Process Scheduling

CS 241

February 24, 2012

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Announcements

Mid-semester feedback survey (linked off web page)

MP4 due Friday (not Tuesday)

Midterm

- Next Tuesday, 7-9 p.m.
- Study guide released this Wednesday
- Next Monday's lecture: review session

Process Scheduling

Deciding which process/thread should occupy each resource (CPU, disk, etc.) at each moment

Scheduling is everywhere...

- disk reads
- process/thread resource allocation
- servicing clients in a web server
- compute jobs in clusters / data centers
- jobs using physical machines in factories

In this lecture

Context: The scheduling problem

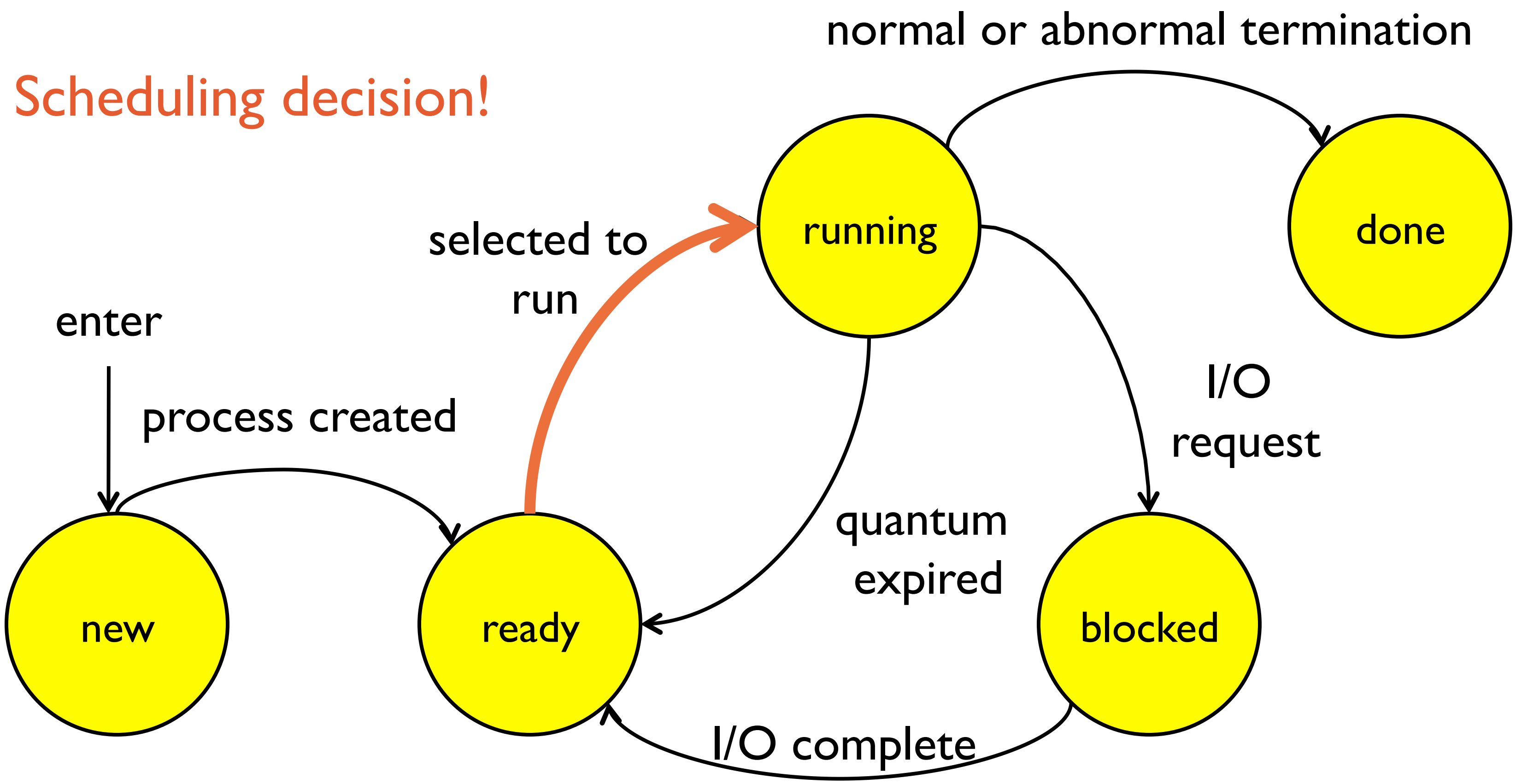
Objectives

Algorithms

Conclusion

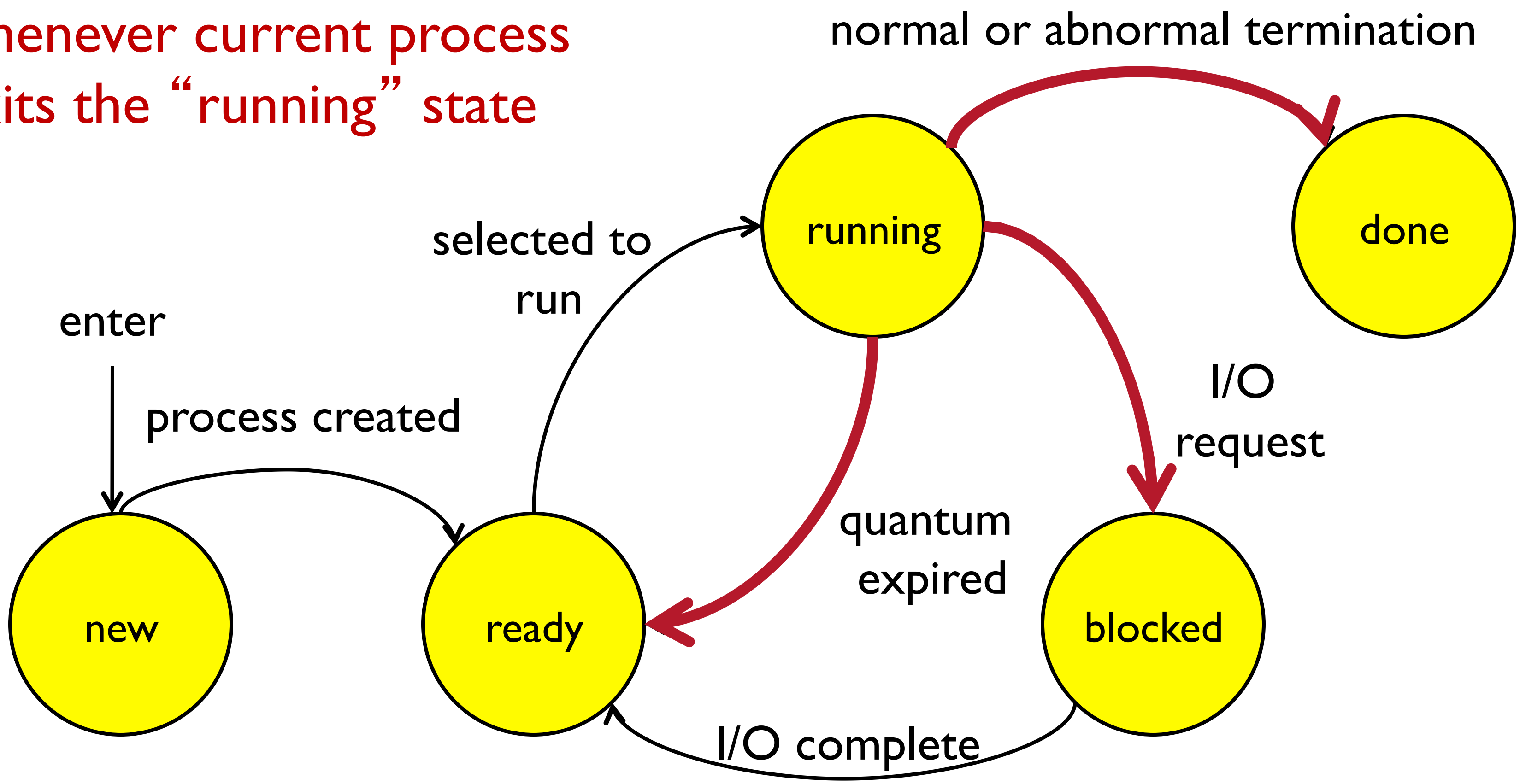
Where scheduling fits

Scheduling decision!

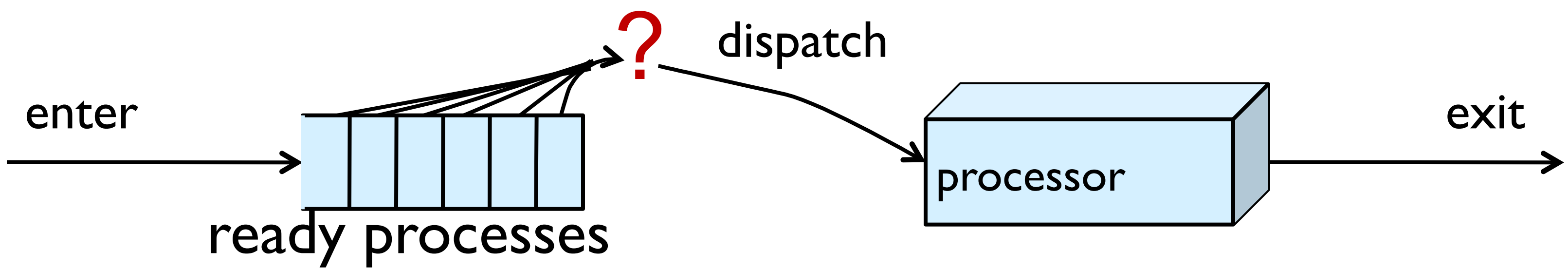


Where scheduling fits

Trigger to make scheduling decision: whenever current process exits the “running” state



The basic scheduling decision



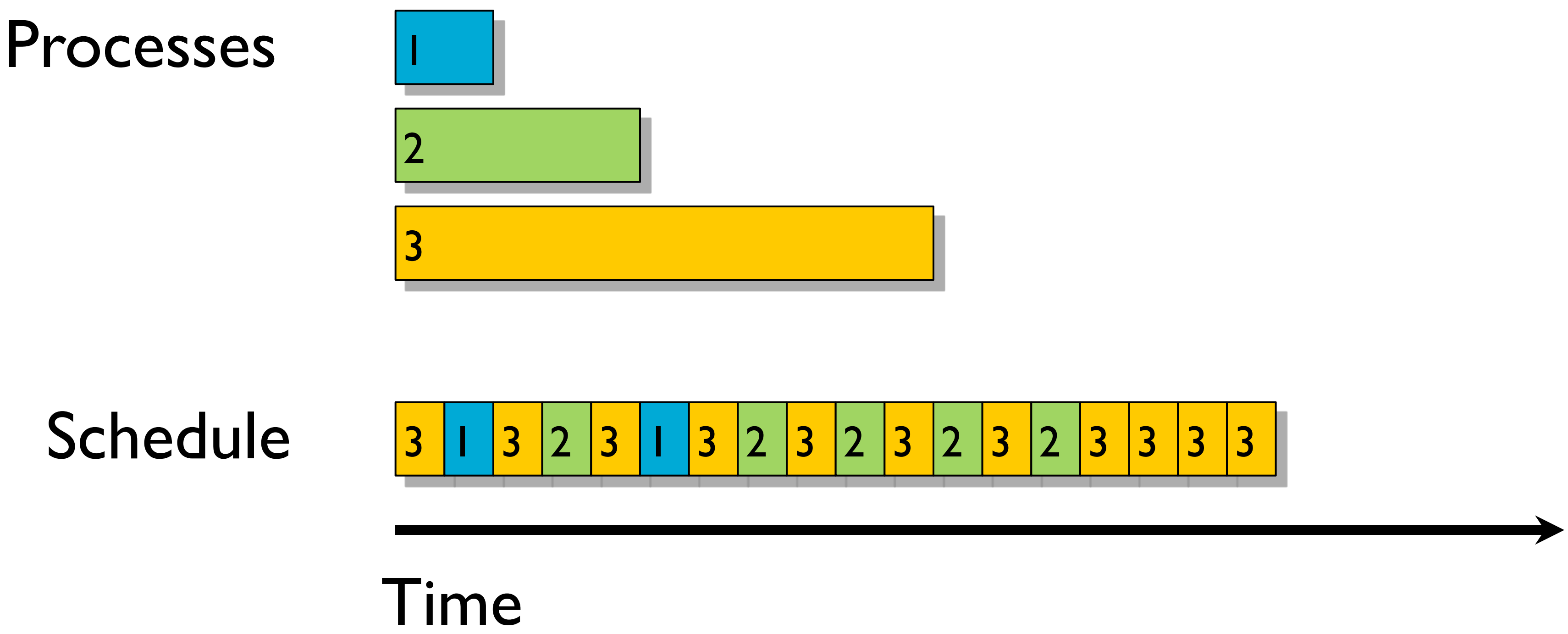
Given a set of ready processes

- Which one should I run next?
- How long should it run?
- ...for each resource (CPU, disk, ...)

Same underlying concepts apply to scheduling processes or threads

- or picking packets to send in routers
- or scheduling jobs in physical factories

Example



Is this a good schedule?

Scheduling is not clear-cut

Could I have done better? Depends!

- Was some job very high priority?
- Did I know when processes were arriving?
- What's the context switch time?
- What's my objective -- fairness, finish jobs quickly, meet deadlines for certain jobs, ...?
- ...

General-purpose OSes try to perform pretty well for the common case

- Is this good enough to fly an airplane?
- Special purpose (e.g., "hard real-time") scheduling exists
- Linux: "Like all general-purpose operating systems, Linux is designed to maximize average case performance instead of worst case performance. ... if you truly are developing a hard real-time application, consider using hard real-time extensions to Linux ... or use a different operating system"

High-level objectives

Objective	
Fairness	Equitable shares of resource
Priority	Allocate to most important first
Efficiency	Make best use of equipment
Encourage good behavior	Can't take advantage of the system
Support heavy loads	Degrade gracefully
Adapting to different environments	Interactive, real-time, multi-media

Quantitative objectives

Objective	
Fairness	Processes get close to equal shares of the CPU
Efficiency	Keep resources as busy as possible
Throughput	Number of processes that complete per unit time
Waiting Time	Time a process spends waiting in kernel's ready queue
Turnaround Time	Time from process start to its completion
Response Time	Amount of time from when a request was first submitted until first response is produced

Types of workloads

I/O-bound

- Does too much I/O to keep CPU busy
- e.g., interactive shell, file transfer

CPU-bound

- Does too much computation to keep I/O busy
- e.g., sorting a million-entry array in RAM, testing primality

We should take advantage of these differences!

- Scheduler should load balance between I/O-bound and CPU-bound processes
- Ideal: run all equipment (CPU, devices) at 100% utilization

Scheduling Algorithms

Batch systems

- Usually non-preemptive: running process keeps CPU until it voluntarily gives it up
  - Process exits
  - Switches to blocked state
- First come first serve (FCFS)
- Shortest job first (SJF) (also preemptive version)

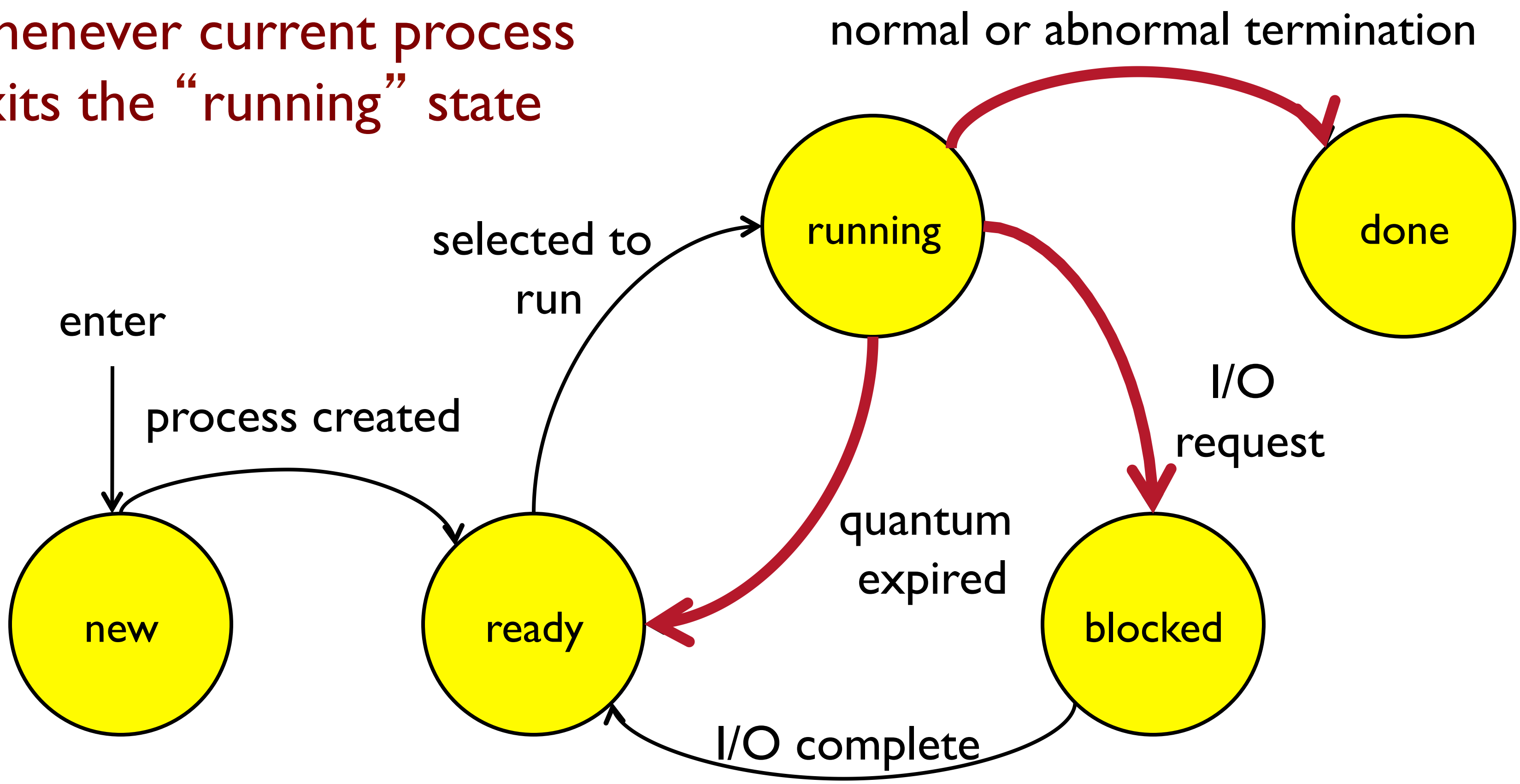
Interactive systems

- Running process is forced to give up CPU after time quantum expires
  - Via interrupts or signals (we'll see these later)
- Round robin
- Priority

These are some of the important ones to know, not a comprehensive list!

Which transitions are preemptive?

Trigger to make scheduling decision:
whenever current process
exits the "running" state



First Come First Serve (FCFS)

Process that requests the CPU first is allocated the CPU first

- Also called FIFO

Non-preemptive

- Used in batch systems

Implementation

- FIFO queues
- A new process enters the tail of the queue
- The scheduler selects next process to run from the head of the queue

FCFS Example

Process	Duration	Order	Arrival Time
P1	24	1	0
P2	3	2	3
P3	4	3	7

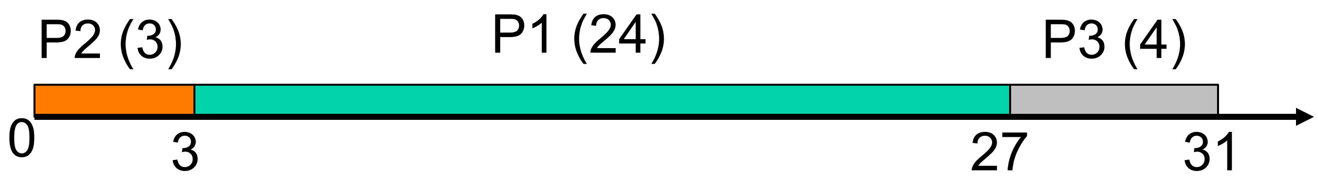
P1 waiting time:
P2 waiting time:
P3 waiting time:

The average waiting time:

FCFS Example

Process	Duration	Order	Arrival Time
P2	24	2	3
P1	3	1	0
P3	4	3	7

What if the arrival times of P1 and P2 are swapped?



P1 waiting time:
P2 waiting time:
P3 waiting time:

The average waiting time:

Problems with FCFS

Non-preemptive

Not optimal AWT

Cannot utilize resources in parallel

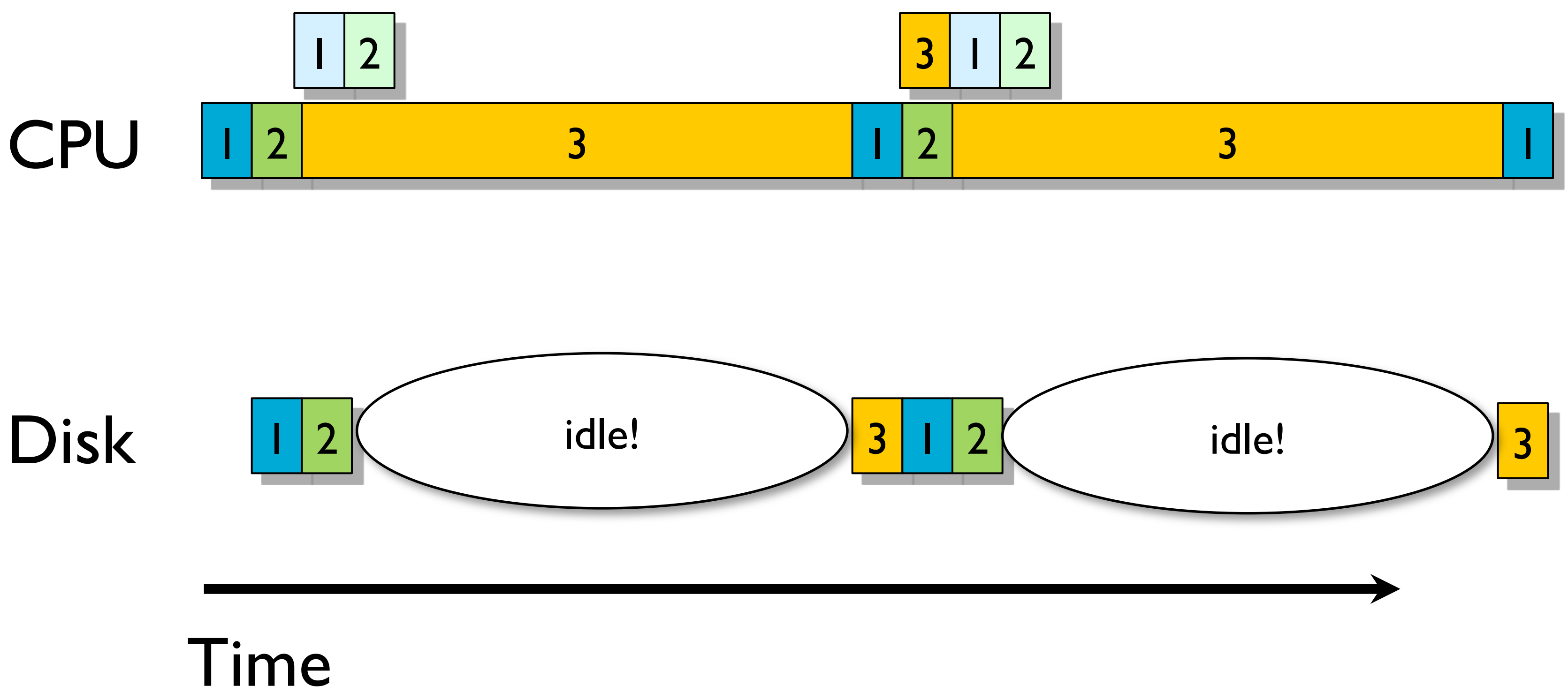
- Assume 1 process CPU bound and many I/O bound processes

Result

- Waiting time depends on arrival order
- Potentially long wait for jobs that arrive later
- Convoy effect, low CPU and I/O device utilization

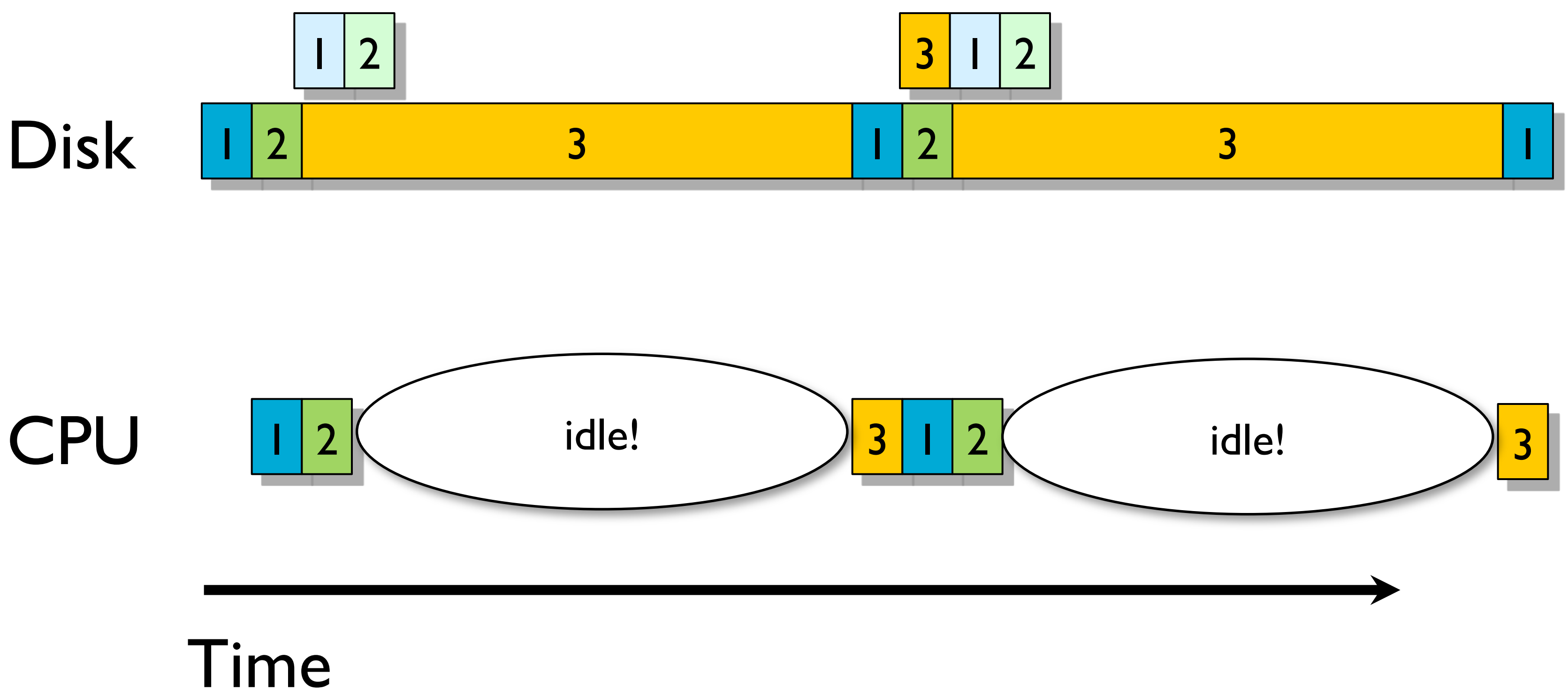
Convoy effect – Low I/O

Jobs 1,2: a **msec** of CPU, a disk read, repeat
Job 3: a **sec** of CPU, a disk read, repeat



Convoy effect – Low CPU

Jobs 1,2: a **msec** of disk, a little CPU, repeat
Job 3: a **sec** of disk, a little CPU, repeat



Shortest Job First (SJF)

Job with shortest CPU time goes first

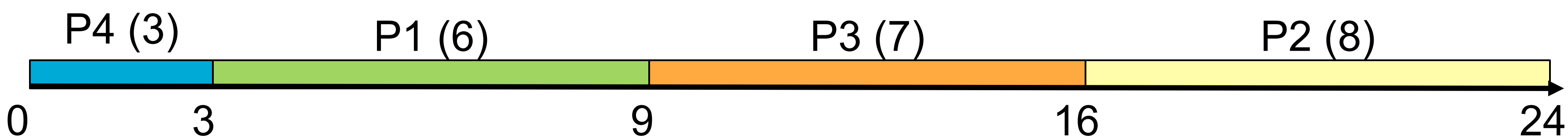
- Often used in batch systems

Two types

- Non-preemptive
- Preemptive

Non-preemptive SJF: Example

Process	Duration	Order	Arrival Time
P1	6	1	0
P2	8	2	0
P3	7	3	0
P4	3	4	0

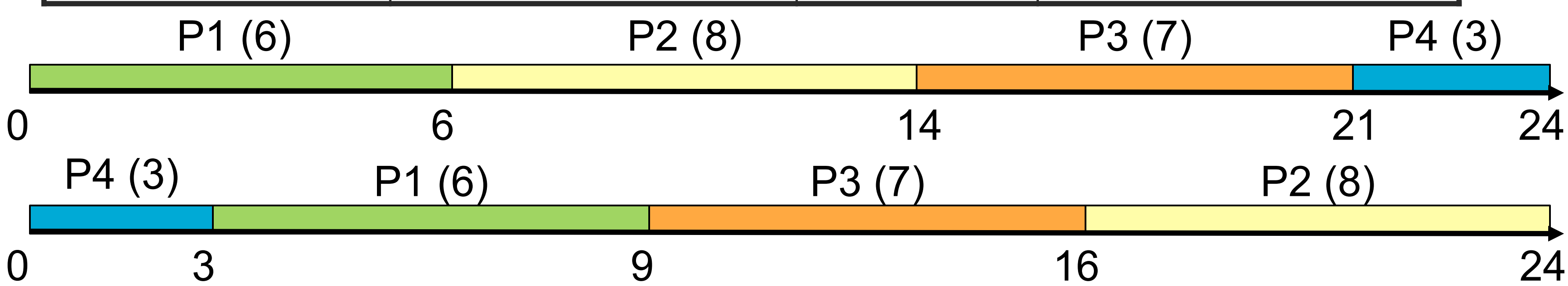


P1 waiting time:
P2 waiting time:
P3 waiting time:
P4 waiting time:

Total waiting time =
Average waiting time =

Compare to FCFS

Process	Duration	Order	Arrival Time
P1	6	1	0
P2	8	2	0
P3	7	3	0
P4	3	4	0



P1 waiting time:
P2 waiting time:
P3 waiting time:
P4 waiting time:

Total waiting time =
Average waiting time =

Non-preemptive SJF

Advantages

- Low average waiting time
- Helps keep I/O devices busy

Disadvantages

- Not practical: Cannot predict future CPU burst time
  - OS solution: Use past behavior to predict future behavior
- Starvation: Long jobs may never be scheduled

Shortest Remaining Proc. Time (Preemptive SJF)

Algorithm

- Job with least remaining time to completion runs
- So, a new job that is shorter than remainder of running job preempts it

Advantages

- Similar to non-preemptive SJF
- Provably minimal average wait time
  - Moving shorter job before longer job improves waiting time of short job more than it harms waiting time of long job

Starvation again

- A long job keeps getting preempted by shorter ones
- Example
  - Process A with CPU time of 1 hour arrives at time 0
  - Every 1 minute, a short process with CPU time of 1 minute arrives
  - What happens to A?

Thus far: Batch scheduling

FCFS, SJF, SRPT useful when fast response not necessary

- weather simulation
- processing click logs to match advertisements with users
- ...

What if we need to respond to events quickly?

- human interacting with computer
- packets arriving every few milliseconds
- ...

Interactive Scheduling

Usually preemptive

- Time is sliced into quanta, i.e., time intervals
- Scheduling decisions are made at the beginning of each quantum

Performance metrics

- Average response time
- Fairness (or proportional resource allocation)

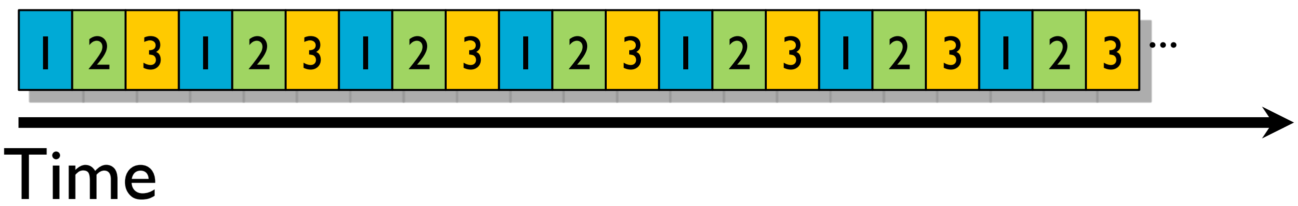
Representative algorithms

- Round-robin
- Priority scheduling

Round-robin

One of the oldest, simplest, most commonly used scheduling algorithms

Select process/thread from ready queue in a round-robin fashion (i.e., take turns)



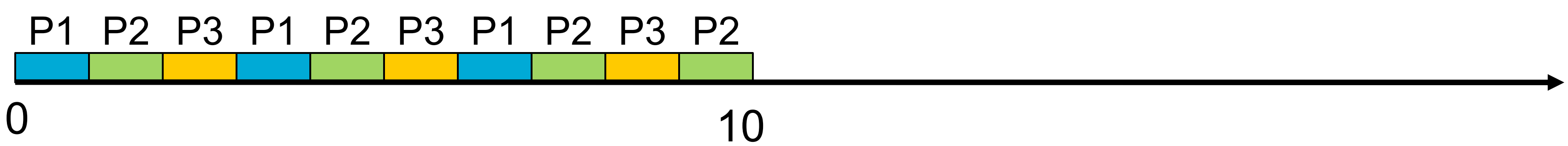
Problems

- Might want some jobs to have greater share
- Context switch overhead

Round-robin: Example

Process	Duration	Order	Arrival Time
P1	3	1	0
P2	4	2	0
P3	3	3	0

Suppose time quantum is 1 unit and P1, P2 & P3 never block



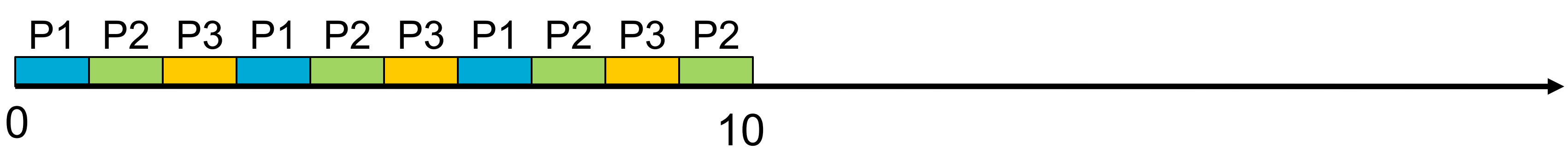
P1 waiting time:
P2 waiting time:
P3 waiting time:

The average waiting time (AWT):

Round-robin: Example

Process	Duration	Order	Arrival Time
P1	3	1	0
P2	4	2	0
P3	3	3	0

Suppose time quantum is 1 unit and P1, P2 & P3 never block



P1 waiting time: 4
P2 waiting time: 6
P3 waiting time: 6

The average waiting time (AWT):
(4+6+6)/3 = 5.33

Round-robin: Summary

Advantages

- Jobs get fair share of CPU
- Shortest jobs finish relatively quickly

Disadvantages

- Poor average waiting time with similar job lengths
  - Example: 10 jobs each requiring 10 time slices
  - RR: All complete after about 100 time slices
  - FCFS performs better!
- Performance depends on length of time quantum

Choosing the time quantum

How should we choose the time quantum?

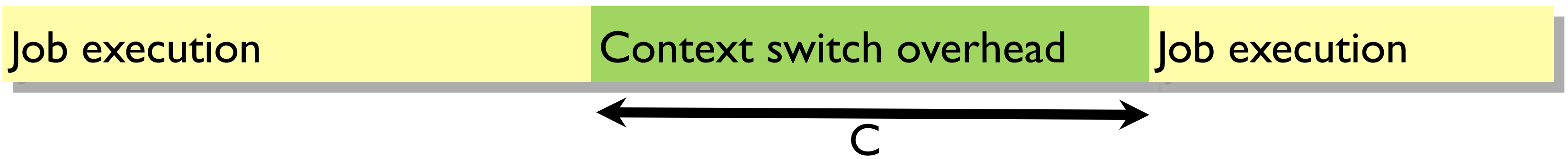
Time quantum too large

- FIFO behavior
- Poor response time

Time quantum too small

- Too many context switches (overhead)
- Inefficient CPU utilization

Choosing the time quantum



Objective 1:
Fast response time

Best case: quantum = 0,
response time = C

Objective 2:
Efficiency

Best case: quantum = infinity,
Job completion time = J

General strategy: set quantum somewhere in the middle

Choosing the time quantum

Choice depends on

- Priorities, architecture, etc.

Typical quantum: 10-100 ms

- Large enough that overhead is small percentage
- Small enough to give illusion of concurrency
- e.g., linux.ews.illinois.edu: 99.98 ms quantum using round-robin

Questions

- Does 100 ms matter? (how long is this in practical terms?)
- Does this mean all processes wait 100 ms to run?

Priority Scheduling

Rationale: higher priority jobs are more mission-critical

- Example: DVD movie player vs. send email

Each job is assigned a priority

Select highest priority runnable job

- FCFS or Round Robin to break ties

Problems

- May not give the best AWT
- Starvation of lower priority processes

Priority Scheduling: Example

(Lower priority number is preferable)

Process	Duration	Priority	Arrival Time
P1	6	4	0
P2	8	1	0
P3	7	3	0
P4	3	2	0

P1 waiting time:
P2 waiting time:
P3 waiting time:
P4 waiting time:

The average waiting time (AWT):

Setting priorities: nice

nice [OPTION] [COMMAND [ARG]...]

- Run COMMAND with an adjusted niceness
- With no COMMAND, print the current niceness.
- Nicenesses range from -20 (most favorable scheduling) to 19 (least favorable).

Options

- -n, --adjustment=N
  - add integer N to the niceness (default 10)
- --help
  - display this help and exit
- --version
  - output version information and exit

Setting priorities in C

```
#include <sys/time.h>
#include <sys/resource.h>
int getpriority(int which, int who);
int setpriority(int which, int who, int prio);
```

Access scheduling priority of process, process group, or user

Returns:

- setpriority() returns 0 if there is no error, or -1 if there is
- getpriority() can return the value -1, so it is necessary to clear errno prior to the call, then check it afterwards to determine if a -1 is an error or a legitimate value

Parameters:

- which
  - PRIO_PROCESS, PRIO_PGRP, or PRIO_USER
- who

  A process identifier for PRIO_PROCESS, a process group identifier for PRIO_PGRP, or a user ID for PRIO_USER

Issues to remember

Why doesn't scheduling have one easy solution?

What are the pros and cons of each scheduling policy?

How does this matter when you're writing multiprocess/ multithreaded code?

- Can't make assumptions about when your process will be running relative to others!
- May need specialized scheduling for specialized applications

Remember

Mid-semester feedback survey (linked off web page)