

15-410

“Strangers in the night...”

Synchronization #2

Feb. 3, 2006

Dave Eckhardt

Bruce Maggs

Project 0 Common Themes

Style/structure

- Integers instead of #defined tokens
 - “2” is not better than “TYPE_DOUBLE”
 - It is much much much worse
 - Don't *ever* do that
- “Code photocopier” - indicates a problem, often serious
- Bad variable/function names
 - initialize() should not terminate
 - `int i; /* number of frogs */` ← Don't apologize; fix the problem!
- Excessively long functions
- while(1) should be *rare*
- Don't make us read...
 - False comments, dead code, extra copies of code
 - Harry Bovik did *not* help you write your P0

Project 0 Common Themes

Style/structure

- Code is *read by people*
 - Us
 - Your partner
 - Your manager
 - ...
- Don't make it painful for us
 - or else...

Robustness

- Creating temporary files in current directory
 - Process may be running in a directory it can't write to!
- Memory leaks (no need for `malloc()` at all!)
- File-descriptor leaks

Project 0 Common Themes

Not following spec

- Hand-verifying addresses (compare vs. 0x0804... 0xc000...)
 - Those *happen* currently; they're not *contracts*
- Give up via `exit()` \Leftarrow caller never authorized that!
- Stopping trace at hard-coded function name

Synchronization

Register your project partner – *today!*

- “Partner registration” page on Projects page
- If you know your partner today, please register today
 - You'll get your shared AFS space sooner
 - Your classmates will appreciate it

Outline

Last time

- Two building blocks
- Three requirements for mutual exclusion
- Algorithms people *don't* use for mutual exclusion

Today

- Ways to *really* do mutual exclusion

Next time

- Inside voluntary descheduling
- Project 2 – thread library

Mutual Exclusion: Reminder

Protects an atomic instruction sequence

- Do "something" to guard against
 - CPU switching to another thread
 - Thread running on another CPU

Assumptions

- Atomic instruction sequence will be “short”
- No other thread “likely” to compete

Mutual Exclusion: Goals

Typical case (no competitor) should be fast

Atypical case can be slow

- Should not be “too wasteful”

Interfering Code Sequences

<i>Customer</i>	<i>Delivery</i>
<code>cash = store->cash;</code>	<code>cash = store->cash;</code>
<code>cash += 50;</code>	<code>cash -= 2000;</code>
<code>wallet -= 50;</code>	<code>wallet += 2000;</code>
<code>store->cash = cash;</code>	<code>store->cash = cash;</code>

Which sequences interfere?

“Easy”: Customer interferes with Customer

Also: Delivery interferes with Customer

Mutex aka Lock aka Latch

Specify interfering code sequences via *object*

- Data item(s) “protected by the mutex”

Object methods encapsulate entry & exit protocols

```
mutex_lock (&store->lock) ;  
cash = store->cash  
cash += 50;  
personal_cash -= 50;  
store->cash = cash;  
mutex_unlock (&store->lock) ;
```

What's inside the object?

Mutual Exclusion: Atomic Exchange

Intel x86 XCHG instruction

- intel-isr.pdf page 754

xchg (%esi), %edi

```
int32 xchg(int32 *lock, int32 val) {  
    register int old;  
    old = *lock; /* bus is locked */  
    *lock = val; /* bus is locked */  
    return (old);  
}
```

Inside a Mutex

Initialization

```
int lock_available = 1;
```

Try-lock

```
i_won = xchg(&lock_available, 0);
```

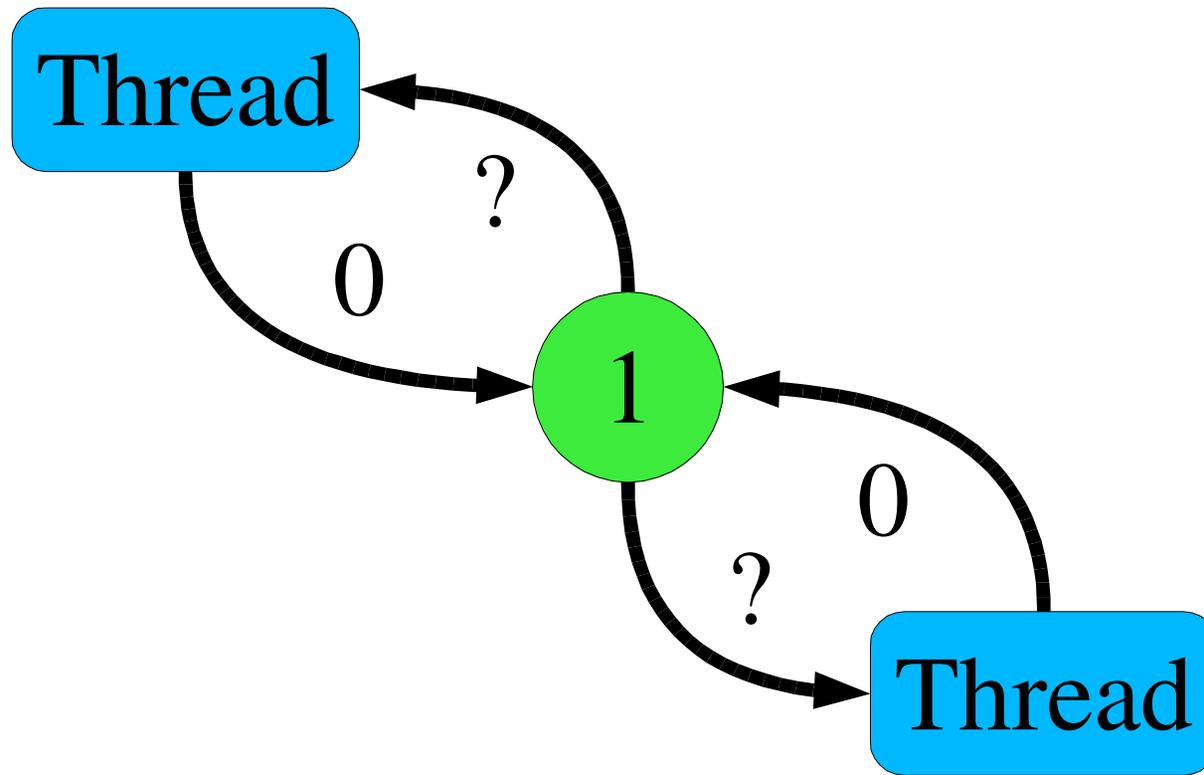
Spin-wait

```
while (!xchg(&lock_available, 0))  
    continue;
```

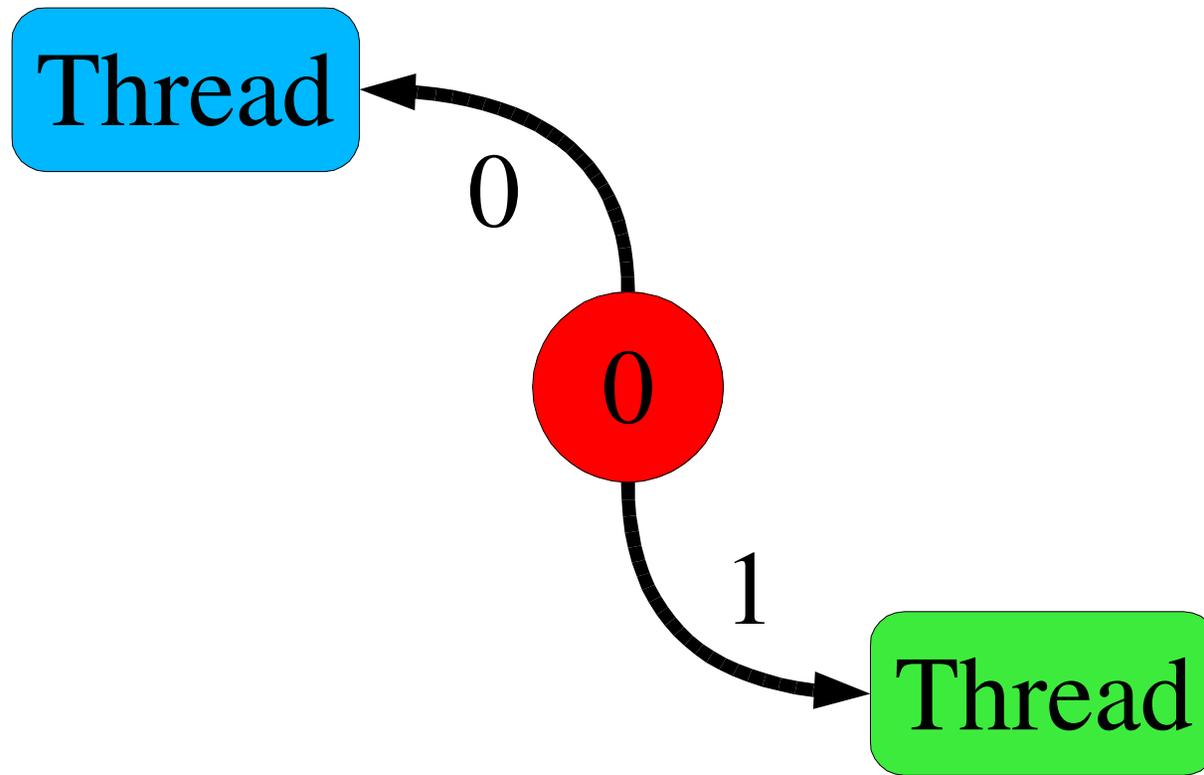
Unlock

```
xchg(&lock_available, 1); /*expect 0*/
```

Strangers in the Night, Exchanging 0's



And the winner is...



Does it work?

[What are the questions, again?]

Does it work?

Mutual Exclusion

Progress

Bounded Waiting

Does it work?

Mutual Exclusion

- There's only one 1; 1's are conserved
- Only one thread can see `lock_available == 1`

Progress

- Whenever `lock_available == 1` a thread will get it

Bounded Waiting

- *No*
- A thread can lose *arbitrarily many times*

Ensuring Bounded Waiting

Lock

```
waiting[i] = true; /*Declare interest*/
got_it = false;
while (waiting[i] && !got_it)
    got_it = xchg(&lock_available,
                false);
waiting[i] = false;
```

Ensuring Bounded Waiting

Unlock

```
j = (i + 1) % n;
while ((j != i) && !waiting[j])
    j = (j + 1) % n;
if (j == i)
    xchg(&lock_available, true); /*W*/
else
    waiting[j] = false;
```

Ensuring Bounded Waiting

Versus (previous edition of) textbook

- Exchange vs. TestAndSet
- “Available” vs. “locked”
- Atomic release vs. normal memory write
 - Text does “blind write” at point “W”

```
lock_available = true;
```
 - This may be illegal on some machines
 - Unlocker may be *required* to use special memory access
 - Exchange, TestAndSet, etc.

Evaluation

One awkward requirement

One unfortunate behavior

Evaluation

One awkward requirement

- Everybody knows size of thread population
 - Always & instantly!
 - Or uses an upper bound

One unfortunate behavior

- Recall: expect *zero* competitors
- Algorithm: $O(n)$ in *maximum possible* competitors

Is this criticism too harsh?

- After all, Baker's Algorithm has these misfeatures...

Looking Deeper

Look beyond abstract semantics

- Mutual exclusion, progress, bounded waiting

Consider

- *Typical* access pattern
- *Particular* runtime environments

Environment

- Uniprocessor vs. Multiprocessor
 - Who is doing what when we are trying to lock/unlock?
- Threads aren't mysteriously “running” or “not running”
 - Decision made by scheduling algorithm with properties

Uniprocessor Environment

Lock

- What if `xchg()` didn't work the first time?
- Some other process has the lock
 - That process isn't running (because we are)
 - *`xchg()` loop is a waste of time*
 - We should let the lock-holder run instead of us

Unlock

- What about bounded waiting?
- When we mark mutex available, who wins next?
 - Whoever *runs* next..only one at a time! (“Fake competition”)
 - How unfair are real OS kernel thread schedulers?
 - If scheduler is vastly unfair, the right thread will *never* run!

Multiprocessor Environment

Lock

- Spin-waiting probably justified
 - (why?)

Unlock

- Next `xchg()` winner “chosen” by memory hardware
- How unfair are real memory controllers?

Test&Set

```
boolean testandset(int32 *lock) {  
    register boolean old;  
    old = *lock;    /* bus is locked */  
    *lock = true;  /* bus is locked */  
    return (old);  
}
```

Conceptually simpler than XCHG?

- Or not

Load-linked, Store-conditional

For multiprocessors

- “Bus locking considered harmful”

Split XCHG into halves

- *Load-linked(addr)* fetches old value from memory
- *Store-conditional(addr,val)* stores new value back
 - If nobody else stored to that address in between
 - If so, instruction “fails” (sets an error code)

Load-linked, Store-conditional

```
loop:  LL    R3, mutex_addr
       BEQ  R3, $0, loop      # avail == 0
       LI   R3, 0            # prep. 0
       SC   R3, mutex_addr   # write 0?
       BEQ  R3, $0, loop     # aborted...
```

Your cache “snoops” the shared memory bus

- Locking would shut down *all* memory traffic
- Snooping allows all traffic, watches for *conflicting* traffic
- Are aborts “ok”? *When* are they “ok”?

Intel i860 magic lock bit

Instruction sets processor in “lock mode”

- Locks bus
- Disables interrupts

Isn't that dangerous?

- 32-instruction countdown timer triggers exception
- Any exceptions (page fault, zero divide, ...) unlock bus

Why would you want this?

- Implement test&set, compare&swap, semaphore – you choose

Mutual Exclusion: Inscrutable Software

Lamport's “Fast Mutual Exclusion” algorithm

- 5 writes, 2 reads (if no contention)
- Not bounded-waiting (in theory, i.e., if contention)
- <http://www.hpl.hp.com/techreports/Compaq-DEC/SRC-RR-7.html>

Why not use it?

- What *kind* of memory writes/reads?
- Remember, the computer is “modern”...

Passing the Buck?

Q: Why not ask the OS for `mutex_lock()` *system call*?

Easy on a uniprocessor...

- Kernel *automatically* excludes other threads
- Kernel can easily disable interrupts
- No need for messy unbounded loop, weird XCHG...

Kernel has special power on a multiprocessor

- Can issue “remote interrupt” to other CPUs
- No need for messy unbounded loop...

So why *not* rely on OS?

Passing the Buck

A: Too expensive

- **Because... (you know this song!)**

Mutual Exclusion: *Tricky* Software

Fast Mutual Exclusion for Uniprocessors

- Bershad, Redell, Ellis: ASPLOS V (1992)

Want uninterruptable instruction sequences?

- Pretend!
`scash = store->cash;`
`scash += 10;`
`wallet -= 10;`
`store->cash = scash;`
- Uniprocessor: interleaving requires thread switch...
- Short sequence *almost always* won't be interrupted...

How can that work?

Kernel *detects* “context switch in atomic sequence”

- Maybe a small set of instructions
- Maybe particular memory areas
- Maybe a flag

```
no_interruption_please = 1;
```

Kernel *handles* unusual case

- Hand out another time slice? (Is that ok?)
- Hand-simulate unfinished instructions (yuck?)
- “Idempotent sequence”: slide PC back to start

Summary

Atomic instruction sequence

- Nobody else may interleave same/”related” sequence

Specify interfering sequences via *mutex object*

Inside a mutex

- Last time: race-condition memory algorithms
- Atomic-exchange, Compare&Swap, Test&Set, ...
- Load-linked/Store-conditional
- Tricky software, weird software

Mutex strategy

- How should you behave given runtime environment?