CS 3204
Operating Systems

Lecture 10

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Announcements

- Project 1 is due Feb 27, 11:59pm
  – I'm not getting enough questions
- Project 1 Repeat Help Session
  – Wednesday (tonight) MCB 126, 7pm
- *nix Crash Course offered: Feb 9, 8:30pm
  – tomorrow
- Reading: Section 5.1 through 5.4

Recap: Disabling Interrupts

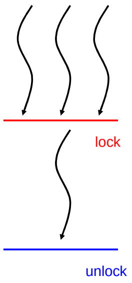
- (this applies to all variations)
- Works for Critical Section, but sledgehammer solution
  – Infinite loop inside CS means machine locks up
  – If you have to block (give up CPU) mutual exclusion with other threads is not guaranteed
    - Any function that transitively calls thread_block() may block
- Use this to protect data structures from concurrent access by interrupt handlers
  – Keep sections of code where irqs are disabled minimal (nothing else can happen until irqs are reenabled – latency penalty!)
- Want something more fine-grained
  – Key insight: don't exclude *everybody* else, only those contending for the same critical section

Critical Section Problem

- A solution for the CS Problem must
  1) Provide mutual exclusion: at most one thread can be inside CS
  2) Guarantee Progress: (no deadlock)
     - if more than one threads attempt to enter, one will succeed
     - ability to enter should not depend on activity of other threads not currently in CS
  3) Bounded Waiting: (no starvation)
     - A thread attempting to enter critical section eventually will (assuming no thread spends unbounded amount of time inside CS)
- A solution for CS problem should be
  – Fair (make sure waiting times are balanced)
  – Efficient (not waste resources)
  – Simple

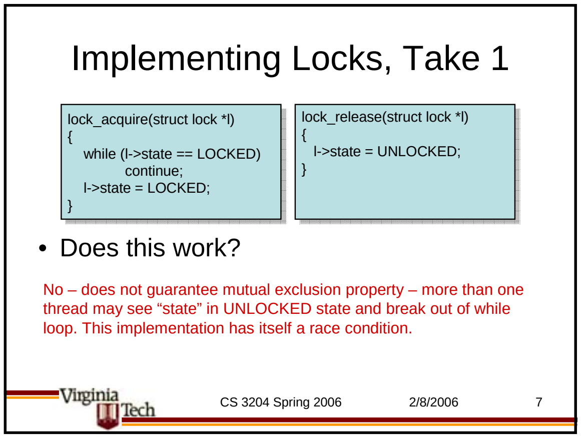
Locks

- Thread that enters CS locks it
  – Others can't get in and have to wait
- Thread unlocks CS when leaving it
  – Lets in next thread
  – which one?
    - FIFO guarantees bounded waiting
    - Highest priority in Proj1
- Lock is an abstract data type
  – Provides (at least) init, acquire, release



Implementing Locks

- Let's discuss how to implement locks to solve CS problem
- Later talk about semaphores
- Different solutions exist to implement locks for uniprocessor and multiprocessors
- Will talk about how to implement locks for uniprocessors first – next slides all assume uniprocessor



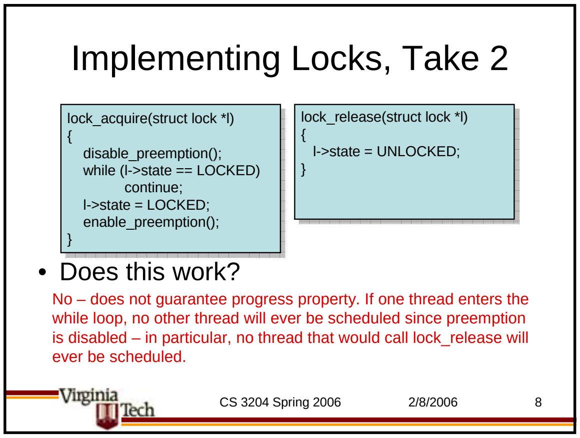
Implementing Locks, Take 1

```
lock_acquire(struct lock *l)
{
   while (l->state == LOCKED)
        continue;
   l->state = LOCKED;
}
```

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

- Does this work?

No – does not guarantee mutual exclusion property – more than one thread may see “state” in UNLOCKED state and break out of while loop. This implementation has itself a race condition.



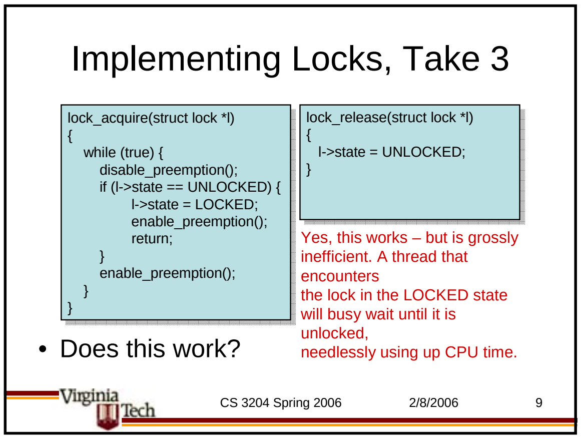
Implementing Locks, Take 2

```
lock_acquire(struct lock *l)
{
   disable_preemption();
   while (l->state == LOCKED)
        continue;
   l->state = LOCKED;
   enable_preemption();
}
```

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

- Does this work?

No – does not guarantee progress property. If one thread enters the while loop, no other thread will ever be scheduled since preemption is disabled – in particular, no thread that would call lock_release will ever be scheduled.



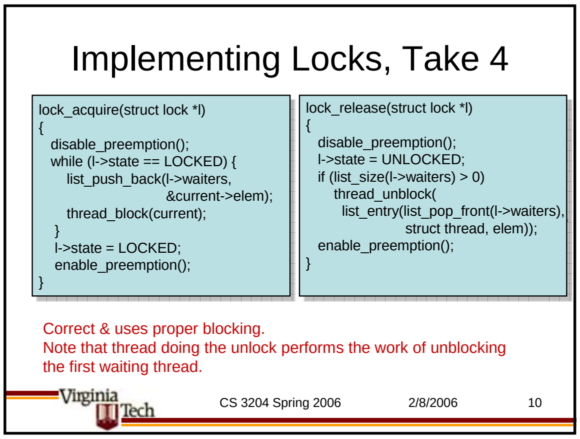
Implementing Locks, Take 3

```
lock_acquire(struct lock *l)
{
   while (true) {
      disable_preemption();
      if (l->state == UNLOCKED) {
           l->state = LOCKED;
           enable_preemption();
           return;
      }
      enable_preemption();
   }
}
```

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

Yes, this works – but is grossly inefficient. A thread that encounters
the lock in the LOCKED state will busy wait until it is unlocked,
needlessly using up CPU time.

- Does this work?

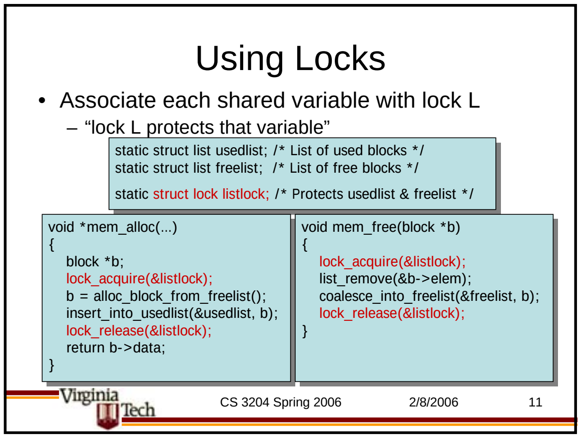


Implementing Locks, Take 4

```
lock_acquire(struct lock *l)
{
  disable_preemption();
  while (l->state == LOCKED) {
     list_push_back(l->waiters,
                     &current->elem);
     thread_block(current);
  }
  l->state = LOCKED;
  enable_preemption();
}
```

```
lock_release(struct lock *l)
{
  disable_preemption();
  l->state = UNLOCKED;
  if (list_size(l->waiters) > 0)
     thread_unblock(
       list_entry(list_pop_front(l->waiters),
                  struct thread, elem));
  enable_preemption();
}
```

Correct & uses proper blocking.
Note that thread doing the unlock performs the work of unblocking the first waiting thread.



Using Locks

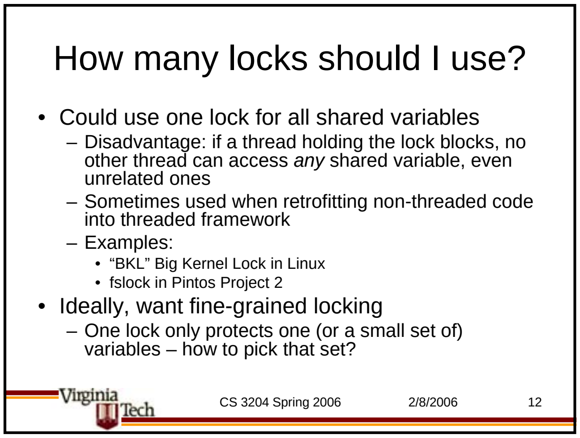
- Associate each shared variable with lock L
  - “lock L protects that variable”

```
static struct list usedlist; /* List of used blocks */
static struct list freelist;  /* List of free blocks */

static struct lock listlock; /* Protects usedlist & freelist */
```

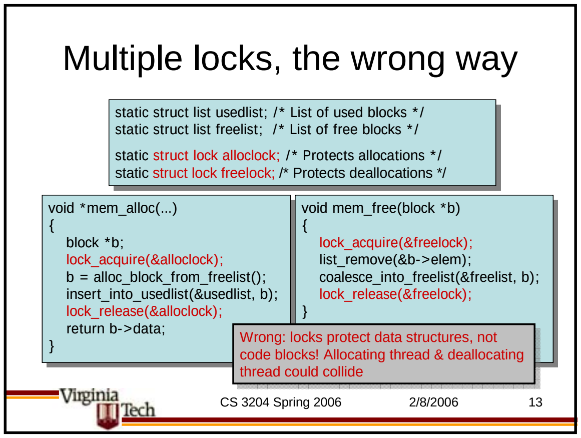
```
void *mem_alloc(...)
{
   block *b;
   lock_acquire(&listlock);
   b = alloc_block_from_freelist();
   insert_into_usedlist(&usedlist, b);
   lock_release(&listlock);
   return b->data;
}
```

```
void mem_free(block *b)
{
   lock_acquire(&listlock);
   list_remove(&b->elem);
   coalesce_into_freelist(&freelist, b);
   lock_release(&listlock);
}
```



How many locks should I use?

- Could use one lock for all shared variables
  - Disadvantage: if a thread holding the lock blocks, no other thread can access *any* shared variable, even unrelated ones
  - Sometimes used when retrofitting non-threaded code into threaded framework
  - Examples:
    - “BKL” Big Kernel Lock in Linux
    - fslock in Pintos Project 2
- Ideally, want fine-grained locking
  - One lock only protects one (or a small set of) variables – how to pick that set?



Multiple locks, the wrong way

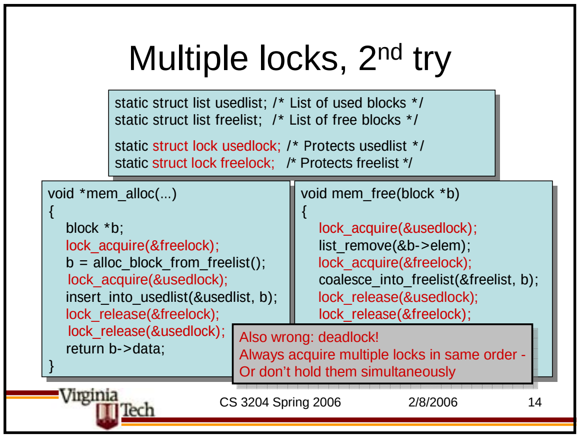
```
static struct list usedlist; /* List of used blocks */
static struct list freelist;  /* List of free blocks */

static struct lock alloclock; /* Protects allocations */
static struct lock freelock; /* Protects deallocations */
```

```
void *mem_alloc(...)
{
    block *b;
    lock_acquire(&alloclock);
    b = alloc_block_from_freelist();
    insert_into_usedlist(&usedlist, b);
    lock_release(&alloclock);
    return b->data;
}
```

```
void mem_free(block *b)
{
    lock_acquire(&freelock);
    list_remove(&b->elem);
    coalesce_into_freelist(&freelist, b);
    lock_release(&freelock);
}
```

Wrong: locks protect data structures, not code blocks! Allocating thread & deallocating thread could collide



Multiple locks, 2nd try

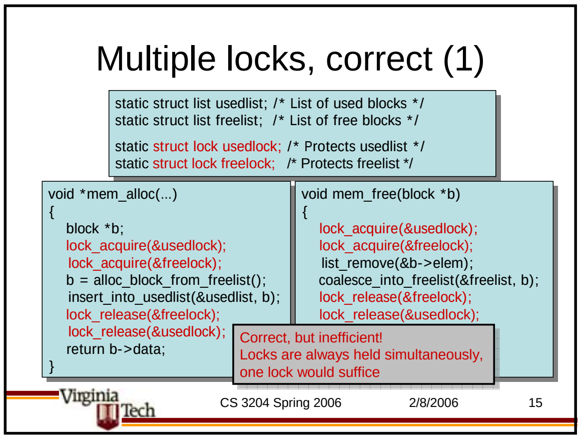
```
static struct list usedlist; /* List of used blocks */
static struct list freelist;  /* List of free blocks */

static struct lock usedlock; /* Protects usedlist */
static struct lock freelock;   /* Protects freelist */
```

```
void *mem_alloc(...)
{
    block *b;
    lock_acquire(&freelock);
    b = alloc_block_from_freelist();
    lock_acquire(&usedlock);
    insert_into_usedlist(&usedlist, b);
    lock_release(&freelock);
    lock_release(&usedlock);
    return b->data;
}
```

```
void mem_free(block *b)
{
    lock_acquire(&usedlock);
    list_remove(&b->elem);
    lock_acquire(&freelock);
    coalesce_into_freelist(&freelist, b);
    lock_release(&usedlock);
    lock_release(&freelock);
```

Also wrong: deadlock!
Always acquire multiple locks in same order -
Or don't hold them simultaneously



Multiple locks, correct (1)

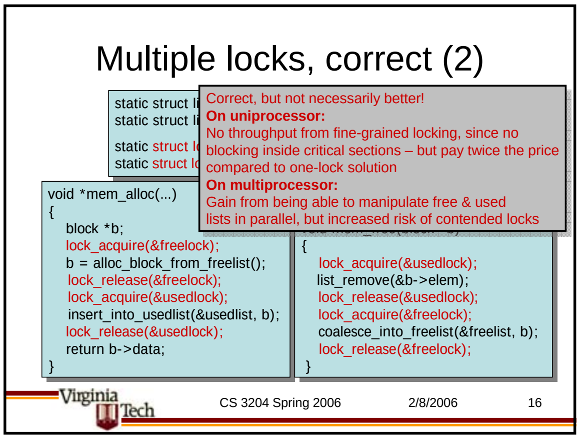
```
static struct list usedlist; /* List of used blocks */
static struct list freelist;  /* List of free blocks */

static struct lock usedlock; /* Protects usedlist */
static struct lock freelock;   /* Protects freelist */
```

```
void *mem_alloc(...)
{
    block *b;
    lock_acquire(&usedlock);
    lock_acquire(&freelock);
    b = alloc_block_from_freelist();
    insert_into_usedlist(&usedlist, b);
    lock_release(&freelock);
    lock_release(&usedlock);
    return b->data;
}
```

```
void mem_free(block *b)
{
    lock_acquire(&usedlock);
    lock_acquire(&freelock);
    list_remove(&b->elem);
    coalesce_into_freelist(&freelist, b);
    lock_release(&freelock);
    lock_release(&usedlock);
```

Correct, but inefficient!
Locks are always held simultaneously, one lock would suffice



Multiple locks, correct (2)

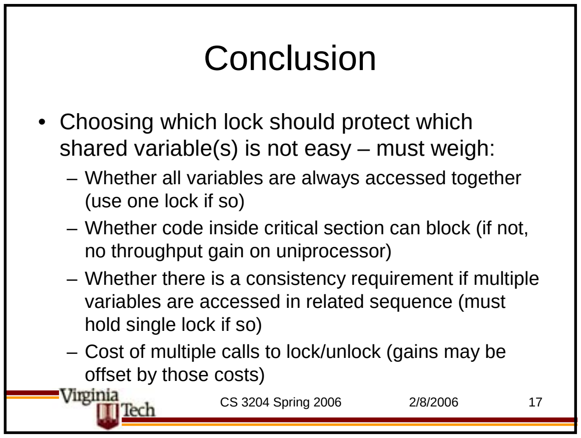
```
static struct li
static struct li

static struct lo
static struct lo
```

Correct, but not necessarily better!
On uniprocessor:
No throughput from fine-grained locking, since no blocking inside critical sections – but pay twice the price compared to one-lock solution
On multiprocessor:
Gain from being able to manipulate free & used lists in parallel, but increased risk of contended locks

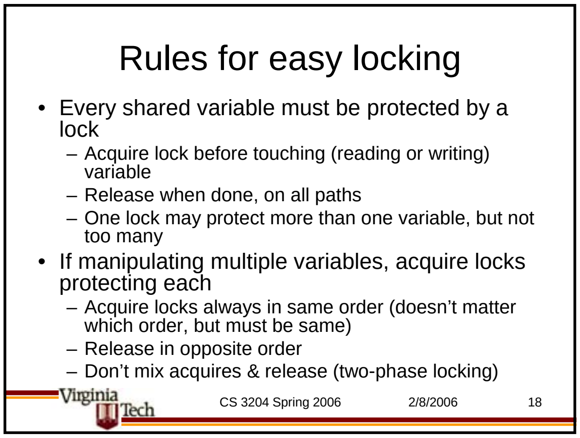
```
void *mem_alloc(...)
{
    block *b;
    lock_acquire(&freelock);
    b = alloc_block_from_freelist();
    lock_release(&freelock);
    lock_acquire(&usedlock);
    insert_into_usedlist(&usedlist, b);
    lock_release(&usedlock);
    return b->data;
}
```

```
{
    lock_acquire(&usedlock);
    list_remove(&b->elem);
    lock_release(&usedlock);
    lock_acquire(&freelock);
    coalesce_into_freelist(&freelist, b);
    lock_release(&freelock);
}
```



Conclusion

- Choosing which lock should protect which shared variable(s) is not easy – must weigh:
  - Whether all variables are always accessed together (use one lock if so)
  - Whether code inside critical section can block (if not, no throughput gain on uniprocessor)
  - Whether there is a consistency requirement if multiple variables are accessed in related sequence (must hold single lock if so)
  - Cost of multiple calls to lock/unlock (gains may be offset by those costs)



Rules for easy locking

- Every shared variable must be protected by a lock
  - Acquire lock before touching (reading or writing) variable
  - Release when done, on all paths
  - One lock may protect more than one variable, but not too many
- If manipulating multiple variables, acquire locks protecting each
  - Acquire locks always in same order (doesn't matter which order, but must be same)
  - Release in opposite order
  - Don't mix acquires & release (two-phase locking)