



# CS307&CS356: Operating Systems

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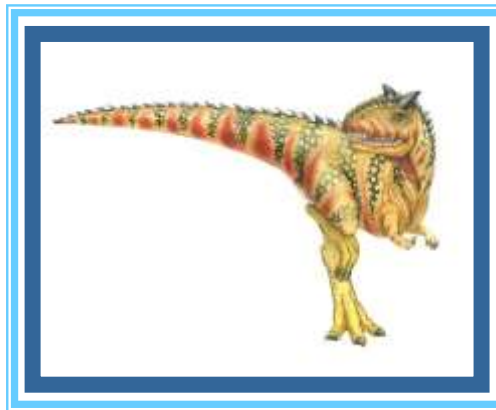
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# Chapter 7: Synchronization Examples

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# Chapter 7: Synchronization Examples

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- Explain the bounded-buffer, readers-writers, and dining philosophers synchronization problems.
- Describe the tools used by Linux and Windows to solve synchronization problems.
- Illustrate how POSIX and Java can be used to solve process synchronization problems.





# Classical Problems of Synchronization

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- Classical problems used to test newly-proposed synchronization schemes
  - Bounded-Buffer Problem
  - Readers and Writers Problem
  - Dining-Philosophers Problem





# Bounded-Buffer Problem

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- $n$  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 in next_produced */  
    ...  
    wait(empty) ;  
    wait(mutex) ;  
  
    ...  
    /* add next produced to the buffer */  
    ...  
    signal(mutex) ;  
    signal(full) ;  
}
```





# Bounded Buffer Problem (Cont.)

- The structure of the consumer process

```
while (true) {  
    wait(full);  
    wait(mutex);  
  
    ...  
    /* remove an item from buffer to  
next_consumed */  
    ...  
    signal(mutex);  
    signal(empty);  
  
    ...  
    /* consume the item in next consumed */  
    ...  
}
```







# Readers-Writers Problem

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- 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
- Several variations of how readers and writers are considered – all involve some form of priorities
- Shared Data
  - Data set
  - Semaphore **rw\_mutex** initialized to 1
  - Semaphore **mutex** initialized to 1
  - Integer **read\_count** initialized to 0





# Readers-Writers Problem (Cont.)

---

- The structure of a writer process

```
while (true) {  
    wait(rw_mutex) ;  
  
    ...  
    /* writing is performed */  
  
    ...  
    signal(rw_mutex) ;  
}
```





# Readers-Writers Problem (Cont.)

- The structure of a reader process

```
while (true){
    wait(mutex) ;
    read_count++;
    if (read_count == 1)
        wait(rw_mutex) ;
    signal(mutex) ;

    ...
    /* reading is performed */
    ...

    wait(mutex) ;
    read_count--;
    if (read_count == 0)
        signal(rw_mutex) ;
    signal(mutex) ;
}
```





# Readers-Writers Problem Variations

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- **First** variation – no reader kept waiting unless writer has permission to use shared object
- **Second** variation – once writer is ready, it performs the write ASAP
- Both may have starvation leading to even more variations
- Problem is solved on some systems by kernel providing reader-writer locks





# Dining-Philosophers Problem



- Philosophers spend their lives alternating thinking and eating
- Don't interact with their neighbors, occasionally try to pick up 2 chopsticks (one at a time) to eat from bowl
  - Need both to eat, then release both when done
- In the case of 5 philosophers
  - Shared data
    - ▶ Bowl of rice (data set)
    - ▶ Semaphore **chopstick** [5] initialized to 1





# Dining-Philosophers Problem Algorithm

- Semaphore Solution
- The structure of Philosopher *i*:

```
while (true){  
    wait (chopstick[i] );  
    wait (chopStick[ (i + 1) % 5] );  
  
    /* eat for awhile */  
  
    signal (chopstick[i] );  
    signal (chopstick[ (i + 1) % 5] );  
  
    /* think for awhile */  
  
}
```

- What is the problem with this algorithm?





# Monitor Solution to Dining Philosophers

```
monitor DiningPhilosophers
{
    enum { THINKING; HUNGRY, EATING} state [5] ;
    condition self [5];

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

    void putdown (int i) {
        state[i] = THINKING;
        // test left and right neighbors
        test((i + 4) % 5);
        test((i + 1) % 5);
    }
}
```





# Solution to Dining Philosophers (Cont.)

---

```
void test (int i) {  
    if ((state[(i + 4) % 5] != EATING) &&  
        (state[i] == HUNGRY) &&  
        (state[(i + 1) % 5] != EATING) ) {  
        state[i] = EATING ;  
        self[i].signal () ;  
    }  
}
```

```
    initialization_code() {  
        for (int i = 0; i < 5; i++)  
            state[i] = THINKING;  
    }  
}
```







# Solution to Dining Philosophers (Cont.)

- Each philosopher  $i$  invokes the operations **pickup()** and **putdown()** in the following sequence:

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

```
/** EAT **/
```

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

- No deadlock, but starvation is possible





# Kernel Synchronization - Windows

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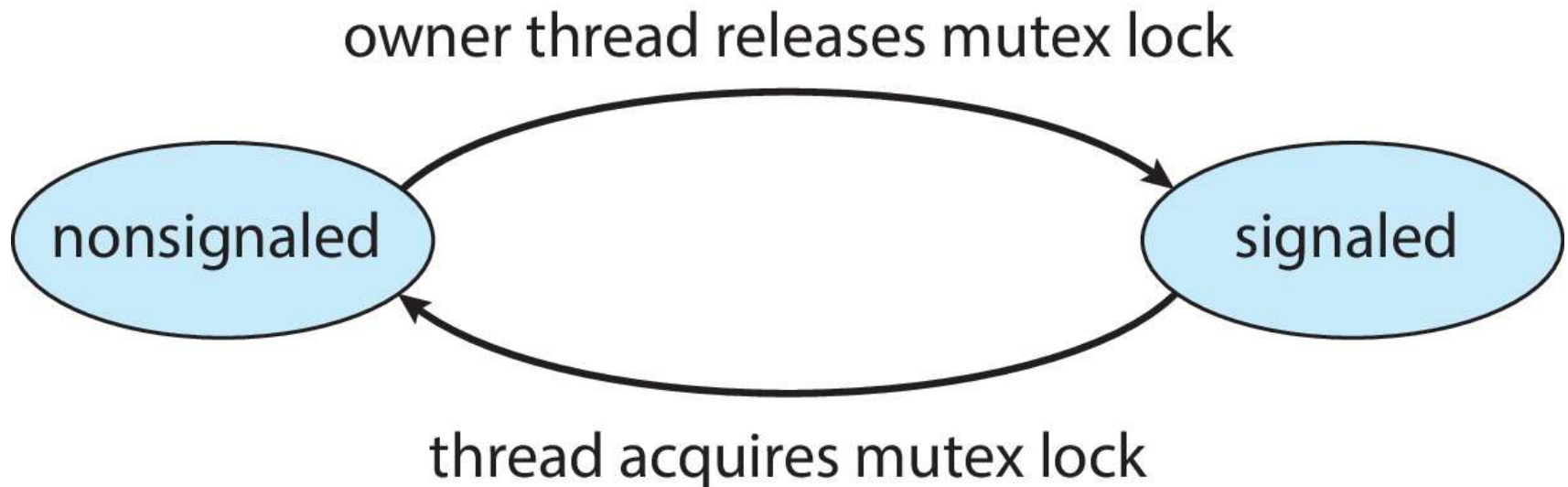
- Uses interrupt masks to protect access to global resources on uniprocessor systems
- Uses **spinlocks** on multiprocessor systems
  - Spinlocking-thread will never be preempted
- Also provides **dispatcher objects** user-land which may act mutexes, semaphores, events, and timers
  - **Events**
    - ▶ An event acts much like a condition variable
  - Timers notify one or more thread when time expired
  - Dispatcher objects either **signaled-state** (object available) or **non-signaled state** (thread will block)





# Kernel Synchronization - Windows

- Mutex dispatcher object





# Linux Synchronization

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- Linux:
  - Prior to kernel Version 2.6, disables interrupts to implement short critical sections
  - Version 2.6 and later, fully preemptive
- Linux provides:
  - Semaphores
  - atomic integers
  - spinlocks
  - reader-writer versions of both
- On single-CPU system, spinlocks replaced by enabling and disabling kernel preemption





# Linux Synchronization

- Atomic variables

`atomic_t` is the type for atomic integer

- Consider the variables

```
atomic_t counter;  
int value;
```

<i>Atomic Operation</i>	<i>Effect</i>
<code>atomic_set(&amp;counter, 5);</code>	<code>counter = 5</code>
<code>atomic_add(10, &amp;counter);</code>	<code>counter = counter + 10</code>
<code>atomic_sub(4, &amp;counter);</code>	<code>counter = counter - 4</code>
<code>atomic_inc(&amp;counter);</code>	<code>counter = counter + 1</code>
<code>value = atomic_read(&amp;counter);</code>	<code>value = 12</code>





# POSIX Synchronization

---

- POSIX API provides
  - mutex locks
  - semaphores
  - condition variable
- Widely used on UNIX, Linux, and macOS





# POSIX Mutex Locks

---

## ■ Creating and initializing the lock

```
#include <pthread.h>

pthread_mutex_t mutex;

/* create and initialize the mutex lock */
pthread_mutex_init(&mutex, NULL);
```

## ■ Acquiring and releasing the lock

```
/* acquire the mutex lock */
pthread_mutex_lock(&mutex);

/* critical section */

/* release the mutex lock */
pthread_mutex_unlock(&mutex);
```





# POSIX Semaphores

---

- POSIX provides two versions – **named** and **unnamed**.
- Named semaphores can be used by unrelated processes, unnamed cannot.







# POSIX Named Semaphores

---

- Creating an initializing the semaphore:

```
#include <semaphore.h>
sem_t *sem;
```

```
/* Create the semaphore and initialize it to 1 */
sem = sem_open("SEM", O_CREAT, 0666, 1);
```

- Another process can access the semaphore by referring to its name **SEM**.
- Acquiring and releasing the semaphore:

```
/* acquire the semaphore */
sem_wait(sem);
```

```
/* critical section */
```

```
/* release the semaphore */
sem_post(sem);
```





# POSIX Unnamed Semaphores

---

- Creating and initializing the semaphore:

```
#include <semaphore.h>
sem_t sem;

/* Create the semaphore and initialize it to 1 */
sem_init(&sem, 0, 1);
```

- Acquiring and releasing the semaphore:

```
/* acquire the semaphore */
sem_wait(&sem);

/* critical section */

/* release the semaphore */
sem_post(&sem);
```





# POSIX Condition Variables

---

- Since POSIX is typically used in C/C++ and these languages do not provide a monitor, POSIX condition variables are associated with a POSIX mutex lock to provide mutual exclusion: Creating and initializing the condition variable:

```
pthread_mutex_t mutex;  
pthread_cond_t cond_var;
```

```
pthread_mutex_init(&mutex, NULL);  
pthread_cond_init(&cond_var, NULL);
```





# POSIX Condition Variables

- Thread waiting for the condition  $a == b$  to become true:

```
pthread_mutex_lock(&mutex);  
while (a != b)  
    pthread_cond_wait(&cond_var, &mutex);  
  
pthread_mutex_unlock(&mutex);
```

- Thread signaling another thread waiting on the condition variable:

```
pthread_mutex_lock(&mutex);  
a = b;  
pthread_cond_signal(&cond_var);  
pthread_mutex_unlock(&mutex);
```

?





# Java Synchronization

---

- Java provides rich set of synchronization features:
  - Java monitors
  - Reentrant locks
  - Semaphores
  - Condition variables





# Java Monitors

---

- Every Java object has associated with it a single lock.
- If a method is declared as **synchronized**, a calling thread must own the lock for the object.
- If the lock is owned by another thread, the calling thread must wait for the lock until it is released.
- Locks are released when the owning thread exits the **synchronized** method.





# Bounded Buffer – Java Synchronization

---

```
public class BoundedBuffer<E>
{
    private static final int BUFFER_SIZE = 5;

    private int count, in, out;
    private E[] buffer;

    public BoundedBuffer() {
        count = 0;
        in = 0;
        out = 0;
        buffer = (E[]) new Object[BUFFER_SIZE];
    }

    /* Producers call this method */
    public synchronized void insert(E item) {
        /* See Figure 7.11 */
    }

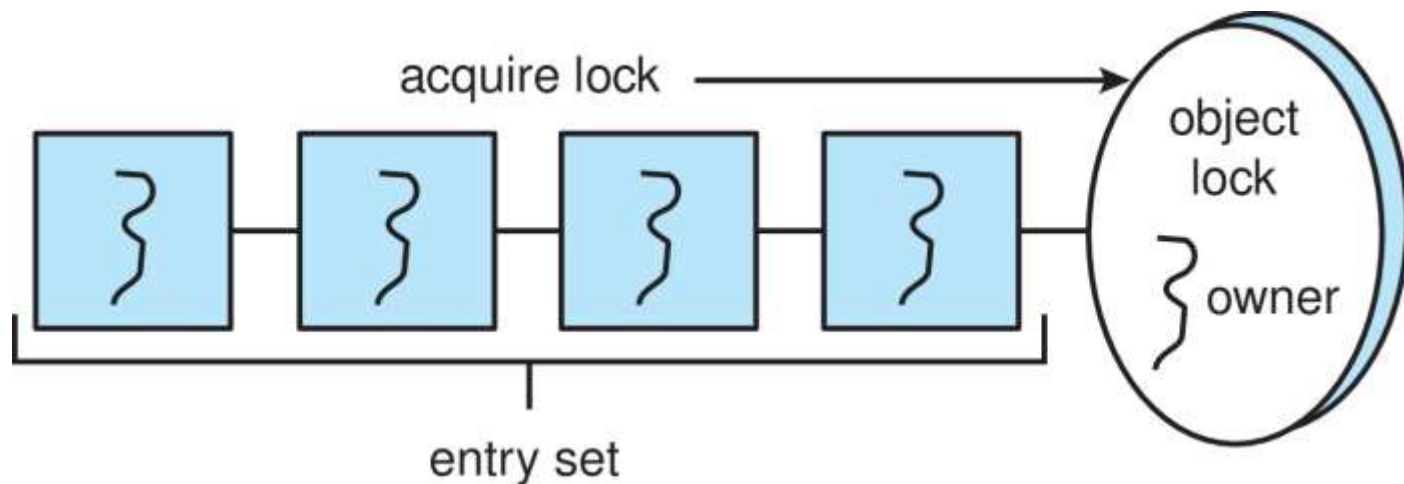
    /* Consumers call this method */
    public synchronized E remove() {
        /* See Figure 7.11 */
    }
}
```





# Java Synchronization

- A thread that tries to acquire an unavailable lock is placed in the object's **entry set**:

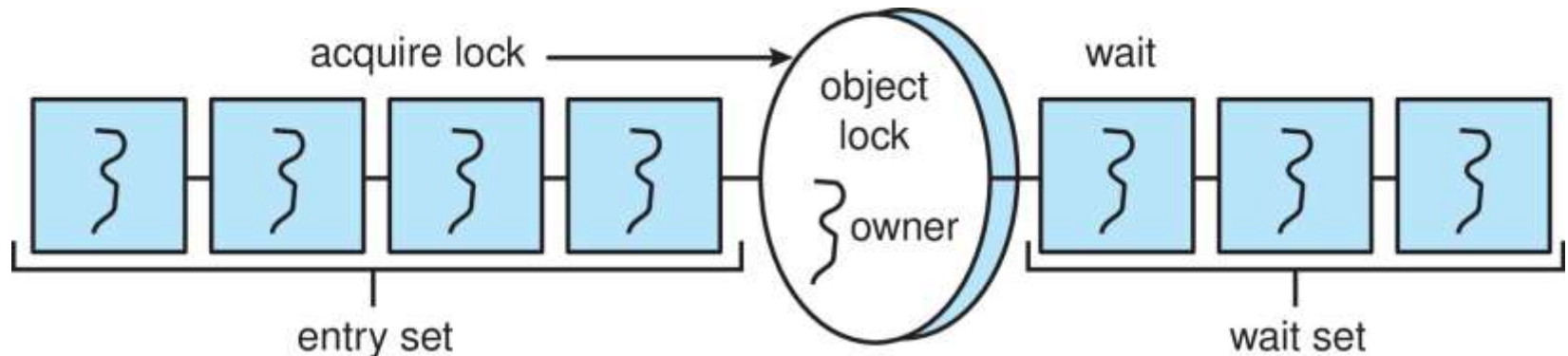






# Java Synchronization

- Similarly, each object also has a **wait set**.
- When a thread calls **wait()**:
  1. It releases the lock for the object
  2. The state of the thread is set to blocked
  3. The thread is placed in the wait set for the object





# Java Synchronization

---

- A thread typically calls `wait()` when it is waiting for a condition to become true.
- How does a thread get notified?
- When a thread calls `notify()`:
  1. An arbitrary thread `T` is selected from the wait set
  2. `T` is moved from the wait set to the entry set
  3. Set the state of `T` from blocked to runnable.
- `T` can now compete for the lock to check if the condition it was waiting for is now true.





# Bounded Buffer – Java Synchronization

---

```
/* Producers call this method */
public synchronized void insert(E item) {
    while (count == BUFFER_SIZE) {
        try {
            wait();
        }
        catch (InterruptedException ie) { }
    }

    buffer[in] = item;
    in = (in + 1) % BUFFER_SIZE;
    count++;

    notify();
}
```





# Bounded Buffer – Java Synchronization

---

```
/* Consumers call this method */
public synchronized E remove() {
    E item;

    while (count == 0) {
        try {
            wait();
        }
        catch (InterruptedException ie) { }
    }

    item = buffer[out];
    out = (out + 1) % BUFFER_SIZE;
    count--;

    notify();

    return item;
}
```





# Java Reentrant Locks

---

- Similar to mutex locks
- The **finally** clause ensures the lock will be released in case an exception occurs in the **try** block.

```
Lock key = new ReentrantLock();

key.lock();
try {
    /* critical section */
}
finally {
    key.unlock();
}
```





# Java Semaphores

---

## ■ Constructor:

```
Semaphore(int value);
```

## ■ Usage:

```
Semaphore sem = new Semaphore(1);

try {
    sem.acquire();
    /* critical section */
}
catch (InterruptedException ie) { }
finally {
    sem.release();
}
```





# Java Condition Variables

---

- Condition variables are associated with an **ReentrantLock**.
- Creating a condition variable using **newCondition()** method of **ReentrantLock**:

```
Lock key = new ReentrantLock();  
Condition condVar = key.newCondition();
```

- A thread waits by calling the **await()** method, and signals by calling the **signal()** method.





# Java Condition Variables

---

- Example:
- Five threads numbered 0 .. 4
- Shared variable `turn` indicating which thread's turn it is.
- Thread calls `doWork()` when it wishes to do some work. (But it may only do work if it is their turn.
- If not their turn, wait
- If their turn, do some work for awhile .....
- When completed, notify the thread whose turn is next.
- Necessary data structures:

```
Lock lock = new ReentrantLock();  
Condition[] condVars = new Condition[5];  
  
for (int i = 0; i < 5; i++)  
    condVars[i] = lock.newCondition();
```







# Java Condition Variables

```
/* threadNumber is the thread that wishes to do some work */
public void doWork(int threadNumber)
{
    lock.lock();

    try {
        /**
         * If it's not my turn, then wait
         * until I'm signaled.
         */
        if (threadNumber != turn)
            condVars[threadNumber].await();

        /**
         * Do some work for awhile ...
         */

        /**
         * Now signal to the next thread.
         */
        turn = (turn + 1) % 5;
        condVars[turn].signal();
    }
    catch (InterruptedException ie) { }
    finally {
        lock.unlock();
    }
}
```





# Alternative Approaches

---

- Transactional Memory
- OpenMP message passing
- Functional Programming Languages





# Transactional Memory

- Consider a function `update()` that must be called atomically. One option is to use mutex locks:

```
void update ()
{
    acquire();

    /* modify shared data */

    release();
}
```

- A **memory transaction** is a sequence of read-write operations to memory that are performed atomically. A transaction can be completed by adding `atomic{S}` which ensure statements in `S` are executed atomically:

```
void update ()
{
    atomic {
        /* modify shared data */
    }
}
```





# OpenMP

- OpenMP is a set of compiler directives and API that support parallel programming.

```
void update(int value)
{
    #pragma omp critical
    {
        count += value
    }
}
```

The code contained within the `#pragma omp critical` directive is treated as a critical section and performed atomically.





# Functional Programming Languages

---

- Functional programming languages offer a different paradigm than procedural languages in that they do not maintain state.
- Variables are treated as immutable and cannot change state once they have been assigned a value.
- There is increasing interest in functional languages such as Erlang and Scala for their approach in handling data races.





# Homework

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- Exercises at the end of Chapter 7 (OS book)
  - 7.8, 7.11, 7.16



# End of Chapter 7

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