Operating Systems

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Chapter 6: Process Synchronization

- Background
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- Peterson's Solution
- Synchronization Hardware
- Semaphores
- Classic Problems of 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.

```
while (true) {

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

Producer

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

                /*  consume the item in nextConsumed
}
```

Consumer

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!

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

            CRITICAL SECTION

        flag[i] = FALSE;

            REMAINDER SECTION

}
```

Algorithm for Process P_i

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

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);
}
```

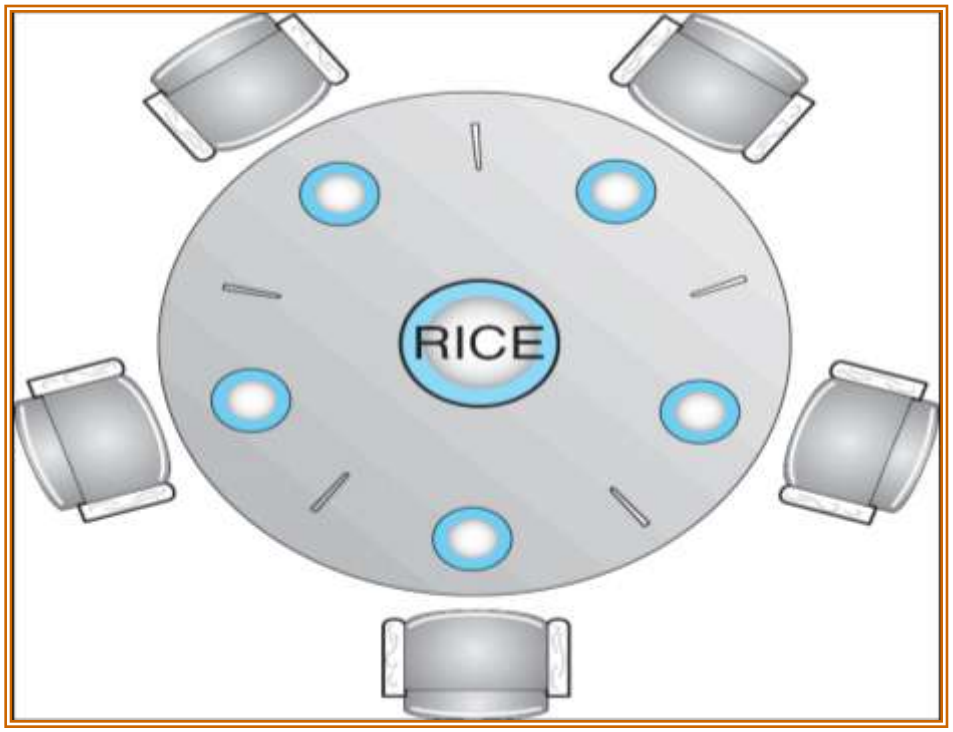
- **The structure of the consumer process**

```
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.

Dining-Philosophers Problem



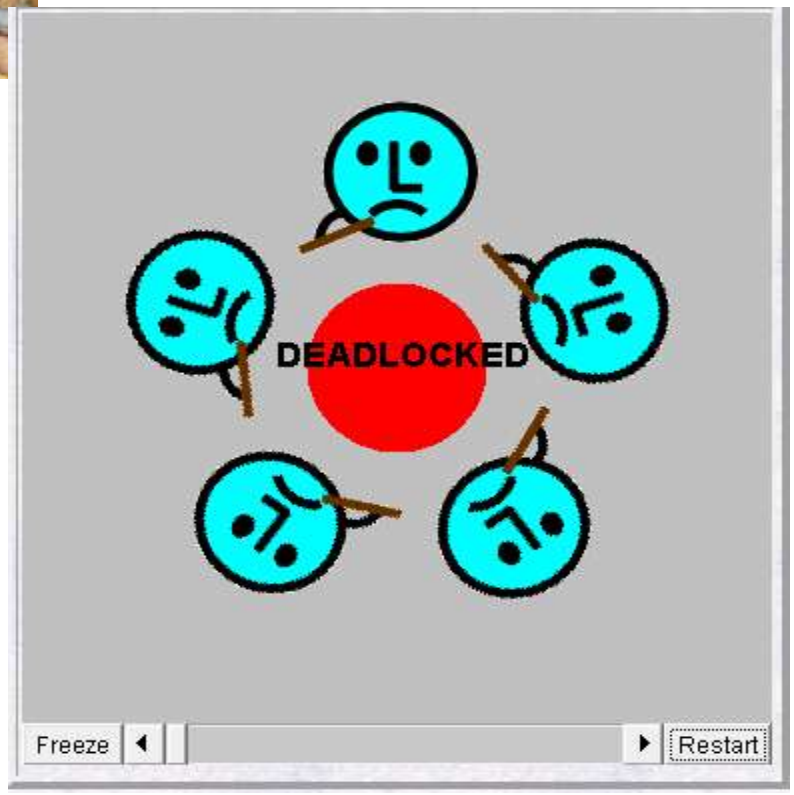
- Shared data
  - Bowl of rice (data set)
  - Semaphore chopstick [5] initialized to 1

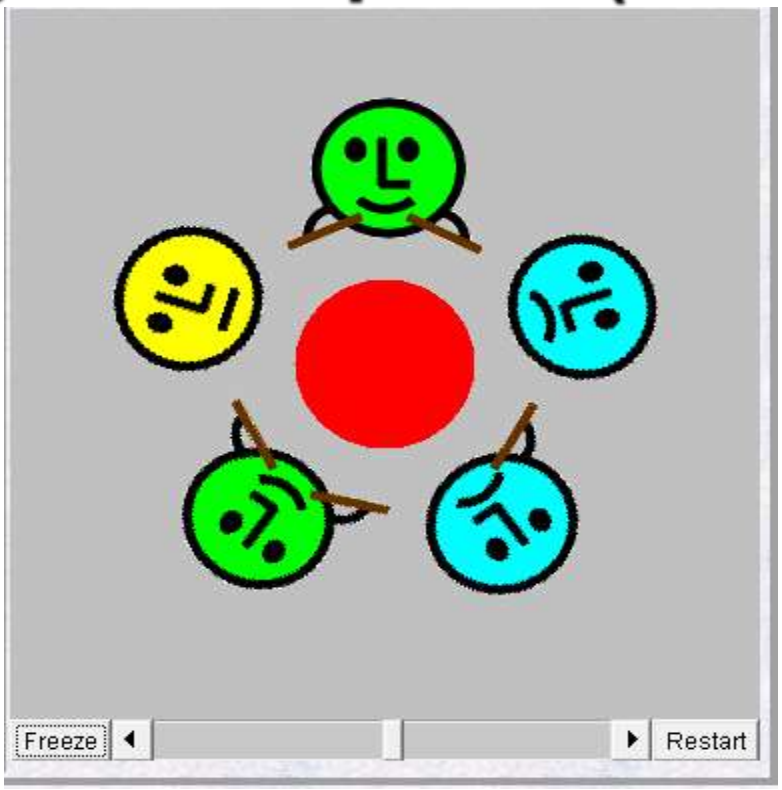
Solution to Dining Philosophers

Dining Philosophers

- Five philosophers sit around a circular table. Each philosopher spends his life alternatively **thinking** and **eating**. In the centre of the table is a large plate of spaghetti. A philosopher needs two **forks** to eat a helping of spaghetti. Unfortunately, as philosophy is not as well paid as computing, the philosophers can only afford five forks. One fork is placed between each pair of philosophers and they agree that each will only use the fork to his immediate right and left..

Solution to Dining Philosophers (cont)





- The slider in the applet below controls the amount of time that a philosopher spends eating and thinking. Philosophers are depicted in **yellow** when they are thinking, **blue** when hungry and **green** when eating
- Note : The Java applete for Demonstration of Dining Philosophers Solution found in the website (*http://www.doc.ic.ac.uk/~jnm/book/book_applets/Diners.html*)

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)

Windows XP Synchronization

- Uses interrupt masks to protect access to global resources on uniprocessor systems
- Uses spinlocks on multiprocessor systems
- Also provides dispatcher objects which may act as either mutexes and semaphores
- Dispatcher objects may also provide events
  - An event acts much like a condition variable