Process synchronization

- 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
}
```

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

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

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

Solution to Critical-section Problem Using Locks

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

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:

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

                //    critical section

        lock = FALSE;

                //     remainder section

 } while (TRUE);
```

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:

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

                    //    critical section

         lock = FALSE;

                   //     remainder section

} while (TRUE);
```

Bounded-waiting Mutual Exclusion with TestandSet()

```
do {
    waiting[i] = TRUE;
    key = TRUE;
    while (waiting[i] && key)
            key = TestAndSet(&lock);
    waiting[i] = FALSE;
            // critical section
    j = (i + 1) % n;
    while ((j != i) && !waiting[j])
            j = (j + 1) % n;
    if (j == i)
            lock = FALSE;
    else
            waiting[j] = FALSE;
            // remainder section
} while (TRUE);
```

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 mutex;    //  initialized to 1
do {
    wait (mutex);
        // Critical Section
     signal (mutex);
    // remainder section
} while (TRUE);
```

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

- Implementation of wait:

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

- Implementation of signal:

```
signal(semaphore *S) {
        S->value++;
        if (S->value <= 0) {
                remove a process P from S->list;
                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
- Priority Inversion - Scheduling problem when lower-priority process holds a lock needed by higher-priority process

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

```
do  {
                //   produce an item in nextp
        wait (empty);
        wait (mutex);
             //  add the item to the  buffer
         signal (mutex);
         signal (full);
    } while (TRUE);
```

The structure of the consumer process

```
do {
         wait (full);
         wait (mutex);
//  remove an item from  buffer to nextc
         signal (mutex);
         signal (empty);
                    //  consume the item in nextc
    } while (TRUE);
```

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

- The structure of a writer process

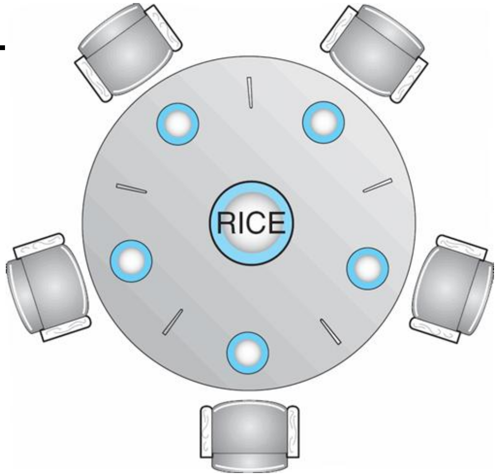
```
do {
    wait (wrt) ; //  writing is performed
    signal (wrt) ;
} while (TRUE);
```

The structure of a reader process

```
do {
        wait (mutex) ;
        readcount ++ ;
        if (readcount == 1)
            wait (wrt) ;
        signal (mutex) //reading is performed                    wait (mutex) ;
            readcount  - - ;
            if (readcount  == 0)
                        signal (wrt) ;
            signal (mutex) ;
    } while (TRUE);
```

Dining-Philosophers Problem

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



do {

- wait (chopstick[i]);
- wait (chopStick[(i + 1) % 5]);
-
- // eat
- signal (chopstick[i]);
- signal (chopstick[(i + 1) % 5]);
-
- // think
- } while (TRUE);

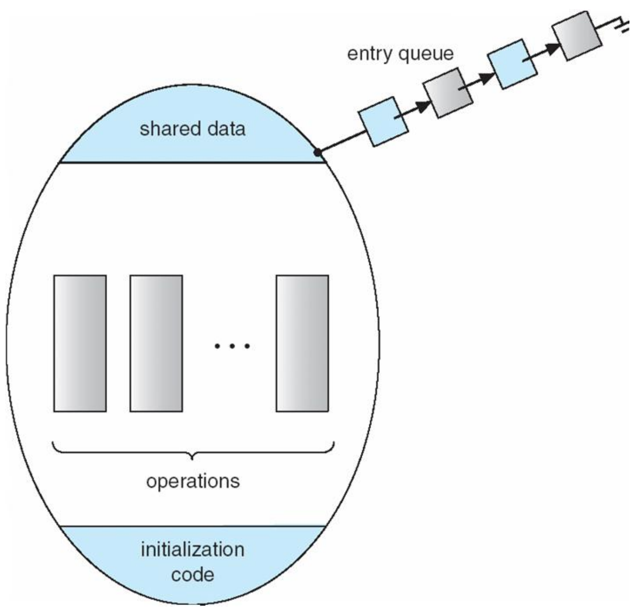
Monitors

- 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 ( ….) { … }
            …
   }
}
```



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);
        }
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;
      }    }
```

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

```
DiningPhilosophters.pickup (i);
    EAT
DiningPhilosophers.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--;
```

Atomic Transactions

- System Model
- Log-based Recovery
- Checkpoints
- Concurrent Atomic Transactions

System Model

- Assures that operations happen as a single logical unit of work, in its entirety, or not at all
- Related to field of database systems
- Challenge is assuring atomicity despite computer system failures
- Transaction - collection of instructions or operations that performs single logical function
  - Here we are concerned with changes to stable storage – disk
  - Transaction is series of read and write operations
  - Terminated by commit (transaction successful) or abort (transaction failed) operation
  - Aborted transaction must be rolled back to undo any changes it performed

Log-Based Recovery

- Record to stable storage information about all modifications by a transaction
- Most common is write-ahead logging
  - Log on stable storage, each log record describes single transaction write operation, including
    - Transaction name
    - Data item name
    - Old value
    - New value
  - <T_i starts> written to log when transaction T_i starts
  - <T_i commits> written when T_i commits
- Log entry must reach stable storage before operation on data occur

Checkpoints

- Log could become long, and recovery could take long
- Checkpoints shorten log and recovery time.
- Checkpoint scheme:
  1. Output all log records currently in volatile storage to stable storage
  2. Output all modified data from volatile to stable storage
  3. Output a log record <checkpoint> to the log on stable storage
- Now recovery only includes Ti, such that Ti started executing before the most recent checkpoint, and all transactions after Ti All other transactions already on stable storage

Concurrent Transactions

- Must be equivalent to serial execution – serializability
- Could perform all transactions in critical section
  - Inefficient, too restrictive
- Concurrency-control algorithms provide serializability

Serializability

- Consider two data items A and B
- Consider Transactions T_0 and T_1
- Execute T_0, T_1 atomically
- Execution sequence called schedule
- Atomically executed transaction order called serial schedule
- For N transactions, there are N! valid serial schedules

Locking Protocol

- Ensure serializability by associating lock with each data item
  - Follow locking protocol for access control
- Locks
  - Shared – T_i has shared-mode lock (S) on item Q, T_i can read Q but not write Q
  - Exclusive – Ti has exclusive-mode lock (X) on Q, T_i can read and write Q
- Require every transaction on item Q acquire appropriate lock
- If lock already held, new request may have to wait

Two-phase Locking Protocol

- Generally ensures conflict serializability
- Each transaction issues lock and unlock requests in two phases
  - Growing – obtaining locks
  - Shrinking – releasing locks
- Does not prevent deadlock