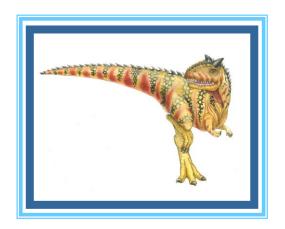
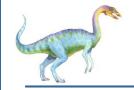
Chapter 7: Synchronization Examples





Outline

- Explain the bounded-buffer synchronization problem
- Explain the readers-writers synchronization problem
- Explain 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

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





Bounded-Buffer Problem

- 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

- 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





Readers-Writers Problem (Cont.)

- 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





Readers-Writers Problem (Cont.)

The structure of a reader process

```
while (true) {
        wait(mutex);
        read count++;
        if (read count == 1) /* first reader */
             wait(rw mutex);
             signal(mutex);
        /* reading is performed */
        wait(mutex);
        read count--;
        if (read_count == 0) /* last reader */
                signal(rw mutex);
        signal(mutex);
```





Readers-Writers Problem Variations

- The solution in previous slide can result in a situation where a writer process never writes. It is referred to as the "First reader-writer" problem.
- The "Second reader-writer" problem is a variation the first reader-writer problem that state:
 - Once a writer is ready to write, no "newly arrived reader" is allowed to read.
- Both the first and second may result in starvation. leading to even more variations
- Problem is solved on some systems by kernel providing reader-writer locks





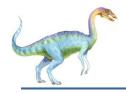
Dining-Philosophers Problem

N philosophers' sit at a round table with a bowel of rice in the middle.



- They spend their lives alternating thinking and eating.
- They do not 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, the shared data
 - Bowl of rice (data set)
 - Semaphore chopstick [5] initialized to 1





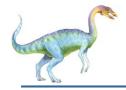
Dining-Philosophers Problem Algorithm

- 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?

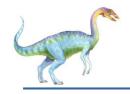




Monitor Solution to Dining Philosophers

```
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

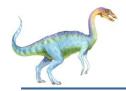




Kernel Synchronization - Windows

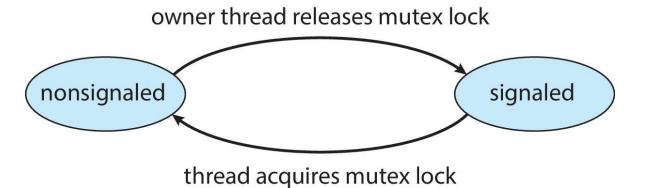
- Uses interrupt masks to protect access to global resources on uniprocessor systems
- Uses spinlocks on multiprocessor systems
 - Spinlocking-thread will never be preempted
- Also provides dispatcher objects user-land which may act mutexes, semaphores, events, and timers
 - Events
 - An event acts much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





Kernel Synchronization - Windows

Mutex dispatcher object





Linux Synchronization

- 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;
```

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





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 an 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 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.





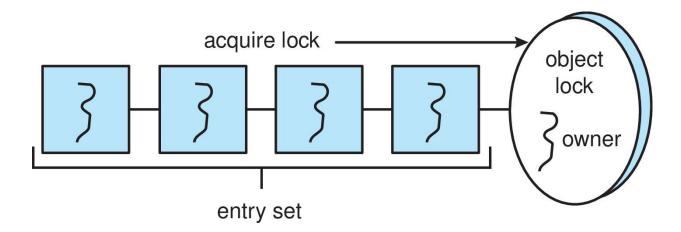
Bounded Buffer – Java Synchronization

```
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 */
```





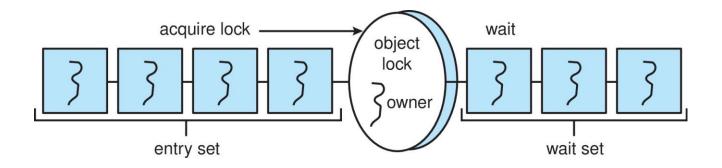
A thread that tries to acquire an unavailable lock is placed in the object's entry set:







- 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







- 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();</pre>
```





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
- Functional Programming Languages





Transactional Memory

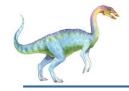
Consider a function update() that must be called atomically.
 One option is to use mutex locks:

```
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.



End of Chapter 7

