Lecture 6

CPU scheduling II & Process Synchronization I

Lecture Information

Ceng328 *Operating Systems* at March 23, 2010

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Contents

First-Come, First-Served Scheduling I

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- The average waiting time under the FCFS policy, however, is often quite long. Consider the following set of processes that arrive at time 0, with the length of the CPU burst given in milliseconds:

Process	Burst Time	Waiting Time	Turnaround Time
P_1	24	0	24
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P_3	3	27	30
Average	-	17	27

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- If the processes arrive in the order P_1, P_2, P_3, and are served in FCFS order, we get the result shown in the following chart:

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- The FCFS scheduling algorithm is nonpreemptive.
- Once the CPU has been allocated to a process, that process keeps the CPU until it releases the CPU, either by terminating or by requesting I/0.

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  - Again, all the I/O processes end up waiting in the ready queue until the CPU-bound process is done.
  - There is a **convoy effect** as all the other processes wait for the one big process to get off the CPU. A long CPU-bound job may take the CPU and may force shorter (or I/O-bound) jobs to wait prolonged periods.
- This effect results in lower CPU and device utilization than might be possible if the shorter processes were allowed to go first.

First-Come, First-Served Scheduling IV

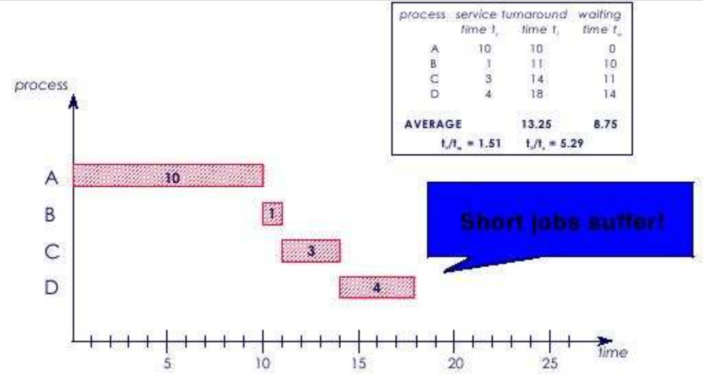

Figure: An example to First-Come First-Served.

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- As an example of SJF scheduling, consider the following set of processes, with the length of the CPU burst given in milliseconds:

Process	Burst Time	Waiting Time	Turnaround Time
P_1	6	3	9
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P_3	7	9	16
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- By comparison, if we were using the FCFS scheduling scheme, the average waiting time would be 10.25 milliseconds.

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- Although the SJF algorithm is optimal, it can not be implemented at the level of short-term CPU scheduling. There is no way to know the length of the next CPU burst.
- Also, long running jobs may starve for the CPU when there is a steady supply of short jobs.
- Example: In Fig. 2a, the average turnaround time is 14 minutes. Consider running these four jobs using SJF, as shown in Fig. 2b, the average turnaround time now becomes 11 minutes.

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

Shortest-Job-First Scheduling III

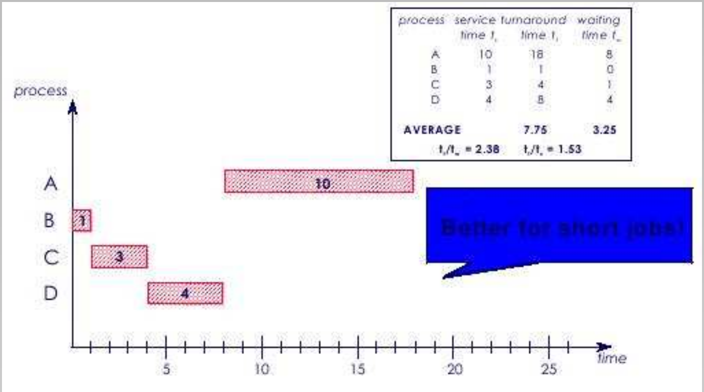

Figure: An example to Shortest Job First.

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- A pre-emptive SJF algorithm will preempt the currently executing process, whereas a nonpreemptive SJF algorithm will allow the currently running process to finish its CPU burst.

Process	Arrival Time	Burst Time	Waiting Time	Turnaround Time
P_1	0	8	9	17
P_2	1	4	0	4
P_3	2	9	15	24
P_4	3	5	2	7
Average	-	-	6.5	13

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- If the processes arrive at the ready queue at the times shown and need the indicated burst times, then the resulting pre-emptive SJF schedule is as depicted in the following chart:

- Nonpreemptive SJF scheduling would result in an average waiting time of 7.75 milliseconds.

Shortest-Job-First Scheduling V

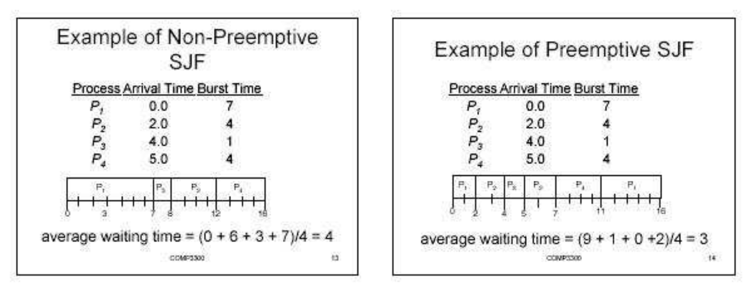

Figure: Example of non-pre-emptive SJF and pre-emptive SJF.

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- A priority is associated with each process, and the CPU is allocated to the process with the highest priority.
- Priorities are generally indicated by some fixed range of numbers, such as 0 to 7 or 0 to 4095. We use as low numbers represent high priority.

Process	Burst Time	Priority	Waiting Time	Turnaround Time
P_1	10	3	6	16
P_2	1	1	0	1
P_3	2	4	16	18
P_4	1	5	18	19
P_5	5	2	1	6
Average	-	-	8.2	12

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- A major problem with priority scheduling algorithms is **indefinite blocking**, or **starvation.** A process that is ready to run but waiting for the CPU can be considered blocked.
  - A priority scheduling algorithm can leave some low priority processes waiting indefinitely.
  - In a heavily loaded computer system, a steady stream of higher-priority processes can prevent a low-priority process from ever getting the CPU.

Priority Scheduling III

- It is often convenient to group processes into priority classes and use priority scheduling among the classes but round-robin scheduling within each class. Figure 5 shows a system with four priority classes.

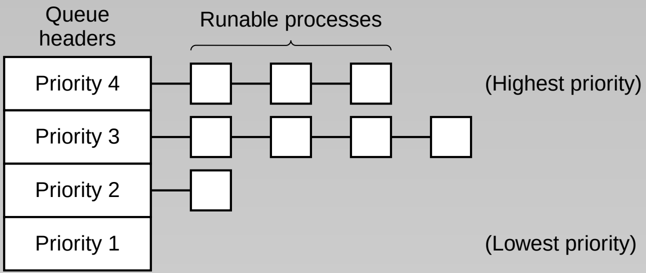

Figure: A scheduling algorithm with four priority classes.

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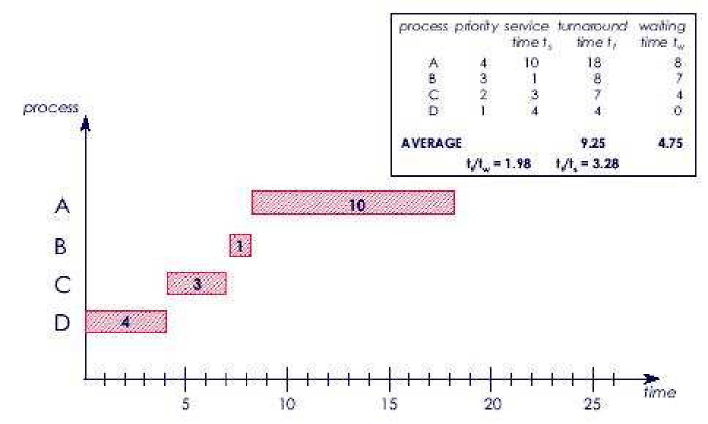
  - For example, if priorities range from 127 (low) to 0 (high), we could increase the priority of a waiting process by 1 every 15 minutes.
  - Eventually, even a process with an initial priority of 127 would have the highest priority in the system and would be executed.

Priority Scheduling V



process	priority	service time t_s	turnaround time t_r	waiting time t_w
A	4	10	18	8
B	3	1	8	7
C	2	3	7	4
D	1	4	4	0
AVERAGE			9.25	4.75
		t_r/t_w = 1.98	t_r/t_s = 3.28	

Figure: An example to Priority-based Scheduling.

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- A time quantum is generally from 10 to 100 milliseconds.
- The ready queue is treated as a circular queue.

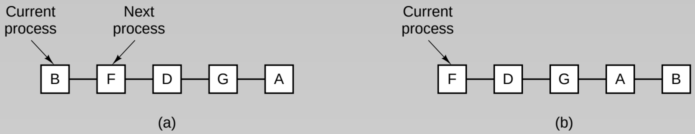

Figure: Round-robin scheduling. (a) The list of runnable processes. (b) The list of runnable processes after B uses up its quantum.

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- The average waiting time under the RR policy is often long.
- Consider the following set of processes that arrive at time 0, with the length of the CPU burst given in milliseconds: (a time quantum of 4 milliseconds)

Process	Burst Time	Waiting Time	Turnaround Time
P_1	24	6	30
P_2	3	4	7
P_3	3	7	10
Average	-	5.66	15.66

Round-Robin Scheduling IV

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- The performance of the RR algorithm depends heavily on the size of the time quantum.
  - If the time quantum is extremely large, the RR policy is the same as the FCFS policy.
  - If the time quantum is extremely small (say, 1 millisecond), the RR approach is called **processor sharing** and (in theory) creates the appearance that each of n processes has its own processor running at $\frac{1}{n}$ the speed of the real processor.

Round-Robin Scheduling V

- We need also to consider the effect of context switching on the performance of RR scheduling (see Fig. 8).

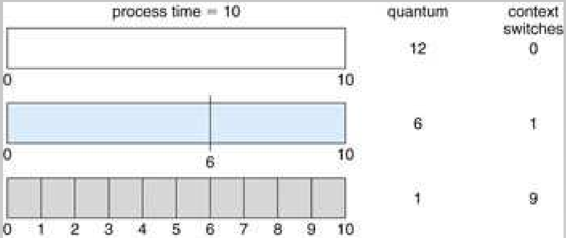

Figure: The way in which a smaller time quantum increases context switches.

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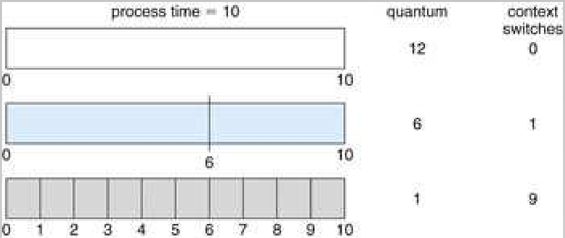
    - Let us assume that we have only one process of 10 time units.



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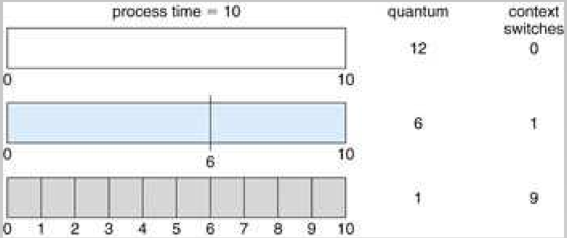

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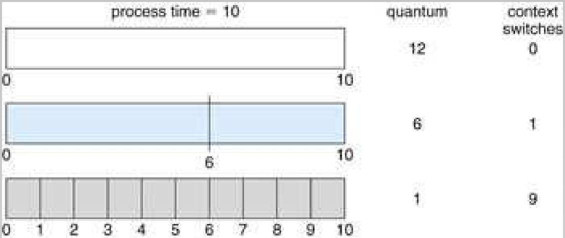

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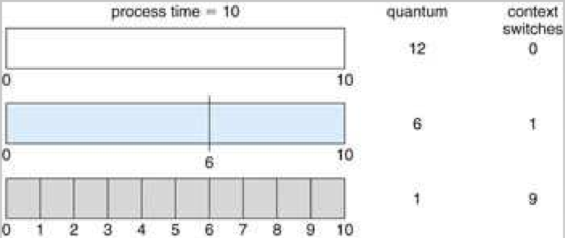
  - If the time quantum is 1 time unit, then nine context switches will occur, slowing the execution of the process accordingly



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- Thus, we want the time quantum to be large with respect to the context-switch time.
  - If the context-switch time is approximately 10 percent of the time quantum, then about 10 percent of the CPU time will be spent in context switching.
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- Thus, we want the time quantum to be large with respect to the context-switch time.
  - If the context-switch time is approximately 10 percent of the time quantum, then about 10 percent of the CPU time will be spent in context switching.
  - In practice, most modern systems have time quanta ranging from 10 to 100 milliseconds.
  - The time required for a context switch is typically less than 10 microseconds; thus, the context-switch time is a small fraction of the time quantum.
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- Thus, we want the time quantum to be large with respect to the context-switch time.
  - If the context-switch time is approximately 10 percent of the time quantum, then about 10 percent of the CPU time will be spent in context switching.
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- Setting the quantum too short causes too many process switches and lowers the CPU efficiency, but setting it too long may cause poor response to short interactive requests.
- Although the time quantum should be large compared with the context-switch time, it should not be too large. If the time quantum is too large, RR scheduling degenerates to FCFS policy.

Round-Robin Scheduling VII

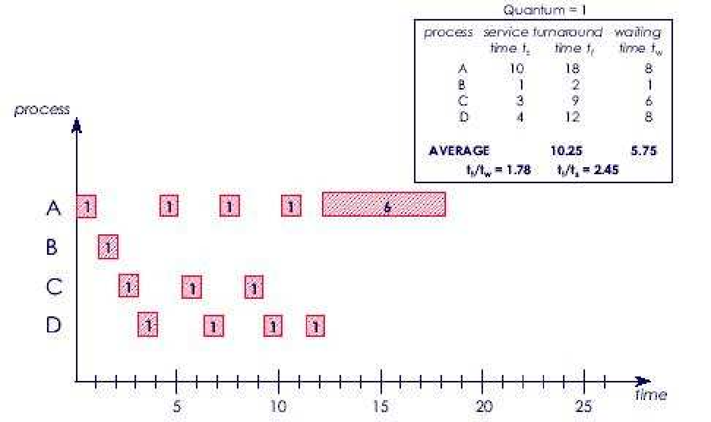

Figure: An example to Round Robin.

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- Another class of scheduling algorithms has been created for situations in which processes are easily classified into different groups.
- A common division is made between **foreground (interactive)** processes and **background (batch)** processes.
- A multilevel queue scheduling algorithm partitions the ready queue into several separate queues (see Fig. 10).

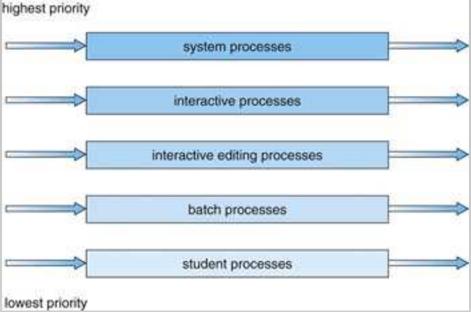

Figure: Multilevel queue scheduling.

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- For example, the foreground queue may have absolute priority over the background queue.

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  - This scheme leaves I/O-bound and interactive processes in the higher-priority queues.
  - In addition, a process that waits too long in a lower-priority queue may be moved to a higher-priority queue.
- The definition of a multilevel feedback-queue scheduler makes it the most general CPU-scheduling algorithm. Unfortunately, it is also the most complex algorithm.

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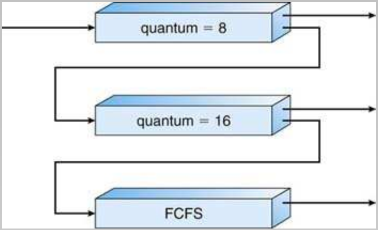

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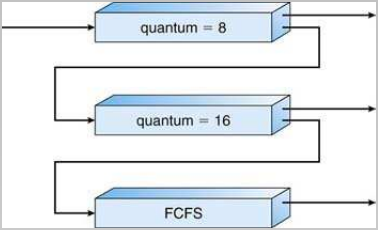

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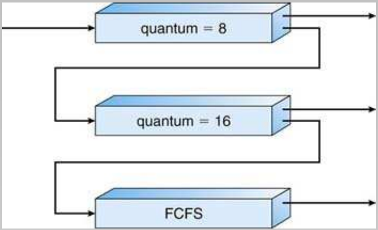

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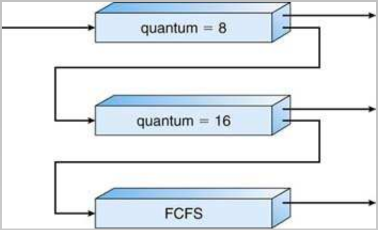

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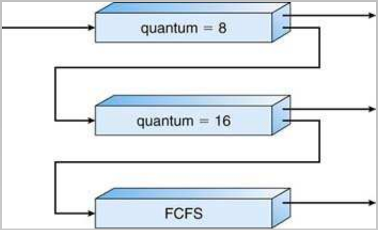

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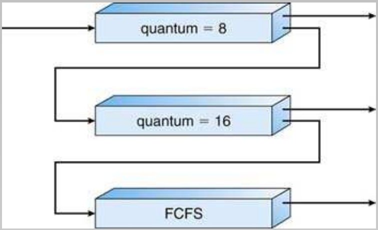

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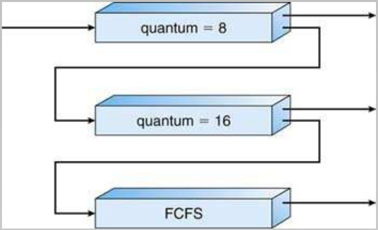

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- Processes in queue 2 are run on an FCFS basis but are run only when queues 0 and 1 are empty.

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  - Regardless, scheduling proceeds by having the scheduler for each processor examine the ready queue and select a process to execute.
- if we have multiple processors trying to access and update a common data structure, we must ensure that two processors do not choose the same process and that processes are not lost from the queue.

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- It is important to note that in most contemporary OSs supporting SMP, each processor does have a private queue of eligible processes.

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- Linux runs its load balancing algorithm every 200 milliseconds (push migration) or whenever the run queue for a processor is empty (pull migration).

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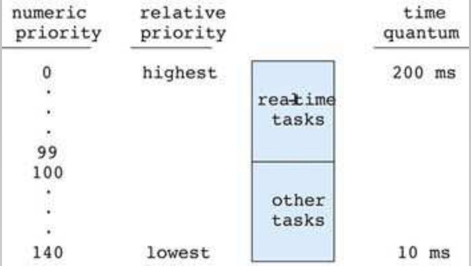

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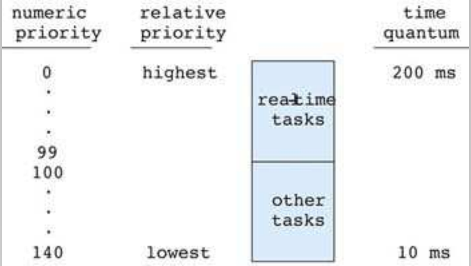

Figure: The relationship between priorities and time-slice length.

- A runnable task is considered eligible for execution on the CPU as long as it has time remaining in its time slice.

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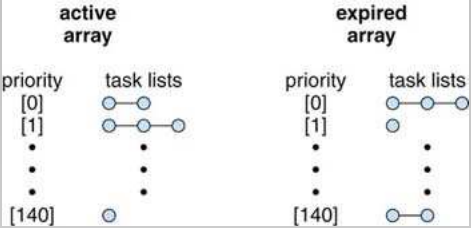

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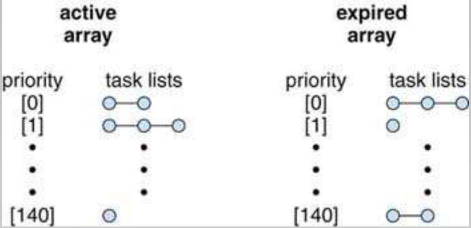

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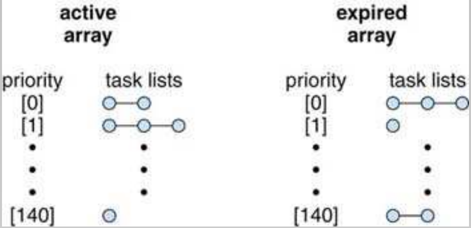

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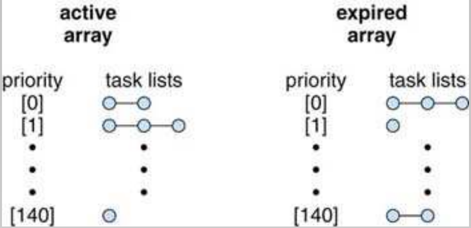

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- Each of these priority arrays contains a list of tasks indexed according to priority (see Fig. 13).

Race Condition I

- A potential problem; the order of instructions of cooperating processes (see Table 1).

Table: Race Condition

Process A	Process B	concurrent access
X = 1;	**Y = 2;**	*does not matter*
X = Y + 1;	**Y = Y * 2;**	*important!*

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X = 1;	Y = 2;	*does not matter*
X = Y + 1;	Y = Y * 2;	*important!*

- A ***race condition*** is a situation where two or more processes access shared data concurrently and final value of shared data depends on *timing* (*race* to access and modify data)

Race Condition I

- A potential problem; the order of instructions of cooperating processes (see Table 1).

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- A ***race condition*** is a situation where two or more processes access shared data concurrently and final value of shared data depends on *timing* (*race* to access and modify data)
- To guard against the race condition above, we need to ensure that only one process at a time can be manipulating the variable counter (**process synchronization**).

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- Although both the producer and consumer routines are correct separately, *they may not function correctly when executed concurrently*.
- We would arrive at incorrect state because we allowed both processes to manipulate the variable *counter* concurrently.

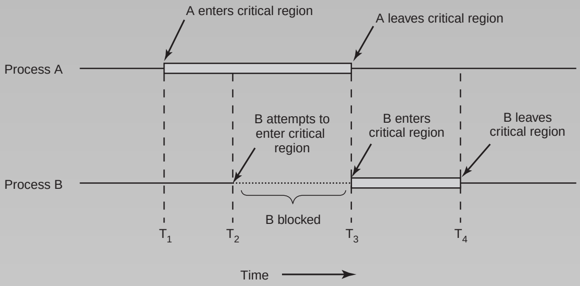
Race Condition III

- The code for the producer process:

```
while (true)
 {
   /* produce an item in next Produced */
   while (counter == BUFFER_SIZE)
     ; /* do nothing */
   buffer [in] = nextProduced;
   in = (in + 1) % BUFFER_SIZE;
   counter++;
 }
```


The Critical-Section Problem I

- How do we avoid *race conditions*? What we need is **mutual exclusion** (see Fig. 14).



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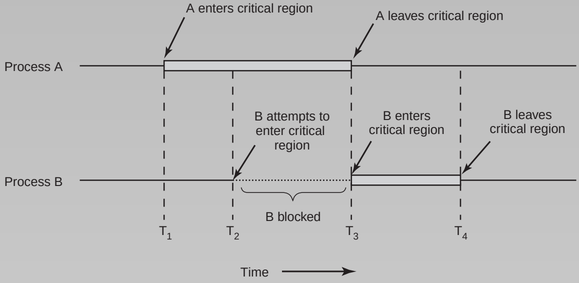

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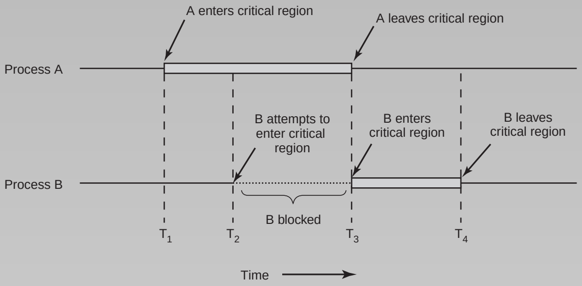

Figure: Mutual exclusion using critical regions.

- Consider a system consisting of *n* processes. Each process has a segment of code, called a **critical section (CS)**, in which the process may be changing common variables, updating a table, writing a file, and so on.
- The important feature of the system is that, when one process is executing in its CS, no other process is to be allowed to execute in its CS.

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- Each process must request permission to enter its CS. The section of code implementing this request is the **entry section**.
- The CS may be followed by an **exit section**.
- The remaining code is the **remainder section** (see Fig. 15).

```
do {
    entry section
        critical section
    exit section
        remainder section
} while (TRUE);
```

Figure: General structure of a typical process P_i.

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  5. **No assumptions** may be made about speeds or the number of CPUs.

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- With interrupts turned off the CPU will not be switched to another process!! Thus, once a process has disabled interrupts, it can examine and update the shared memory without fear that any other process will intervene.
- This approach is generally unattractive because it is unwise to give user processes the power to turn off interrupts. Suppose that one of them did it and never turned them on again? That could be the end of the system.
- On the other hand, it is frequently convenient for the kernel itself to disable interrupts for a few instructions while it is updating variables or lists.

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do {

    acquire lock

        critical section

    release lock

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} while (TRUE);
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Figure: Solution to the critical-section problem using locks.

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  - If the lock is 0, the process sets it to 1 and enters the CS.
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  - Thus, a 0 means that no process is in its CS, and a 1 means that some process is in its CS.

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  - Suppose that one process reads the lock and sees that it is 0.
  - Before it can set the lock to 1, another process is scheduled, runs, and sets the lock to 1.
  - When the first process runs again, it will also set the lock to 1, and two processes will be in their CSs at the same time.

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- **Busy waiting** (notice the semicolons terminating the while statements in Fig. 17); continuously testing a variable until some value appears, a lock that uses busy waiting is called a **spin lock**.

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- **Busy waiting** (notice the semicolons terminating the while statements in Fig. 17); continuously testing a variable until some value appears, a lock that uses busy waiting is called a **spin lock**.
- It should usually be avoided, since it wastes CPU time.

```
while (TRUE) {
    while (turn != 0)       /* loop */ ;
    critical_region( );
    turn = 1;
    noncritical_region( );
}

            (a)

while (TRUE) {
    while (turn != 1)       /* loop */ ;
    critical_region( );
    turn = 0;
    noncritical_region( );
}

            (b)
```

Figure: A proposed solution to the critical region problem. (a) Process 0. (b) Process 1.

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- it hangs in its while loop until process 1 sets turn to 0,
- this algorithm does avoid all races. But violates condition **Fault tolerance**.

Dr. Cem Özdoğan