Synchronization

CS 416: Operating Systems Design, Spring 2011

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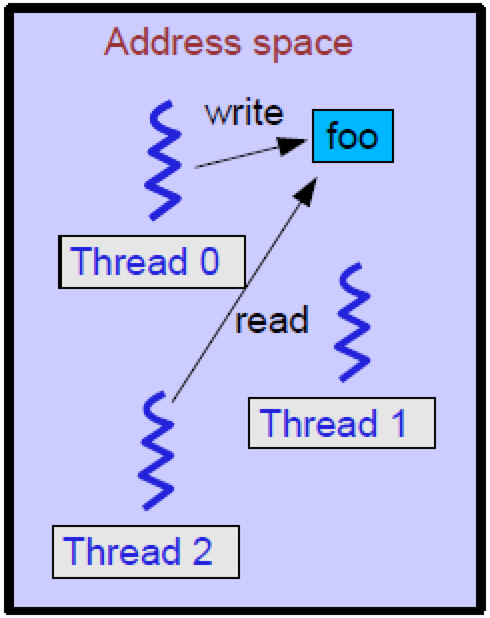
Synchronization

Basic problem:

Threads are concurrently accessing shared variables

The access should be controlled for predictable result.



Solution: Need a mechanism to control the access

Low-Level Mechanism

- Locks

Higher Level Mechanism

- Semaphores
- Mutexes
- Condition Variables
- Monitors

Higher-Level Synchronization primitives

Locks are useful for mutual exclusion. But programs have different requirements.

Examples:

- Say we had a shared variable where any number of threads could **read** but only one thread could **write**.
- How would you do this with locks ?

```
Reader() {
  lock.acquire();
  mycopy = shared_var;
  lock.release();
  return mycopy;
}
```

```
Writer() {
  lock.acquire();
  shared_var = NEW_VALUE;
  lock.release();
}
```

- What's wrong with this code ?

Semaphores

Semaphore

- Higher level construct
- Shared Counter

Operations on Semaphores:

P() or wait() or down()

- Atomically wait for semaphore value to become > 0, then decrement it

V() or signal() or up()

- Atomically increments semaphore by 1

Semaphore Example

Semaphores can be used to implement Mutual Exclusion

```
Semaphore my_semaphore = 1 // Initialize to nonzero
int withdraw(account, amount) {
    P(my_semaphore)
    balance = get_balance()
    balance = balance - amount;          CRITICAL SECTION
    put_balance(balance,account);
    V(my_semaphore)
}
```

A semaphore where the counter value is only 0 or 1 is called a binary semaphore. A Binary Semaphore similar to **lock**

Simple Semaphore Implementation

```
struct semaphore {
    int val;
    thread_list waiting;  // List of threads waiting for semaphore
}

P(semaphore Sem):    // Wait until > 0 then decrement
    while (Sem.val <= 0) {
        add this thread to Sem.waiting;
        block(this thread);  // What does this do??
    }
    Sem.val = Sem.val -1;
    return;

V(semaphore Sem):    // Increment value and wake up next thread
    Sem.val = Sem.val + 1;
    if (Sem.waiting is nonempty) {
        remove a thread T from Sem.waiting;
        wakeup(T);
    }
```

Why is this a while loop and not just an if statement?

What is wrong with the above code ?

Simple Semaphore Implementation

```
struct semaphore {
    int val;
    thread_list waiting;  // List of threads waiting for semaphore
}

P(semaphore Sem):    // Wait until > 0 then decrement
    while (Sem.val <= 0) {
        add this thread to Sem.waiting;
        block(this thread);  // What does this do??
    }
    Sem.val = Sem.val -1;
    return;

V(semaphore Sem):    // Increment value and wake up next thread
    Sem.val = Sem.val + 1;
    if (Sem.waiting is nonempty) {
        remove a thread T from Sem.waiting;
        wakeup(T);
    }
```

P() and V() must be atomic actions!

Semaphore Implementation

How do we ensure that the semaphore operations are atomic?

This is similar to Lock:

One Approach: Make them *System Calls* and ensure only one P() or V() operation can be executed by any process at a time

- This effectively puts a lock around the P() and V() operations
- Since system calls are executed in privileged mode, interrupts could be disabled to preserve atomicity

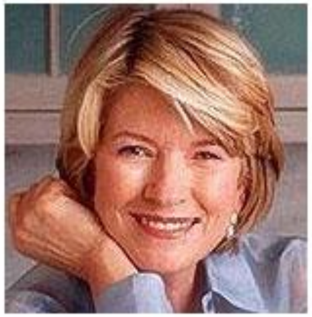
Second Approach: Use hardware support:

- Say the CPU had atomic P() and V() operations

Why are semaphores any better than Lock ?

- A binary semaphore is basically a lock
- The real value of Semaphores becomes apparent when the counter can be initialized to a value other than 0 or 1
- Say we initialize a semaphore's value to 50
  - What does this mean about P() and V() operations?

The Producer/Consumer Problem



Producer pushes items into a buffer

Consumer pulls items from the buffer

Producer needs to wait when buffer is full

Consumer needs to wait when the buffer is empty

One Implementation

`int count=0 -> Shared Variable`

```
Producer(){
    int item;
    while(TRUE) {
          item = produce();
          if(count==N) sleep();
          insert_item(item);
          count = count + 1;
          if(count == 1)
                    wakeup(consumer);
    }
}
```

Needs to be atomic

```
Consumer(){
    int item;
    while(TRUE)    {
          if(count==0)
                    sleep();
          item = remove_item();
          count = count-1;
          if(count == N-1)
                    wakeup(producer)
          consume(item);
    }
}
```

What is the problem with this code ?

Context Switching ? – Lost wakeup problem !

A Fix using Semaphore

```
Semaphore mutex=1;
Semaphore empty=N;
Semaphore full=0;
```

```
Producer {
   int item;
   while(TRUE) {
         item=produce();
         P(empty);
         p(mutex);
         insert_item(item);
         v(mutex);
         v(full);
   }
}
```

```
Consumer {
   while(TRUE){
         p(full);
         p(mutex);
         item = remove_item();
         v(mutex);
         v(empty);
         consume(item);
   }
}
```

Does the order matter ?

Readers/Writers Problem

- Want any number of threads to read simultaneously
- But only one thread should be able to write to a object at a time

```
semaphore wrt = 1
int readcount = 0
```

```
writer() {
P(wrt)
do_write()
V(wrt)
}
```

```
reader(){
        readcount ++;
        if(readcount == 1)
                p(wrt);
        }

        do_read();

        readcount --;
        if(readcount ==0 )
                V(wrt);
```

Where is the race condition ?

Readers/Writers Fixed

```
semaphore mutex = 1
semaphore wrt = 1
int readcount = 0
```

```
writer() {
P(wrt)
do_write()
V(wrt)
}
```

```
reader(){
        p(mutex)
        readcount ++;
        if(readcount == 1)
                p(wrt);
        }
        v(mutex)

        do_read();

        p(mutex)
        readcount --;
        if(readcount ==0 )
                V(wrt);
        v(mutex)
}
```

This is also called :
First Readers Writers Problem

- Can lead to ***writer starvation***

Second Readers/Writers Problem

-No writer should starve (The readers could starve).

-If a writer is waiting, no new reader can enter the shared memory

```
semaphore mutex = 1
semaphore wrt = 1, read = 1
semaphore mutex2 = 1, mutex3 =1
int readcount = 0
int writecount = 0
```

```
writer() {
P(mutex2)
writecount ++
If(writecount == 1)
         p(read)
V(mutex2)
P(wrt)
do_write()
V(wrt)
P(mutex2)
writecount—
If(writecount==0)
         v(read)
}
```

Only when all writers finish, the writer releases the read lock

```
reader(){
p(mutex3)
  p(read)
    p(mutex)
         readcount ++;
         if(readcount == 1)
                p(wrt);
         }
    v(mutex)
  v(read)
V(mutex3)

do_read();

p(mutex)
  readcount --;
  if(readcount ==0 )
     V(wrt);
 v(mutex)
}
```

Issues with Semaphore

Unlike locks, P() and V() do not have to be paired

Therefore, it is a lot easier to get into trouble with semaphore

- User needs to ensure its correctness

Wouldn't it be nice if we had a clean, well-defined language support for synchronization..

- Java does !

Java Synchronization Support : Mutexes

Every Java object can be used as a mutex

```
Object foo;
synchronized (foo) {
  /* Do some stuff with 'foo' locked... */
  foo.counter++;
}
```

Compiler ensures that the lock is released before exiting the synchronized block – Even if there is an ***exception***.

```
try {
  synchronized(foo) {
     if (foo.doSomething() == false) {
       throw new Exception("Bad!!");
     }
  }
catch (Exception e) {
  /* Lock was released before getting here! */
  System.err.println("Something bad happened!");
}
```

Java Condition Variables

A ***conditional variable*** represents some condition that a thread can:

- ***Wait on,*** until the condition occurs
- ***Notify,*** other waiting threads that the condition has occurred

Three operations on Condition Variables

- wait(): Block on the condition variable
- notify(): Wake up one thread waiting on a CV
- notifyAll(): Wake up all threads waiting on a CV

Revisiting Producer/Consumer

int count=0 -> Shared Variable

```
Producer(){
    int item;
    while(TRUE) {
        item = produce();
        lock->acquire()
        if(count==N) sleep();
        insert_item(item);
        count = count + 1;
        if(count == 1)
                wakeup(consumer);
        lock->release()

    }
}
```

```
Consumer(){
    int item;
    while(TRUE)    {
        lock->acquire()
        if(count==0)
                sleep();
        item = remove_item();
        count = count-1;
        if(count == N-1)
                wakeup(producer)
        lock->release()

        consume(item);
    }
}
```

Whats wrong with this?

Producer/Consumer Fix-1

`int count=0 -> Shared Variable`

```
Producer(){
    int item;
    while(TRUE) {
        item = produce();
        lock->acquire()
        if(count==N){
        lock->release()
        sleep();
        }
        insert_item(item);
        count = count + 1;
        if(count == 1)
            wakeup(consumer);
        lock->release()
    }
}
```

```
Consumer(){
    int item;
    while(TRUE)   {
        lock->acquire()
        if(count==0){
        lock->release()
        sleep();
        }
        item = remove_item();
        count = count-1;
        if(count == N-1)
            wakeup(producer)
        lock->release()
        consume(item);
    }
}
```

Whats wrong with this?