Goals for Today

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne

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- Continue with Synchronization Abstractions
  - Semaphores and monitors

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  - Semaphores and monitors
- Readers-Writers problem and solutoin
- Language Support for Synchronization

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Recall: Semaphores

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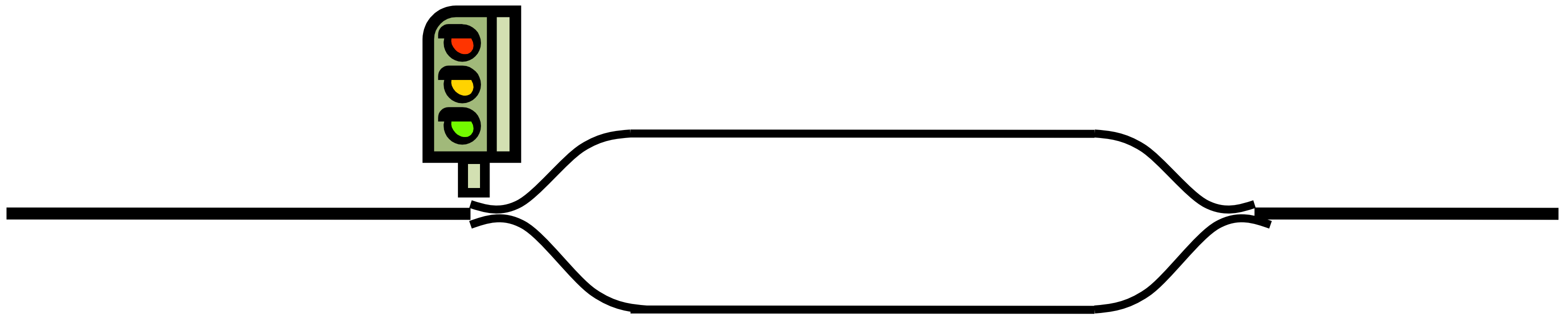

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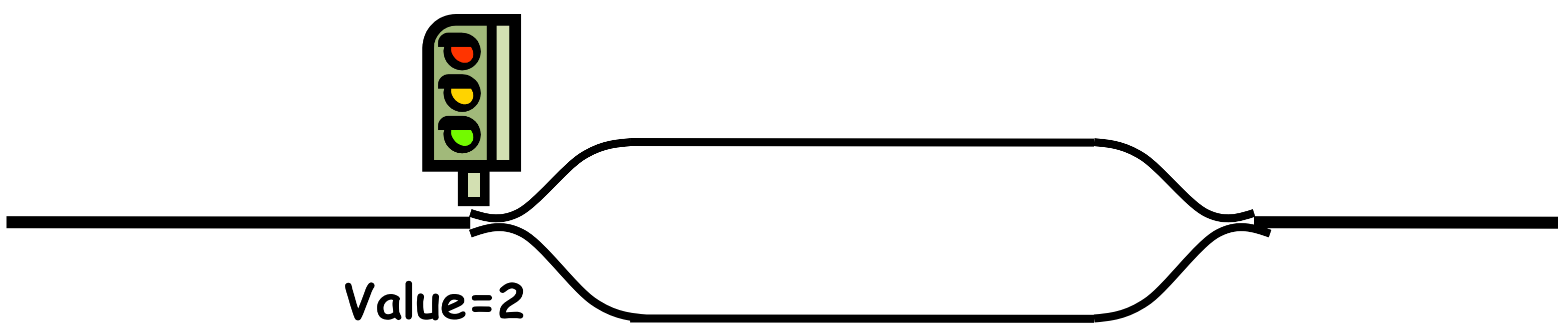

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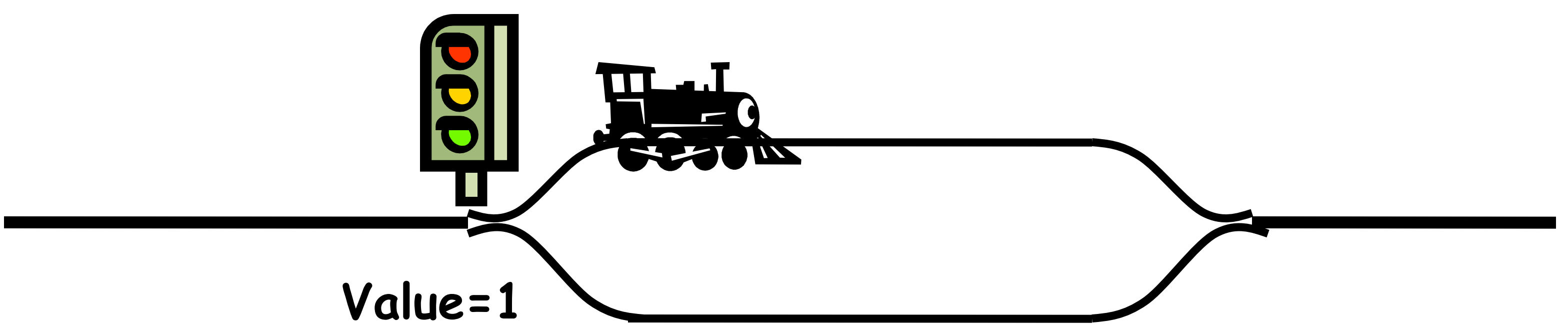

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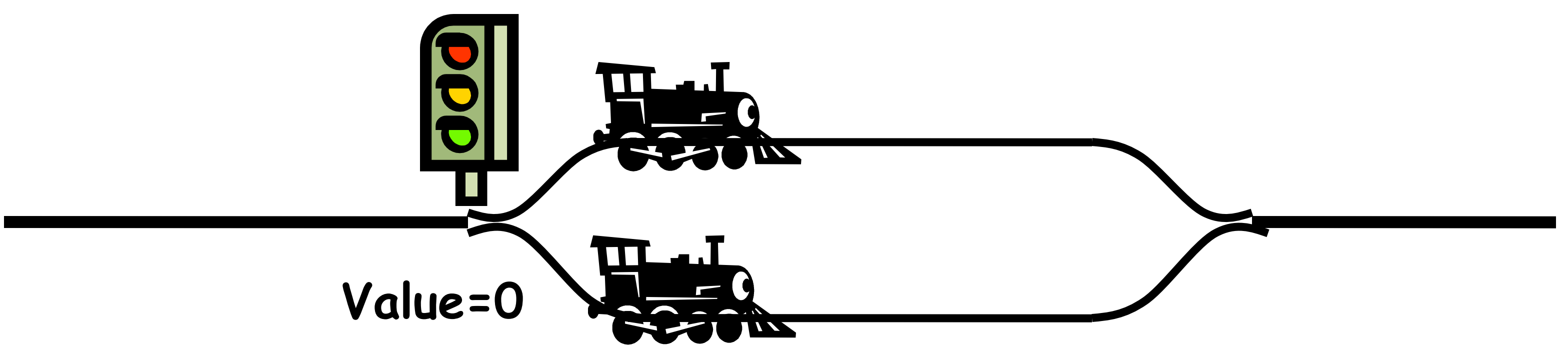

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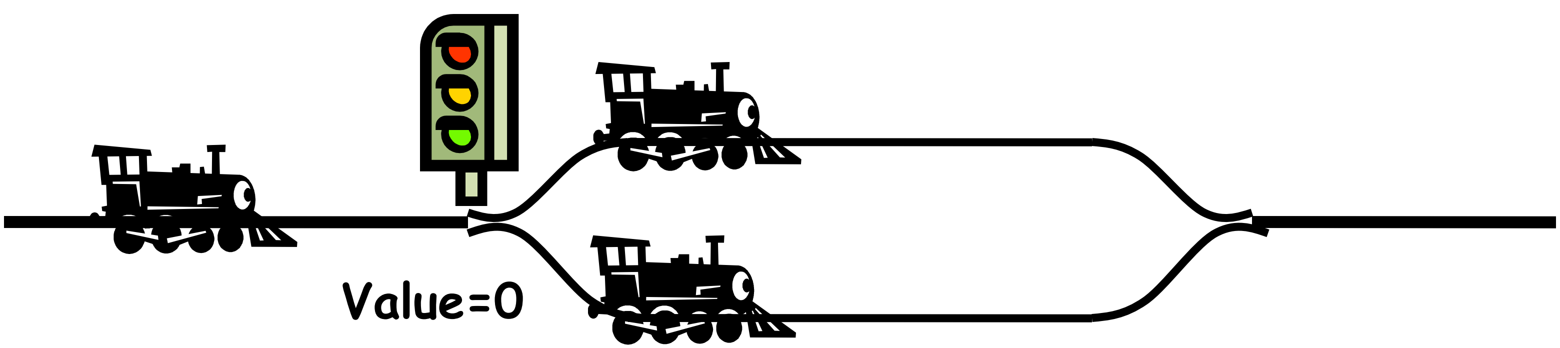

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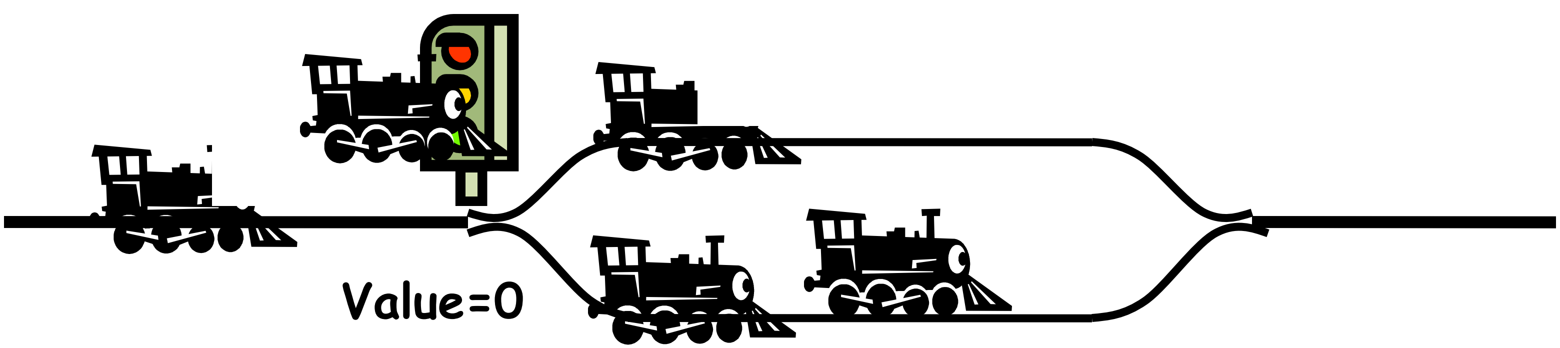

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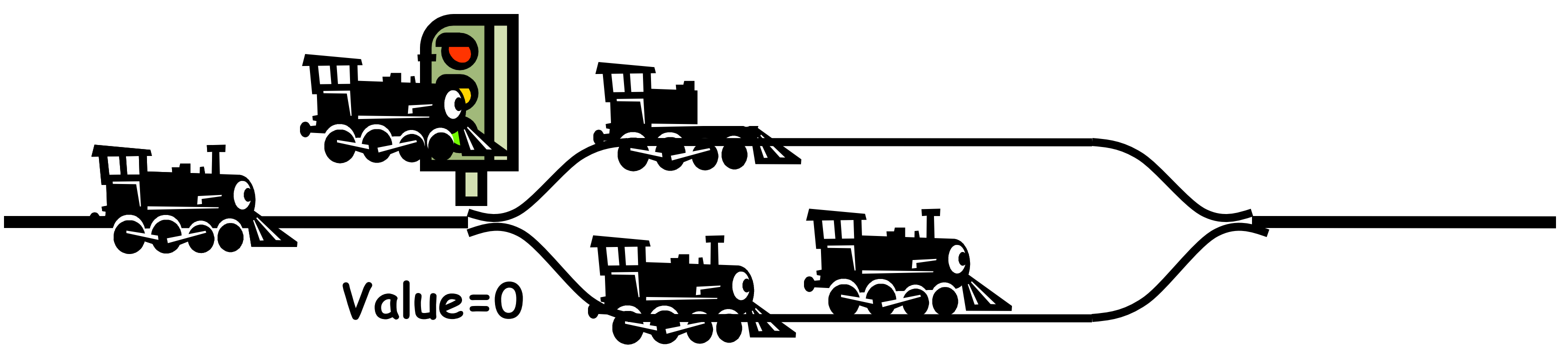

Producer-consumer with a bounded buffer

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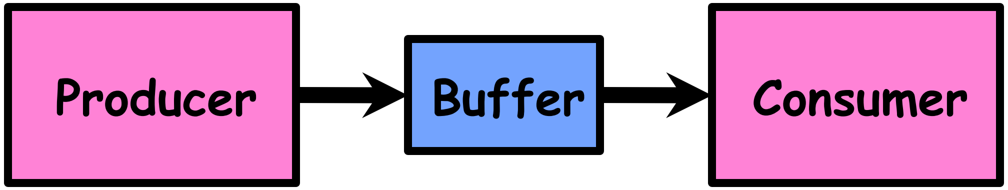

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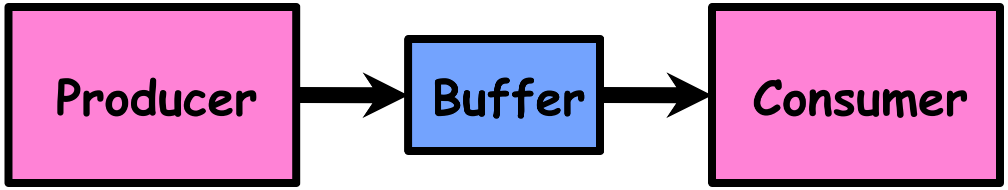

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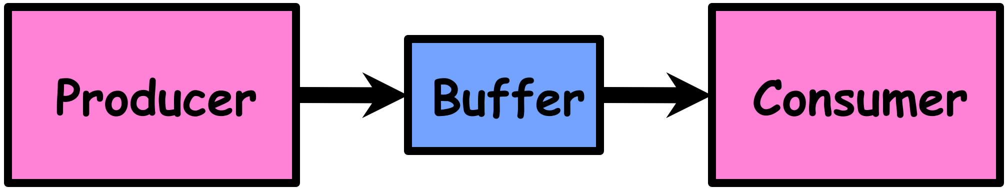

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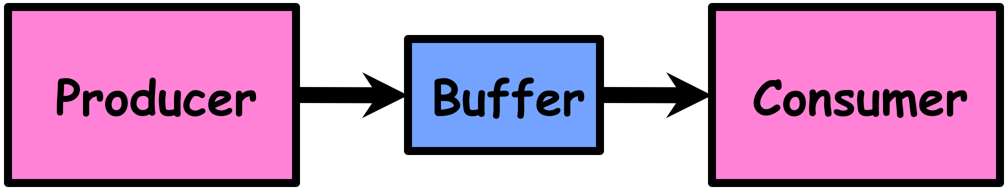

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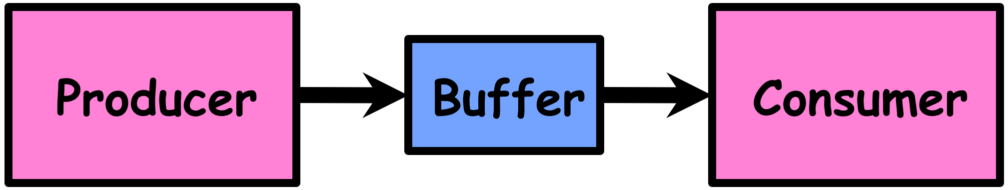

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- Example 1: GCC compiler
  - cpp | cc1 | cc2 | as | ld

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- **Correctness Constraints:**
  - Consumer must wait for producer to fill buffers, if none full (scheduling constraint)
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- 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 fullBuffers; // consumer's constraint`
  - `Semaphore emptyBuffers;// producer's constraint`
  - `Semaphore mutex;       // mutual exclusion`

Full Solution to Bounded Buffer (Coke Machine)

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Semaphore mutex = 1;         // No one using machine

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

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

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- Is order of P's important?
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- 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?

Motivation for Monitors and Condition Variables

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- Semaphores are a huge step up, but:
  - They are confusing because they are dual purpose:
    - » Both mutual exclusion and scheduling constraints
    - » Example: the fact that flipping of P's in bounded buffer gives deadlock is not immediately obvious
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- Definition: Monitor: a lock and zero or more condition variables for managing concurrent access to shared data
  - Use of Monitors is a programming paradigm
  - Some languages like Java provide monitors in the language
- The lock provides mutual exclusion to shared data:
  - Always acquire before accessing shared data structure
  - Always release after finishing with shared data

Critical Section: Monitors

- Basic idea:
  - Restrict programming model
  - Permit access to shared variables only within a critical section
- General program structure
  - Entry section
    - “Lock” before entering critical section
    - Wait if already locked
    - Key point: synchronization may involve wait
  - Critical section code
  - Exit section
    - “Unlock” when leaving the critical section
- Object-oriented programming style
  - Associate a lock with each shared object
  - Methods that access shared object are critical sections
  - Acquire/release locks when entering/exiting a method that defines a critical section

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AddToQueue(item) {
   lock.Acquire();           // Lock shared data
   queue.enqueue(item);      // Add item
   lock.Release();           // Release Lock
}
```

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Queue queue;


AddToQueue(item) {
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   queue.enqueue(item);     // Add item
   lock.Release();          // Release Lock
}


RemoveFromQueue() {
   lock.Acquire();          // Lock shared data
   item = queue.dequeue();// Get next item or null
   lock.Release();          // Release Lock
   return(item);            // Might return null
}
```

Mesa vs. Hoare monitors

Mesa vs. Hoare monitors

- Need to be careful about precise definition of signal and wait. Consider a piece of our dequeue code:

```
while (queue.isEmpty()) {
   dataready.wait(&lock); // If nothing, sleep
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    » Signaler gives lock, CPU to waiter; waiter runs immediately
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    - » Waiter placed on ready queue with no special priority
    - » Practically, need to check condition again after wait

Hoare Monitors: Semantics

- Hoare monitor semantics:
  - Assume thread *T1* is waiting on condition *x*
  - Assume thread *T2* is in the monitor
  - Assume thread *T2* calls *x*.signal
  - *T2* gives up monitor, *T2* blocks!
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x.wait      // T1 blocks
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                                 …
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Hansen (Mesa) Monitors: Semantics

- Hansen monitor semantics:
  - Assume thread *T1* waiting on condition *x*
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  - *T2* continues, finishes
  - When T1 get a chance to run, *T1* takes over monitor, runs
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// T1 resumes
// T1 finishes
```

Tradeoff

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Hoare

- Claims:
  - Cleaner, good for proofs
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    while (soda.atDoor() != coke) {
            cokeAvailable.wait(&lock);}
    Unload soda closest to door;
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- 5. P2 runs again, preventing P3 from running, subverting the priority system.
- A simple way to avoid this situation is to associate with each monitor the priority of the highest priority process which ever enters that monitor.

Other Interesting Topics

- Exception handling
  - What if a process waiting in a monitor needs to time out?
- Naked notify
  - How do we synchronize with I/O devices that do not grab monitor locks, but can notify condition variables.
- Butler Lampson and David Redell, “Experience with Processes and Monitors in Mesa.”

Condition Variables

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- Rule: Must hold lock when doing condition variable ops!

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    lock.Release();             // Release Lock
}

RemoveFromQueue() {
    lock.Acquire();             // Get Lock
    while (queue.isEmpty()) {
        dataready.wait(&lock); // If nothing, sleep
    }
    item = queue.dequeue();     // Get next item
    lock.Release();             // Release Lock
    return(item);
}
```

Questions

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- **Can readers starve? Consider Reader() entry code:**

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- Finally, what if we use only one condition variable (call it "`okToContinue`") instead of two separate ones?
  - Both readers and writers sleep on this variable
  - Must use broadcast() instead of signal()

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  - Not legal to look at contents of semaphore queue
  - There is a race condition – signaler can slip in after lock release and before waiter executes semaphore.P()
- It is actually possible to do this correctly
  - Complex solution for Hoare scheduling in book

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  - Wait if necessary
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- Basic structure of monitor-based program:

```
lock
while (need to wait) {
   condvar.wait();
}
unlock

do something so no need to wait

lock

condvar.signal();

unlock
```

Check and/or update state variables
Wait if necessary

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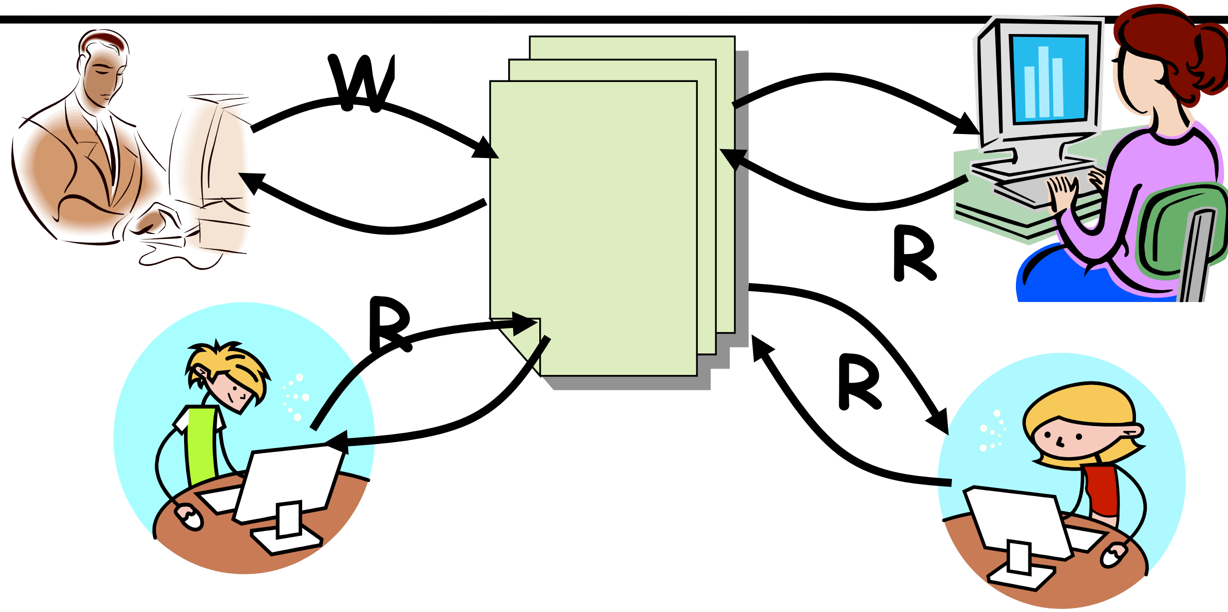
Readers/Writers Problem



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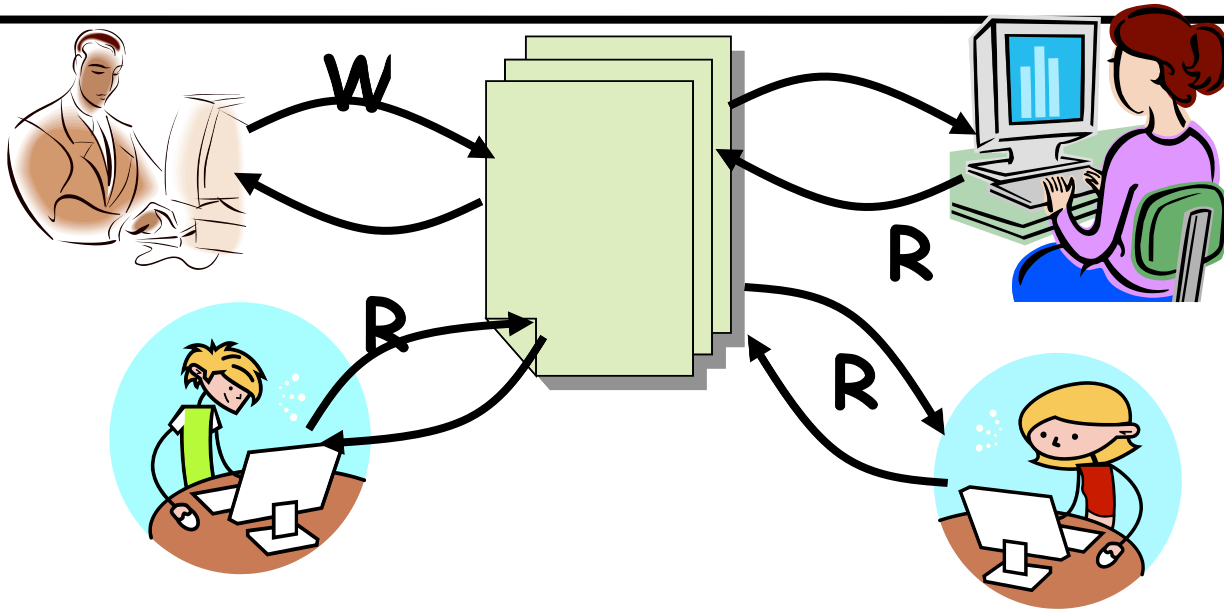

- **Motivation: Consider a shared database**

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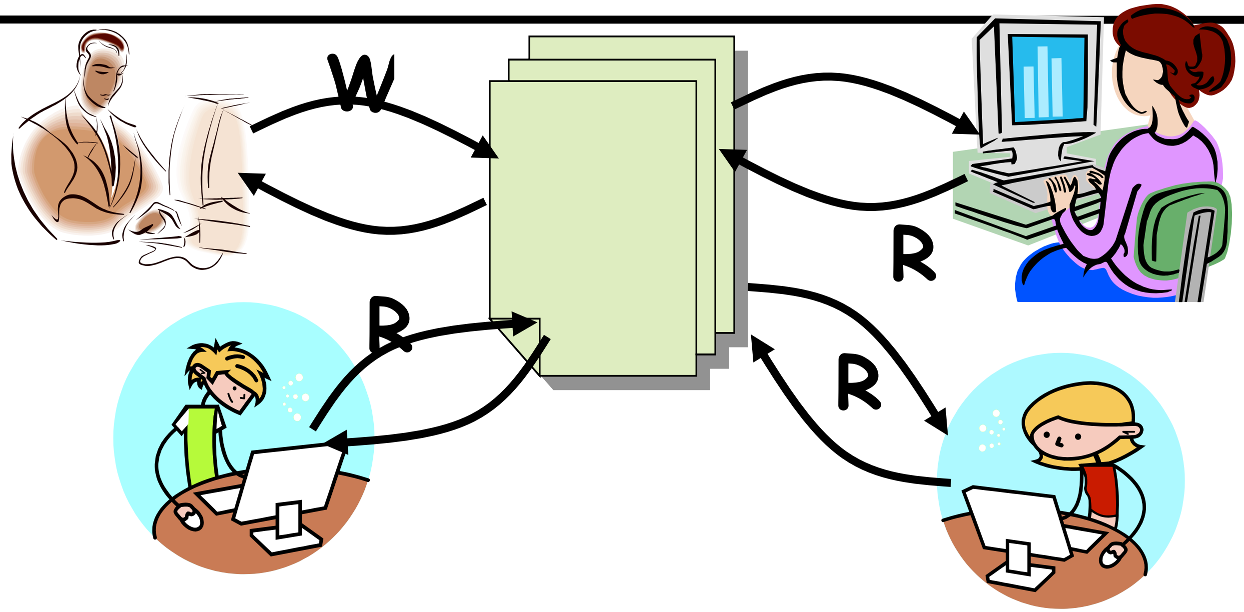

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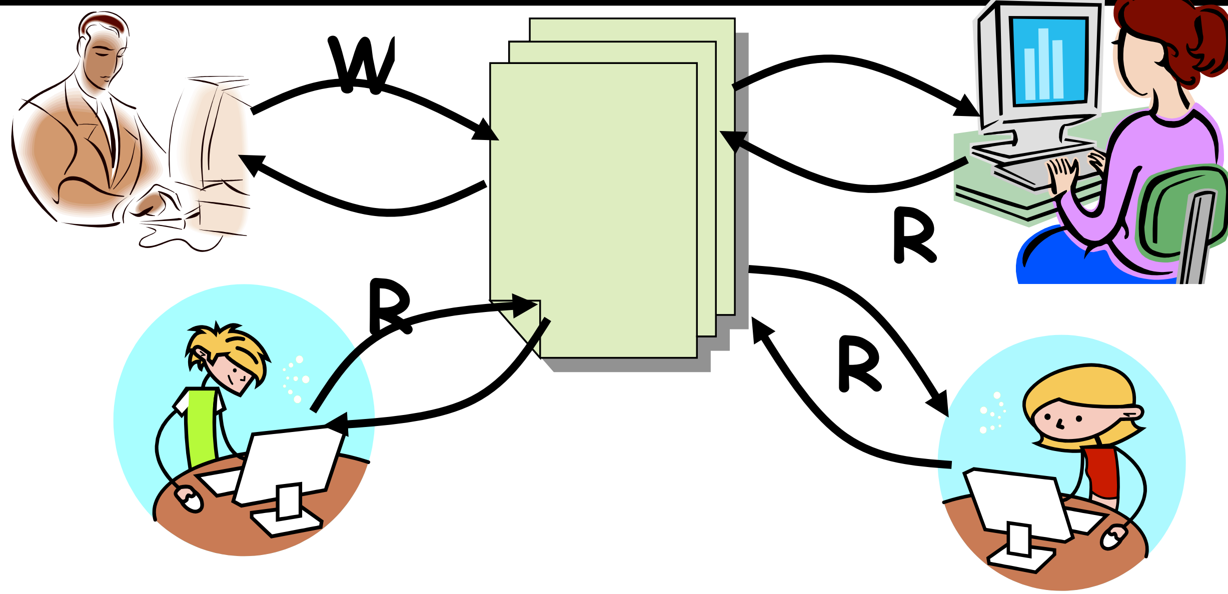

- Motivation: Consider a shared database
  - Two classes of users:
    - » Readers – never modify database
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  - Is using a single lock on the whole database sufficient?
    - » Like to have many readers at the same time
    - » Only one writer at a time

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    ```
  - State variables (Protected by a lock called "lock):
    - » int AR: Number of active readers; initially = 0
    - » int WR: Number of waiting readers; initially = 0
    - » int AW: Number of active writers; initially = 0
    - » int WW: Number of waiting writers; initially = 0
    - » Condition okToRead = NIL

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  // Perform actual read-only access
  AccessDatabase(ReadOnly);
```

Code for a Reader

```
Reader() {
  // First check self into system
  lock.Acquire();
  while ((AW + WW) > 0) { // Is it safe to read?
    WR++;                 // No. Writers exist
    okToRead.wait(&lock); // Sleep on cond var
    WR--;                 // No longer waiting
  }
  AR++;                   // Now we are active!
  lock.release();
  // Perform actual read-only access
  AccessDatabase(ReadOnly);
  // Now, check out of system
  lock.Acquire();
  AR--;                   // No longer active
  if (AR == 0 && WW > 0)  // No other active readers
    okToWrite.signal();   // Wake up one writer
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Why Release the Lock here?

Code for a Writer

Code for a Writer

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  lock.release();

  // Perform actual read/write access
  AccessDatabase(ReadWrite);

  // Now, check out of system
  lock.Acquire();
  AW--;                   // No longer active
  if (WW > 0){            // Give priority to writers
    okToWrite.signal();   // Wake up one writer
  } else if (WR > 0) {    // Otherwise, wake reader
    okToRead.broadcast(); // Wake all readers
  }
  lock.Release();
}
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Why broadcast() here instead of signal()?

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Why broadcast() here instead of signal()?

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- First, R1 comes along:

  AR = 1, WR = 0, AW = 0, WW = 0

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- First, R1 comes along:

  AR = 1, WR = 0, AW = 0, WW = 0
- Next, R2 comes along:

  AR = 2, WR = 0, AW = 0, WW = 0

Simulation(2)

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- **Next, W1 comes along:**

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while ((AW + AR) > 0) { // Is it safe to write?
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- **Can't start because of readers, so go to sleep:**

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- When writer completes, we are finished

C-Language Support for Synchronization

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- C language: Pretty straightforward synchronization
  - Just make sure you know all the code paths out of a critical section

```
int Rtn() {
     lock.acquire();
     …
     if (exception) {
        lock.release();
        return errReturnCode;
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  - Watch out for `setjmp/longmp`!
  - Can cause a non-local jump out of procedure

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  - Consider:

```
void Rtn() {
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   DoFoo();
   …
   lock.release();
}
void DoFoo() {
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void DoFoo() {
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  - Notice that an exception in DoFoo() will exit without releasing the lock

C++ Language Support for Synchronization (con't)

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- Must catch all exceptions in critical sections
  - Must catch exceptions, release lock, then re-throw the exception:

```
void Rtn() {
   lock.acquire();
   try {
      …
      DoFoo();
      …
   } catch (…) {        // catch exception
      lock.release(); // release lock
      throw;          // re-throw the exception
   }
   lock.release();
}

void DoFoo() {
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   if (exception) throw errException;
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}
```

Java Language Support for Synchronization

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- Java has explicit support for threads and thread synchronization

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- Bank Account example:

```
class Account {
   private int balance;
   // object constructor
   public Account (int initialBalance) {
      balance = initialBalance;
   }
   public synchronized int getBalance() {
      return balance;
   }
   public synchronized void deposit(int amount) {
      balance += amount;
   }
}
```

  – Every object has an associated lock which gets automatically acquired and released on entry and exit from a synchronized method.

Java Language Support for Synchronization (con't)

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- **Java also has synchronized statements:**

Java Language Support for Synchronization (con't)

- Java also has synchronized statements:

```
synchronized (object) {
    …
}
```

  - Since every Java object has an associated lock, this type of statement acquires and releases the object's lock on entry and exit of the body
  - Works properly even with exceptions:

```
synchronized (object) {
   …
   DoFoo();
   …
}
void DoFoo() {
   throw errException;
}
```

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    - » `void wait(long timeout); // Wait for timeout`
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  - Condition variables can wait for a bounded length of time. This is useful for handling exception cases:

```
t1 = time.now();
while (!ATMRequest()) {
   wait (CHECKPERIOD);
   t2 = time.new();
   if (t2 – t1 > LONG_TIME) checkMachine();
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  - Not all Java VMs equivalent!
    - » Different scheduling policies, not necessarily preemptive!

Summary

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- Semaphores: Like integers with restricted interface
  - Two operations:
    - `P()`: Wait if zero; decrement when becomes non-zero
    - `V()`: Increment and wake a sleeping task (if exists)
    - Can initialize value to any non-negative value
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- Readers/Writers
  - Readers can access database when no writers
  - Writers can access database when no readers
  - Only one thread manipulates state variables at a time
- Language support for synchronization:
  - Java provides synchronized keyword and one condition-variable per object (with `wait()` and `notify()`)