Lecture 29: Locking in xv6

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Why locking in xv6?

P1 P2

kernel data

- No threads in xv6, so no two user programs can access same userspace memory image
  - No need for userspace locks like pthreads mutex
- However, scope for concurrency in xv6 kernel
  - Two processes in kernel mode in different CPU cores can access same kernel data structures

    P1 → kernel → intr
  - When a process is running in kernel mode, another trap occurs, and the trap handler can access data that was being accessed by previous kernel code
- Solution: spinlocks used to protect critical sections
  - Limit concurrent access to kernel data structures that can result in race conditions
- xv6 also has a sleeping lock (built on spinlock, not discussed)

Spinlocks in xv6

- Acquiring lock: uses xchg x86 atomic instruction (test and set)
  - Atomically set lock variable to 1 and returns previous value
  - If previous value is 0, it means free lock has been acquired, success!
  - If previous value is 1, it means lock is held by someone, continue to spin in a busy while loop till success
- Releasing lock: set lock variable to 0
- Must disable interrupts on CPU core before spinning for lock
  - Interrupts disabled only on this CPU core to prevent another trap handler running and requesting same lock, leading to deadlock
  - OK for process on another core to spin for same lock, as the process on this core will release it
  - Disable interrupts before starting to spin (otherwise, vulnerable window after lock acquired and before interrupts disabled)

```
// Mutual exclusion lock.
struct spinlock {
  uint locked;       // Is the lock held?

  // For debugging:
  char *name;        // Name of lock.
  struct cpu *cpu;   // The cpu holding the lock.
  uint pcs[10];      // The call stack (an array of program counters)
                     // that locked the lock.
};
```

```
void
acquire(struct spinlock *lk)
{
  pushcli(); // disable interrupts to avoid deadlock.
  if(holding(lk))
    panic("acquire");

  // The xchg is atomic.
  while(xchg(&lk->locked, 1) != 0)
    ;

  // Tell the C compiler and the processor to not move loads or stores
  // past this point, to ensure that the critical section's memory
  // references happen after the lock is acquired.
  __sync_synchronize();

  // Record info about lock acquisition for debugging.
  lk->cpu = mycpu();
  getcallerpcs(&lk, lk->pcs);
}
```

=0 ✓ success

spin

C1 P1 → L → ~~intr.~~

C2 P2 → L spinning ✓

Disabling interrupts

L1 L2

- Must disable interrupts on CPU core before beginning to spin for spinlock
- Interrupts stay disabled until lock is released
- What if multiple spinlocks are acquired?
  - Interrupts must stay disabled until all locks are released
- Disabling/enabling interrupts:
  - pushcli disables interrupts on first lock acquire, increments count for future locks
  - popcli decrements count, reenables interrupts only when all locks released and count is zero

```
// Pushcli/popcli are like cli/sti except that they are matched:
// it takes two popcli to undo two pushcli.  Also, if interrupts
// are off, then pushcli, popcli leaves them off.

void
pushcli(void)
{
  int eflags;

  eflags = readeflags();
  cli();
  if(mycpu()->ncli == 0)
    mycpu()->intena = eflags & FL_IF;
  mycpu()->ncli += 1;
}

void
popcli(void)
{
  if(readeflags()&FL_IF)
    panic("popcli - interruptible");
  if(--mycpu()->ncli < 0)
    panic("popcli");
  if(mycpu()->ncli == 0 && mycpu()->intena)
    sti();
}
```

ptable.lock (1)

```
struct {
  struct spinlock lock;
  struct proc proc[NPROC];
} ptable;
```

- The process table protected by a lock, any access to ptable must be done with ptable.lock held
- Normally, a process in kernel mode acquires ptable.lock, changes ptable, releases lock
  - Example: when allocproc allocates new struct proc
- But during context switch from process P1 to P2, ptable structure is being changed all through context switch, so when to release lock?
  - P1 acquires lock, switches to scheduler, switches to P2, P2 releases lock

If the process is context switched out from P1 to P2, and lock held, then the destination process releases the lock held by the initial process.

ptable.lock (2)

- Every function that calls sched() to give up CPU will do so with ptable.lock held. Which functions invoke sched()?
  - Yield, when a process gives up CPU due to timer interrupt
  - Sleep, when process wishes to block
  - Exit, when process terminates
- Every function that swtch switches to will release ptable.lock. What functions does swtch return to?
  - Yield, when switching in a process that is resuming after yielding is done
  - Sleep, when switching in a process that is waking up after sleep
  - Forkret for newly created processes
- Purpose of forkret: to release ptable.lock after context switch, before returning from trap to userspace

That's why we don't directly return from the trapret but instead we take the path of forkret to release the lock and then return.

```
// Give up the CPU for one scheduling round.
void
yield(void)
{
  acquire(&ptable.lock);
  myproc()->state = RUNNABLE;
  sched();
  release(&ptable.lock);
}
```

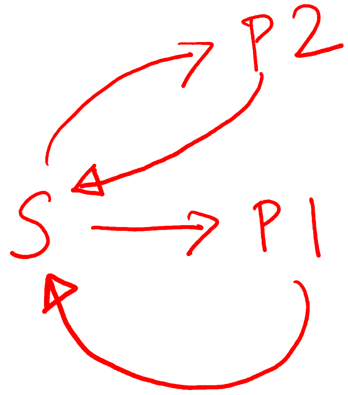
P1 → P2

```
void
forkret(void)
{
  static int first = 1;
  // Still holding ptable.lock from scheduler.
  release(&ptable.lock);

  if (first) {
    // Some initialization functions must be run in the context
    // of a regular process (e.g., they call sleep), and thus cannot
    // be run from main().
    first = 0;
    iinit(ROOTDEV);
    initlog(ROOTDEV);
  }
```

trapret

ptable.lock (3)



- Scheduler goes into loop with lock held
- Switch to P1, P1 switches back to scheduler with lock held, scheduler switches to P2, P2 releases lock
- Periodically, end of looping over all processes, releases lock temporarily
  – What if no runnable process found due to interrupts being disabled? Release lock, enable interrupts, allow processes to become runnable.

```
void
scheduler(void)
{
  struct proc *p;
  struct cpu *c = mycpu();
  c->proc = 0;

  for(;;){
    // Enable interrupts on this processor.
    sti();

    // Loop over process table looking for process to run.
    acquire(&ptable.lock);
    for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
      if(p->state != RUNNABLE)
        continue;

      // Switch to chosen process.  It is the process's job
      // to release ptable.lock and then reacquire it
      // before jumping back to us.
      c->proc = p;
      switchuvm(p);
      p->state = RUNNING;

      swtch(&(c->scheduler), p->context);
      switchkvm();

      // Process is done running for now.
      // It should have changed its p->state before coming back.
      c->proc = 0;
    }
    release(&ptable.lock);

  }
}
```

Summary

- Spinlocks in xv6 based on xchg atomic instruction
- Processes in kernel mode hold spinlock when accessing shared data structures, disabling interrupts on that core while lock is held
- Special ptable.lock held across context switch