Locks (ch 28) pt. 2

Operating Systems
Based on: Three Easy Pieces by Arpaci-Dusseaux

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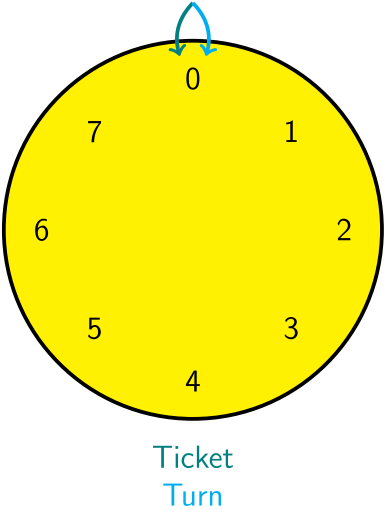
Fetch-And-Add

- We can now build a fair **ticket lock**:

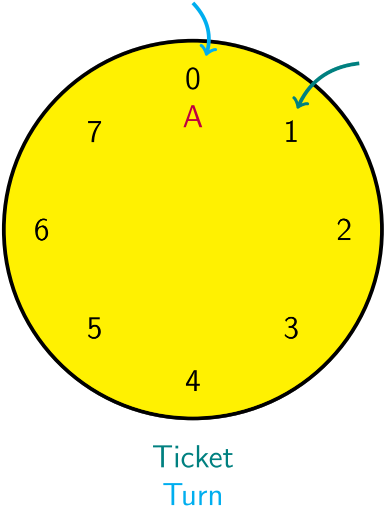
```c
typedef struct __lock_t {
    int ticket;
    int turn;
} lock_t;

void init(lock_t* lock) {
    lock->ticket = 0;
    lock->turn = 0;
}
void lock(lock_t* lock) {
    int myturn = FetchAndAdd(&lock->ticket);
    while (lock->turn != myturn)
        ; // spin
}
void unlock(lock_t* lock) {
    lock->turn = lock->turn + 1;
}
```

Ticket Lock



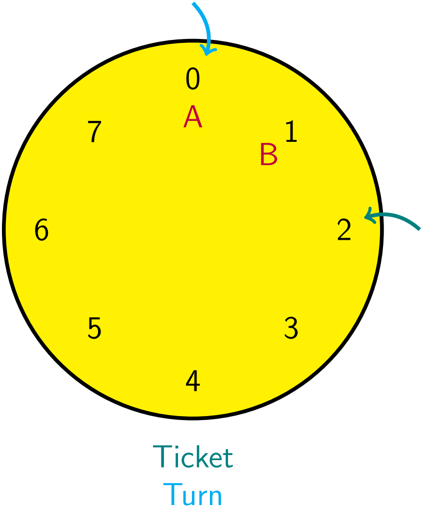
Ticket Lock

- A: lock(), gets ticket 0 & runs



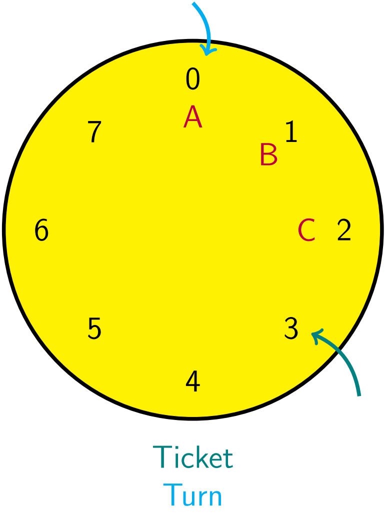
Ticket Lock

- A: lock(), gets ticket 0 & runs
- B: lock(), gets ticket 1, spins



Ticket Lock

- A: lock(), gets ticket 0 & runs
- B: lock(), gets ticket 1, spins
- C: lock(), gets ticket 2, spins



Ticket Lock

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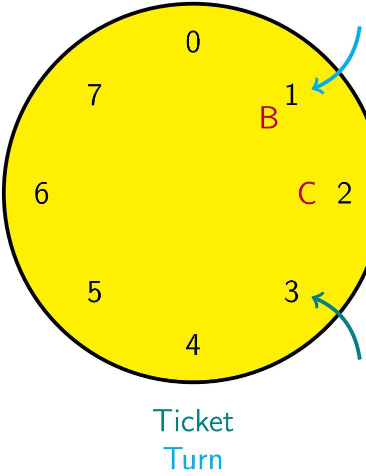
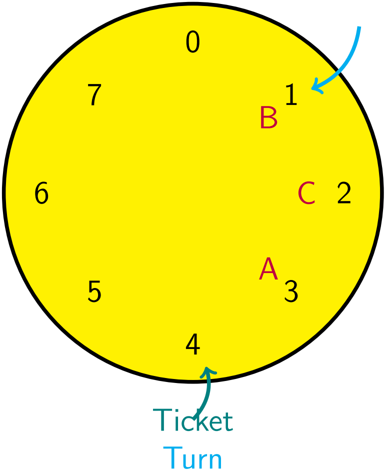
- C: lock(), gets ticket 2, spins
- A: unlock(), turn++, B runs



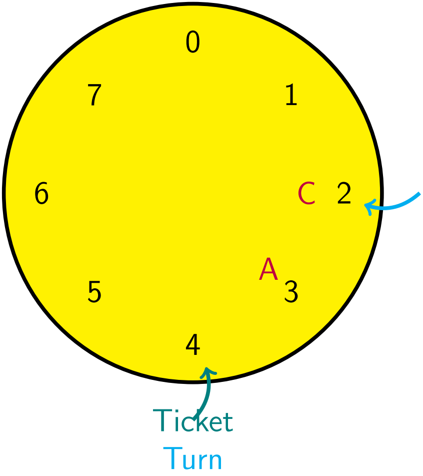
Ticket Lock

- A: lock(), gets ticket 0 & runs
- B: lock(), gets ticket 1, spins
- C: lock(), gets ticket 2, spins
- A: unlock(), turn++, B runs
- A: lock(), gets ticket 3, spins



Ticket Lock

- A: lock(), gets ticket 0 & runs
- B: lock(), gets ticket 1, spins
- C: lock(), gets ticket 2, spins
- A: unlock(), turn++, B runs
- A: lock(), gets ticket 3, spins
- B: unlock(), turn++, C runs
- ...



Decker's Algorithm

- What about a lock without hardware support?

```c
int flag[2];     // wants to grab lock?
int turn;        // whose turn?

void init() {
    flag[0] = flag[1] = 0;
    turn = 0;
}
void lock(int self) {
    flag[self] = 1;
    turn = 1 - self;    // let other run
    while ((flag[1-self] == 1) && (turn == 1-self))
        ; // spin-wait
}
void unlock(int self) {
    flag[self] = 0;
}
```

- Various issues → concurrency course

Too Much Spinning

- Locks so far used spinning
  - Quite inefficient
- Consider N threads
  - Thread 1 grabs lock, $N - 1$ threads waiting for lock
  - Timer interrupt $\rightarrow$ context switch
  - $N - 1$ threads execute, waste $N - 1$ time slices
- Solution? hardware again!

Too Much Spinning

- When you are going to spin, give up CPU
  - `yield()`: system call to change caller state
    - From **running** to **ready**
    - Essentially **deschedules** itself

```
void lock(lock_t* mutex) {
    while (TestAndSet(&mutex->flag, 1))
        yield(); // give up the CPU
    mutex->flag = 1;
}
```

Too Much Spinning

- When you are going to spin, give up CPU
  - `yield()`: system call to change caller state
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void lock(lock_t* mutex) {
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        yield(); // give up the CPU
    mutex->flag = 1;
}
```

- Still costly
  - $N-1$ system calls and context switches
  - Does not handle **starvation**

Using Queues

- Use **queue** to keep track of threads waiting for lock
- In **Solaris**: `park()`
  - Put calling thread to sleep
  - Until another thread calls `unpark(threadID)`

Using Queues

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```
typedef struct __lock_t {
    int flag;
    int guard;
    queue_t *q;
} lock_t;

void init(lock_t *m) {
    m->flag = 0;
    m->guard = 0;
    queue_init(m->q);
}
```

Using Queues

```
void lock(lock_t *m) {
    while (TestAndSet(&m->guard, 1) == 1)
        ; // acquire guard lock by spinning
    if (m->flag == 0) {
        m->flag = 1;
        m->guard = 0;
    } else {
        queue_add(m->q, gettid());
        m->guard = 0;
        park();
    }
}
void unlock(lock_t *m) {
    while (TestAndSet(&m->guard, 1) == 1)
        ; // acquire guard lock by spinning
    if (queue_empty(m->q))
        m->flag = 0;
    else
        unpark(queue_remove(m->q));
    m->guard = 0;
}
```

Using Queues

- Race condition:
  1. Thread adds itself to queue, releases lock
  2. Context switch just before call to `park()`
  3. Owner thread is done, removes new item from queue
  4. Calls `unpark()` for new thread: not yet parked!

Using Queues

- Also in Solaris: `setpark()`
  - Thread about to call `park()`
  - If interrupted and `unpark()` is called for it:
  - Subsequent `park()` returns immediately

```
void lock(lock_t *m) {
    ...
    } else {
        setpark(); // <- new code
        queue_add(m->q, gettid());
        m->guard = 0;
        park();
    }
}
```

Using Queues: Different OS

- Support details vary between OS
- Linux: **futex**
  - Similar to Solaris
  - `futex_wait(address,expected)`
    - Puts calling thread to sleep if `address` is equal to `expected`
  - `futex_wake(address)`
    - Wakes one thread waiting on `address`

Using Queues: Different OS

- Snippet from POSIX thread library:

```c
void mutex_lock(int *mutex) {
    int v;
    // Bit 31 was clear, we got the mutex (fastpath)
    if (atomic_bit_test_set(mutex, 31) == 0)
        return;
    atomic_increment(mutex);
    while (1) {
        if (atomic_bit_test_set(mutex, 31) == 0) {
            atomic_decrement(mutex);
            return;
        }
        v = *mutex;
        if (v >= 0)
            continue;
        futex_wait(mutex, v);
    }
}
void mutex_unlock(int *mutex) {
    if (atomic_add_zero(mutex, 0x80000000))
        return; // zero iff no other interested threads

    // there are other threads waiting
    futex_wake(mutex);
}
```

Two-Phase Locks

- Hybrid approach: **two-phase lock**
    - Spinning can be useful
    - Particularly if lock is about to be released
- **First phase**: lock spins for a while
- **Second phase**: caller put to sleep, wakes up when lock becomes free

Summary

- **Lock**
  - Execute a series of actions **atomically**
  - Evaluated by: **Mutual exclusion**, **Deadlock-freedom**, **fairness**, **performance**
  - POSIX library: **mutex**, **futex**
- Disabling interrupts: problematic, used by OS
- Hardware support: **test&set**, **compare&swap**, **fetch&add**
- Spin-locks: TAS lock & CAS lock
  - Avoid spinning with `yield()`
- Fairness: **ticket lock** or queue lock
- **Condition variables**