CS 370: OPERATING SYSTEMS [PROCESS SYNCHRONIZATION]

Shrideep Pallickara
Computer Science
Colorado State University

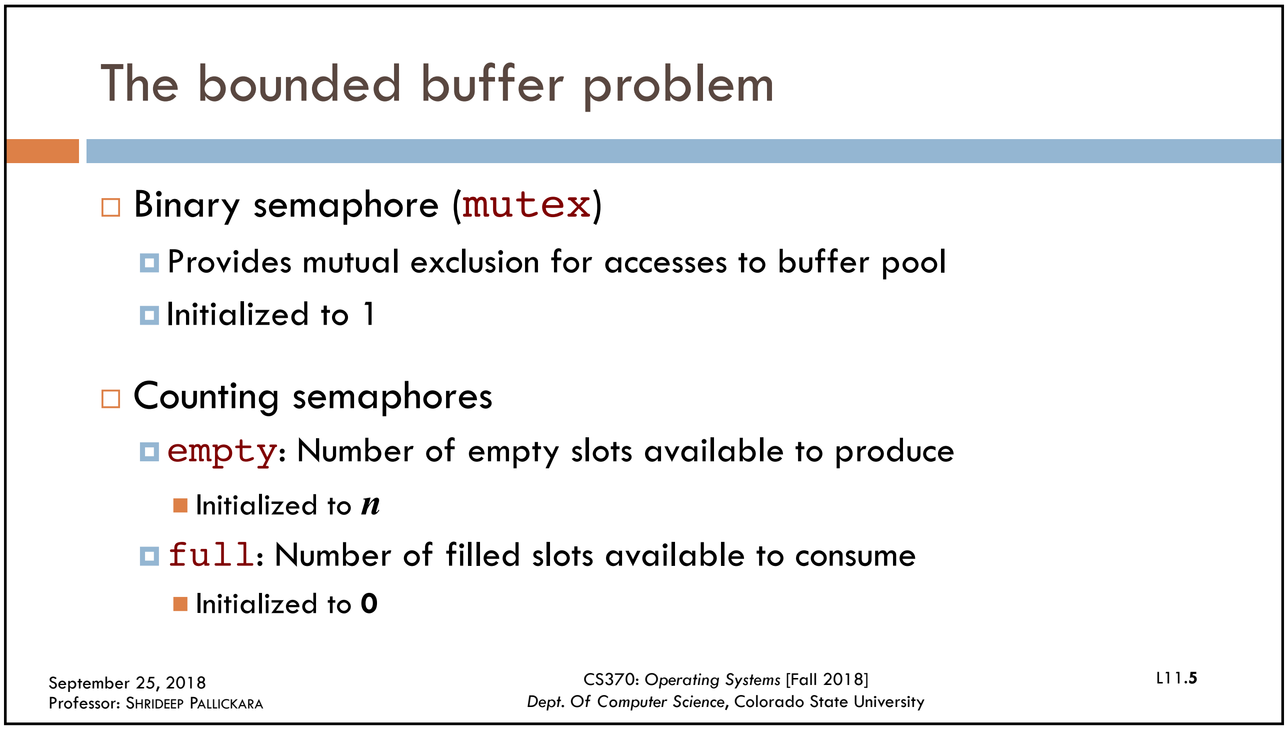
Frequently asked questions from the previous class survey

- What is the difference between a semaphore and a mutex?
  - Mutex: locking mechanism, semaphore: signaling mechanism
- What is preemption?
- Remainder section?

Topics covered in the lecture

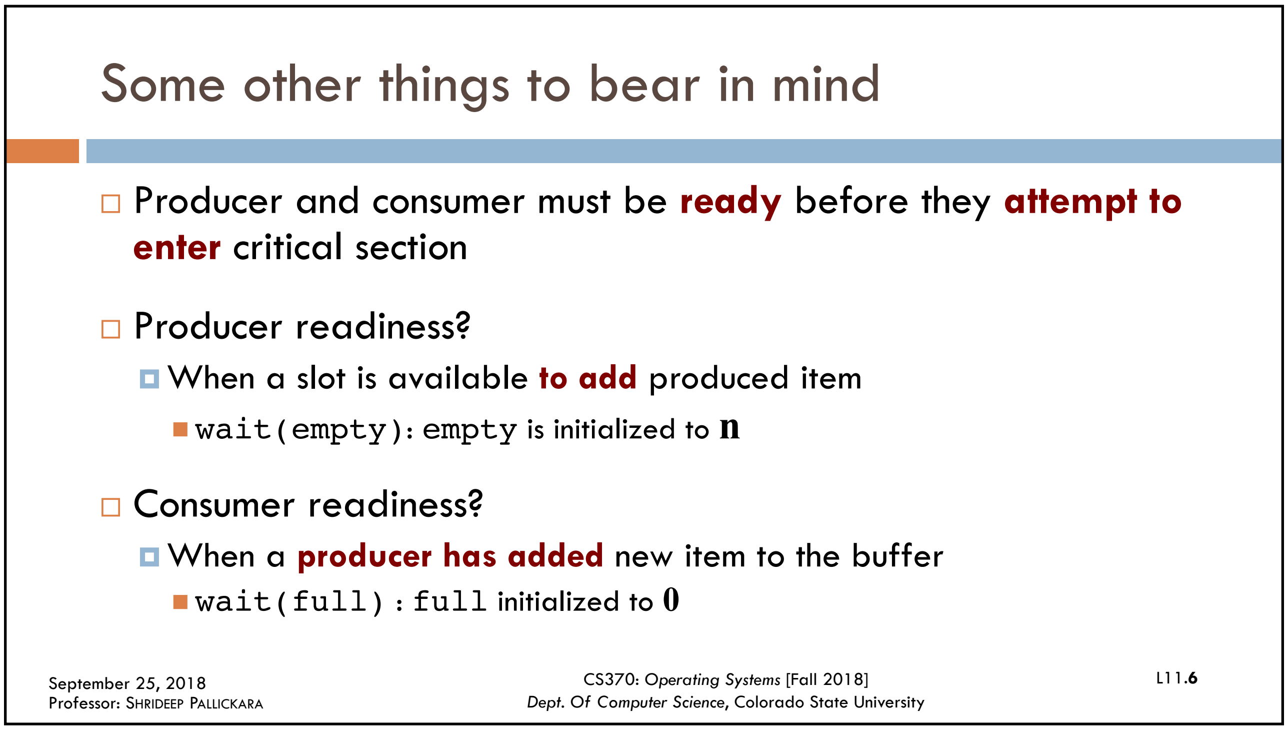
- Classical process synchronization problems
  - Producer-Consumer problem
  - Readers Writers
  - Dining philosopher's problem
- Monitors
  - Solving dining philosopher's problem using monitors
- Midterm

CLASSIC PROBLEMS OF SYNCHRONIZATION



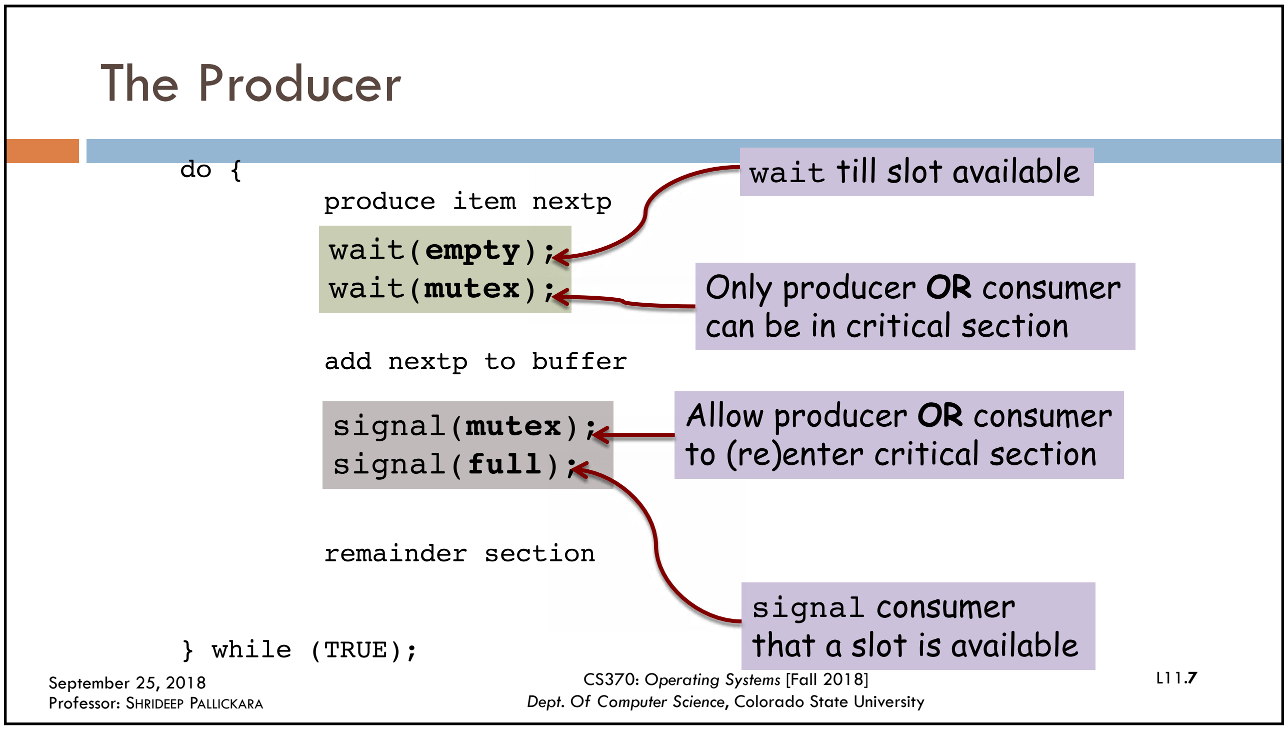
The bounded buffer problem

- Binary semaphore (`mutex`)
  - Provides mutual exclusion for accesses to buffer pool
  - Initialized to 1
- Counting semaphores
  - `empty`: Number of empty slots available to produce
    - Initialized to n
  - `full`: Number of filled slots available to consume
    - Initialized to **0**



Some other things to bear in mind

- Producer and consumer must be **ready** before they **attempt to enter** critical section
- Producer readiness?
  - When a slot is available **to add** produced item
    - `wait(empty)`: `empty` is initialized to **n**
- Consumer readiness?
  - When a **producer has added** new item to the buffer
    - `wait(full)` : `full` initialized to **0**



The Producer

```
do {
          produce item nextp
          wait(empty);
          wait(mutex);

          add nextp to buffer

          signal(mutex);
          signal(full);

          remainder section

} while (TRUE);
```

wait till slot available

Only producer **OR** consumer can be in critical section

Allow producer **OR** consumer to (re)enter critical section

signal consumer that a slot is available

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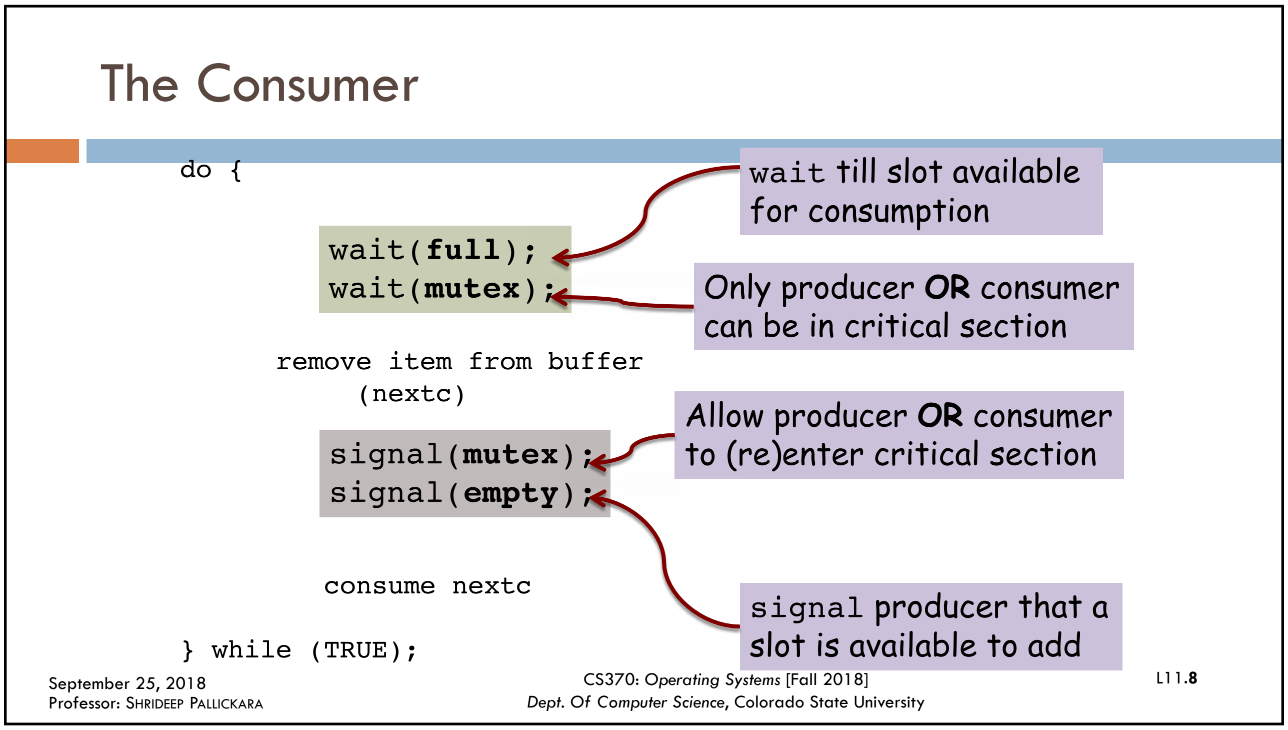
L11.**7**



The Consumer

```
do {

          wait(full);
          wait(mutex);

       remove item from buffer
            (nextc)

          signal(mutex);
          signal(empty);

          consume nextc

} while (TRUE);
```

wait till slot available for consumption

Only producer **OR** consumer can be in critical section

Allow producer **OR** consumer to (re)enter critical section

signal producer that a slot is available to add

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THE READERS-WRITERS PROBLEM

The Readers-Writers problem

- A database is **shared** among several concurrent processes
- Two types of processes
  - Readers
  - Writers

Readers-Writers: Potential for adverse effects

- If *two readers* access shared data simultaneously?
  - No problems
- If a *writer and some other reader* (or writer) access shared data simultaneously?
  - Chaos

Writers must have exclusive access to shared database while writing

- FIRST readers-writers problem:
  - No reader should wait for other readers to finish; simply because a writer is waiting
    - Writers may starve
- SECOND readers-writers problem:
  - If a writer is ready it performs its write ASAP
    - Readers may starve

Solution to the FIRST readers-writers problem

- Variable `int readcount`
  - Tracks how many readers are reading object
- Semaphore **`mutex`** **{1}**
  - Ensure mutual exclusion when `readcount` is accessed
- Semaphore **`wrt`** **{1}**
  1. Mutual exclusion for the writers
  2. First (last) reader that enters (exits) critical section
     - Not used by readers, when **other** readers **are in** their critical section

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The Writer: When a writer signals either a waiting writer or the readers resume

```
do {

        wait(wrt);


     writing is performed


        signal(wrt);



} while (TRUE);
```

When:
writer in critical section
and if n readers waiting

1 reader is queued on **`wrt`**
(n-1) readers queued on **`mutex`**

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The Reader process

```
do {
        wait(mutex);
        readcount++;
        if (readcount ==1) {
          wait(wrt);
        }
        signal(mutex);

        reading is performed

        wait(mutex);
        readcount--;
        if (readcount ==0) {
          signal(wrt);
        }
        signal(mutex);
} while (TRUE);
```

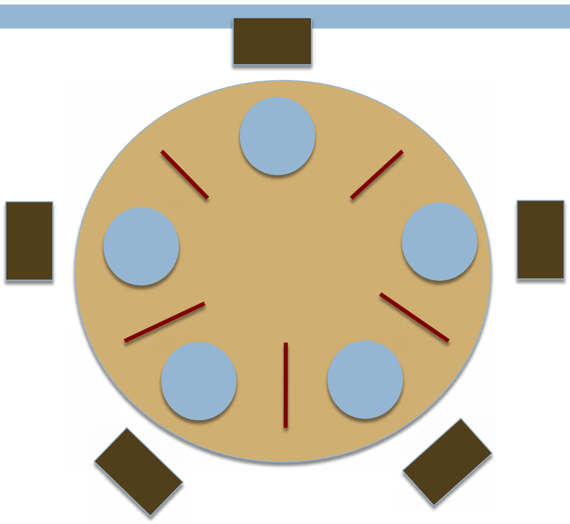
mutex for mutual exclusion to readcount

When:
writer in critical section and if n readers waiting

1 is queued on **wrt**
(n-1) queued on **mutex**

The Dining Philosophers Problem

The situation



The Problem

① Philosopher tries to *pick up two closest* {**LR**} chopsticks

② Pick up only **1 chopstick at a time**
- Cannot pick up a chopstick being used

③ Eat only when you have *both* chopsticks

④ When done; *put down both* the chopsticks

Why is the problem important?

- Represents allocation of **several resources**
  - AMONG **several processes**
- Can this be done so that it is:
  - Deadlock free
  - Starvation free

Dining philosophers: Simple solution

- Each chopstick is a semaphore
  - Grab by executing `wait()`
  - Release by executing `signal()`
- Shared data
  - `semaphore chopstick[5];`
  - All elements are initialized to 1

What if all philosophers get hungry and grab the same {L/R} chopstick?

```
do {

        wait(chopstick[i]);
        wait(chopstick[(i+1)%5]);


          //eat

        signal(chopstick[i]);
        signal(chopstick[(i+1)%5]);


          //think

} while (TRUE);
```

Deadlock:
If all processes access chopstick with same hand

We will look at solution with monitors

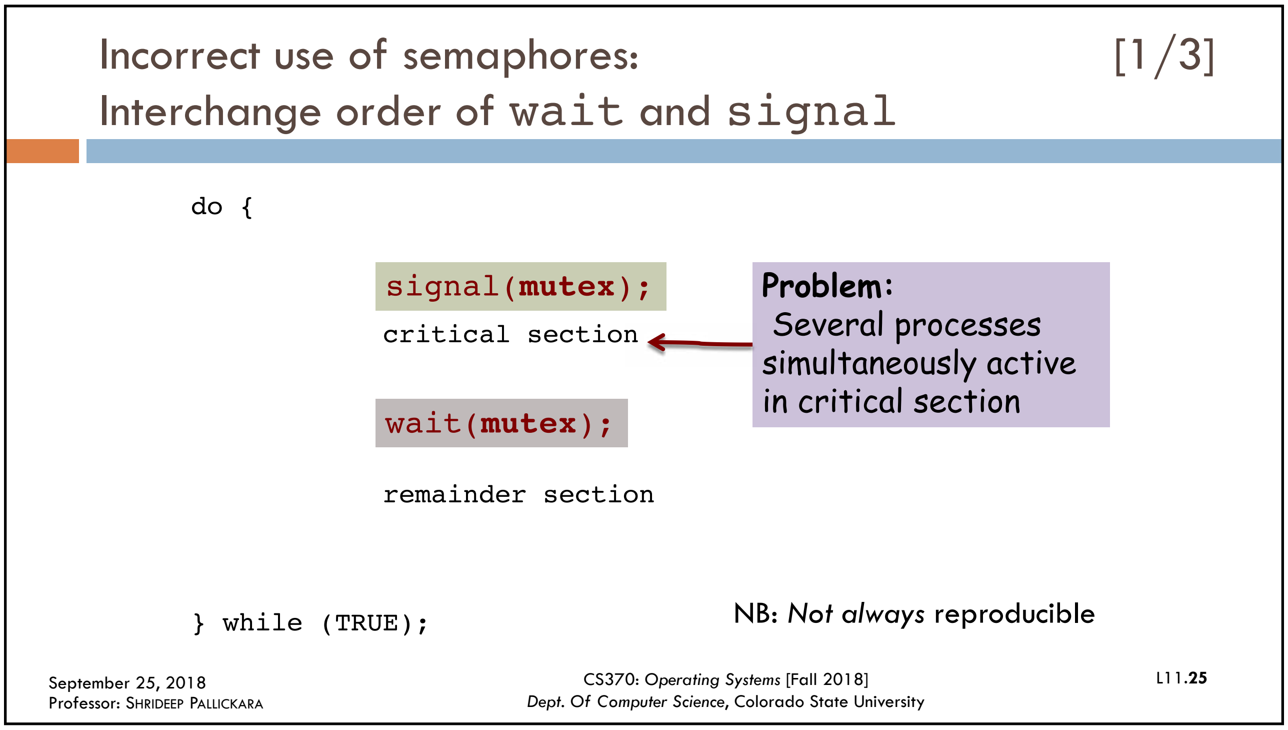
Monitors

Overview of the semaphore solution

- Processes share a semaphore **`mutex`**
  - Initialized to 1
- Each process MUST execute
  - **`wait`** *before entering* critical section
  - **`signal`** *after exiting* critical section

Incorrect use of semaphores can lead to timing errors

- Hard to detect
  - Reveal themselves only during specific execution sequences
- If correct sequence is not observed
  - 2 processes may be in critical section simultaneously
- Problems even if *only one* process is not well behaved

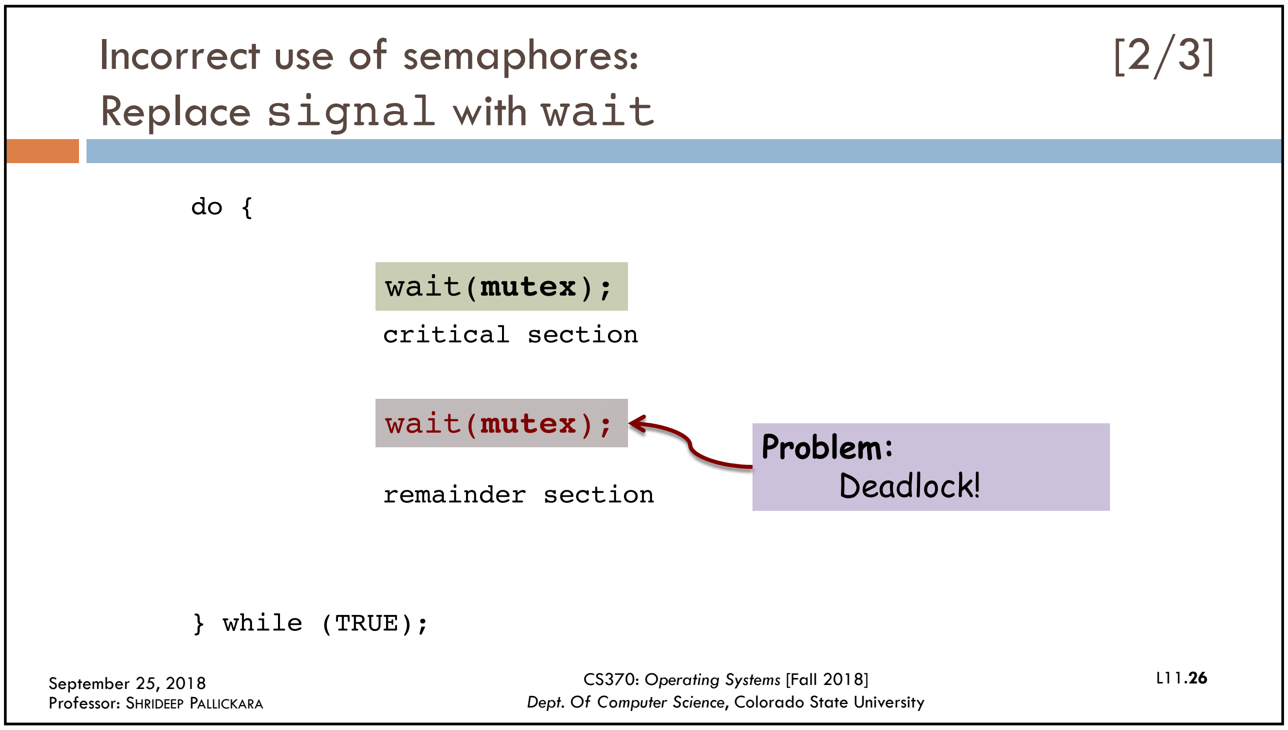


Incorrect use of semaphores: Interchange order of `wait` and `signal` [1/3]

```
do {

        signal(mutex);
        critical section

        wait(mutex);

        remainder section


} while (TRUE);
```

Problem:
Several processes simultaneously active in critical section

NB: *Not always* reproducible



Incorrect use of semaphores: Replace `signal` with `wait` [2/3]

```
do {

        wait(mutex);
        critical section

        wait(mutex);

        remainder section


} while (TRUE);
```

Problem:
Deadlock!

Incorrect use of semaphores: [3/3]
What if you omit `signal` AND/OR `wait`?

```
do {

        wait(mutex);
        critical section

        signal(mutex);

        remainder section


} while (TRUE);
```

Omission: Mutual exclusion violated

Omission: Deadlock!

When programmers use semaphores incorrectly problems arise

- We need a higher-level synchronization construct
  - **Monitor**
- Before we move ahead: Abstract Data Types
  - Encapsulates *private data* with
    - *Public methods* to operate on them

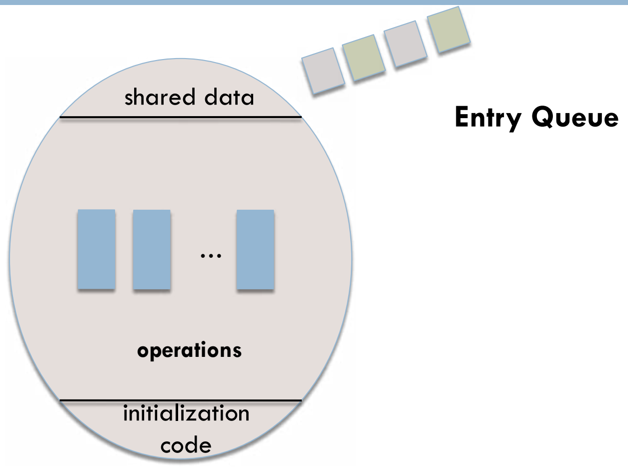
A monitor is an abstract data type

- Mutual exclusion provided **within** the monitor
- Contains:
  - Declaration of variables
    - Defining the instance's state
  - Functions that operate on these variables

Monitor construct ensures that only one process at a time is active within monitor

```
monitor monitor name {

    //shared variable declarations

    function F1(..) {.. .}

    function F2(..) {.. .}

    function Fn(..) {.. .}

    initialization code(..) {.. .}


}
```

Programmer does not code synchronization constraint explicitly



Basic monitor scheme not sufficiently powerful

- Provides an easy way to achieve mutual exclusion
- But … we also need a way for processes to **block** when they cannot proceed

This blocking capability is provided by the condition construct

- The **`condition`** construct
  - `condition x, y;`
- Operations on a **`condition`** variable
  - `wait`: e.g. **`x`**`.wait()`
    - Process invoking this is suspended UNTIL
  - `signal`: e.g. **`x`**`.signal()`
    - Resumes exactly-one suspended process
    - If no process waiting; NO EFFECT on state of **`x`**

Semantics of `wait` and `signal`

- `x.signal()` invoked by process **P**
- **Q** is the suspended process waiting on `x`
- *Signal and wait*: **P** waits for **Q** to leave monitor
- *Signal and continue*: **Q** waits till **P** leaves monitor
- PASCAL: When thread **P** calls signal
  - **P** leaves immediately
  - **Q** immediately resumed

Difference between the `signal()` in semaphores and monitors

- Monitors {condition variables}: Not persistent
  - If a signal is performed and no waiting threads?
    - Signal is simply ignored
  - During subsequent `wait` operations
    - Thread blocks
- Semaphores
  - Signal **increments** semaphore value *even if* there are no waiting threads
    - Future `wait` operations would immediately succeed!

Dining Philosophers Using Monitors

Dining-Philosophers Using Monitors Deadlock-free

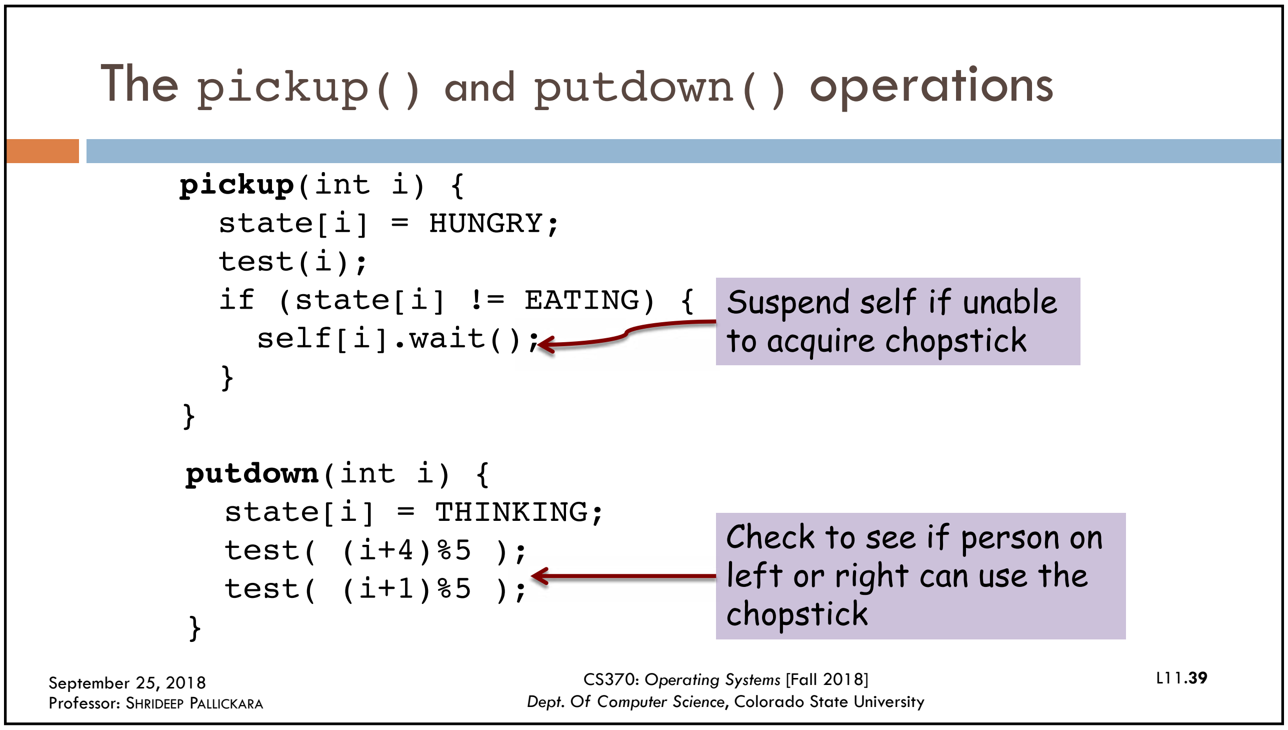
```
enum {THINKING,HUNGRY,EATING} state[5];
```

- `state[i] = EATING` only if
  - `state[(i+4)%5] != EATING &&`
    `state[(i+1)%5] != EATING`
- `condition self[5]`
  - **Delay** self when *HUNGRY but unable* to get chopsticks

Sequence of actions

- Before eating, must invoke `pickup()`
  - May result in suspension of philosopher process
  - After completion of operation, philosopher may eat

```
DiningPhilosophers.pickup(i);
          ...

          eat
          ...
DiningPhilosophers.putdown(i);
```



The `pickup()` and `putdown()` operations

```
pickup(int i) {
  state[i] = HUNGRY;
  test(i);
  if (state[i] != EATING) {
    self[i].wait();
  }
}

putdown(int i) {
  state[i] = THINKING;
  test( (i+4)%5 );
  test( (i+1)%5 );
}
```

Suspend self if unable to acquire chopstick

Check to see if person on left or right can use the chopstick

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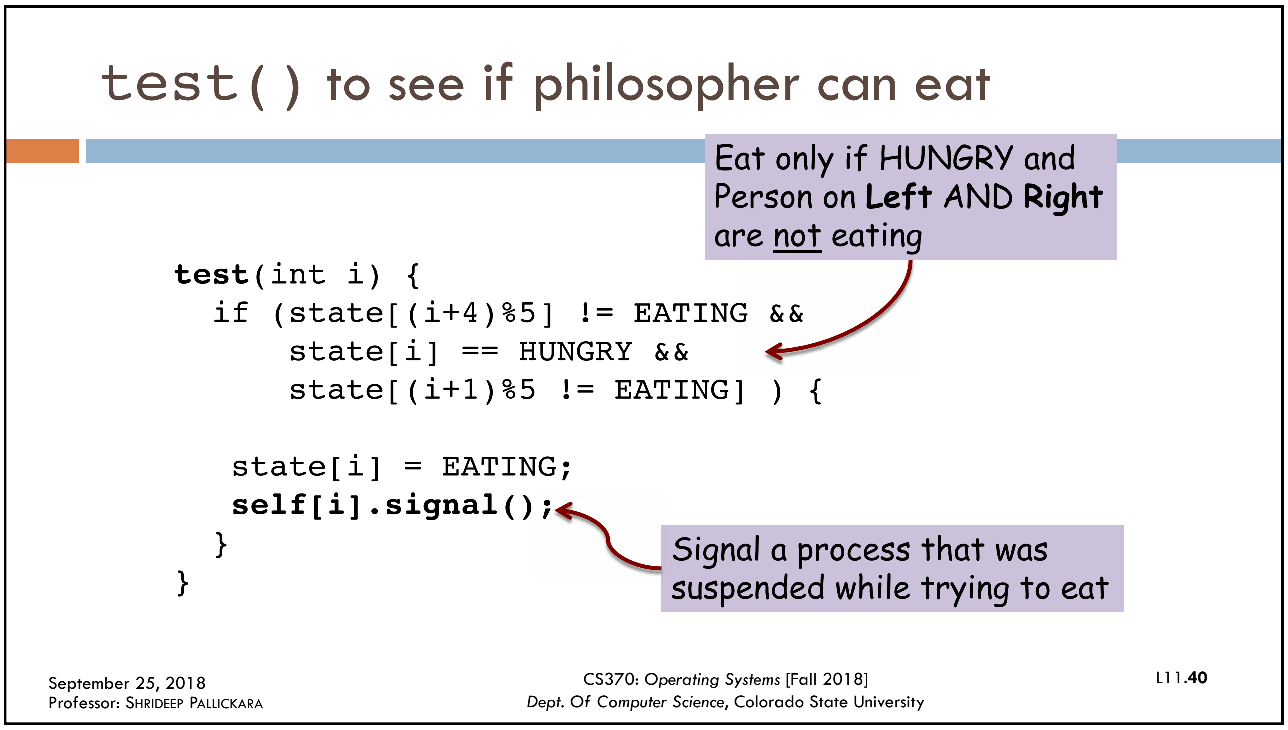

`test()` to see if philosopher can eat

Eat only if HUNGRY and Person on **Left** AND **Right** are not eating

```
test(int i) {
  if (state[(i+4)%5] != EATING &&
      state[i] == HUNGRY &&
      state[(i+1)%5 != EATING] ) {

   state[i] = EATING;
   self[i].signal();
  }
}
```

Signal a process that was suspended while trying to eat

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Possibility of starvation

- Philosopher **`i`** can **starve** if eating periods of philosophers on left and right overlap

- Possible solution
  - Introduce new state: STARVING
  - Chopsticks can be picked up if **no** neighbor is starving
    - Effectively wait for neighbor's neighbor to stop eating
    - REDUCES concurrency!

MIDTERM

Midterm will be for 80 points

- Processes and Inter-Process Communications: 30 points
- Threads: 20 points
- Process Synchronization: 30 points

The contents of this slide set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 5]
- *Andrew S Tanenbaum and Herbert Bos. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620.* [Chapter 2]