasks and their properties, a schedule (table) is precomputed offline.
 - Used for periodic task set
 - Requires entire schedule to be recomputed if we need to change the task set
- Static priority-driven scheduling
 - Given a set of tasks and their properties, each task is assigned a fixed priority
 - A preemptive priority-driven scheduler used in conjunction with the assigned priorities
 - Used for periodic task sets



Real-time scheduling approaches

- Dynamic scheduling
 - Task arrives prior to execution
 - The scheduler determines whether the new task can be *admitted*
 - Can all other admitted tasks and the new task meet their deadlines?
 - If no, reject the new task
 - Can handle both *periodic* and *aperiodic* tasks



Scheduling in Real-Time Systems

- We will only consider periodic systems

Schedulable real-time system

- Given
 - m periodic events
 - event i occurs within period P_i and requires C_i seconds
- Then the load can only be handled if

$$\sum_{i=1}^m \frac{C_i}{P_i} \leq 1$$



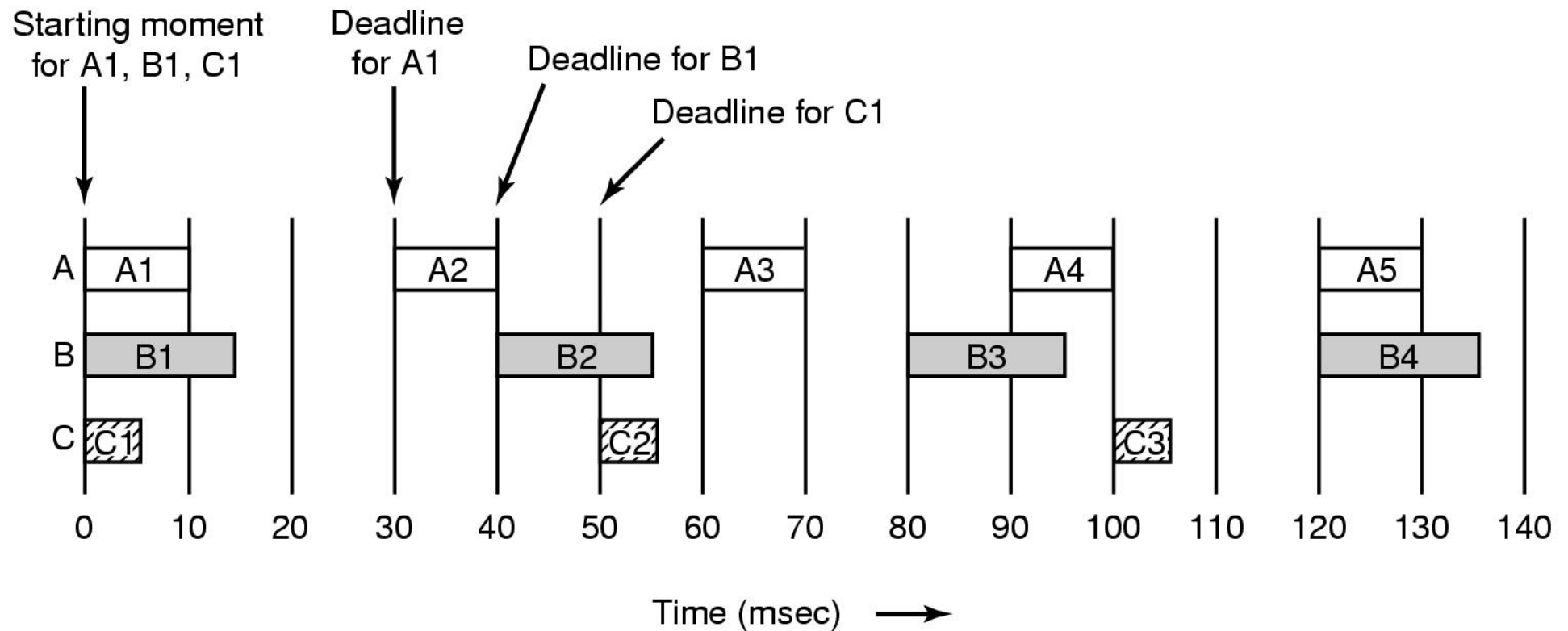
Two Typical Real-time Scheduling Algorithms

- Rate Monotonic Scheduling
 - Static Priority priority-driven scheduling
 - Priorities are assigned based on the period of each task
 - The shorter the period, the higher the priority
- Earliest Deadline First Scheduling
 - The task with the earliest deadline is chosen next



A Scheduling Example

- Three periodic Tasks



Is the Example Schedulable

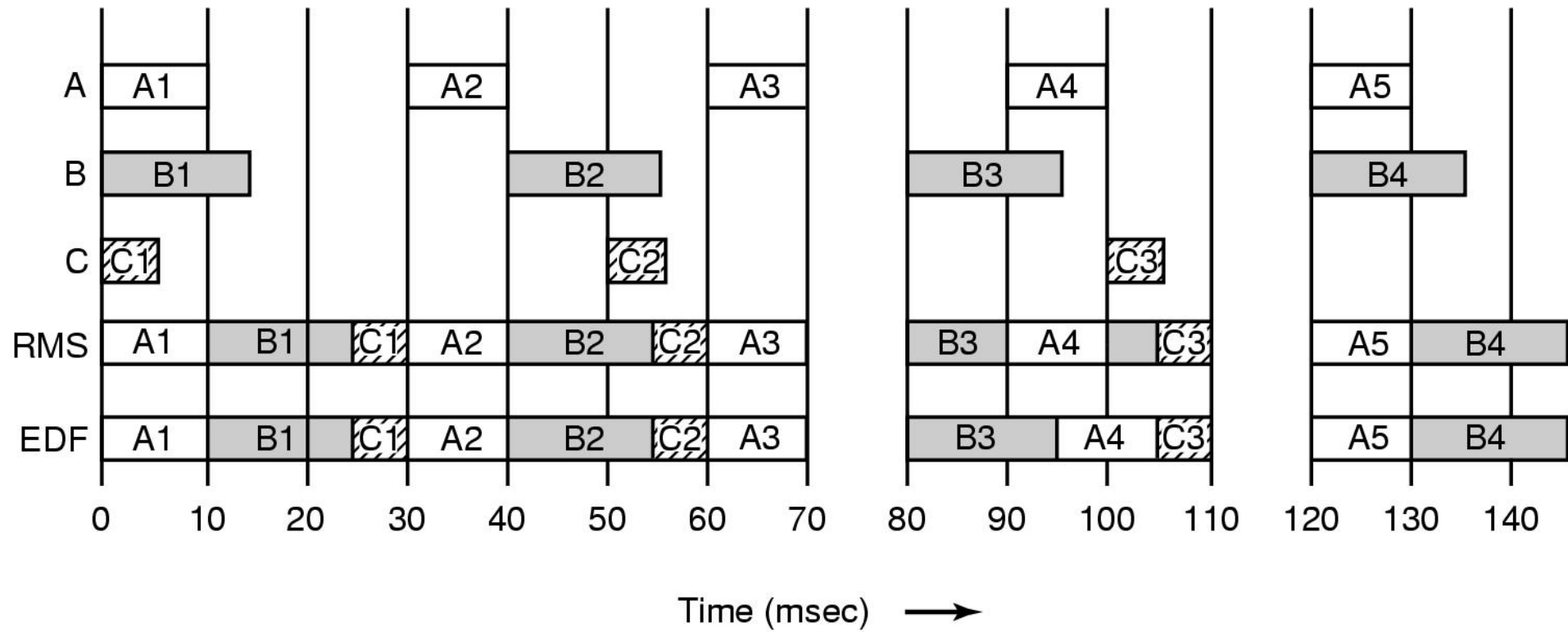
$$\sum_{i=1}^m \frac{C_i}{P_i} \leq 1$$

$$\frac{10}{30} + \frac{15}{40} + \frac{5}{50} = 0.808$$

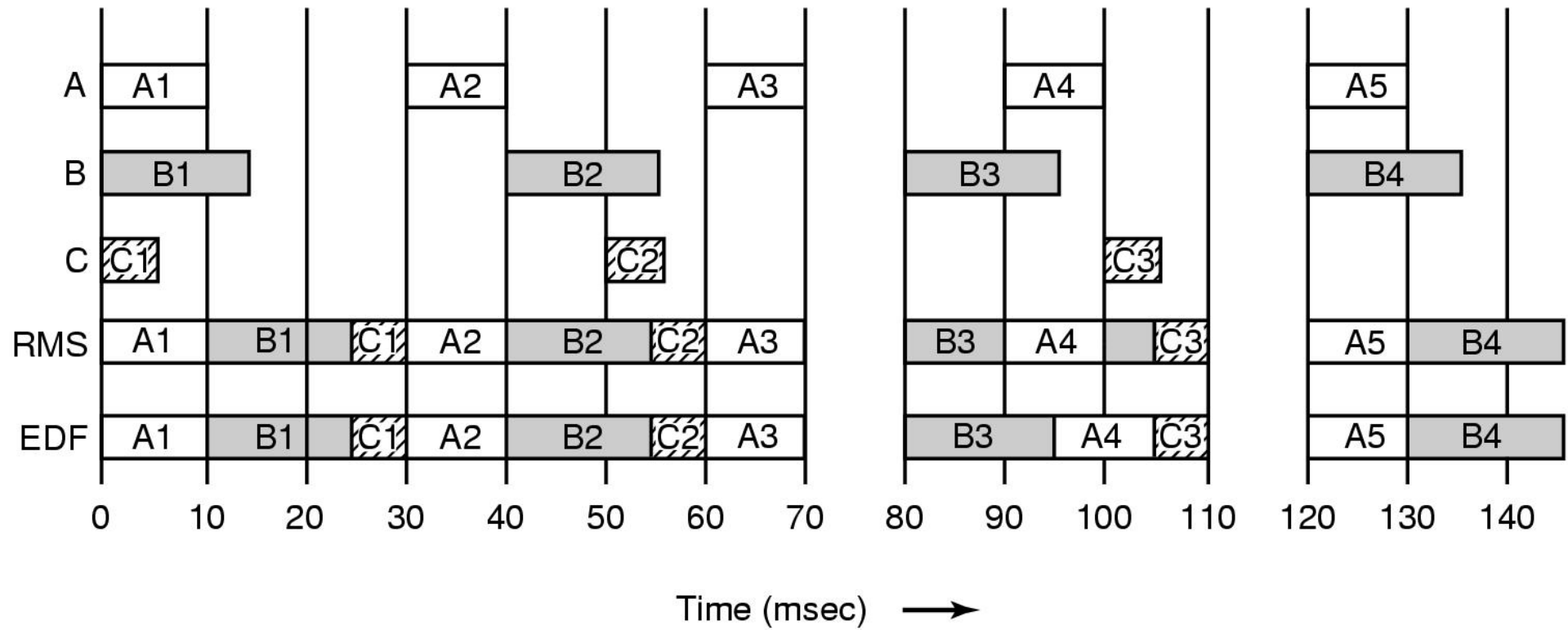
- YES



Two Schedules: RMS and EDF



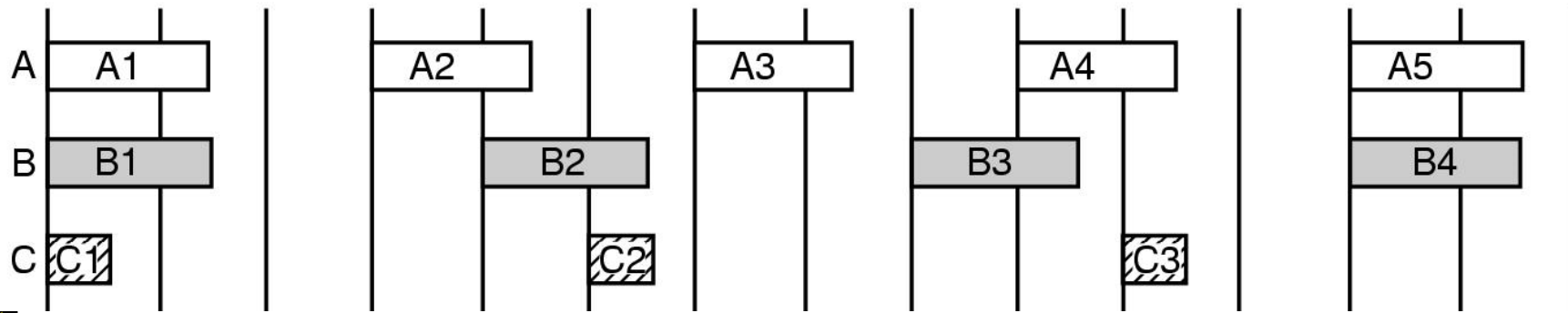
Two Schedules: RMS and EDF



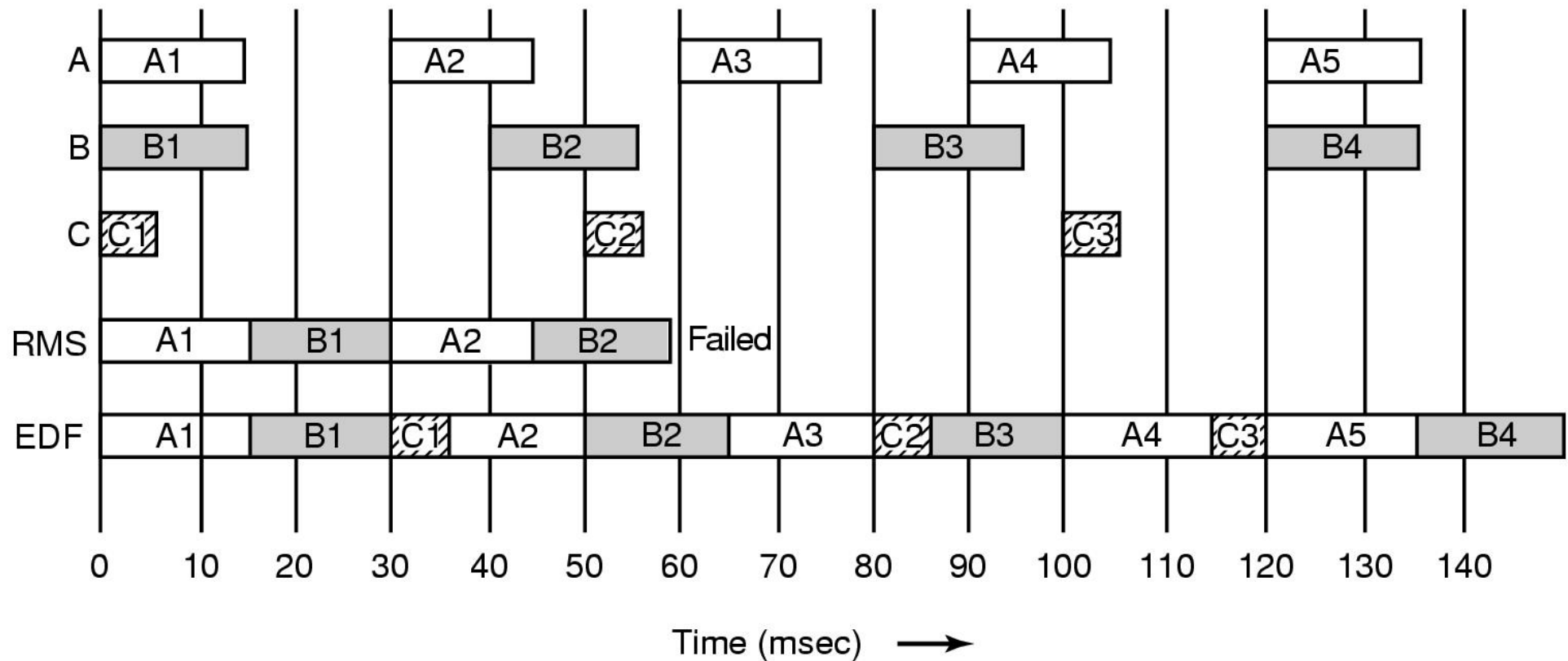
Let's Modify the Example Slightly

- Increase A's CPU requirement to 15 msec
- The system is still schedulable

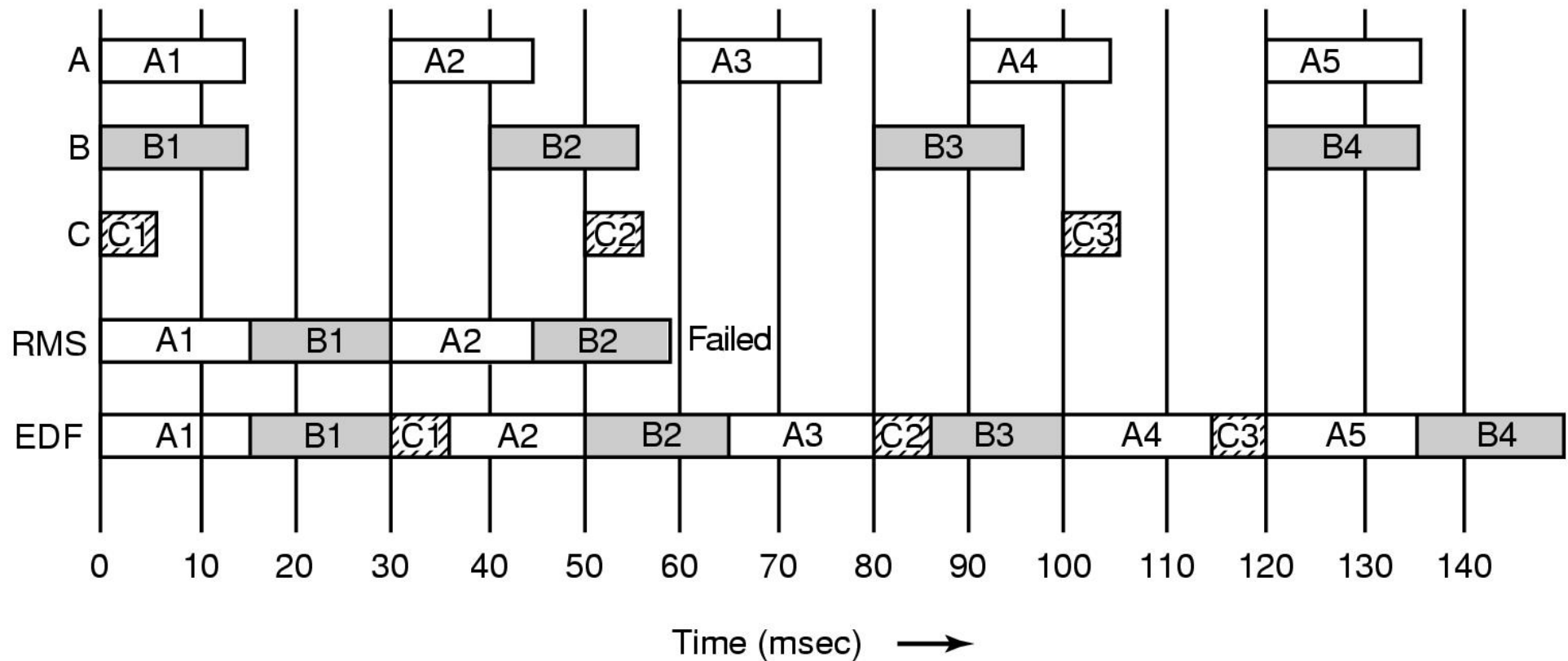
$$\frac{15}{30} + \frac{15}{40} + \frac{5}{50} = 0.975$$



RMS and EDF



RMS and EDF



RMS failed, why?

- It has been proven that RMS is only guaranteed to work if the CPU utilisation is not too high
 - For three tasks, CPU utilisation must be less than 0.780
 - We were lucky with our original example

$$\sum_{i=1}^m \frac{C_i}{P_i} \leq m(2^{1/m} - 1)$$



EDF

- EDF always works for any schedulable set of tasks, i.e. up to 100% CPU utilisation
- Summary
 - If CPU utilisation is low (usual case, due to safety factor in estimating execution times)
 - Can use RMS which is simple and easy to implement
 - If CPU utilisation is high
 - Must use EDF

