OPERATING SYSTEMS

Mutual Exclusion & Synchronization: Hardware

Nitin V Pujari
Faculty, Computer Science
Dean - IQAC, PES University

OPERATING SYSTEMS

Course Syllabus - Unit 2

12 Hours

Unit 2: Threads & Concurrency

Introduction to Threads, types of threads, Multicore Programming, Multithreading Models, Thread creation, Thread Scheduling, PThreads and Windows Threads, Mutual Exclusion and Synchronization: software approaches, principles of concurrency, hardware support, Mutex Locks, Semaphores. Classic problems of Synchronization: Bounded-Buffer Problem, Readers -Writers problem, Dining Philosophers Problem concepts. Synchronization Examples - Synchronisation mechanisms provided by Linux/Windows/Pthreads. Deadlocks: principles of deadlock, tools for detection and Prevention.

OPERATING SYSTEMS

Course Outline

13	Introduction to Threads, types of threads, Multicore Programming, Multithreading Models	4.1 - 4.3	42.8
14	Thread creation, Thread Scheduling	5.4	
15	Pthreads and Windows Threads	4.4	
16	Mutual Exclusion and Synchronization: software approaches,	6.1-6.2	
17	principles of concurrency, hardware support	6.3-6.4	
18	Mutex Locks, Semaphores	6.5, 6.6	
19	Classic problems of Synchronization: Bounded-Buffer Problem, Readers-Writers problem	6.7-6.8	
20	Dining-Philosophers Problem	6.8	
21	Synchronization Examples: Synchronisation mechanisms provided by Linux/Windows/Pthreads.	6.9	
22	Deadlocks: principles of deadlock, Deadlock Characterization	7.1-7.3	
23	Deadlock Prevention, Deadlock example	7.4-7.5	
24	Deadlock Detection, Algorithm	7.6	

Course Outline

17	principles of concurrency, hardware support	6.3-6.4
18	Mutex Locks, Semaphores	6.5, 6.6

Topic Outline

- Synchronization Hardware
- Hardware Solution to Critical Section Problem
- Test and Set Instruction
- Compare and Swap Instruction

Synchronization Hardware

- Many systems provide hardware support for implementing the critical section code.
- All solutions below based on idea of locking
- Protecting critical regions via locks
- Uniprocessors – could disable interrupts
- Currently running code would execute without preemption
- Generally too inefficient on multiprocessor systems
- Operating systems using this not broadly scalable

Synchronization Hardware

- Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes
- Modern machines provide special atomic hardware instructions
- Atomic mean non-interruptible
- Either test memory word and set value or swap contents of two memory words

Synchronization Hardware

- Hardware features can make any programming task easier and improve system efficiency.
- Some simple hardware instructions that are available on many systems and show how they can be used effectively in solving the critical-section problem.
- The critical-section problem could be solved simply in a uniprocessor environment if we could prevent interrupts from occurring while a shared variable was being modified.
- In this manner, one could be sure that the current sequence of instructions would be allowed to execute in order without preemption.

- No other instructions would be run, so no unexpected modifications could be made to the shared variable.

- This is the approach taken by non-preemptive kernels. Unfortunately, this solution is not as feasible in a multiprocessor environment.

- Disabling interrupts on a multiprocessor can be time consuming, as the message is passed to all the processors.

- This message passing delays entry into each critical section, and system efficiency decreases.

- Also, consider the effect on a system's clock, if the clock is kept updated by interrupts.

- Many modern computer systems therefore provide special hardware instructions that allow us either to test and modify the content of a word or to swap the contents of two words atomically that is, as one uninterruptible unit.

- One can use these special instructions to solve the critical-section problem in a relatively simple manner.

- Rather than discussing one specific instruction for one specific machine, one can abstract the main concepts behind these types of instructions.

Solution to Critical-section Problem Using Locks

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

Solution to Critical-section Problem Using Test_and_Set

```
boolean test_and_set (boolean *target)
        {
            boolean rv = *target;
            *target = TRUE;
            return rv:
        }
```

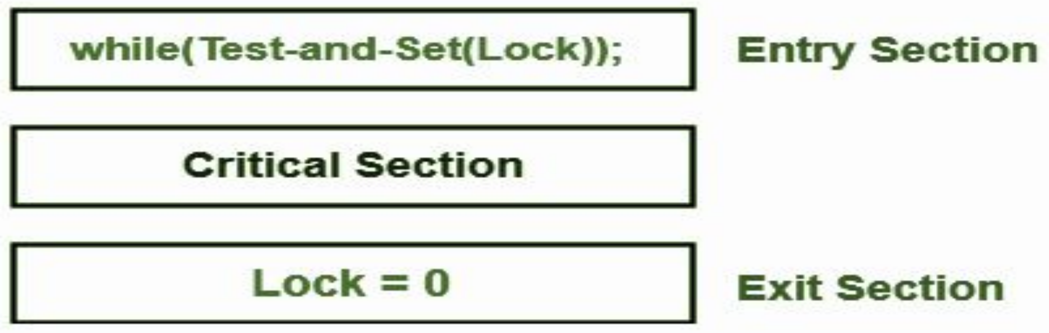
- Executed atomically
- Returns the original value of passed parameter
- Set the new value of passed parameter to "TRUE".

Solution to Critical-section Problem Using Test_and_Set

```
boolean test_and_set (boolean *target)
        {
            boolean rv = *target;
            *target = TRUE;
            return rv:
        }
```

- The important characteristic is that this instruction is executed atomically.
- Thus, if two TestAndSet instructions are executed simultaneously (each on a different CPU), they will be executed sequentially in some arbitrary order.
- If the machine supports the TestAndSet () instruction, then we can implement mutual exclusion by declaring a Boolean variable lock, initialized to false.

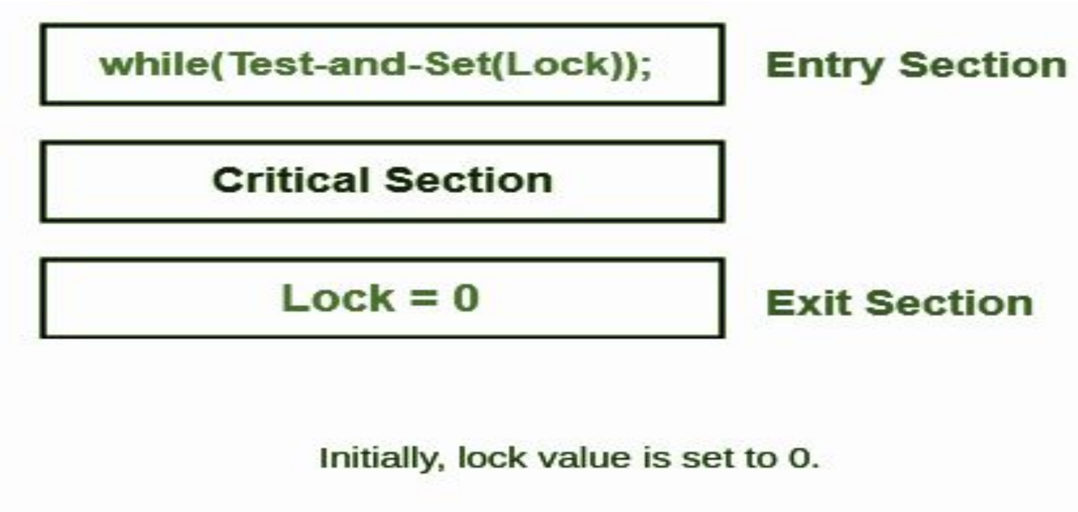
Solution to Critical-section Problem Using Test_and_Set



Initially, lock value is set to 0.

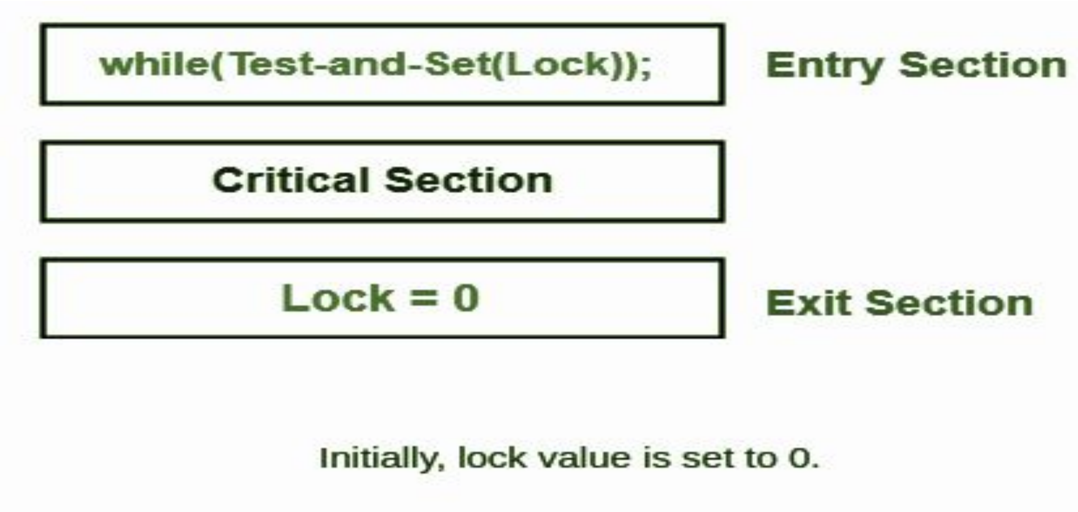
- Process P_0 arrives.
- It executes the test-and-set(Lock) instruction.
- Since lock value is set to 0, so it returns value 0 to the while loop and sets the lock value to 1.
- The returned value 0 breaks the while loop condition.
- Process P_0 enters the critical section and executes.
- Now, even if process P_0 gets preempted in the middle, no other process can enter the critical section.
- Any other process can enter only after process P_0 completes and sets the lock value to 0.

Solution to Critical-section Problem Using Test_and_Set



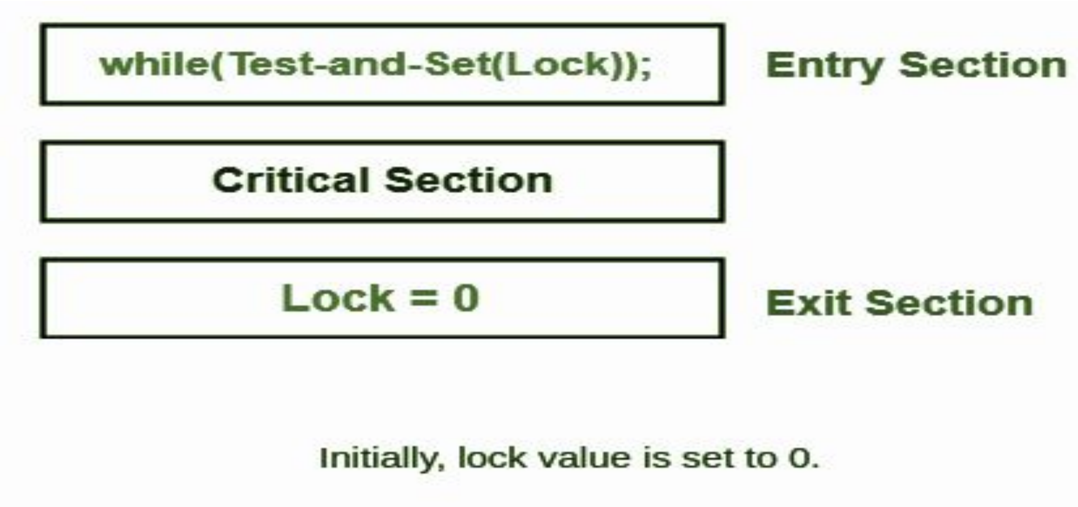
- Another process P_1 arrives.
- It executes the test-and-set(Lock) instruction.
- Since lock value is now 1, so it returns value 1 to the while loop and sets the lock value to 1.
- The returned value 1 does not break the while loop condition.
- The process P_1 is trapped inside an infinite while loop.
- The while loop keeps the process P_1 busy until the lock value becomes 0 and its condition breaks.

Solution to Critical-section Problem Using Test_and_Set



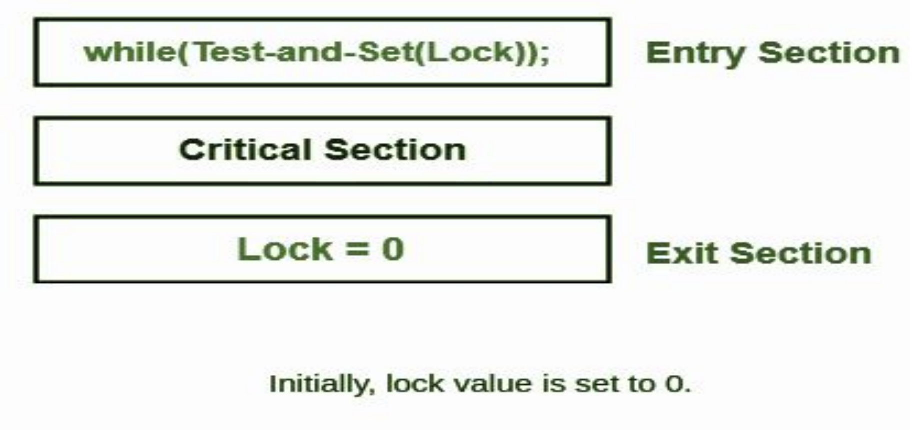
- Process P_0 comes out of the critical section and sets the lock value to 0.
- The while loop condition breaks.
- Now, process P_1 waiting for the critical section enters the critical section.
- Now, even if process P_1 gets preempted in the middle, no other process can enter the critical section.
- Any other process can enter only after process P_1 completes and sets the lock value to 0.

Solution to Critical-section Problem Using Test_and_Set



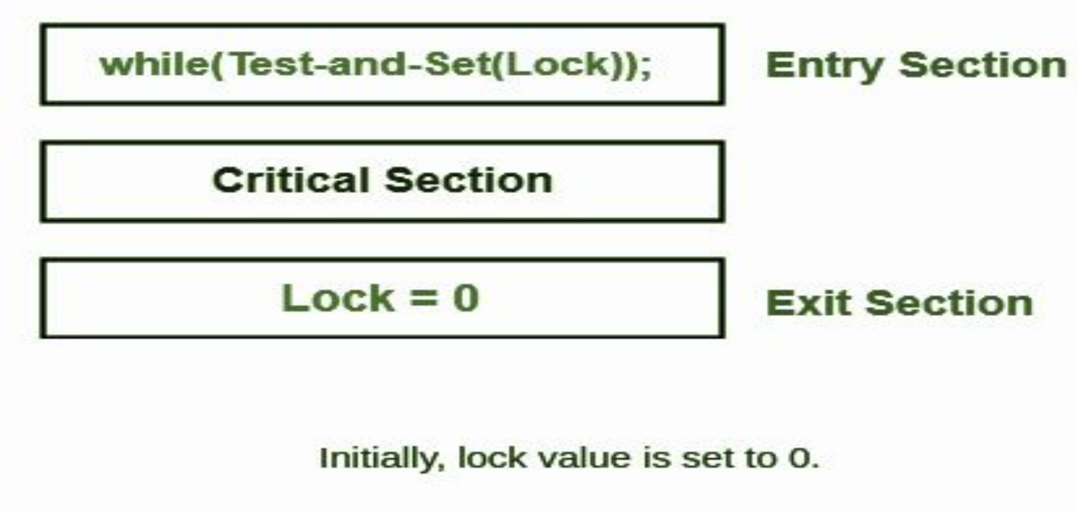
- It ensures mutual exclusion.
- It is deadlock free.
- It does not guarantee bounded waiting and may cause starvation.
- It suffers from spin lock.
- It is not architectural neutral since it requires the operating system to support test-and-set instruction.
- It is a busy waiting solution which keeps the CPU busy when the process is actually waiting.

Solution to Critical-section Problem Using Test_and_Set



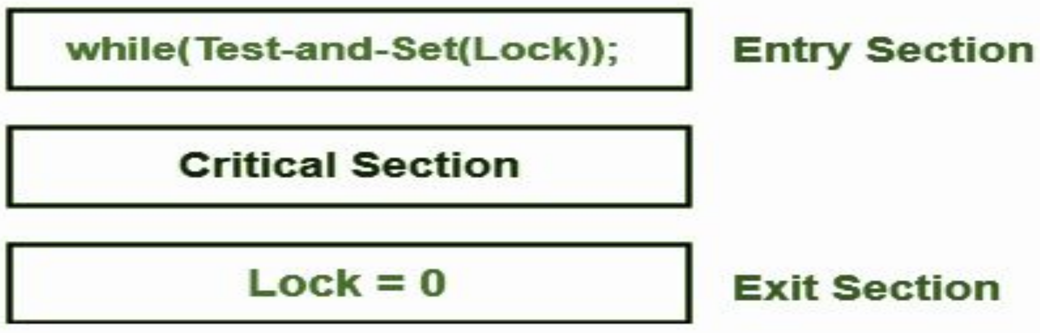
- **This synchronization mechanism guarantees mutual exclusion.**
- The success of the mechanism in providing mutual exclusion lies in the test-and-set instruction.
- Test-and-set instruction returns the old value of memory location (lock) and updates its value to 1 simultaneously.
- The fact that these two operations are performed as a single atomic operation ensures mutual exclusion.
- Preemption after reading the lock value was a major cause of failure of lock variable synchronization mechanism.
- Now, no preemption can occur immediately after reading the lock value.

Solution to Critical-section Problem Using Test_and_Set



- **This synchronization mechanism guarantees freedom from deadlock.**
- After arriving, process executes the test-and-set instruction which returns the value 0 to while loop and sets the lock value to 1.
- Now, no other process can enter the critical section until the process that has begin the test-and-set finishes executing the critical section.
- Other processes can enter only after the process that has begin the test-and-test finishes and set the lock value to 0.
- This prevents the occurrence of deadlock.

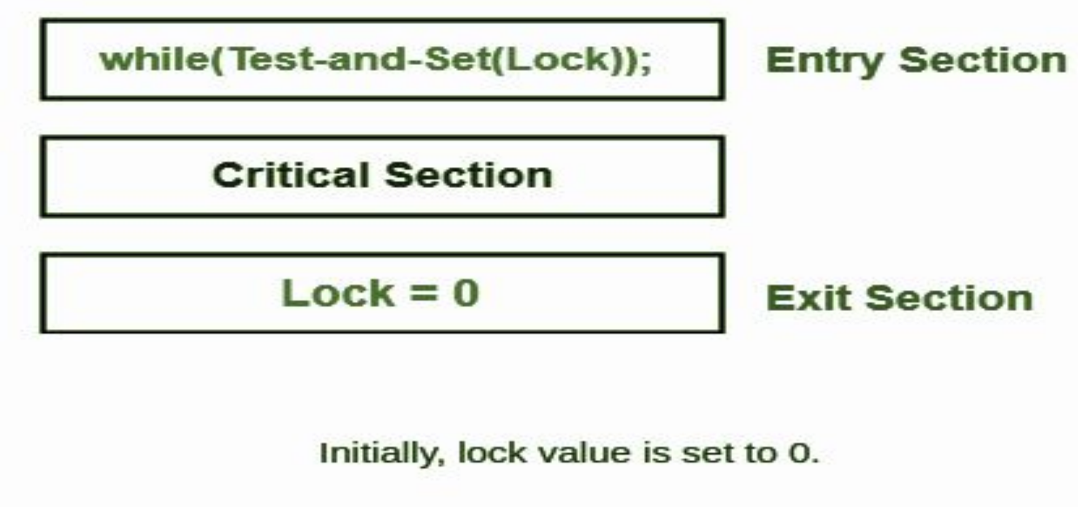
Solution to Critical-section Problem Using Test_and_Set



Initially, lock value is set to 0.

- **This synchronization mechanism does not guarantee bounded waiting.**
- This synchronization mechanism may cause a process to starve for the CPU.
- There might exist an unlucky process which when arrives to execute the critical section finds it busy.
- So, it keeps waiting in the while loop and eventually gets preempted.
- When it gets rescheduled and comes to execute the critical section, it finds another process executing the critical section.
- So, again, it keeps waiting in the while loop and eventually gets preempted.
- This may happen several times which causes that unlucky process to starve for the CPU.

Solution to Critical-section Problem Using Test_and_Set



- **This synchronization mechanism suffers from spin lock where the execution of processes is blocked.**

Consider a scenario where-

- Priority scheduling algorithm is used for scheduling the processes.
- On arrival of a higher priority process, a lower priority process is preempted from the critical section.

Now,

- Higher priority process comes to execute the critical section.
- But synchronization mechanism does not allow it to enter the critical section before lower priority process completes.
- But lower priority process cannot be executed before the higher priority process completes execution.
- Thus, the execution of both the processes is blocked.

compare and swap (CAS)

- **Compare and swap** is a technique used when designing concurrent algorithms.
- Basically, compare and swap compares an expected value to the concrete value of a variable, and if the concrete value of the variable is equals to the expected value, swaps the value of the variable for a new variable.
- Compare and swap may sound a bit complicated but it is actually reasonably simple once one understand it,
- CAS is a technique used to obtain synchronization during multiple writes where each write value depends upon the current state of the shared variable.
- It basically means that a variable will first be compared with a value to see if it has changed.

compare and swap (CAS)

- If it has changed, then it means its value has been updated by some other process or thread and hence swap is not possible.

- In such a case, current value of the shared variable is obtained and new value is calculated from it.

- If it has not changed, then it means that its value has not been modified by any other process or thread and so it can be swapped.

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

- **Executed atomically**
- **Returns the original value of passed parameter “value”**
- **Set the variable “value” the value of the passed parameter “new_value” but only if “value” ==“expected”. That is, the swap takes place only under this condition.**

THANK YOU

Nitin V Pujari
Faculty, Computer Science
Dean - IQAC, PES University

nitin.pujari@pes.edu

For Course Deliverables by the Anchor Faculty click on www.pesuacademy.com