Process

- **Process**: a program in execution, which forms the basis of all computation
- Various features of processes, including scheduling, creation and termination, and communication
- **Inter-process communication:** using shared memory and message passing

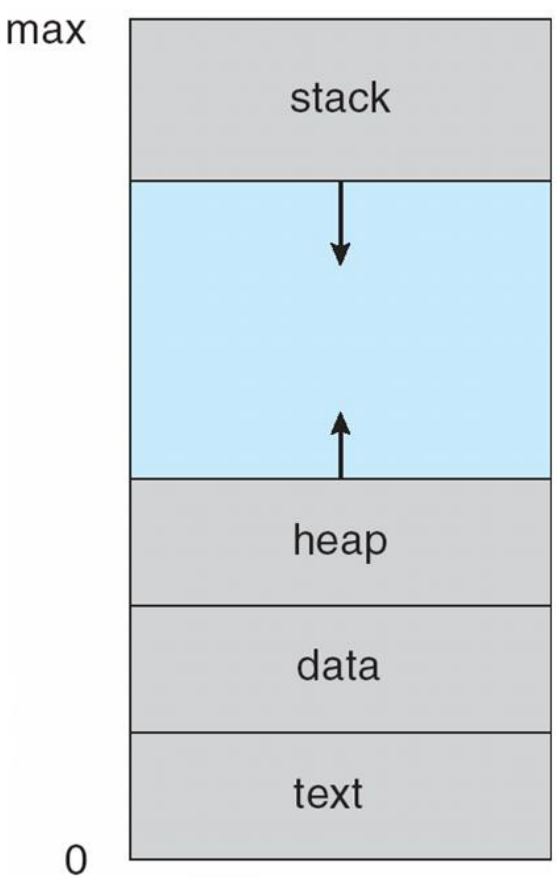
Process

- An operating system executes a variety of programs:
  - Batch system – **jobs**
  - Time-shared systems – **user programs** or **tasks**
- Textbook uses the terms ***job*** and ***process*** almost interchangeably
- **Process** – a program in execution; process execution must progress in sequential fashion

Process

- **Component:**
  - The program code, also called **text section**
  - Current activity including **program counter**, processor register
  - **Stack** containing temporary data
    Function parameters, return addresses, local variables
  - **Data section** containing global variables
  - **Heap** containing memory dynamically allocated during run time

Process in memory



Program

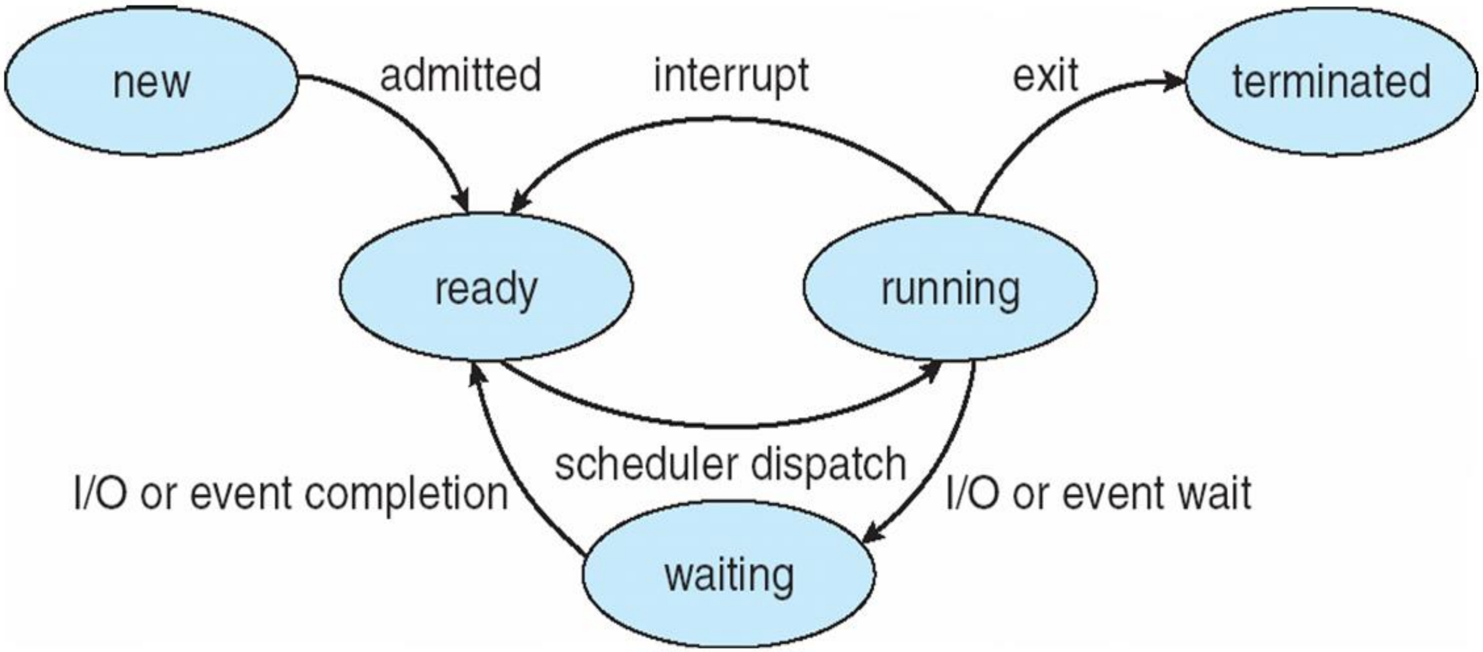
- Program is ***passive*** entity stored on HDD (**executable file**), whereas process is ***active***
  - *Program becomes process when executable file loaded into memory*
- Execution of program started via GUI mouse clicks, command line entry of its name, etc.

- One program can be several processes
  e.g. consider multiple users executing the same program

Process states

- As a process executes, it changes **state**
  - **new**: The process is being created
  - **running**: Instructions are being executed
  - **waiting**: The process is waiting for some event to occur
  - **ready**: The process is waiting to be assigned to a processor
  - **terminated**: The process has finished execution

Process states



Process Synchronization

- Background
- The Critical-Section Problem
- Peterson’s Solution
- Synchronization Hardware
- Semaphores
- Classic Problems of Synchronization

Process Synchronization

- On the basis of synchronization, processes are categorized as one of the following two types:

  - **Independent Process** : Execution of one process does not affects the execution of other processes.
  - **Cooperative Process** : Execution of one process affects the execution of other processes.

- Process synchronization problem arises in the case of Cooperative process also because resources are shared in Cooperative processes.
- **Assumption:** both process arrive same time, and sharing resources, code, memory, variable, etc.

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.

Process Synchronization-objective

- To introduce the critical-section problem, whose solutions can be used to ensure the consistency of shared data
- To present both software and hardware solutions of the critical-section problem
- To introduce the concept of an atomic transaction and describe mechanisms to ensure atomicity

Critical section

- Critical section is a code segment that can be accessed by only one process at a time. Critical section contains shared variables which need to be synchronized to maintain consistency of data variables.

```
do {
    entry section
        critical section
    exit section
        remainder section
} while (TRUE);
```

Producer

Produces an item and places in 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++;
}
```

Shared variable: ***Count***

Shared m/m: Buffer [0…n-1]

Consumer

```
while (true)  {
        while (count == 0)
              ; // do nothing
              nextConsumed =  buffer[out];
               out = (out + 1) % BUFFER_SIZE;
                count--;
                 /*  consume the item in nextConsumed
  }
```

Race Condition

Microinstruction for count++

register1 = count
register1 = register1 + 1
count = register1

I1: Load Rp,m[count]
I2: INCR Rp
I3: Store m[count], Rp

Microinstruction for count--

register2 = count
register2 = register2 - 1
count = register2

I1: Load m[count], Rc
I2: INCR Rc
I3: Store m[count], Rc

Race Condition

Consider the case:
Producer interrupts after I2
and, Consumer interrupts after I2

Producer

I1: Load Rp,m[count]
I2: INCR Rp
I3: Store m[count], Rp

Consumer

I1: Load m[count], Rc
I2: INCR Rc
I3: Store m[count], Rc

Execution sequence:

Producer interrupted

Producer I1, I2, Consumer I1, I2,
Producer I3, Consumer I3

Consumer interrupted

Race Condition-Example

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

Requirements:

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.

Solution to Critical-Section Problem

Requirements:

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 **Pi** is ready!

Algorithm for Process Pi

```
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 system
  - Operating systems using this not broadly scalable

Solution to Critical-section Problem Using Locks

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

Test And Set Instruction

Definition:

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

Must be executed atomically

Solution using Test And Set

- 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 Test and Set()

```
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

Semaphore

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

Semaphore as General Synchronization Tool

- **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 critical section.

Semaphore Implementation

- However, we 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();
        }
}
```

Semaphore Implementation with no Busy waiting

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);

Deadlock and Starvation

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

Classical Synchronization Problems

- 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

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);
```

Bounded-Buffer Problem

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.

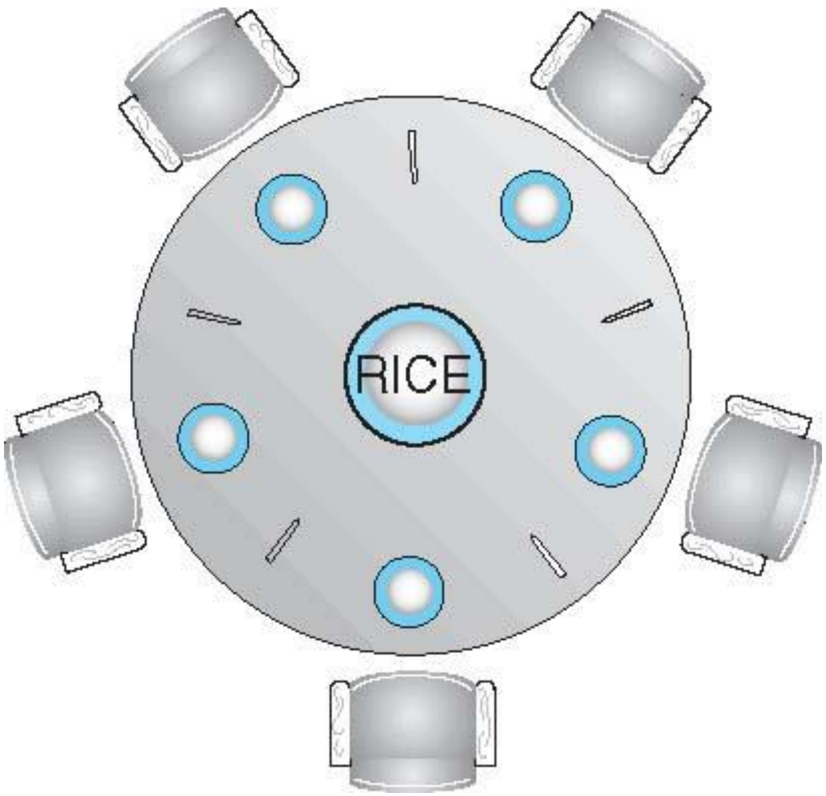
Readers-Writers Problem

- Shared Data
  - Data set
  - Semaphore mutex initialized to 1 (controls access to read count)
  - Semaphore wrt initialized to 1 (writer access)
  - Integer readcount initialized to 0 (how many processes are reading object)

Readers-Writers Problem

- **Question:** Write the structure of writer and reader process.

Dining-Philosophers Problem



Shared data:

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

Dining-Philosophers Problem

The structure of Philosopher *i*:

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

Problem with the above??

More Problems with Semaphores

- Relies too much on programmers not making mistakes (accidental or deliberate)

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