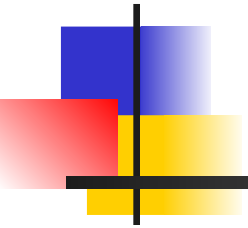
Operating System Principles

操作系统原理



Process/Thread Scheduling

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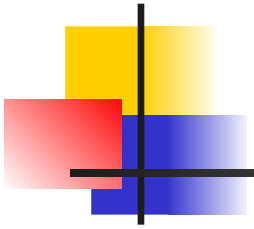
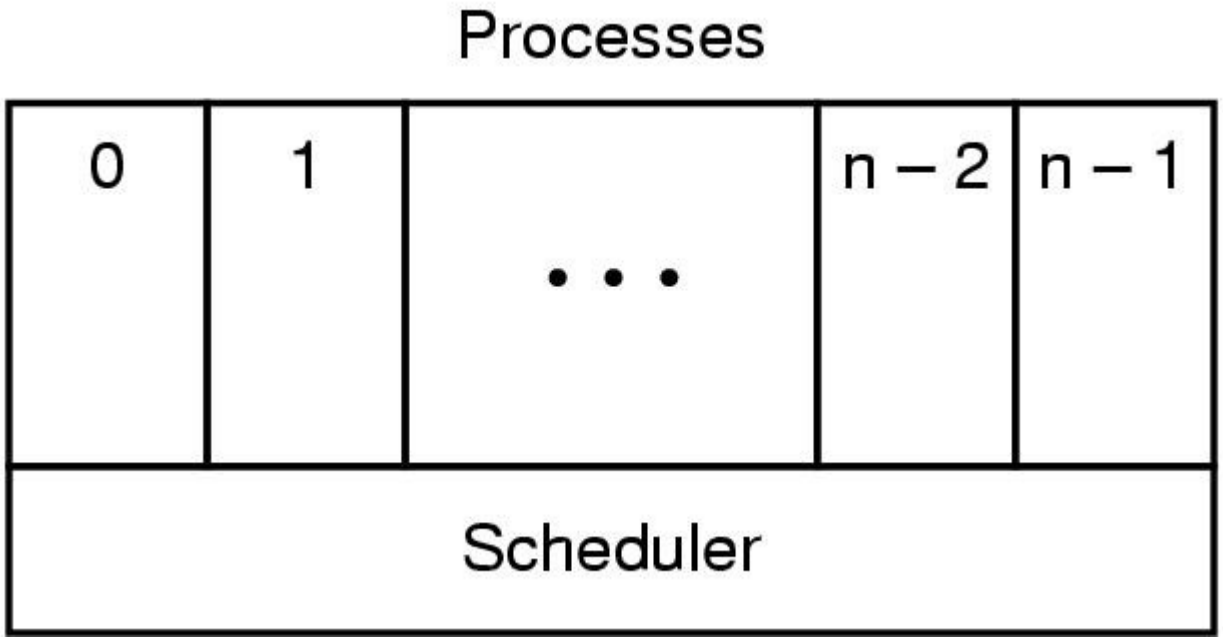


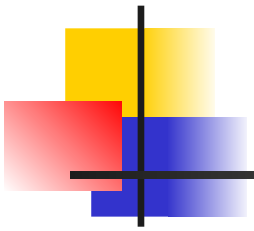
Objectives

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

MultiProgramming

- Scheduler
- Scheduling algorithm

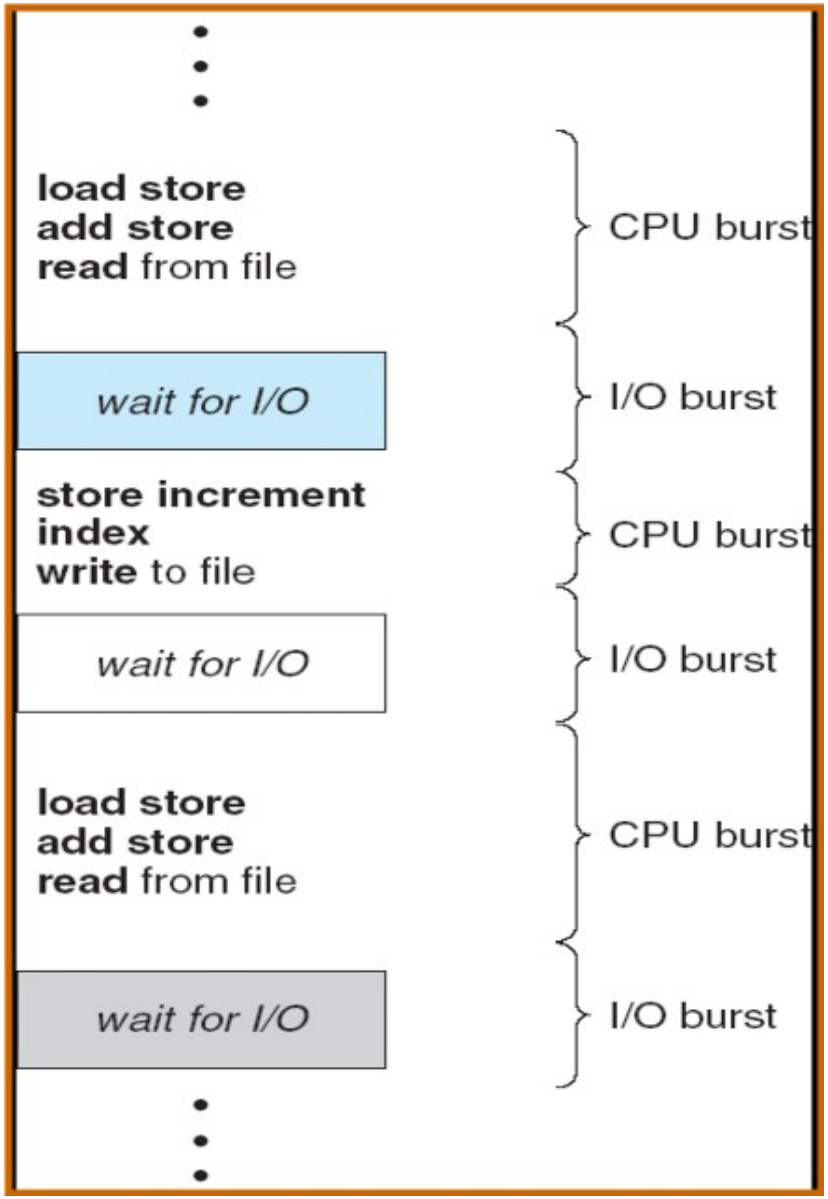




Scheduler

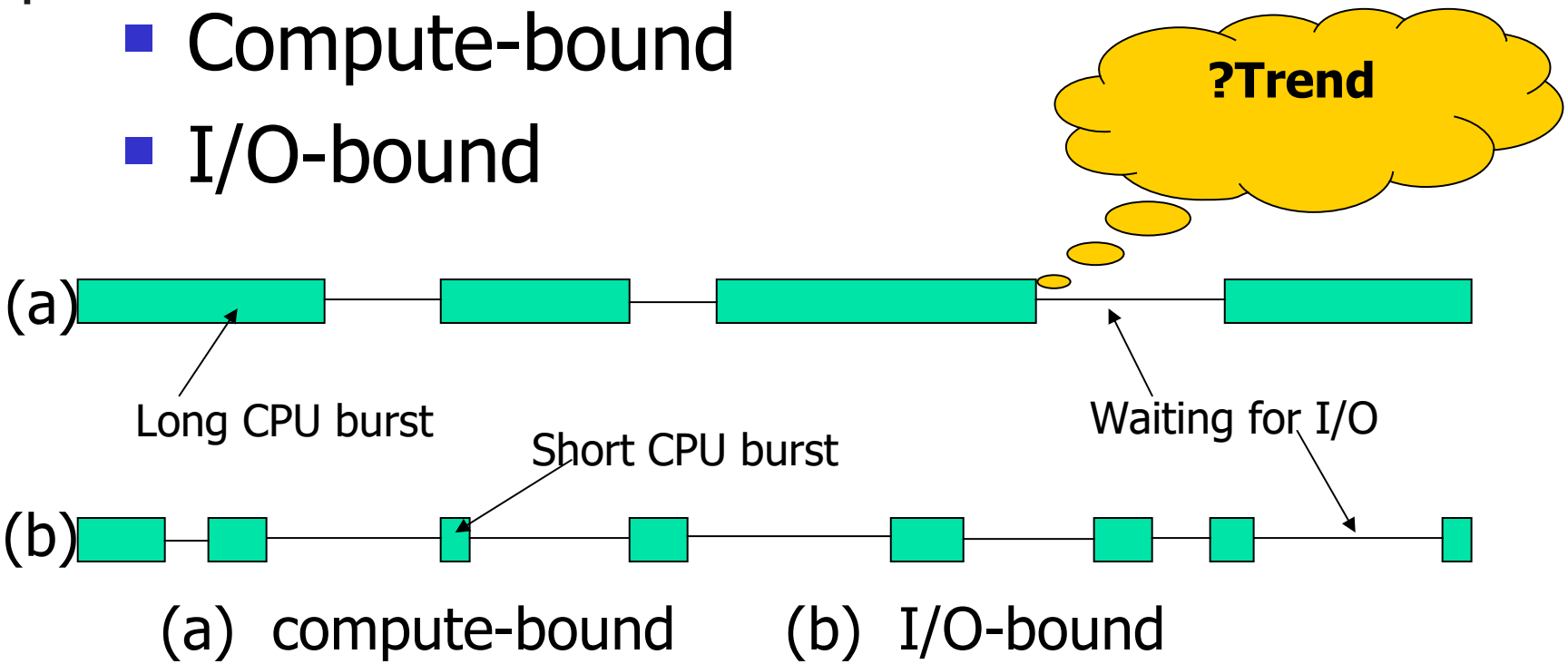
- Short-term Scheduler
  - CPU
- Middle-term Scheduler
  - Memory
- Long-term Scheduler
  - Job

CPU And I/O Bursts in a Process



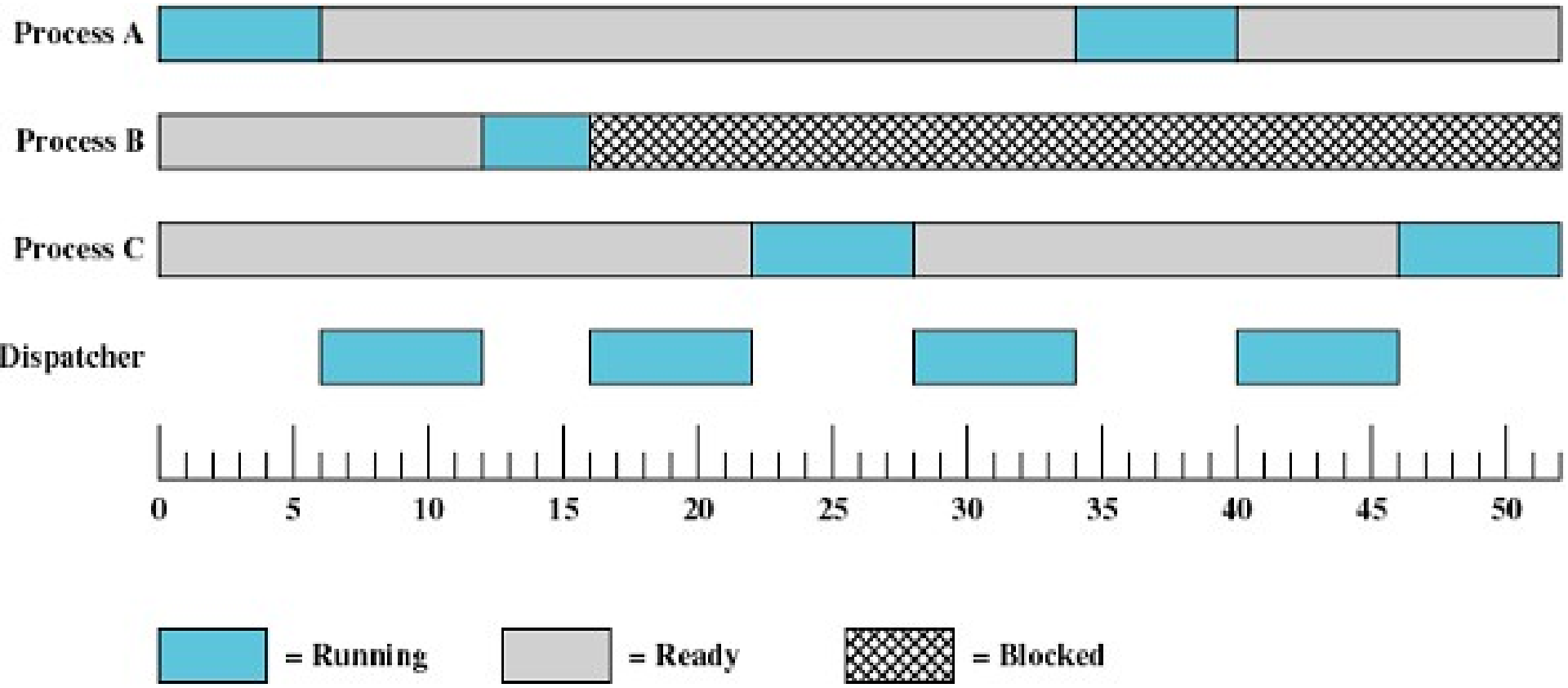
Process Behavior

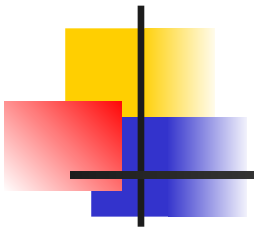
- Compute-bound
- I/O-bound



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

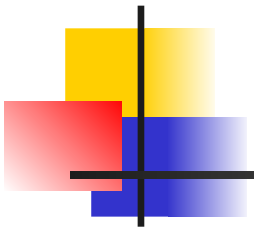
Multi-Processes Trace





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

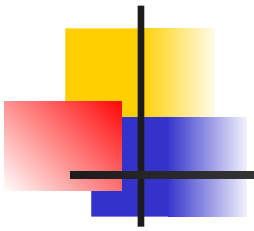


Dispatcher

- 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
- Realtime

Scheduling Criteria

- CPU utilization
- Throughout
- Turnaround time
  - 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

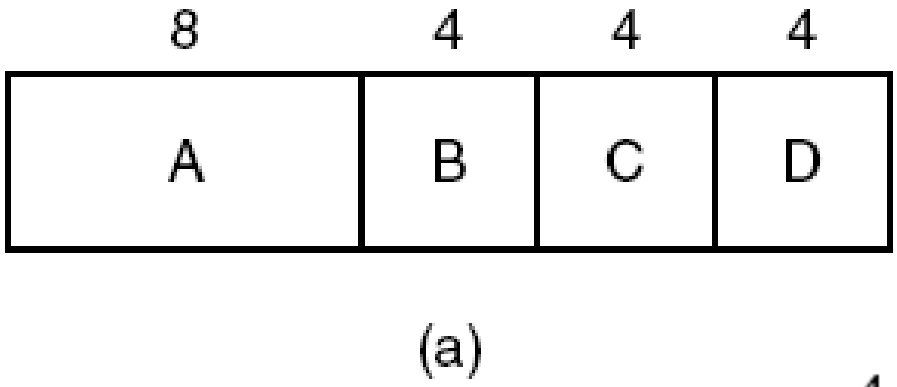
- Average waiting time

Process	Burst Time
P_1	24
P_2	3
P_3	3

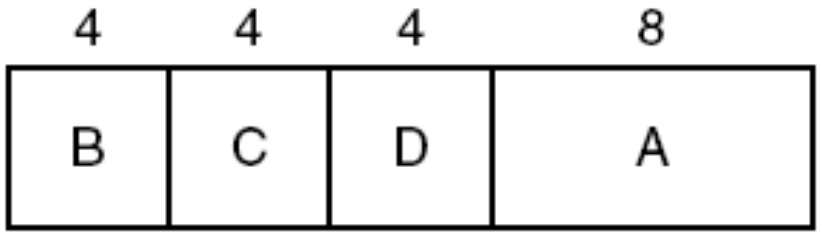
Awt=(0+24+27)/3=17

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

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

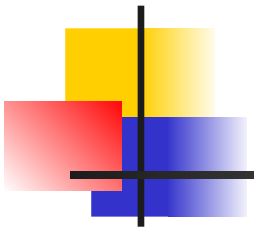
Shortest remaining Time next

- 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

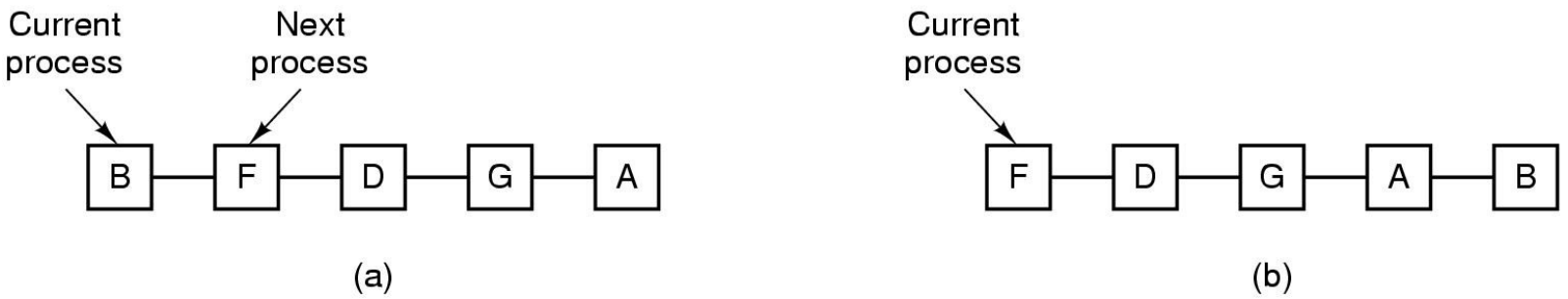
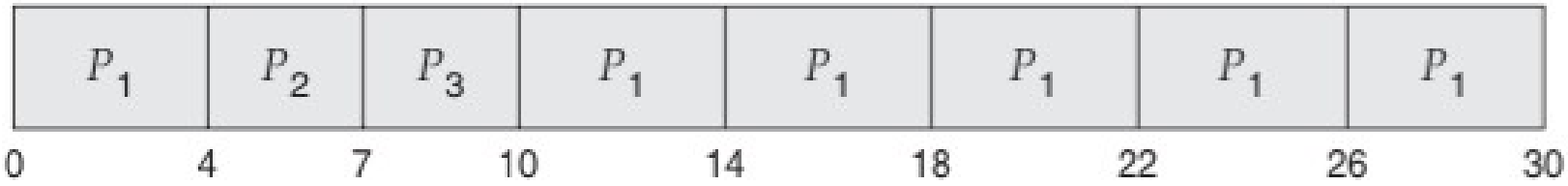


Figure 2-41. Round-robin scheduling.
(a) The list of runnable processes.
(b) The list of runnable processes after B uses up its quantum.

Round-Robin Scheduling

Process	Burst Time
P_1	24
P_2	3
P_3	3

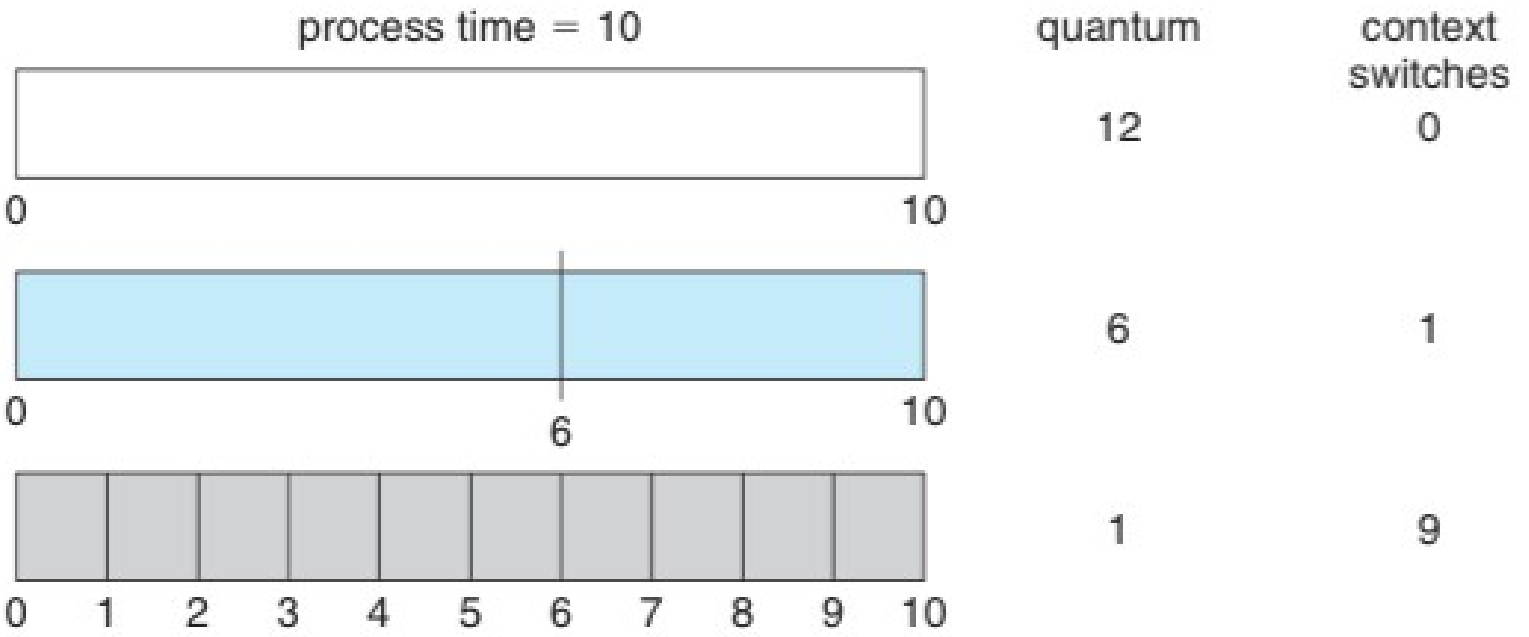
a time quantum of 4 milliseconds



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

Quantum Value

- How a smaller time quantum increases context switches



Priority Scheduling

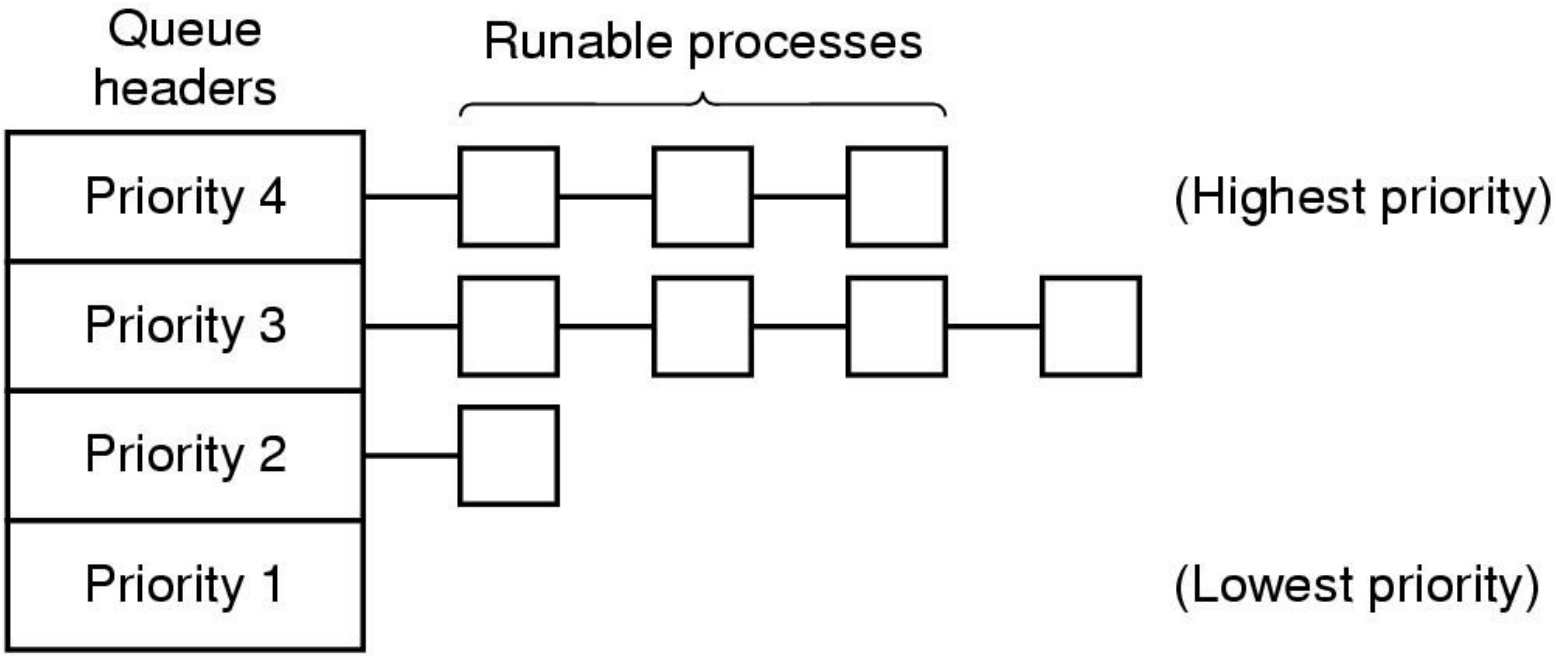
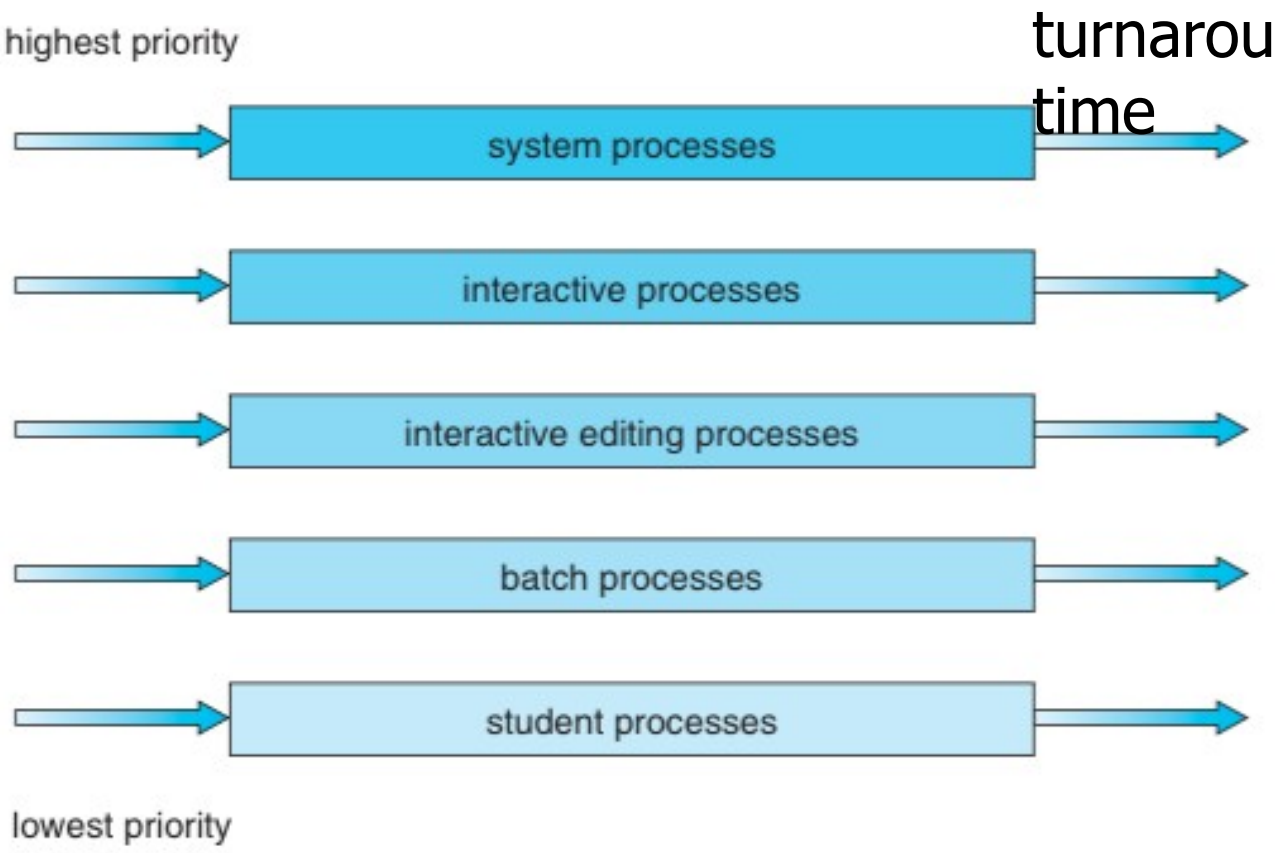


Figure. A scheduling algorithm with four priority classes.

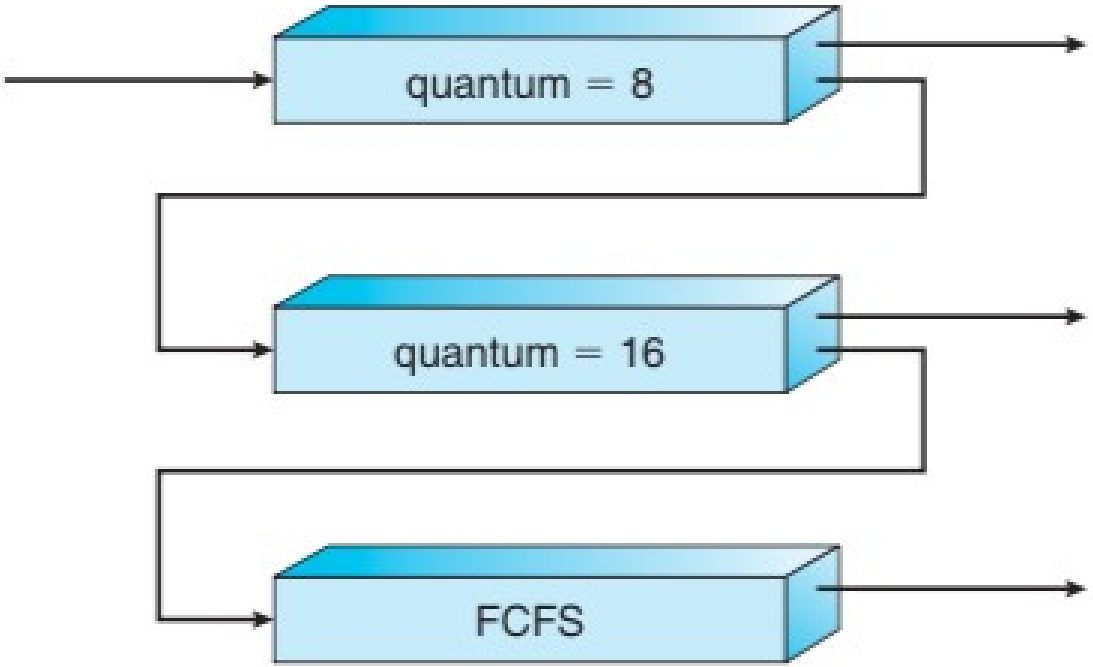
Multilevel Queue Scheduling

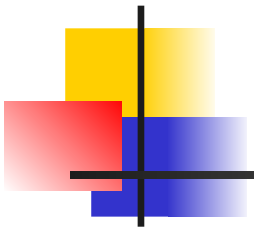
- Foreground (interactive) processes
- Background (batch) processes



Mutlilevel Feedback Queue Scheduling

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





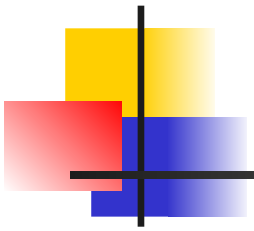
Mutli-level Feedback Queue Scheduling

- 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
- ...

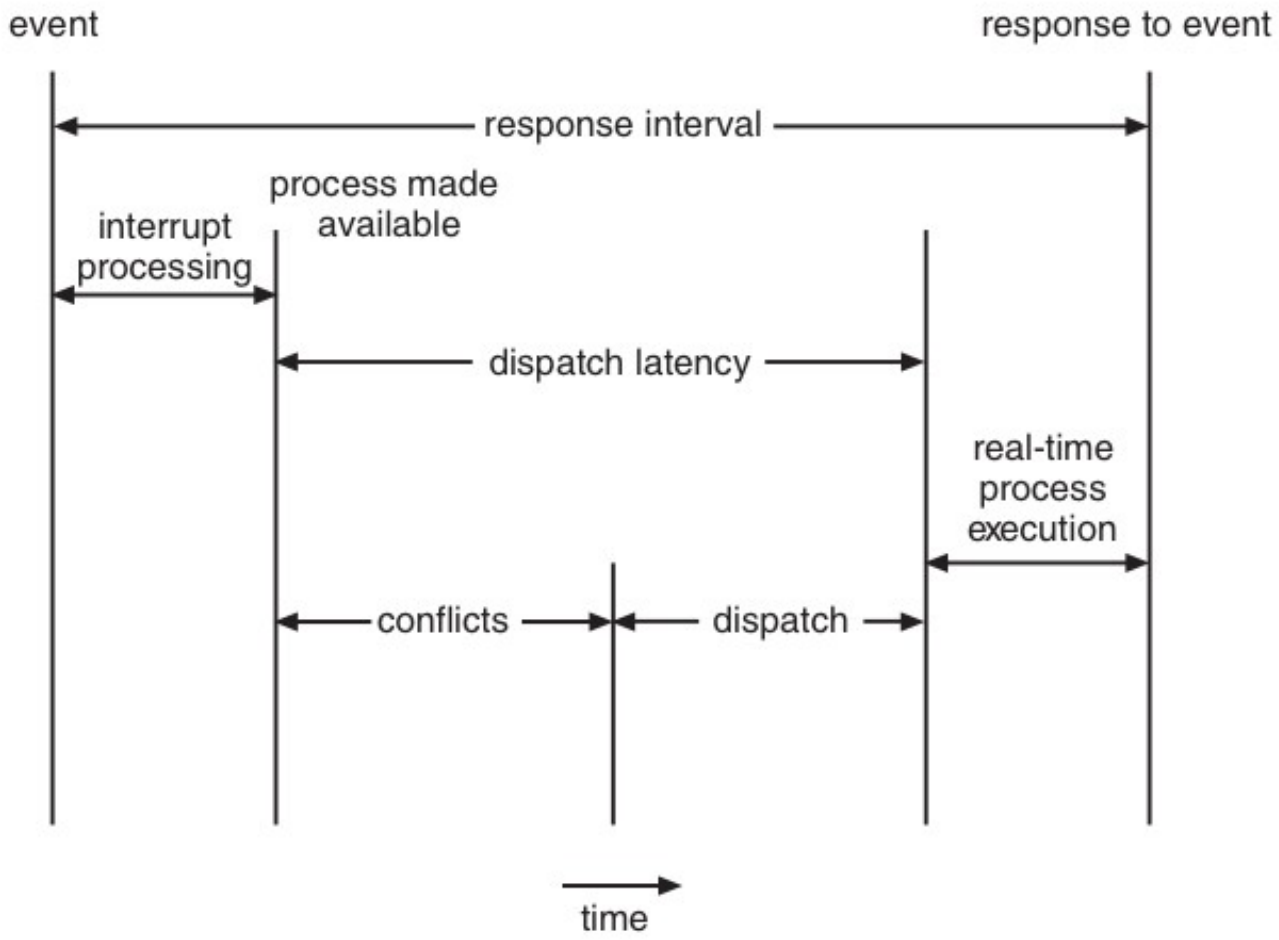


Scheduling in RealTime System

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

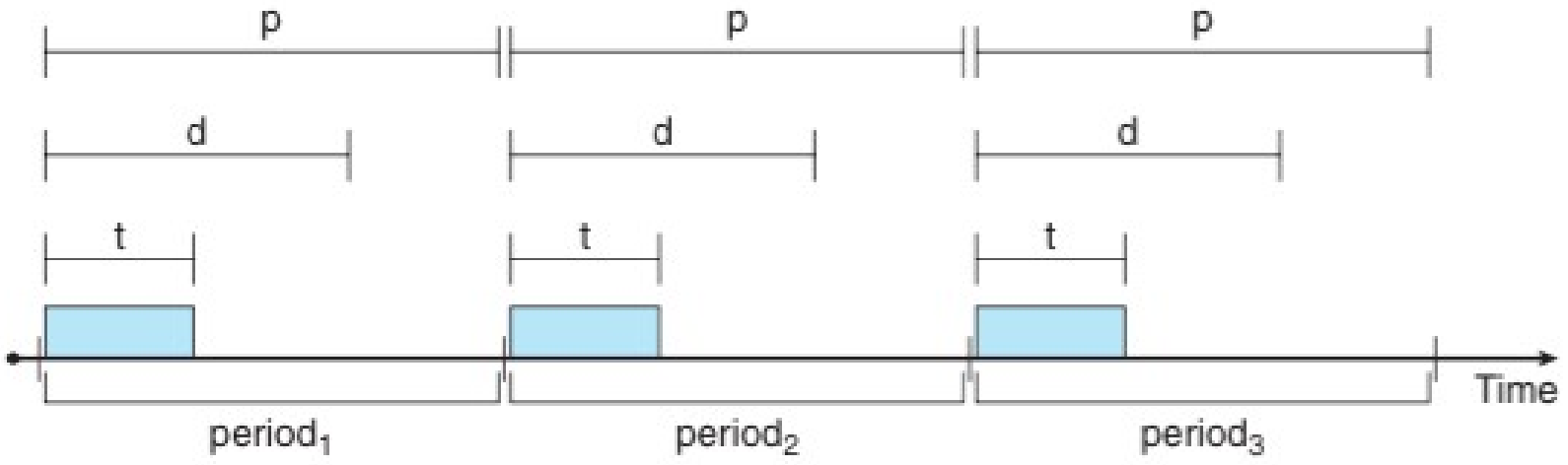
Real-time CPU Scheduling

- Minimizing Latency
  - Interrupt latency, Dispatch latency

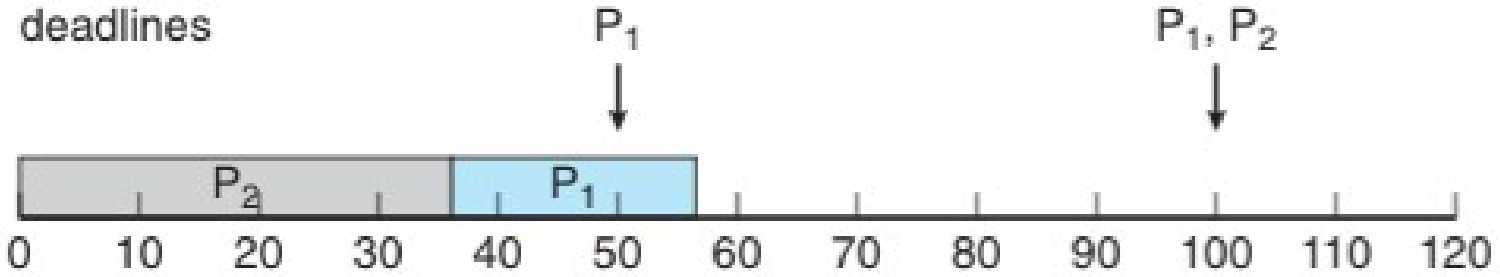


Real-time CPU Scheduling

- Priority-Based Scheduling



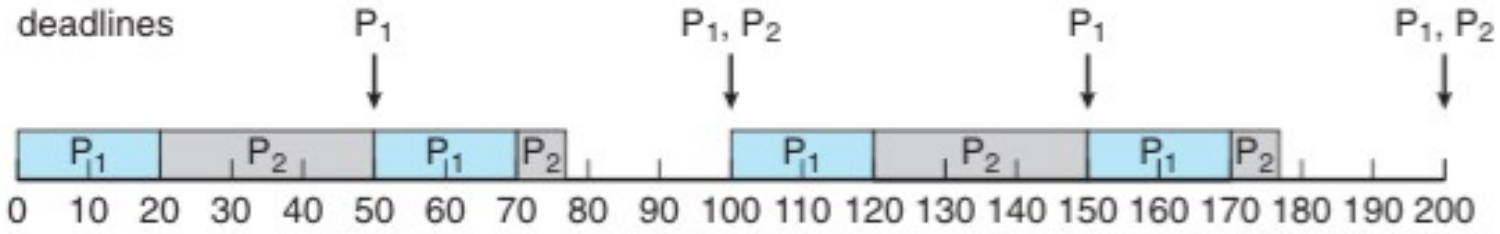
Example: P2 has a higher priority than P1



Real-time CPU Scheduling

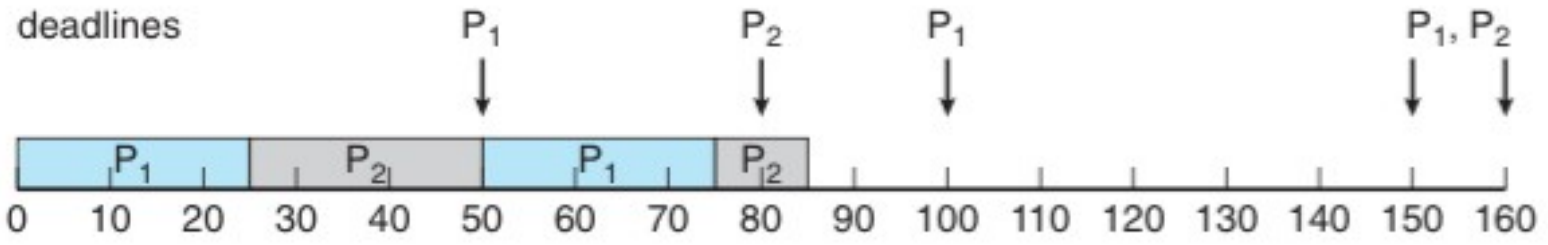
- Rate-Monotonic Scheduling
  - a static priority policy with preemption

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

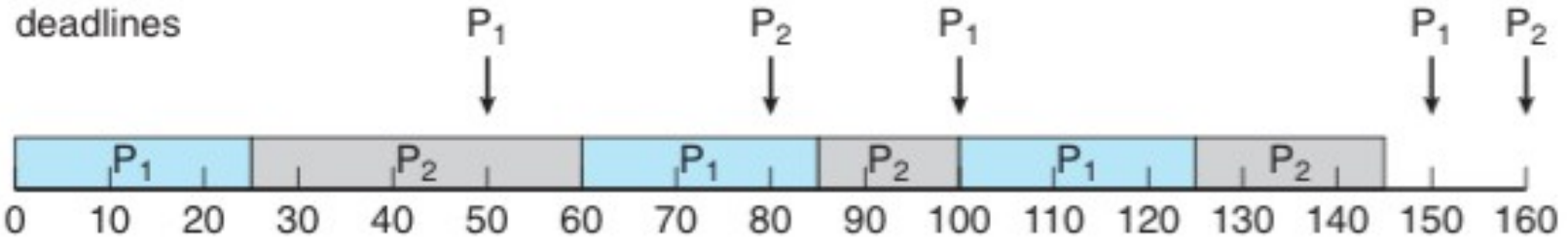


Real-time CPU Scheduling

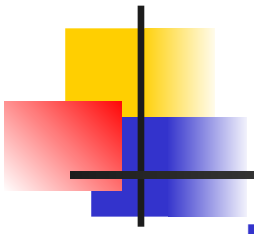
- Earliest-Deadline-First Scheduling
  - dynamically assigns priorities according to deadline



Missing deadlines with rate-monotonic scheduling



Earliest-deadline-first scheduling



Real-time CPU Scheduling

- Proportional 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
- 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)

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

```
3193 }
3194
3195 /*
3196  * Pick up the highest-prio task:
3197  */
3198 static inline struct task_struct *
3199 pick_next_task(struct rq *rq, struct task_struct *prev, struct rq_flags *rf)
3200 {
3201         const struct sched_class *class;
3202         struct task_struct *p;
3203
3204         /*
3205          * Optimization: we know that if all tasks are in the fair class we can
3206          * call that function directly, but only if the @prev task wasn't of a
3207          * higher scheduling class, because otherwise those loose the
3208          * opportunity to pull in more work from other CPUs.
3209          */
3210         if (likely((prev->sched_class == &idle_sched_class ||
3211                     prev->sched_class == &fair_sched_class) &&
3212                    rq->nr_running == rq->cfs.h_nr_running)) {
3213
3214                 p = fair_sched_class.pick_next_task(rq, prev, rf);
3215                 if (unlikely(p == RETRY_TASK))
3216                         goto again;
3217
3218                 /* Assumes fair_sched_class->next == idle_sched_class */
3219                 if (unlikely(!p))
3220                         p = idle_sched_class.pick_next_task(rq, prev, rf);
3221
3222                 return p;
3223         }
3224
3225 again:
3226         for_each_class(class) {
3227                 p = class->pick_next_task(rq, prev, rf);
3228                 if (p) {
3229                         if (unlikely(p == RETRY_TASK))
3230                                 goto again;
3231                         return p;
3232                 }
3233         }
3234
3235         /* The idle class should always have a runnable task: */
3236         BUG();
3237 }
3238
3239 /*
3240  * __schedule() is the main scheduler function.
```

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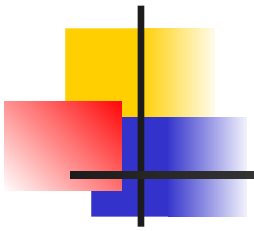
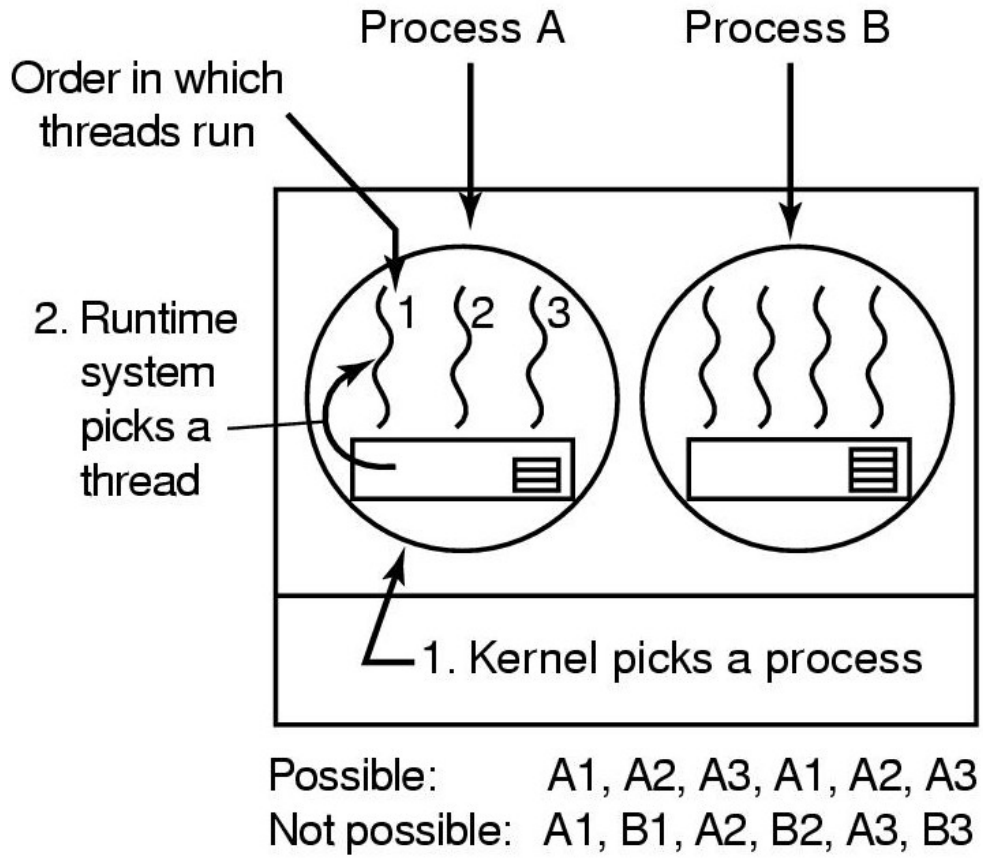


Thread Scheduling

- Two levels of parallelism
- Thread scheduler
  - Kernel-level thread
  - User-level thread

Thread Scheduling

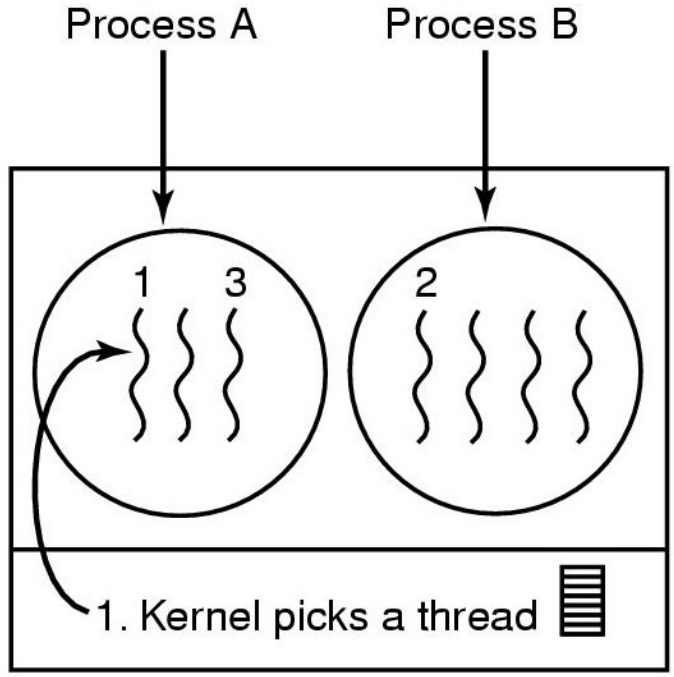
User-level thread: process-contention scope (PCS)
进程范围竞争



(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

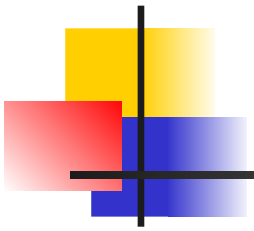
```
/* now join on each thread */
for (i = 0; i < NUM THREADS; i++)
pthread_join(tid[i], NULL);
}

 /* 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
- Scheduling policy



Summary

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