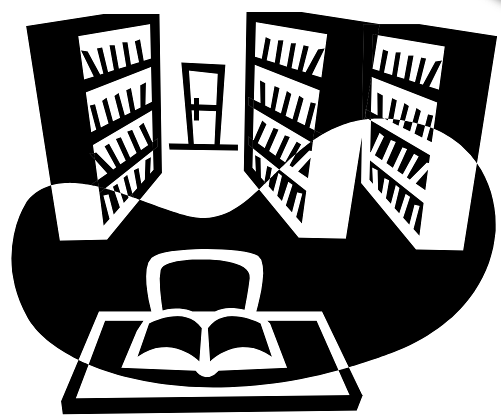
Classic Problems of Synchronization

- Bounded-Buffer Problem
- Readers-Writers Problem
- Dining Philosophers Problem
- Monitors

Readers-Writers Problem

Readers

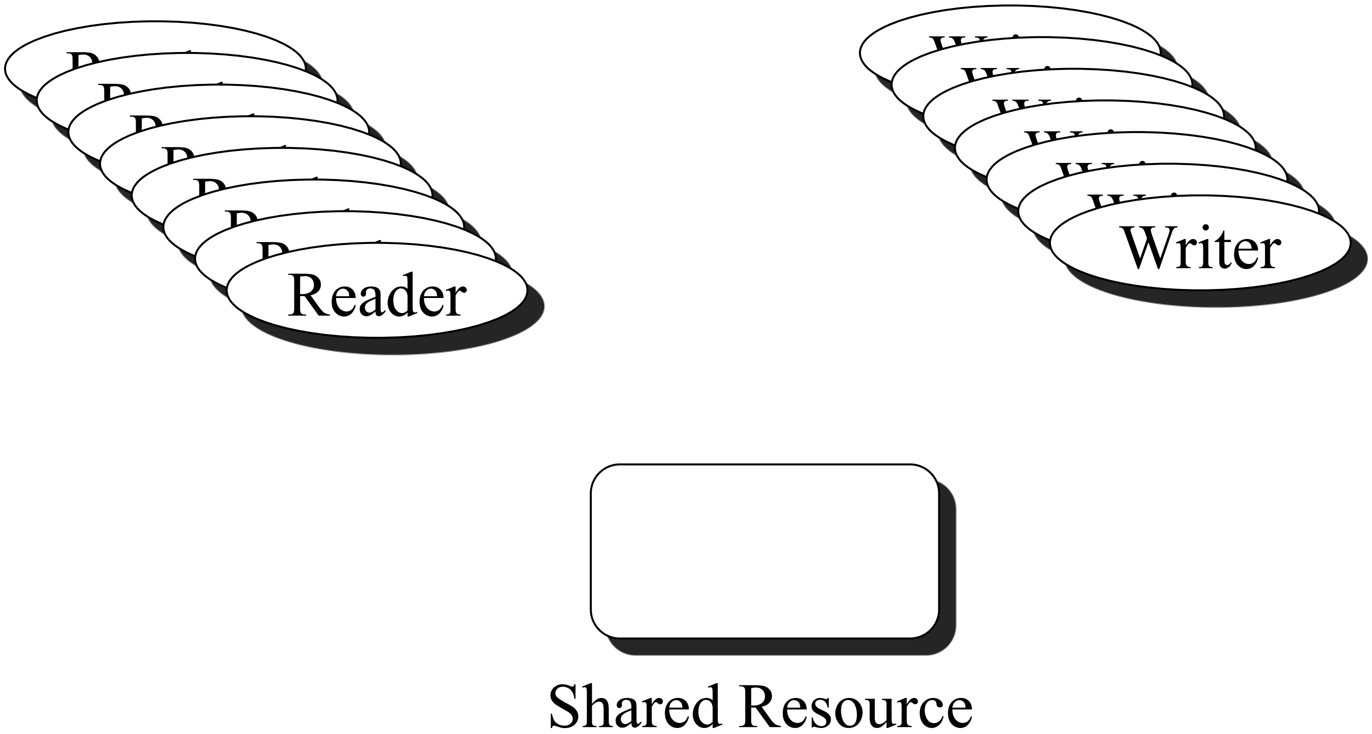
Writers



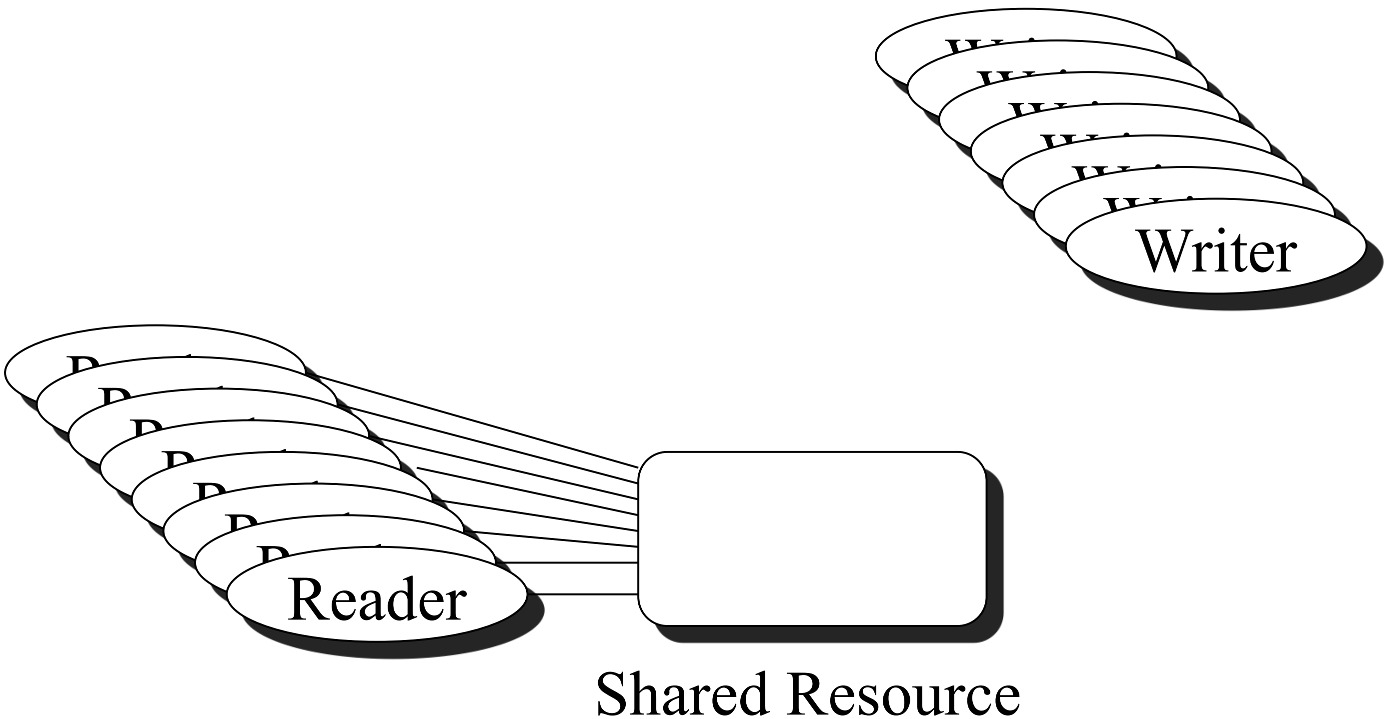
Problem Definition

- Database to be shared among several concurrent processes
- Some processes want to read-only
- Some processes want to read-write
- Several different versions
  - First readers-writers problem
  - Second readers-writers problem

Readers-Writers Problem (Cont.)

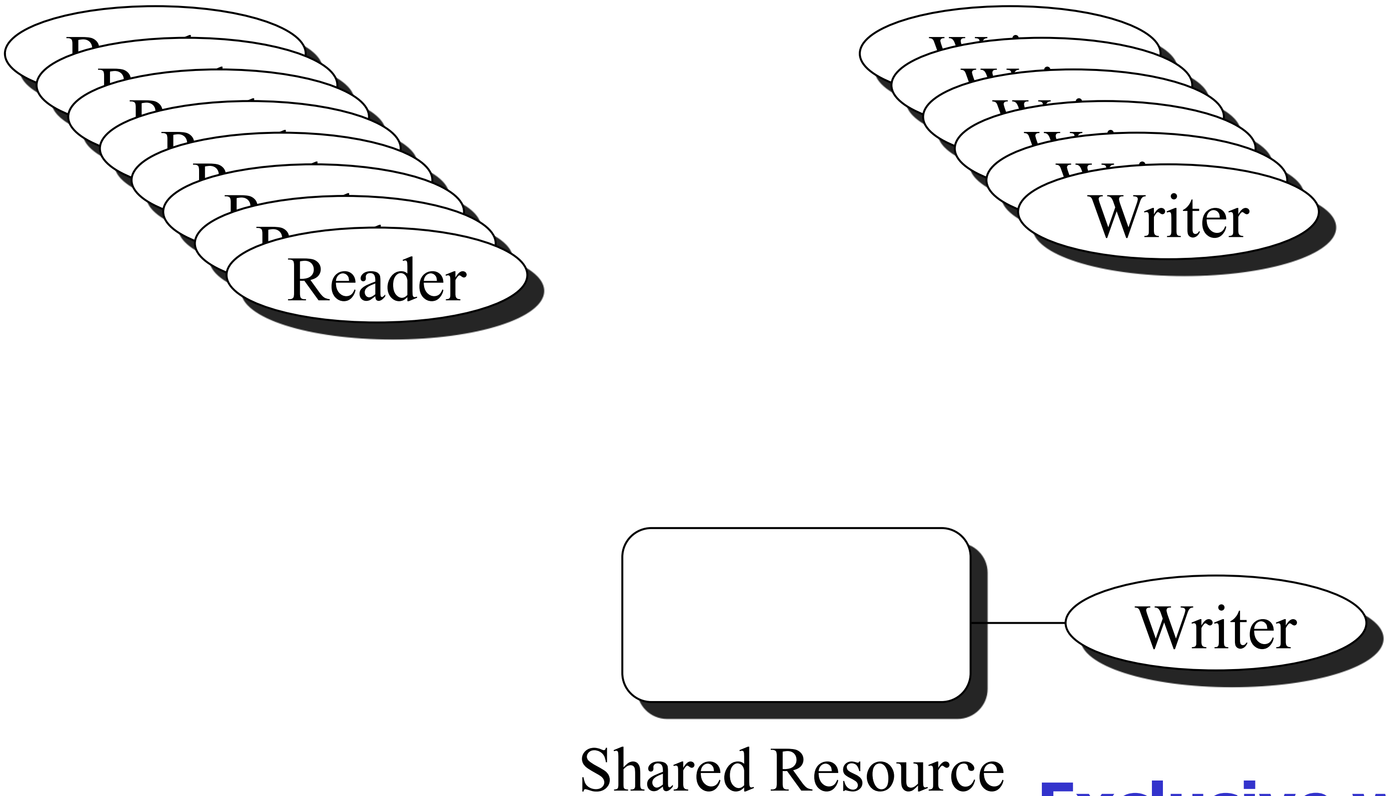


Readers-Writers Problem (Cont.)



Concurrent readers

Readers-Writers Problem (Cont.)



Exclusive writer

First Solution

```
Reader() {
  while(TRUE) {
     wait(mutex);
      readCount++;
      if(readCount==1)
        wait(wrt);
     signal(mutex);

     read(resource);

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

```
Writer() {
  while(TRUE) {
    wait(wrt);

     write(resource);

    signal(wrt);
  }
}
```

```
resourceType *resource;
int readCount = 0;
semaphore mutex = 1;
semaphore wrt = 1;
```

- First reader competes with writers
- Last reader signals writers

First Solution (Cont.)

```
Reader() {
  while(TRUE) {
     wait(mutex);
      readCount++;
      if(readCount == 1)
        wait(wrt);
     signal(mutex);

     read(resource);

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

```
Writer() {
  while(TRUE) {
    wait(wrt);

     write(resource);

    signal(wrt);
  }
}
```

- First reader competes with writers
- Last reader signals writers
- Any writer must wait for all readers
- Readers can starve writers
- "Updates" can be delayed forever

Second Solution: Writer Precedence

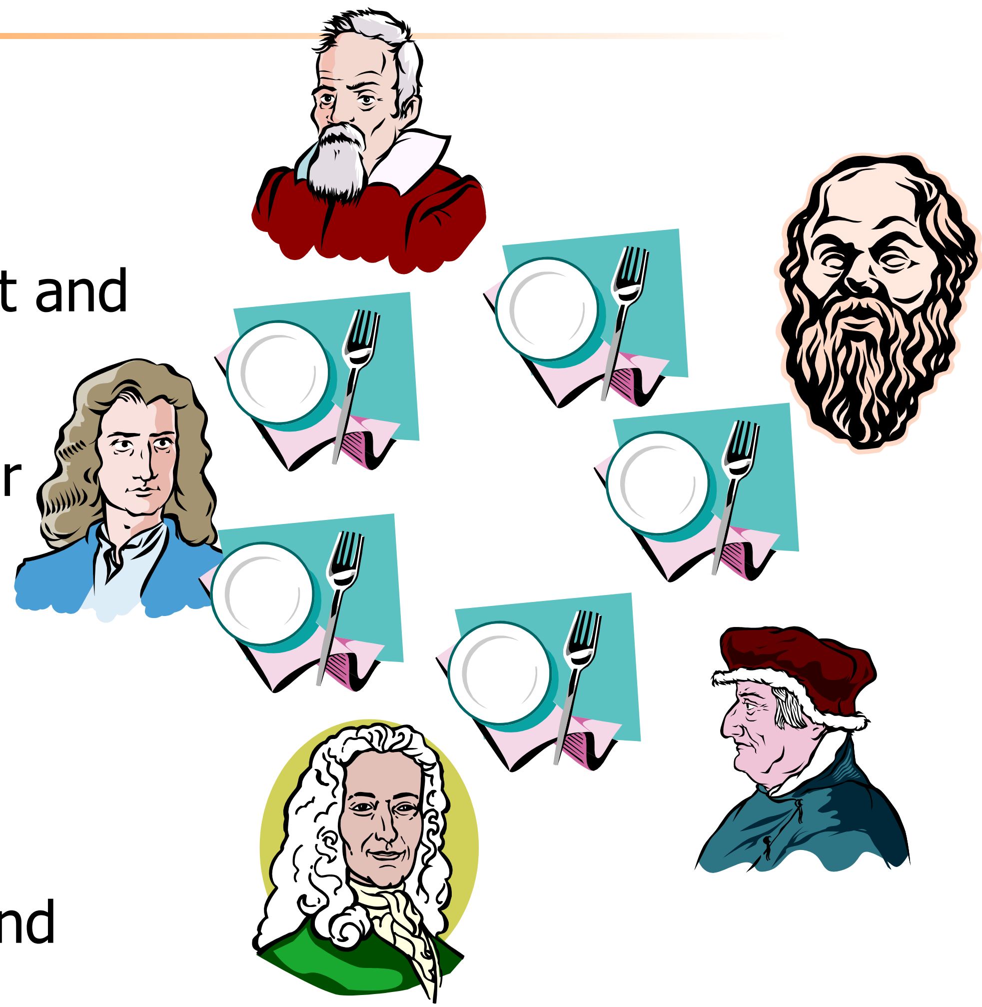
```
Reader() {
  while(TRUE) {
    wait(rd);
      wait(mutex1);
        readCount++;
        if(readCount == 1)
          wait(wrt);
      signal(mutex1);
    signal(rd);

    read(resource);

   wait(mutex1);
    readCount--;
    if(readCount == 0)
      signal(wrt);
   signal(mutex1);
  }
}
```

```
writer() {
  while(TRUE) {
    wait(mutex2);
      writeCount++;
      if(writeCount == 1)
        wait(rd);
    signal(mutex2);
    wait(wrt);

      write(resource);

    signal(wrt);
    wait(mutex2)
      writeCount--;
      if(writeCount == 0)
        signal(rd);
    signal(mutex2);
  }
}
```

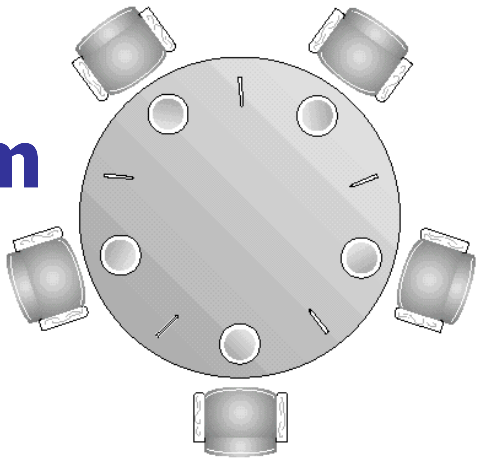
```
int readCount = 0, writeCount = 0;
semaphore mutex1 = 1, mutex2 = 1;
semaphore rd = 1, wrt = 1;
```

The Dining Philosophers Problem

- A classical synchronization problem
- 5 philosophers who only eat and think
- Each need to use 2 forks for eating
- There are only 5 forks
- Illustrates the difficulty of allocating resources among process without deadlock and starvation



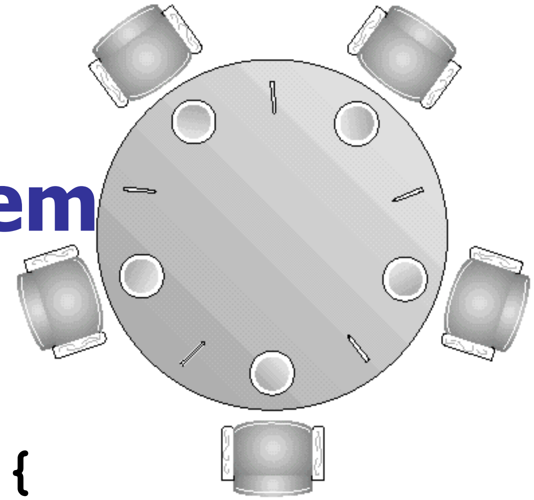
The Dining Philosophers Problem



- Each philosopher is a process
- One semaphore per fork:
  - Fork: array[0..4] of semaphores
  - Initialization: fork [i].count:=1 for i:=0..4
- A first attempt:
  - Deadlock if each philosopher starts by picking his left fork!

```
Pi() {
 while(TRUE){
  think;
  wait(fork[i]);
   wait(fork[i+1 mod 5]);
    eat;
   signal(fork[i+1 mod 5]);
  signal(fork[i]);
 }
}
```

The Dining Philosophers Problem



- Idea: admit only 4 philosophers at a time who try to eat
- Then, one philosopher can always eat when the other 3 are holding one fork
- Solution: use another semaphore T to limit at 4 the number of philosophers "sitting at the table"
- Initialize: T.count:=4

```
Pi(){
 while(TRUE){
  think;
  wait(T);
   wait(fork[i]);
    wait(fork[i+1 mod 5]);
     eat;
    signal(fork[i+1 mod 5]);
   signal(fork[i]);
  signal(T);
 }
}
```

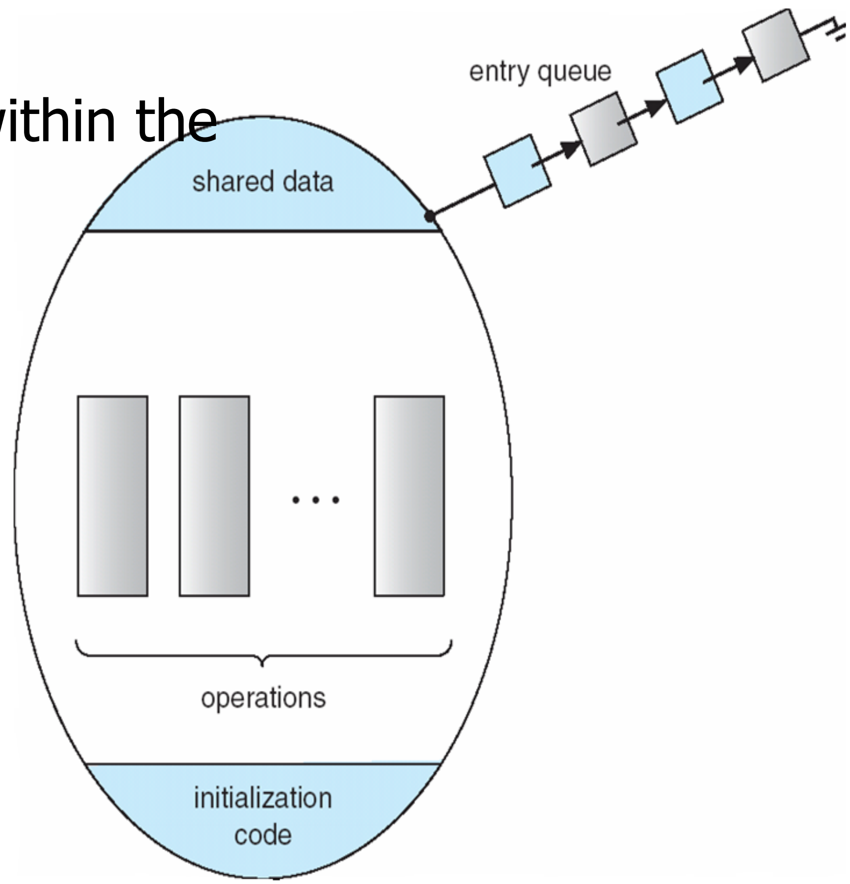
Recall: Problems with Semaphores

- Semaphores are a powerful tool for enforcing mutual exclusion and coordinate processes
- Problem: wait(S) and signal(S) are scattered among several processes
  - It is difficult to understand their effects
  - Usage must be correct in all processes
  - One bad (or malicious) process can fail the entire collection of processes

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 ( ….) { … }
}
```



Monitors

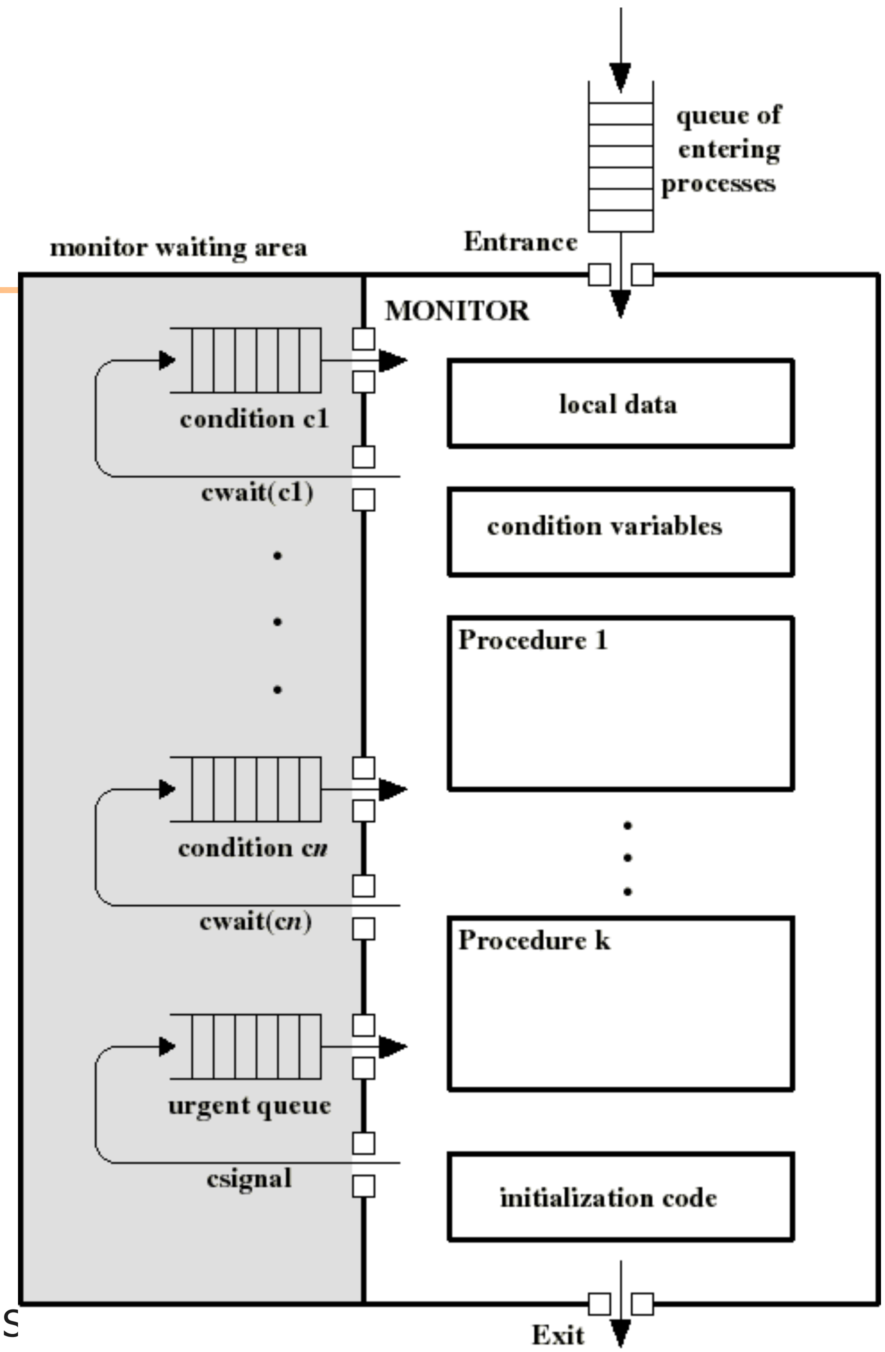
- Is a software module containing:
  - one or more procedures
  - an initialization sequence
  - local shared data variables
- Characteristics:
  - Local shared variables accessible only by monitor’s procedures
  - a process enters the monitor by invoking one of it’s procedures
  - only one process can be in the monitor at any one time
- The monitor ensures mutual exclusion
  - no need to program this constraint explicitly
- Shared data are protected by placing them in the monitor
  - The monitor locks the shared data on process entry

Condition Variables

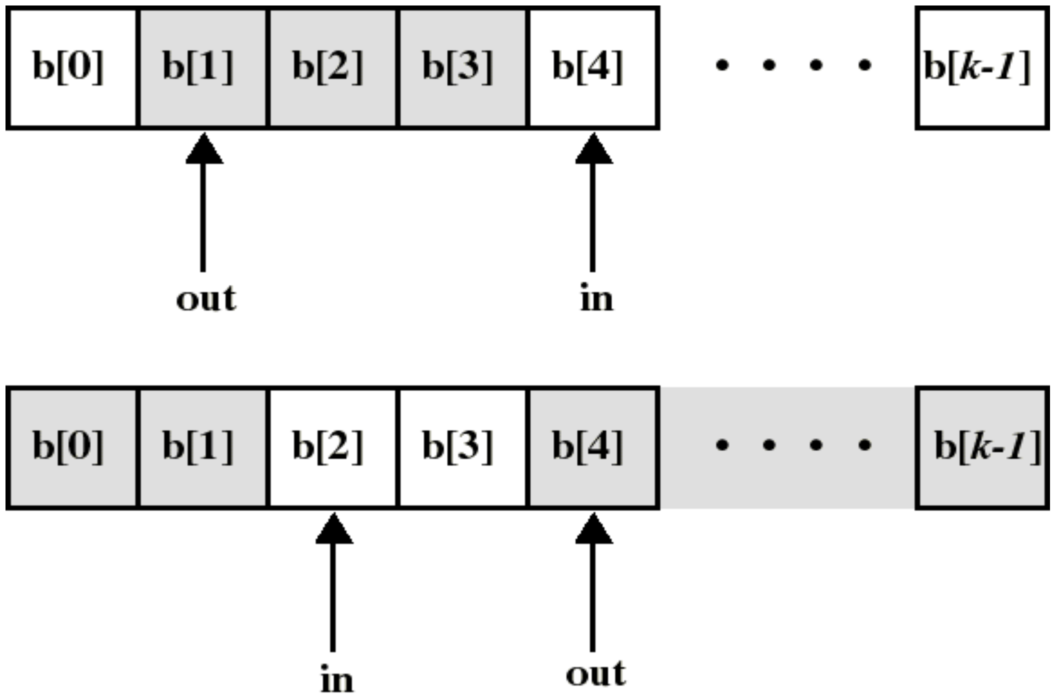
- Process synchronization is done using condition variables, which represent *conditions a process may need to wait for before executing in the monitor*
- condition x, y;
- Local to the monitor (accessible only within the monitor)
- Can be accessed and changed only by two functions:
  - x.wait(): blocks execution of the calling process on condition *x*
    - the process can resume execution only if another process executes x.signal()
  - x.signal(): resume execution of some process blocked on condition *x*.
    - If several such process exists: choose any one
    - If no such process exists: do nothing

Monitors

- Awaiting processes are either in the entrance queue or in a condition queue
- A process puts itself into condition queue cn by issuing cn.wait()
- cn.signal() brings into the monitor one process in condition cn queue
- *signal-and-wait* and *signal-and-continue*



P/C: Finite Circular Buffer of Size k



- Can consume only when the number *full* of (consumable) items is at least 1
- Can produce only when the number *empty* of empty spaces is at least 1

Solution of P/C: Finite Circular Buffer of Size k

Initialization:

```
mutex.count:=1;   in:=0;
full.count:=0;    out:=0;
empty.count:=k;
```

Producer:

```
while(TRUE){
  produce item;
  wait(empty);
  wait(mutex);
  append(item);
  signal(mutex);
  signal(full);
}
```

Consumer:

```
While(TRUE){
  wait(full);
  wait(mutex);
  item=take();
  signal(mutex);
  signal(empty);
  consume(item);
}
```

append(v):

```
b[in]:=v;
in:=(in+1)
      mod k;
```

take():

```
w:=b[out];
out:=(out+1)
      mod k;
return w;
```

■ critical sections

Producer/Consumer Using Monitors

- Two types of processes:
  - producers
  - consumers
- Synchronization is now confined within the monitor
- append(.) and take(.) are procedures within the monitor: are the only means by which P/C can access the buffer
- If these procedures are correct, synchronization will be correct for all participating processes

```
Producer:
 while(TRUE){
  produce item;
  append(item);
 }

Consumer:
 while(TRUE){
  item=take();
  consume item;
 }
```

Monitor for the Bounded P/C Problem

- Buffer:
  - *buffer*: array[0..k-1] of items;
- Buffer pointers and counts:
  - *nextin*: points to next item to be appended
  - *nextout*: points to next item to be taken
  - *count*: holds the number of items in the buffer
- Condition variables:
  - *notfull*: notfull.signal() indicates that the buffer is not full
  - *notempty*: notempty.signal() indicates that the buffer is not empty

Monitor for the Bounded P/C Problem

```
Monitor boundedbuffer {
  Item buffer[k];
  integer nextin, nextout, count;
  condition notfull, notempty;

  Append(v){
    if (count==k) notfull.wait();
    buffer[nextin] = v;
    nextin = (nextin+1) mod k;
    count++;
    notempty.signal();
  }

  Item Take(){
    if (count==0)
      notempty.wait();
    v = buffer[nextout];
    nextout =
      (nextout+1) mod k;
    count--;
    notfull.signal();
    return v;
  }

  initialization_code(){
    nextin=0; nextout=0; count=0;
  }
}
```

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

Linux Synchronization

- Linux:
  - Prior to kernel Version 2.6, disables interrupts to implement short critical sections
  - Version 2.6 and later, fully preemptive
  - Disable kernel preemption on single processors
- Linux provides:
  - semaphores
  - spin locks (mostly on SMP machines)

Pthreads Synchronization

- Pthreads API is OS-independent
- It provides:
  - mutex locks
  - condition variables
- Non-portable extensions include:
  - read-write locks
  - spin locks

Transactional Memory

- Multi-core systems
- A memory transaction
  - Sequence of memory read-only operations that are atomic
- If all operations are completed, transaction is committed
- Otherwise, rolled back