OPERATING SYSTEMS

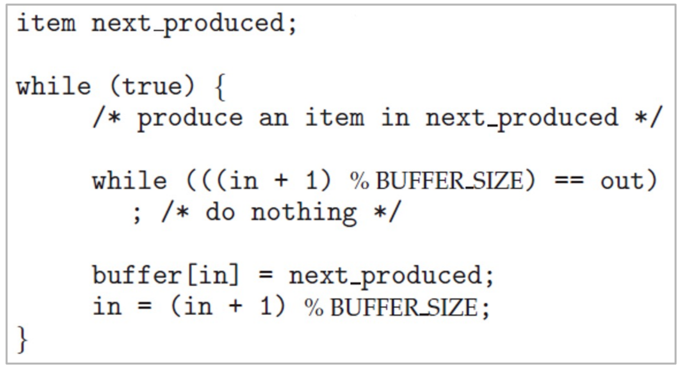
Process Synchronization

FBA

BACKGROUND

- Processes can execute concurrently or in parallel
- CPU scheduler switches rapidly between processes to provide concurrent execution
- A process may be interrupted at any point in its instruction stream
- Parallel execution, in which two instruction streams execute simultaneously on separate processing cores
- We will explain how concurrent or parallel execution can contribute to issues involving the integrity of data shared by several processes

PRODUCER-CONSUMER PROBLEM: Producer



```
item next_produced;

while (true) {
     /* produce an item in next_produced */

     while (((in + 1) % BUFFER_SIZE) == out)
        ; /* do nothing */

     buffer[in] = next_produced;
     in = (in + 1) % BUFFER_SIZE;
}
```

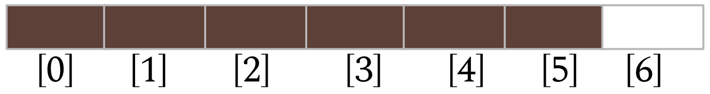
in: next free position in buffer
out: first full position in buffer

Both initialized with 0.

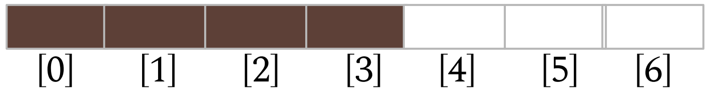
in = 0
out = 0

Here, BUFFER_SIZE = 7

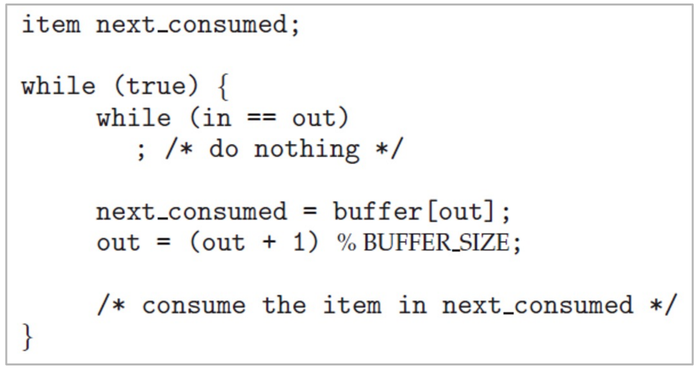
When buffer is full,
in = 6 , out = 0



When buffer is not full,
in = 4, out = 0



PRODUCER-CONSUMER PROBLEM: Consumer



```
item next_consumed;

while (true) {
     while (in == out)
        ; /* do nothing */

     next_consumed = buffer[out];
     out = (out + 1) % BUFFER_SIZE;

     /* consume the item in next_consumed */
}
```

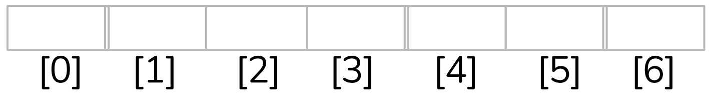
in: next free position in buffer
out: first full position in buffer

Both initialized with 0.

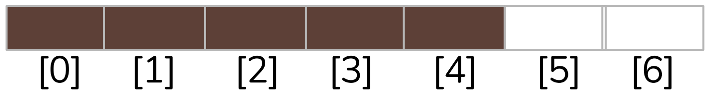
in = 0
out = 0

Here, BUFFER_SIZE = 7

When buffer is empty,
in = 0 , out = 0

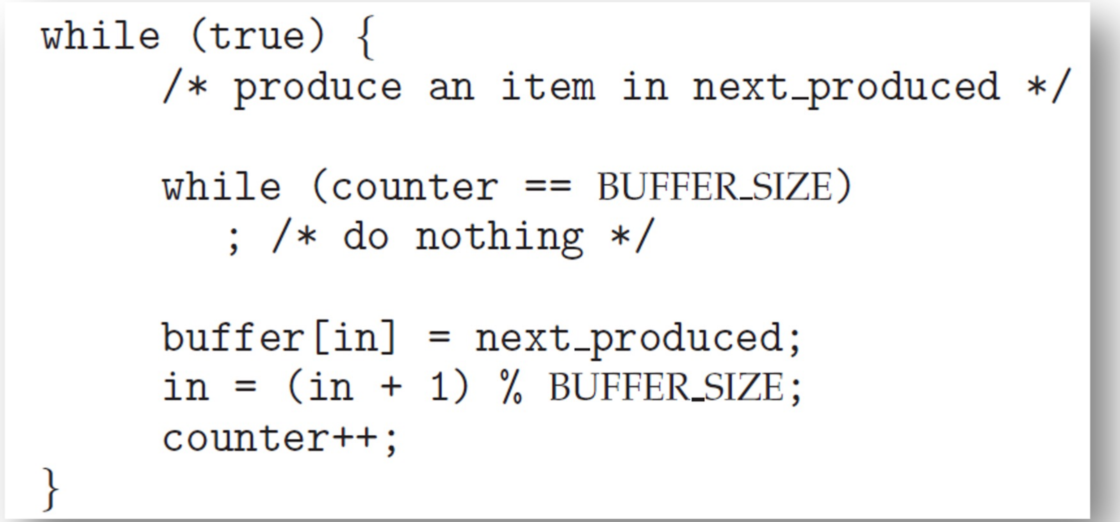


When buffer is not empty,
in = 5, out = 0

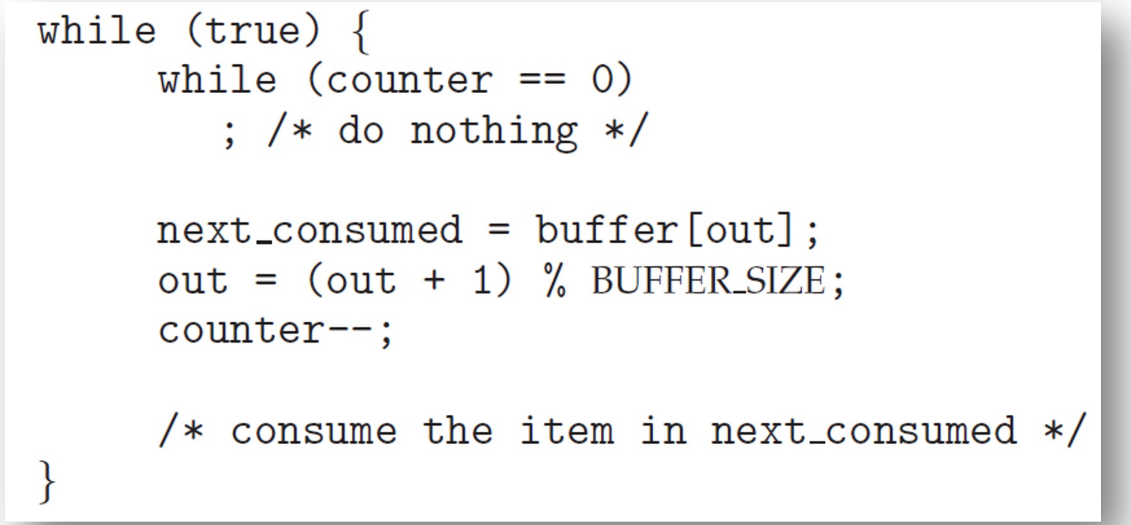


PRODUCER-CONSUMER PROBLEM

- Modify the algorithm to remedy this deficiency - add an integer variable *counter*, initialized to 0
- *counter* is incremented every time we add a new item to the buffer
- decremented every time we remove one item from the buffer



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

     while (counter == BUFFER_SIZE)
        ; /* do nothing */

     buffer[in] = next_produced;
     in = (in + 1) % BUFFER_SIZE;
     counter++;
}
```



```
while (true) {
     while (counter == 0)
        ; /* do nothing */

     next_consumed = buffer[out];
     out = (out + 1) % BUFFER_SIZE;
     counter--;

     /* consume the item in next_consumed */
}
```

DATA INTEGRITY PROBLEM

$$\begin{aligned} &register_1 = \texttt{counter} \\ &register_1 = register_1 + 1 \\ &\texttt{counter} = register_1 \end{aligned} \qquad\qquad \begin{aligned} &register_2 = \texttt{counter} \\ &register_2 = register_2 - 1 \\ &\texttt{counter} = register_2 \end{aligned}$$

- “*counter++*” and “*counter--* “ in machine language is like in the above.
- *register1* and *register2* is local CPU registers.
- Concurrent execution of “*counter++*” and “*counter--*” and allowing them to manipulate the counter variable create incorrect state.

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	$\texttt{counter} = register_2$	$\{counter = 4\}$

RACE CONDITION

- Several process access and manipulate the same data concurrently
- Outcome of the execution depends on the particular order in which the access takes place
- To guard against this condition –
  - Ensure that only one process at a time can manipulate the counter variable (shared data)
  - The processes should be synchronized

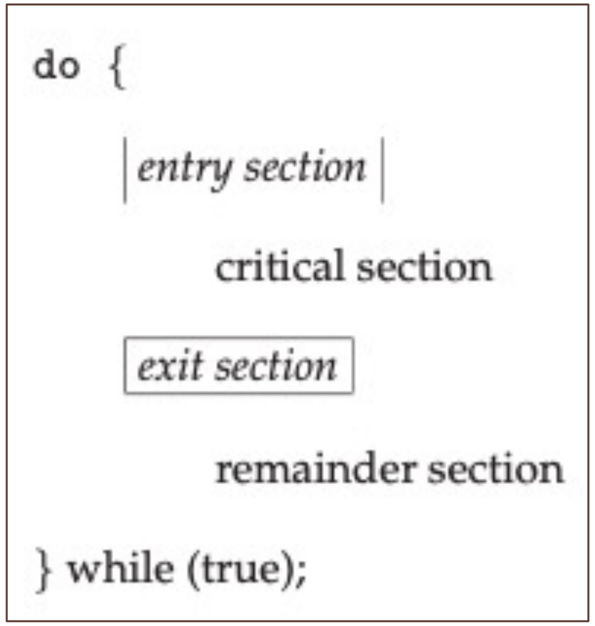
OPERATING SYSTEMS

Critical Section

FBA

CRITICAL SECTION

- Consider a system consisting of ***n*** processes $\{P_0, P_1, \ldots, P_{n-1}\}$.
- ***Critical Section:*** segment of code of each process, which may change common variables, update a table, write a file and so on.
- While one process execute its critical section, no other process can execute their own critical section.
- ***Entry Section:*** section of code implementing critical section execution request
- ***Exit Section:*** section of code exiting from critical section
- ***Remainder section:*** Remaining code of the program.



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

REQUIREMENTS OF SOLUTION TO CRITICAL SECTION PROBLEM

1. ***Mutual exclusion:***
   - ❑ If a process is executing its critical section, no other process can be executing in their critical sections.
2. ***Progress:***
   - ❑ No process is executing in its critical section
   - ❑ Some process wish to enter their critical sections
   - ❑ Only those, who are not executing in their remainder section can participate in deciding which will enter the CS.
   - ❑ This selection cannot be postponed indefinitely.
3. ***Bounded waiting:***
   - ❑ Bound or Limit on number of times other process can enter their CS after a process has made request to enter its CS and the request is granted

CRITICAL SECTIONS IN OPERATING SYSTEMS

Two general approach to handle CS in Operating System –

1. *Preemptive kernel:* allows a process to be preempted while it is running in kernel mode
2. *Non-preemptive kernel:* a kernel-mode process will run until it exits kernel mode, blocks, or voluntarily yields control of the CPU

- Non-preemptive kernel is free from race condition
- Preemptive kernel must be carefully designed to ensure that shared kernel data are free from race condition

OPERATING SYSTEMS

Peterson's solution for Critical Section Problem

SOFTWARE-BASED SOLUTION TO THE CRITICAL SECTION PROBLEM

- Known as "**Perterson's Solution**"
- Restricted to two processes that alternate execution between their critical sections and remainder sections
- Peterson's solution requires the two processes to share two data items:

  int turn;

  boolean flag[2];

- turn: indicates whose turn it is to enter its critical section
- flag: an array used to indicate if a process is ready to enter its critical section.

PETERSON'S SOLUTION

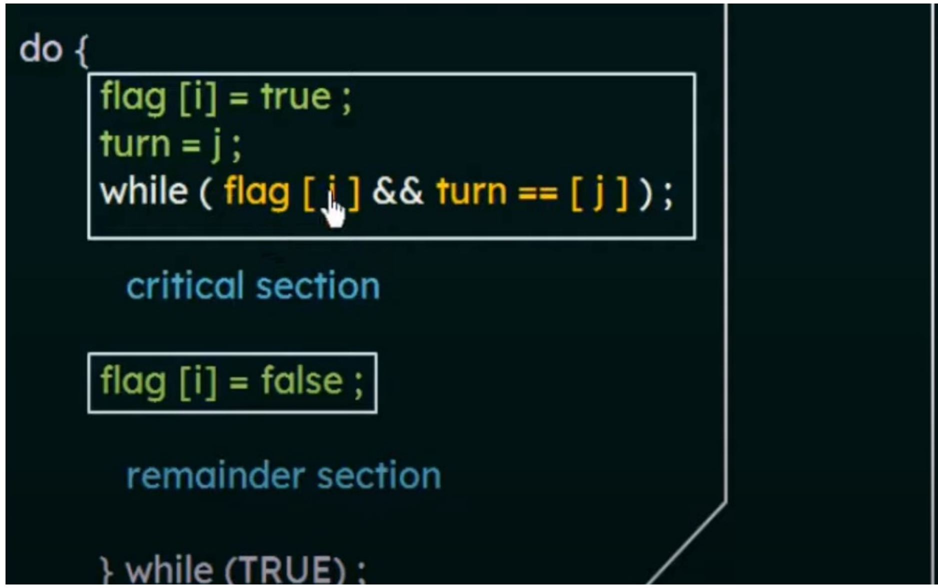
```
do {

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

          critical section

     flag[i] = false;

          remainder section

} while (true);
```

The structure of process P_i in Peterson's solution.

- Process ***Pi*** first sets *flag[i]* to be *true* and then sets *turn* to the value *j*, so that if the other process wants to enter its CS, it can do so.
- If both try to enter at the same time, turn will be both *i* and *j* at the same time, but, only one of these will last.
- The eventual value of *turn* determines which process will enter its critical section.

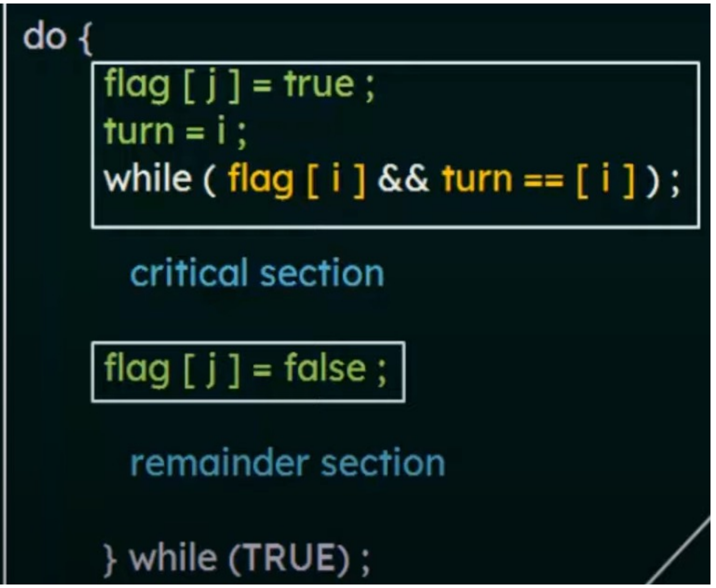
It may not work correctly on modern computer architecture as they perform basic machine-language instructions such as load and store.

PETERSON'S SOLUTION



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

    critical section

    flag [i] = false ;

    remainder section

} while (TRUE) ;
```

Process P_i



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

    critical section

    flag [ j ] = false ;

    remainder section

} while (TRUE) ;
```

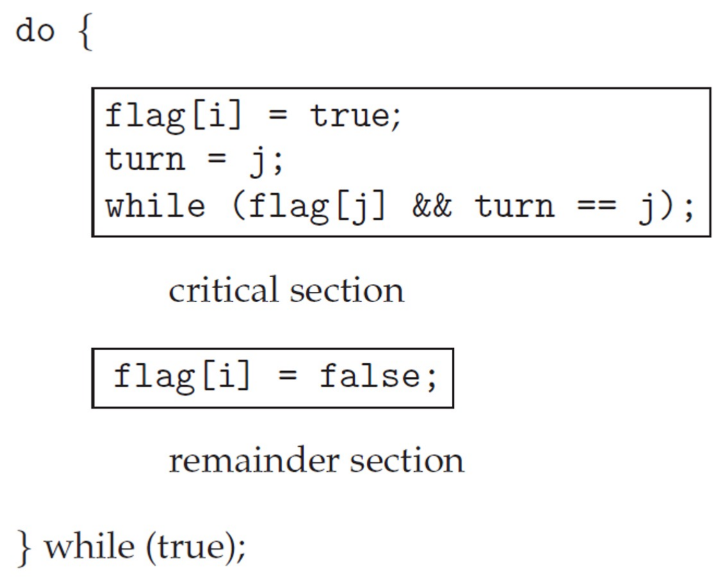
Process P_j

- Process ***Pi*** first sets *flag[i]* to be *true* and then sets *turn* to the value *j*, so that if the other process wants to enter its CS, it can do so.
- If both try to enter at the same time, turn will be both *i* and *j* at the same time, but, only one of these will last.
- The eventual value of *turn* determines which process will enter its critical section.

It may not work correctly on modern computer architecture as they perform basic machine-language instructions such as load and store.

Example

- Each Statement takes 2ms to execute, Process 1 gets executed first
- Context Switch will occur after 6ms
- Critical section contains 4 statements
- Remainder section contains 2 statements
- turn=0
- Flag[0] = FALSE, flag[1] = TRUE



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

            critical section

      flag[i] = false;

            remainder section

} while (true);
```

The structure of process P_i in Peterson's solution.

Process 0 (i = 0, j = 1)	**Process 1** (i = 1, j = 0)

	flag[1] = TRUE
	turn = 0
	While loop condition

flag[0] = TRUE
turn = 1
Stuck in while loop	

	CS1 CS2 CS3
Stuck in while loop	
	CS4 flag[1] = FALSE RS1
While loop condition CS1 CS2	
	RS2
CS3 CS4 flag[0] = FALSE	
RS1 RS2	

OPERATING SYSTEMS

Hardware based solution for Critical Section Problem

HARDWARE-BASED SOLUTION TO THE CRITICAL SECTION PROBLEM

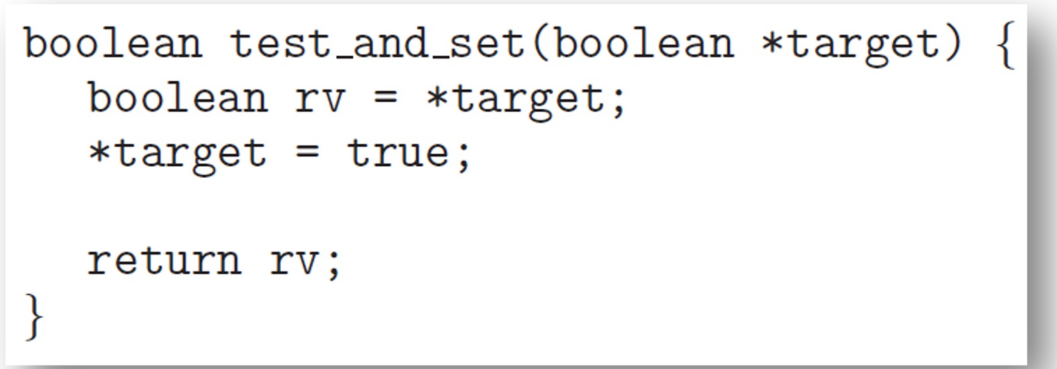
- More solutions to the critical-section problem using techniques ranging from hardware to software-based APIs
- These solutions are based on the premise of **locking** — protecting critical regions through the use of locks.
- In a single-processor environment CS problem can be solved by preventing interrupts from occurring while a shared variable is being modified.
- For multiprocessor environment, we need different measures.

- Modern computer systems allow to test and modify the content of a word or to swap the contents of two words atomically – which is uninterruptable unit. We can use *test_and_set()* and *compare_and_swap()* instructions.

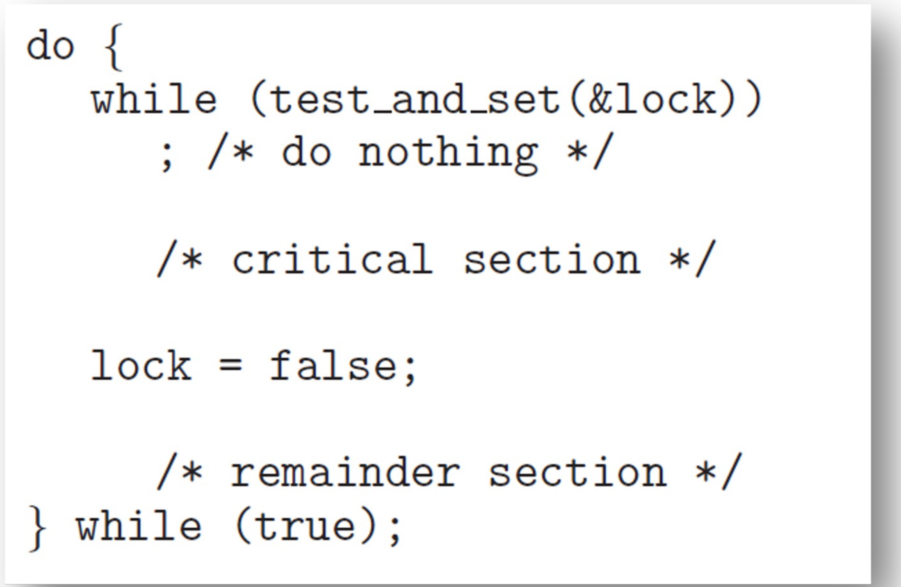
TEST_AND_SET( )

Executed atomically

Mutual exclusion can be implemented by initializing a Boolean variable lock to false



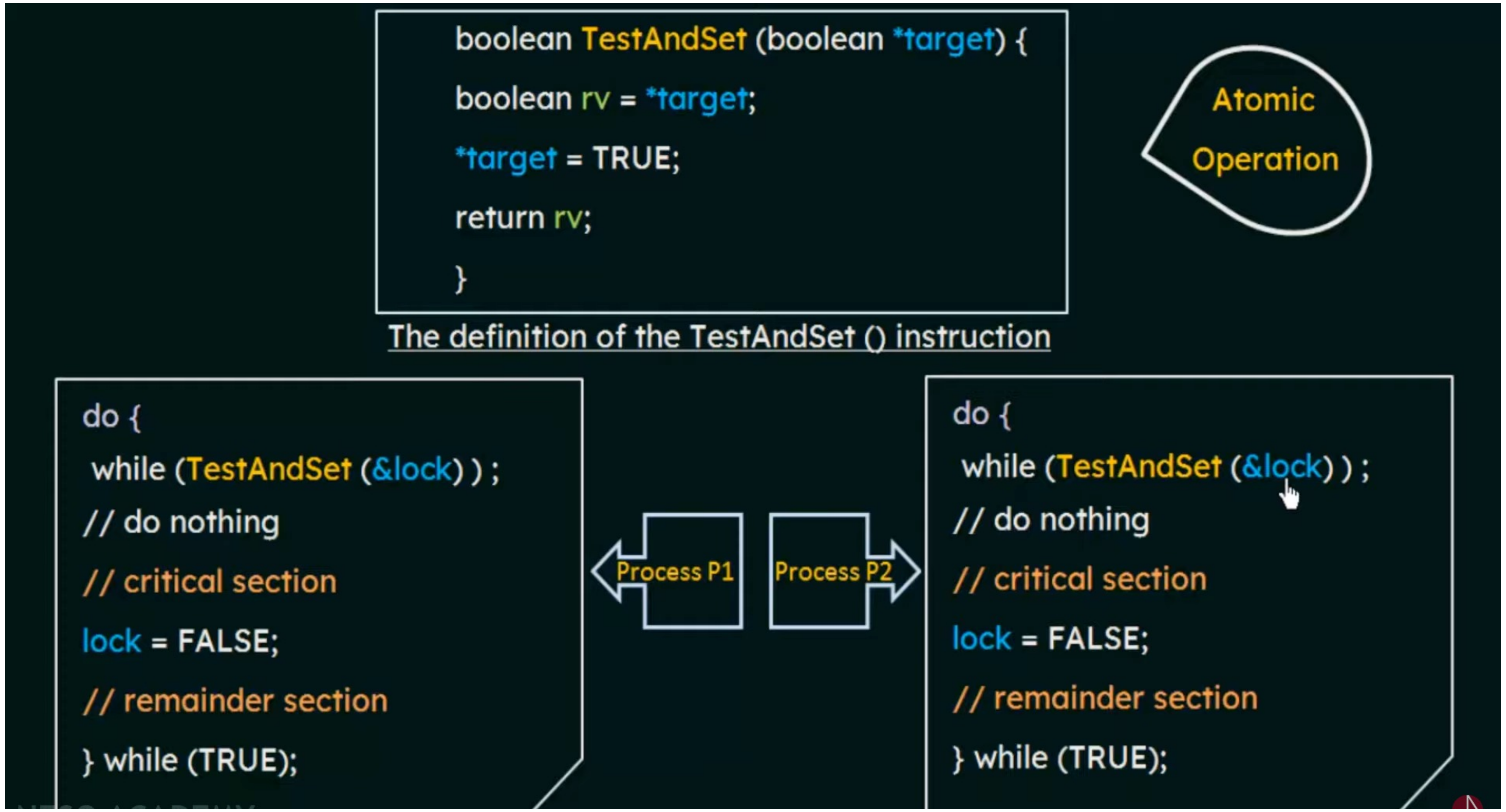
```
boolean test_and_set(boolean *target) {
   boolean rv = *target;
   *target = true;

   return rv;
}
```



```
do {
   while (test_and_set(&lock))
      ; /* do nothing */

      /* critical section */

   lock = false;

      /* remainder section */
} while (true);
```

TEST_AND_SET( )

Executed atomically
Mutual exclusion can be implemented by initializing a Boolean variable lock to false



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

The definition of the TestAndSet () instruction

```
do {
 while (TestAndSet (&lock) ) ;
// do nothing
// critical section
lock = FALSE;
// remainder section
} while (TRUE);
```

```
do {
 while (TestAndSet (&lock) ) ;
// do nothing
// critical section
lock = FALSE;
// remainder section
} while (TRUE);
```

COMPARE_AND_SWAP( )

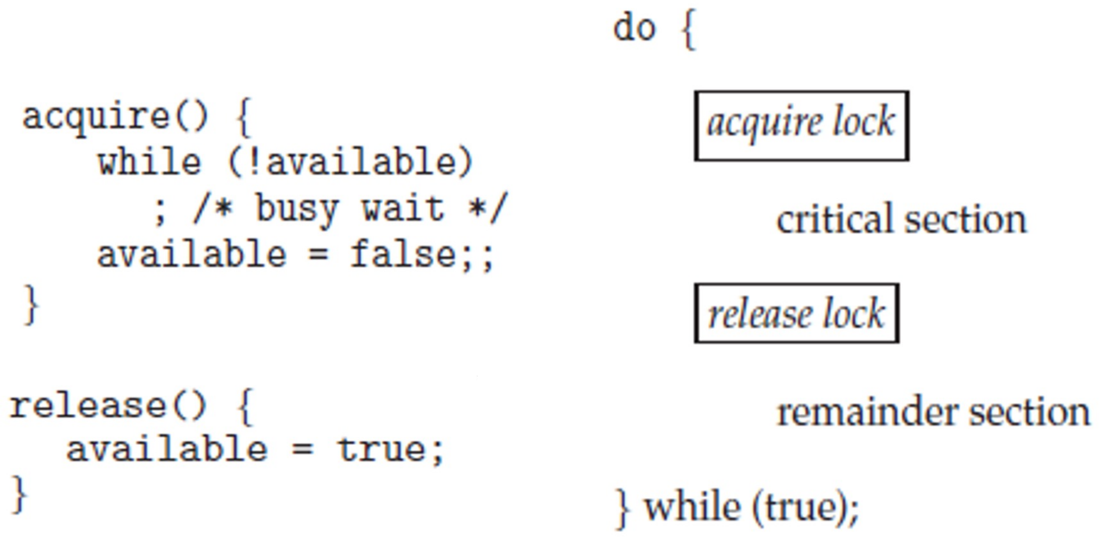
- Mutual exclusion can be achieved by declaring a global variable *lock* and initializing it to *0*
- First process that invokes this instruction will set *lock* to *1* and no other process can execute CS until this process updates it to *0* after CS execution.

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

   if (*value == expected)
      *value = new_value;

   return temp;
}
```

```
do {
   while (compare_and_swap(&lock, 0, 1) != 0)
      ; /* do nothing */

      /* critical section */

   lock = 0;

      /* remainder section */
} while (true);
```

MUTEX LOCKS

- Operating-systems designers build software tools to solve CS problem.
- Simplest of these tools is “Mutex Lock” (Mutex = Mutual Exclusion)
- A process must acquire the lock before entering CS [*acquire()* function]
- A process must release the lock after exiting the CS [*release()* function]
- Mutex lock has a variable, *available* which indicates if the lock is available.



```
acquire() {
    while (!available)
       ; /* busy wait */
    available = false;;
}

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

```
do {

    acquire lock

        critical section

    release lock

        remainder section

} while (true);
```

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

OPERATING SYSTEMS

Semaphore

FBA

SEMAPHORE

- A semaphore S is an integer variable
- Is accessed only through two standard atomic operations: **wait**() and **signal**().
- When one process modifies the semaphore value, no other process can simultaneously modify that same semaphore value.
- In case of wait(S), the testing of the integer value of S ($S \le 0$), as well as its possible modification (S--), must be executed without interruption, i.e., **this operations are atomic**.

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

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

Types of Semaphores

- **Counting Semaphore**: The value can range over an unrestricted domain.
  - Used to control access to a given resource consisting of finite number of instances
  - Solves various synchronization problems.
- **Binary Semaphore:** The value can range only between 0 and 1. This behaves similar to Mutex Lock.

Counting Semaphore

- initialized to the number of resources available, **S** = **n**
- Each process that wishes to use a resource performs a wait() operation

    S = **S** -**1**

- When a process releases a resource, it performs a signal() operation

    S = **S** +**1**

- When **S** becomes **0**, all resources are being used
- processes that wish to use a resource will block until **S**>**0**

Binary Semaphore - Synchronization

- P_1 has statement S_1
- P_2 has statement S_2

- We want to make sure that S_1 executes before S_2
- We can use a semaphore variable **sync** and initialize it to **0**

P1:

```
S1;
signal(sync);
```

P2:

```
wait(sync);
S2;
```

Mutual Exclusion With Semaphores

- Binary Semaphores (mutex) can be used to solve CS problem.
- A semaphore variable (say mutex) can be shared by n processes and initialized to 1.
- Each process is structured as follows :

```
do{
    wait (mutex);
            //critical section
    signal(mutex);
            //remainder section
}while (TRUE);
```

Deadlock & Starvation

- Two or more process can wait indefinitely for an event - **DEADLOCK** !!!
- It occurs because - two process depends on each other for causing an event in a specific manner

P_0	**P_1**
wait(S);	wait(Q);
wait(Q);	wait(S);
. .	. .
. .	. .
. .	. .
signal(S);	signal(Q);
signal(Q);	signal(S);

- **Starvation**: Processes wait indefinitely within the semaphore
- Occurs if we remove processes from the list associated with a semaphore in LIFO (last-in, first-out) order

OPERATING SYSTEMS

Semaphore Implementation

SEMAPHORE IMPLEMENTATION

- Must guarantee that no two processes can execute the **wait**() and **signal**() on the same semaphore at the same time
- Thus, the implementation becomes the critical section problem where the **wait** and **signal** code are placed in the critical section
- Could now have **busy waiting** in critical section implementation
  - But implementation code is short
  - Little busy waiting if critical section rarely occupied
- Note that applications may spend lots of time in critical sections and therefore this is not a good solution

SEMAPHORE IMPLEMENTATION

- When a process executes the wait() operation and finds that the semaphore value is not positive, it must wait
- Rather than this busy waiting, the process can block itself which places it into a waiting queue associated with the semaphore
- State of the process is switched to the waiting state and control is transferred to CPU scheduler which selects another process to execute.
- It will be restarted when some other process executes a signal() operation
- Restarted by a **wakeup**() operation that changes it from waiting state to ready state.

SEMAPHORE IMPLEMENTATION

Definition of a semaphore:

```
typedef struct {
    int value;
    struct process *list;
} semaphore;
```

Definition of wait():

```
wait(semaphore *S) {
        S->value--;
        if (S->value < 0) {
                add this process to
                S->list;
                block();
        }
}
```

Definition of signal():

```
signal(semaphore *S) {
        S->value++;
        if (S->value >= 0) {
                remove a process P
                from S->list;
                wakeup(P);
        }
}
```