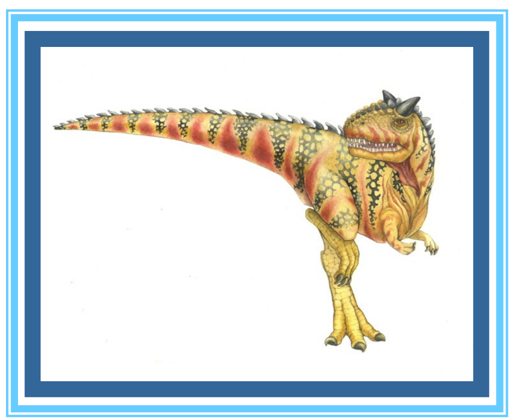
Chapter 5: Process Synchronization



Chapter 5: Process Synchronization

- Background
- The Critical-Section Problem
- Peterson's Solution
- Synchronization Hardware
- Mutex Locks
- Semaphores
- Classic Problems of Synchronization
- Synchronization Examples
- Alternative Approaches

Objectives

- To present the concept of process synchronization.
- To introduce the critical-section (CS) problem, whose solutions can be used to ensure the consistency of shared data
- To present both software and hardware solutions of the critical-section problem
- To examine several classical process-synchronization problems
- To explore several tools that are used to solve process synchronization problems

Background

- **Processes** can execute concurrently
  - May be interrupted at any time, partially completing execution
- Concurrent access to **shared data** may result in **data inconsistency**
  - Maintaining **data consistency** requires mechanisms to ensure the *orderly execution of cooperating processes*
    - **Illustration of the problem:**
      Suppose that we wanted to provide a solution to the **consumer-producer problem** that fills ***all*** the buffers.
    - an integer **`counter`** that keeps track of the number of full buffers.
    - Initially, **`counter`** is set to 0. It is incremented by the **producer** after it produces a new buffer location and is decremented by the **consumer** after it consumes a buffer.

Producer

```
while (true) {
      /* produce an item in next
produced */

      while (counter == BUFFER_SIZE) ;
            /* do nothing */
      buffer[in] = next_produced;
      in = (in + 1) % BUFFER_SIZE;
      counter++;
}
```

Consumer

```
while (true) {
      while (counter == 0)
            ; /* do nothing */
      next_consumed = buffer[out];
      out = (out + 1) % BUFFER_SIZE;
         counter--;
      /* consume the item in next consumed */
}
```

Race Condition

- **`counter++`** could be implemented as

```
register1 = counter
register1 = register1 + 1
counter = register1
```

- **`counter--`** could be implemented as

```
register2 = counter
register2 = register2 - 1
counter = register2
```

Race Condition

The concurrent execution of "`counter++`" and "`counter--`" is equivalent to a sequential execution in which the lower-level statements presented previously are interleaved in some arbitrary order (but the order within each high-level statement is preserved). One such interleaving is the following:

T_0:	*producer*	execute	$register_1 = \texttt{counter}$	$\{register_1 = 5\}$
T_1:	*producer*	execute	$register_1 = register_1 + 1$	$\{register_1 = 6\}$
T_2:	*consumer*	execute	$register_2 = \texttt{counter}$	$\{register_2 = 5\}$
T_3:	*consumer*	execute	$register_2 = register_2 - 1$	$\{register_2 = 4\}$
T_4:	*producer*	execute	$\texttt{counter} = register_1$	$\{counter = 6\}$
T_5:	*consumer*	execute	$\texttt{counter} = register_2$	$\{counter = 4\}$

Notice that we have arrived at the incorrect state "`counter` == 4", indicating that four buffers are full, when, in fact, five buffers are full. If we reversed the order of the statements at T_4 and T_5, we would arrive at the incorrect state "`counter` == 6".

Producer-Consumer Problem: Race condition

- We would arrive at this incorrect state because we allowed both processes to manipulate the **variable counter concurrently.**
- A situation like this, where several processes access and manipulate the same data concurrently and the outcome of the execution depends on the particular order in which the access takes place, is called a **race condition.**
- To guard against the **race condition** we need to ensure that only one process at a time can be manipulating the variable counter.

Principles of Concurrency-Race condition

- Suppose that two processes ***P*1** and ***P*2** share the global variable ***a***. At some point in its execution, ***P*1** updates ***a*** to the value **1**, and at some point in its execution, ***P*2** updates ***a*** to the value **2**. Thus, the two tasks are in a race to write variable ***a***.
  - In this example, the process that updates last determines the final value of ***a***.
- Consider two processes, ***P*3** and ***P*4**, that share global variables ***b*** and ***c***, with initial values ***b*** = **1** and ***c*** = **2**. At some point in its execution, ***P*3** executes ***b* = *b* + *c*** and at some point in its execution, ***P*4** executes ***c* = *b* + *c***.
  - The final values of the two variables depend on the order in which the two processes execute their assignments.
  - If ***P*3** executes its assignment first, then ***b*** = **3** and ***c*** = **5**.
  - If ***P*4** executes its assignment first, then ***b*** = **4** and ***c*** = **3**.

Critical Section (CS)

- A **critical section** (**CS**) is a *code segment* in a process in which a **shared resource is allowed to access**:
  - Only one process can execute its CS at any one time
  - When no process is executing in its CS, any process that requests entry to its CS must be permitted without delay
  - When two or more processes compete to enter their *respective* CSs, the selection cannot be postponed indefinitely
  - No process can prevent any other process from entering its CS indefinitely
  - Every process should be given a **fair chance** to access the shared resource through CS

CS Problem

- Consider system of ***n*** processes {$p_0, p_1, \ldots p_{n-1}$}
- Each process has **CS** segment
  - Process may be changing common variables, updating table, writing file, etc
  - When one process in **CS**, no other may be in its **CS**
  - Each process must ask permission to enter CS in **entry section**, may follow critical section with **exit section**, then **remainder section.**
  - **The general structure of** a typical process *Pi* is shown in **Figure 5.1**.
  - <u>**No two processes are executing in their critical sections at the same time**</u>.

CS

- General structure of process P_i

```
do {

    entry section

        critical section

    exit section

        remainder section

} while (true);
```

Figure 5.1 General structure of a typical process P_i.

Solution to CS Problem

1. **Mutual Exclusion** - If process P_i is executing in its **critical section** (**CS**), then no other processes can be executing in their **critical sections**
2. **Progress** - If no process is executing in its **CS** and there exist some processes that wish to enter their CS, then the selection of the processes that will enter the **CS** next cannot be postponed indefinitely
3. **Bounded Waiting** - A bound must exist on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted
   - Assume that each process executes at a nonzero speed
   - No assumption concerning **relative speed** of the ***n*** processes

CS Handling in OS

Two approaches depending on if **kernel** is *preemptive* or *non- preemptive*

- **Preemptive** – allows preemption of process when running in kernel mode
  - **Preemptive kernels** are especially difficult to design for **SMP** architectures, since in these environments it is possible for two kernel-mode processes to run simultaneously on different processors.
- **Non-preemptive** – runs until exits kernel mode, blocks, or voluntarily yields CPU
  - Essentially free of race conditions in kernel mode, as only one process is active in the kernel at a time.

Critical-Section Handling in OS

- **Why, then, would anyone favor a preemptive kernel over a non-preemptive one?**
  - A **preemptive kernel** may be less risk that a **kernel-mode** process can run for an arbitrarily long period before relinquishing it by the processor.
  - A **preemptive kernel** is more suitable for real-time programming, as it will allow a real-time process to preempt a process currently running in the kernel.

Critical-Section Problem: Peterson's Solution

- **Peterson's solution to CS problem** is restricted to two processes that alternate execution between their **critical sections** and **remainder sections**.
  - The processes are numbered P_i and P_j (where $i = 0$ and $j = 1$)
  - **Figure 5.2** The structure of process in Peterson's solution.
  - **int turn;**
    - The integer variable ***turn*** indicates whose turn it is to enter its CS.
      - if *turn* == i, then process *Pi is allowed to execute in its CS*
  - **boolean flag[2];**
    - A **size two array** is used to indicate if a process is ready to enter its CS.
    - For example, if flag[i] is true, this value indicates that *Pi is ready to enter* its critical section.

Critical-Section Problem: Peterson's Solution

```
do {

     flag[i] = true;
     turn = j;
     while (flag[j] && turn == j){

          critical section

     flag[i] = false;
     }
          remainder section

} while (true);
```

Figure 5.2 The structure of process P_i in Peterson's solution.

Critical-Section Problem: Peterson's Solution

- Each P_i enters its CS only if either (flag[j] == *false*) or (turn == P_i), where P_i = 0
- If (flag[i] == flag[j] == *true*), then it imply that P_i *and* P_j *could not have* successfully executed their while statements at about the same time, since the value of **turn** can be either 0 or 1 but cannot be both. **So this situation is not valid!**
- If (flag[j] == *true* and turn == P_j), and this condition will cause P_j *is in its critical section*, where P_j = 1
- If P_j is not ready to enter its CS, then (flag[j] == *false*), and P_i can enter its CS.
- Mutual exclusion is preserved

  $\mathbf{P_i}$ enters CS only if: either **`flag[j] = false`** or **`turn = i`**

Simulation

Code in C++

Critical Section

- General structure of process P_i

```
do {

    entry section

        critical section

    exit section

        remainder section

} while (true);
```

Solution to CS: mutual exclusion locks

- OS designers build software tools to solve **CS** problem, simplest is **mutex lock** (called **mutual exclusion lock**) to protect critical regions and thus prevent **race conditions**.
- That is, a process must **acquire the lock** before entering a **CS**; it **releases the lock** when it exits the **CS**.
  - Protect a **CS** by first **acquire()** a lock then **release()** the lock;

```
do {
      acquire lock
            critical section
      release lock
            remainder section
   } while (TRUE);
```

Mutex Locks

```
do {
        acquire lock
            critical section
        release lock
            remainder section
} while (true);
```

Figure 5.8 Solution to the critical-section problem using mutex locks.

The definition of `release()` is as follows:

```
release() {
   available = true;
}
```

Calls to either `acquire()` or `release()` must be performed atomically.

Disadvantage of Mutex Locks

- The **main disadvantage** of **mutex lock** is that it requires **busy waiting** (**spinlock**)
  - **Spinlock** means processors continuously execute the ***atomic instruction*** to check for the status of the **shared variable**
    - It wastes processor cycles and consumes network bandwidth
- While a process is in its **CS**, any other process that tries to enter its **CS** must loop continuously in the call to **acquire().**
- Calls to **`acquire()`** and **`release()`** must be **atomic**
  - But this solution requires **busy waiting**
  - This lock therefore called a **spinlock**

Atomic hardware instructions for Critical Section

- **Atomic HW instructions for CS through mutex are:**
  - **Test-and-Set ()** instruction
  - **Compare-and-Swap()** Instruction

Atomic hardware instructions for Critical Section (mutex)

- **Test-and-Set ()** instruction
  - "Test" the requested process is sanctioned to enter CS by checking a memory location or a Boolean variable
  - If yes (the memory location match), then "Set" the selected process for CS
- The **Test-and -Set()** instruction can be defined as shown in **Figure 5.3.**
  - If the machine supports the **test and set()** instruction, then we can implement **mutex** by declaring a boolean variable **lock**, initialized to *false*.

test and set() instruction

```
boolean test_and_set(boolean *target) {
    boolean rv = *target;
    *target = true;

    return rv;
}
```

Figure 5.3 The definition of the `test_and_set()` instruction.

1. Executed atomically
2. Returns the original value of passed parameter **target* and set it as *true*

compare_and_swap Instruction

```
int compare _and_swap(int *value, int
                        expected, int new_value)
{
       int temp = *value;

       if (*value == expected)
          *value = new_value;
    return temp;
   }
```

1. Executed atomically
2. Returns the original value of passed parameter **"*value**" – a **shared variable**
3. If ***value** and **expected** are same, then assigns **new_value** to ***value** and return ***value.** That is, the swap takes place only under this condition.

Semaphores

- **Mutex locks**, are generally considered the simplest of *process synchronization* tools.
- A **semaphore** is a more robust synchronization tool that provides more sophisticated ways (than Mutex locks) for *process synchronization*.
- A *semaphore* ***S*** *is an integer variable* that, apart from initialization, is accessed only through two standard atomic operations:
  - **wait()**
  - **signal()**

Semaphores

- The **wait()** operation was originally termed **P** ("*to test*").
- The definition of **wait()** is as follows:

  P(S) or wait(S): send a wait to waiting processes until the S access operation (S = S - 1)by the current process(s) has been completed.

- The **signal()** was originally called **V** ("*to increment* ").
- The definition of **signal()** is as follows:

  V(S) or signal(S): Signal a waiting process if the previous process has been released all S by incrementing (S = S + 1)it.

Semaphores

The definition of `wait()` is as follows:

```
wait(S) {
    while (S <= 0)
       ; // busy wait
    S--;
}
```

The definition of `signal()` is as follows:

```
signal(S) {
    S++;
}
```

Semaphores

```
P(S)
        Semaphore S; // initialize resource size S
        {
          while (S > 0) ;   // wait until  resource accessed
          S = S - 1; // resource access
        }
V(S)
        Semaphore S; // initialize resource size S
        {
          S = S+1; // free resources by processes
        }
Init(S, v)  // initialize S with v values before a new request
        Semaphore S; // initialize resource size S
        Int v;
        {
        S = v;
         }
```

Semaphores

- All modifications to the integer value of the semaphore in the **wait()** and **signal()** operations must be executed **indivisibly**.
  - That is, when one process modifies the semaphore value, no other process can simultaneously modify that same semaphore value.
- In addition, in the case of **wait(S)**, the testing of the integer value of **S** (**S ≤ 0**), as well as its possible modification (**S--**), must be executed **without interruption**.

Semaphore Usage

- Operating systems often distinguish between **counting** and **binary** semaphores.
- The value of a **counting semaphore** can range over an unrestricted domain.
- The value of a **binary semaphore** can range only between 0 and 1.
  - Thus, binary semaphores behave similarly to **mutex locks**.
    - on systems that do not provide **mutex locks**, binary semaphores can be used instead for providing mutual exclusion.

Semaphores

- Use **semaphores** to solve **synchronization problems**: For example, consider two **concurrently** running processes:
  - ***P*1** with a statement ***S*1** and ***P*2** with a statement ***S*2**. Suppose we require that ***S*2** be executed only after ***S*1** has completed.
  - We can implement this scheme readily by letting ***P*1** and ***P*2** share a common semaphore **synch**, initialized with its size.
  - In process ***P*1**, we insert the statement

```
S1;
wait(synch); // P1 using semaphore synch (P1
                       in CS) and P2 should wait
```

  - In process *P*2, we insert the statements:

```
signal(synch); // Signal to P2 indicates P1 has
                    completed its semaphore synch
                     (means, its CS).
```

Semaphores

- Possibly the simplest use for a semaphore is **signaling**
  - Means that one thread sends a **signal** to another thread to indicate that something has happened
  - Signaling makes it possible to guarantee that one thread will run CS before another thread
  - Assume that semaphore **s** with initial value **0** (*no resource available*), and that **Threads A** and **B** have shared access to it

Thread-A	**Thread-B**
t1. statement a1 (in CS) t2. s.signal()	t1. s.wait() t2. statement b1 (in CS)

    - At time t1, ThreadA in CS and ThreadB in waiting state
    - At time t2, ThreadA frees **s** and ThreadB gets **s** (in its CS)
  - The semaphore guarantees that Thread-A has completed **a1** before Thread-B begins **b1**

Semaphores - Puzzle

Thread A

1 statement a1
2 Statement a2

Thread B

1 Statement b1
2 Statement b2

- Given this code we want to guarantee **that a1 happens before b2 and b1 happens before a2**

(Hint: *use semaphores as the previous example. Don't forget to specify the names and initial values of your semaphores*)

Semaphores – Puzzle Answer

Thread A

t1: a1(in CS)
t2: a1.signal
t3: a2.wait
t4: a2 (in CS)
t5: a2 (in CS)
t6: a2.signal

Thread B

t1: b1.wait
t2: b1(in CS)
t3: b1(in CS)
t4: b1.signal
t5: b2.wait
t6: b2 (in CS)

Semaphores

- **Advantages**
  - Semaphores impose deliberate constraints that help programmers to avoid errors
  - Solutions using semaphores are often clean and organized
  - Semaphore can be implemented efficiently on many systems, so solutions that use semaphores are portable and usually efficient

Semaphores

- **Drawbacks**
  - A process that uses a semaphore has to know which other processes use the semaphore (or waiting for semaphore)
    - the semaphore operations of all interacting processes have to be coordinated
  - Semaphore operations must be carefully positioned in a process
    - The omission of a P or V operation may result in deadlock or inconsistencies
  - Programs with semaphores extremely hard to verify for their correctness

Deadlock and Starvation

- **Deadlock** – two or more processes are waiting indefinitely for an event that can be caused by only one of the waiting processes
- Let ***S*** and ***Q*** be two semaphores initialized to 1

P_0

```
wait(S);
 wait(Q);
...
 signal(S);
  signal(Q);
```

P_1

```
wait(Q);
 wait(S);
...
     signal(Q);
      signal(S);
```

- Suppose that ***P*0** executes **wait(S)** and then ***P*1** executes **wait(Q)**. When ***P*0** executes **wait(Q)**, it must wait until ***P*1** executes **signal(Q)**.
- Similarly, when ***P*1** executes **wait(S)**, it must wait until ***P*0** executes **signal(S)**. Since these **signal()** operations cannot be executed, ***P*0** and ***P*1** are **deadlocked**.

Deadlock and Starvation

- **Starvation** – **indefinite blocking**
  - A process may never be removed from the semaphore queue in which it is suspended
- **Priority Inversion** – Scheduling problem when lower-priority process holds a lock needed by higher-priority process
  - Solved via **priority-inheritance protocol**

Classical Problems of Synchronization

- Classical problems used to test newly-proposed synchronization schemes
  - **Bounded-Buffer Problem**
  - **Readers and Writers Problem**
  - **Dining-Philosophers Problem**

Bounded-Buffer Problem

- ***n*** buffers, each can hold one item
- Semaphore **mutex** initialized to the value 1
- Semaphore **full** initialized to the value 0
- Semaphore **empty** initialized to the value n

The Producer-Consumer - Semaphore

- The structure of the **producer process**

```
do {
      ...
      /* produce an item in next_produced */
      ...
   wait(empty);
   wait(mutex);
       ...
      /* add next produced to the buffer */
       ...
   signal(mutex);
   signal(full);
} while (true);
```

The Producer-Consumer - Semaphore

- The structure of the **consumer process**

```
    Do {
         wait(full);
         wait(mutex);
             ...
         /* remove an item from buffer to
next_consumed */
             ...
         signal(mutex);
         signal(empty);
             ...
         /* consume the item in next consumed */
             ...
      } while (true);
```

The Producer-Consumer - Semaphore

- The structure of the **producer process**

```
do  {
     //   produce an item
     wait (empty);  // consumer should wait  because buffer is empty
     wait (mutex);  // consumer wait, mutex  semaphore  is with producer
     add the item to the  buffer;  // fill buffer (CS)
     signal (mutex);  // signal to consumer that 'mutex' is free and get it
     signal (full);  // signal to consumer that buffer is full
} while (TRUE);
```

- The structure of the **consumer process**

```
do {
     wait (full);  // producer wait because buffer is full
     wait (mutex);  // producer wait 'mutex'  is with consumer
      remove an item from  buffer;  // consume buffer (CS)
     signal (mutex);  // signal to producer that mutex is free and get it
     signal (empty);  // signal to producer that buffer is  empty
     } while (TRUE);
```

The Producer-Consumer problem

- In multithreaded programs there is often a division of **labor** between processes (or threads)
- And some processes are **producers** and some are **consumers**
  - **Producers** create **items** of some kind and add them to a **data structure (buffer);**
  - **Consumers** remove (consume) the items from **buffer** and process them

Producer-Consumer Problem

- There are several *synchronization constraints* that we need to enforce to make this **producer-consumer** system work correctly
  - **Producer** processes (or threads) supplies/produce messages
  - **Consumer** processes (or threads) consume messages
  - Both processes (*asynchronous in nature*) share a **common buffer**
  - conditional synchronization as well as mutual exclusion needed:
    - No **consumer** can access the buffer **when it is empty** and no producer can access the buffer **when it is full**
    - If a **consumer** process (or thread) arrives while the **buffer** is empty, it blocks until a producer adds a new item into it

Producer-Consumer Problem

- **Event-driven** programs are a good example:
  - Whenever and **event** occurs, a **producer thread** creates an **event object** and adds it to the **event buffer**
  - Concurrently, **consumer threads** take **events** out of the **buffer** and execute them
  - In this case, the **consumers** are called "**event handlers**"

Readers-Writers Problem

- Here a data set is shared among a number of **concurrent processes**
  - **Readers** – only read the data set; they do ***not*** perform any updates
  - **Writers** – can both read and write
- **Problem** – *allow multiple readers to read at the same time* and *only one single writer can access the shared data at the same time.*
- Several variations of how readers and writers are considered – all involve some form of priorities
- **Shared Data**
  - Data set
  - Semaphore **`rw_mutex`** initialized to 1 // *this one for writes*
  - Semaphore **`mutex`** initialized to 1 // both readers and writers needed
  - Integer **`read_count`** initialized to 0

Readers-Writers Problem (Cont.)

- The structure of a **writer process**

```
do {
     wait(rw_mutex);
        ...
     /* writing is performed */
        ...
   signal(rw_mutex);
} while (true);
```

Readers-Writers Problem (Cont.)

- The structure of **a reader process**

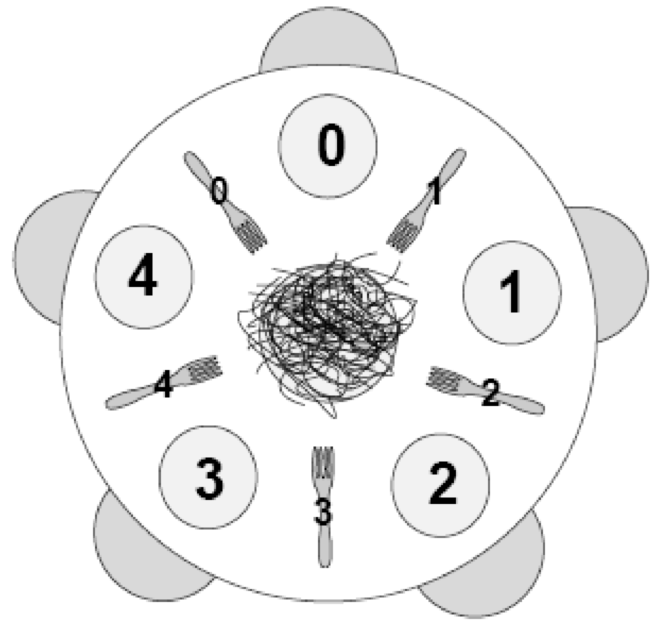
```
do {  //  first finding readers using 'mutex'
        wait(mutex);  // mutex is with a reader other readers/writers wait
          read_count++;  // get readers
          if (read_count == 1)  //if at least one reader
           wait(rw_mutex);  // send  wait (rw_mutex) writers
       signal(mutex);  // send signal (mutex) next waiting reader

          /* reading is performed */
      wait(mutex);  // reading is going on (readers/writers waits)
          read count--;  // get count of read readers
          if (read_count == 0)  // if no more readers
       signal(rw_mutex);  // signal 'rw_mutex' to writers to synch
       signal(mutex);  // signal 'mutex' to synchronized writers
 } while (true);
```

The Dining Philosophers (cont.)

- **Five philosophers** are sitting in a circle, attempting to eat spaghetti with the help of forks
- A common bowl of spaghetti for each philosopher but there are only **five forks** (forks are placed between left and right of each philosopher) to share among them
- But both forks are needed at a time to consume spaghetti
- A philosopher alternates between **two phases:**
  - **Thinking** and **eating**
- In the **thinking mode**, a philosopher does not hold a fork
- When hungry, a philosopher attempts to pick up both forks on left and right sides
  - A philosopher can start eating only after **obtaining both forks**
  - Once start eating the **forks are not relinquished** until the eating phase is over

The Dining Philosophers (cont.)

- Note that **no two neighboring philosophers can eat simultaneously**
- In order to find any solution, *the act of picking up a fork by a philosopher must be a **critical section***
- The solution should be a *deadlock free one*, in which no philosopher starves



The Dining Philosophers (cont.)

- Five philosophers, who represent interacting threads, come to the table and execute the following loop:

```
while true
    think()
    get_forks()
    eat()
    put_forks()
```

The program should satisfy the following constraints:

1. Only one philosopher can hold a fork at a time.
2. It must be impossible for a deadlock to occur.
3. It must be impossible for a philosopher to starve waiting for a fork.
4. It must be possible for more that one philosopher to eat at the same time.

Windows Synchronization

- Windows uses interrupt masks to protect access to global resources on uniprocessor systems.
- Uses **spinlocks** on multiprocessor systems
  - **Spinlocking-thread** will never be preempted
- Also provides **dispatcher objects** user-land which may act as mutexes, semaphores, events, and timers
  - **Events**
    - An event acts much like a condition variable
  - Timers notify one or more thread when time expired
  - Dispatcher objects either **signaled-state** (object available) or **non-signaled state** (thread will block)

Linux Synchronization

- **Linux:**
  - Prior to kernel Version 2.6, disables interrupts to implement short critical sections
  - Version 2.6 and later, fully preemptive
- **Linux provides:**
  - Semaphores
  - atomic integers
  - spinlocks
  - reader-writer versions of both
- On single CPU system, **spinlocks** replaced by enabling and disabling kernel preemption.

```
#include <cstdlib>
#include <iostream>
#include <string>
#include <time.h>
#include<windows.h>
using namespace std;
void delay()
{ time_t start_time, cur_time;
  time(&start_time);
  do{ time(&cur_time);}
  while((cur_time - start_time) < 2.5); // 2.5 ms delay
}
int main(int argc, char *argv[])
{
    bool flag[2]= {false, false};
    int turn;
    int count = 1;
    int bount = 1;
    string turnVal;
    do{
        system("CLS");
         srand (time(NULL));
         int ran = rand() % 2; // generate 0 = i or 1 = j
        flag[ran] = true;// i == true
        turn = ran; //j = 1
    while(flag[ran] && turn == ran)// while both flag and turn are same then
       {
            cout << "\n\n";
             for (int i = 0; i < 2; i++)
            { if (i == 0 && flag[i] == 1) {cout << "  flag[Pi] = true  " ;}
             else if(i == 0 && flag[i] == 0){cout << "  flag[Pi] = false "  ;}
             else if(i == 1 && flag[i] == 1){cout << "  flag[Pj] =  true  ";}
             else {cout << "  flag[Pj] =  false  ";}}//for ends
             if(turn == 0)turnVal = " Pi ( value is 0) ";
             else turnVal = " Pj (value is 1) ";
             cout << "   turn = " << turnVal <<  endl;
    if(ran == 0) // print the equivalent process critical status
    { if (count == 1)
    {Beep(1568, 300); //cout << '\a';// window beep
    count = 0;}
    cout << "\n ============================================\n";
    cout << " \n  Process Pi is in its Critical Section (CS).\n";
    cout << "\n ============================================\n" ;
    bount = 1;}
    else { if(bount == 1){
     Beep(1275, 400); //cout << '\a';// window beep
    bount = 0;}
    cout << "\n ============================================\n";
    cout << " \n  Process Pj is in its Critical Section (CS).\n";
    cout << "\n ============================================\n" ;
    count = 1;
    }
    flag[ran] = false; // clear the flag status for next process
    delay();// call 2 ms delay
    }
}while(true);
    system("PAUSE");
    return EXIT_SUCCESS;
}
```

BACK

End of Chapter 5