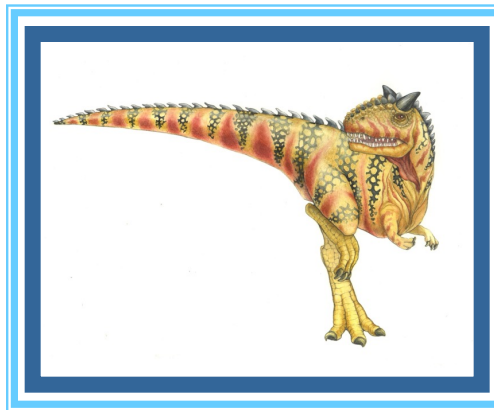


Chapter 7: Synchronization Examples





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.





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

- 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

- 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

```
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) /* 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

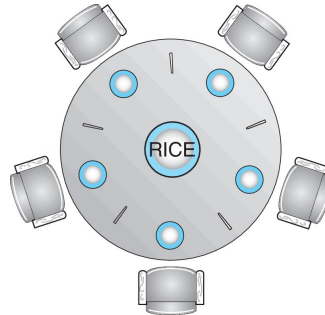
- The solution in previous slide can result in a situation where a writer process never writes. It is referred to as the “First reader-writer” problem.
- The “Second reader-writer” problem is a variation the first reader-writer problem that state:
 - Once a writer is ready to write, no “newly arrived 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 bowl 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 **non-signaled state** (thread will block)





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;
```

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





POSIX Synchronization

- POSIX (Portable Operating System Interface) is a set of standard operating system interfaces based on the Unix operating system.
- 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

- Condition variables are synchronization primitives that enable threads to wait until a particular condition occurs. Condition variables are user-mode objects that cannot be shared across processes. Condition variables enable threads to atomically release a lock and enter the sleeping state
- 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





Alternative Approaches

- Transactional Memory
- OpenMP





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.



End of Chapter 7

