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Solving Mutual Exclusion (2)

Concurrency and Parallelism — 2017-18

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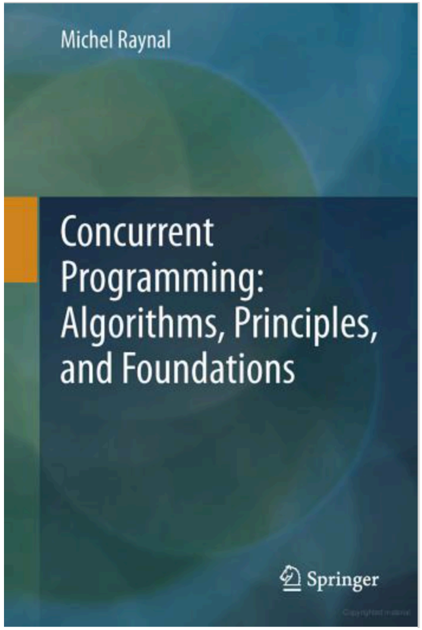
Summary

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

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

Starvation freedom

- All the previous algorithms for implementing mutexes with

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

  are not starvation free!

✓ mutual exclusion
X progress for all the processes

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) $FLAG[i] \leftarrow up;$
(2) **wait** $(TURN = i) \vee (FLAG[TURN] = down)$;
(3) $LOCK$.acquire_lock(i);
(4) return()
end operation.

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

✓mutual exclusion
✓progress
✓no starvation

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