Operating Systems
Lecture 10

lock and conditional variable design

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Much of the contents are from Prof. Ion Stoica (cs162@Berkeley)

Recap: Scheduling

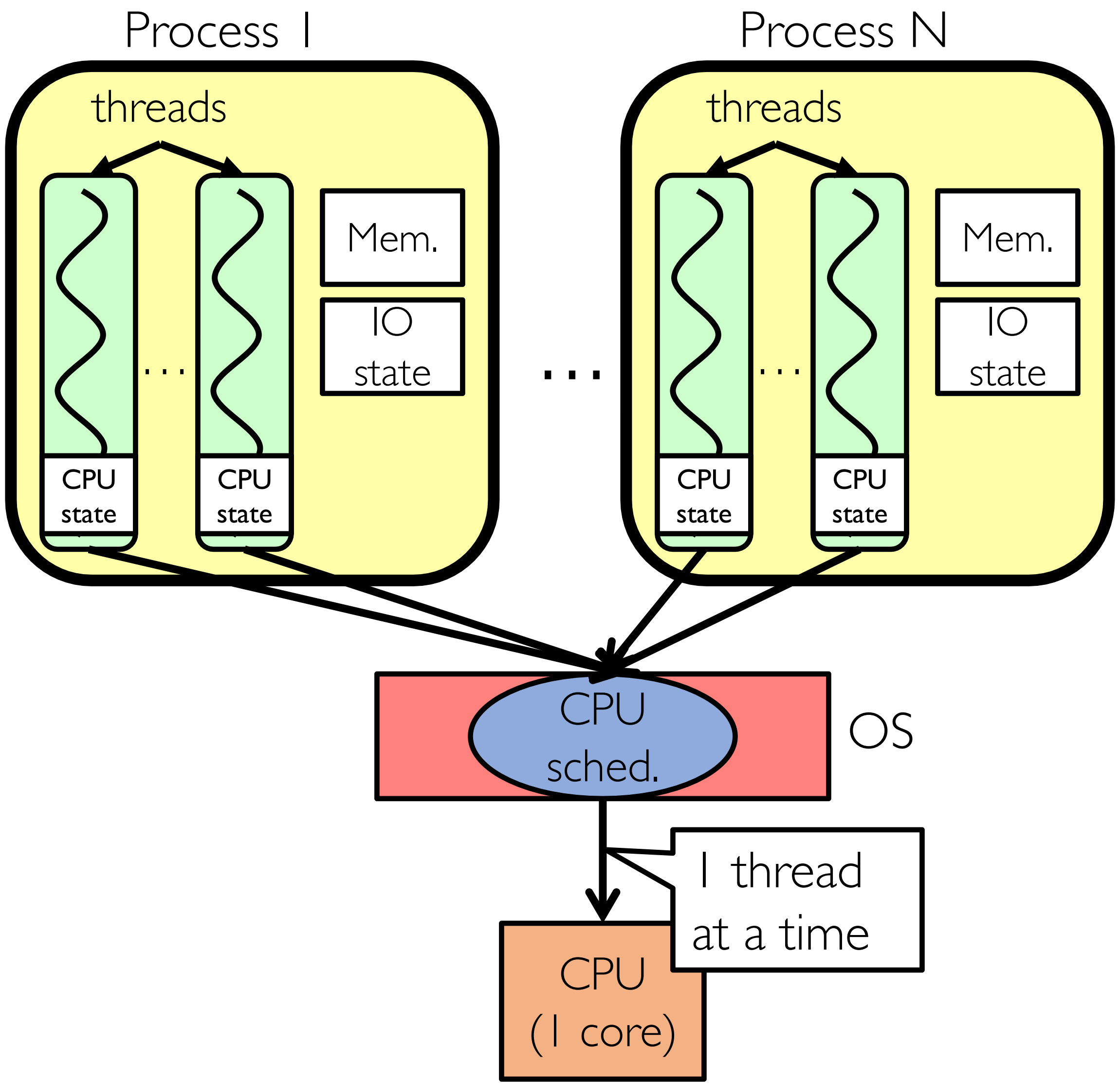
- Round-Robin Scheduling:
  - Give each thread a small amount of CPU time when it executes; cycle between all ready threads
  - Pros: Better for short jobs

- Shortest Job First (SJF) / Shortest Remaining Time First (SRTF):
  - Run whatever job has the least amount of computation to do/least remaining amount of computation to do
  - Pros: Optimal (average response time)
  - Cons: Hard to predict future, Unfair

Recap: Scheduling

- Lottery Scheduling:
  - Give each thread a priority-dependent number of tokens (short tasks $\Rightarrow$ more tokens)
- Multi-Level Feedback Scheduling:
  - Multiple queues of different priorities and scheduling algorithms
  - Automatic promotion/demotion of process priority in order to approximate SJF/SRTF
- Real-time scheduling
  - Need to meet a deadline, predictability essential
  - Earliest Deadline First (EDF) and Rate Monotonic (RM) scheduling

OS Conceptual Framework

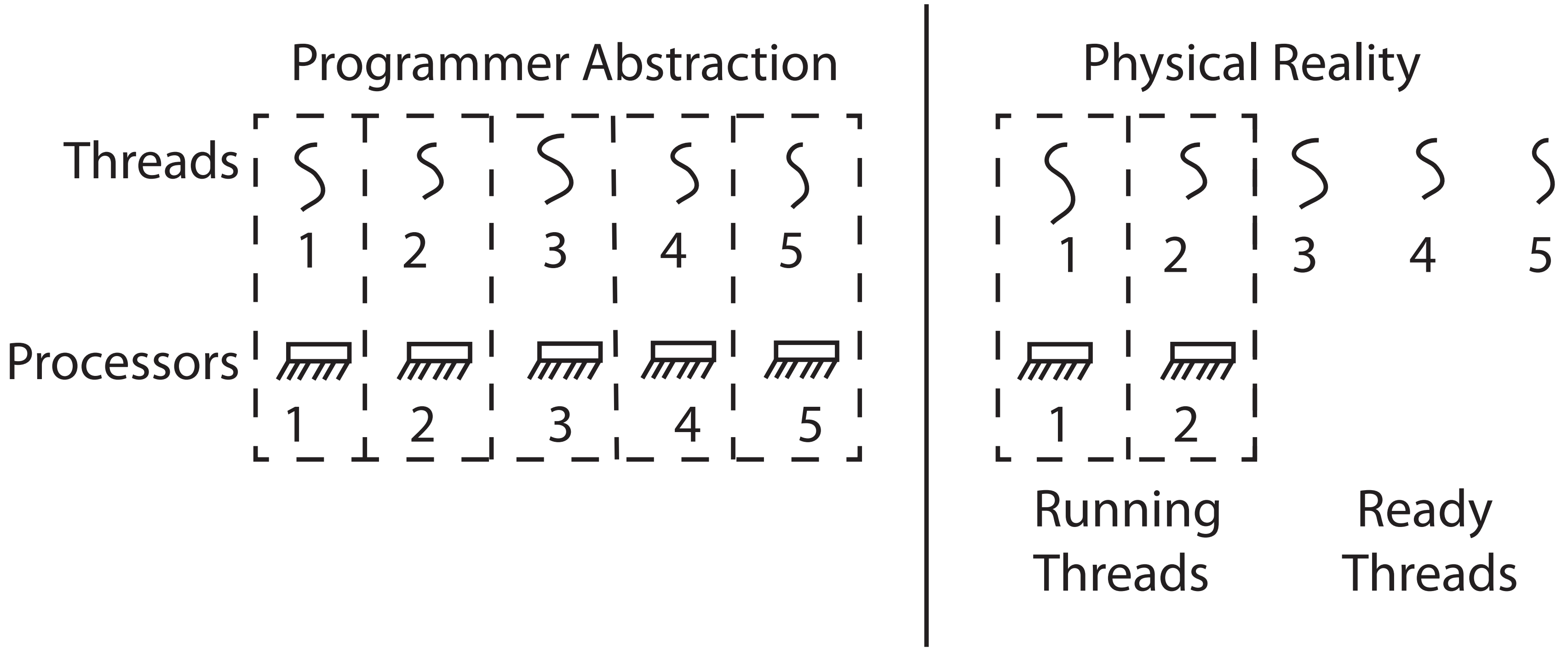


- Physical addresses shared
  - **So:** Processes and Address Translation
- CPU must be Shared
  - **So:** Threads
- Processes aren't trusted
  - **So:** Kernel/Userspace Split
- Threads might not cooperate
  - **So:** Use timer interrupts to context switch ("preemption")

Goals for Today

- Motivating synchronization: why it's difficult
- Locks
- Condition variables
- Semaphores

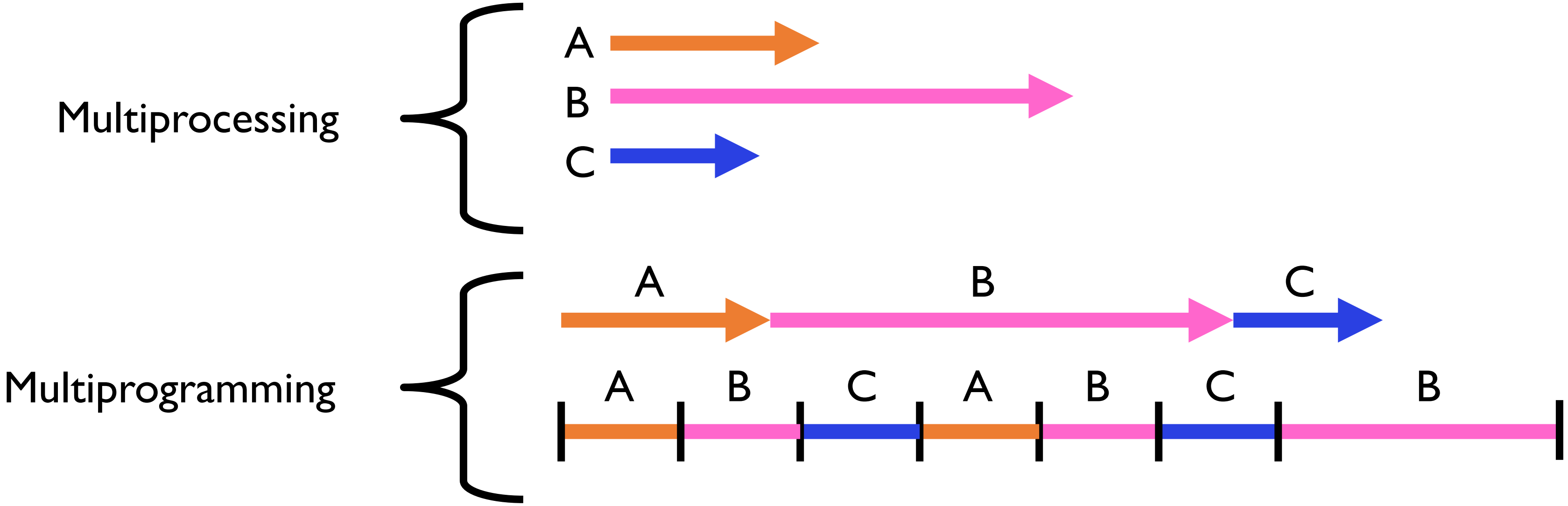
Recall: Thread Abstraction



- Infinite number of processors
- Threads execute with variable speed
  - Programs must be designed to work with any schedule

Multiprocessing vs Multiprogramming

- Remember Definitions:
  - Multiprocessing ≡ Multiple CPUs or cores or hyperthreads (HW per-instruction interleaving)
  - Multiprogramming ≡ Multiple Jobs or Processes
  - Multithreading ≡ Multiple threads per Process
- What does it mean to run two threads "concurrently"?
  - Scheduler is free to run threads in any order and interleaving: FIFO, Random, …



Why Allow Cooperating Threads?

- Advantage 1: Share resources
  - One computer, many users
  - One bank balance, many ATMs
    - ❑ What if ATMs were only updated at night?
  - Embedded systems (robot control: coordinate arm & hand)
- Advantage 2: Speedup
  - Overlap I/O and computation
    - ❑ Many different file systems do read-ahead
  - Multiprocessors – chop up program into parallel pieces
- Advantage 3: Modularity
  - More important than you might think
  - Chop large problem up into simpler pieces
    - ❑ To compile, for instance, `gcc` calls `cpp | cc1 | cc2 | as | ld`
    - ❑ Makes system easier to extend

Correctness for Systems with Concurrency

- If dispatcher can schedule threads in any way, programs must work under all circumstances
  - Can you test for this?
  - How can you know if your program works?
- Independent Threads:
  - No state shared with other threads
  - Deterministic ⇒ Input state determines results
  - Reproducible ⇒ Can recreate Starting Conditions, I/O
  - Scheduling order doesn't matter (if `switch()` works!!!)
- Cooperating Threads:
  - Shared State between multiple threads
  - Non-deterministic
  - Non-reproducible
- Non-deterministic and Non-reproducible means that bugs can be intermittent
  - Sometimes called "Heisenbugs"

Interactions Complicate Debugging

- Is any program truly independent?
  - Every process shares the file system, OS resources, network, etc.
  - Extreme example: buggy device driver causes thread A to crash "independent thread" B

- Non-deterministic errors are really difficult to find
  - Example: Memory layout of kernel+user programs
    - ❑ Depends on scheduling, which depends on timer/other things
    - ❑ Original UNIX had a bunch of non-deterministic errors

Problem is at the Lowest Level

- Most of the time, threads are working on separate data, so scheduling doesn't matter:

Thread A	Thread B
x = 1;	y = 2;

- However, what about (Initially, y = 12):

Thread A	Thread B
x = 1;	x = 2;

  - X could be 1 or 2 (non-deterministic!)
  - Could even be 3 for serial processors:
    - ❑ Thread A writes 0001, B writes 0010 → scheduling order ABABABBA yields 3!

Problem is at the Lowest Level

- A more complex case (Initially, x = 0):

Thread A	Thread B
x = x + 1;	x = x + 2;

```
load r1, x
add r2, r1, 1
store x, r2
```

```
load r1, x
add r2, r1, 2
store x, r2
```

- What are the possible outputs?

Problem is at the Lowest Level

- A more complex case (Initially, x = 0):

Thread A: `x = x + 1;`

Thread B: `x = x + 2;`

```
load r1, x
add r2, r1, 1
store x, r2
                load r1, x
                add r2, r1, 2
                store x, r2
```

Final: x = 3

```
load r1, x
                load r1, x
add r2, r1, 1
                add r2, r1, 2
store x, r2
                store x, r2
```

Final: x = 2

```
load r1, x
add r2, r1, 1
                load r1, x
                add r2, r1, 2
                store x, r2
store x, r2
```

Final: x = 1

What's Worse: Reordered Instructions by Compiler

- Compilers could reorder the instructions to maximize the instruction level parallelism.
  - Yet, it only ensures the dependency correctness within a thread, not across threads.
  - pInitialized could be set to true before funcA().

Thread A	Thread B
p = funcA();	y = 2;
pInitialized = true;	while(!pInitialized); // wait
	q = funcB(p)

Atomic Operations

- To understand a concurrent program, we need to know what the underlying indivisible operations are!
- Atomic Operation (原子操作): an operation that always runs to completion or not at all
  - It is *indivisible:* it cannot be stopped in the middle and state cannot be modified by someone else in the middle
  - Fundamental building block – if no atomic operations, then have no way for threads to work together
- On most machines, memory references and assignments (i.e. loads and stores) of words are atomic
  - Consequently – weird example that produces "3" on previous slide can't happen
- Many instructions are not atomic
  - Double-precision floating point store often not atomic
  - VAX and IBM 360 had an instruction to copy a whole array

Motivation: "Too Much Milk"

- Great thing about OS's – analogy between problems in OS and problems in real life
  - Help you understand real life problems better
  - But, computers are much stupider than people
- Example: People need to coordinate:

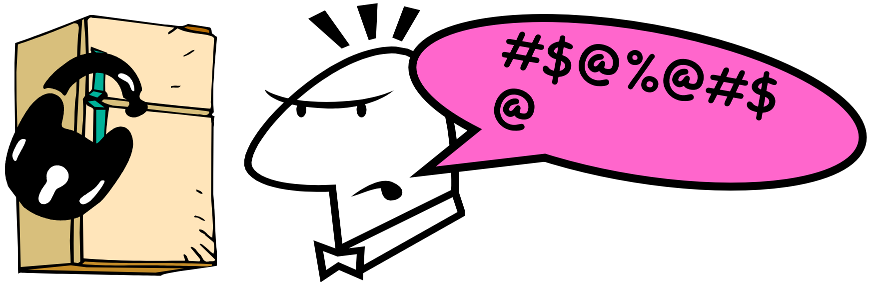
Time	Person A	Person B
3:00	Look in Fridge. Out of milk	
3:05	Leave for store	
3:10	Arrive at store	Look in Fridge. Out of milk
3:15	Buy milk	Leave for store
3:20	Arrive home, put milk away	Arrive at store
3:25		Buy milk
3:30		Arrive home, put milk away

Definitions

- Synchronization (同步): using atomic operations to ensure cooperation between threads
  - For now, only loads and stores are atomic
  - We are going to show that its hard to build anything useful with only reads and writes
- Mutual Exclusion (互斥): ensuring that only one thread does a particular thing at a time
  - One thread *excludes* the other while doing its task
- Critical Section (临界区): piece of code that only one thread can execute at once.
  - Critical section is the result of mutual exclusion
  - Critical section and mutual exclusion are two ways of describing the same thing

Definitions

- Lock: prevents someone from doing something
  - Lock before entering critical section and before accessing shared data
  - Unlock when leaving, after accessing shared data
  - Wait if locked
    - Important idea: all synchronization involves waiting
- For example: fix the milk problem by putting a key on the refrigerator
  - Lock it and take key if you are going to go buy milk
  - Fixes too much: roommate angry if only wants orange



  - Of Course – We don't know how to make a lock yet

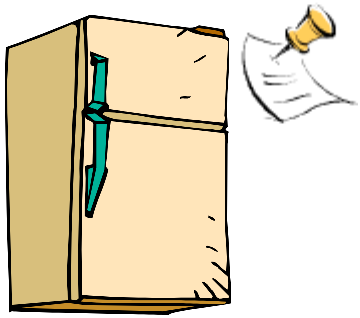
Too Much Milk: Correctness Properties

- Need to be careful about correctness of concurrent programs, since non-deterministic
  - Impulse is to start coding first, then when it doesn't work, pull hair out
  - Instead, think first, then code
  - Always write down behavior first
- What are the correctness properties for the "Too much milk" problem???
  - Never more than one person buys
  - Someone buys if needed
- Restrict ourselves to use only atomic load and store operations as building blocks

Too Much Milk: Solution #1

- Use a note to avoid buying too much milk:
  - Leave a note before buying (kind of "lock")
  - Remove note after buying (kind of "unlock")
  - Don't buy if note (wait)
- Suppose a computer tries this (remember, only memory read/write are atomic):

```
if (noMilk) {
   if (noNote) {
      leave Note;
      buy milk;
      remove note;
   }
}
```



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  - Remove note after buying (kind of "unlock")
  - Don't buy if note (wait)
- Suppose a computer tries this (remember, only memory read/write are atomic):

Thread A

```
if (noMilk) {


   if (noNote) {
    leave Note;
    buy Milk;
    remove Note;
   }
}
```

Thread B

```

if (noMilk) {
   if (noNote) {






      leave Note;
      buy Milk;
      remove Note;
   }
}
```

Too Much Milk: Solution #1

- Use a note to avoid buying too much milk:
  - Leave a note before buying (kind of "lock")
  - Remove note after buying (kind of "unlock")
  - Don't buy if note (wait)
- Suppose a computer tries this (remember, only memory read/write are atomic):

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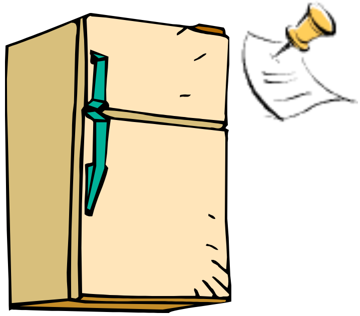
      remove note;
   }
}
```



- Result?
  - Still too much milk but only occasionally!
  - Thread can get context switched after checking milk and note but before buying milk!
- Solution makes problem worse since fails intermittently
  - Makes it really hard to debug…
  - Must work despite what the dispatcher does!

Too Much Milk: Solution #1½

- Clearly the Note is not quite blocking enough
  - Let's try to fix this by placing note first
- Another try at previous solution:

```
leave Note;
if (noMilk) {
   if (noNote) {
      buy milk;
   }
}
remove Note;
```

- What happens here?
  - Well, with human, probably nothing bad
  - With computer: no one ever buys milk

Too Much Milk Solution #2

- How about labeled notes?
  - Now we can leave note before checking
- Algorithm looks like this:

Thread A

```
leave note A;
if (noNote B) {
   if (noMilk) {
      buy Milk;
   }
}
remove note A;
```

Thread B

```
leave note B;
if (noNoteA) {
   if (noMilk) {
      buy Milk;
   }
}
remove note B;
```

- Does this work?

Too Much Milk Solution #2

- How about labeled notes?
  - Now we can leave note before checking
- Algorithm looks like this:

Thread A

```
leave note A;
if (noNote B) {
   if (noMilk) {
      buy Milk;
   }
}
remove note A;
```

Thread B

```
leave note B;
if (noNoteA) {
   if (noMilk) {
      buy Milk;
   }
}
remove note B;
```

- Does this work?
- Possible for neither thread to buy milk
  - Context switches at exactly the wrong times can lead each to think that the other is going to buy
- Really insidious:
  - Extremely unlikely this would happen, but will at worse possible time
  - Probably something like this in UNIX

Too Much Milk Solution #3

- Here is a possible two-note solution:

Thread A

```
leave note A;
while (note B) {\\X
   do nothing;
}
if (noMilk) {
   buy milk;
}
remove note A;
```

Thread B

```
leave note B;
if (noNote A) {\\Y
   if (noMilk) {
      buy milk;
   }
}
remove note B;
```

- Does this work?

Too Much Milk Solution #3

- Here is a possible two-note solution:

Thread A

```
leave note A;
while (note B) { \\X
    do nothing;
}
if (noMilk) {
    buy milk;
}
remove note A;
```

Thread B

```
leave note B;
if (noNote A) { \\Y
    if (noMilk) {
        buy milk;
    }
}
remove note B;
```

- Does this work? Yes. Both can guarantee that:
  - It is safe to buy, or
  - Other will buy, ok to quit
- At **X**:
  - If no note B, safe for A to buy,
  - Otherwise wait to find out what will happen
- At **Y**:
  - If no note A, safe for B to buy
  - Otherwise, A is either buying or waiting for B to quit

Case 1

- "`leave note A`" happens before "`if (noNote A)`"

```
leave note A;
while (note B) {\\X

    do nothing;
};




if (noMilk) {

    buy milk;}
}
remove note A;
```

happened before

```
leave note B;
if (noNote A) {\\Y
    if (noMilk) {
        buy milk;

    }
}
remove note B;
```

Case 1

- "`leave note A`" happens before "`if (noNote A)`"

```
leave note A;
while (note B) {\\X
    do nothing;
};
```

happened before

```
leave note B;
if (noNote A) {\\Y
    if (noMilk) {
        buy milk;
    }
}
remove note B;
```

```
if (noMilk) {
    buy milk;}
}
remove note A;
```

Case I

- "`leave note A`" happens before "`if (noNote A)`"

```
leave note A;
while (note B) {\\X
    do nothing;
};
```

happened before

```
leave note B;
if (noNote A) {\\Y
    if (noMilk) {
        buy milk;
    }
}
remove note B;
```

Wait for note B to be remove

```
if (noMilk) {
    buy milk;}
}
remove note A;
```

Case 2

- "`if (noNote A)`" happens before "`leave note A`"

```
leave note A;
while (note B) {\\X

    do nothing;
};



if (noMilk) {

    buy milk;}
}
remove note A;
```

happened before

```
leave note B;
if (noNote A) {\\Y
    if (noMilk) {
        buy milk;
    }
}
remove note B;
```

Case 2

- "`if (noNote A)`" happens before "`leave note A`"

```
leave note A;
while (note B) {\\X
    do nothing;
};
```

happened before

```
leave note B;
if (noNote A) {\\Y
    if (noMilk) {
        buy milk;
    }
}
remove note B;
```

```
if (noMilk) {
    buy milk;}
}
remove note A;
```

Case 2

- "`if (noNote A)`" happens before "`leave note A`"

```
leave note A;
while (note B) {\\X
    do nothing;
};
```

happened before

```
leave note B;
if (noNote A) {\\Y
    if (noMilk) {
        buy milk;
    }
}
remove note B;
```

Wait for note B to be remove

```
if (noMilk) {
    buy milk;}
}
remove note A;
```

Solution #3 Discussion

- Our solution protects a single "Critical-Section" piece of code for each thread:

```
if (noMilk) {
   buy milk;
}
```

- Solution #3 works, but it's really unsatisfactory
  - Really complex – even for this simple example
    - ❑ Hard to convince yourself that this really works
  - A's code is different from B's – what if lots of threads?
    - ❑ Code would have to be slightly different for each thread
  - While A is waiting, it is consuming CPU time
    - ❑ This is called "busy-waiting"
- There's a better way
  - Have hardware provide higher-level primitives than atomic load & store
  - Build even higher-level programming abstractions on this hardware support

Too Much Milk: Solution #4

- Suppose we have some sort of implementation of a lock
  - `lock.Acquire()` – wait until lock is free, then grab
  - `lock.Release()` – Unlock, waking up anyone waiting
  - These must be atomic operations – if two threads are waiting for the lock and both see it's free, only one succeeds to grab the lock
- Then, our milk problem is easy:

```
milklock.Acquire();
if (nomilk)
   buy milk;
milklock.Release();
```

- Once again, section of code between `Acquire()` and `Release()` called a "Critical Section"

Where are we going with synchronization?

Programs	Shared Programs
Higher-level API	Locks Semaphores Monitors Send/Receive
Hardware	Load/Store Disable Ints Test&Set Compare&Swap

- We are going to implement various higher-level synchronization primitives using atomic operations
  - Everything is pretty painful if only atomic primitives are load and store
  - Need to provide primitives useful at user-level

Lock

- Suppose we have some sort of implementation of a lock
  - `lock.Acquire()` – wait until lock is free, then grab
  - `lock.Release()` – Unlock, waking up anyone waiting
  - These must be atomic operations – if two threads are waiting for the lock and both see it's free, only one succeeds to grab the lock
- 3 formal properties
  - Mutual exclusion: at most one thread holds the lock
  - Progress: if no thread holds the lock and any thread attempts to acquire the lock, then eventually some thread succeeds in acquiring the lock
  - Bounded waiting: if thread T attempts to acquire a lock, then there exists a bound on the number of times other threads can successfully acquire the lock before T does
    - ❑ Yet, it does not promise that waiting threads acquire the lock in FIFO order.

What does a Lock Guarantee?

- A simple case of lock.
  - Assuming x is shared among threads
  - Other threads only access x with lock

```
int x = 0;
// T1: can we ensure x = 0 here?
lock.acquire();
// T2: can we ensure x = 0 here?
x = 1;
// T3: can we ensure x = 1 here?
lock.release();
// T4: can we ensure x = 1 here?
x = 2;
// T5: can we ensure x = 2 here?
```

What does a Lock Guarantee?

- A simple case of lock.
  - Assuming x is shared among threads
  - Other threads only access x with lock

If a lock is not held, nothing can be guaranteed!

```
int x = 0;
// T1: can we ensure x = 0 here?
lock.acquire();
// T2: can we ensure x = 0 here?
x = 1;
// T3: can we ensure x = 1 here?
lock.release();
// T4: can we ensure x = 1 here?
x = 2;
// T5: can we ensure x = 2 here?
```

Condition Variable

- Condition Variable (条件变量): a queue of threads waiting for something *inside* a critical section
  - Key idea: allow sleeping inside critical section by atomically releasing lock at time we go to sleep
- Operations:
  - `Wait(&lock)`: Atomically release lock and go to sleep. Re-acquire lock later, before returning.
  - `Signal()`: Wake up one waiter, if any
  - `Broadcast()`: Wake up all waiters
  - Differentiate them from UNIX wait and signal

Condition Variable Example

- Condition Variable (条件变量): a queue of threads waiting for something *inside* a critical section
  - Key idea: allow sleeping inside critical section by atomically releasing lock at time we go to sleep
- A common pattern:

```
FuncA_wait() {
    lock.acquire();
    // read/write shared state here
    while (!testOnSharedState())
        cv.wait(&lock);
    assert(testOnSharedState());
    lock.release();
}
```

```
FuncB_signal() {
    lock.acquire();
    // read/write shared state here
    // If state has changed that allows
another thread to make progress, call
signal or broadcast
    cv.signal();
    lock.release();
}
```

Condition Variable Example

- A concrete example of bounded queue implementation (or producer-consumer, 生产者消费者)

```
class bounded_queue {
    Lock lock;
    CV itemAdded;
    CV itemRemoved;
    void insert(int item);
    int remove();
}
```

```
void bounded_queue::insert(int item) {
    lock.acquire();
    while (queue.full()) {
        itemRemoved.wait(&lock);
    }
    add_item(item);
    itemAdded.signal();
    lock.release();
}
```

How to implement remove()?

Condition Variable Example

- A concrete example of bounded queue implementation (or producer-consumer, 生产者消费者)

- Two key principles
  - CV is always used with lock acquired
  - CV is put in a while loop. Why?

```
void bounded_queue::insert(int item) {
    lock.acquire();
    while (queue.full()) {
        itemRemoved.wait(&lock);
    }
    add_item(item);
    itemAdded.signal();
    lock.release();
}
```

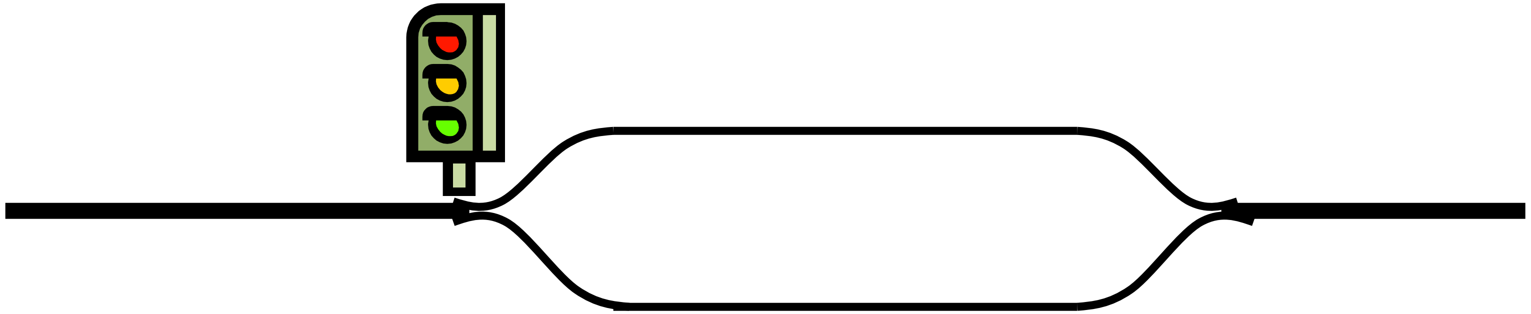
Semaphores

- Semaphores (信号量) are a kind of generalized lock
  - First defined by Dijkstra in late 60s
  - Main synchronization primitive used in original UNIX

- Definition: a Semaphore has a non-negative integer value and supports the following two operations:
  - P(): an atomic operation that waits for semaphore to become positive, then decrements it by 1
    - ❑Think of this as the wait() operation
  - V(): an atomic operation that increments the semaphore by 1, waking up a waiting P, if any
    - ❑This of this as the signal() operation
  - Note that P() stands for "*proberen*" (to test) and V() stands for "*verhogen*" (to increment) in Dutch

Semaphores vs. Integers

- Semaphores are like integers, except
  - No negative values
  - Only operations allowed are P and V – can't read or write value, except to set it initially
  - Operations must be atomic
    - ❑ Two P's together can't decrement value below zero
    - ❑ Similarly, thread going to sleep in P won't miss wakeup from V – even if they both happen at same time
- Semaphore from railway analogy
  - Here is a semaphore initialized to 2 for resource control:



Two Uses of Semaphores

1. Mutual Exclusion (initial value = 1)

- Also called "Binary Semaphore".
- Can be used for mutual exclusion:

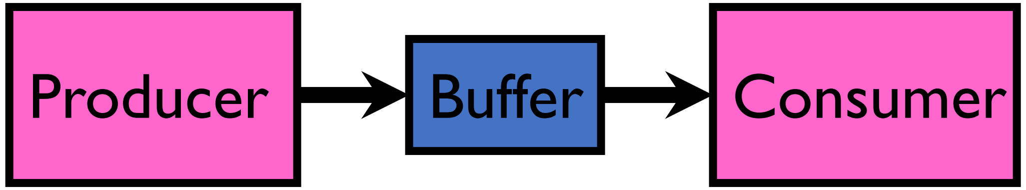
```
semaphore.P();
// Critical section goes here
semaphore.V();
```

2. Scheduling Constraints (initial value = 0)

- Allow thread 1 to wait for a signal from thread 2, i.e., thread 2 schedules thread 1 when a given event occurs
- Example: suppose you had to implement ThreadJoin which must wait for thread to terminate:

```
Initial value of semaphore = 0
ThreadJoin {
   semaphore.P();
}
ThreadFinish {
   semaphore.V();
}
```

Producer-Consumer with a Bounded Buffer



- Problem Definition
  - Producer puts things into a shared buffer
  - Consumer takes them out
  - Need synchronization to coordinate producer/consumer
- Don't want producer and consumer to have to work in lockstep, so put a fixed-size buffer between them
  - Need to synchronize access to this buffer
  - Producer needs to wait if buffer is full
  - Consumer needs to wait if buffer is empty
- Example 1: GCC compiler
  - `cpp | cc1 | cc2 | as | ld`
- Example 2: Coke machine
  - Producer can put limited number of Cokes in machine
  - Consumer can't take Cokes out if machine is empty

Correctness constraints for solution

- Correctness Constraints:
  - Consumer must wait for producer to fill buffers, if none full (scheduling constraint)
  - Producer must wait for consumer to empty buffers, if all full (scheduling constraint)
  - Only one thread can manipulate buffer queue at a time (mutual exclusion)
- Remember why we need mutual exclusion
  - Because computers are stupid
  - Imagine if in real life: the delivery person is filling the machine and somebody comes up and tries to stick their money into the machine
- General rule of thumb:
  Use a separate semaphore for each constraint
  - `Semaphore fullSlots; // consumer's constraint`
  - `Semaphore emptySlots;// producer's constraint`
  - `Semaphore mutex;       // mutual exclusion`

Full Solution to Bounded Buffer

```
Semaphore fullSlots = ?;
Semaphore emptySlots = ?;

Semaphore mutex = 1;          // No one using machine

Producer(item) {
    emptySlots.P();           // Wait until space
    mutex.P();                // Wait until machine free
    Enqueue(item);
    mutex.V();
    fullSlots.V();            // Tell consumers there is
                              // more coke
}

Consumer() {
    fullSlots.P();            // Check if there's a coke
    mutex.P();                // Wait until machine free
    item = Dequeue();
    mutex.V();
    emptySlots.V();           // tell producer need more
    return item;
}
```

Full Solution to Bounded Buffer

```
Semaphore fullSlots = 0;      // Initially, no coke
Semaphore emptySlots = bufSize;
                              // Initially, num empty slots
Semaphore mutex = 1;          // No one using machine

Producer(item) {
    emptySlots.P();           // Wait until space
    mutex.P();                // Wait until machine free
    Enqueue(item);
    mutex.V();
    fullSlots.V();            // Tell consumers there is
                              // more coke
}

Consumer() {
    fullSlots.P();            // Check if there's a coke
    mutex.P();                // Wait until machine free
    item = Dequeue();
    mutex.V();
    emptySlots.V();           // tell producer need more
    return item;
}
```

Discussion about Solution

Why asymmetry?

- Producer does: `emptySlots.P()`, `fullSlots.V()`
- Consumer does: `fullSlots.P()`, `emptySlots.V()`

Decrease # of empty slots

Increase # of occupied slots

Decrease # of occupied slots

Increase # of empty slots

Discussion about Solution

Is order of P's important?

Is order of V's important?

What if we have 2 producers or 2 consumers?

```
Producer(item) {
    mutex.P();
    emptySlots.P();
    Enqueue(item);
    mutex.V();
    fullSlots.V();
}
Consumer() {
    fullSlots.P();
    mutex.P();
    item = Dequeue();
    mutex.V();
    emptySlots.V();
    return item;
}
```

Discussion about Solution

Is order of P's important?

- Yes! Can cause deadlock

Is order of V's important?

- No, except that it might affect scheduling efficiency

What if we have 2 producers or 2 consumers?

- Do we need to change anything?

```
Producer(item) {
    mutex.P();
    emptySlots.P();
    Enqueue(item);
    mutex.V();
    fullSlots.V();
}
Consumer() {
    fullSlots.P();
    mutex.P();
    item = Dequeue();
    mutex.V();
    emptySlots.V();
    return item;
}
```

Some Advices

- Always acquire the lock at the beginning of a method and release it right before the return
  - Consistent behavior makes it easier to program
  - Also makes it easier to read and debug

Some Advices

- Always acquire the lock at the beginning of a method and release it right before the return
  - Consistent behavior makes it easier to program
  - Also makes it easier to read and debug
- A case: double-checked locking

```
Singleton* Singleton::instance() {
    if (pInstance == NULL) {
        pInstance = new Instance();
    }
    return pInstance;
}
```

An unsafe solution

```
Singleton* Singleton::instance() {
    lock.acquire();
    if (pInstance == NULL) {
        pInstance = new Instance();
    }
    lock.release();
    return pInstance;
}
```

A safe solution

```
Singleton* Singleton::instance() {
    if (pInstance == NULL) {
        lock.acquire();
        if (pInstance == NULL) {
            pInstance = new Instance();
        }
        lock.release();
    }
    return pInstance;
}
```

An ``optimized" solution.

Is it safe?

https://www.cs.umd.edu/~pugh/java/memoryModel/DoubleCheckedLocking.html