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COURSE NAME : 19CSB201 – OPERATING SYSTEMS

II YEAR/ IV SEMESTER

UNIT – II Process Scheduling And Synchronization

Topic: SEMAPHORES

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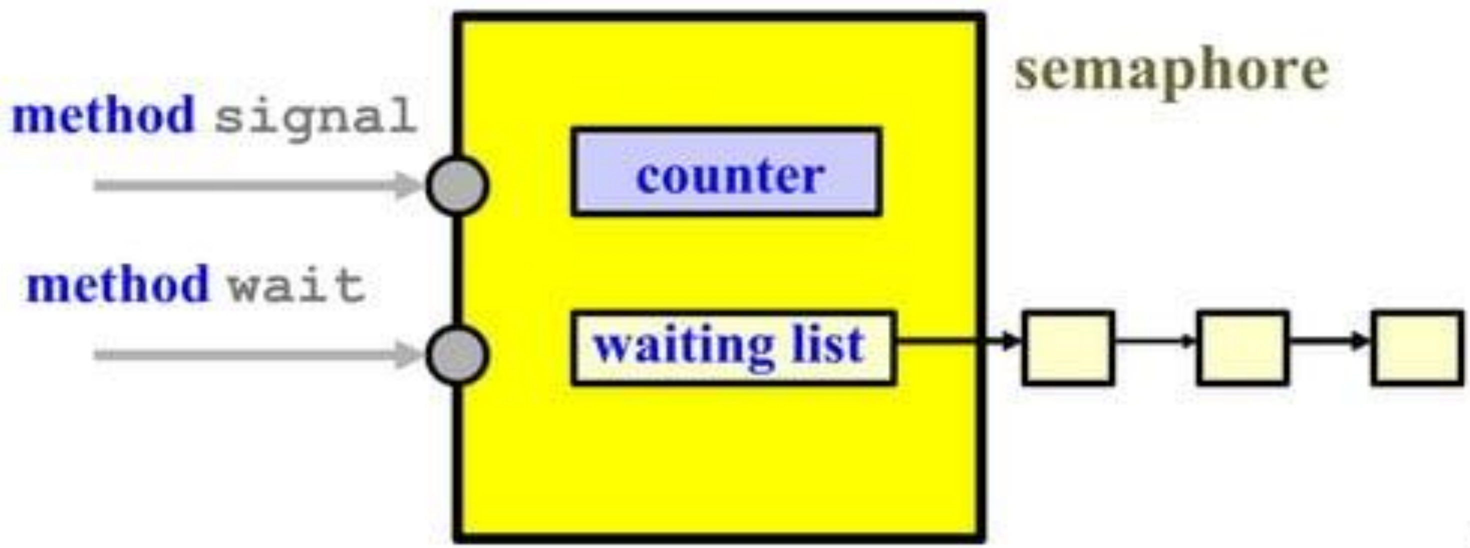
Semaphores

- A *semaphore* is an object that consists of a **counter**, a **waiting list** of processes and two **methods** (*e.g.*, functions): `signal` and `wait`.



1

Semaphore Method: wait

```
void wait(sem S)
{
    S.count--;
    if (S.count < 0) {
        add the caller to the waiting list;
        block();
    }
}
```

- After decreasing the counter by 1, if the counter value becomes negative, then
  - add the caller to the waiting list, and then
  - block itself.

2

Semaphore Method: signal

```
void signal(sem S)
{
    S.count++;
    if (S.count <= 0) {
        remove a process P from the waiting list;
        resume(P);
    }
}
```

- After increasing the counter by 1, if the new counter value is not positive, then
  - remove a process P from the waiting list,
  - resume the execution of process P, and return

3

Important Note: 1/4

```
S.count--;                    S.count++;
if (S.count<0) {              if (S.count<=0) {
    add to list;                  remove P;
    block();                      resume(P);
}                             }
```

- If `S.count < 0`, `abs(S.count)` is the number of waiting processes.
- This is because processes are added to (*resp.*, removed from) the waiting list only if the counter value is `< 0` (*resp.*, `<= 0`).

Important Note: 2/4

```
S.count--;                    S.count++;
if (S.count<0) {              if (S.count<=0) {
    add to list;                  remove P;
    block();                      resume(P);
}                             }
```

- The waiting list can be implemented with a queue if FIFO order is desired.
- However, the correctness of a program should not depend on a particular implementation of the waiting list.
- Your program should not make any assumption about the ordering of the waiting list.

Important Note: 3/4

```
S.count--;                S.count++;
if (S.count<0) {          if (S.count<=0) {
    add to list;              remove P;
    block();                  resume(P);
}                         }
```

- The caller may be blocked in the call to `wait()`.
- The caller never blocks in the call to `signal()`. If `S.count > 0`, `signal()` returns and the caller continues. Otherwise, a waiting process is released and the caller continues. In this case, *two* processes continue.

The Most Important Note: 4/4

```
S.count--;                S.count++;
if (S.count<0) {          if (S.count<=0) {
    add to list;              remove P;
    block();                  resume(P);
}                         }
```

- `wait()` and `signal()` must be executed *atomically* (*i.e.*, as one uninterruptible unit).
- Otherwise, *race conditions* may occur.
- Homework: use execution sequences to show race conditions if `wait()` and/or `signal()` is not executed atomically.

Three Typical Uses of Semaphores

- There are three typical uses of semaphores:
  - **mutual exclusion:**
    Mutex (*i.e.*, *Mut*ual *Ex*clusion) locks
  - **count-down lock:**
    Keep in mind that semaphores have a counter.
  - **notification:**
    Indicate an event has occurred.

8

Use 1: Mutual Exclusion (Lock)

initialization is important

```
semaphore S = 1;
int       count = 0;
```

Process 1

```
while (1) {
   // do something
   S.wait();
      count++;
   S.signal();
   // do something
}
```

Process 2

```
while (1) {
   // do something
   S.wait();
      count--;
   S.signal();
   // do something
}
```

entry

critical sections

exit

- What if the initial value of S is zero?
- S is a *binary semaphore* (similar to a *lock*).

9

Use 2: Count-Down Counter

```
semaphore  S = 3
```

Process 1	Process 2
`while (1) {`	`while (1) {`
`// do something`	`// do something`
`S.wait();`	`S.wait();`

at most 3 processes can be here!!!

`S.signal();`	`S.signal();`
`// do something`	`// do something`
`}`	`}`

- **After three processes pass through `wait()`, this section is locked until a process calls `signal()`.**

Use 3: Notification

```
semaphore S1 = 1, S2 = 0;
```

process 1

```
while (1) {
   // do something
   S1.wait();
      cout << "1";
   S2.signal();
   // do something
}
```

process 2

```
while (1) {
   // do something
   S2.wait();
      cout << "2";
   S1.signal();
   // do something
}
```

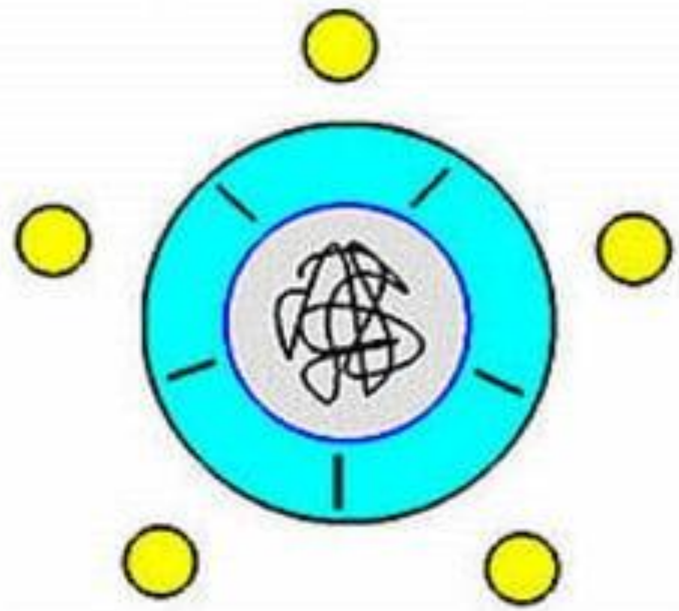
notify

notify

- **Process 1 uses `S2.signal()` to notify process 2, indicating "I am done. Please go ahead."**
- **The output is** `1 2 1 2 1 2 ......`
- **What if both `S1` and `S2` are both 0's or both 1's?**
- **What if `S1` = 0 and `S2` = 1?**

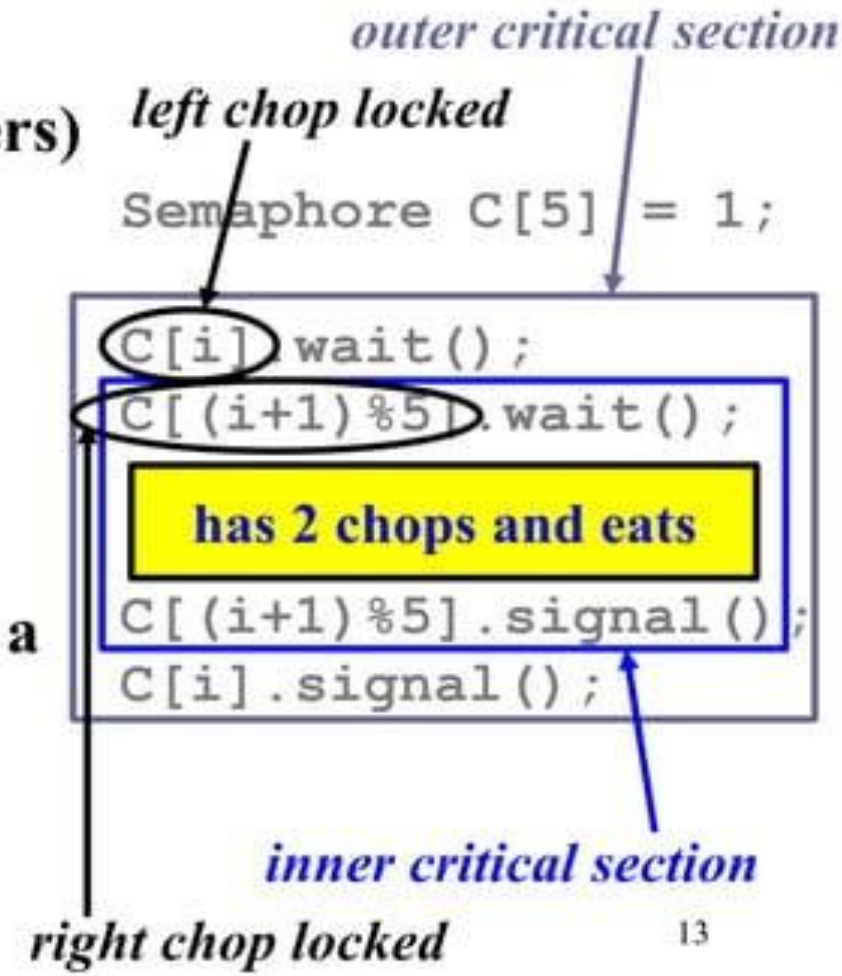
Lock Example: Dining Philosophers

- Five philosophers are in a **thinking - eating** cycle.
- When a philosopher gets hungry, he sits down, picks up *two nearest* chopsticks, and eats.
- A philosopher can eat only if he has ***both*** chopsticks.
- After eating, he puts down both chopsticks and thinks.
- This cycle continues.



Dining Philosopher: Ideas

- Chopsticks are shared items (by two philosophers) and must be protected.
- Each chopstick has a semaphore with initial value 1.
- A philosopher calls `wait()` before picks up a chopstick and calls `signal()` to release it.



Dining Philosophers: Code

```
semaphore  C[5] = 1;
```

philosopher *i*

```
while (1) {
   // thinking
   C[i].wait();
   C[(i+1)%5].wait();
   // eating
   C[(i+1)%5].signal();
   C[i].signal();
   // finishes eating
}
```

wait for my left chop

wait for my right chop

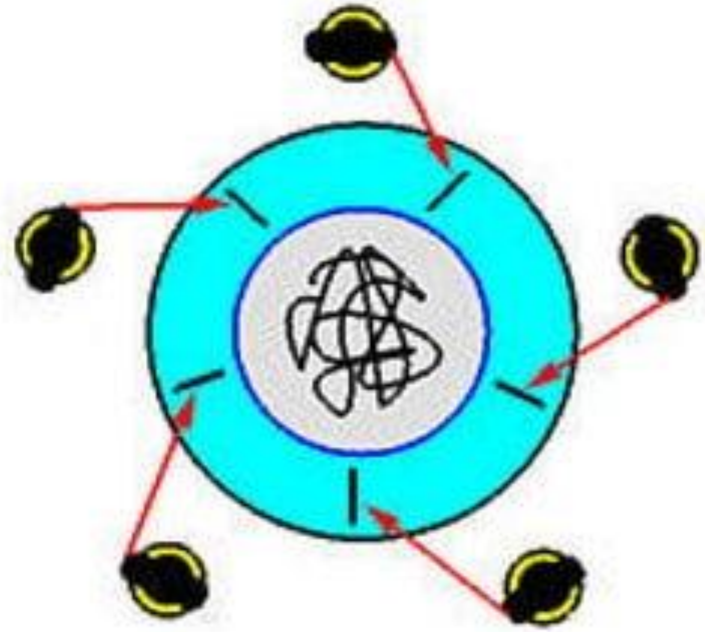
release my right chop

release my left chop

Does this solution work?

Dining Philosophers: Deadlock!

- **If all five philosophers sit down and pick up their left chopsticks at the same time, this program has a *circular waiting* and deadlocks.**
- **An easy way to remove this deadlock is to introduce a weirdo who picks up his right chopstick first!**



Dining Philosophers: A Better Idea

```
semaphore C[5] = 1;
```

philosopher *i* (0, 1, 2, 3)

```
while (1) {
   // thinking
   C[i].wait();
   C[(i+1)%5].wait();
   // eating
   C[(i+1)%5].signal();
   C[i].signal();
   // finishes eating;
}
```

Philosopher 4: the weirdo

```
while (1) {
   // thinking
   C[(i+1)%5].wait();
   C[i].wait();
   // eating
   C[i].signal();
   C[(i+1)%5].signal();
   // finishes eating
}
```

lock left chop

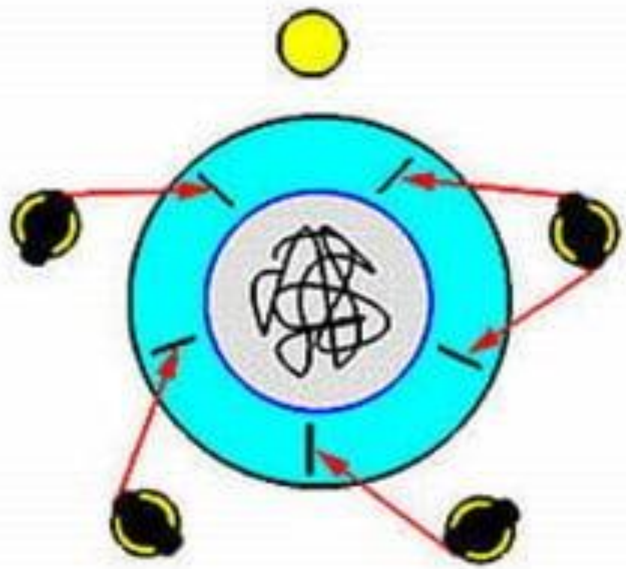
lock right chop

16

Dining Philosophers: Questions

- The following are some important questions for you to work on.
  - We choose philosopher 4 to be the weirdo. Does this choice matter?
  - Show that this solution does not cause *circular waiting*.
  - Show that this solution will not have *circular waiting* if we have more than 1 and less than 5 weirdoes.
- These questions may appear as exam problems.

Count-Down Lock Example



- The naïve solution to the dining philosophers causes circular waiting.
- If only four philosophers are allowed to sit down, no deadlock can occur.
- Why? If all four of them sit down at the same time, the right-most philosopher can have both chopsticks!
- How about fewer than four? This is obvious.

Count-Down Lock Example

```
semaphore C[5]= 1;
semaphore Chair = 4;

while (1) {
   // thinking
   Chair.wait();
      C[i].wait();
      C[(i+1)%5].wait();
      // eating
      C[(i+1)%5].signal();
      C[i].signal();
   Chair.signal();
}
```

get a chair

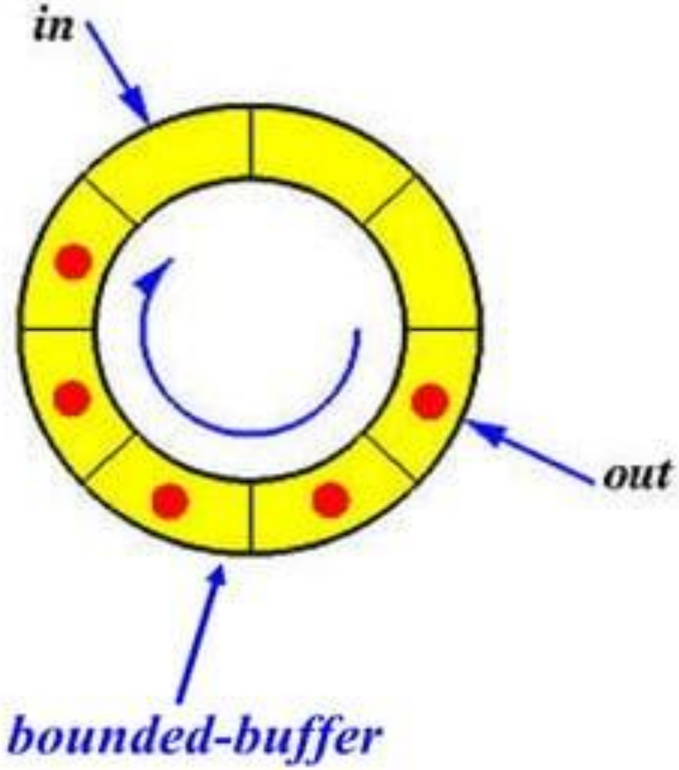
this is a count-down lock that only allows 4 to go!

this is our old friend

release my chair

19

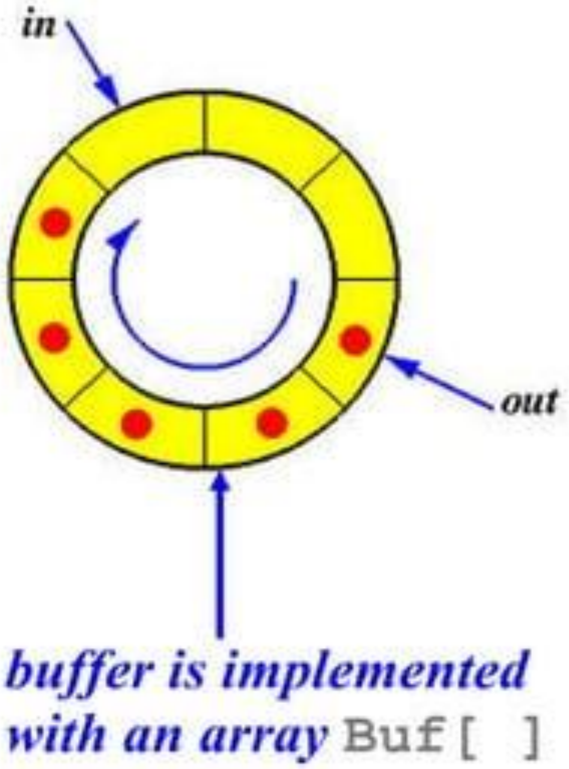
The Producer/Consumer Problem



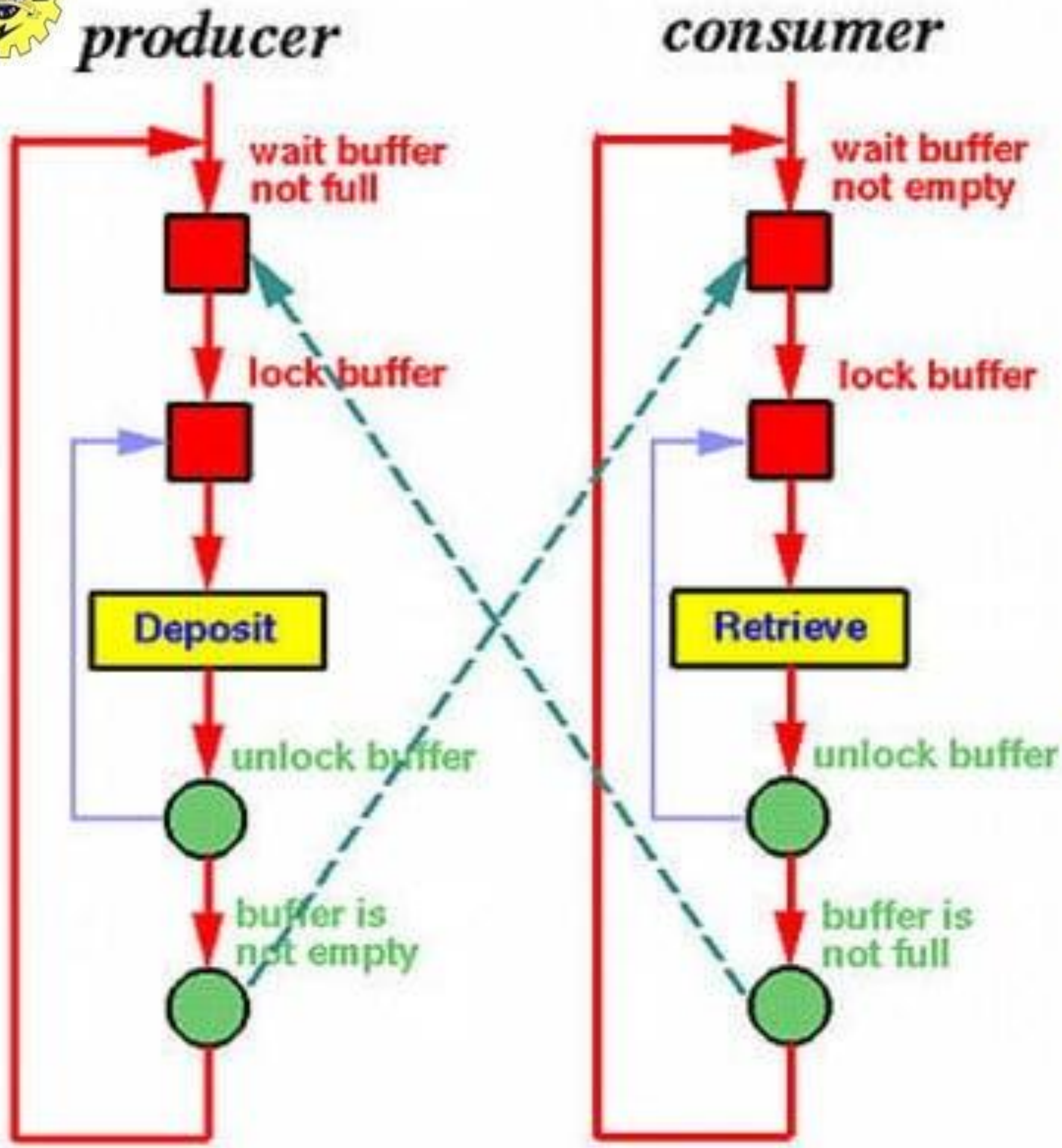
- Suppose we have a circular buffer of *n* slots.
- Pointers *in* (*resp*., *out*) points to the first empty (*resp*., filled) slot.
- Producer processes keep adding info into the buffer
- Consumer processes keep retrieving info from the buffer.

20

Problem Analysis



- A producer deposits info into `Buf[in]` and a consumer retrieves info from `Buf[out]`.
- `in` and `out` must be advanced.
- `in` is shared among producers.
- `out` is shared among consumers.
- If `Buf` is full, producers should be blocked.
- If `Buf` is empty, consumers should be blocked.



- We need a sem. to protect the buffer.
- A second sem. to block producers if the buffer is full.
- A third sem. to block consumers if the buffer is empty.

22

Solution

no. of slots

```
semaphore NotFull=n, NotEmpty=0, Mutex=1;
```

producer

```
while (1) {
  NotFull.wait();
    Mutex.wait();
      Buf[in] = x;
      in = (in+1)%n;
    Mutex.signal();
  NotEmpty.signal();
}
```

consumer

```
while (1) {
  NotEmpty.wait();
    Mutex.wait();
      x = Buf[out];
      out = (out+1)%n;
    Mutex.signal();
  NotFull.signal();
}
```

notifications

critical section

23

Question

- What if the producer code is modified as follows?
- **Answer:** a deadlock may occur. Why?

order changed

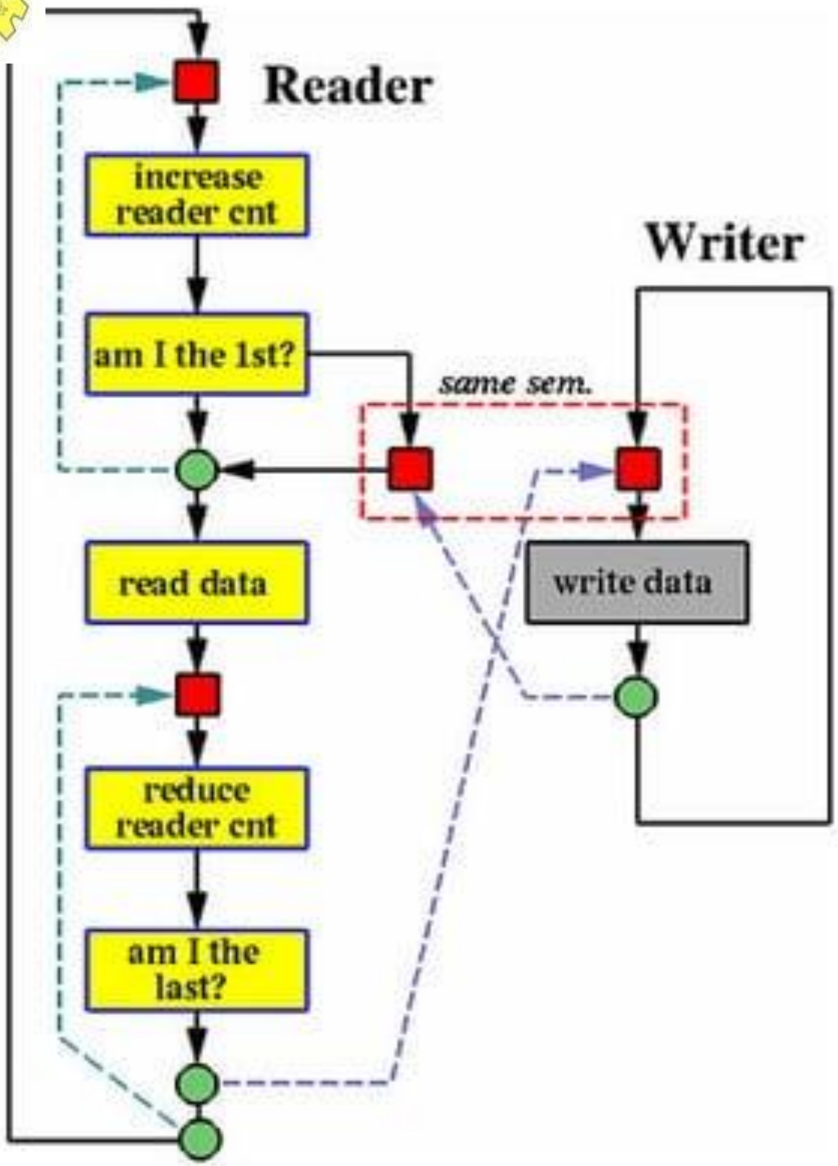
```
while (1) {
  Mutex.wait();
    NotFull.wait();
      Buf[in] = x;
      in = (in+1)%n;
    NotEmpty.signal();
  Mutex.signal();
}
```

The Readers/Writers Problem

- Two groups of processes, **readers** and **writers**, are accessing a shared resource by the following rules:
  - Readers can **read simultaneously**.
  - **Only one** writer can write at any time.
  - When a writer is writing, no reader can read.
  - If there is any reader reading, all **incoming writers must wait**. Thus, readers have higher priority.

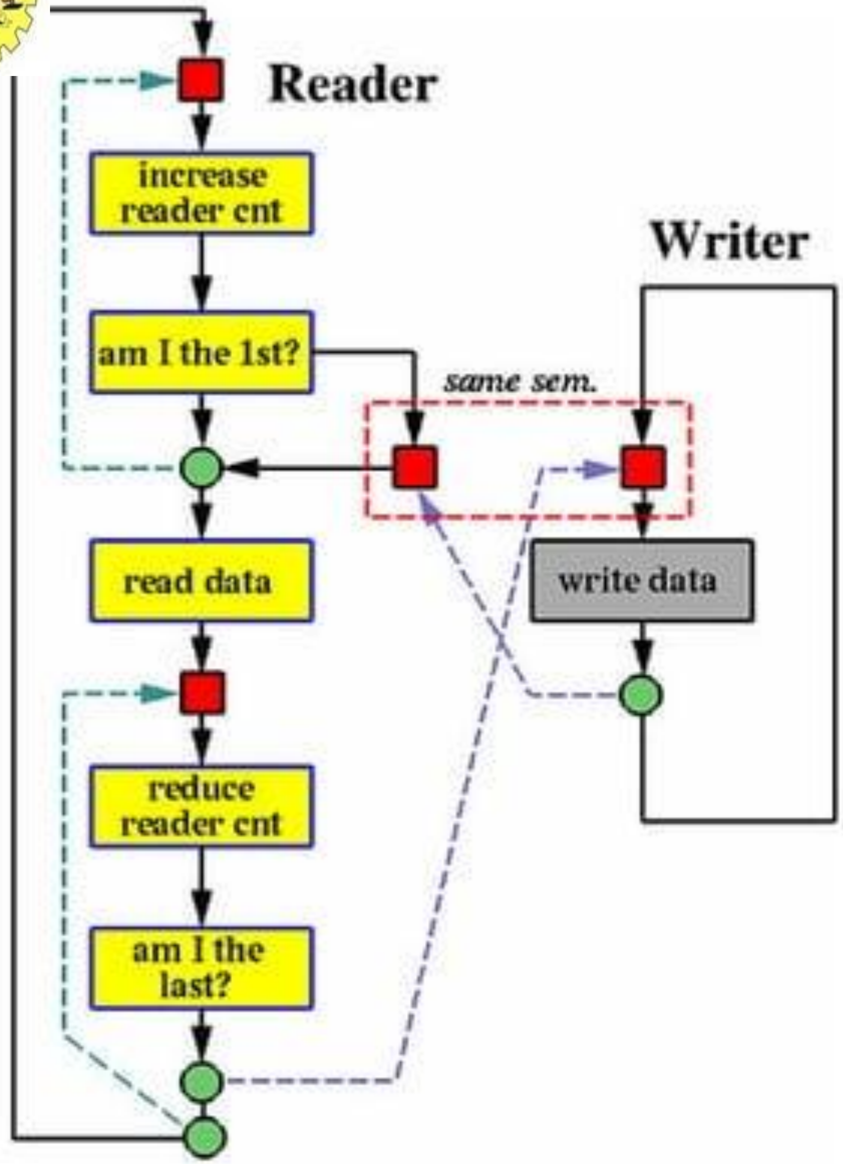
Problem Analysis

- We need a semaphore to **block readers if a writer is writing**.
- When a writer arrives, it must be able to **know if there are readers reading**. So, a reader count is required which must be protected by a lock.
- This **reader-priority** version has a problem: bounded waiting condition may be violated if readers keep coming, causing the waiting writers no chance to write.



- When a reader comes in, it increase the count.
- If it is the 1st reader, waits until no writer is writing,
- Reads data.
- Decreases the counter.
- Notifies the writer that no reader is reading if it is the last.

27



- When a writer comes in, it waits until no reader is reading and no writer is writing.
- Then, it writes data.
- Finally, notifies readers and writers that no writer is in.

Solution

```
semaphore Mutex = 1, WrtMutex = 1;
int       RdrCount;
```

reader

```
while (1) {
  Mutex.wait();
    RdrCount++;
    if (RdrCount == 1)
      WrtMutex.wait();
  Mutex.signal();
  // read data
  Mutex.wait();
    RdrCount--;
    if (RdrCount == 0)
      WrtMutex.signal();
  Mutex.signal();
}
```

writer

```
while (1) {
  WrtMutex.wait();
  // write data
  WrtMutex.signal();
}
```

blocks both readers and writers

29