Recap: Synchronization

Disabling IRQs – use to protect against concurrent access by IRQ handler

Locks – use to protect against concurrent access by other threads

Direct implementation of locks on uniprocessor
- Requires disable_preemption
- Involves state change of thread if contended

Today: multiprocessor locks, locking strategies

Multiprocessor Locks

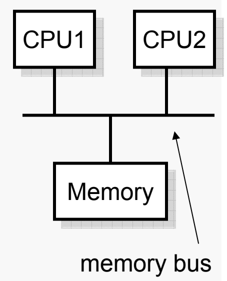
Can't stop threads running on other processors
- too expensive (interprocessor irq)
- also would create conflict with protection (locking = unprivileged op, stopping = privileged op), involving the kernel in *every* acquire/release

Instead: use atomic instructions provided by hardware
- E.g.: test-and-set, atomic-swap, compare-and-exchange, fetch-and-add
- All variations of "read-and-modify" theme

Locks are built on top of these

Atomic Swap


```
// In C, an atomic swap instruction would like this
void
atomic_swap(int *memory1, int *memory2)
{
        [ disable interrupts in CPU;
          lock memory bus for other processors ]
        int tmp = *memory1;
        *memory1 = *memory2;
        *memory2 = tmp;
        [ unlock memory bus; reenable interrupts ]
}
```



Spinlocks


```
lock_acquire(struct lock *l)
{
   int lockstate = LOCKED;
   while (lockstate == LOCKED) {
     atomic_swap(&lockstate,
                 &l->state);
   }
}
```

```
lock_release(struct lock *l)
{
  l->state = UNLOCKED;
}
```

Thread spins until it acquires lock

- Q1: when should it block instead?
- Q2: what if spin lock holder is preempted?

Spinning vs Blocking

Blocking has a cost

- Shouldn't block if lock becomes available in less time than it takes to block

Strategy: spin for time it would take to block

- Even in worst case, total cost for lock_acquire is less than 2*block time

Spinlocks vs Disabling Preemption

What if spinlocks were used on single CPU? Consider:

- thread 1 takes spinlock
- thread 1 is preempted
- thread 2 with higher priority runs
- thread 2 tries to take spinlock, finds it taken
- thread 2 spins forever → deadlock!

Thus in practice, usually combine spinlocks with disabling preemption

- E.g., spin_lock_irqsave() in Linux
  - UP kernel: reduces to disable_preemption
  - SMP kernel: disable_preemption + spinlock

Spinlocks are used when holding resources for small periods of time (same rule as for when it's ok to disable irqs)

Spinlocks (Faster)


```
lock_acquire(struct lock *l)
{
    int lockstate = LOCKED;
    while (lockstate == LOCKED) {
      while (l->state == LOCKED)
        continue;
      atomic_swap(&lockstate,
                  &l->state);
    }
}
```

```
lock_release(struct lock *l)
{
  l->state = UNLOCKED;
}
```

Only try “expensive” atomic_swap instruction if you’ve seen lock in unlocked state

Locks: Ownership & Recursion

Locks typically (not always) have notion of ownership

- Only lock holder is allowed to unlock
- See Pintos lock_held_by_current_thread()

What if lock holder tries to acquire locks it already holds?

- Nonrecursive locks: deadlock!
- Recursive locks:
  - inc counter
  - dec counter on lock_release
  - release when zero

Implementing Locks: Practical Issues

How expensive are locks?

Two considerations:

- Cost to acquire uncontended lock
  - UP Kernel: disable/enable irq + memory access
  - In other scenarios: needs atomic instruction (relatively expensive in terms of processor cycles, especially if executed often)
- Cost to acquire contended lock
  - Spinlock: blocks current CPU entirely (if no blocking is employed)
  - Regular lock: cost at least two context switches, plus associated management overhead

Conclusions

- Optimizing uncontended case is important
- "Hot locks" can sack performance easily