departamento de informática
FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

Solving Mutual Exclusion (2)

lecture 15 (2020-04-21s)

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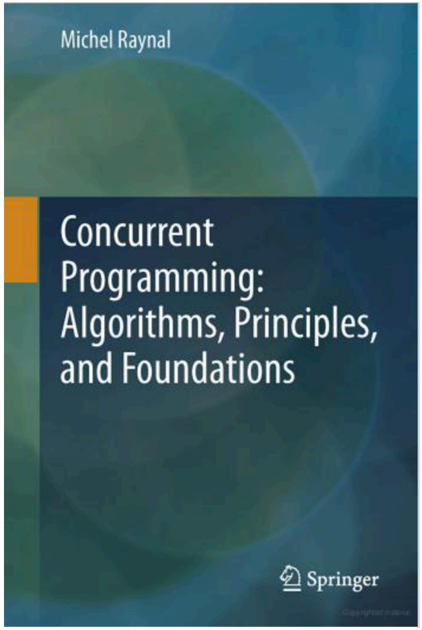
João Lourenço <joao.lourenco@fct.unl.pt>

Summary

- **Solving Mutual Exclusion**
  - Mutex based on Specialized Hardware Primitives



- **Reading list:**
  - **Chapter 2** of the book
    Raynal M.;
    Concurrent Programming: Algorithms, Principles, and Foundations;
    Springer-Verlag Berlin Heidelberg (2013);
    ISBN: 978-3-642-32026-2

Mutex Based on Specialized Hardware Primitives

- In the previous class we studied mutual exclusion algorithms based on atomic read/ write registers
- These algorithms are important because
  - Understanding their design and their properties provides us with precise knowledge of the difficulty and subtleties that have to be addressed when one has to solve synchronization problems.
  - They capture the essence of synchronization in a read/write shared memory model
- Nearly all shared memory multiprocessors propose built-in primitives (i.e., atomic operations implemented in hardware) specially designed to address synchronization issues

The *test&set()/reset()* primitives

- This pair of primitives, denoted **test&set()** and **reset()**, is defined as follows:

- Let X be a shared register initialized to 1
- **X.test&set()** sets X to 0 and returns its previous value
- **X.reset()** writes 1 into X (i.e., resets X to its initial value)
- Both **test&set()** and **reset()** are atomic

Mutual exclusion with *test&set()/reset()*

Invariant? $X + \sum_{i=1}^{n} r_i = 1$

operation acquire_mutex() **is**
    repeat $r \leftarrow X$.test&set() **until** $(r = 1)$ **end repeat**;
    return()
end operation.

operation release_mutex() **is**
    X.reset(); return()
end operation.

✓mutual exclusion
✓progress **Really??**

The *swap()* primitive

- Let X be a shared register
- The primitive **X.swap(v)** atomically assigns v to X and returns the previous value of X

Mutual exclusion with *swap()*

Invariant? $X + \sum_{i=1}^{n} r_i = 1$

operation acquire_mutex() **is**
$r \leftarrow 0$;
repeat $r \leftarrow X$.swap(r) **until** $(r = 1)$ **end repeat**;
return()
end operation.

operation release_mutex() **is**
X.swap(r); return()
end operation.

Assumes 'r' was not changed (i.e., r=1)

✓mutual exclusion
✓progress **Really??**

The *compare&swap()* primitive

- Let 'X' be a shared register and 'old' and 'new' be two values
- The primitive **X.compare&swap(old, new)**
  - returns a Boolean value
  - is defined by the following code that is assumed to be executed atomically:

X.compare&swap(old, new) **is**
    if $(X = old)$ **then** $X \leftarrow new$; return($true$)
        else return($false$)
    end if.

Mutual exclusion with *compare&swap()*

X is an atomic *compare&swap* register initialized to 1

old new

operation acquire_mutex() **is**
  repeat $r \leftarrow X$.compare&swap$(1, 0)$ **until** (r) **end repeat**;
  return()
end operation.

operation release_mutex() **is**
  $X \leftarrow 1$; return()
end operation.

Mutual exclusion with *compare&swap()*

X is an atomic *compare&swap* register initialized to 1

operation acquire_mutex() **is**
    repeat $r \leftarrow X$.compare&swap$(1, 0)$ **until** (r) **end repeat**;
    return()
end operation.

operation release_mutex() **is**
    $X \leftarrow 1$; return()
end operation.

Invariant?

$$X + \sum_{i=0}^{n} (r_i = TRUE) = 1$$

✓mutual exclusion
✓progress **Really??**

Starvation freedom

- All the previous algorithms, implementing mutexes with

  test&set()
  swap()
  compare&swap()

  ✓ mutual exclusion
  X progress for all the processes

  are not starvation free!

  This means that in presence of contention a process p_i may always "loose the race" and never get the lock

Mutual exclusion: deadlock and starvation-free algorithm

```
operation acquire_mutex(i) is
 (1)  FLAG[i] ← up;
 (2)  wait (TURN = i) ∨ (FLAG[TURN] = down) ;
 (3)  LOCK.acquire_lock(i);
 (4)  return()
end operation.

operation release_mutex(i) is
 (5)  FLAG[i] ← down;
 (6)  if (FLAG[TURN] = down) then TURN ← (TURN mod n) + 1 end if;
 (7)  LOCK.release_lock(i);
 (8)  return()
end operation.
```

✓ mutual exclusion
✓ progress
✓ no starvation
X fairness

The *fetch&add()* primitive

- Let X be a shared register
- The primitive **X.fetch&add()** atomically adds 1 to X and returns the new value
  - In some variants the value that is returned is the previous value of X
  - In other variants, a value c is passed as a parameter and, instead of being increased by 1, X becomes X + c

Mutual exclusion with *fetch&add()*

operation acquire_mutex() **is**
    $my\_turn \leftarrow TICKET$.fetch&add();
    repeat no-op **until** $(my\_turn = NEXT)$ **end repeat**;
    return()
end operation.

operation release_mutex() **is**
    $\boxed{NEXT \leftarrow NEXT + 1;}$ return()
end operation.

Not atomic!
Why does it work?

- ✓ mutual exclusion
- ✓ progress
- ✓ no starvation
- ✓ fairness

The END