Synchronization Part 1

CSE 410, Spring 2004
Computer Systems

http://www.cs.washington.edu/education/courses/410/04sp/
Readings and References

• Reading
  » Chapter 7, *Operating System Concepts*, Silberschatz, Galvin, and Gagne. Read the following sections: 7.1, 7.2 (skim subsections), 7.3

• Other References
  » Sections 5.8.3, Atomicity and Atomic Changes, 5.8.4, Critical Regions with Interrupts Enabled, *See MIPS Run*, Dominic Sweetman
## Too Much Milk

<table>
<thead>
<tr>
<th>Time</th>
<th>Task</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>3:00</td>
<td>Look in fridge; no milk</td>
<td>Look in fridge; no milk</td>
</tr>
<tr>
<td>3:05</td>
<td>Leave for store</td>
<td>Leave for store</td>
</tr>
<tr>
<td>3:10</td>
<td>Arrive at store</td>
<td>Arrive at store</td>
</tr>
<tr>
<td>3:15</td>
<td>Buy milk</td>
<td>Buy milk</td>
</tr>
<tr>
<td>3:20</td>
<td>Arrive home; put milk away</td>
<td>Arrive home; put milk away</td>
</tr>
<tr>
<td>3:25</td>
<td></td>
<td>Buy milk</td>
</tr>
<tr>
<td>3:30</td>
<td></td>
<td>Arrive home; put milk away</td>
</tr>
</tbody>
</table>

**Oh no, Mr. Bill, too much milk!**
Modeling the Problem

- Model you and your roommate as threads
- “Looking in the fridge” and “putting away milk” are reading/writing a variable

**YOU:**

```c
// look in fridge
if( milkAmount == 0 ) {
    // buy milk
    milkAmount++;
}
```

**YOUR ROOMMATE:**

```c
// look in fridge
if( milkAmount == 0 ) {
    // buy milk
    milkAmount++;
}
```
Correctness Properties

• Decomposed into safety and liveness
  » safety
    • the program never does anything bad
  » liveness
    • the program eventually does something good

• Although easy to state, these properties are not always easy to meet
Synchronization Definitions

• Synchronization
  » coordinated access by more than one thread to shared state variables

• Mutual Exclusion
  » only one thread does a particular thing at a time. One thread doing it excludes all others.

• Critical Section
  » only one thread executes in a critical section at once
Locks

• A lock provides mutual exclusion
  » Only one thread can hold the lock at a time
  » A lock is also called a mutex (for mutual exclusion)

• Thread must *acquire the lock* before entering a critical section of code

• Thread *releases the lock* after it leaves the critical section
Too Much Milk: A Solution

**YOU:**

```cpp
MilkLock->Acquire();
if( milkAmount == 0 ){
    // buy milk
    milkAmount++;
}
MilkLock->Release();
```

**YOUR ROOMMATE:**

```cpp
MilkLock->Acquire();
delay
if( milkAmount == 0 ){
    // buy milk
    milkAmount++;
}
MilkLock->Release();
```
A context switch can happen *at any time*
» very simple acquire/release functions don’t work
» in this case, both threads think they set lockInUse

```cpp
Lock::Acquire() {
    while( lockInUse ) {}
    lockInUse = true;
}

Lock::Release() {
    lockInUse = false;
}
```

```cpp
Lock::Acquire() {
    while( lockInUse ) {}
    lockInUse = true;
}
```
Disable interrupts during critical section

• disable interrupts to prevent a context switch
  » simple but imperfect solution

  Lock::Acquire() {
    disable interrupts;
  }

  Lock::Release() {
    enable interrupts;
  }

• Kernel can’t get control when interrupts disabled
• Critical sections may be long
  » turning off interrupts for a long time is very bad
• Turning off interrupts is difficult and costly in multiprocessor systems
Disable Interrupts with flag

Only disable interrupts when updating a lock flag

initialize value = FREE;

Lock::Acquire() {
disable interrupts;
while(value != FREE) {
    enable interrupts;
    disable interrupts;
}
value = BUSY;
enable interrupts
}

Lock::Release() {
disable interrupts;
value = FREE;
enable interrupts;
}
Atomic Operations

• An *atomic operation* is an operation that cannot be interrupted
• On a multiprocessor disabling interrupts doesn’t work well
• Modern processors provide **atomic read-modify-write** instruction or equivalent
• These instructions allow locks to be implemented on a multiprocessor
Examples of Atomic Instructions

• **Test and set** (many architectures)
  » sets a memory location to 1 and returns the previous value
  » if result is 1, lock was already taken, keep trying
  » if result is 0, you are the one who set it so you’ve got the lock

• **Exchange** (x86)
  » swaps value between register and memory

• **Compare & swap** (68000)
  
  ```
  read location value
  if location value equals comparison value
    store update value, set flag true
  else
    set flag false
  ```
Quasi-atomic for load/store ISA

• **Remember our MIPS pipeline**
  » only one memory stage per instruction
  » thus, can’t do atomic “read, modify, write” directly

• **Load linked and store conditional**
  » read value in one instruction (LL—load linked) and remember where the value came from
  » do some operation on the value
  » when store occurs, check if value has been modified in the meantime (SC—store conditional)
  » if not modified, store new value and return “success”
  » if modified, return “failure”
Locks with Test and Set

Lock::Release() {
    value = 0;
}

Lock::Acquire() {
    while (TestAndSet(value)) {}
}

This works, but take a careful look at the while loop ... when does it exit?
Busy Waiting

- CPU cycles are consumed while the thread is waiting for value to become 0
- This is very inefficient
- Big problem if the thread that is waiting has a higher priority than the thread that holds the lock
Locks with Minimal Busy Waiting

- Use a queue for threads waiting on the lock
- A guard variable provides mutual exclusion

```
Lock::Acquire() {
    while (TestAndSet(guard)) {}
    if (value != FREE) {
        Put self on wait queue;
        guard = 0 and switch();
    } else {
        value = BUSY;
        guard = 0;
    }
}

Lock::Release() {
    while (TestAndSet(guard)) {
        if (anyone on wait queue) {
            move thread from wait
            queue to ready queue;
        } else {
            value = FREE;
        }
    }
    guard = 0;
}
```
Synchronization Summary

- Threads often work independently
- But sometimes threads need to access shared data
- Access to shared data must be mutually exclusive to ensure safety and liveness
- Locks are a good way to provide mutual exclusion