Chapter 6: Process Synchronization

Module 6: Process Synchronization

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Background

- Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes
- Suppose that we wanted to provide a solution to the consumer-producer problem that fills all the buffers. We can do so by having an integer count that keeps track of the number of full buffers. Initially, count is set to 0. It is incremented by the producer after it produces a new buffer and is decremented by the consumer after it consumes a buffer.

Producer

```
while (true) {

      /*produce an item and put in nextProduced */
        while (count == BUFFER_SIZE)
              ; // do nothing
              buffer [in] = nextProduced;
              in = (in + 1) % BUFFER_SIZE;
              count++;
}
```

Consumer

```
while (true) {
        while (count == 0)
            ; // do nothing
            nextConsumed = buffer[out];
            out = (out + 1) % BUFFER_SIZE;
             count--;

           /* consume the item in nextConsumed
  }
```

Race Condition

- count++ could be implemented as

  register1 = count
  register1 = register1 + 1
  count = register1

- count-- could be implemented as

  register2 = count
  register2 = register2 - 1
  count = register2

- Consider this execution interleaving with "count = 5" initially:

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

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

Peterson's Solution

- Two process solution
- Assume that the LOAD and STORE 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 P_i is ready!

Algorithm for Process P_i

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

            CRITICAL SECTION

      flag[i] = FALSE;

            REMAINDER SECTION

}
```

Synchronization Hardware

- Many systems provide hardware support for critical section code
- 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-interruptable
  - Either test memory word and set value
  - Or swap contents of two memory words

TestAndndSet Instruction

- Definition:

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

Solution using TestAndSet

- Shared boolean variable lock., initialized to false.
- Solution:

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

               //   critical section

        lock = FALSE;

               //     remainder section

}
```

Swap Instruction

- Definition:

```
void Swap (boolean *a, boolean *b)
{
        boolean temp = *a;
        *a = *b;
        *b = temp:
}
```

Solution using Swap

- Shared Boolean variable lock initialized to FALSE; Each process has a local Boolean variable key.
- Solution:

```
while (true) {
        key = TRUE;
        while ( key == TRUE)
                Swap (&lock, &key );

                //    critical section

        lock = FALSE;

                //      remainder section

}
```

Semaphore

- Synchronization tool that does not require busy waiting
- Semaphore *S* – integer variable
- Two standard operations modify S: wait() and signal()
  - Originally called P() and V()
- Less complicated
- Can only be accessed via two indivisible (atomic) operations
  - ```
    wait (S) {
        while S <= 0
            ; // no-op
          S--;
     }
    ```
  - ```
    signal (S) {
      S++;
    }
    ```

Semaphore as General Synchronization Tool

- 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
  - Also known as mutex locks
- Can implement a counting semaphore S as a binary semaphore
- Provides mutual exclusion
  - Semaphore S; // initialized to 1
  - wait (S);

    Critical Section

    signal (S);

Semaphore Implementation

- Must guarantee that no two processes can execute wait () and signal () on the same semaphore at the same time
- Thus, implementation becomes the critical section problem where the wait and signal code are placed in the crtical 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 with no Busy waiting

- With each semaphore there is an associated waiting queue. Each entry in a waiting queue has two data items:
  - value (of type integer)
  - pointer to next record in the list

- Two operations:
  - block – place the process invoking the operation on the appropriate waiting queue.
  - wakeup – remove one of processes in the waiting queue and place it in the ready queue.

Semaphore Implementation with no Busy waiting (Cont.)

- Implementation of wait:

```
wait (S){
        value--;
        if (value < 0) {
           add this process to waiting queue
            block();  }
 }
```

- Implementation of signal:

```
Signal (S){
          value++;
           if (value <= 0) {
              remove a process P from the waiting queue
               wakeup(P);  }
}
```

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	P_1
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.

Classical Problems of Synchronization

- 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.

Bounded Buffer Problem (Cont.)

- The structure of the producer process

```
while (true) {

        //   produce an item

    wait (empty);
    wait (mutex);

        // add the item to the  buffer

    signal (mutex);
    signal (full);
}
```

Bounded Buffer Problem (Cont.)

- The structure of the consumer process

```
while (true) {
        wait (full);
        wait (mutex);

                // remove an item from  buffer

        signal (mutex);
        signal (empty);

                // consume the removed item

}
```

Readers-Writers Problem

- 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. Only one single writer can access the shared data at the same time.
- Shared Data
  - Data set
  - Semaphore mutex initialized to 1.
  - Semaphore wrt initialized to 1.
  - Integer readcount initialized to 0.

Readers-Writers Problem (Cont.)

- The structure of a writer process

```
while (true) {
        wait (wrt) ;

            //    writing is performed

        signal (wrt) ;
}
```

Readers-Writers Problem (Cont.)

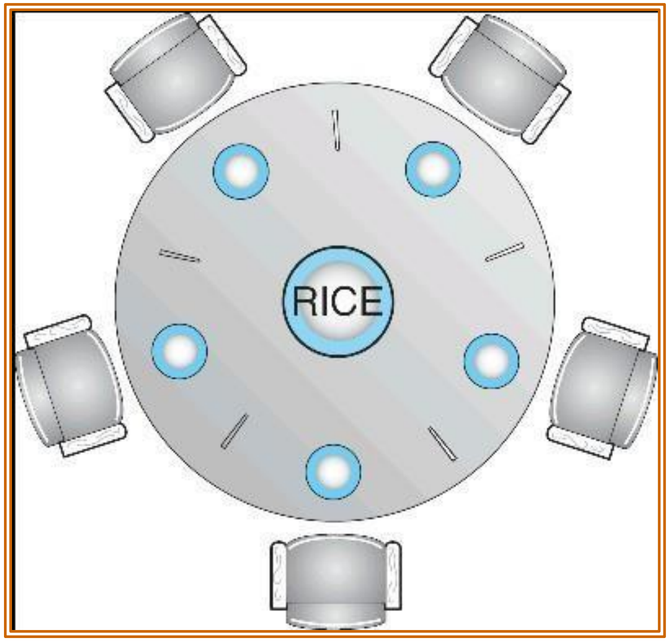
- The structure of a reader process

```
while (true) {
        wait (mutex) ;
        readcount ++ ;
        if (readcount == 1)  wait (wrt) ;
        signal (mutex)

                // reading is performed

        wait (mutex) ;
        readcount  - - ;
        if (readcount  == 0)  signal (wrt) ;
        signal (mutex) ;
}
```

Dining-Philosophers Problem



- Shared data
    - Bowl of rice (data set)
    - Semaphore chopstick [5] initialized to 1

Dining-Philosophers Problem (Cont.)

- The structure of Philosopher *i*:

```
While (true) {
        wait ( chopstick[i] );
         wait ( chopStick[ (i + 1) % 5] );

              // eat

         signal ( chopstick[i] );
         signal (chopstick[ (i + 1) % 5] );

             // think

}
```

Problems with Semaphores

- Incorrect use of semaphore operations:
  - signal (mutex) …. wait (mutex)
  - wait (mutex) … wait (mutex)
  - Omitting of wait (mutex) or signal (mutex) (or both)

Monitors

- A high-level abstraction that provides a convenient and effective mechanism for process synchronization
- Only one process may be active within the monitor at a time

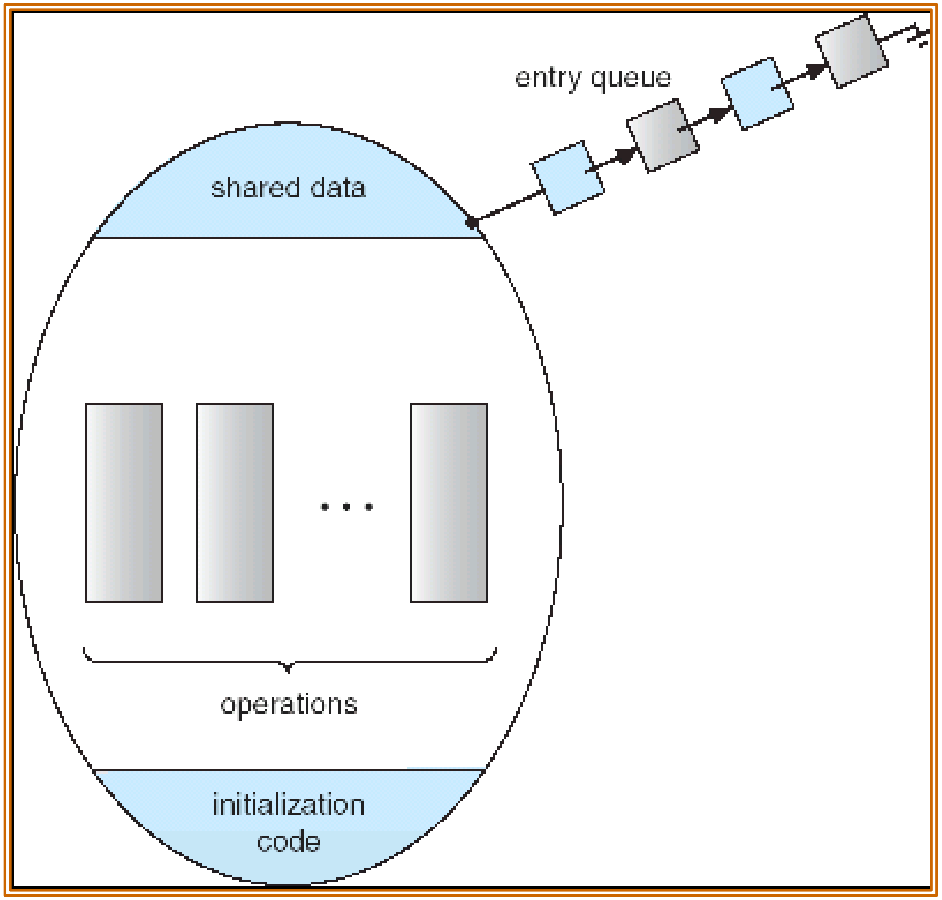
```
monitor monitor-name
{
    // shared variable declarations
    procedure P1 (…) { …. }
          …

    procedure Pn (…) {……}

  Initialization code ( ….) { … }

          …
    }
}
```

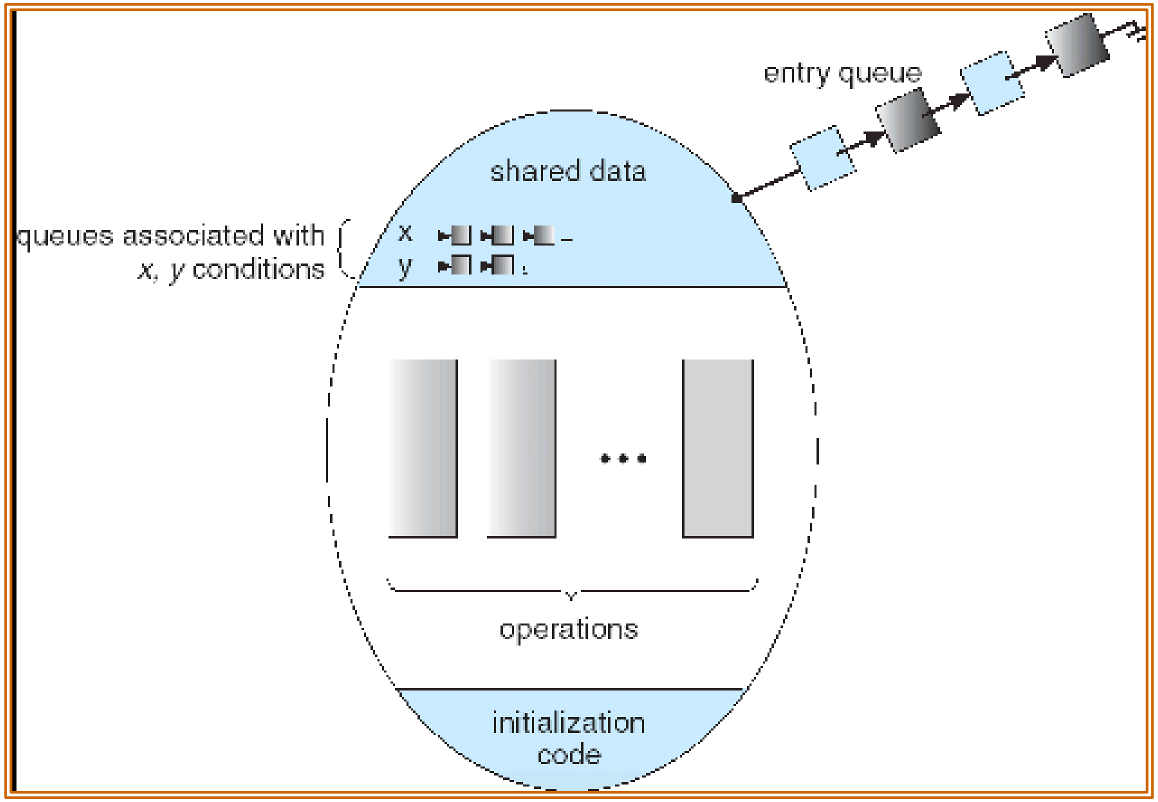
Schematic view of a Monitor



Condition Variables

- condition x, y;
- Two operations on a condition variable:
  - x.wait () – a process that invokes the operation is suspended.
  - x.signal () – resumes one of processes (if any) that invoked x.wait ()

Monitor with Condition Variables



Solution to Dining Philosophers

```
monitor DP
  {
      enum { THINKING; HUNGRY, EATING) state [5] ;
      condition self [5];

      void pickup (int i) {
             state[i] = HUNGRY;
             test(i);
             if (state[i] != EATING) self [i].wait;
      }

     void putdown (int i) {
             state[i] = THINKING;
                 // test left and right neighbors
              test((i + 4) % 5);
              test((i + 1) % 5);
      }
```

Solution to Dining Philosophers (cont)

```
void test (int i) {
        if ( (state[(i + 4) % 5] != EATING) &&
        (state[i] == HUNGRY) &&
        (state[(i + 1) % 5] != EATING) ) {
             state[i] = EATING ;
            self[i].signal () ;
         }
 }

initialization_code() {
        for (int i = 0; i < 5; i++)
        state[i] = THINKING;
 }
}
```

Solution to Dining Philosophers (cont)

- Each philosopher *I* invokes the operations pickup() and putdown() in the following sequence:

  dp.pickup (i)

  EAT

  dp.putdown (i)

Monitor Implementation Using Semaphores

- Variables

```
semaphore mutex;  // (initially  = 1)
semaphore next;   // (initially  = 0)
int next-count = 0;
```

- Each procedure ***F*** will be replaced by

```
wait(mutex);
        …
                body of F;

        …
    if (next-count > 0)
        signal(next)
    else
        signal(mutex);
```

- Mutual exclusion within a monitor is ensured.

Monitor Implementation

- For each condition variable ***x***, we have:

```
semaphore x-sem; // (initially = 0)
int x-count = 0;
```

- The operation x.wait can be implemented as:

```
x-count++;
        if (next-count > 0)
                signal(next);
        else
                signal(mutex);
        wait(x-sem);
        x-count--;
```

Monitor Implementation

- The operation x.signal can be implemented as:

```
if (x-count > 0) {
        next-count++;
        signal(x-sem);
        wait(next);
        next-count--;
}
```

Semaphore Implementation

- Void philosopher (void)
- {
- While(true)
- {
- Thinking()
- Wait(take fork (si))
- Wait(take fork (si+1 mod n))
- Eat()
- Signal (put fork(i))
- Signal (put fork(i+1)/n)
- }
- }

Synchronization Examples

- Solaris
- Windows XP
- Linux
- Pthreads