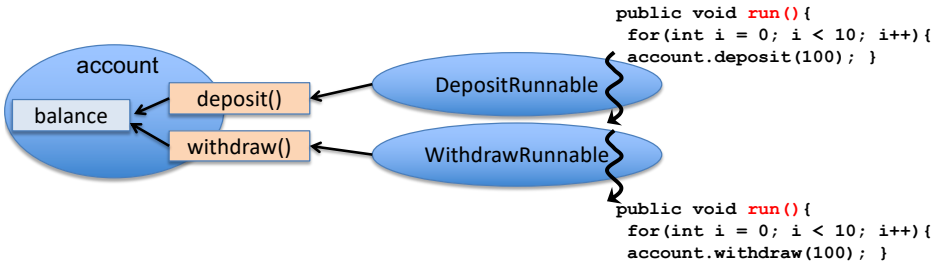
Deadlock

Thread Safety Issues

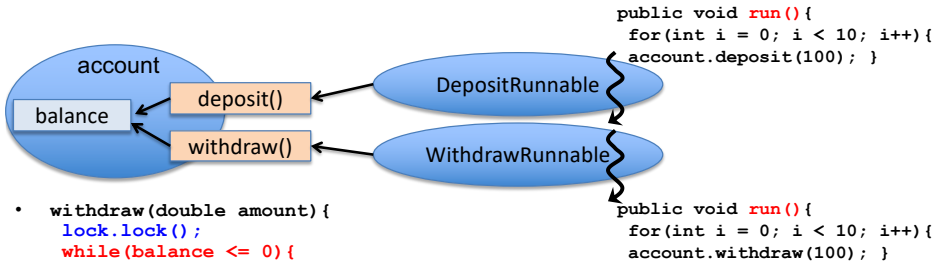
- Race conditions
- Deadlocks

- Thread-safe code is free from both race conditions and deadlocks.

DeadlockedBankAccount.java



DeadlockedBankAccount.java

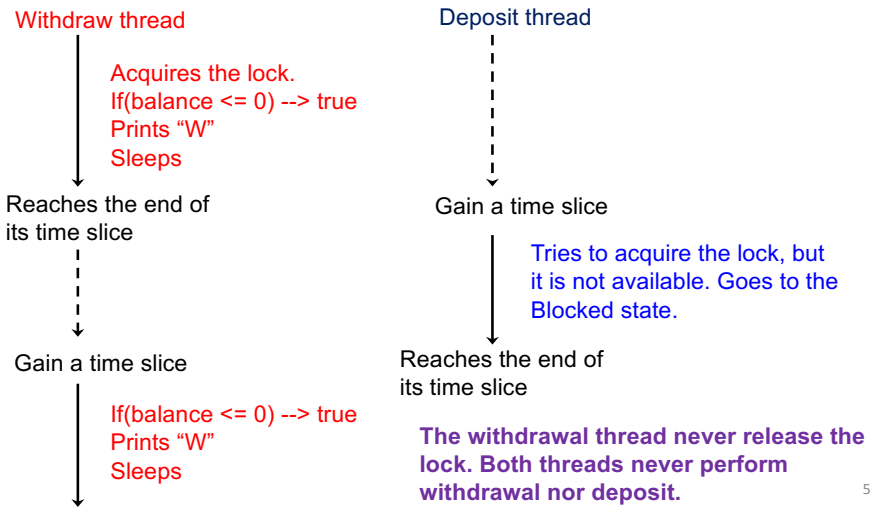



```
withdraw(double amount){
 lock.lock();
 while(balance <= 0){
      System.out.print("W");
      // waiting for the balance to exceed 0
      Thread.sleep(1000);
 }
 balance -= amount;
 lock.unlock(); }
```

```
deposit(double amount){
 lock.lock();
 while(balance >= 300){
      System.out.print("W");
      // waiting for the balance to go below 300
      Thread.sleep(1000)
 }
 balance += amount;
 lock.unlock(); }
```

How Can a Deadlock Occur?

- Suppose the withdrawal thread goes ahead.



Note

- A JVM can perform context switches even when a thread runs atomic code.
  - A lock guarantees that only one thread exclusively runs atomic code at a time.
    - It does NOT control when to (or when not to) perform context switches.
  - Some resources explicitly/implicitly say that context switches never occur when a thread runs atomic code.
    - It is WRONG!

DeadlockedBankAccount2.java

- Previous version

```
– withdraw(double amount){
    lock.lock();
    while( balance <= 0 ){
        System.out.print("W");
        Thread.sleep(1000);
    }
    balance -= amount;
    lock.unlock();
  }

– deposit(double amount){
    lock.lock();
    while( balance >= 300 ){
        System.out.print("W");
        Thread.sleep(1000)
    }
     balance += amount;
    lock.unlock();
  }
```

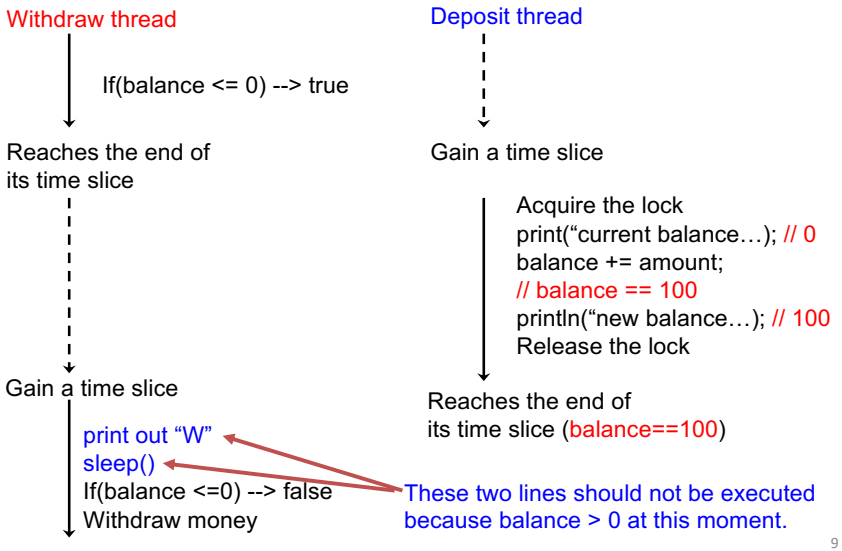
- New version

```
– withdraw(double amount){
    while( balance <= 0 ){
        System.out.print("W");
        Thread.sleep(1000);
    }
    lock.lock();
    balance -= amount;
    lock.unlock();
  }

– deposit(double amount){
    while( balance >= 300 ){
        System.out.print("W");
        Thread.sleep(1000);
    }
    lock.lock();
    balance += amount;
    lock.unlock();
  }
```


- Has no deadlock problems.
- Can generate race conditions.

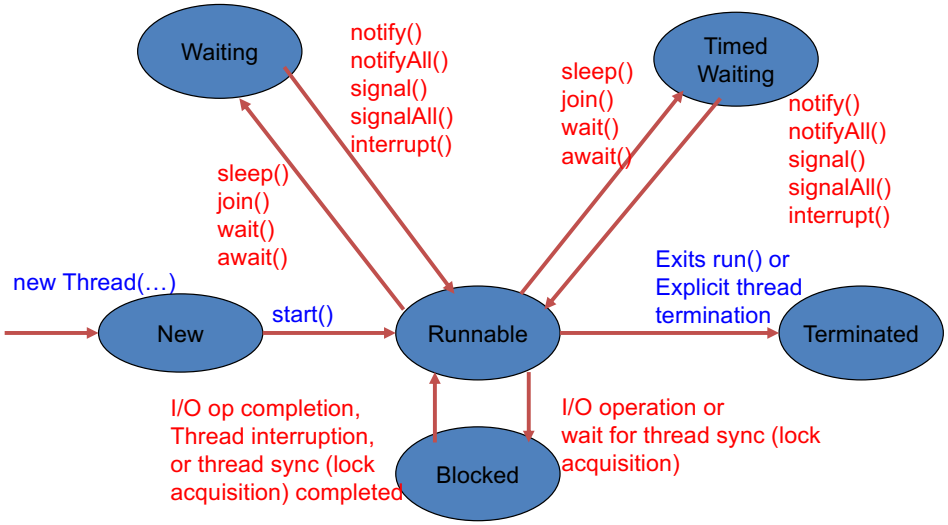
A Potential Race Condition in DeadlockedBankAccount2



Avoiding Deadlocks and Race Conditions

- Use a `Condition` object(s).
  - Allows a thread to
    - Temporarily release a lock so that another thread can acquire it and proceed.
    - Re-acquire the lock later.
- `java.util.concurrent.locks.Condition`
  - Use a lock to obtain a `Condition` instance
    - ```
      ReentrantLock lock = new ReentrantLock();
      Condition condition = lock.newCondition(); // Factory method
      condition.await();   // Temporarily releases the lock
                           // Goes to the Waiting state until getting
                           // signaled.
      ```


States of a Thread



ThreadSafeBankAccount2.java

- ```
  Condition sufficientFundsCondition = lock.newCondition();
  Condition belowUpperLimitFundsCondition = lock.newCondition();
  ```
- ```
  withdraw(double amount){
   lock.lock();
   while(balance <= 0){
       // Wait for the balance to exceed 0
      sufficientFundsCondition.await(); }
   balance -= amount;
   belowUpperLimitFundsCondition.signalAll();
   lock.unlock(); }
  ```
- ```
  deposit(double amount){
   lock.lock();
   while(balance >= 300){
      // Wait for the balance to go below 300.
      belowUpperLimitFundsCondition.await(); }
   balance += amount;
   sufficientFundsCondition.signalAll();
   lock.unlock(); }
  ```

ThreadSafeBankAccount2.java

```
Condition sufficientFundsCondition = lock.newCondition();
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withdraw(double amount){
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    sufficientFundsCondition.await(); }
 balance -= amount;
 belowUpperLimitFundsCondition.signalAll();
 lock.unlock(); }

deposit(double amount){
 lock.lock();
 while(balance >= 300){
    // Wait for the balance to go below 300.
    belowUpperLimitFundsCondition.await(); }
 balance += amount;
 sufficientFundsCondition.signalAll();
 lock.unlock(); }
```

A "deposit" thread calls signalAll() to wake up a thread(s) that is/are waiting until balance > 0.

ThreadSafeBankAccount2.java

```
Condition sufficientFundsCondition = lock.newCondition();
Condition belowUpperLimitFundsCondition = lock.newCondition();

withdraw(double amount){
 lock.lock();
 while(balance <= 0){
     // Wait for the balance to exceed 0
    sufficientFundsCondition.await(); }
 balance -= amount;
 belowUpperLimitFundsCondition.signalAll();
 lock.unlock(); }

deposit(double amount){
 lock.lock();
 while(balance >= 300){
    // Wait for the balance to go below 300.
    belowUpperLimitFundsCondition.await(); }
 balance += amount;
 sufficientFundsCondition.signalAll();
 lock.unlock(); }
```

A "withdraw" thread calls signalAll() to wake up a thread(s) that is/are waiting until balance < 300.

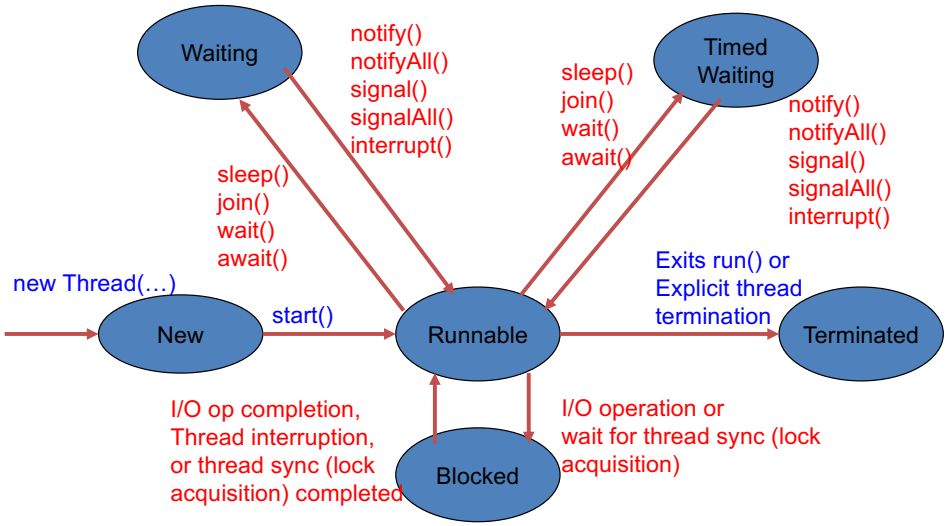
ThreadSafeBankAccount2.java

```
Condition sufficientFundsCondition = lock.newCondition();
Condition belowUpperLimitFundsCondition = lock.newCondition();

withdraw(double amount){
 lock.lock();
 while(balance <= 0){
     // Wait for the balance to exceed 0
    sufficientFundsCondition.await(); }
 balance -= amount;
 belowUpperLimitFundsCondition.signalAll();
 lock.unlock(); }

deposit(double amount){
 lock.lock();
 while(balance >= 300){
    // Wait for the balance to go below 300.
    belowUpperLimitFundsCondition.await(); }
 balance += amount;
 sufficientFundsCondition.signalAll();
 lock.unlock(); }
```


Condition

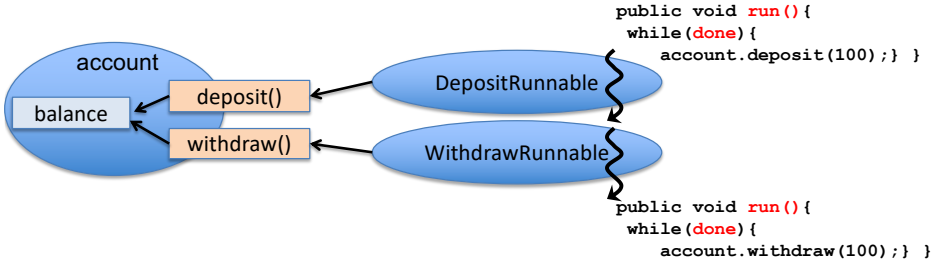
- **`await()`**
  - Will wait until it is signaled or interrupted
  - Will wait until it is signaled or interrupted, or until a specified waiting time (relative time) elapsed.
  - Will wait until it is signaled or interrupted, or until a specified deadline (absolute time).
  - goes to the Runnable state and re-acquires a lock, if signaled.
    - Will be "blocked" if the thread re-acquisition fails.
  - Throws an **`InterruptedException`**, if interrupted.
    - c.f. A previous lecture note on thread interruption
- **`signalAll()`**
  - Wakes up all waiting threads on a condition object.
    - All of them go to the "runnable" state.
    - One of them will re-acquire a lock.

States of a Thread



- When a thread calls await(), signalAll() or signal() on a Condition object,
  - the thread is assumed to hold a lock associated with the Condition object.
  - If the thread does not, an `IllegalMonitorStateException` is thrown.

2-Step Thread Termination




```
withdraw(double amount){
    lock.lock();
    while(balance =< 0){
        try{
            // waiting for the balance to exceed 0
            sufficientFundsCondition.await();
        }catch(InterruptedException e){
            break; // Balking
        }
    }
    ...}
```

HW 14

- Implement 2-step termination for “deposit” and “withdraw” threads.
  - Have the main thread call interrupt() on “deposit” and “withdraw” threads
    - To let those threads to wake up in case they are in the Waiting state due to await() or sleep().
- Due: April 18 (Thu) midnight

`signalAll()` *Before* or *After* a State Change?

```
withdraw(double amount){
  lock.lock();
  while(balance =< 0){
      // waiting for the balance to exceed 0
     sufficientFundsCondition.await(); }
  balance -= amount;
  belowUpperLimitFundsCondition.signalAll();
  lock.unlock(); }
```

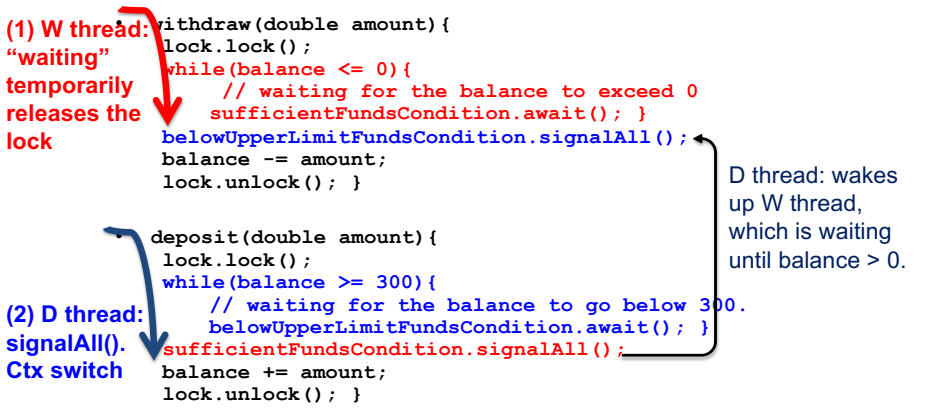
```
deposit(double amount){
  lock.lock();
  while(balance >= 300){
     // waiting for the balance to go below 300.
     belowUpperLimitFundsCondition.await(); }
  balance += amount;
  sufficientFundsCondition.signalAll();
  lock.unlock(); }
```

- What if you call signalAll() first and then update the balance? Will any thread safety issues come out?

```
withdraw(double amount){
  lock.lock();
  while(balance =< 0){
      // waiting for the balance to exceed 0
     sufficientFundsCondition.await(); }
  belowUpperLimitFundsCondition.signalAll();
  balance -= amount;
  lock.unlock(); }
```

```
deposit(double amount){
  lock.lock();
  while(balance >= 300){
     // waiting for the balance to go below 300.
     belowUpperLimitFundsCondition.await(); }
  sufficientFundsCondition.signalAll();
  balance += amount;
  lock.unlock(); }
```

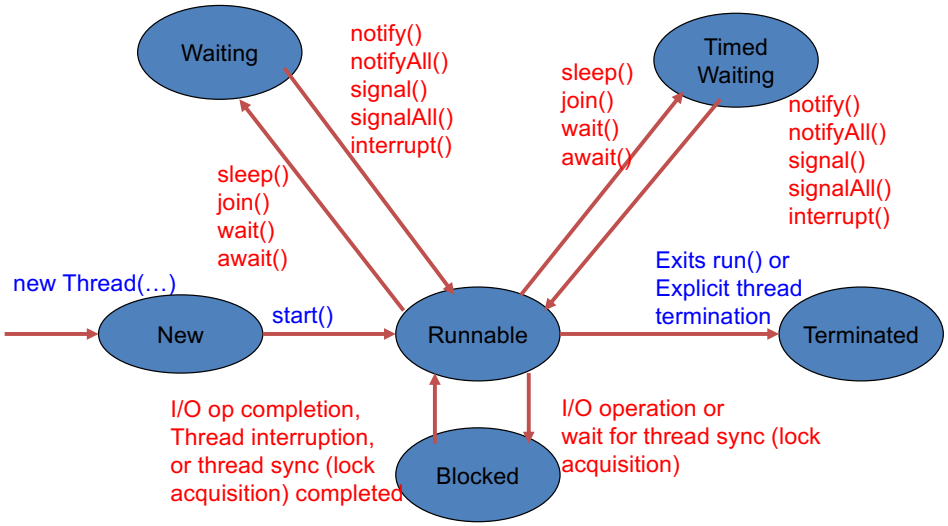
- For example, do you need to worry about race conditions in this case?



- Can the "W" thread withdraw money before the "D" thread deposits money?
  - Can the balance have a negative value?
    - The answer is NO.

- "W" thread CANNOT withdraw money before "D" thread deposits money.
- "D" thread CANNOT deposit money before "W" thread withdraws money.

States of a Thread



Two Important Things (1)

- You can safely change the state/value of a shared variable after calling signalAll().
  - AS FAR AS the state changes in atomic code
- That said, common programming convention/practice is:
  - A state change first, followed by signalAll().

Two Important Things (2)

- A JVM can perform context switches even when a thread runs atomic code.
  - A lock guarantees that only one thread exclusively runs atomic code at a time.
  - Some resources (books, online materials, etc.) explicitly/implicitly say that context switches never occur when a thread runs atomic code.
    - It is WRONG!

signal() and signalAll()

- signalAll()
  - Wakes up all waiting threads on a condition object.
    - All of them go to the "runnable" state.
    - One of them will re-acquire a lock. The others will go to the "blocked" state.
- signal()
  - Wakes up one of waiting threads on a condition object.
    - The selected thread goes to the "runnable" state. The others stay at the "waiting" state.
    - JVM's thread scheduler selects one of them. Assume random selection.
      - Not predictable which waiting thread to be selected.

signal() and signalAll()?

- Either one works well.
- signalAll() is favored in many cases/projects.
  - I prefer signalAll() in my personal taste.

ThreadSafeBankAccount2.java

```
Condition sufficientFundsCondition = lock.newCondition();
Condition belowUpperLimitFundsCondition = lock.newCondition();
```

```
withdraw(double amount){
 lock.lock();
 while(balance <= 0){
     // waiting for the balance to exceed 0
    sufficientFundsCondition.await(); }
 balance -= amount;
 belowUpperLimitFundsCondition.signalAll();
 lock.unlock(); }
```

```
deposit(double amount){
 lock.lock();
 while(balance >= 300){
    // waiting for the balance to go below 300.
    belowUpperLimitFundsCondition.await(); }
 balance += amount;
 sufficientFundsCondition.signalAll();
 lock.unlock(); }
```

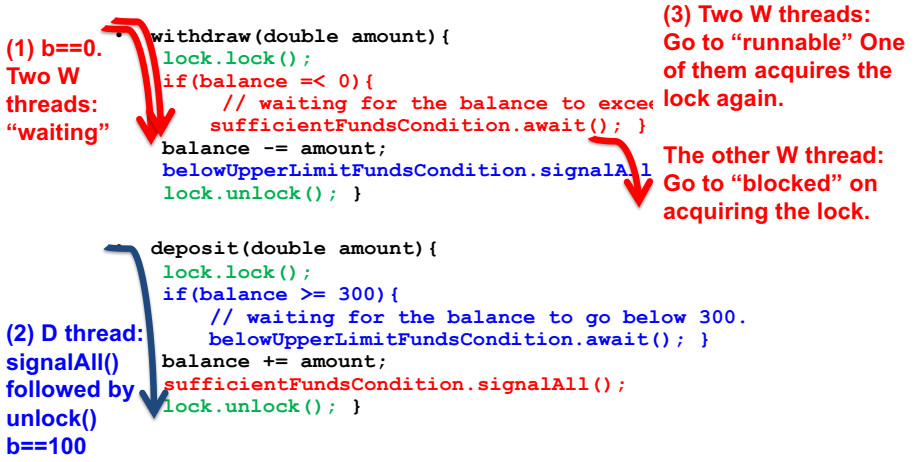

"while" or "if" to Surround await()?

```
withdraw(double amount){
 lock.lock();
 while(balance <= 0){
     // waiting for the balance to exceed 0
    sufficientFundsCondition.await(); }
 balance -= amount;
 belowUpperLimitFundsCondition.signalAll();
 lock.unlock(); }
```

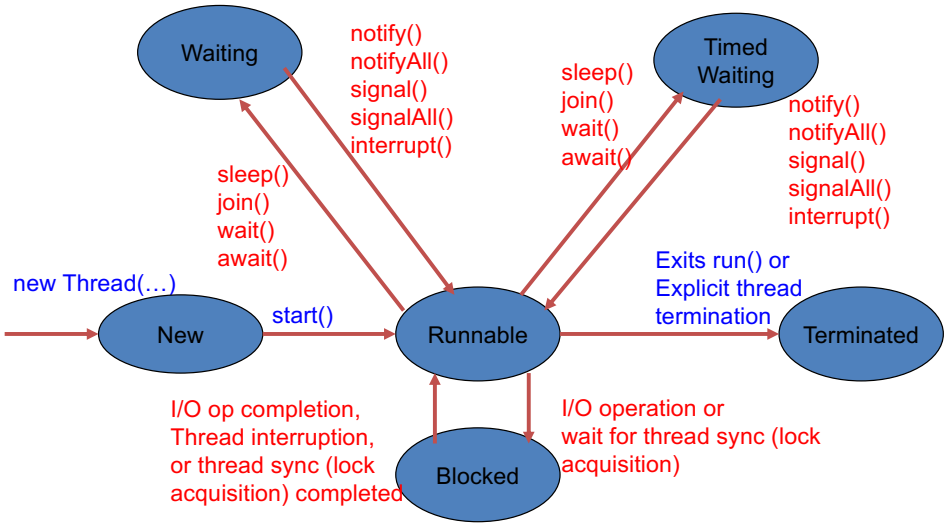
```
deposit(double amount){
 lock.lock();
 while(balance >= 300){
    // waiting for the balance to go below 300.
    belowUpperLimitFundsCondition.await(); }
 balance += amount;
 sufficientFundsCondition.signalAll();
 lock.unlock(); }
```

- "while" should be used rather than "if" when multiple threads call withdraw() concurrently. Why?

A Potential Problem



States of a Thread



(1) b==0. Two W threads: "waiting"

(2) D thread: signalAll() followed by unlock() b==100

(3) Two W threads: Go to "runnable" One of them acquires the lock again, withdraws money and releases the lock. b==0.

(4) The 2nd W thread acquires the lock and withdraws money. b==-100.

```
withdraw(double amount){
  lock.lock();
  if(balance =< 0){
     // waiting for the balance to exceed 0
    sufficientFundsCondition.await(); }
  balance -= amount;
  belowUpperLimitFundsCondition.signalAll();
  lock.unlock(); }

deposit(double amount){
  lock.lock();
  if(balance >= 300){
     // waiting for the balance to go below 300.
    belowUpperLimitFundsCondition.await(); }
  balance += amount;
  sufficientFundsCondition.signalAll();
  lock.unlock(); }
```

(1) b=0. Two W threads: "waiting"

(2) D thread: signalAll() followed by unlock() balance==100

(3) Two W threads: "runnable" One of them acquires the lock again and releases it. balance==0. The other W thread: "blocked" on acquiring the lock.

(4) The 2nd W thread acquires the lock and releases it. b==-100.

```
withdraw(double amount){
  lock.lock();
  if(balance =< 0){
     // waiting for the balance to exce
    sufficientFundsCondition.await(); }
  balance -= amount;
  belowUpperLimitFundsCondition.signalAl
  lock.unlock(); }

deposit(double amount){
  lock.lock();
  if(balance >= 300){
     // waiting for the balance to go below 300.
    belowUpperLimitFundsCondition.await(); }
  balance += amount;
  sufficientFundsCondition.signalAll();
  lock.unlock(); }
```

- The 2nd "W" thread should have made sure if balance>0.
- If only one "W" thread runs, this problem does not occur.
- Just always use a while loop regardless of the number of threads you use.

"if" or "while" in Atomic Code?

- You can use "if", rather than "while," for a conditional check
  - if you use signal(), not signalAll().
- However, in practice, the **while-signalAll** pair is more common than the **if-signal** pair.