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.)

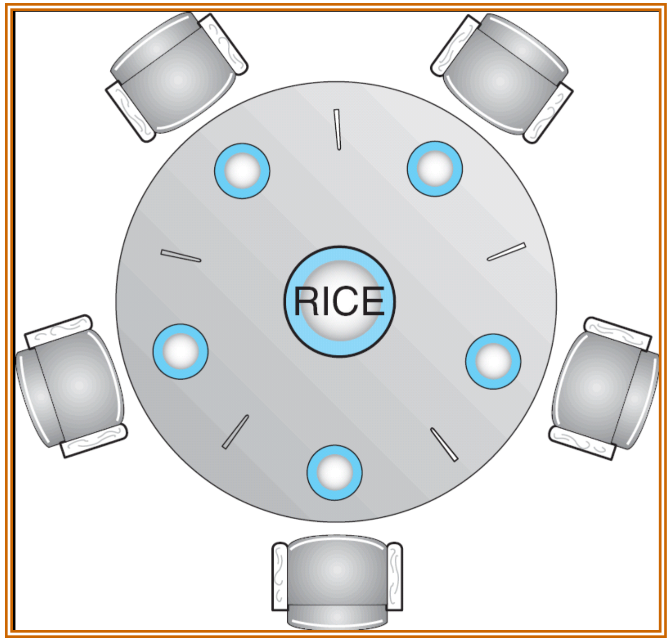
- The structure of a reader process

```
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

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