

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

COMP 530: Operating Systems

Too Much Milk

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Portions courtesy Emmett Witchel



Critical Sections are Hard, Part 2

- The following example will demonstrate the difficulty of providing mutual exclusion with memory reads and writes
 - Hardware support is needed
- The code must work *all* of the time
 - Most concurrency bugs generate correct results for some interleavings
- Designing mutual exclusion in software shows you how to think about concurrent updates
 - Always look for what you are checking and what you are updating
 - A meddlesome thread can execute between the check and the update, the dreaded race condition



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Thread Coordination

Too much milk!

Jack

- Look in the fridge; out of milk
- Go to store
- Buy milk
- Arrive home; put milk away

Jill

- Look in fridge; out of milk
- Go to store
- Buy milk
- Arrive home; put milk away
- Oh, no!

Fridge and Milk are Shared Data Structures



Formalizing "Too Much Milk"

- Shared variables
 - "Look in the fridge for milk" check a variable
 - "Put milk away" update a variable
- Safety property
 - At most one person buys milk
- Liveness
 - Someone buys milk when needed
- How can we solve this problem?



How to think about synchronization code

- Every thread has the same pattern
 - Entry section: code to attempt entry to critical section
 - Critical section: code that requires isolation (e.g., with mutual exclusion)
 - Exit section: cleanup code after execution of critical region
 - Non-critical section: everything else
- There can be multiple critical regions in a program
 - Only critical regions that access the same resource (e.g., data structure) need to synchronize with each other

```
while(1) {
   Entry section
   Critical section
   Exit section
   Non-critical section
```





The Correctness Conditions

- Safety
 - Only one thread in the critical region
- Liveness
 - Some thread that enters the entry section eventually enters the critical region
 - Even if some thread takes forever in non-critical region
- Bounded waiting
 - A thread that enters the entry section enters the critical section within some bounded number of operations.
- Failure atomicity
 - It is OK for a thread to die in the critical region
 - Many techniques do not provide failure atomicity

while(1) {
 Entry section
 Critical section
 Exit section
 Non-critical section
}



Solution #0



- Is this solution
 - 1. Correct
 - 2. Not safe
 - 3. Not live
 - 4. No bounded wait
 - 5. Not safe and not live

What if we switch the order of checks?

- It works sometime and doesn't some other times
 - Threads can be context switched between checking and leaving note
 - Live, note left will be removed
 - Bounded wait ('buy milk' takes a finite number of steps)



Solution #1

turn := Jill // Initialization

while(1) {
 while(turn ≠ Jack); //spin
 while (Milk); //spin
 buy milk; // Critical section
 turn := Jill // Exit section
 // Non-critical section
}

while(1) { while(turn ≠ Jill) ; //spin while (Milk) ; //spin buy milk; turn := Jack // Non-critical section }

- Is this solution
 - 1. Correct
 - 2. Not safe
 - > 3. Not live
 - 4. No bounded wait
 - > 5. Not safe and not live

At least it is safe



Solution #2: Peterson's Algorithm

Variables:

- thread T_i is executing, or attempting to execute, in CS - in_i:
- id of thread allowed to enter CS if multiple want to – turn:

Claim: We can achieve mutual exclusion if the following invariant holds before thread i enters the critical section:

$$\{(\neg in_j \lor (in_j \land turn = i)) \land in_i\}$$

Intuitively: j doesn't want to execute or it is i's turn to execute



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Peterson's Algorithm

 $in_0 = in_1 = false;$



turn=Jack, in_0 = false, in_1 := true

Save, live, and bounded waiting; but only 2 threads



Too Much Milk: Lessons

- Peterson's works, but it is really unsatisfactory
 - Limited to two threads
 - Solution is complicated; proving correctness is tricky even for the simple example
 - While thread is waiting, it is consuming CPU time
- How can we do better?
 - Use hardware to make synchronization faster
 - Define higher-level programming abstractions to simplify concurrent programming