CS 423
Operating System Design: Synchronization II

Professor Adam Bates
Fall 2018

Goals for Today

- Learning Objectives:
  - Discuss OS support for Synchronization
- Announcements:
  - MP1 available on Compass2G. **Due February 19th!**

Reminder: Please put away devices at the start of class

Too Much Milk, Try #4

Locks allow concurrent code to be much simpler:

```
lock.acquire();
if (!milk)
    buy milk
lock.release();
```

Rules for Using Locks

- Lock is initially free
- Always acquire before accessing shared data structure
  - Beginning of procedure!
- Always release after finishing with shared data
  - End of procedure!
  - Only the lock holder can release
  - DO NOT throw lock for someone else to release
- Never access shared data without lock
  - Danger!

Ex: Thread-Safe Bounded Queue

```
tryget() {
    item = NULL;
    lock.acquire();
    if (front < tail) {
        item = buf[front % MAX];
        front++;
    }
    lock.release();
    return item;
}
```

```
tryput(item) {
    lock.acquire();
    if ((tail – front) < size) {
        buf[tail % MAX] = item;
        tail++;
    }
    lock.release();
}
```

Initially: front = tail = 0; lock = FREE; MAX is buffer capacity

Question(s)

- If tryget returns NULL, do we know the buffer is empty?

- If we poll tryget in a loop, what happens to a thread calling tryput?

Condition Variables

- Waiting inside a critical section
  - Called only when holding a lock
- CV::Wait — atomically release lock and relinquish processor
  - Reacquire the lock when wakened
- CV::Signal — wake up a waiter, if any
- CV::Broadcast — wake up all waiters, if any

Condition Variables

```
methodThatWaits() {
    lock.acquire();
    // Read/write shared state

    while (!testSharedState()) {
        cv.wait(&lock);
     }

    // Read/write shared state
    lock.release();
}
```

```
methodThatSignals() {
    lock.acquire();
    // Read/write shared state

    // If testSharedState is now true
    cv.signal(&lock);


    // Read/write shared state
    lock.release();
}
```

Ex: Bounded Queue w/ CV

```
get() {
    lock.acquire();
    while (front == tail) {
        empty.wait(lock);
    }
    item = buf[front % MAX];
    front++;
    full.signal(lock);
    lock.release();
    return item;
}
```

```
put(item) {
    lock.acquire();
    while ((tail – front) == MAX) {
        full.wait(lock);
    }
    buf[tail % MAX] = item;
    tail++;
    empty.signal(lock);
    lock.release();
}
```

Initially: front = tail = 0; MAX is buffer capacity
empty/full are condition variables

Pre/Post Conditions

- What is state of the bounded buffer at lock acquire?
  - front <= tail
  - front + MAX >= tail
- These are also true on return from wait
- And at lock release
- Allows for proof of correctness

Pre/Post Conditions

```
methodThatWaits() {
    lock.acquire();
    // Pre-condition: State is consistent

    // Read/write shared state

    while (!testSharedState()) {
         cv.wait(&lock);
     }
    // WARNING: shared state may
    // have changed!  But
   // testSharedState is TRUE
   // and pre-condition is true

   // Read/write shared state
    lock.release();
}
```

```
methodThatSignals() {
    lock.acquire();
    // Pre-condition: State is consistent

    // Read/write shared state

    // If testSharedState is now true
    cv.signal(&lock);

    // NO WARNING: signal keeps lock

    // Read/write shared state
    lock.release();
}
```

Condition Variables

- ALWAYS hold lock when calling wait, signal, broadcast
  - Condition variable is sync FOR shared state
  - ALWAYS hold lock when accessing shared state

- Condition variable is memoryless
  - If signal when no one is waiting, no op
  - If wait before signal, waiter wakes up

- Wait atomically releases lock
  - What if wait, then release?
  - What if release, then wait?

Condition Variables

- When a thread is woken up from wait, it may not run immediately
  - Signal/broadcast put thread on ready list
  - When lock is released, anyone might acquire it

- Wait MUST be in a loop

```
while (needToWait()) {
    condition.Wait(lock);
}
```

- Simplifies implementation
  - Of condition variables and locks
  - Of code that uses condition variables and locks

Mesa vs. Hoare Semantics

- Mesa
  - Signal puts waiter on ready list
  - Signaller keeps lock and processor
- Hoare
  - Signal gives processor and lock to waiter
  - When waiter finishes, processor/lock given back to signaller
  - Nested signals possible!

FIFO Bounded Queue

(Hoare Semantics)

```
get() {
    lock.acquire();
    if (front == tail) {
        empty.wait(lock);
    }
    item = buf[front % MAX];
    front++;
    full.signal(lock);
    lock.release();
    return item;
}
```

```
put(item) {
    lock.acquire();
    if ((tail – front) == MAX) {
        full.wait(lock);
    }
    buf[last % MAX] = item;
    last++;
    empty.signal(lock);
  // CAREFUL: someone else ran
    lock.release();
}
```

Initially: front = tail = 0; MAX is buffer capacity
empty/full are condition variables

FIFO Bounded Queue

(Mesa Semantics)

- Create a condition variable for every waiter
- Queue condition variables (in FIFO order)
- Signal picks the front of the queue to wake up
- CAREFUL if spurious wakeups!

- Easily extends to case where queue is LIFO, priority, priority donation, …
    - With Hoare semantics, not as easy

Synchronization Best Practices

- Identify objects or data structures that can be accessed by multiple threads concurrently
- Add locks to object/module
  - Grab lock on start to every method/procedure
  - Release lock on finish
- If need to wait
  - while(needToWait()) { condition.Wait(lock); }
  - Do not assume when you wake up, signaller just ran
- If do something that might wake someone up
  - Signal or Broadcast
- Always leave shared state variables in a consistent state
  - When lock is released, or when waiting

Remember the rules…

- Use consistent structure
- Always use locks and condition variables
- Always acquire lock at beginning of procedure, release at end
- Always hold lock when using a condition variable
- Always wait in while loop
- Never spin in sleep()

Implementing Synchronization

Concurrent Applications

Semaphores | Locks | Condition Variables

Interrupt Disable | Atomic Read/Modify/Write Instructions

Multiple Processors | Hardware Interrupts

Implementing Synchronization

- Take 1: using memory load/store
  - See too much milk solution/Peterson's algorithm
- Take 2:
  - Lock::acquire()
  - Lock::release()

Lock Implementation for Uniprocessor?

```
Lock::acquire() {
    disableInterrupts();
    if (value == BUSY) {
        waiting.add(myTCB);
        myTCB->state = WAITING;
        next = readyList.remove();
        switch(myTCB, next);
        myTCB->state = RUNNING;
    } else {
        value = BUSY;
    }
    enableInterrupts();
}
```

```
Lock::release() {
    disableInterrupts();
    if (!waiting.Empty()) {
        next = waiting.remove();
        next->state = READY;
        readyList.add(next);
    } else {
     value = FREE;
    }
    enableInterrupts();
}
```