# Operating System Principles

# 操作系统原理

## Process/Thread Scheduling

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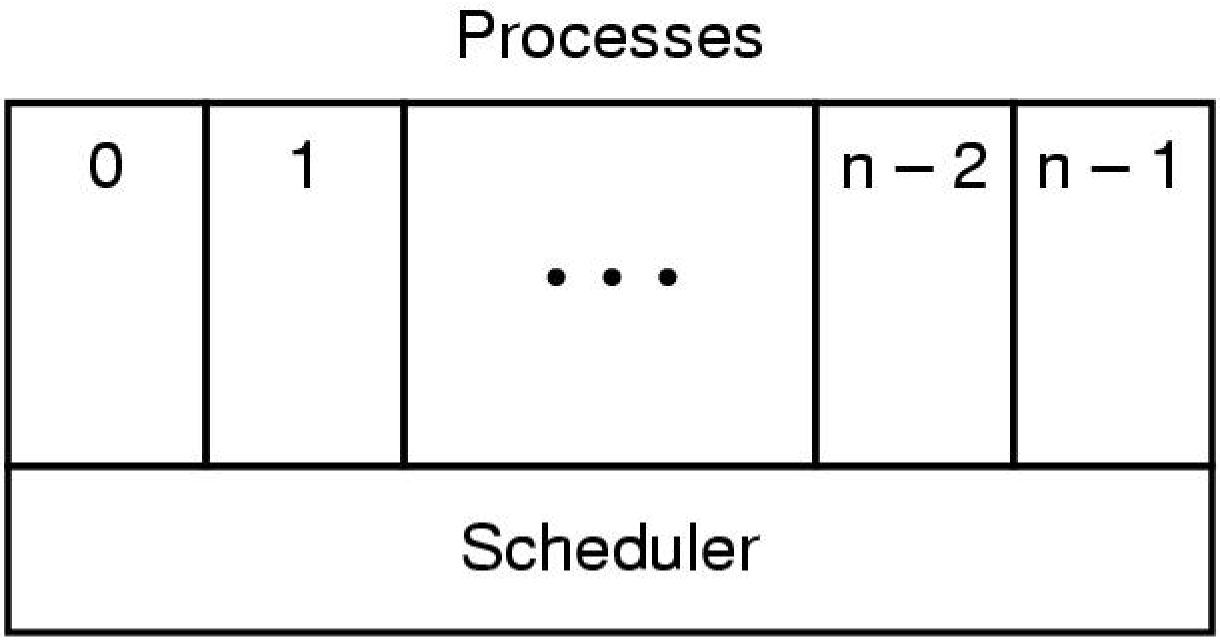
# Objectives

- Scheduler
- Process Behavior
- Scheduling Mode
- Scheduling Criteria
- Scheduling Algorithms
- Thread Scheduling

# MultiProgramming

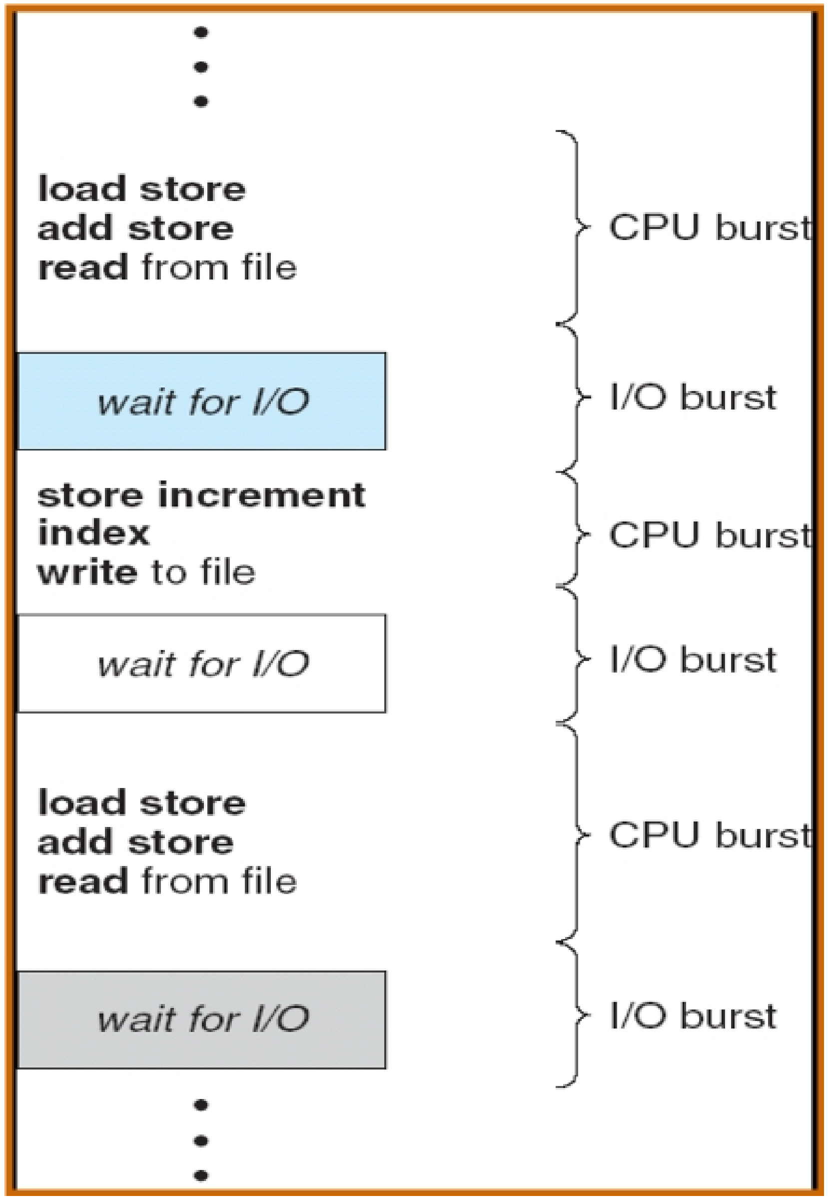
- Scheduler
- Scheduling algorithm



# Scheduler

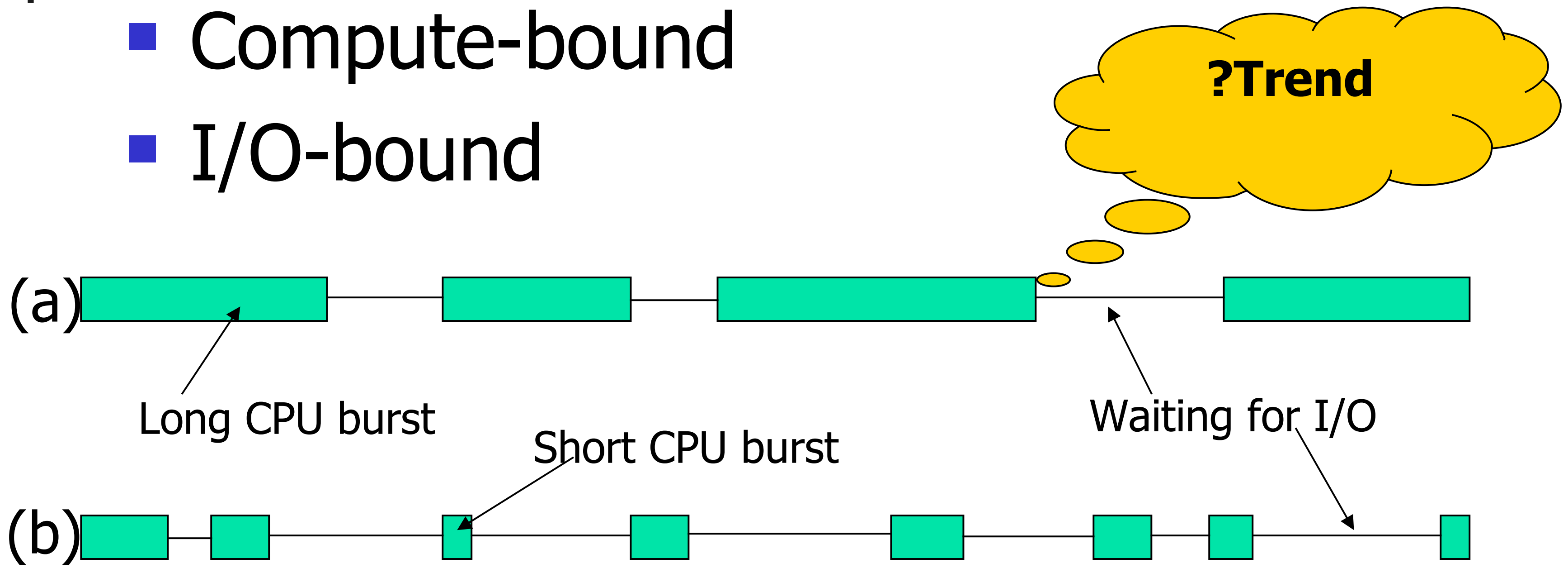
- Short-term Scheduler
  - CPU
- Middle-term Scheduler
  - Memory
- Long-term Scheduler
  - Job

# CPU And I/O Bursts in a Process



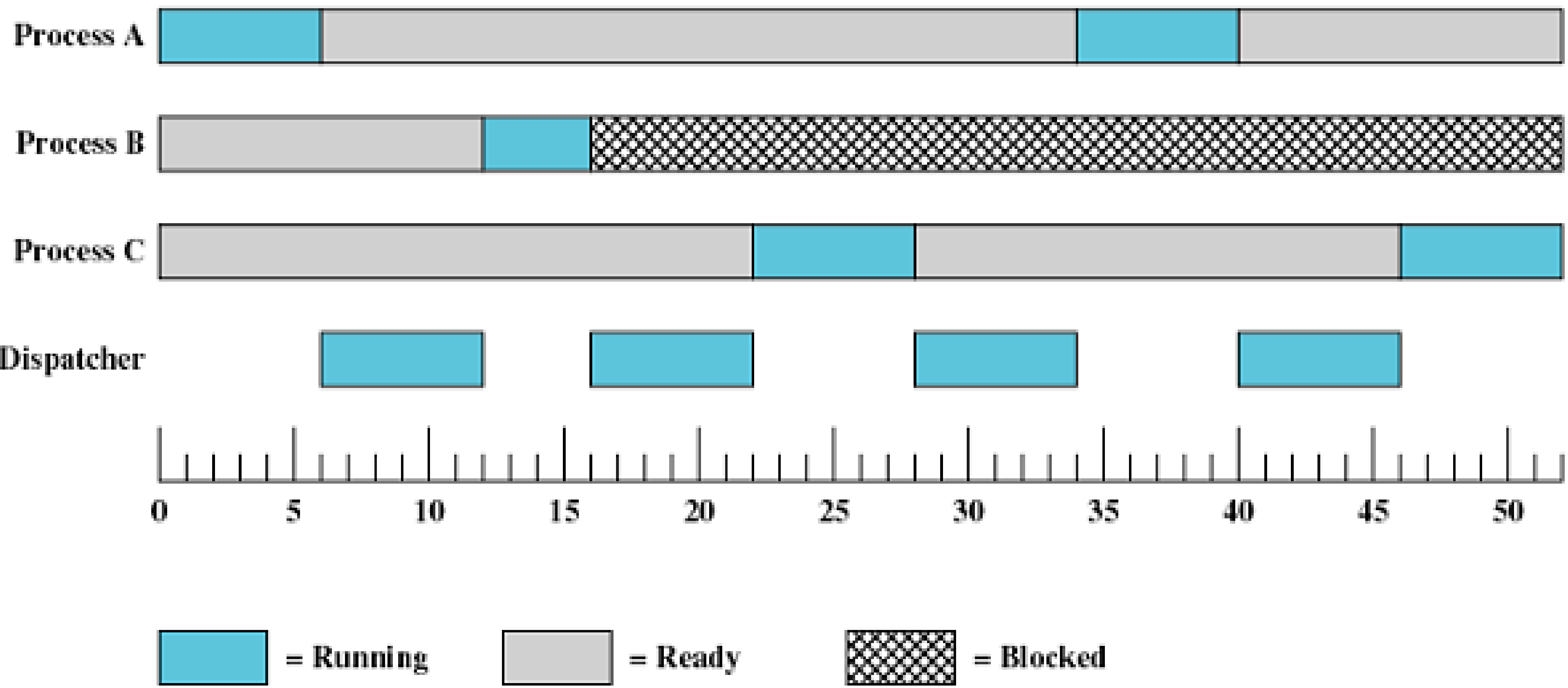
# Process Behavior

- Compute-bound
- I/O-bound




(a) compute-bound (b) I/O-bound

# Multi-Processes Trace



# When to Schedule

- A new process is created
- A process exits
- A process blocks on I/O, on a semaphore, or for some other reason
- An I/O interrupt occurs

# Dispatcher

- A module that gives control of the CPU to the process selected by the short-term scheduler
  - Switching context
  - Switching to user mode
  - Jumping to the proper location in the user program to restart that program
- Dispatch latency 调度延迟
  - The time it takes for the dispatcher to stop one process and start another running

# Scheduling Modes

- Preemptive
  - 抢占式
- Nonpreemptive
  - 非抢占式，非剥夺式

# Categories of Scheduling Algorithms

- Batch
- Interactive
- Real-time

# Scheduling Criteria

- CPU utilization 利用率
- Throughout 吞吐量
- Turnaround time 周转时间
  - Waiting to get into memory
  - Waiting in the ready queue
  - Executing on the CPU
  - Doing I/O
- Waiting time
- Response time
- …

# Scheduling Algorithm Goals

**All systems**

Fairness - giving each process a fair share of the CPU
Policy enforcement - seeing that stated policy is carried out
Balance - keeping all parts of the system busy

**Batch systems**

Throughput - maximize jobs per hour
Turnaround time - minimize time between submission and termination
CPU utilization - keep the CPU busy all the time

**Interactive systems**

Response time - respond to requests quickly
Proportionality - meet users' expectations

**Real-time systems**

Meeting deadlines - avoid losing data
Predictability - avoid quality degradation in multimedia systems

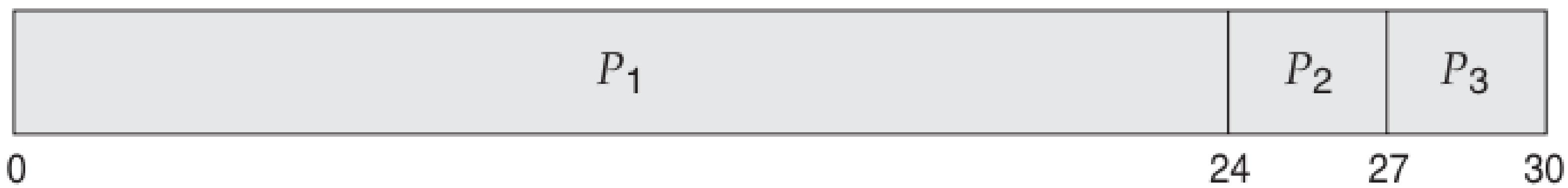
# Scheduling in Batch System

- First-come first-served
- Shortest job first
- Shortest remaining Time next

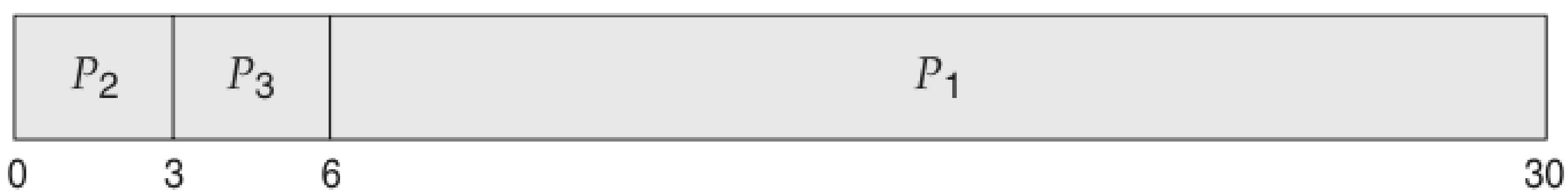
# First-come first-served

- Average waiting time

| Process | Burst Time |
|---|---|
| $P_1$ | 24 |
| $P_2$ | 3 |
| $P_3$ | 3 |

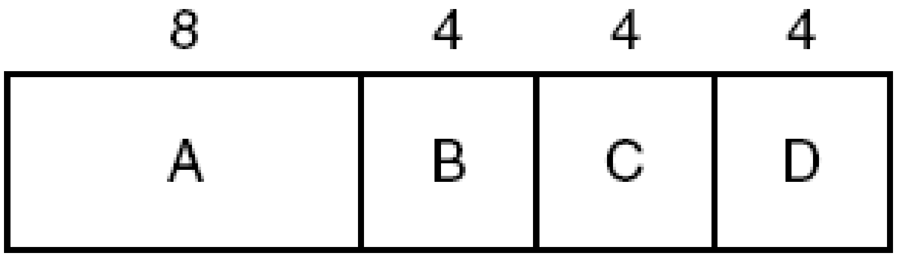



Awt=(0+24+27)/3=17

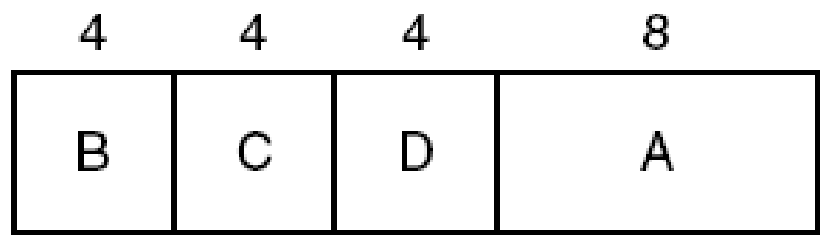



Awt=?

# Shortest job first




(a)




(b)

1.nonpreemptive
2.preemptive

Figure 2-40. An example of shortest job first scheduling.
(a) Running four jobs in the original order.
(b) Running them in shortest job first order.

# Quiz

| Process | Burst Time |
|---|---|
| $P_1$ | 6 |
| $P_2$ | 8 |
| $P_3$ | 7 |
| $P_4$ | 3 |

SJF: AWT=?

FCFS: AWT=?

# Shortest job first

- How to predict length of the next CPU burst?
  - exponential average

$$T_{n+1} = at_n + (1-a)T_{n-1}, \quad 0 \leqslant a \leqslant 1$$

$$t_n \, the\ length\ of\ the\ nth\ CPU\ burst$$

$$T_{n+1} \, the\ predicted\ value\ of\ the\ next\ CPU\ burst$$

$$T_{n+1} = at_n + (1-a)at_{n-1} + \cdots + (1-a)^j at_{n-j} + \cdots + (1-a)^{n+1} T_0$$

# Shortest remaining Time next

- i.e. Preemptive SJF sheduling

| Process | Arrival Time | Burst Time |
|---|---|---|
| $P_1$ | 0 | 8 |
| $P_2$ | 1 | 4 |
| $P_3$ | 2 | 9 |
| $P_4$ | 3 | 5 |

Nonpreemptive SJF scheduling: AWT=?

Preemptive SJF scheduling: AWT=?

# Scheduling in Interactive System

- Round-Robin Scheduling
- Priority Scheduling
- Multiple Queues
- Shortest Process Next
- Guaranteed Scheduling
- Lottery Scheduling
- Fair-Share Scheduling

# Round-Robin Scheduling

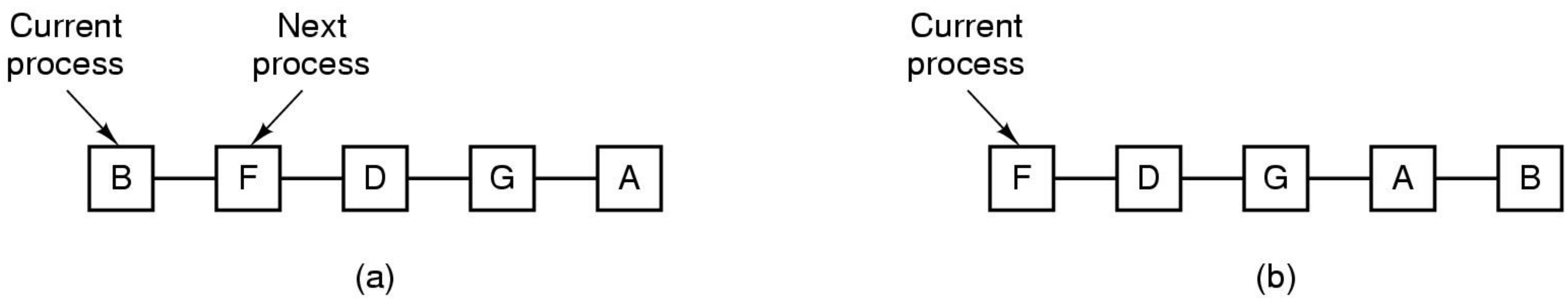
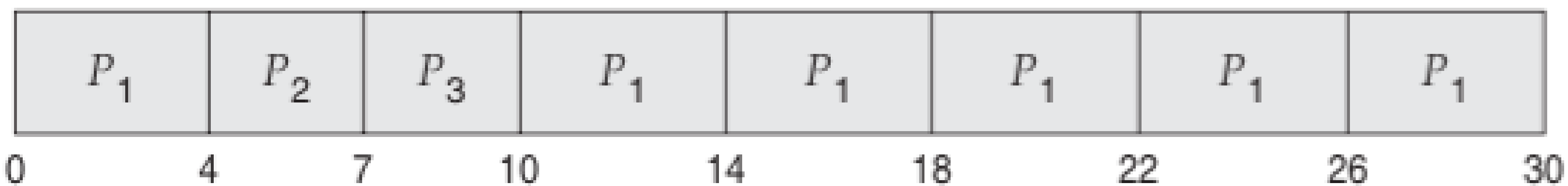



Figure 2-41. Round-robin scheduling.
(a) The list of runnable processes.
(b) The list of runnable processes after B uses up its quantum.

# Round-Robin Scheduling

| Process | Burst Time |
|---|---|
| $P_1$ | 24 |
| $P_2$ | 3 |
| $P_3$ | 3 |

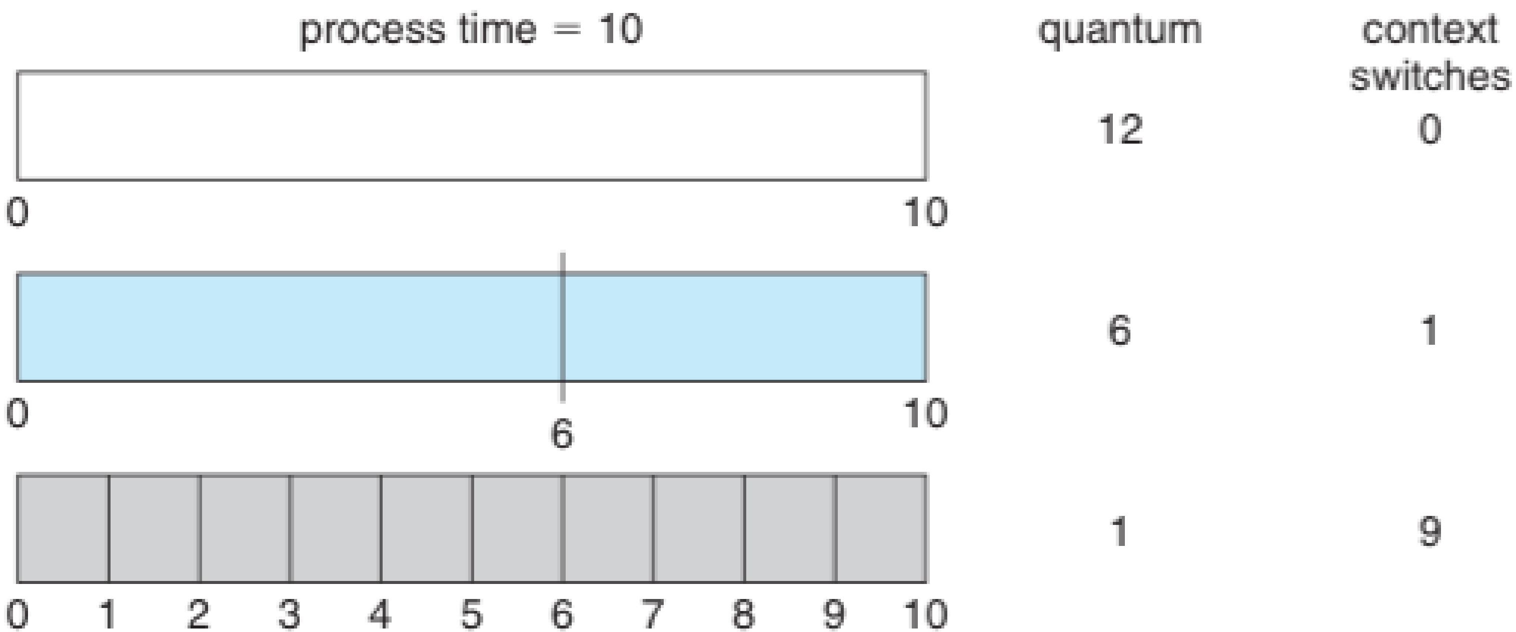
a time quantum of 4 milliseconds




AWT=(6+4+7)/3=5.66

# Quantum Value

- How a smaller time quantum increases context switches



# Priority Scheduling

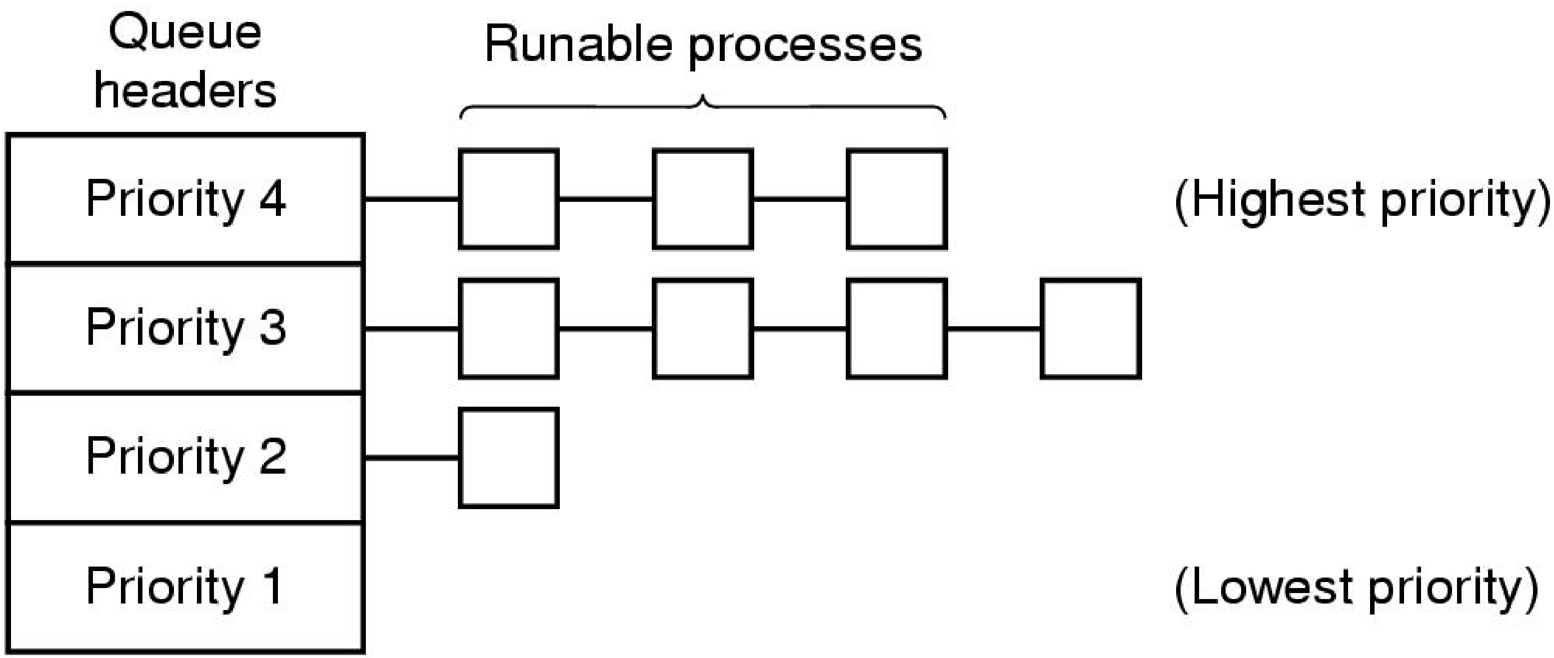
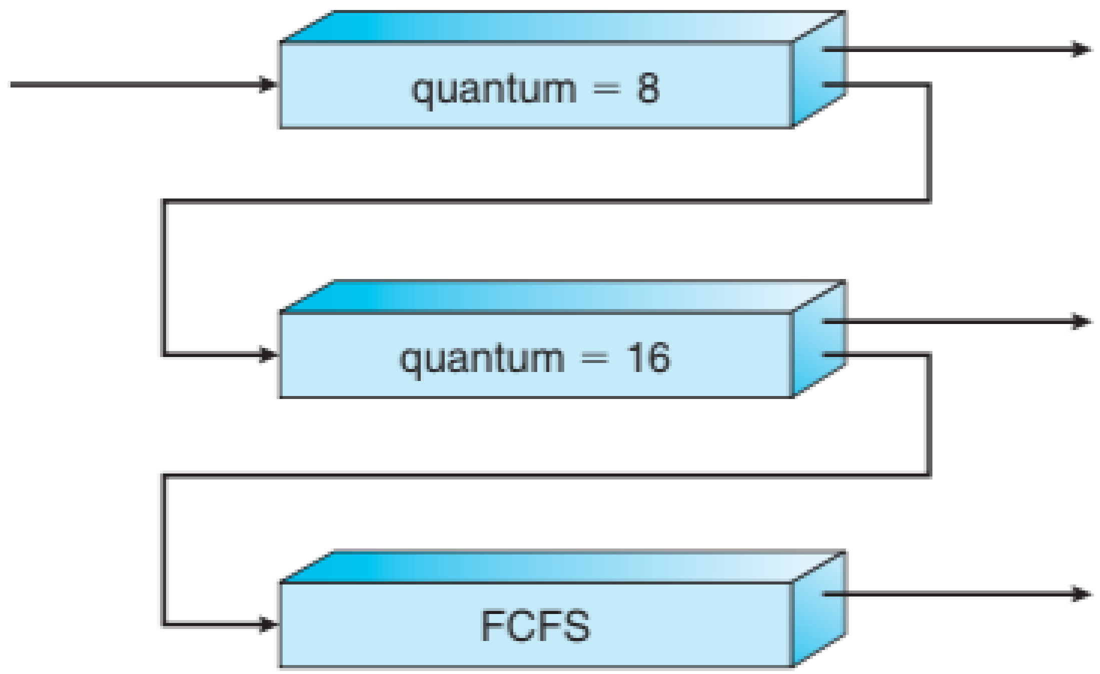



Figure. A scheduling algorithm with four priority classes.

# Mutlilevel Feedback Queue Scheduling

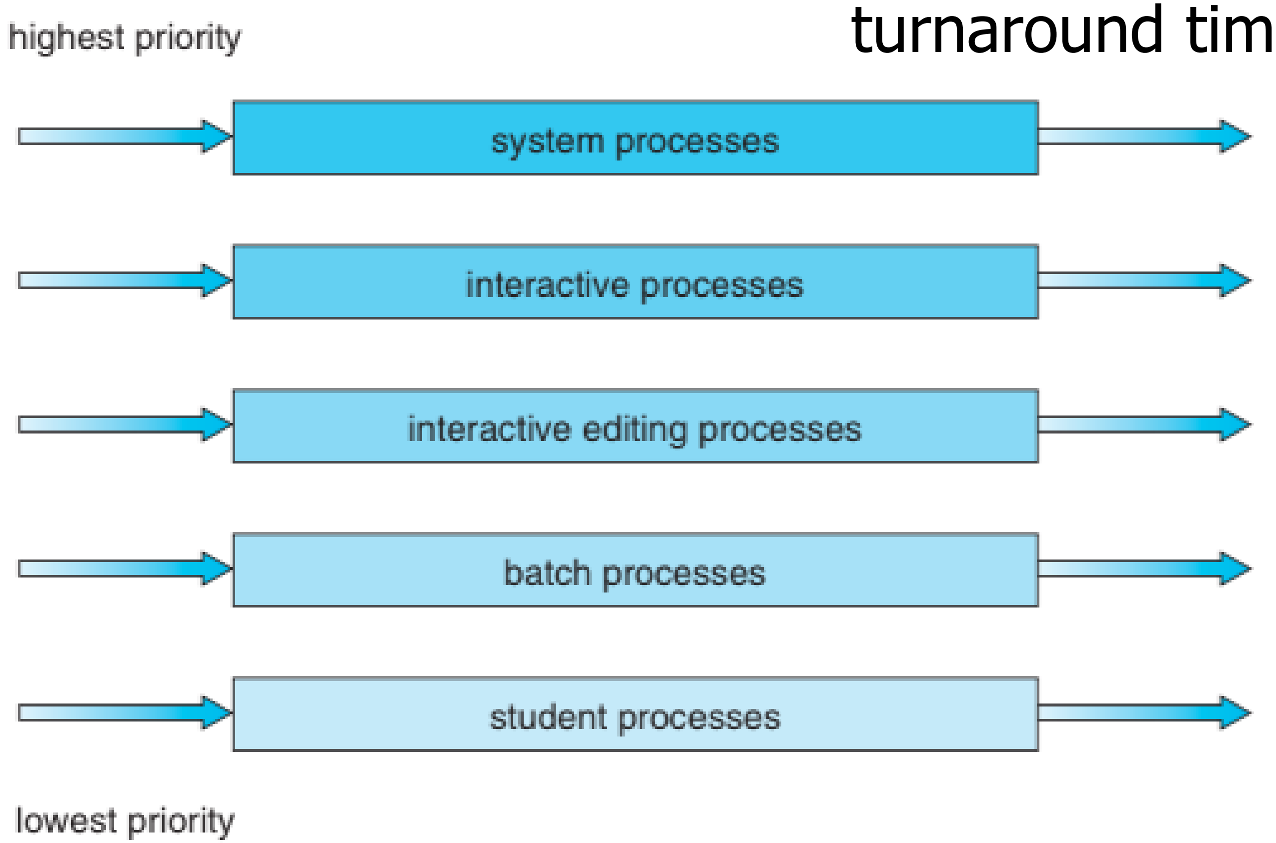
- Idea
  - Separate processes with different CPU-burst characteristics
  - Allow a process to move between queues



# Multilevel Queue Scheduling

- Foreground (interactive) processes
- Background (batch) processes

turnaround time



# Mutli-level Feedback Queue Scheduling

- the scheduler is defined by the following parameters:
  - The number of queues
  - The scheduling algorithm for each queue
  - The method used to determine when to upgrade a process to a higher-priority queue
  - The method used to determine when to demote a process to a lower-priority queue
  - The method used to determine which queue a process will enter when that process needs service

# Lottery Scheduling

# More Scheduling Algorithms

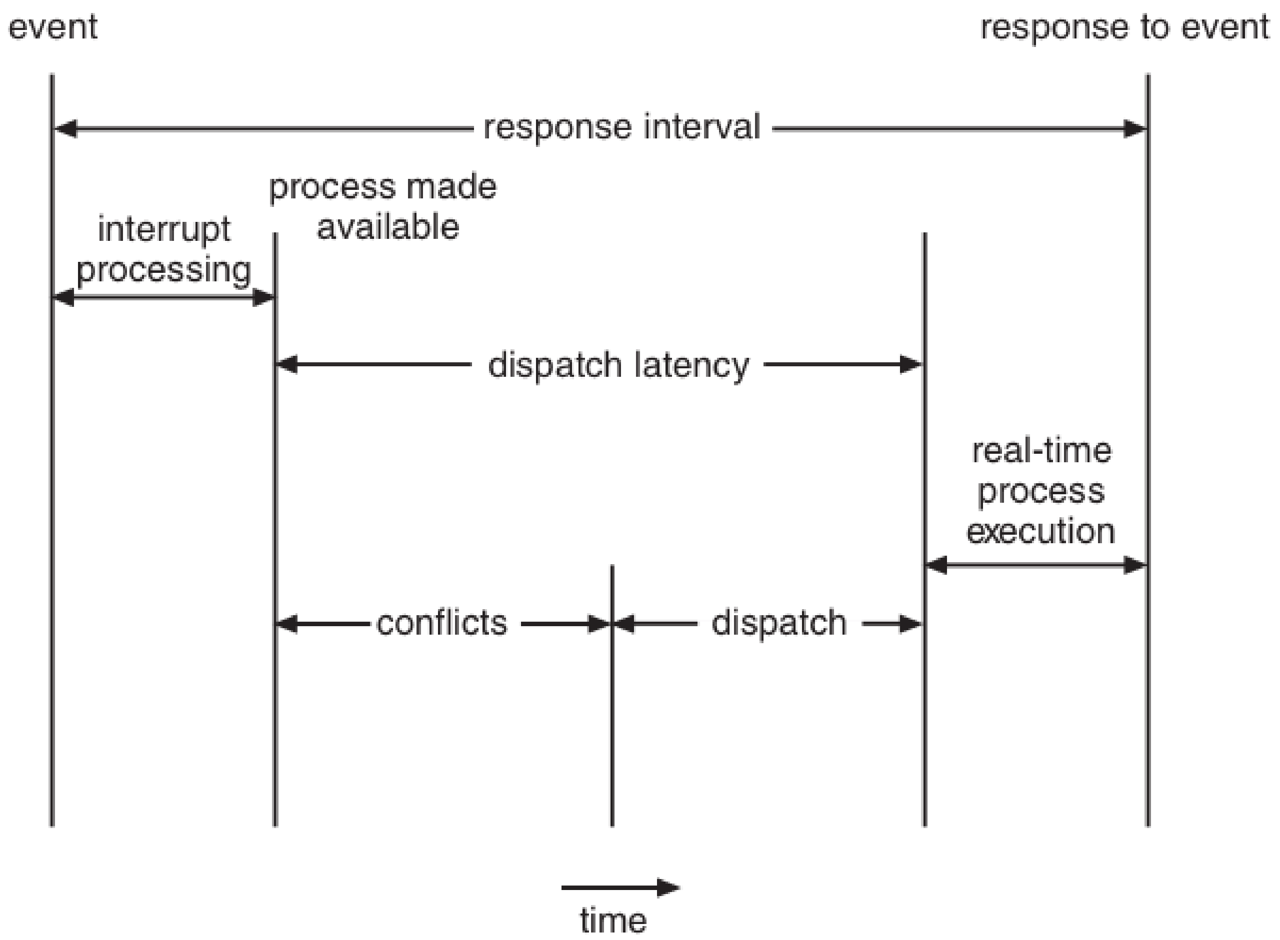
- Guaranteed Scheduling
- Fair-Share Scheduling
- ...

# Scheduling in Real-time System

- Categories I
  - Hard real time
  - Soft real time
- Categories II
  - Periodic
  - Aperiodic
- Categories III
  - Static
  - dynamic

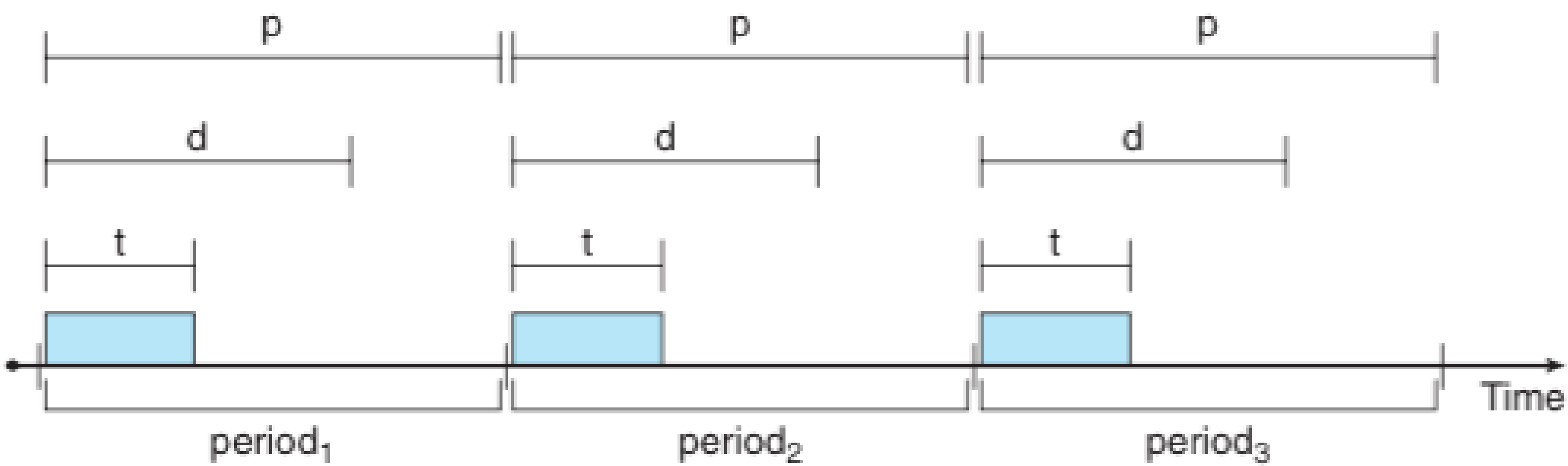
# Real-time CPU Scheduling

- Minimizing Latency 最小化延迟
  - Interrupt latency, Dispatch latency

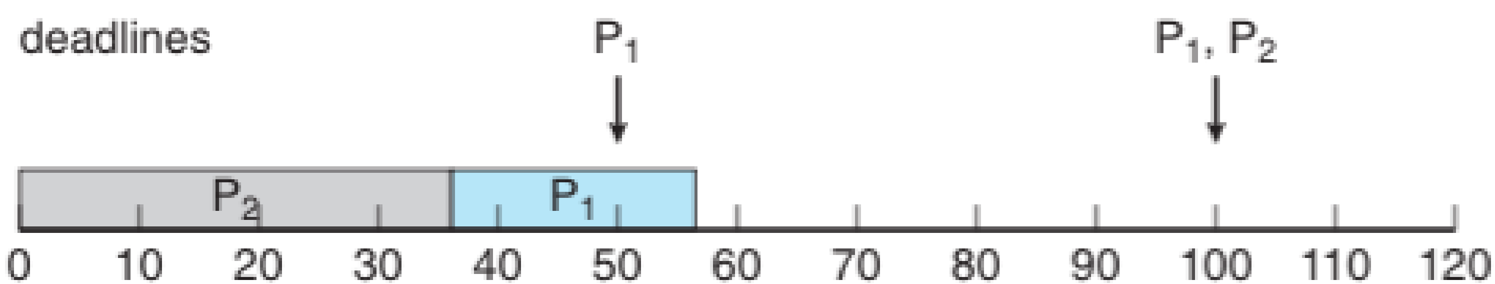


# Real-time CPU Scheduling

- Priority-Based Scheduling



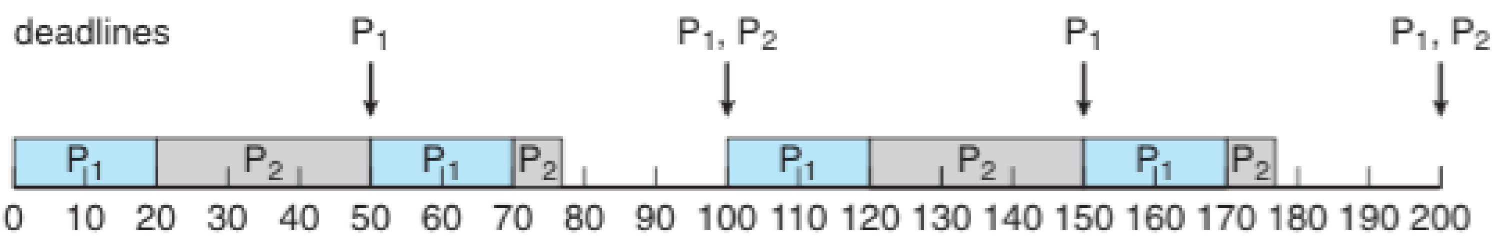

Example: P2 has a higher priority than P1



# Real-time CPU Scheduling

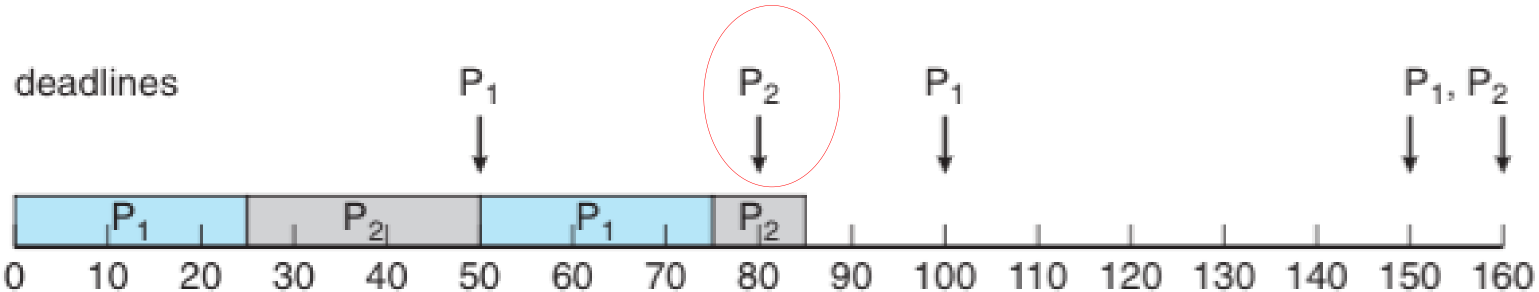
- Rate-Monotonic Scheduling
  - 单一速率
  - a static priority policy with preemption

Example:
P1 a higher priority than P2;
the period of P1 is shorter than that of P2

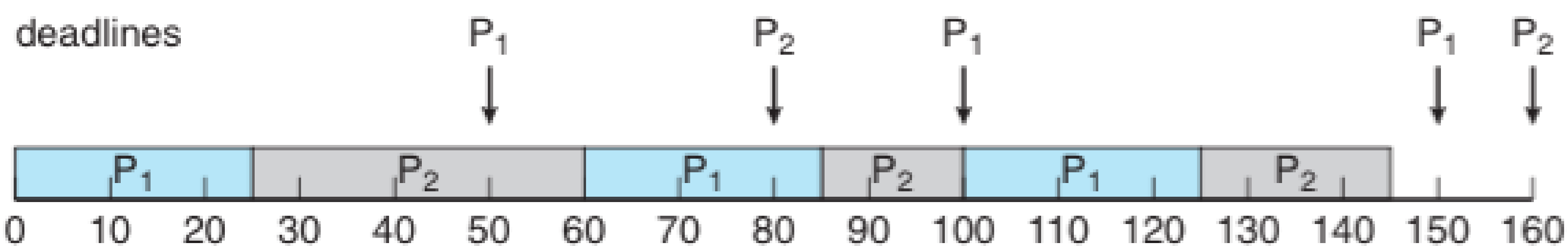


# Real-time CPU Scheduling

- Earliest-Deadline-First Scheduling
  - dynamically assigns priorities according to deadline




Missing deadlines with rate-monotonic scheduling




Earliest-deadline-first scheduling

# Real-time CPU Scheduling

- Proportional 成比例的 Share Scheduling
  - Proportional share schedulers operate by allocating T shares among all applications
  - An application can receive N shares of time, thus ensuring that the application will have N/T of the total processor time

# Real-time CPU Scheduling

- POSIX Real-Time Scheduling
  - SCHED_FIFO
  - SCHED_RR
  - SCHED_OTHER
  - pthread attr_getsched_policy(pthread_attr_t *attr, int *policy)
  - pthread attr_setsched_policy(pthread_attr_t *attr, int policy)

# Multiple-Processor Scheduling

- multiple CPUs
  - load sharing becomes possible—but scheduling problems become correspondingly more complex
- Approaches to Multiple-Processor Scheduling
  - asymmetric multiprocessing
    - all scheduling decisions, I/O processing, and other system activities handled by a single processor—the master server.
    - The other processors execute only user code.
  - symmetric multiprocessing (SMP)
    - Each processor is self-scheduling. All processes may be in a common ready queue, or each processor may have its own private queue of ready processes.

# Multiple-Processor Scheduling

- Processor Affinity 处理器亲和性
  - Consider what happens to cache memory when a process has been running on a specific processor. The data most recently accessed by the process populate the cache for the processor.
  - As a result, successive memory accesses by the process are often satisfied in cache memory.
- Deference Forms of Processor Affinity
  - soft affinity
    - When an operating system has a policy of attempting to keep a process running on the same processor—but not guaranteeing that it will do so
  - hard affinity
    - sched_setaffinity() system call

# Linux Scheduler

- /kernel/sched/core.c
  - static void __sched notrace __schedule(bool preempt)
  - static __always_inline struct rq *
    context_switch(struct rq *rq, struct task_struct *prev,
    struct task_struct *next, struct rq_flags *rf)
  - static inline struct task_struct *
    pick_next_task(struct rq *rq, struct task_struct *prev,
    struct rq_flags *rf)

# Linux Scheduler (cont.,)

Filter tags

- v4
  - v4.14
    - v4.14
    - v4.14-rc8
    - v4.14-rc7
    - v4.14-rc6
    - v4.14-rc5
    - v4.14-rc4
    - v4.14-rc3
    - v4.14-rc2
    - v4.14-rc1
  - v4.13
  - v4.12
  - v4.11
  - v4.10
  - v4.9
  - v4.8
  - v4.7
  - v4.6
  - v4.5
  - v4.4
  - v4.3
  - v4.2
  - v4.1
  - v4.0
- v3
- v2.6

/ kernel / sched / core.c

Search Identifier

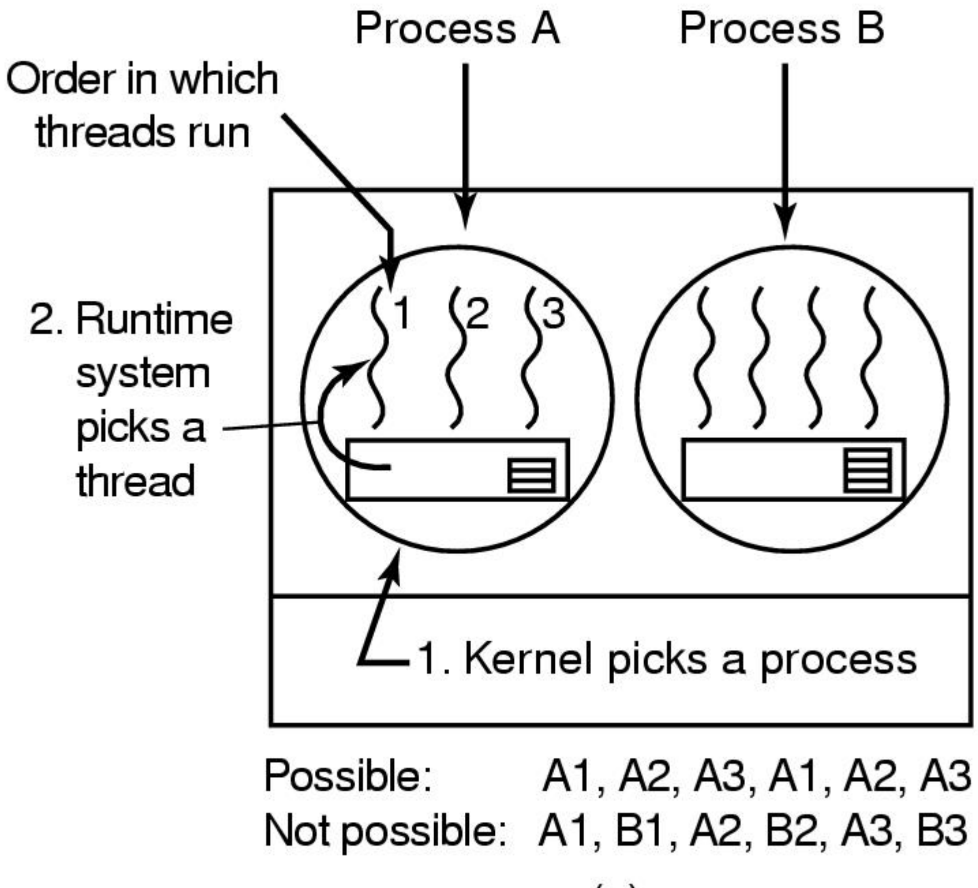
```c
}

/*
 * Pick up the highest-prio task:
 */
static inline struct task_struct *
pick_next_task(struct rq *rq, struct task_struct *prev, struct rq_flags *rf)
{
	const struct sched_class *class;
	struct task_struct *p;

	/*
	 * Optimization: we know that if all tasks are in the fair class we can
	 * call that function directly, but only if the @prev task wasn't of a
	 * higher scheduling class, because otherwise those loose the
	 * opportunity to pull in more work from other CPUs.
	 */
	if (likely((prev->sched_class == &idle_sched_class ||
		    prev->sched_class == &fair_sched_class) &&
		   rq->nr_running == rq->cfs.h_nr_running)) {

		p = fair_sched_class.pick_next_task(rq, prev, rf);
		if (unlikely(p == RETRY_TASK))
			goto again;

		/* Assumes fair_sched_class->next == idle_sched_class */
		if (unlikely(!p))
			p = idle_sched_class.pick_next_task(rq, prev, rf);

		return p;
	}

again:
	for_each_class(class) {
		p = class->pick_next_task(rq, prev, rf);
		if (p) {
			if (unlikely(p == RETRY_TASK))
				goto again;
			return p;
		}
	}

	/* The idle class should always have a runnable task: */
	BUG();
}

/*
 * __schedule() is the main scheduler function.
```

# Thread Scheduling

- Two levels of parallelism
- Thread scheduler
  - User-level thread
  - Kernel-level thread
  - (Hyper Thread)

# Thread Scheduling

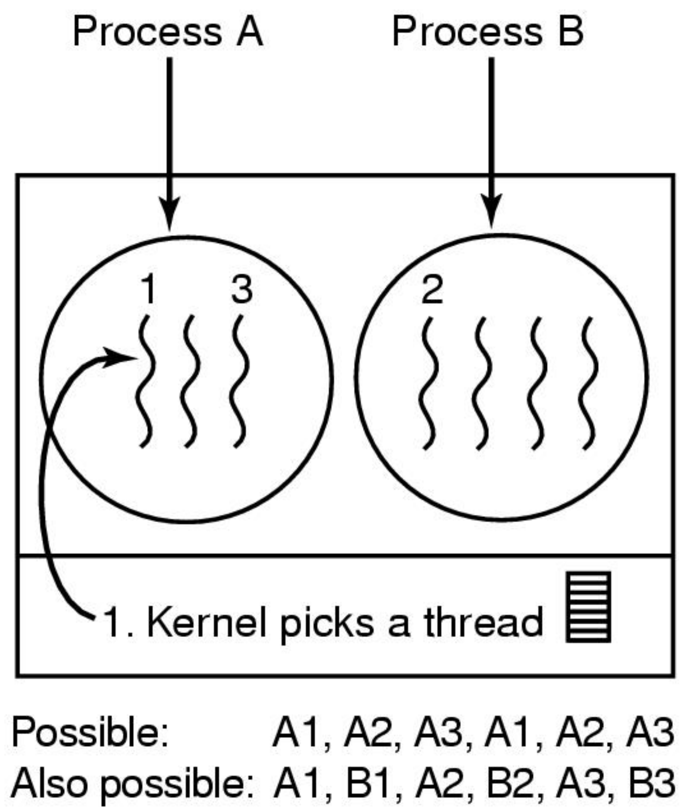
User-level thread: process-contention scope (PCS) 进程范围竞争




(a) Possible scheduling of user-level threads with a 50-msec process quantum and threads that run 5 msec per CPU burst.

# Thread Scheduling

Kernel-level thread: system-contention scope (SCS)




(b) Possible scheduling of kernel-level threads with the same characteristics as (a).

# Thread Scheduling Case

```
#include <pthread.h>  #include <stdio.h>
#define NUM THREADS 5
int main(int argc, char *argv[]){
 int i;
pthread_t tid[NUM THREADS];
pthread_attr t attr;
/* get the default attributes */
pthread_attr init(&attr);
/* set the scheduling algorithm to PROCESS or SYSTEM */
pthread_attr setscope(&attr, PTHREAD_SCOPE_SYSTEM);
/* set the scheduling policy - FIFO, RT, or OTHER */
pthread attr setschedpolicy(&attr, SCHED OTHER);
/* create the threads */
for (i = 0; i < NUM THREADS; i++)
pthread_create(&tid[i],&attr,runner,NULL);
```

# Thread Scheduling Case

```
/* now join on each thread */
for (i = 0; i < NUM THREADS; i++)
  pthread_join(tid[i], NULL);
}

 /* Each thread will begin control in this function */
void *runner(void *param)
{
   printf("I am a thread\n");
   pthread_exit(0);
}
```

# Thread Scheduling

- Pthread Scheduling
  - PTHREAD_SCOPE_PROCESS schedules threads using PCS scheduling
  - PTHREAD_SCOPE_SYSTEM schedules threads using SCS scheduling
- pthread attr setscope(pthread attr t *attr, int scope)
- pthread attr getscope(pthread attr t *attr, int *scope)

# Policy v.s. Mechanism

- Scheduling mechanism 调度机制
- Scheduling policy 调度策略

# Summary

- Scheduler
- Process Behavior
- Scheduling Mode
- Scheduling Criteria
- Scheduling Algorithms
- Thread Scheduling
- …

# Q&A?


рахмат
danke
謝謝
ngiyabonga
teşekkür ederim
Баярлалаа
спасибо
faafetai lava
vinaka
mersi
kia ora
barka
welalin
spas
tack
dank je
misaotra
matondo
paldies
grazzi
mahalo
tapadh leat
спасибі
blagodaram
kiitos
dankie
nanni
nandri
dhanyavad
thank you
gracias
хвала
asante
manana
obrigada
tenki
bedankt
bayarlalaa
gràcie
hvala
mauruuru
köszönöm
akun dankon aciū
enkosi
djiere dieuf
tau
mochchakkeram
murakoze
mamnun
дякую
chokrane
dziękuję
chnorakaloutioun
gratias ago
grácies
sulpáy
go raibh maith agat
sobodi
dekuji
obrigado
sagolun
sukriya
kop khun krap
taiku
arigatô
takk
dakujem
trugarez
mèsi
didi madloba
najis tuke
ありがとう
tanemirt
grazie
terima kasih
rahmet
kam sah hamnida
rahmat
diolch
dhanyavadagalu
shukriya
merce
мерси
তোমাকে ধন্যবাদ
감사합니다
xièxie
ευχαριστώ
merci