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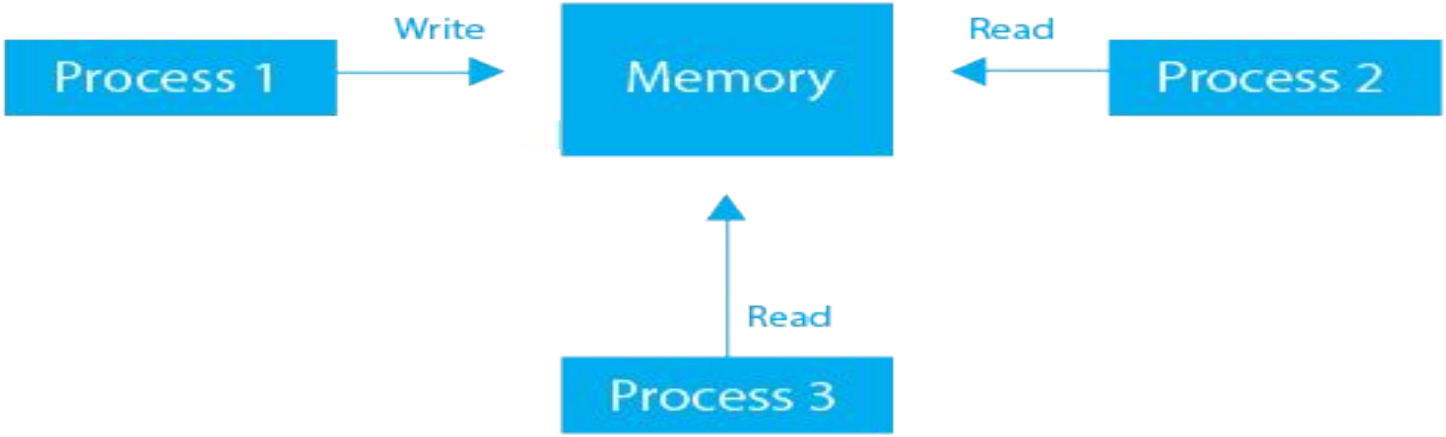
Process Synchronization

Process Synchronization

- Process Synchronization is the coordination of execution of multiple processes in a multi-process system to ensure that they access shared resources in a controlled and predictable manner.

- The main objective of process synchronization is to ensure that multiple processes access shared resources without interfering with each other and to prevent the possibility of inconsistent data due to concurrent access. To achieve this, various synchronization techniques such as semaphores, monitors, and critical sections are used.



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
```

- Consider this execution interleaving with “count = 5” initially:

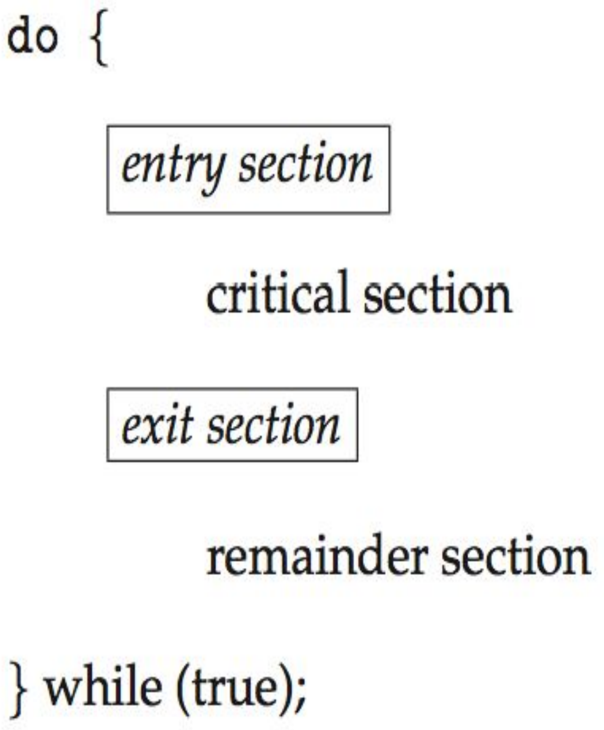
S0: producer execute `register1 = counter` {register1 = 5}
S1: producer execute `register1 = register1 + 1` {register1 = 6}
S2: consumer execute `register2 = counter` {register2 = 5}
S3: consumer execute `register2 = register2 – 1` {register2 = 4}
S4: producer execute `counter = register1` {counter = 6 }
S5: consumer execute `counter = register2` {counter = 4}

Critical Section Problem

- Consider system of ***n*** processes {$\boldsymbol{p_0}$, $\boldsymbol{p_1}$, **…** $\boldsymbol{p_{n-1}}$}
- Each process has **critical section** segment of code
  - Process may be changing common variables, updating table, writing file, etc
  - When one process in critical section, no other may be in its critical section
- ***Critical section problem*** is to design protocol to solve this
- Each process must ask permission to enter critical section in **entry section**, may follow critical section with **exit section**, then **remainder section**

Critical Section

- General structure of process P_i



```
do {

     entry section

          critical section

     exit section

          remainder section

} while (true);
```

Algorithm for Process P_i

```
do {

 while (turn == j);
    critical section
 turn = j;
    remainder section
  } while (true);
```

Solution to Critical-Section Problem

1. **Mutual Exclusion** - If process P_i is executing in its critical section, then no other processes can be executing in their critical sections
2. **Progress** - If no process is executing in its critical section and there exist some processes that wish to enter their critical section, then the selection of the processes that will enter the critical section 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

Critical-Section Handling in OS

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

- **Preemptive** – allows preemption of process when running in kernel mode
- **Non-preemptive** – runs until exits kernel mode, blocks, or voluntarily yields CPU
  - Essentially free of race conditions in kernel mode

Peterson’s Solution

- Good algorithmic description of solving the problem
- Two process solution
- Assume that the load and store machine-language instructions are atomic; that is, cannot be interrupted
- The two processes share two variables:
  - int turn;
  - Boolean flag[2]

- The variable turn indicates whose turn it is to enter the critical section
- The flag array is used to indicate if a process is ready to enter the critical section. flag[i] = true implies that process Pi is ready!

Algorithm for Process P_i

```
do   {
 flag[i] = true;
 turn = j;
 while (flag[j] && turn = = j);
    critical section
 flag[i] = false;
    remainder section
 } while (true);
```

Peterson’s Solution (Cont.)

- Provable that the three CS requirement are met:
  1. Mutual exclusion is preserved

     Pi enters CS only if:

     either **flag[j] = false** or **turn = i**
  2. Progress requirement is satisfied
  3. Bounded-waiting requirement is met

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
- Modern machines provide special atomic hardware instructions
    - Atomic = non-interruptible
  - Either test memory word and set value
  - Or swap contents of two memory words

Solution to Critical-section Problem Using Locks

```
    do {
     acquire lock
        critical section
     release lock

 remainder section
    } while (TRUE);
```

Mutex Locks

- Previous solutions are complicated and generally inaccessible to application programmers
- OS designers build software tools to solve critical section problem
- Simplest is mutex lock
- Protect a critical section by first **acquire()** a lock then **release()** the lock
  - Boolean variable indicating if lock is available or not
- Calls to **acquire()** and **release()** must be atomic
  - Usually implemented via hardware atomic instructions
- But this solution requires busy waiting
  - This lock therefore called a spinlock

acquire() and release()

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

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

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

Semaphore

- Synchronization tool that provides more sophisticated ways (than Mutex locks) for process to synchronize their activities.
- Semaphore ***S*** – integer variable
- Can only be accessed via two indivisible (atomic) operations
  - `wait()` and `signal()`
    - Originally called `P()` and `V()`
- Definition of the `wait() operation`

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

- Definition of the `signal() operation`

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

Semaphore Usage

- **Counting semaphore** – integer value can range over an unrestricted domain
- **Binary semaphore** – integer value can range only between 0 and 1
  - Same as a **mutex lock**
- Can solve various synchronization problems
- Consider ***P_1*** and ***P_2*** that require ***S_1*** to happen before ***S_2***

  Create a semaphore "**synch**" initialized to 0

```
 P1:
     S1;
     signal(synch);
 P2:
     wait(synch);
     S2;
```

- Can implement a counting semaphore ***S*** as a binary semaphore

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

```
        P0                          P1
            wait(S);                    wait(Q);
            wait(Q);                    wait(S);
  ...           ...
            signal(S);                  signal(Q);
            signal(Q);                  signal(S);
```

- **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**

Monitors

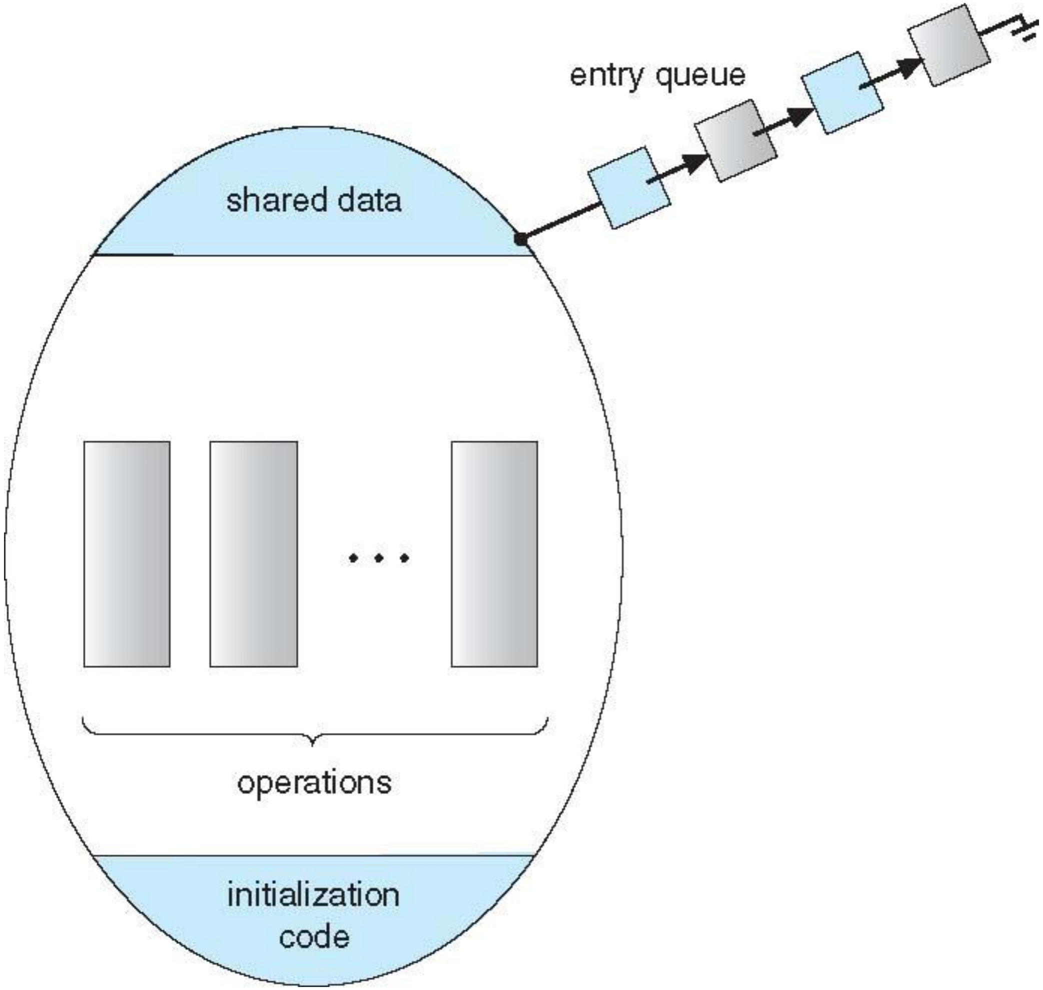
- A high-level abstraction that provides a convenient and effective mechanism for process synchronization
- *Abstract data type*, internal variables only accessible by code within the procedure
- Only one process may be active within the monitor at a time
- But not powerful enough to model some synchronization schemes

```
monitor monitor-name
{
  // shared variable declarations
  procedure P1 (…) { …. }

  procedure Pn (…) {……}

    Initialization code (…) { … }
  }
}
```

Schematic view of a Monitor


entry queue
shared data
. . .
operations
initialization
code