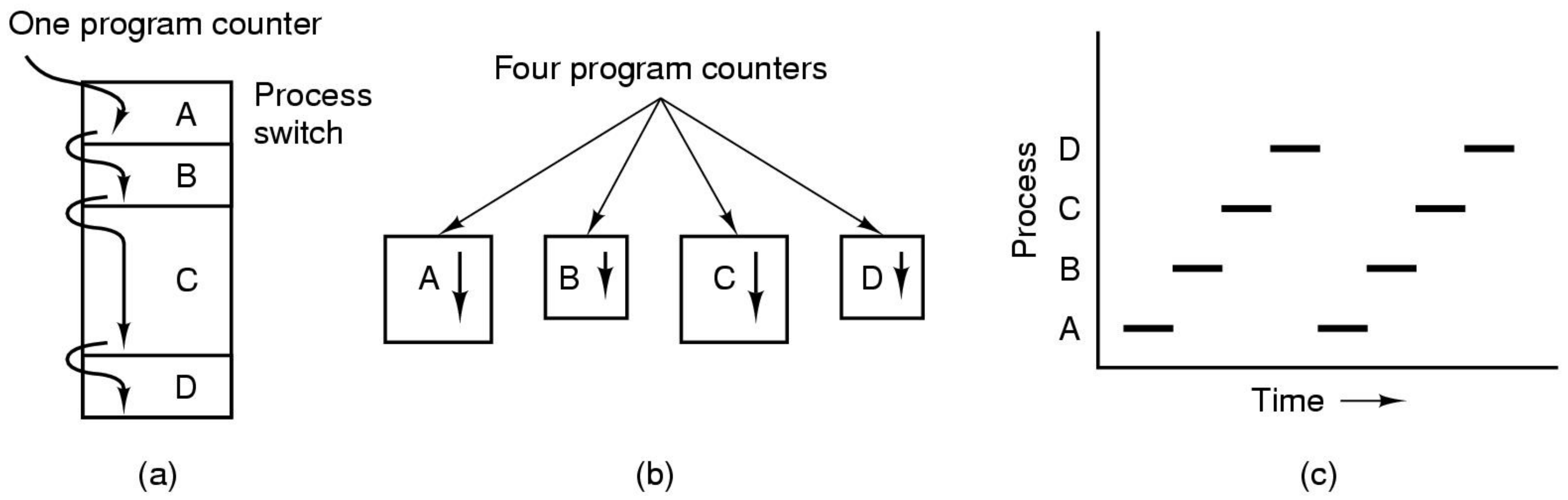
# Part 2

# Processes and Threads

## 2.1 Processes

# Processes
## The Process Model



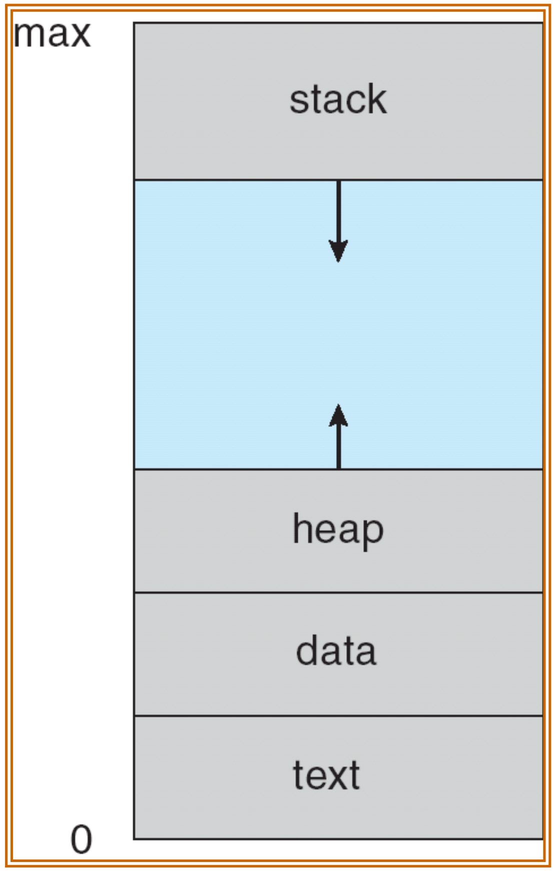
- (a) Multiprogramming of four programs
- (b) Conceptual model of 4 independent, sequential processes
- (c) Only one program active at any instant-Pseudoparallelism

# Processes
## Process Concept

- An operating system executes a variety of programs:
  - Batch system – jobs
  - Time-shared systems – user programs or tasks
- Process – a program in execution; process execution must progress in sequential fashion
- A process resources includes:
  - Address space (text segment, data segment, stack segment)
  - CPU (virtual)
    - program counter
    - registers
    - stack
  - Other resource (open files, child processes…)

# Processes

## Process in Memory



# Processes

## Process Creation (1)

Principal events that cause process creation

1. System initialization
2. Execution of a process creation system Call
3. User request to create a new process
4. Initiation of a batch job

System Call

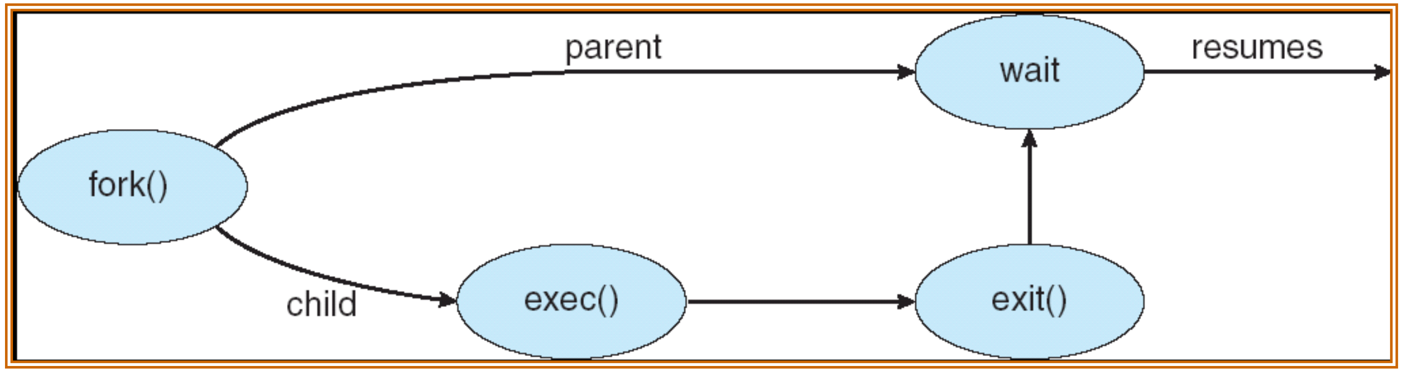
- Unix: fork
- Window: CreateProcess

## Processes
### Process Creation (2)

- Address space
  - Child duplicate of parent
  - Child has a program loaded into it
- UNIX examples
  - **fork** system call creates new process
  - **exec** system call used after a **fork** to replace the process' memory space with a new program

# Processes

## Process Creation (3) : Example



# Processes

## Process Termination

Conditions which terminate processes

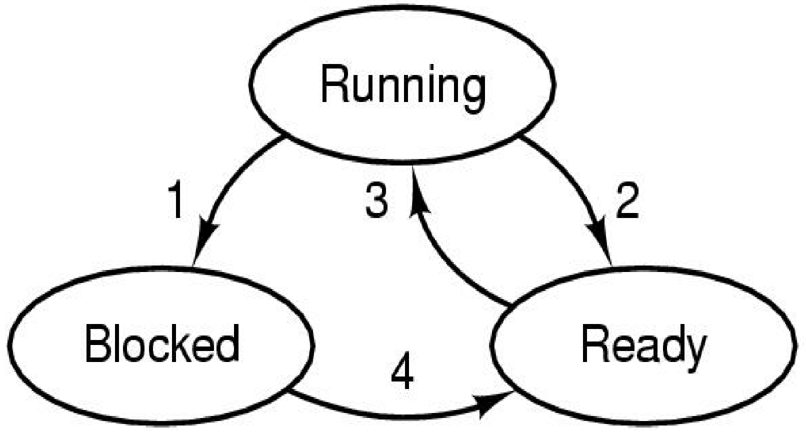
1. Normal exit (voluntary )
   - System Call:
     - Unix: exit
     - Window: ExitProcess
2. Error exit (voluntary)
3. Fatal error (involuntary)
4. Killed by another process (involuntary)
   - System Call:
     - Unix: kill,
     - Window: TerminateProcess

# Processes

## Process Hierarchies

- Parent creates a child process, child processes can create its own process
- Forms a hierarchy
  - UNIX calls this a "process group"
- Windows has no concept of process hierarchy
  - all processes are created equal

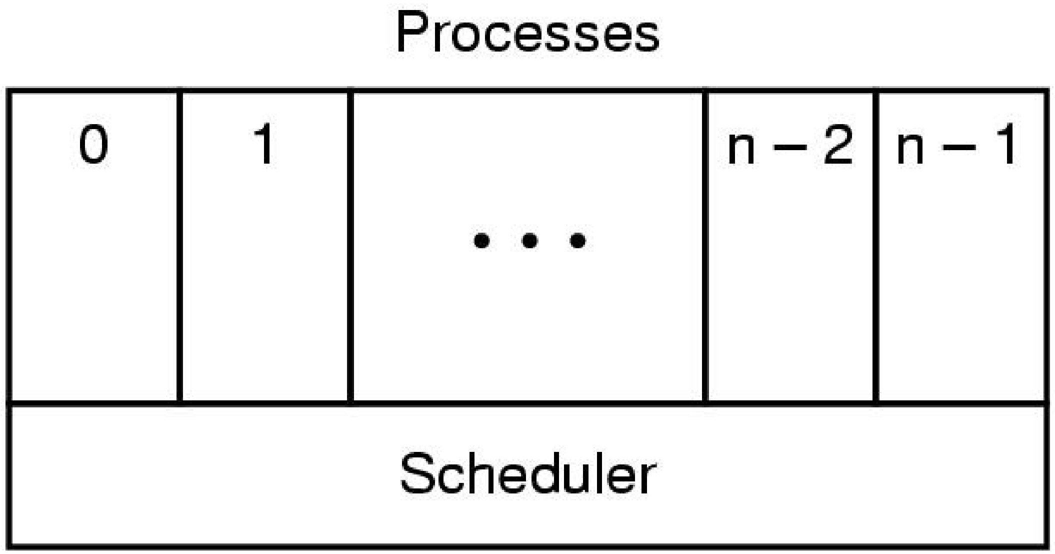
# Processes
## Process States (1)



1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

- Possible process states
  - running
  - blocked
  - ready
- Transitions between states shown

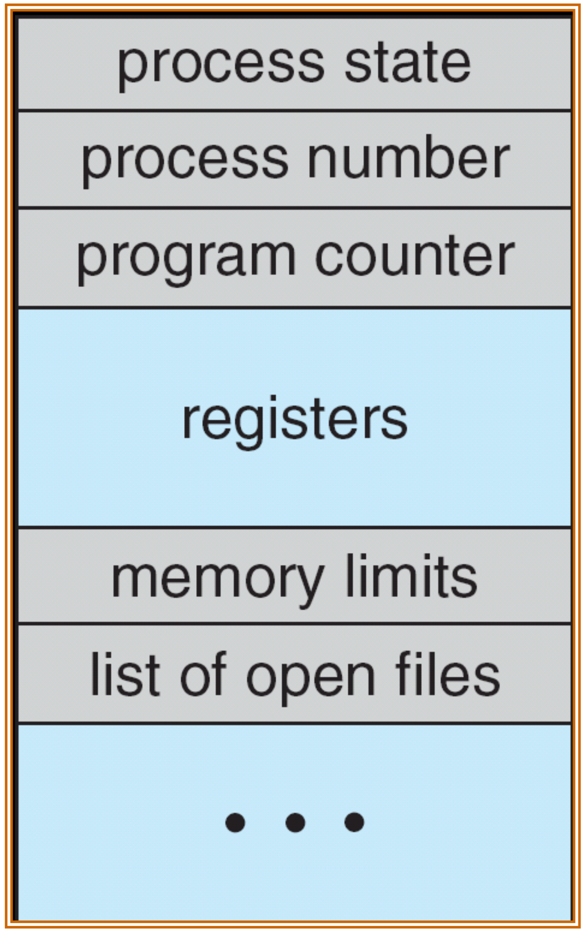
## Processes
### Process States (2)



- Lowest layer of process-structured OS
  - handles interrupts, scheduling
- Above that layer are sequential processes

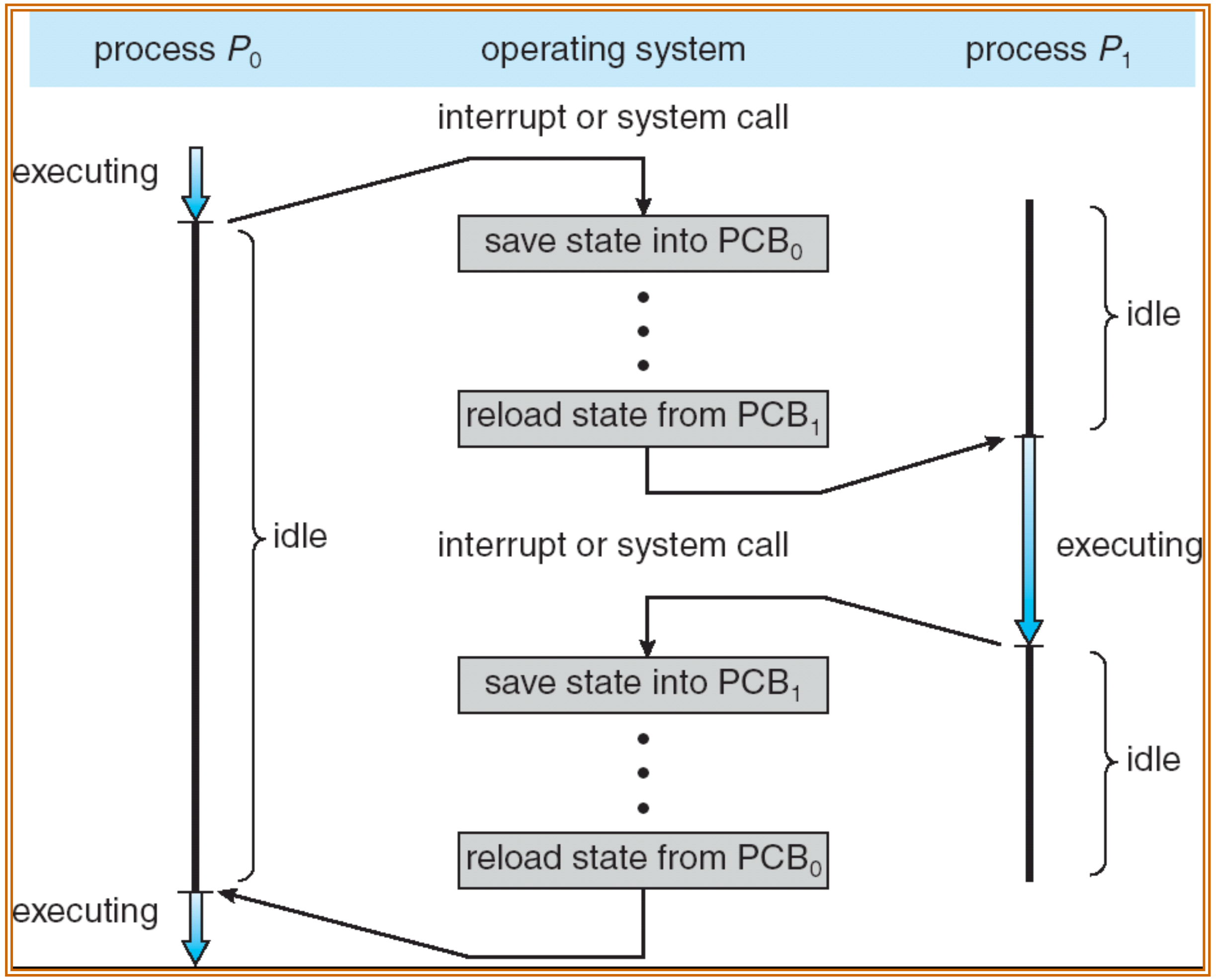
# Processes

## Process Control Block (PCB)



# Processes

## context switch



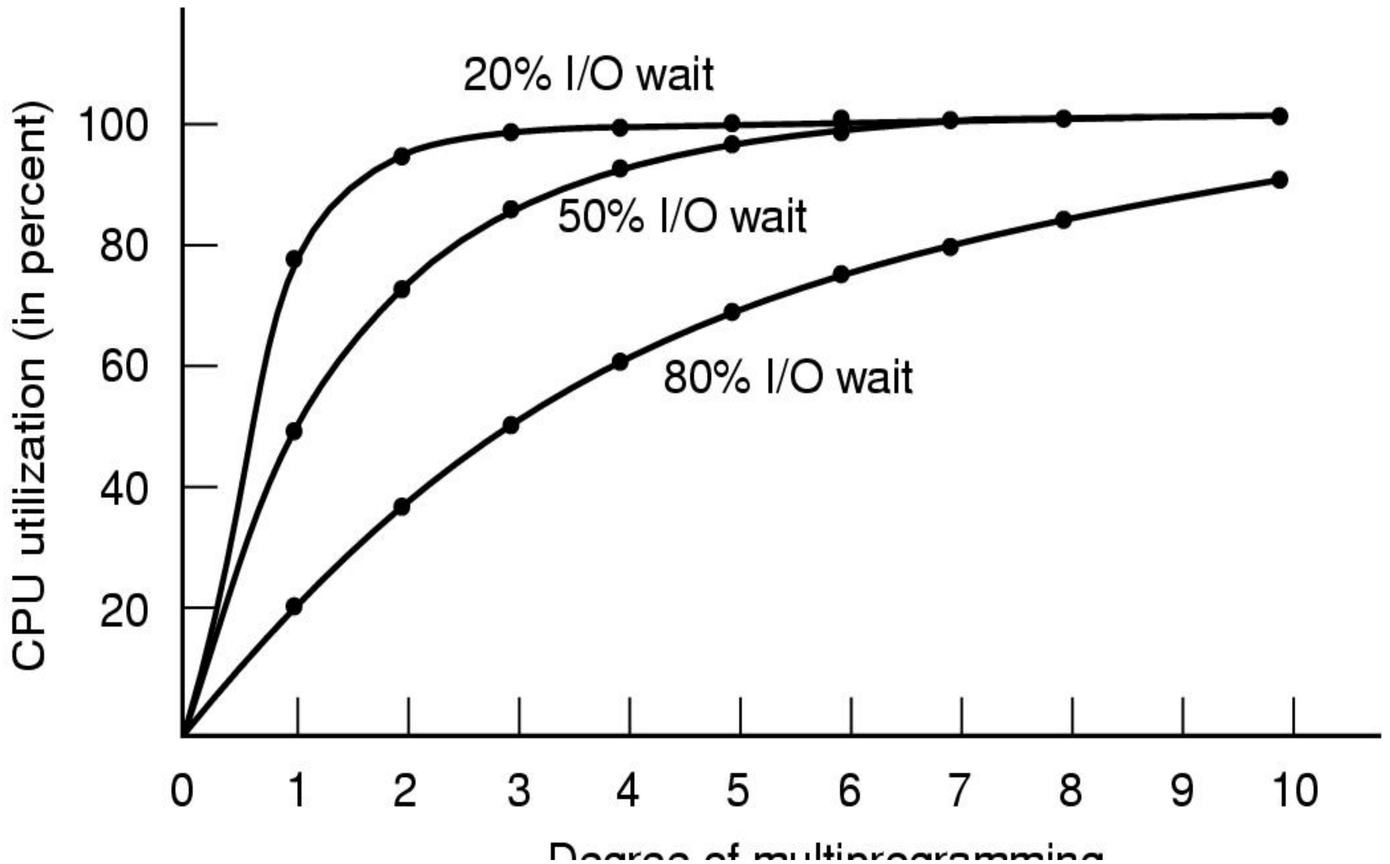
# Processes

## Implementation of Processes (1)

| **Process management** | **Memory management** | **File management** |
|---|---|---|
| Registers | Pointer to text segment | Root directory |
| Program counter | Pointer to data segment | Working directory |
| Program status word | Pointer to stack segment | File descriptors |
| Stack pointer | | User ID |
| Process state | | Group ID |
| Priority | | |
| Scheduling parameters | | |
| Process ID | | |
| Parent process | | |
| Process group | | |
| Signals | | |
| Time when process started | | |
| CPU time used | | |
| Children's CPU time | | |
| Time of next alarm | | |

Fields of a process table entry

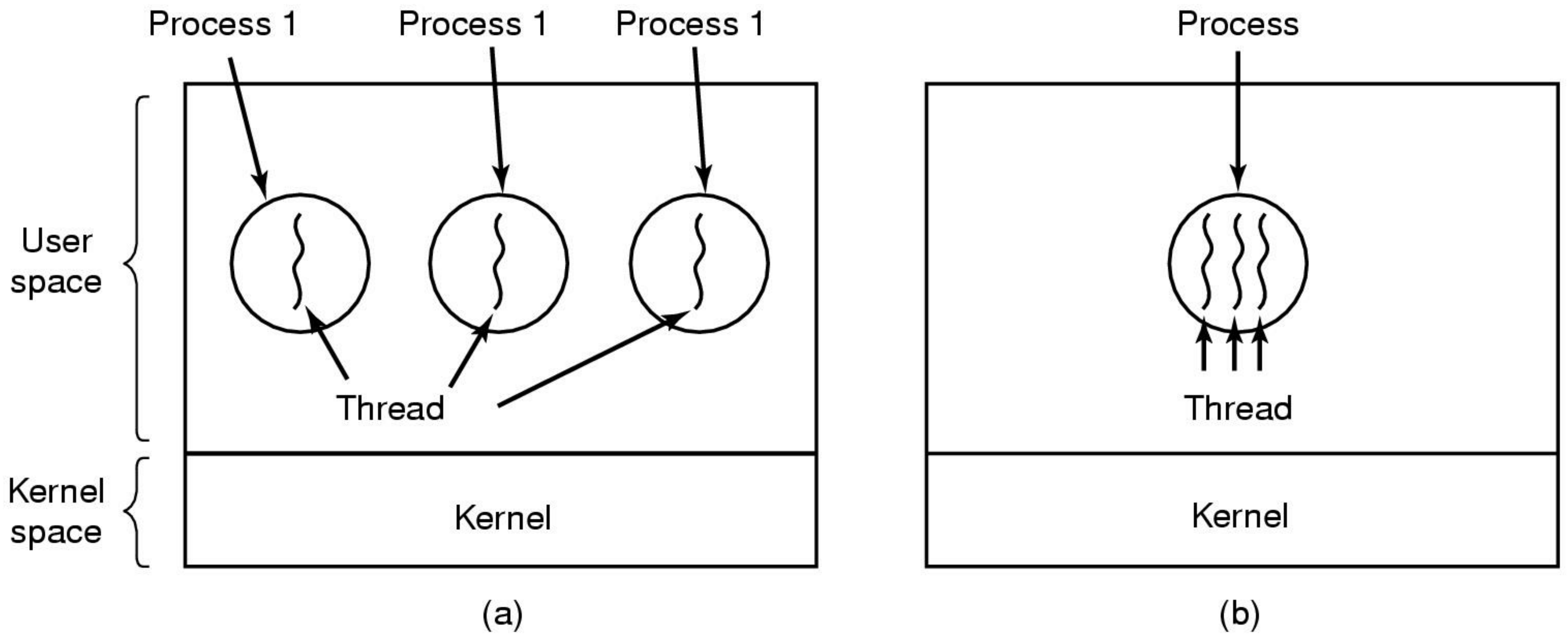
## Modeling Multiprogramming



CPU utilization as a function of the number of processes in memory.

## 2.2 Threads

# Threads
## The Thread Model



(a) Three processes each with one thread
(b) One process with three threads

- A thread – Lightweight Process is a basic unit of CPU utilization

# Threads

## Process with single thread

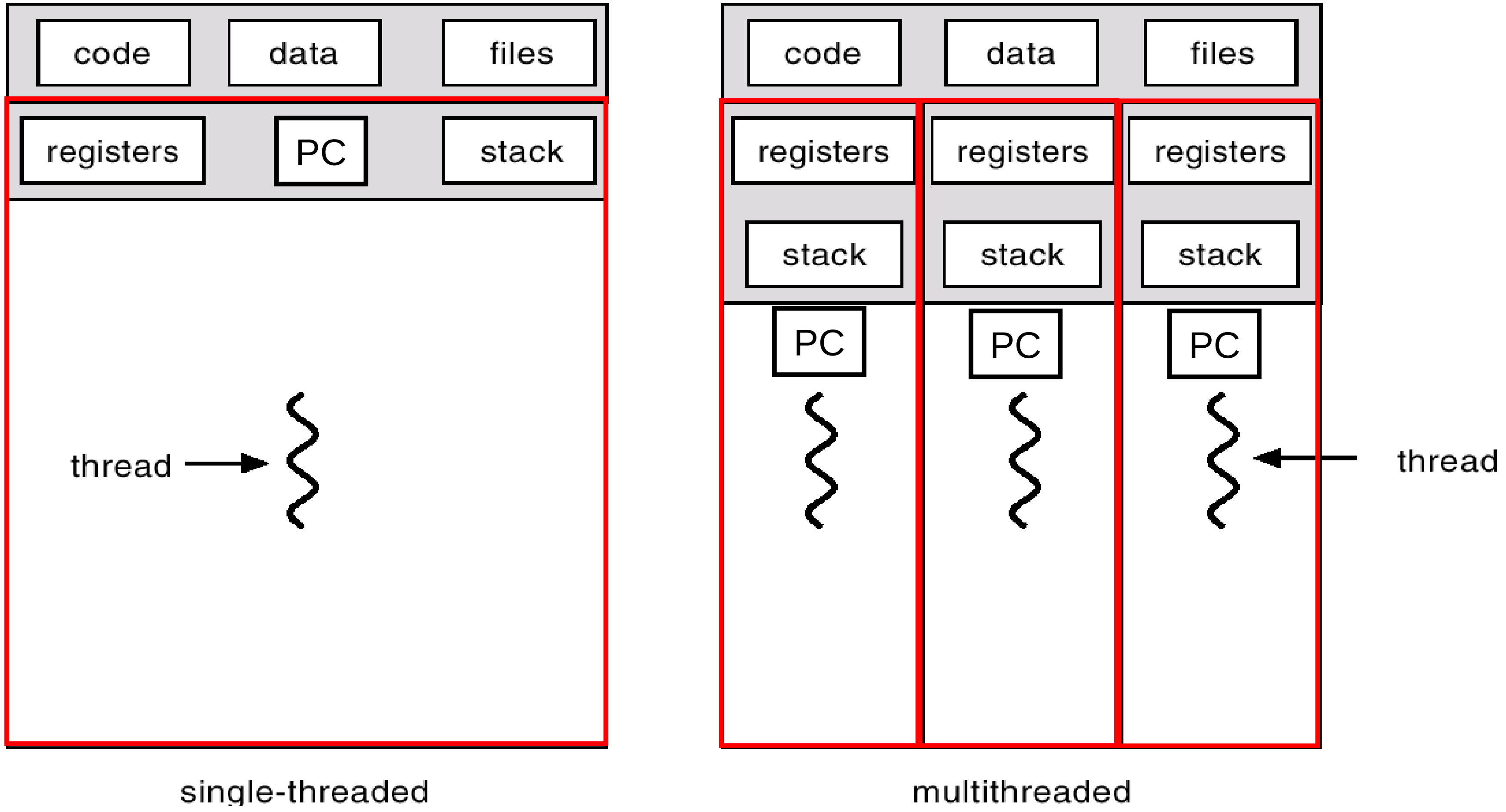
- A process (heavyweight):
  - Address space (text segment, data segment, stack segment)
  - Single thread of execution
    - program counter
    - registers
    - Stack
  - Other resource (open files, child processes…)

## Threads
### Process with multiple threads

**Multiple threads of execution in the same environment of process**

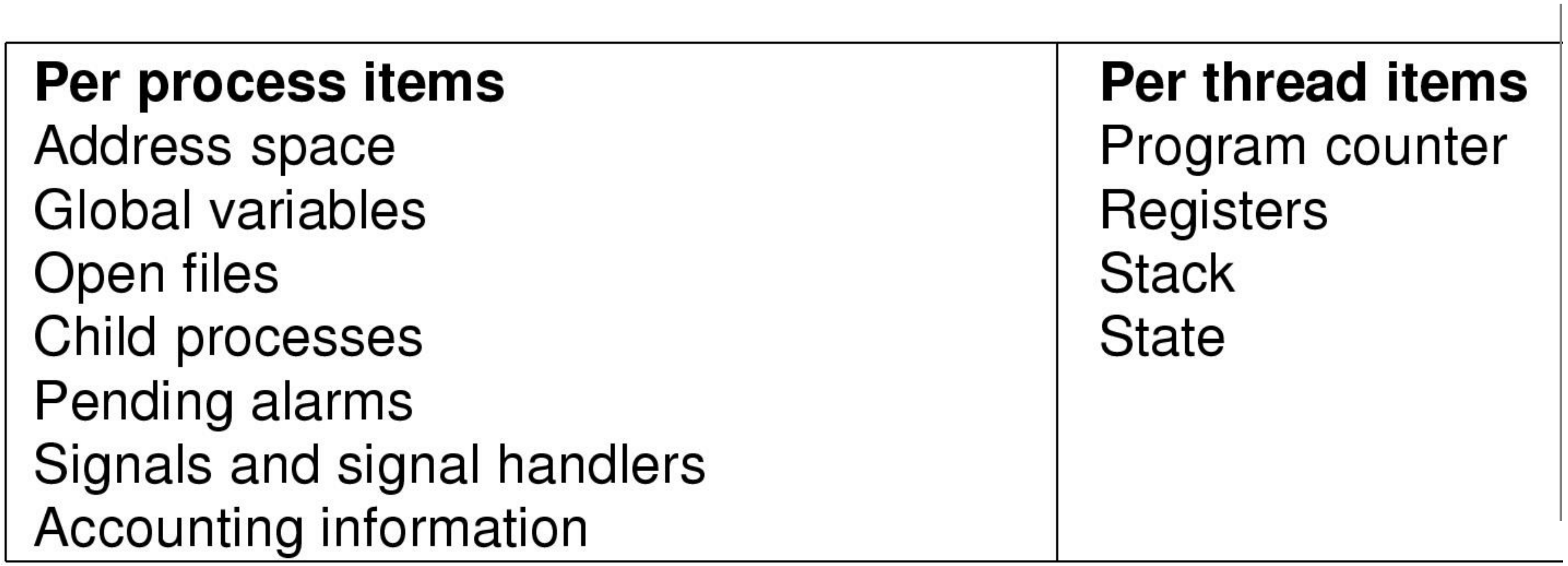
- Address space (text segment, data segment, stack segment)
- Multiple threads of execution, each thread has private set:
  - program counter
  - registers
  - stack
- Other resource (open files, child processes…)

# Threads
## Single and Multithreaded Processes



# Threads

## Items shared and Items private



| Per process items | Per thread items |
|---|---|
| Address space | Program counter |
| Global variables | Registers |
| Open files | Stack |
| Child processes | State |
| Pending alarms | |
| Signals and signal handlers | |
| Accounting information | |

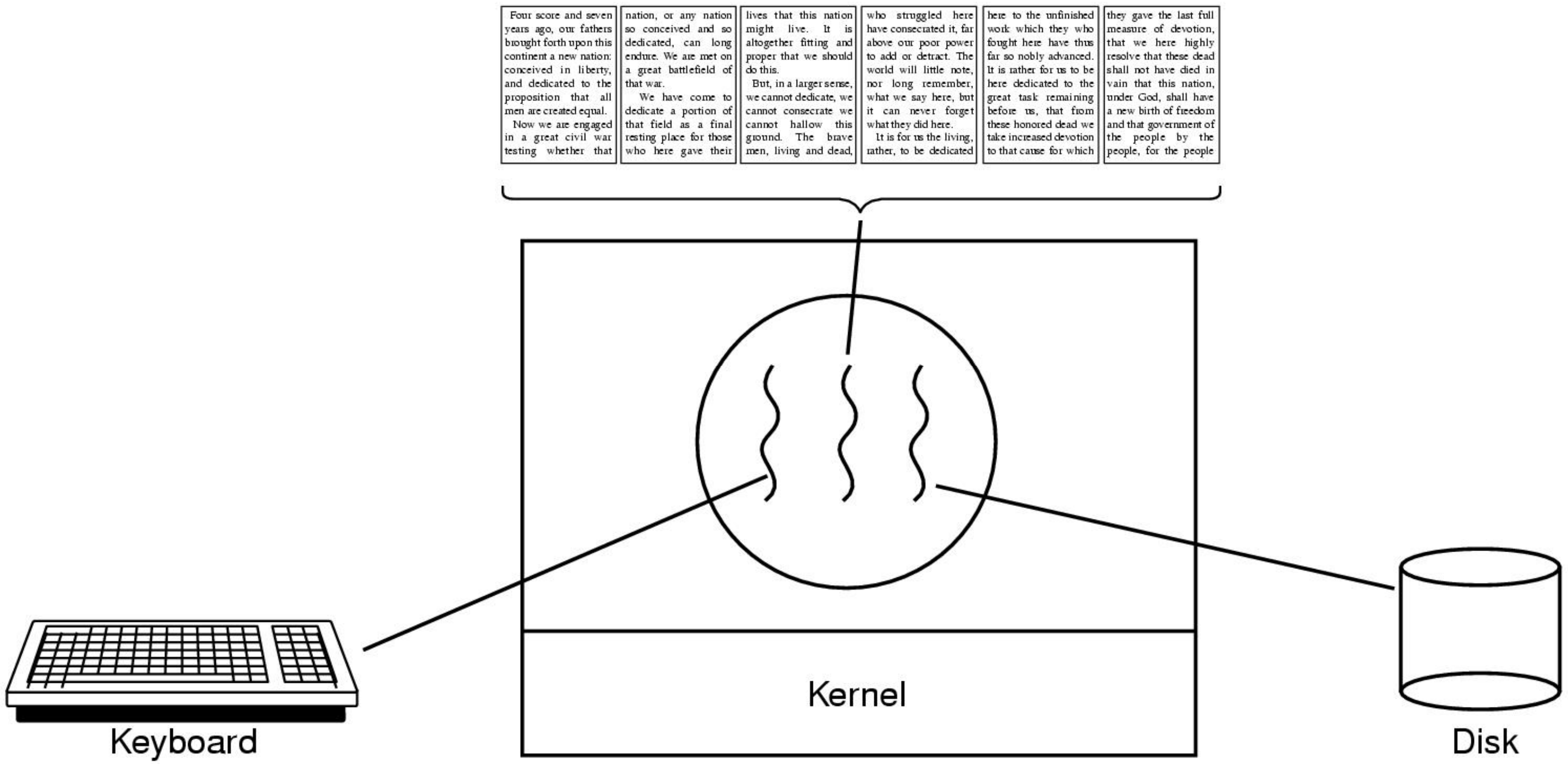
- Items shared by all threads in a process
- Items private to each thread

## Threads
### Benefits

- Responsiveness
- Resource Sharing
- Economy
- Utilization of Multiprocessor Architectures

# Threads

## Thread Usage (1)



Four score and seven years ago, our fathers brought forth upon this continent a new nation: conceived in liberty, and dedicated to the proposition that all men are created equal.

Now we are engaged in a great civil war testing whether that nation, or any nation so conceived and so dedicated, can long endure. We are met on a great battlefield of that war.

We have come to dedicate a portion of that field as a final resting place for those who here gave their lives that this nation might live. It is altogether fitting and proper that we should do this.

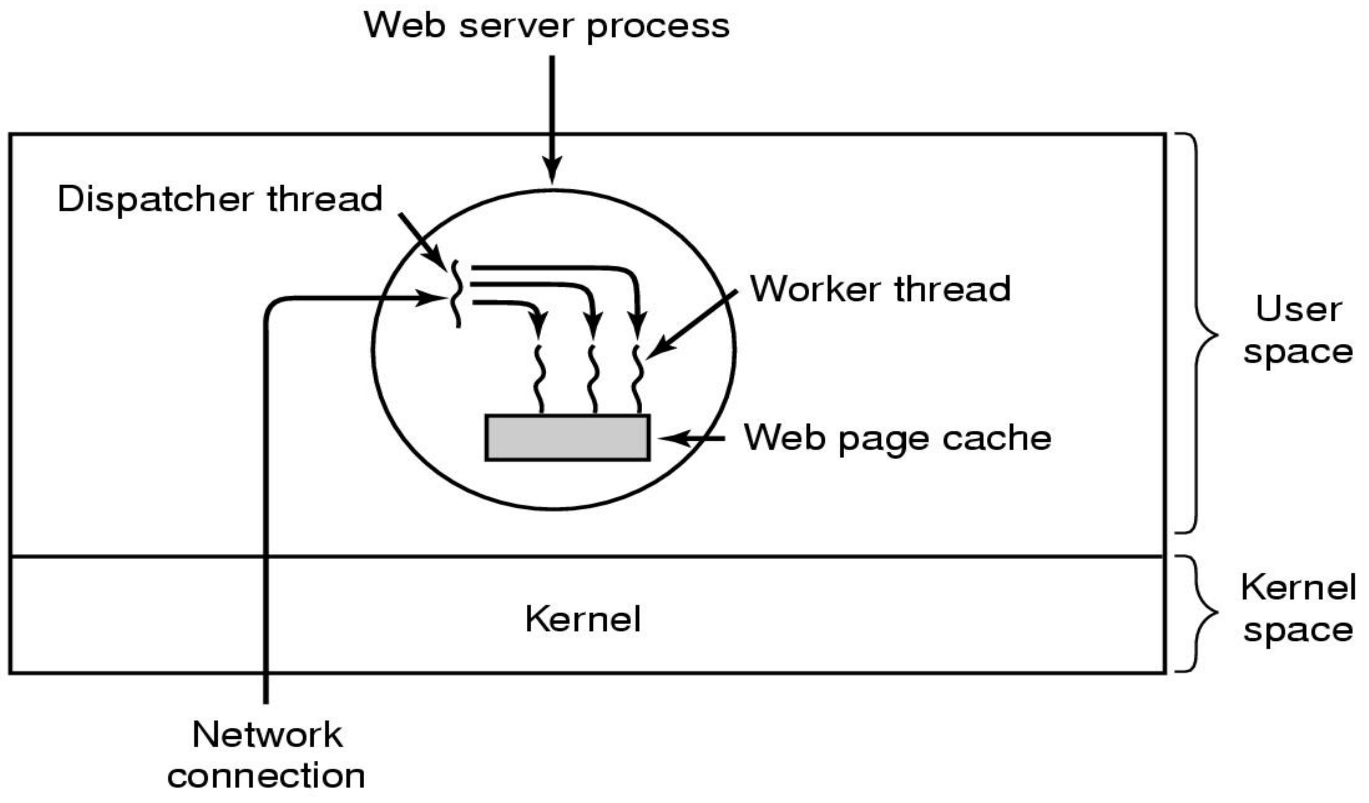
But, in a larger sense, we cannot dedicate, we cannot consecrate we cannot hallow this ground. The brave men, living and dead, who struggled here have consecrated it, far above our poor power to add or detract. The world will little note, nor long remember, what we say here, but it can never forget what they did here.

It is for us the living, rather, to be dedicated here to the unfinished work which they who fought here have thus far so nobly advanced. It is rather for us to be here dedicated to the great task remaining before us, that from these honored dead we take increased devotion to that cause for which they gave the last full measure of devotion, that we here highly resolve that these dead shall not have died in vain that this nation, under God, shall have a new birth of freedom and that government of the people by the people, for the people

A word processor with three threads

# Threads

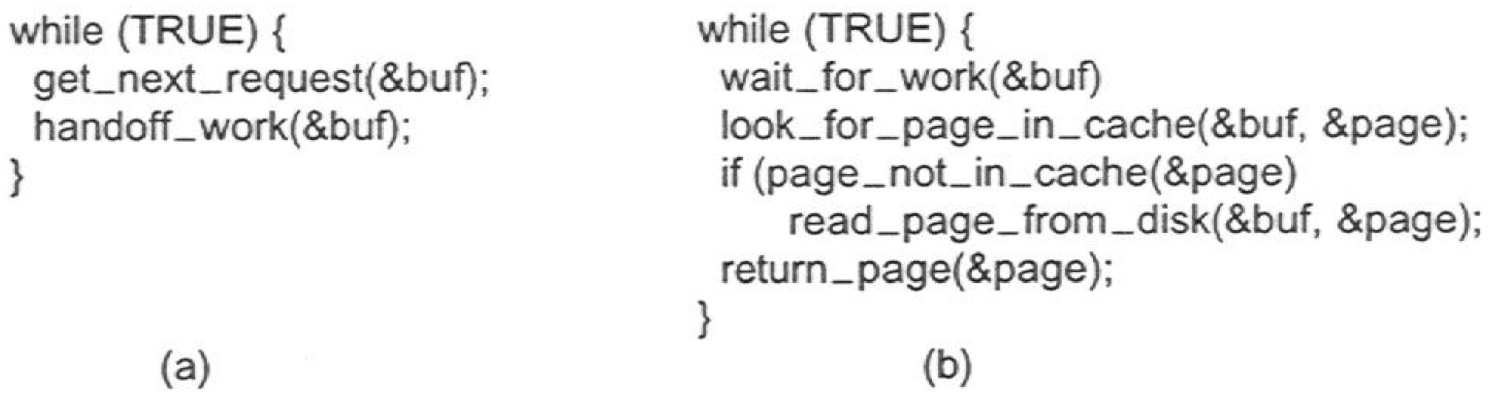
## Thread Usage (2)



A multithreaded Web server

# Threads

## Thread Usage (3)



```
while (TRUE) {
  get_next_request(&buf);
  handoff_work(&buf);
}
```

(a)

```
while (TRUE) {
  wait_for_work(&buf)
  look_for_page_in_cache(&buf, &page);
  if (page_not_in_cache(&page)
       read_page_from_disk(&buf, &page);
  return_page(&page);
}
```

(b)

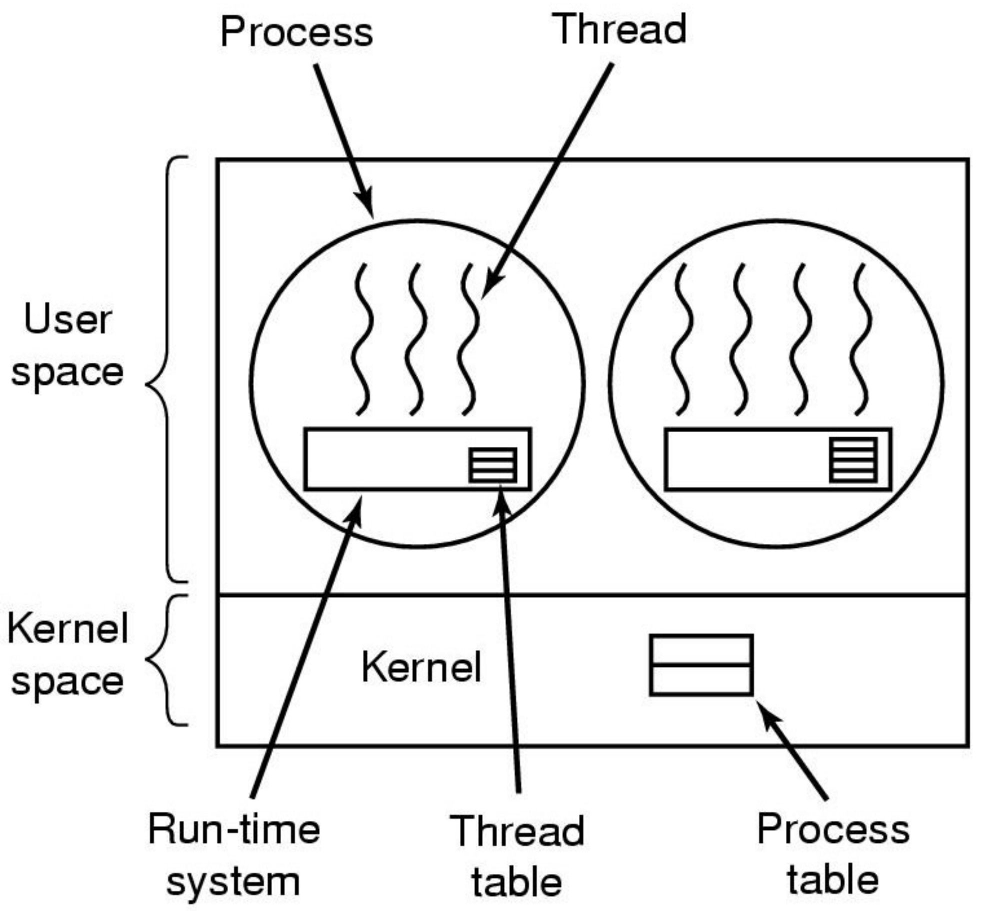
- Rough outline of code for previous slide

  (a) Dispatcher thread

  (b) Worker thread

# Threads

## Implementing Threads in User Space (1)



A user-level threads package

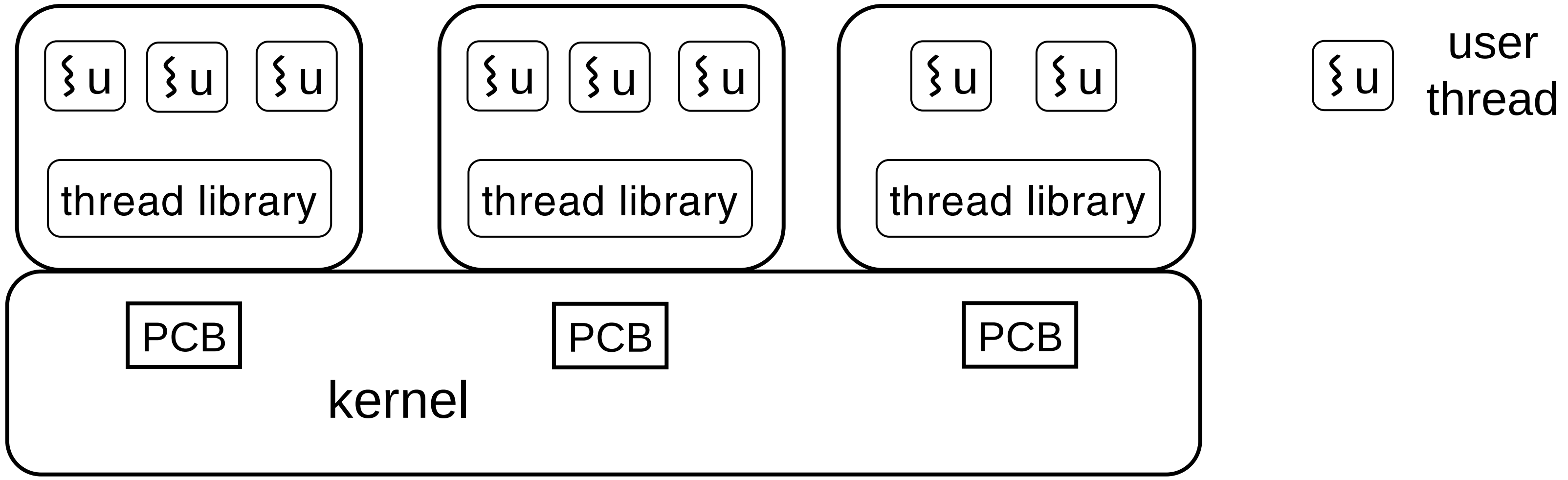
## Threads

### Implementing Threads in User Space (2)

- Thread library, (run-time system) in user space
  - thread_create
  - thread_exit
  - thread_wait
  - thread_yield (to voluntarily give up the CPU)
  - ……
- Thread control block (TCB) ( Thread Table Entry) stores states of  user thread (program counter, registers, stack)
- Kernel does not know the present of user thread

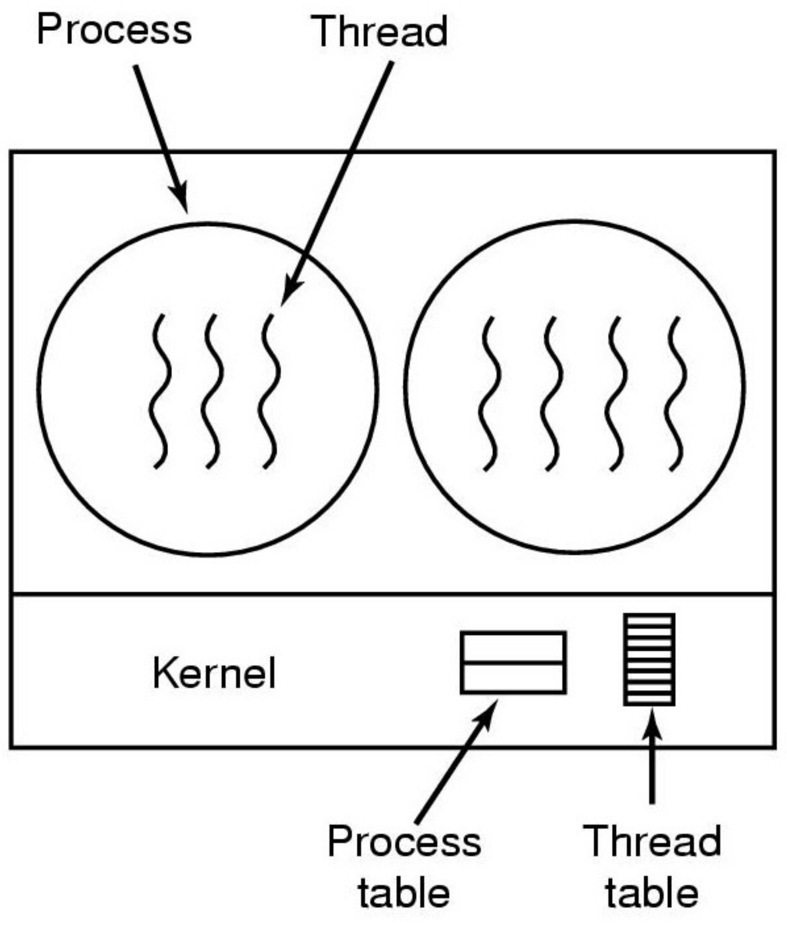
# Threads
## Implementing Threads in User Space (3)

- Traditional OS provide only one "kernel thread" presented by PCB for each process.
  - *Blocking problem*: If one user thread is blocked ->the kernel thread is blocked, -> all other threads in process are blocked.



# Threads

## Implementing Threads in the Kernel (1)



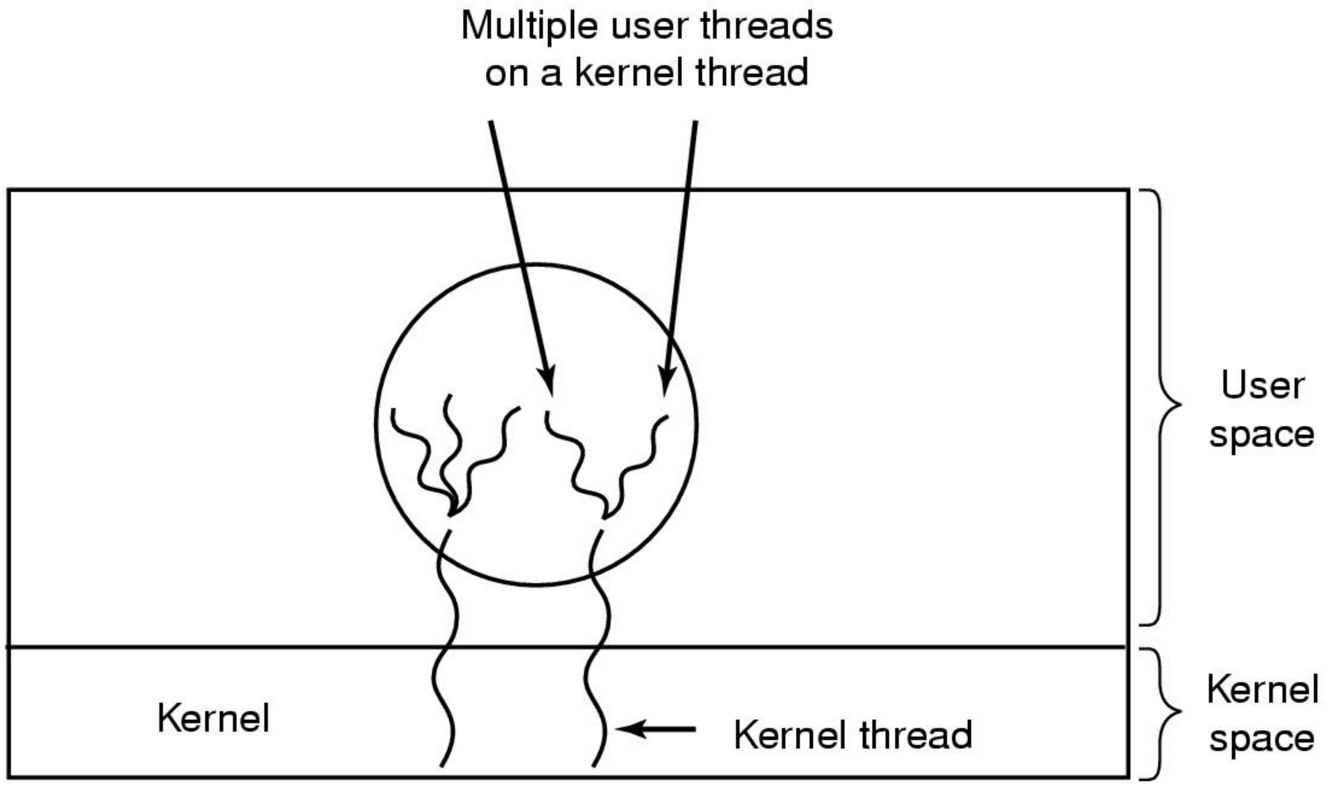
A threads package managed by the kernel

# Threads
## Implementing Threads in the Kernel (2)

- Multithreading is directly supported by OS:
  - Kernel manages processes and threads
  - CPU scheduling for thread is performed in kernel
- Advantage of multithreading in kernel
  - Is good for multiprocessor architecture
  - If one thread is blocked does not cause the other thread to be blocked.
- Disadvantage of Multithreading in kernel
  - Creation and management of thread is slower

# Threads

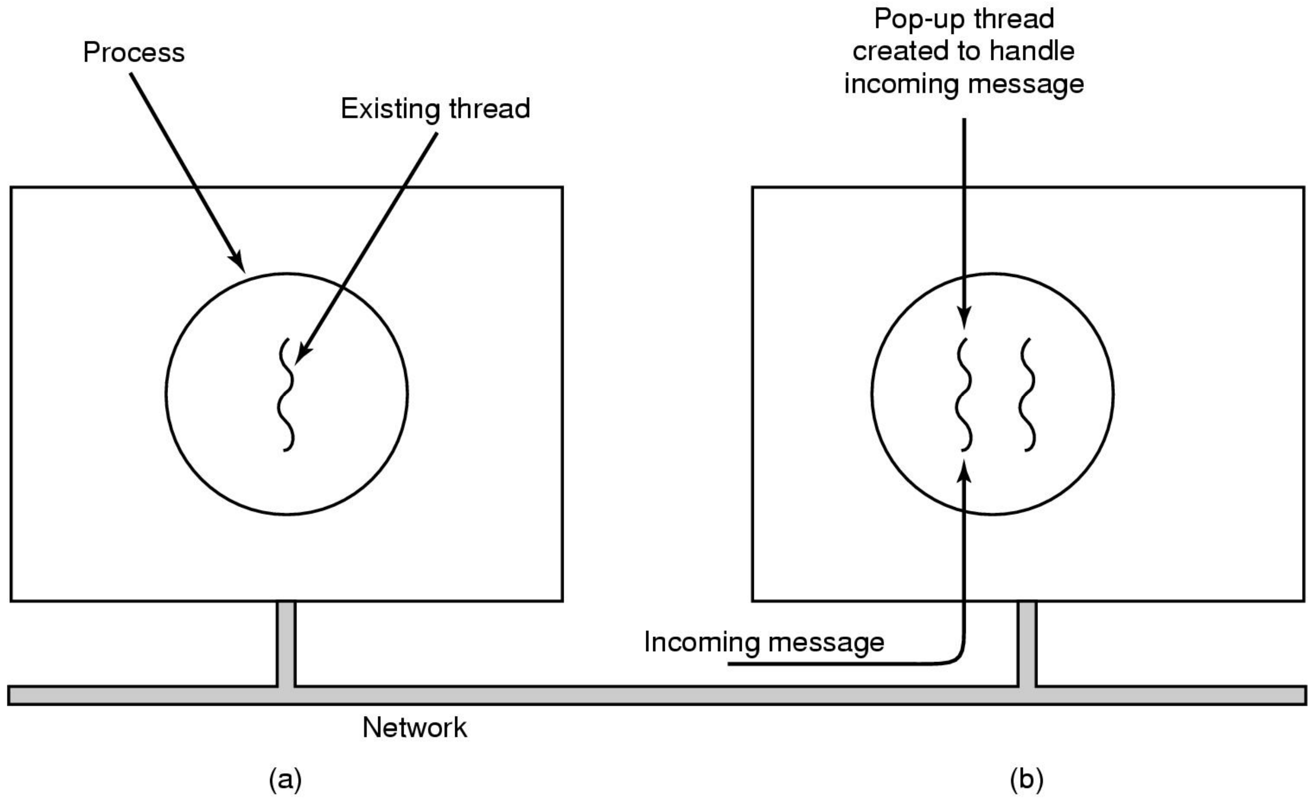
## Hybrid Implementations



Multiplexing user-level threads onto kernel-level threads

# Threads

## Pop-Up Threads



Creation of a new thread when a message arrives.

(a) Before the message arrives.

(b) After the message arrives.

## 2.3 Interprocess Communication

## Cooperating Processes

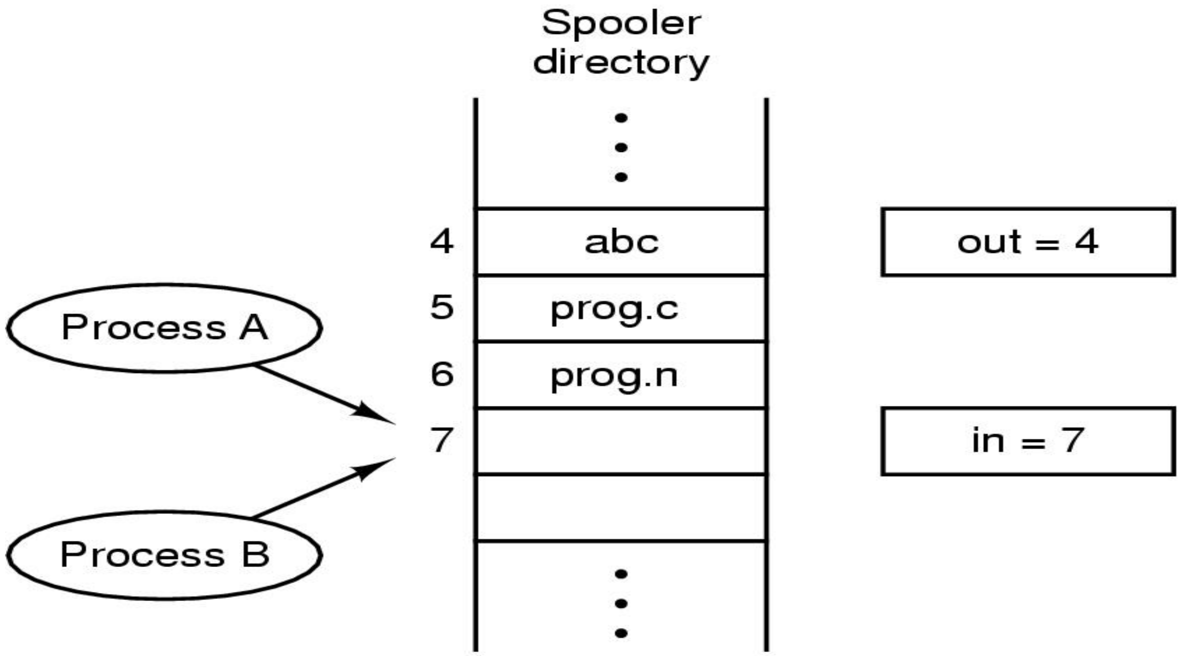
- **Independent** process cannot affect or be affected by the execution of another process
- **Cooperating** process can affect or be affected by the execution of another process
- Advantages of process cooperation
  - Information sharing
  - Computation speed-up
  - Modularity
  - Convenience

## Problem of shared data

- Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes
- Need of mechanism for processes to communicate and to synchronize their actions

## Race Conditions

- Two processes want to access shared memory at same time and the final result depends who runs precisely, are called **race condition**
- **Mutual exclusion** is the way to prohibit more than one process from accessing to shared data at the same time
- Example of race condition



## Critical Regions (1)

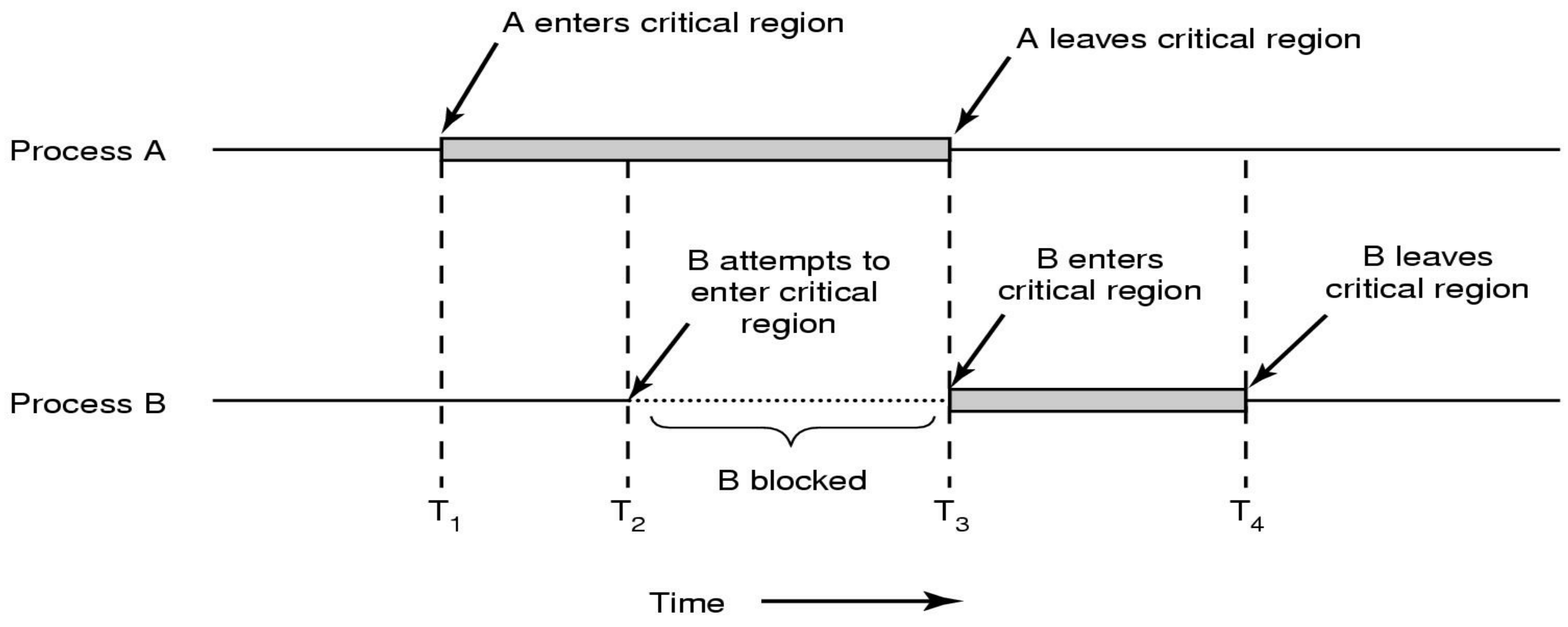
The Part of the program where the shared memory is accessed is called **Critical Regions (Critical Section)**

Four conditions to provide mutual exclusion

1. No two processes simultaneously in critical region
2. No assumptions made about speeds or numbers of CPUs
3. No process running outside its critical region may block another process
4. No process must wait forever to enter its critical region

## Critical Regions (2)

### Mutual exclusion using critical regions (Example)

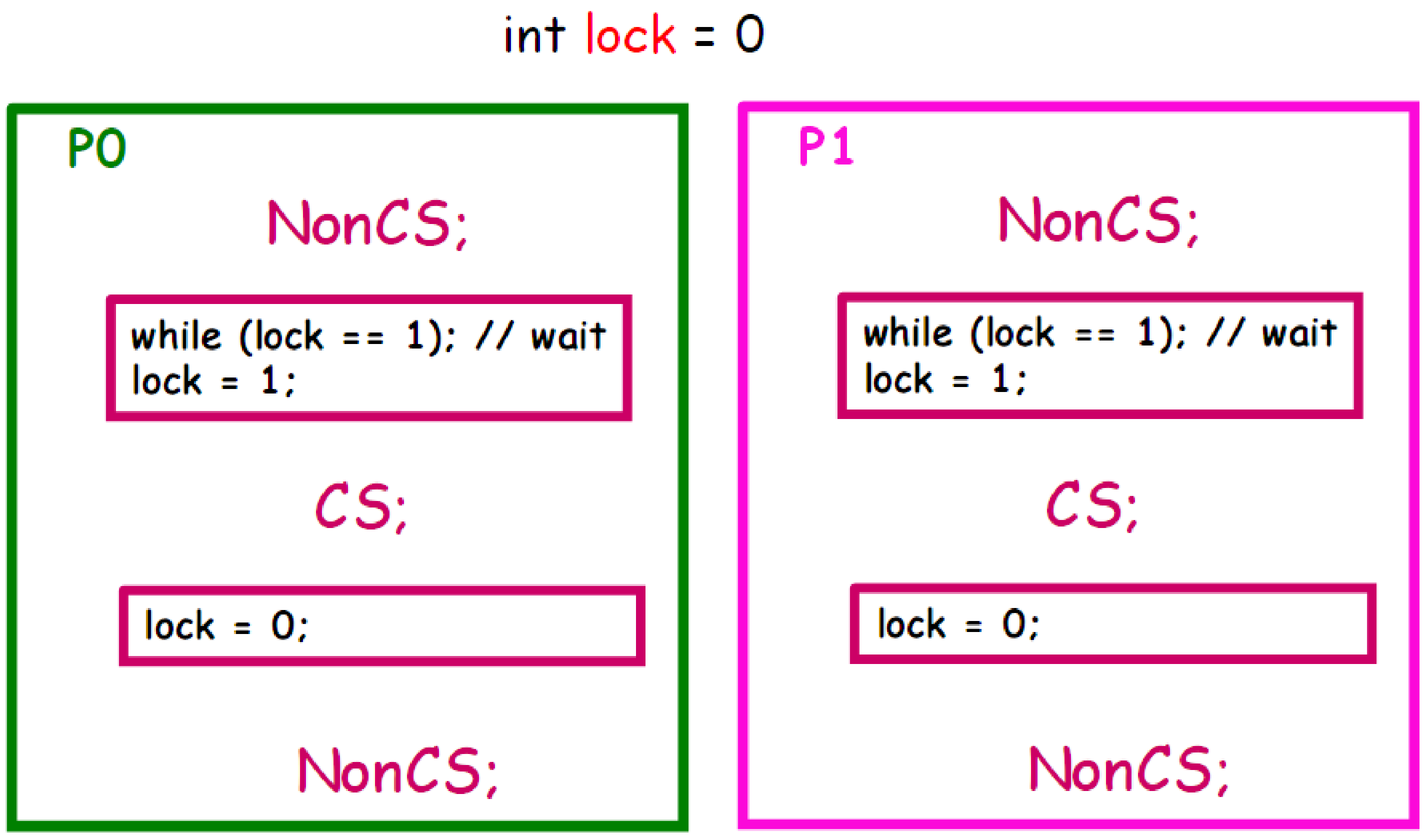


## Solution: Mutual exclusion with Busy waiting

- Software proposal
  - Lock Variables
  - Strict Alternation
  - Peterson's Solution
- Hardware proposal
  - Disabling Interrupts
  - The TSL Instruction

# Mutual exclusion with Busy waiting

## Software Proposal 1: Lock Variables



```
int lock = 0
```

P0

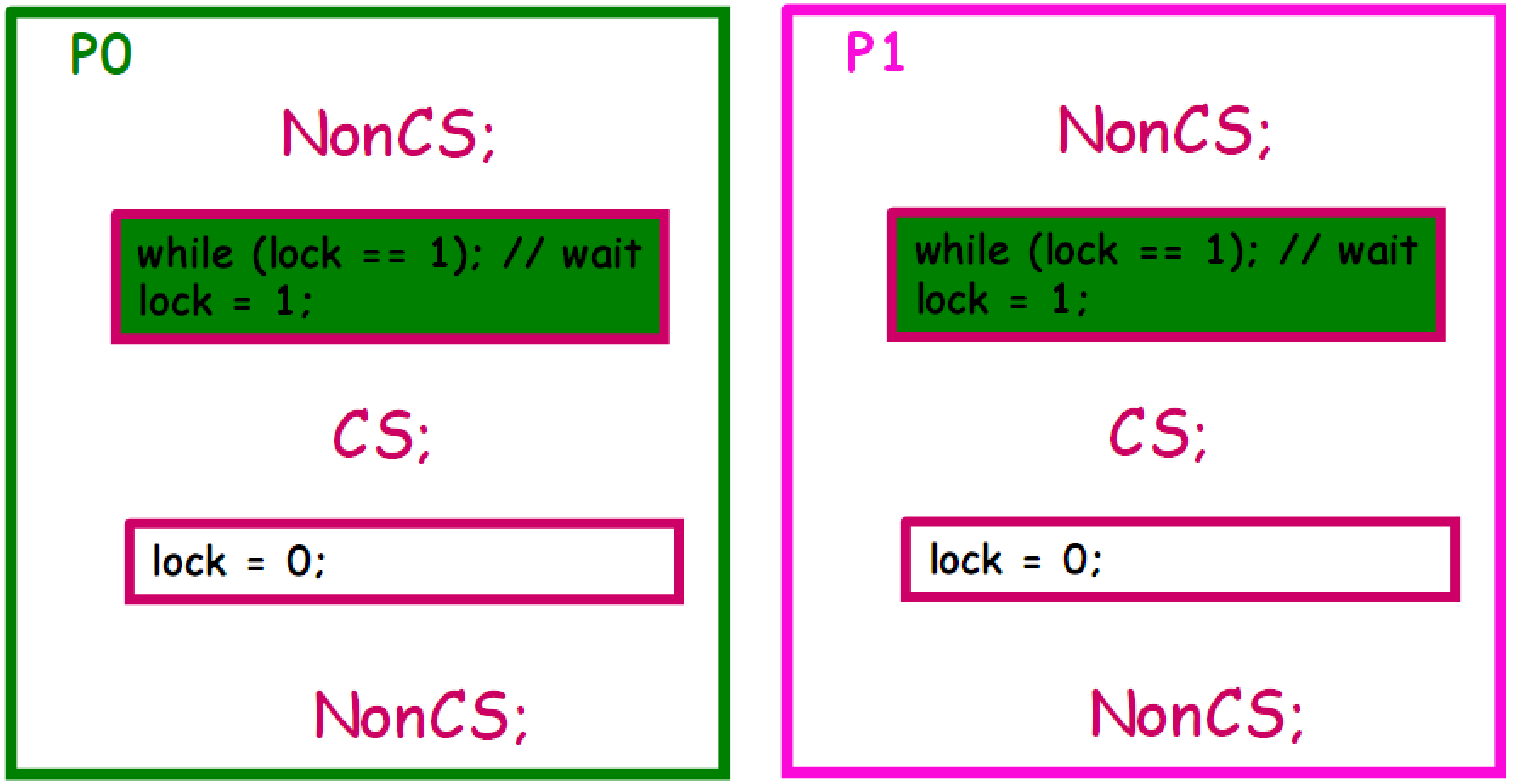
```
NonCS;

while (lock == 1); // wait
lock = 1;

CS;

lock = 0;

NonCS;
```

P1

```
NonCS;

while (lock == 1); // wait
lock = 1;

CS;

lock = 0;

NonCS;
```

## Mutual exclusion with Busy waiting
### Software Proposal 1: Event

int lock = 0



P0

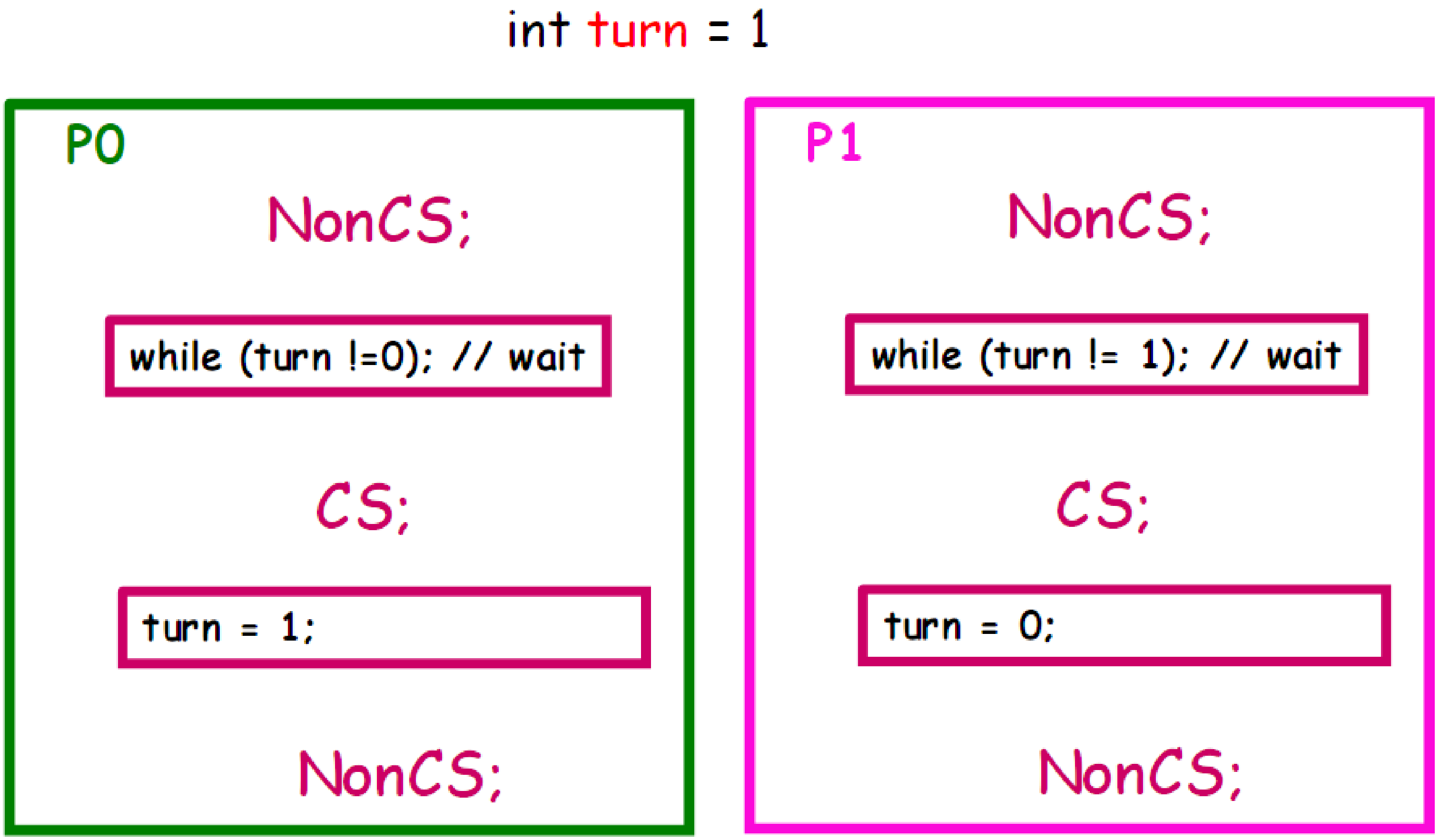
```
NonCS;

while (lock == 1); // wait
lock = 1;

CS;

lock = 0;

NonCS;
```

P1

```
NonCS;

while (lock == 1); // wait
lock = 1;

CS;

lock = 0;

NonCS;
```

# Mutual exclusion with Busy waiting

## Software Proposal 2: Strict Alternation



```
int turn = 1
```

P0

```
NonCS;

while (turn !=0); // wait

CS;

turn = 1;

NonCS;
```

P1

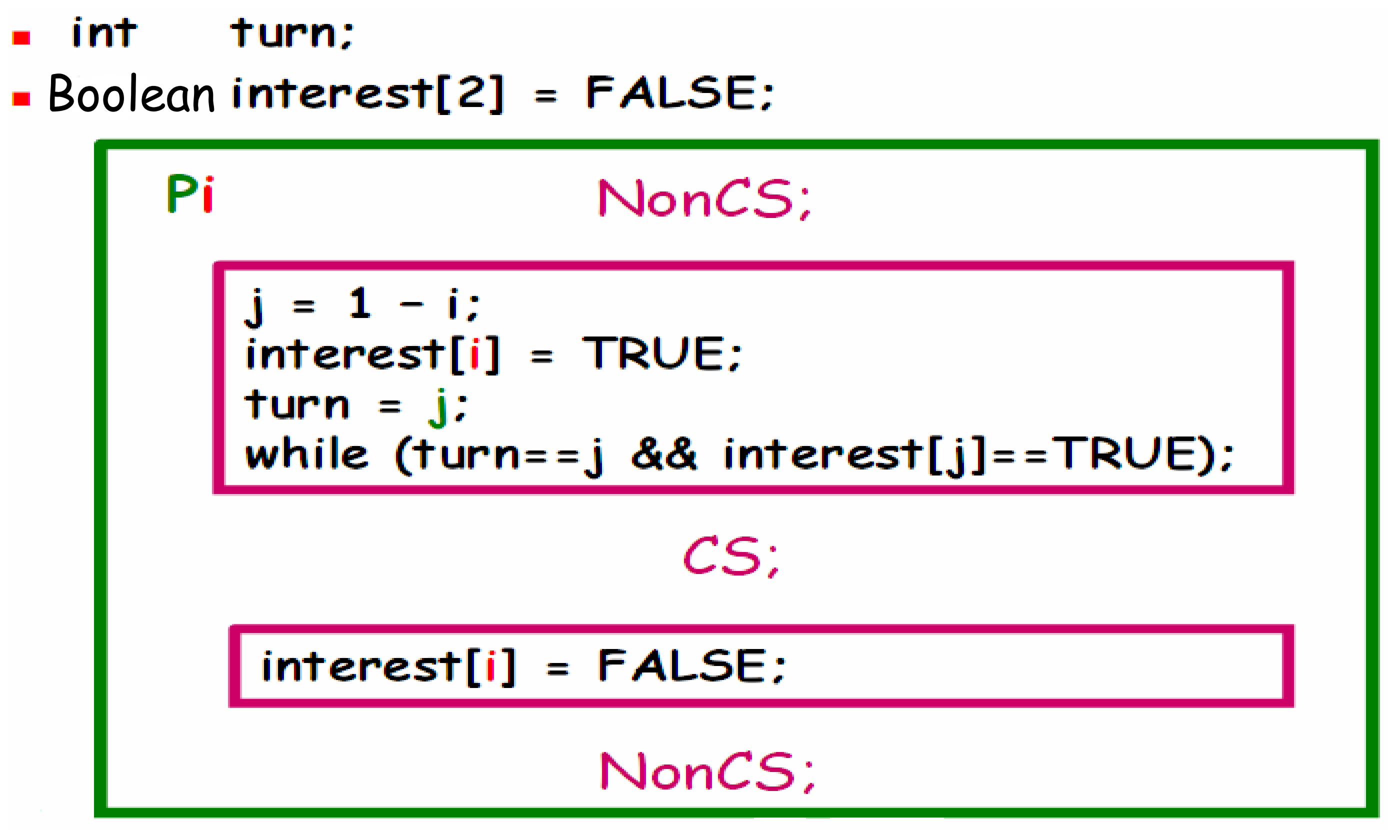
```
NonCS;

while (turn != 1); // wait

CS;

turn = 0;

NonCS;
```

## Mutual exclusion with Busy waiting
### Software Proposal 2: Strict Alternation

- Only 2 processes
- Responsibility Mutual Exclusion
  - One variable "*turn*“, one process “*turn*” come in CS at the moment.

# Mutual exclusion with Busy waiting

## Software Proposal 3: Peterson's Solution

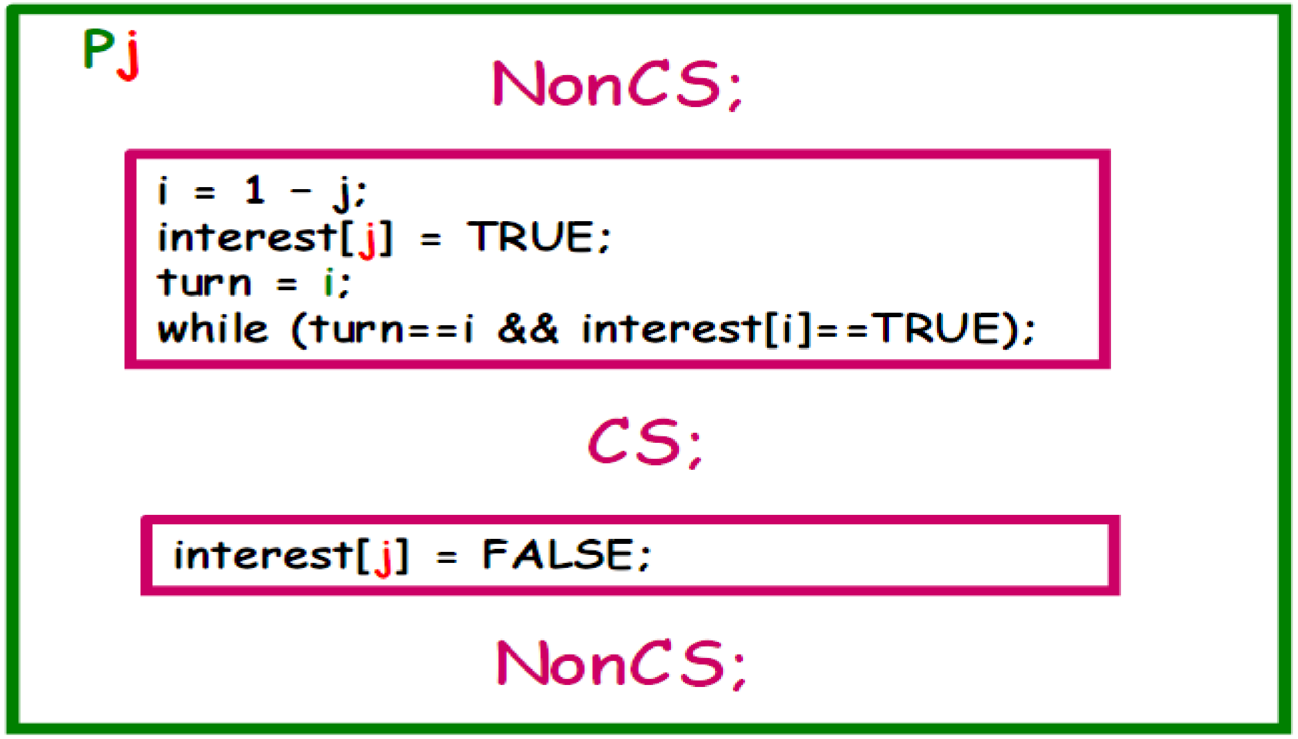


- int turn;
- Boolean interest[2] = FALSE;

```
Pi                  NonCS;

    j = 1 - i;
    interest[i] = TRUE;
    turn = j;
    while (turn==j && interest[j]==TRUE);

                     CS;

    interest[i] = FALSE;

                    NonCS;
```

# Mutual exclusion with Busy waiting

## Software Proposal 3: Peterson's Solution



```
Pj
                NonCS;

  i = 1 - j;
  interest[j] = TRUE;
  turn = i;
  while (turn==i && interest[i]==TRUE);

                  CS;

  interest[j] = FALSE;

                NonCS;
```

## Mutual exclusion with Busy waiting
### Comment for Software Proposal 3: Peterson's Solution

- Satisfy 3 conditions:
  - Mutual Exclusion
    - Pi can enter CS when *interest[j] == F, or turn == i*
    - If both want to come back, because *turn* can only receive value 0 or 1, so one process enter CS
  - Progress
    - Using 2 variables distinct *interest[i]* ==> opposing cannot lock
  - Bounded Wait: both *interest[i]* and *turn* change value
- Not extend into N processes

## Mutual exclusion with Busy waiting
### Comment for Busy-Waiting solutions

- Don't need system’s support
- Hard to extend
- Solution 1 is better when *atomicity* is supported

## Mutual exclusion with Busy waiting
## Hardware Proposal 1: Disabling Interrupt (1)

```
NonCS;

Disable Interrupt;

CS;

Enable Interrupt;

NonCS;
```

- Disable Interrupt: prohibit all interrupts, including spin interrupt
- Enable Interrupt: permit interrupt

## Mutual exclusion with Busy waiting
### Hardware proposal 1: Disable Interrupt (2)

- Not be careful
  - If process is locked in CS?
    - System Halt
  - Permit process use command privileges
    - Danger!
- System with N CPUs?
  - Don't ensure Mutual Exclusion

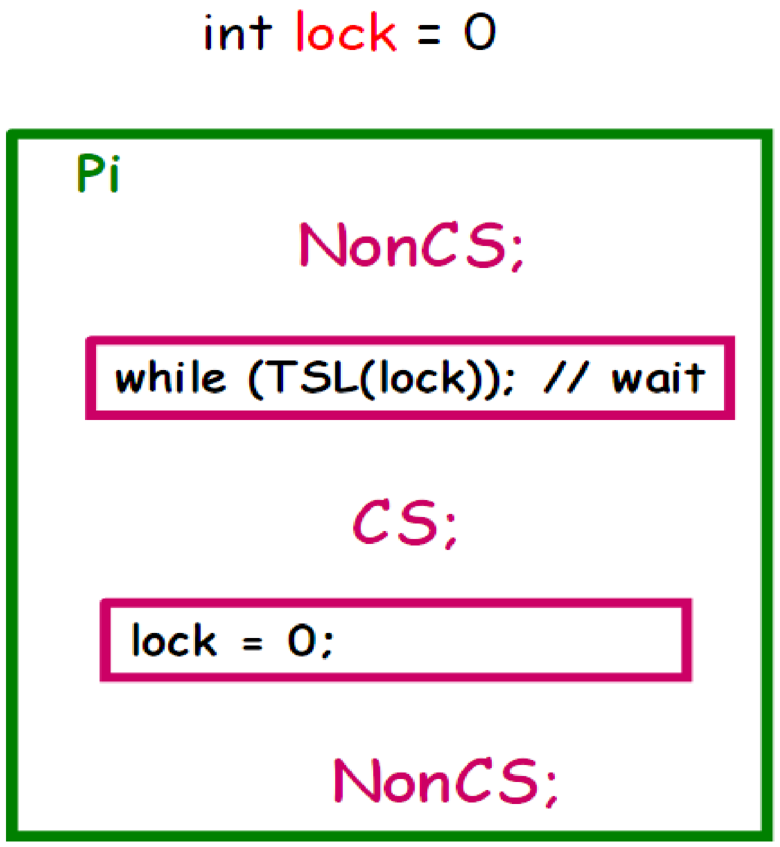
## Mutual exclusion with Busy waiting
### Hardware proposal 2: TSL Instruction

- CPU support primitive Test and Set Lock
  - Return a variable's current value, set variable to true value
  - Cannot divide up to perform (Atomic)

```
TSL (boolean &target)
{
        TSL = target;
        target = TRUE;
}
```

## Mutual exclusion with Busy waiting

### Hardware proposal 2: Applied TSL



```
int lock = 0

Pi
        NonCS;

    while (TSL(lock)); // wait

            CS;

    lock = 0;

            NonCS;
```

## Mutual exclusion with Busy waiting
### Comment for hardware solutions

- Necessary hardware mechanism's support
  - Not easy with n-CPUs system
- Easily extend to N processes

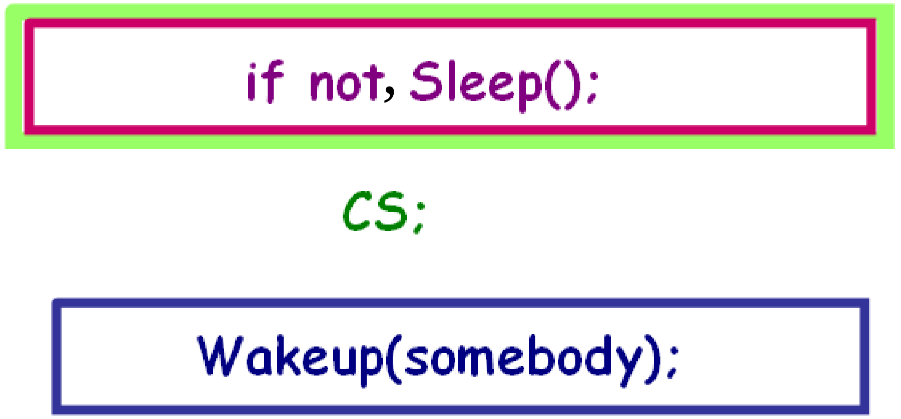
## Mutual exclusion with Busy waiting
### Comment

- Using CPU not effectively
  - Constantly test condition when wait for coming in CS
- Overcome
  - Lock processes that not enough condition to come in CS, concede CPU to other process
    - Using Scheduler
    - Wait and See...

## Synchronous solution with Sleep & Wakeup

- Sleep & Wakeup
- Semaphore
- Monitor
- Message passing

## Synchronous solution with Sleep & Wakeup
## "Sleep & Wakeup" solution



```
if not, Sleep();

CS;

Wakeup(somebody);
```

- Give up CPU when not come in CS
- When CS is empty, will be waken up to come in CS
- Need support of OS
  - Because of changing status of process

## Synchronous solution with Sleep & Wakeup
## "Sleep & Wake up" solution: Idea

- OS support 2 primitive:
  - Sleep(): System call receives blocked status
  - WakeUp(P): P process receives ready status
- Application
  - After checking condition, coming in CS or calling Sleep() depend on result of checking
  - Process that using CS before, will wake up processes blocked before

## Synchronous solution with Sleep & Wakeup
## Apply Sleep() and Wakeup()

- int busy;
- int blocked;

```
if (busy) {
                    blocked = blocked + 1;
                    Sleep();
          }
else busy = 1;
```

CS;

```
busy = 0;
             if(blocked) {          WakeUp(P);
                                    blocked = blocked - 1;
                              }
```

## Synchronous solution with Sleep & Wakeup
## Problem with Sleep & WakeUp

- Reason:
  - Checking condition and giving up CPU can be broken
  - Lock variable is not protected

## Synchronous solution with Sleep & Wakeup
## Semaphore

- Suggested by Dijkstra, 1965
- Properties: Semaphore s (special integer variable;)
  - Unique value
  - Manipulate with 2 primitives:
    - Down(s), (Originally called P(s))
    - Up(s), (Originally called V(s))
  - Down and Up primitives executed cannot divide up (atomic)

## Synchronous solution with Sleep & Wakeup Semaphore

- Counting semaphore – integer value can range over an unrestricted domain
- Binary semaphore – integer value can range only between 0 and 1; can be simpler to implement
- Mutexs
  - A simplified version of the semaphore when the semaphore's ability to count is not needed
  - Is good only for managing mutual exclusion to some shared resource or piece of code
  - Is a variable that can be in one of two states: unlocked or locked
- Can implement a counting semaphore S as a binary semaphore

## Synchronous solution with Sleep & Wakeup Semaphore

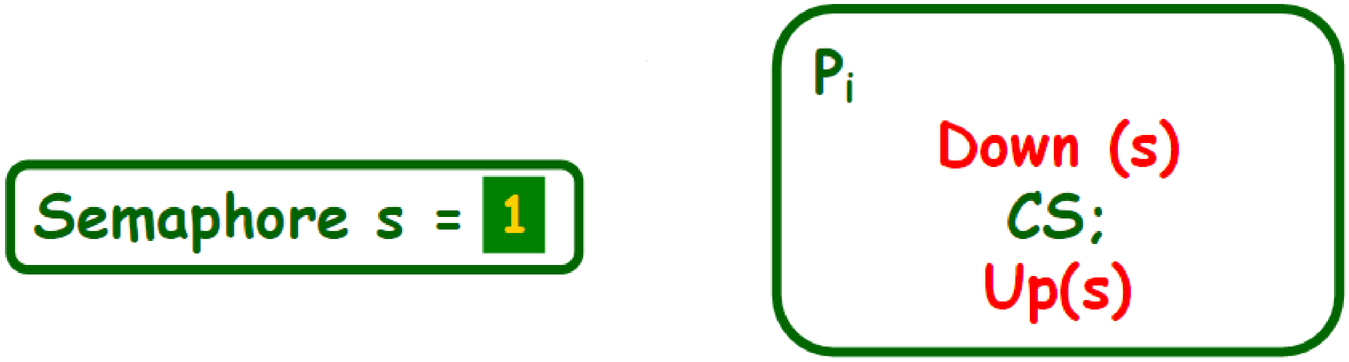
Provides mutual exclusion

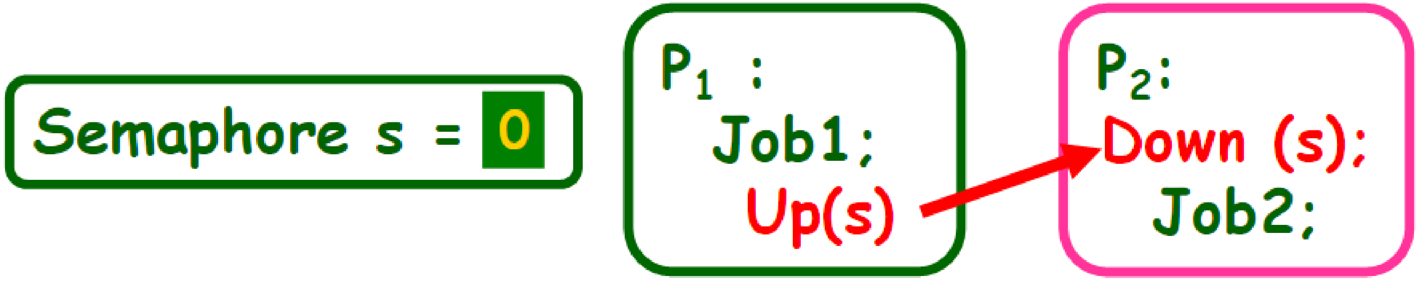
- Semaphore S;    //  initialized to 1
- Down(s);

        Critical Section

- Up(s);

# Synchronous solution with Sleep & Wakeup Using Semaphore

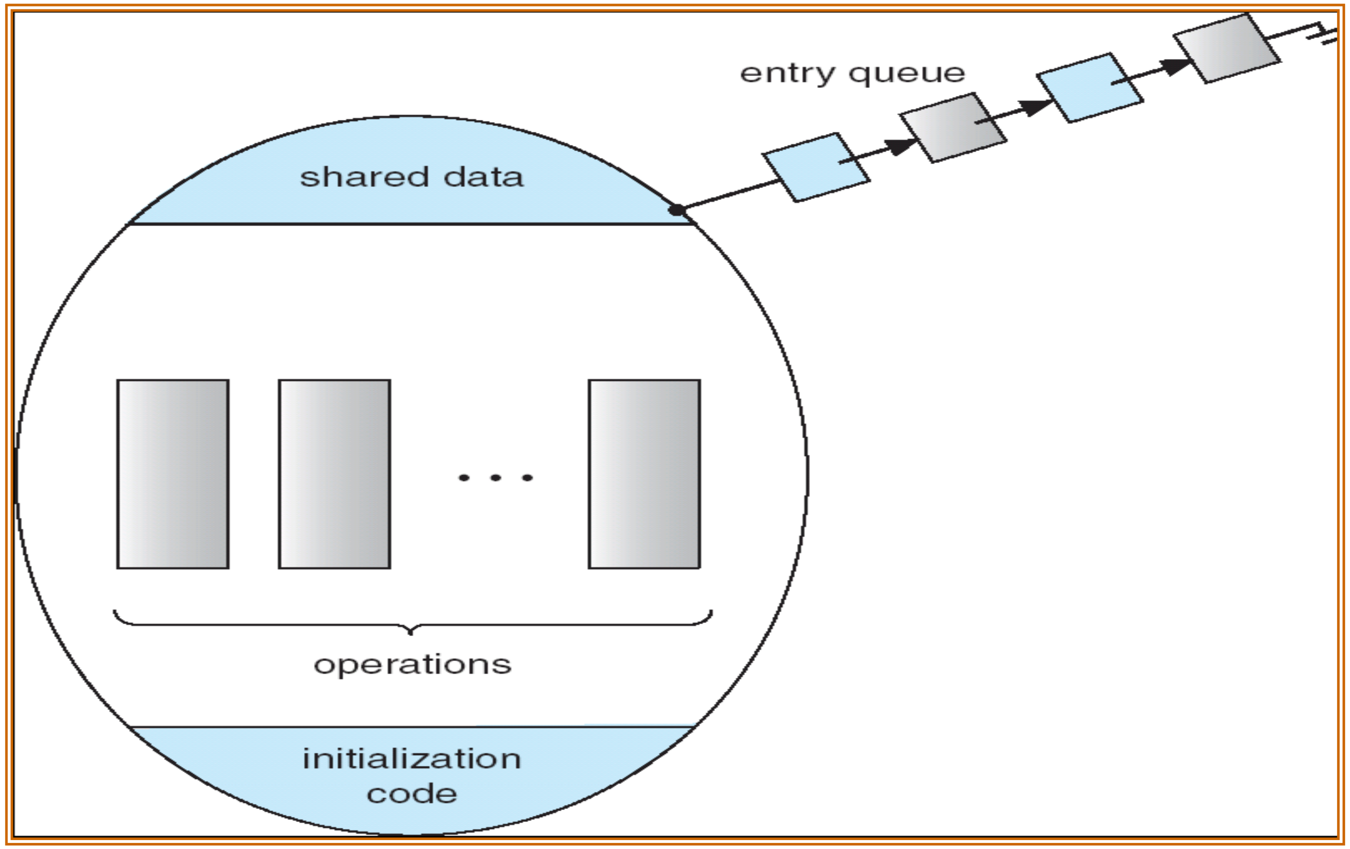




## Synchronous solution with Sleep & Wakeup Monitor

- Hoare (1974) & Brinch (1975)
- Synchronous mechanism is provided by programming language
  - Support with functions, such as Semaphore
  - Easier for using and detecting than Semaphore
    - Ensure Mutual Exclusion automatically
    - Using condition variable to perform Synchronization

## Synchronous solution with Sleep & Wakeup Monitor: structure

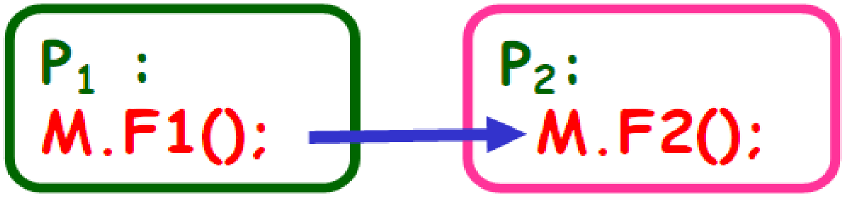


## Synchronous solution with Sleep & Wakeup Using Monitor

```
Monitor         M
<resource type> RC;
Function   AccessMutual
                CS; // access RC
```

```
Pi
  M.AccessMutual(); //CS
```

```
Monitor    M
Condition  c;
Function   F1
           Job1;
           Signal(c);
Function F2
           Wait(c);
           Job2;
```



## Synchronous solution with Sleep & Wakeup Message Passing

- Processes must name each other explicitly:
  - **send** (*P*, *message*) – send a message to process P
  - **receive**(*Q*, *message*) – receive a message from process Q
- Properties of communication link
  - Links are established automatically
  - A link is associated with exactly one pair of communicating processes
  - Between each pair there exists exactly one link
  - The link may be unidirectional, but is usually bi-directional

## Classical Problems of Synchronization

- Bounded-Buffer Problem
  (Producer-Consumer Problem)
- Readers and Writers Problem
- Dining-Philosophers Problem
  (Lab)

## 2.4 Scheduling

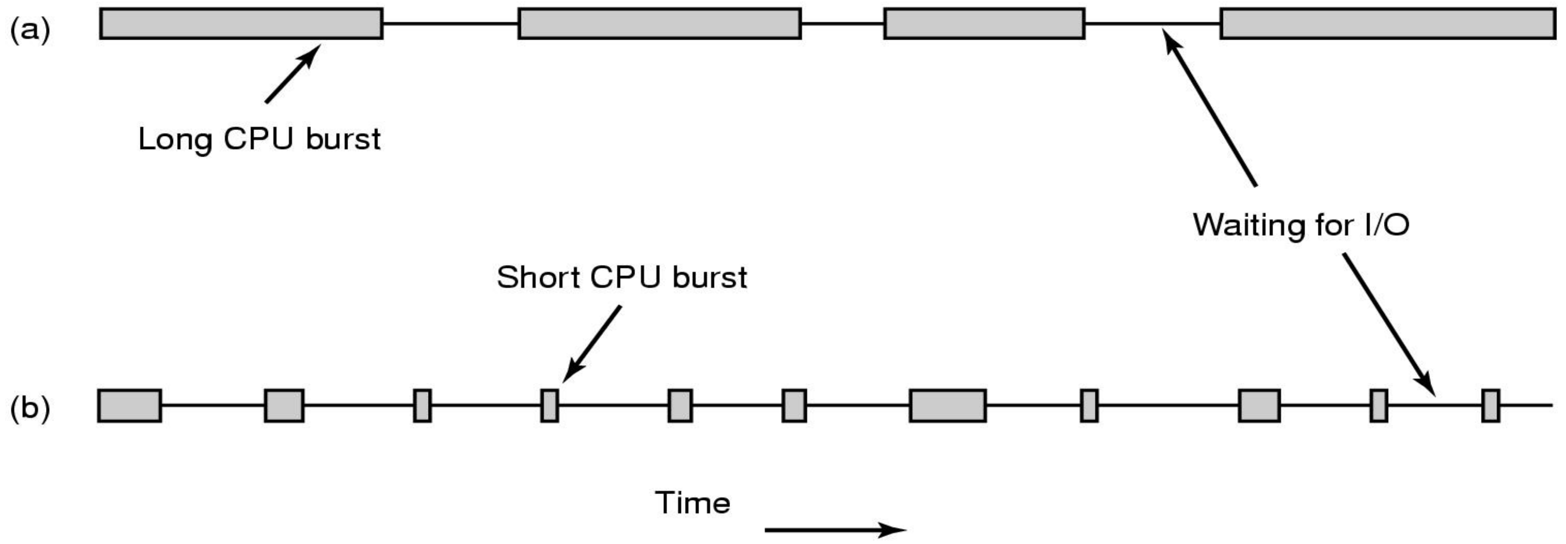
# Scheduling

## Introduction to Scheduling (1)

- Maximum CPU utilization obtained with multiprogramming
- CPU–I/O Burst Cycle – Process execution consists of a *cycle* of CPU execution and I/O wait
- CPU burst distribution

# Scheduling

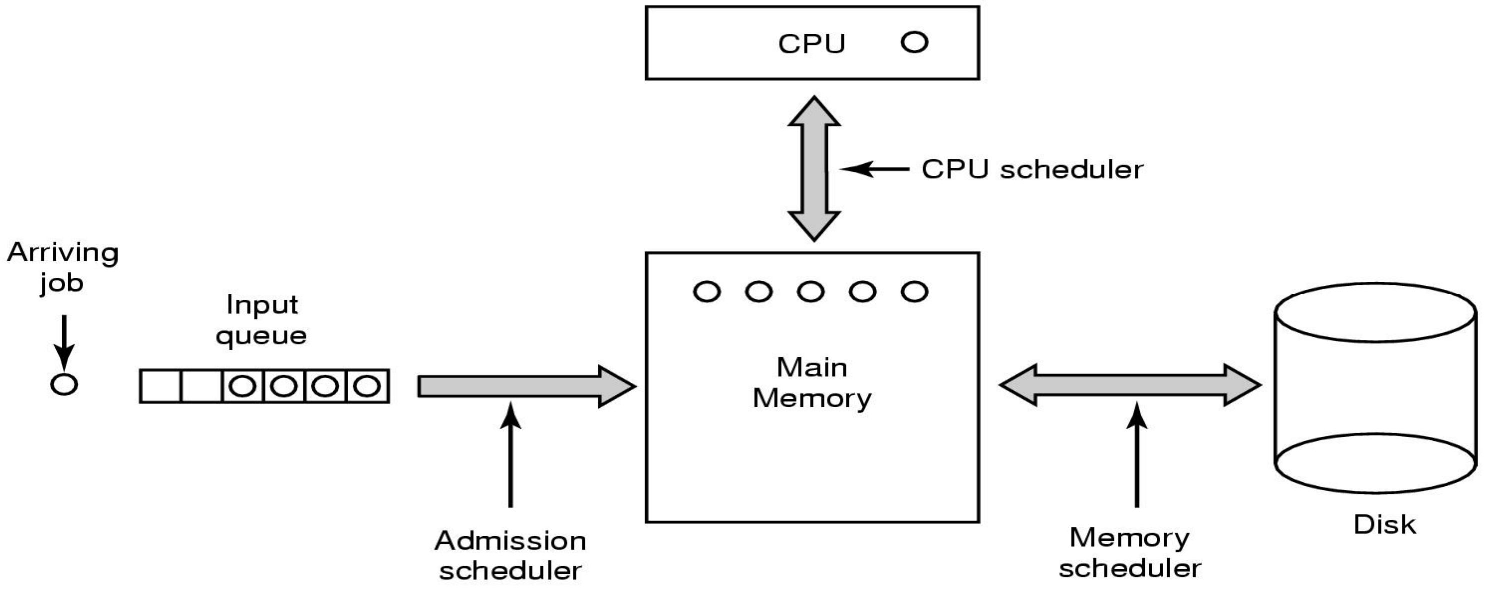
## Introduction to Scheduling (2)



- Bursts of CPU usage alternate with periods of I/O wait
  - (a) a CPU-bound process
  - (b) an I/O-bound process

# Scheduling

## Introduction to Scheduling (3)



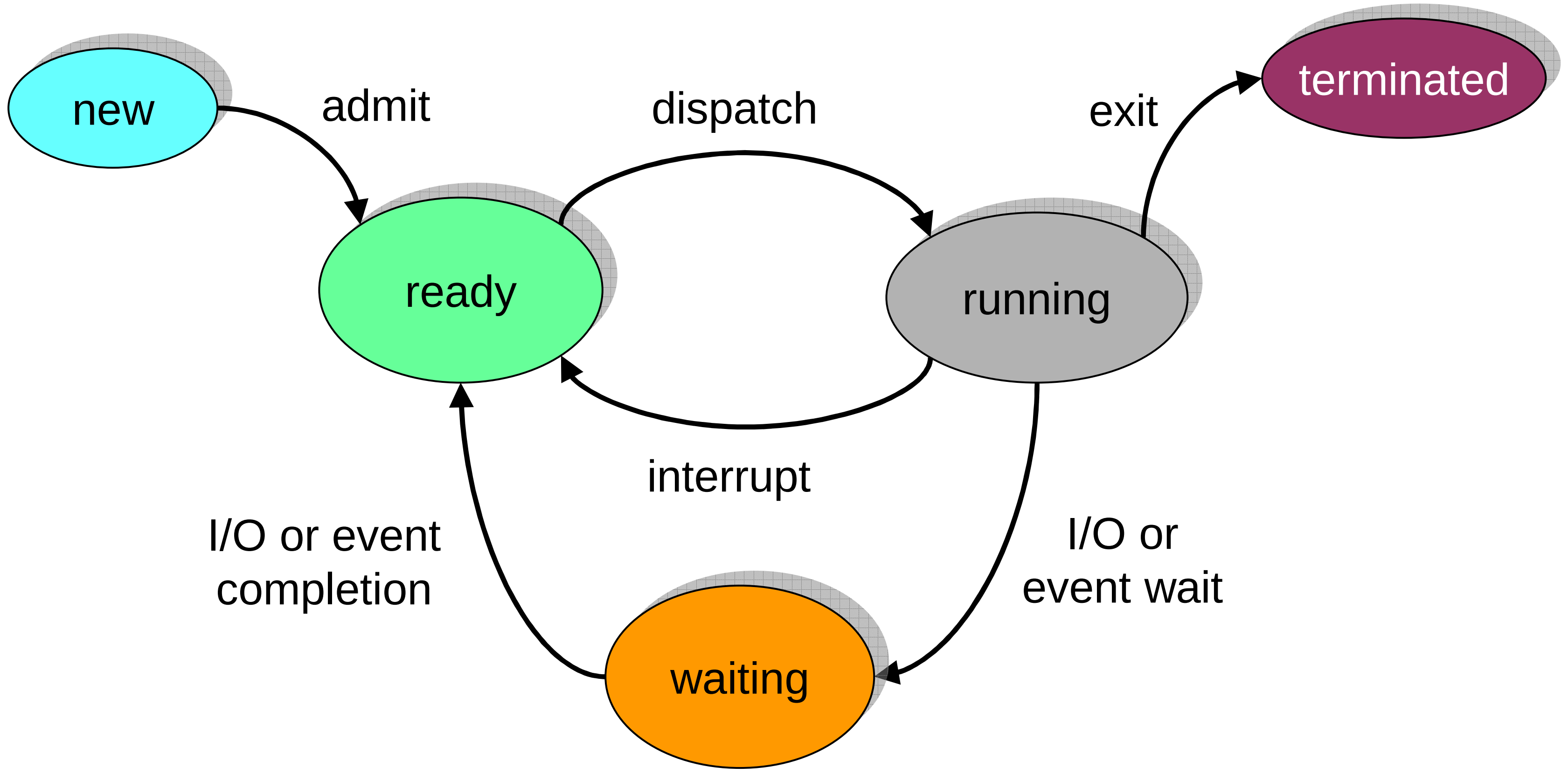
Three level scheduling

# Scheduling
## Introduction to Scheduling (4)

- Selects from among the processes in memory that are ready to execute, and allocates the CPU to one of them
- CPU scheduling decisions may take place when a process:
  1. Switches from running to waiting state
  2. Switches from running to ready state
  3. Switches from waiting or new process is created to ready
  4. Terminates
- *Nonpreemptive* scheduling algorithm picks process and let it run until it blocks or until it voluntarily releases the CPU
- *preemptive* scheduling algorithm picks process and let it run for a maximum of fix time

# Scheduling

## Introduction to Scheduling (5)



# Scheduling

## Introduction to Scheduling (6)

### Scheduling Criteria

- CPU utilization – keep the CPU as busy as possible
- Throughput – # of processes that complete their execution per time unit
- Turnaround time – amount of time to execute a particular process
- Waiting time – amount of time a process has been waiting in the ready queue
- Response time – amount of time it takes from when a request was submitted until the first response is produced, **not** output (for time-sharing environment)

# Scheduling

## Introduction to Scheduling (7)

**Optimization Criteria**

- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time

# Scheduling

## Introduction to Scheduling (8)

### 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

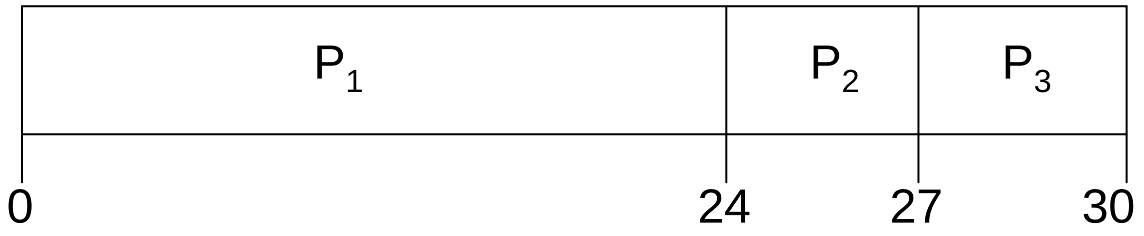
# Scheduling

## Scheduling in Batch Systems (1)

### First-Come, First-Served (FCFS) Scheduling

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

- Suppose that the processes arrive in the order: $P_1$ , $P_2$ , $P_3$
  The Gantt Chart for the schedule is:



- Waiting time for $P_1$ = 0; $P_2$ = 24; $P_3$ = 27
- Average waiting time: (0 + 24 + 27)/3 = 17

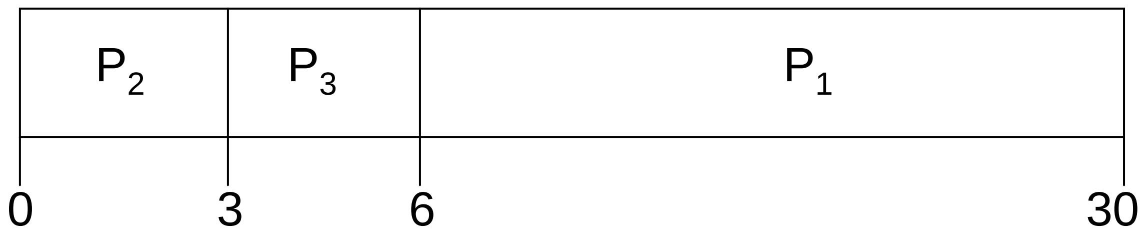
# Scheduling
## Scheduling in Batch Systems (2)

**FCFS Scheduling (Cont.)**

Suppose that the processes arrive in the order

$$P_2 , P_3 , P_1$$

- The Gantt chart for the schedule is:



- Waiting time for $P_1 = 6;$ $P_2 = 0;$ $P_3 = 3$
- Average waiting time: (6 + 0 + 3)/3 = 3
- Much better than previous case
- ***Convoy effect*** **short process behind long process**

## Scheduling
### Scheduling in Batch Systems (3)

**Shortest-Job-First (SJF) Scheduling**

- Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time
- Two schemes:
  - nonpreemptive – once CPU given to the process it cannot be preempted until completes its CPU burst
  - preemptive – if a new process arrives with CPU burst length less than remaining time of current executing process, preempt. This scheme is know as the
    Shortest-Remaining-Time-Next (SRTF)
- SJF is optimal – gives minimum average waiting time for a given set of processes

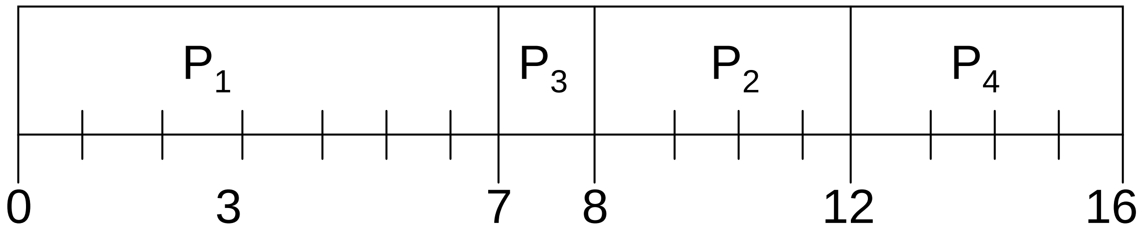
# Scheduling

## Scheduling in Batch Systems (4)

### Example of Non-Preemptive SJF

| Process | Arrival Time | Burst Time |
|---|---|---|
| $P_1$ | 0.0 | 7 |
| $P_2$ | 2.0 | 4 |
| $P_3$ | 4.0 | 1 |
| $P_4$ | 5.0 | 4 |

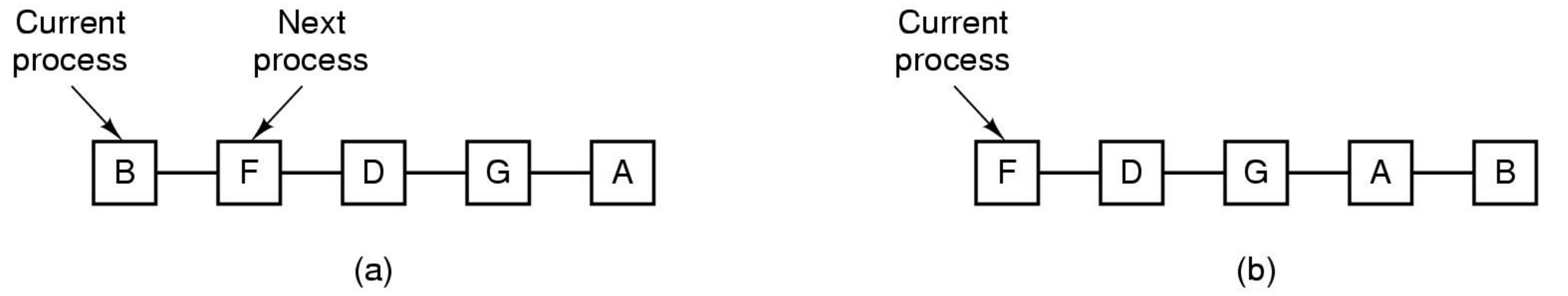
- SJF (non-preemptive)



- Average waiting time = (0 + 6 + 3 + 7)/4 = 4

# Scheduling

## Scheduling in Interactive Systems (1)



- Round Robin Scheduling
  - list of runnable processes (a)
  - list of runnable processes after B uses up its quantum (b)

# Scheduling

## Scheduling in Interactive Systems (2)

### Round Robin (RR)`

- Each process gets a small unit of CPU time (*time quantum*), usually 20-50 milliseconds. After this time has elapsed, the process is preempted and added to the end of the ready queue.
- If there are *n* processes in the ready queue and the time quantum is *q*, then each process gets 1/*n* of the CPU time in chunks of at most *q* time units at once. No process waits more than (*n*-1)*q* time units.
- Performance
  - $q$ large $\Rightarrow$ FCFS
  - $q$ small $\Rightarrow$ overhead is too high respect to context switch

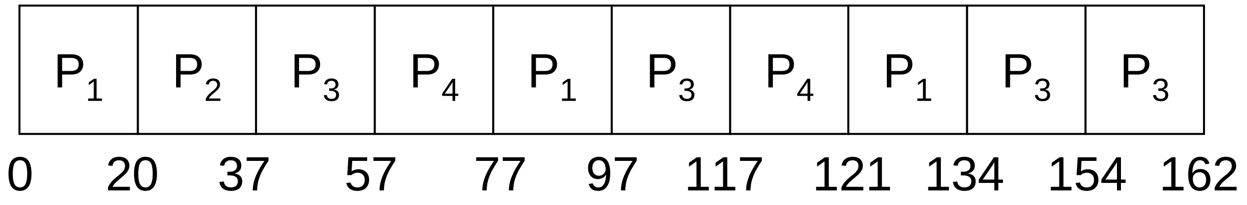
# Scheduling

## Scheduling in Interactive Systems (3)

**Example of RR with Time Quantum = 20**

| Process | Burst Time |
|---|---|
| $P_1$ | 53 |
| $P_2$ | 17 |
| $P_3$ | 68 |
| $P_4$ | 24 |

- The Gantt chart is:



Typically, higher average turnaround than SJF, but better *response*

# Scheduling

## Priority Scheduling (1)

**Priority Scheduling:** A priority number (integer) is associated with each process

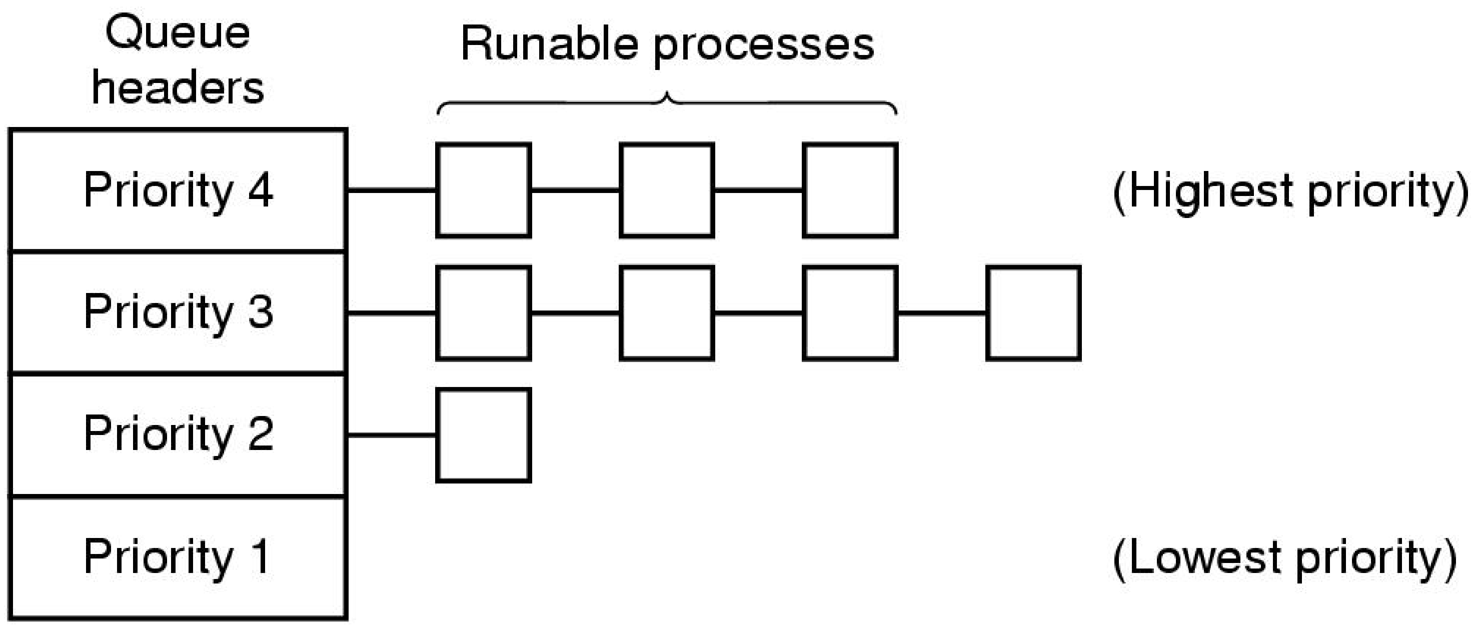
- The CPU is allocated to the process with the highest priority
- Preemptive
- nonpreemptive

- SJF is a priority scheduling where priority is the predicted next CPU burst time
- Problem ≡ Starvation – low priority processes may never execute
- Solution ≡ Aging – as time progresses increase the priority of the process

# Scheduling

## Priority Scheduling (2)

A scheduling algorithm with four priority classes



# Scheduling

## Priority Scheduling (3)

Example of Multilevel Queue

- Ready queue is partitioned into separate queues:
  foreground (interactive)
  background (batch)
- Each queue has its own scheduling algorithm
  - foreground – RR
  - background – FCFS
- Scheduling must be done between the queues
  - Fixed priority scheduling; (i.e., serve all from foreground then from background). Possibility of starvation.
  - Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its processes; i.e., 80% to foreground in RR, 20% to background in FCFS

# Scheduling

## Scheduling in Real-Time Systems (1)

- *Hard real-time* systems – required to complete a critical task within a guaranteed amount of time
- *Soft real-time* computing – requires that critical processes receive priority over less fortunate ones

# Scheduling

## Scheduling in Real-Time Systems(2)

Schedulable real-time system

- Given
  - *m* periodic events
  - event *i* occurs within period $P_i$ and requires $C_i$ seconds
- Then the load can only be handled if

$$\sum_{i=1}^{m} \frac{C_i}{P_i} \leq 1$$

## Scheduling
### Policy versus Mechanism

- Separate what is allowed to be done with 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

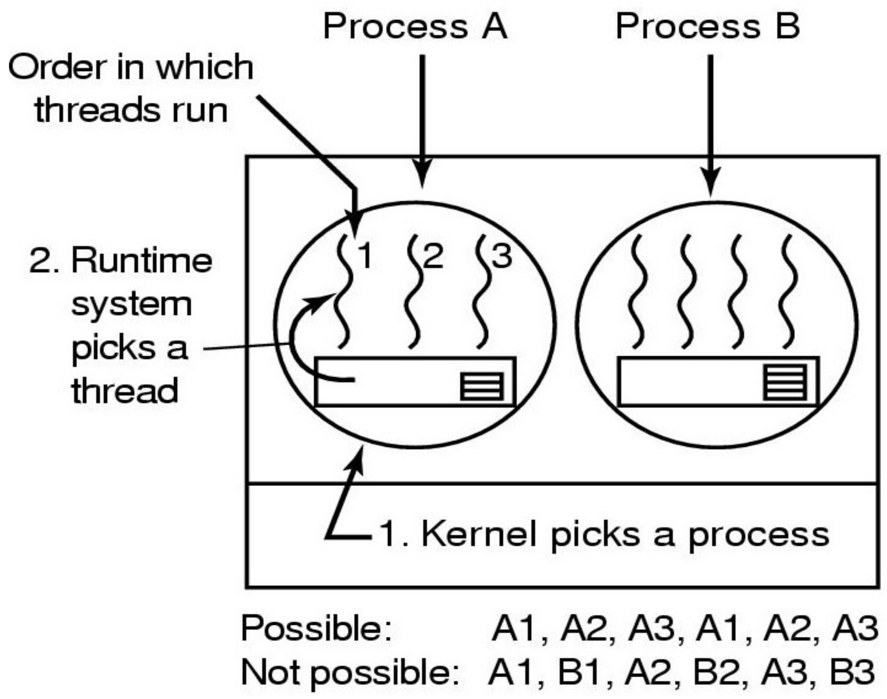
# Scheduling

## Thread Scheduling (1)

- Local Scheduling – How the threads library decides which thread to put onto an available
- Global Scheduling – How the kernel decides which kernel thread to run next

# Scheduling

## Thread Scheduling (2)

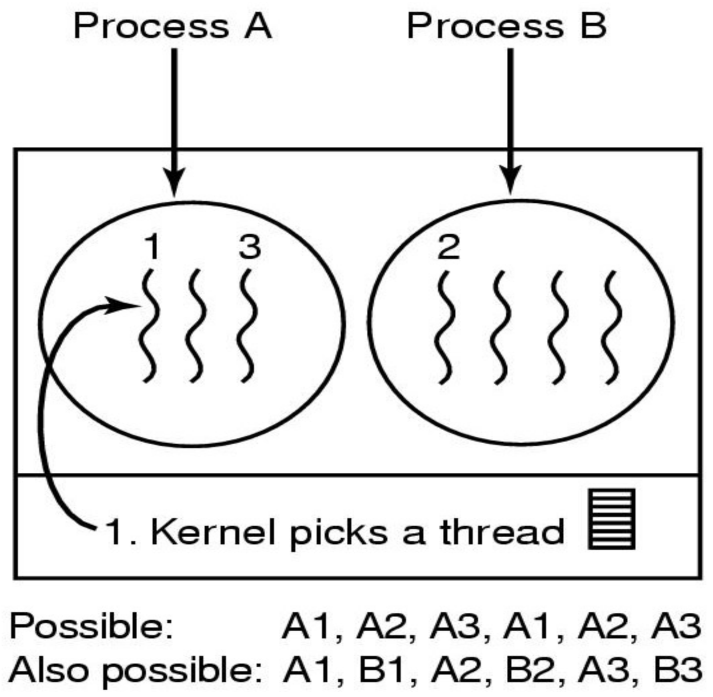

Process A
Process B
Order in which threads run
1
2
3
2. Runtime system picks a thread
1. Kernel picks a process
Possible: A1, A2, A3, A1, A2, A3
Not possible: A1, B1, A2, B2, A3, B3

Possible scheduling of user-level threads

- 50-msec process quantum
- threads run 5 msec/CPU burst

# Scheduling

## Thread Scheduling (3)



Process A
Process B
1
3
2
1. Kernel picks a thread
Possible: A1, A2, A3, A1, A2, A3
Also possible: A1, B1, A2, B2, A3, B3

Possible scheduling of kernel-level threads

- 50-msec process quantum
- threads run 5 msec/CPU burst