Scheduling

Scheduler tasks and goals

Process states

Pre-emption

Scheduling strategies

- First come first served, Round robin (time sliced),
  Shortest job first, Priority based,
  Multi level feedback queues, Lottery

Thread scheduling

Scheduler Tasks

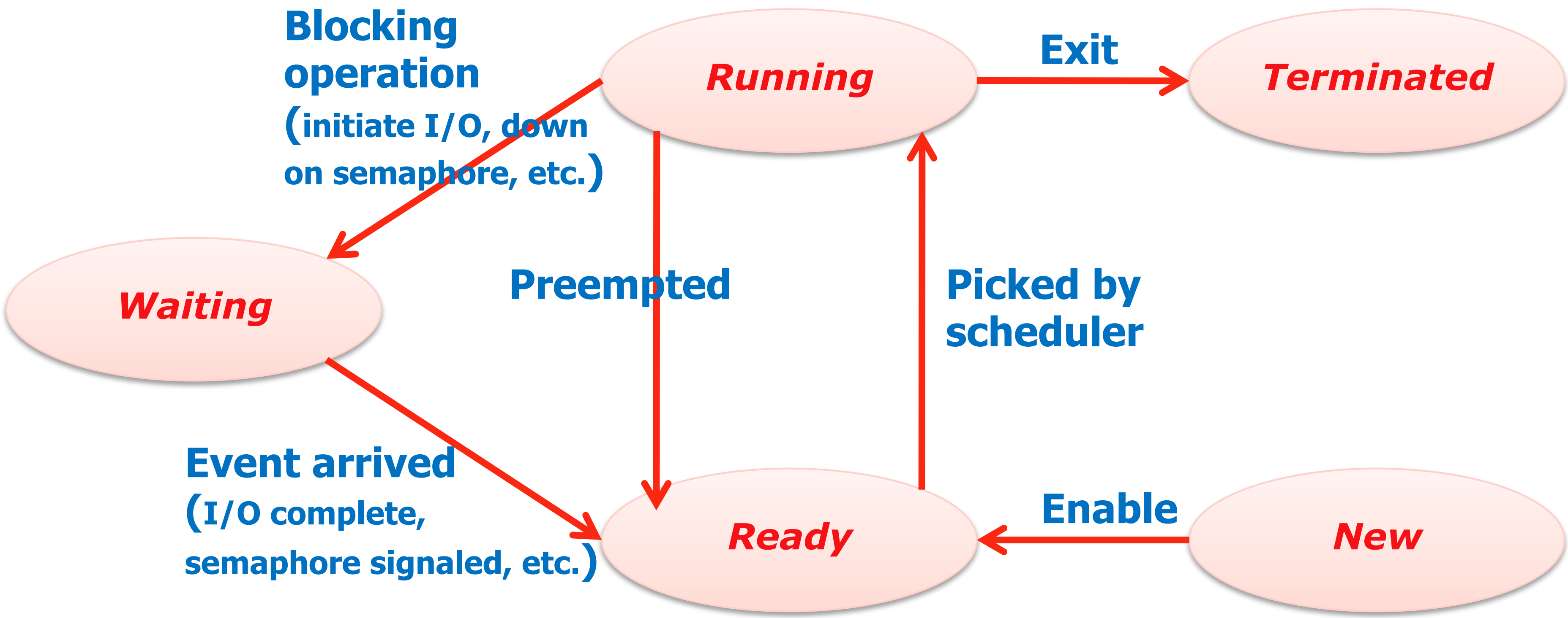
The scheduler

- Allocates processes to processors.
- Selects highest priority ready process (from head of Ready Queue) and moves it to the running state, i.e., allows it to start executing on the processor.
- Gets invoked after every entry to the kernel.

Current process continues unless:

- Kernel call moved it into waiting state (e.g. waiting on I/O).
- Error trap occurred (e.g. memory protection violation).
- Time slice expired.
- A higher priority process is made ready.

Process States



- **New**: the process is being created
- **Ready**: runnable and waiting for processor
- **Running**: executing on a processor
- **Waiting/Blocked**: waiting for an event
- **Terminated**: process is being deleted

If multiple processes are ready, which one should be run?

Goals of Scheduling Algorithms

Ensure fairness

- Comparable processes should get comparable services

Avoid indefinite postponement

- No process should starve

Enforce policy

- E.g., priorities

Maximize resource utilization

- CPU, I/O devices

Minimize overhead

- From context switches, scheduling decisions

Goals of Scheduling Algorithms

Batch systems:

- Throughput ➔ maximize jobs per unit of time
- Turnaround time ➔ minimize time between job submission and termination
- Maximize CPU utilization

Interactive systems:

- Response time crucial ➔ quick response to requests
- Meet users expectations ➔ predictability

Real-time systems:

- Meeting deadlines
  - Soft deadlines: e.g., leads to degraded video quality
  - Hard deadline: e.g., leads to plane crash
- Predictability

Preemptive vs. Non-Preemptive Scheduling

Non-preemptive

- Let process run until it blocks or voluntarily releases the CPU

Preemptive:

- Let process run for a maximum amount of fixed time
  - Requires clock interrupt
- External event results in higher priority process being run

CPU-bound vs. I/O-bound Processes

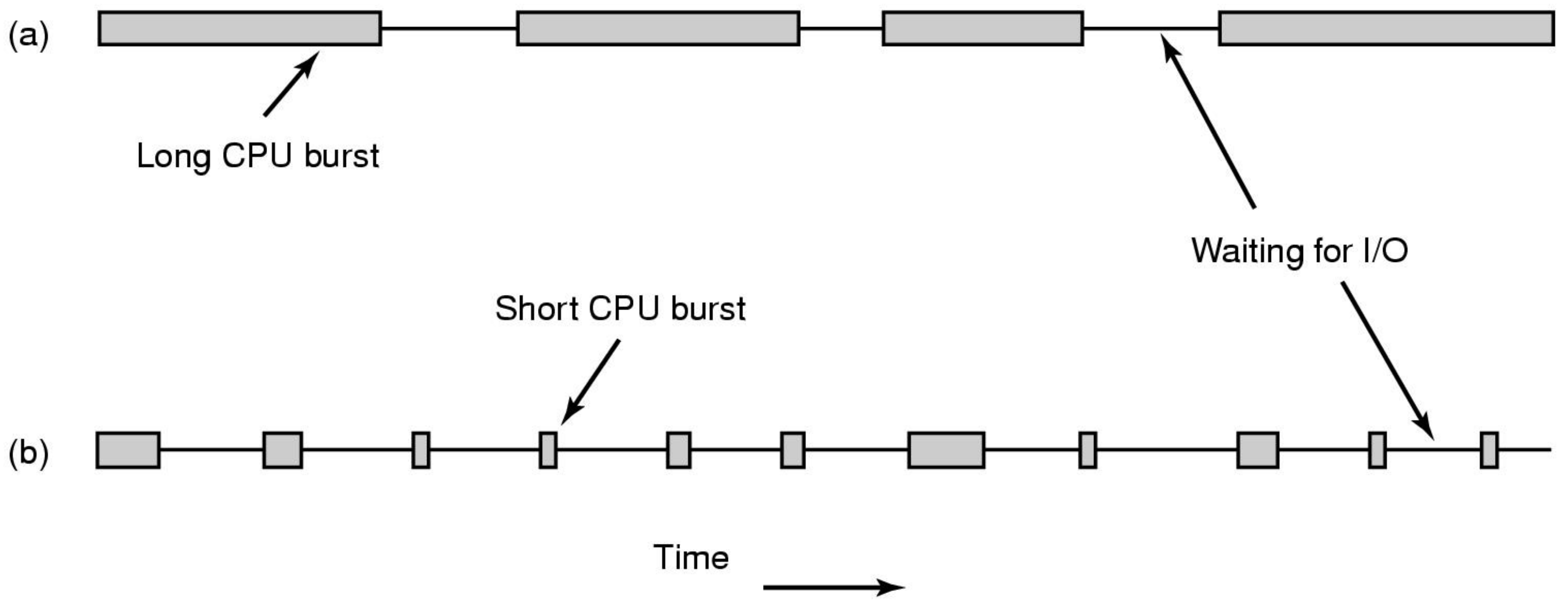
CPU-bound processes

– Spend most of their time using the CPU

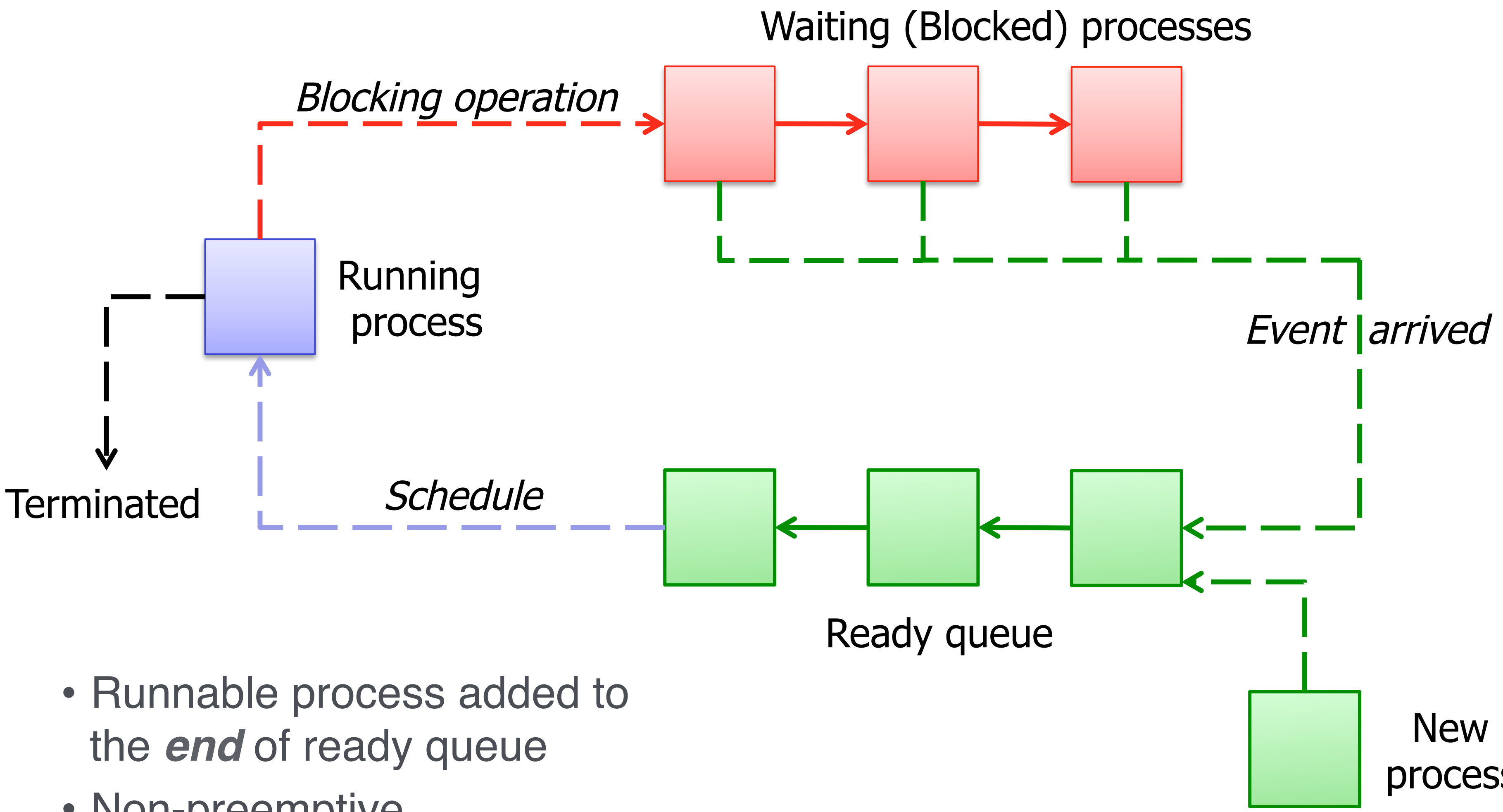
I/O-bound processes

– Spend most of their time waiting for I/O

– Tend to only use CPU briefly before issuing I/O request



First-Come First-Served (FCFS) (non-preemptive)



- Runnable process added to the ***end*** of ready queue
- Non-preemptive

FCFS Advantages

No indefinite postponement
- All processes are eventually scheduled

Really easy to implement

FCFS Disadvantages

What happens if a long job is followed by many short jobs?

– E.g., 1h, 1s, 1s, 1s, with jobs 2-4 submitted just after job 1

3600s	*1s*	*1s*	*1s*

- Throughput? `4 jobs / 3603s ≈ 0.0011 jobs/s`
- Average turnaround time? `(3600+3601+3602+3603)/4 = 3601.5s`

1s	*1s*	*1s*	*3600s*

- Throughput? `4 jobs / 3603s ≈ 0.0011 jobs/s`
- Average turnaround time? `(1+2+3+3603)/4 = 902.25s`

FCFS Disadvantages

What about I/O bound processes?

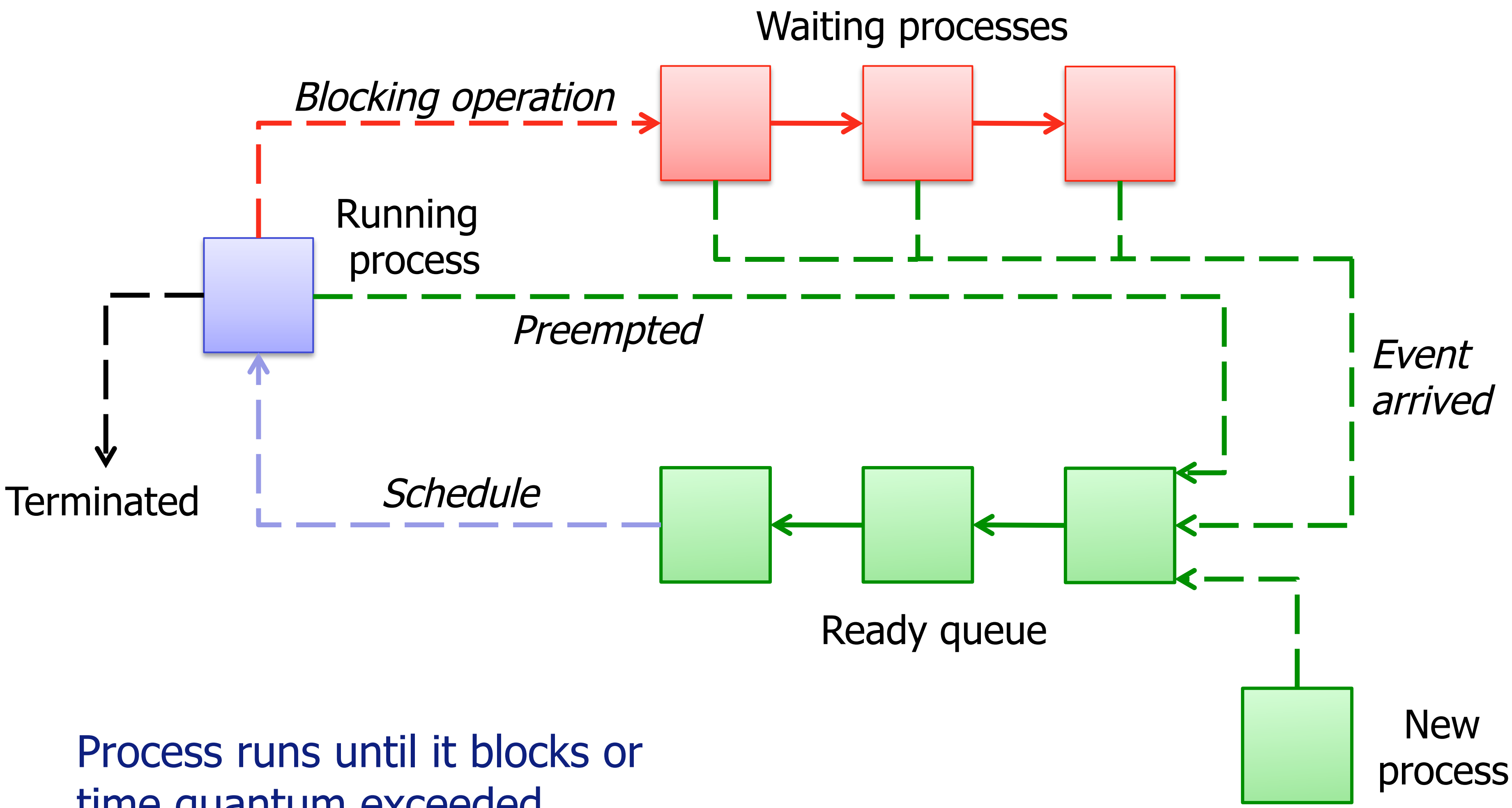
E.g., one CPU-bound process runs for 1s each time, before doing I/O to release processor. Needs > 1000s CPU time

Many I/O-bound process needs to perform 1000 disk reads to complete, with minimal processing between I/O

Compute process runs for 1 sec then starts read so I/O process can then run and start their read, but only do 1 read per sec.

- I/O bound processes initiates 1 request at a time?
  - 1000s to complete
- Preempting CPU-bound process every 10ms?
  - 10s to complete

Round-Robin Scheduling (RR)



Process runs until it blocks or time quantum exceeded

Round-Robin

Fairness
- Ready jobs get equal share of the CPU

Response time
- Good for small number of jobs

Average turnaround time:
- Low when run-times differ
- Poor for similar run-times

```
Quantum = 100ms,
Context switch time = negligible
```

```
A: 200ms, B: 10s
Turnaround time:
  FCFS:  A = 200ms, B = 10,200ms
         Avg = 5200ms
  RR:    A ≈ 300ms, B ≈ 10,200ms
         Avg ≈ 5250m → 1.01x
```

```
A: 10s, B: 10s
Turnaround time:
  FCFS:  A = 10s, B = 20s
         Avg = 15s
  RR:    A ≈ 20s, B ≈ 20s
         Avg ≈ 20s → 1.33x
```

RR Quantum (Time Slice)

RR Overhead:

- 4ms quantum, 1ms context switch time:
  20% of time → overhead high
- 1s quantum, 1ms context switch time:
  only 0.1% of time → overhead low

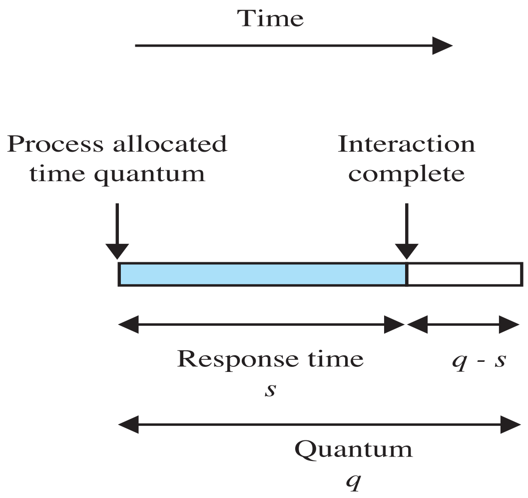
Large quantum:

- Smaller overhead
- Worse response time
    - Quantum = ∞ → FCFS

Small quantum:

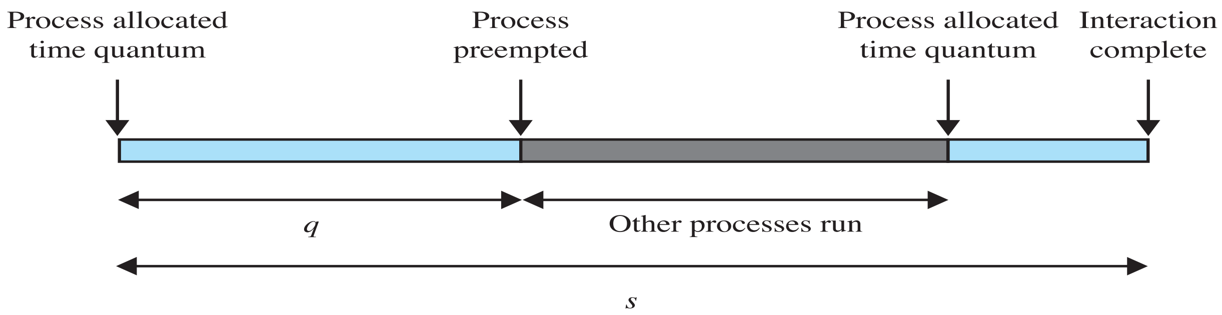
- Larger overhead
- Better response time
- Ideal quantum ≈ ave. CPU time between I/O

Time quantum vs I/O times



(a) Time quantum greater than typical interaction

If time quantum is too small, most processes will require > 1 quantum to complete, which increases response time.



(b) Time quantum less than typical interaction

RR Quantum

Choosing a quantum value:

- Should be much larger than context switch cost
- But provide decent response time

Typical values: 10-200ms

Some example values for standard processes (values vary depending on process type and behaviour, priority, etc.):

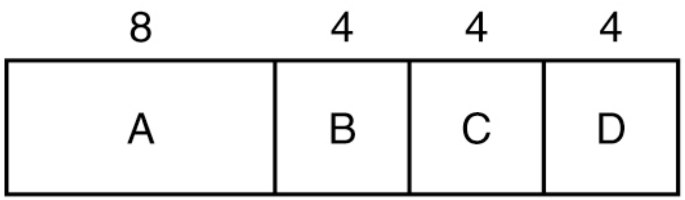
- Linux: 100ms
- Windows client: 20ms
- Windows server: 180ms

Shortest Job First (SJF)

Non-preemptive scheduling with run-times known in advance

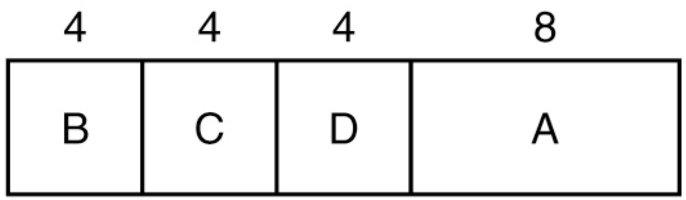
Pick the shortest job first

– Process with shortest CPU burst



Turnaround time:

```
  A:  8s
  B: 12s
  C: 16s
  D: 20s
Avg: 56/4 = 14s
```



Turnaround time:

```
  B:  4s
  C:  8s
  D: 12s
  A: 20s
Avg: 44/4 = 11s
```

- Provably optimal when all jobs are available simultaneously

Shortest Remaining Time (SRT)

Preemptive version of shortest job first

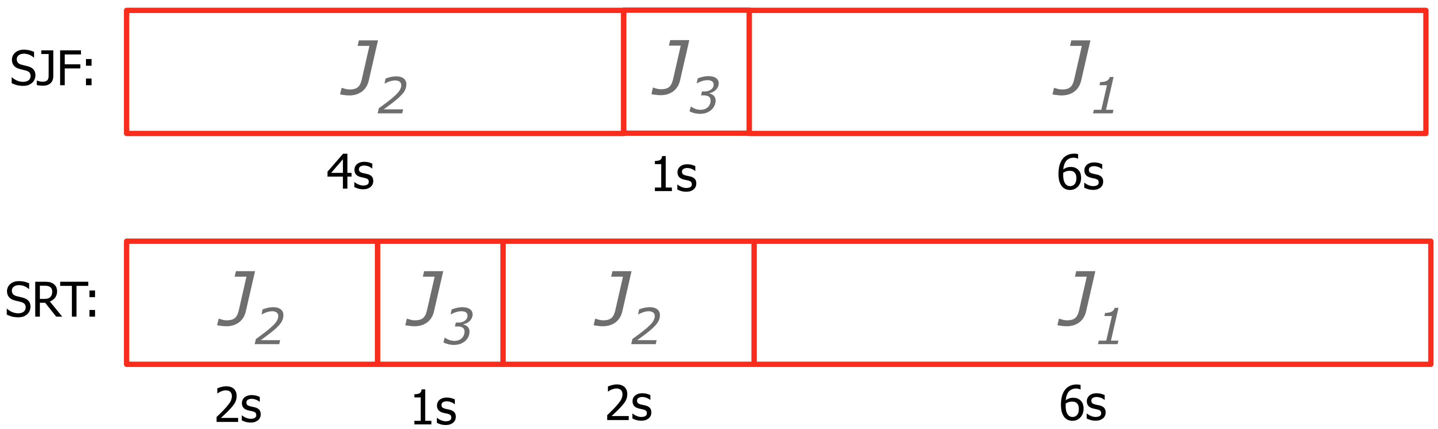
- Again, runtimes have to be known in advance

Choose process whose remaining time is shortest

- When new process arrives with execution time less than the remaining time for the running process, run it

Allows new short jobs to get good service

Example: 3 jobs: J_1 = 6s, J_2 = 4s, J_3 = 1s, & arrives after 2s



Shortest Remaining Time (SRT)

What if a running process is almost complete and a shorter job arrives?

- Might want to disallow preemption when remaining run-time reaches a low threshold to avoid indefinite postponement
- What if context switch overhead is greater than the difference in remaining run-times for the two jobs?

Knowing Run-times in Advance

Run-times are usually not available in advance

Compute CPU burst estimates based on various heuristics?

- E.g., based on previous history
- Not always applicable

User-supplied estimates?

- Need to counteract cheating to get higher priority
- E.g., terminate or penalize processes after they exceed their estimated run-time

Fair-Share Scheduling

Users are assigned some fraction of the CPU

- Scheduler takes into account who owns a process before scheduling it

E.g., two users each with 50% CPU share

- User 1 has 4 processes: A, B, C, D
- User 2 has 2 processes: E, F

What does a fair-share RR scheduler do?

- A, E, B, F, C, E, D, F, A, E, B, F…

Priority Scheduling

- Jobs are run based on their priority
  - Always run the job with the highest priority
- Priorities can be externally defined (e.g., by user) or based on some process-specific metrics (e.g., their expected CPU burst)
- Priorities can be static (i.e. they don't change) or dynamic (they may change during execution)

- Example: consider three processes arriving at essentially the same time with externally defined static priorities
  A = 4, B = 7, C = 1, where a higher value means higher priority.
  - Processes are run to completion in the order B, A, C.

General-Purpose Scheduling

Favor short and I/O-bound jobs

- Get good resource utilization
- And short response times

Quickly determine the nature of the job and adapt to changes

- Processes have periods when they are I/O-bound and periods when they are CPU-bound

Multilevel Feedback Queues 1

A form of priority scheduling

- Shortest remaining time also a form of priority scheduling!

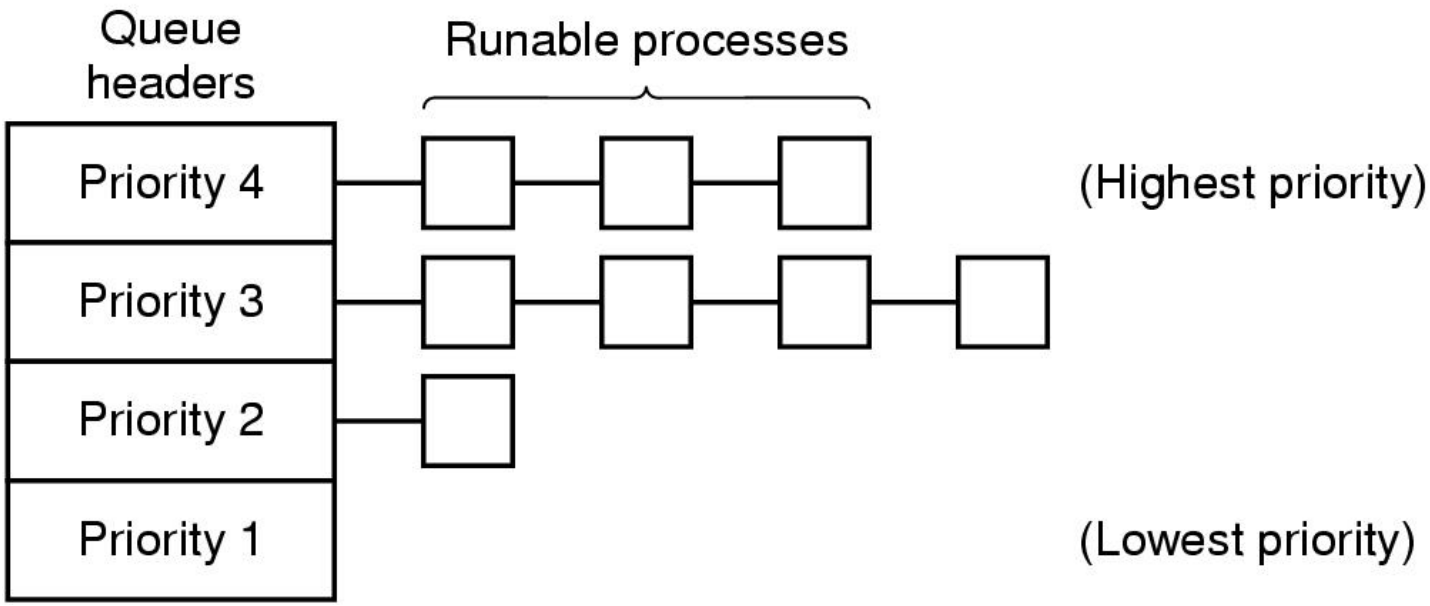
Implemented by many OSs:

- Windows Vista, Windows 7
- Mac OS X
- Linux 2.6 - 2.6.23

Multilevel Feedback Queues 2

One queue for each priority level

- Run job on highest non-empty priority queue
- Each queue can use different scheduling algorithm
  - Usually round-robin
  - Could be different quantum eg highest priority is I/O bound with short quantum. Exceed quantum, then move down level but get bigger quantum.



Multilevel Feedback Queues 3

Need to determine current nature of job

- I/O-bound? CPU-bound?

Need to worry about starvation of lower-priority jobs

Feedback mechanism:

- Job priorities recomputed periodically, e.g., based on how much CPU they have recently used
  - Exponentially-weighted moving average
- *Aging*: increase job's priority as it waits

Multilevel Feedback Queues 4

Not very flexible
- Applications basically have no control
- Priorities make no guarantees
  - What does priority 15 mean?

Does not react quickly to changes
- Often needs *warm-up* period
  - Running system for a while to get better results
- Problem for real-time systems, multimedia apps

Cheating is a concern
- Add meaningless I/O to boost priority?

Cannot donate priority

Lottery Scheduling [Waldspurger and Weihl 1994]

Jobs receive lottery tickets for various resources

- E.g., CPU time

At each scheduling decision, one ticket is chosen at random and the job holding that ticket wins

Example: 100 lottery tickets for CPU time, P1 has 20 tickets

- Chance of P1 running during the next CPU quantum: 20%
- In the long run, P1 gets 20% of the CPU time

Lottery Scheduling

Number of lottery tickets meaningful

- Job holding p% of tickets, gets p% of resource
- Unlike priorities

Highly responsive:

- New job given p% of tickets has the p% chance to get the resource at the ***next*** scheduling decision

No starvation

Jobs can exchange tickets

- Allows for priority donation
- Allows cooperating jobs to achieve certain goals

Adding/removing jobs affect remaining jobs proportionally

Unpredictable response time

- What if interactive process is unlucky for a few lotteries?

Policy versus Mechanism

Separate what is allowed to be done from how it is done

- a process knows which of its children threads are important and need priority

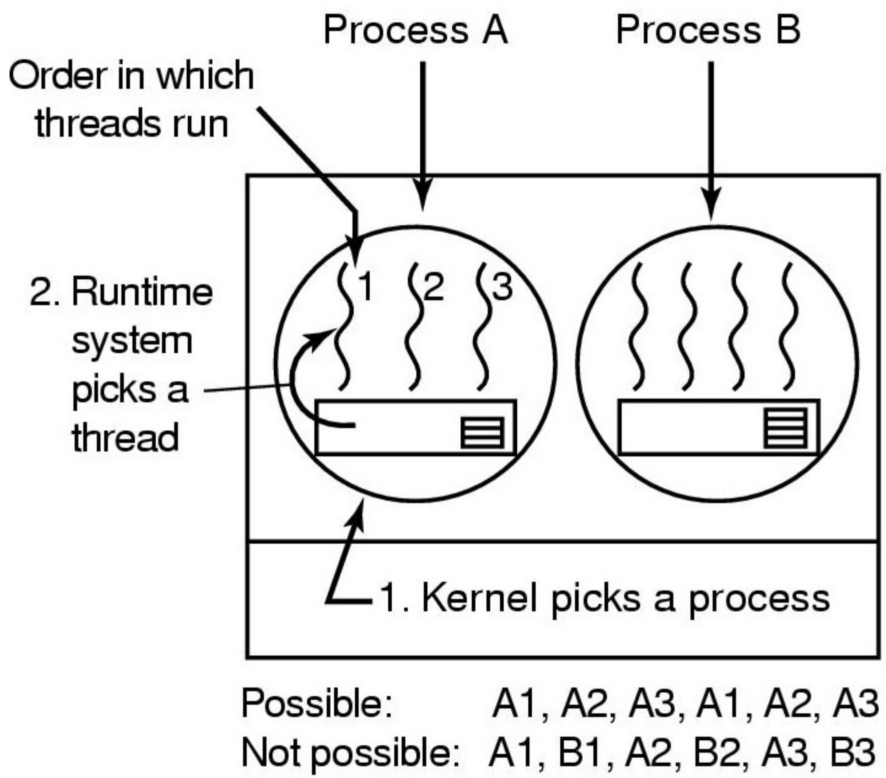
Scheduling algorithm parameterized

- mechanism in the kernel

Parameters filled in by user processes

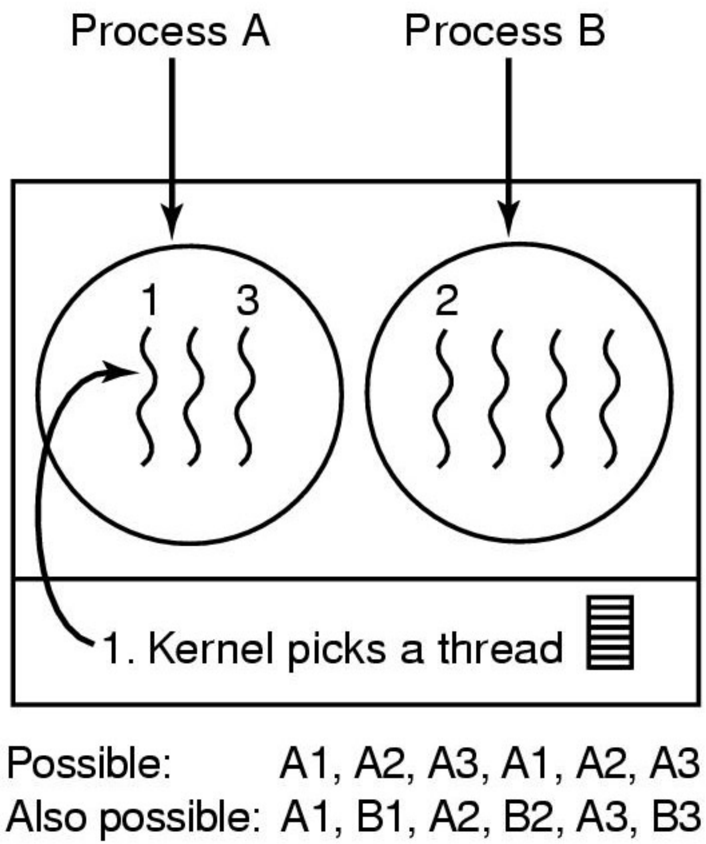
- policy set by user process

User Thread Scheduling



Possible scheduling of user-level threads
50-msec process quantum
Threads run 5 msec/CPU burst

Kernel Thread Scheduling



Possible scheduling of kernel-level threads

50-msec process quantum

Threads run 5 msec/CPU burst

Summary

- Scheduling algorithms often need to balance conflicting goals
  - E.g., ensure fairness, enforce policy, maximize resource utilization
- Different scheduling algorithms appropriate in different contexts
  - E.g., batch systems vs interactive systems vs real-time systems
- Well-studied scheduling algorithms include
  - First-Come First-Served FCFS, Round Robin, Shortest Job First (SJF), Shortest Remaining Time (SRT), Multilevel Feedback Queues and Lottery Scheduling