AARHUS UNIVERSITET

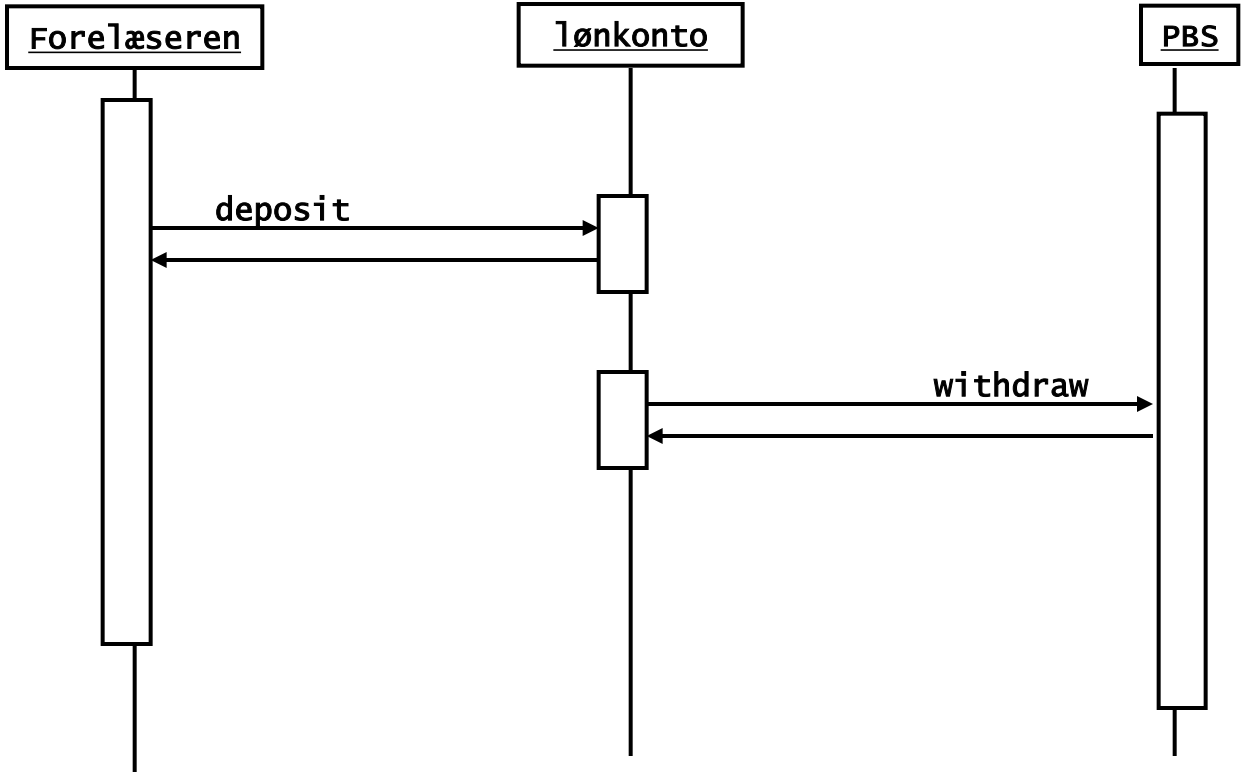
Software Engineering and Architecture

Concurrency

Shared Resources

AARHUS UNIVERSITET

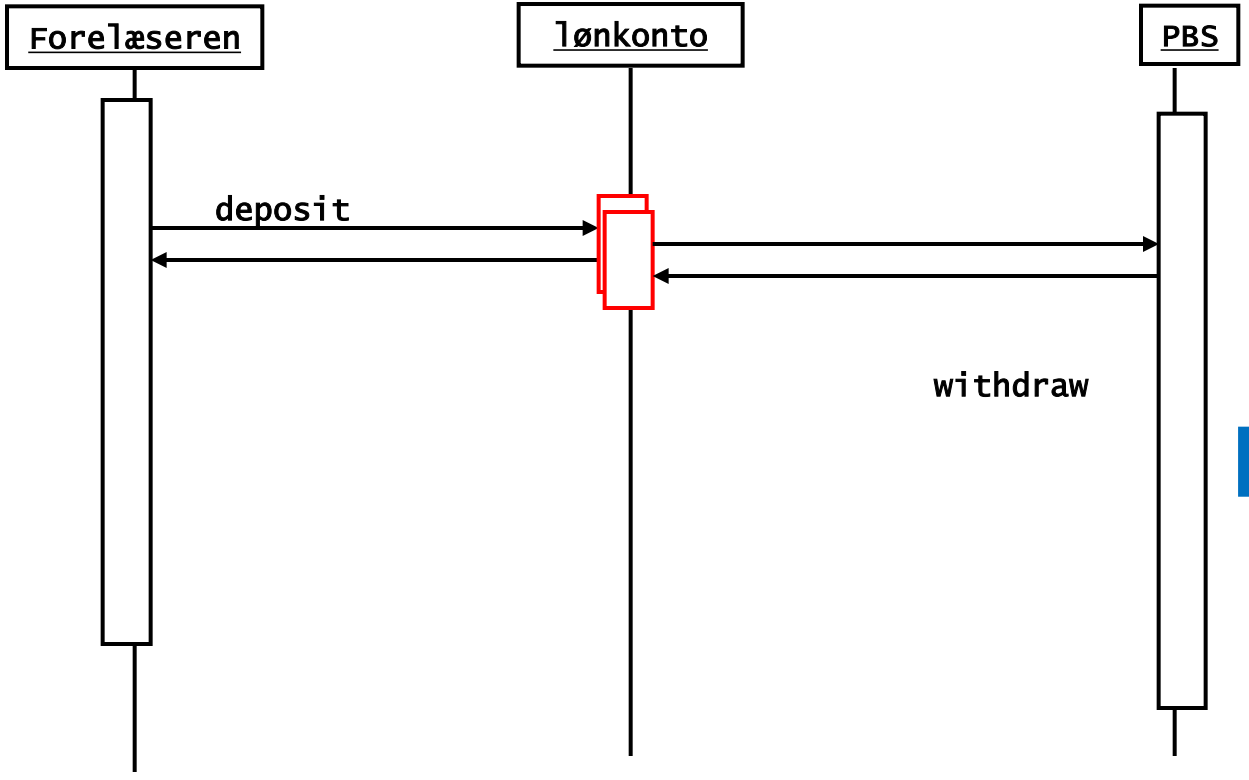
Two Threads – One Account



OK

AARHUS UNIVERSITET

Two Threads – One Account



Not OK

Example

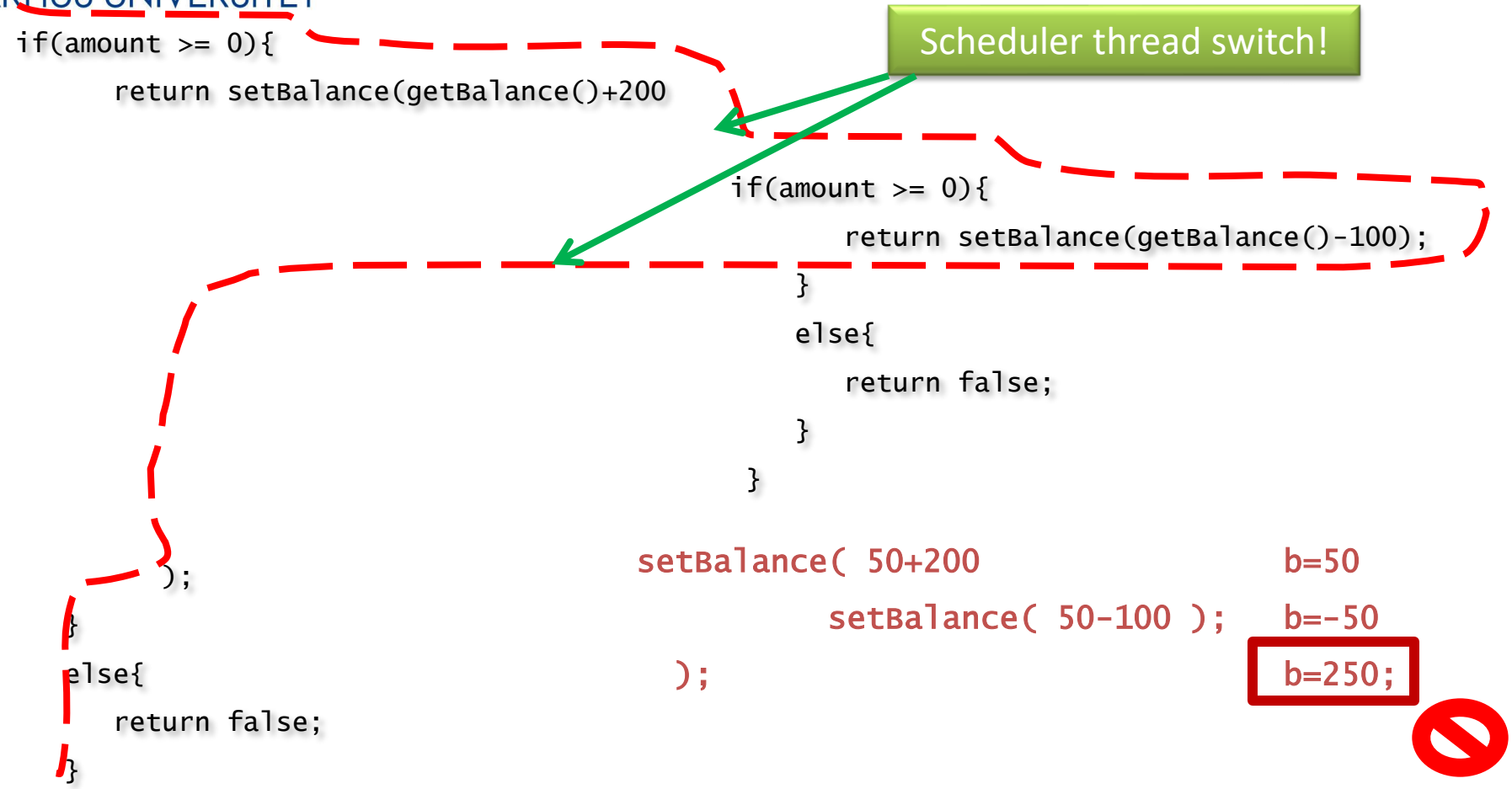
- I insert 200kr while PBS withdraws 100kr. The balance is initially 50kr.

```
public boolean deposit(long amount){
  if(amount >= 0){
     return setBalance(getBalance()+amount);
  }
  else {
     return false;
  }
}
```

```
public boolean withdraw(long amount){
   if(amount >= 0){
      return setBalance(getBalance()-amount);
   }
   else {
      return false;
   }
}
```

- Hopefully, the result should be 50+200-100 = 150 kr.

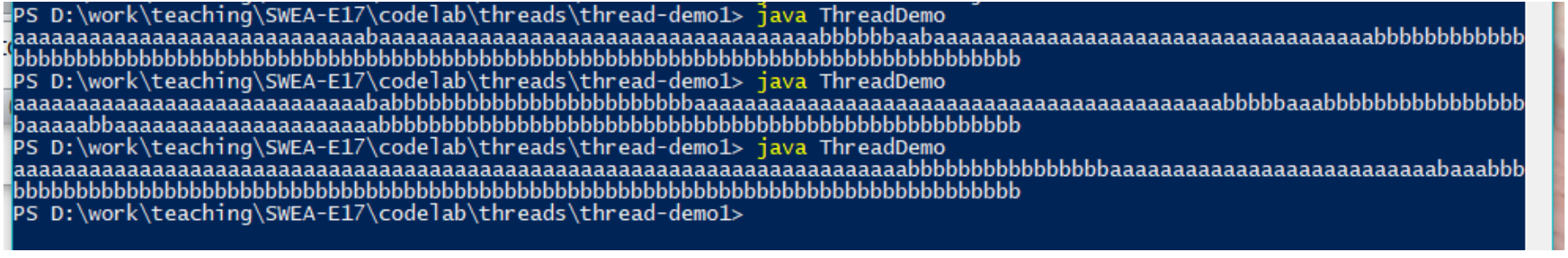
Concurrent Execution



AARHUS UNIVERSITET

Example

- The ‘System.out’ is a shared resource !



Example: Shared Counter

```
public class CounterTest {

   public static void main(String[] args) throws InterruptedException {

      final Counter counter = new Counter();

      // create 1000 threads
      ArrayList<MyThread> threads = new ArrayList<MyThread>();
      for (int x = 0; x < 1000; x++) {
         threads.add(new MyThread(counter));
      }

      // start all of the threads
      Iterator i1 = threads.iterator();
      while (i1.hasNext()) {
         MyThread mt = (MyThread) i1.next();
         mt.start();
      }

      // wait for all the threads to finish
      Iterator i2 = threads.iterator();
      while (i2.hasNext()) {
         MyThread mt = (MyThread) i2.next();
         mt.join();
      }

      System.out.println("Count    : " + counter.getCount());
      System.out.println("Expected: " + 1000 * 10000);
   }
}
```

```
class Counter {
  private Integer count = new Integer(0);

  public void incrementCount() {
    count++;
  }
  public int getCount() {
    return count;
  }
}
```

```
// thread that increments the counter 10.000 times.
class MyThread extends Thread {
   Counter counter;

   MyThread(Counter counter){
      this.counter = counter;
   }
   public void run() {
      for (int x = 0; x < 10000; x++) {
         counter.incrementCount();
      }
   }
}
```

Source: http://www.javacodex.com/Concurrency/AtomicInteger-Counter

Example: Shared Counter

```
public class CounterTest {

    public static void main(String[] args) throws InterruptedException {

        final Counter counter

        // create 1000 threads
        ArrayList<MyThread> th
        for (int x = 0; x < 10
            threads.add(new MyT
        }

        // start all of the th
        Iterator i1 = threads.
        while (i1.hasNext()) {
            MyThread mt = (MyThread) i1.next();
            mt.start();
        }

        // wait for all the threads to finish
        Iterator i2 = threads.iterator();
        while (i2.hasNext()) {
            MyThread mt = (MyThread) i2.next()
            mt.join();
        }

        System.out.println("Count    : " + cou
        System.out.println("Expected: " + 100
    }
}
```

```
d:\proj\frsproject\concurrency>java CounterTest
Count    : 3492772
Expected: 10000000

d:\proj\frsproject\concurrency>java CounterTest
Count    : 3547105
Expected: 10000000

d:\proj\frsproject\concurrency>java CounterTest
Count    : 3062784
Expected: 10000000
```

```
class Counter {
  private Integer count = new Integer(0);

d incrementCount() {

 getCount() {
ount;
```

```
ter 10.000 times.
```

```
        this.counter = counter;
    }
```

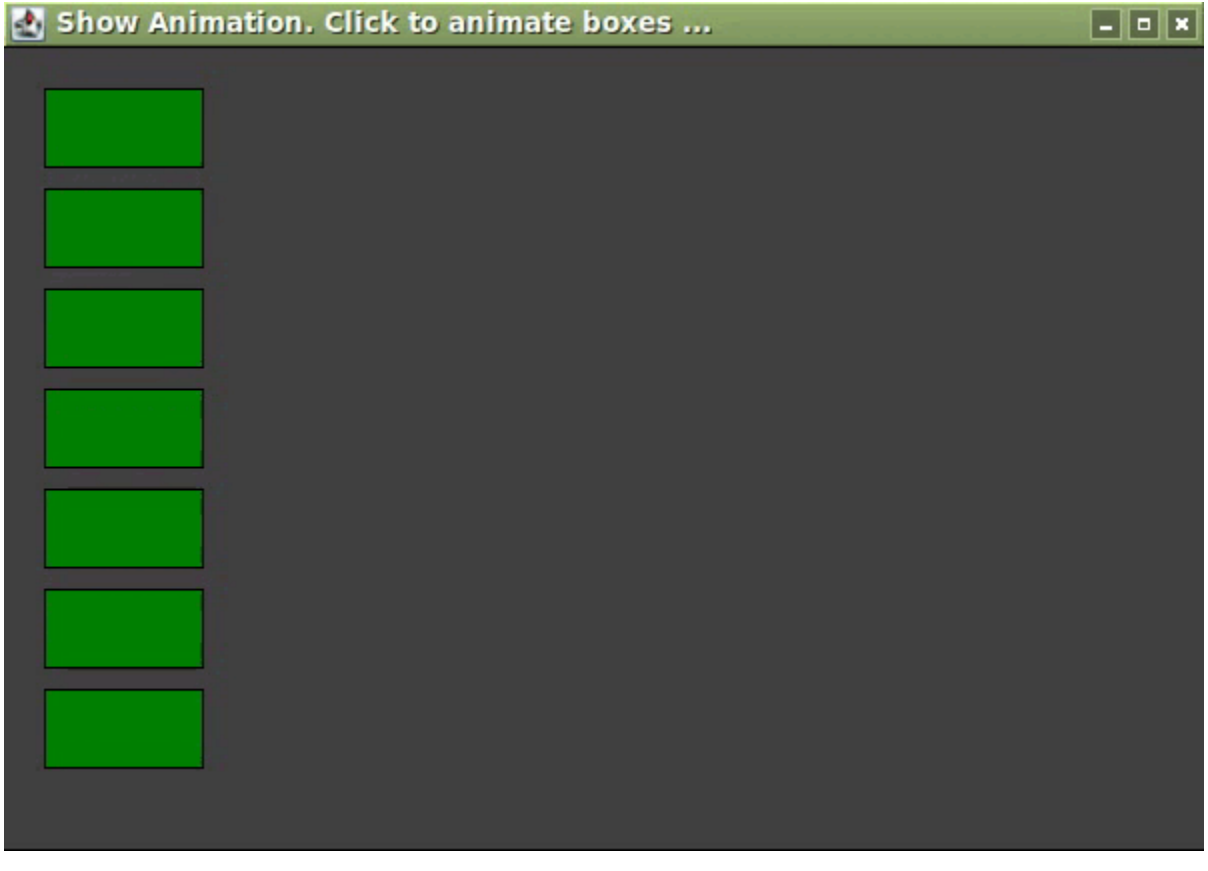
```
csdev@m1:~/proj/frsproject/threads$ java CounterTest
Count    : 99213454
Expected: 100000000
csdev@m1:~/proj/frsproject/threads$ java CounterTest
Count    : 99754194
Expected: 100000000
csdev@m1:~/proj/frsproject/threads$ java CounterTest
Count    : 99697896
Expected: 100000000
```

Source: http://www.javacodex.com/Concurrency/AtomicInteger-Counter

AARHUS UNIVERSITET

Example: MiniDraw Animation

- ‘dirtyRectangle’ is a shared resource ☹
  - Threads move the boxes
  - MiniDraw’s Jframe does the drawing
  - The rectangles are shared resources



Race Condition

- Race Condition:
  - If multiple threads *writes* to resources then the outcome is determined by the sequence/timing in which events occur.
  - **BAD!** You have no control of the behavior of your program; and the result is erroneous
    - Inserting 200 and withdrawing 100 on balance 50 must be **150**
    - Our particular execution gave **250**
    - The next one may give **-50**

- Critical Section:
  - The code section in which race conditions can occur

AARHUS UNIVERSITET

The Solution

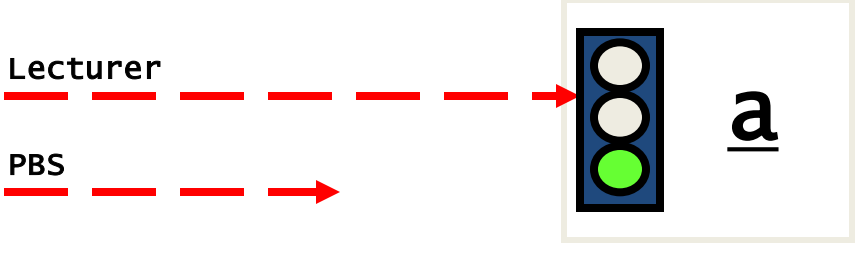
- *Critical sections must be treated as an atomic instruction*
  - *Da: ”Udelelig adgang”*

- That is, only one thread is allowed to be executing in a critical region at a time…

- *Also called : Mutual exclusion*

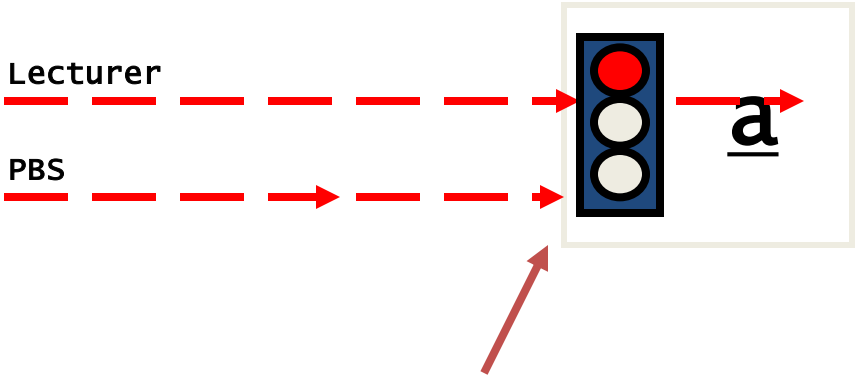
The Lock

- Guard critical regions
- Example:
  - Our two threads will try to invoke deposit() and withdraw()
- But our account object, a, has an ”lock” associated
  - Only one thread may acquire the lock at any time!



The ‘mutex’
or ‘semaphore’

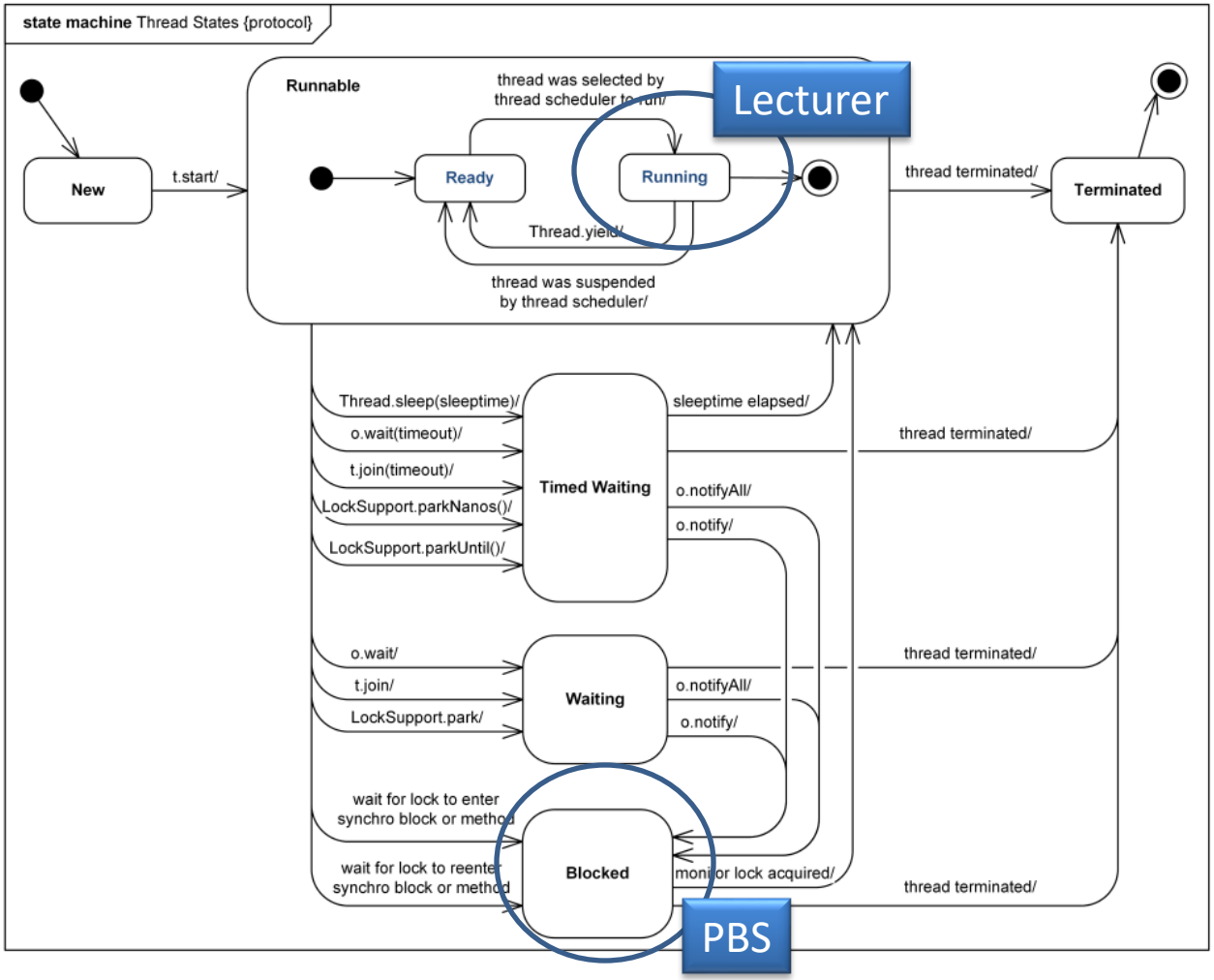
In ‘deposit()’



RUNNING state
BLOCKED state

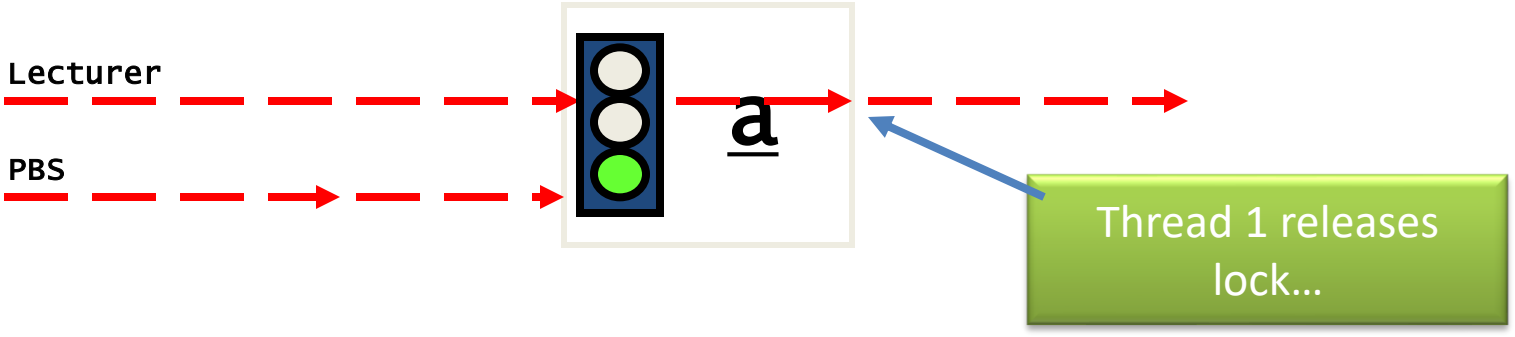
The PBS thread cannot acquire the ‘lock’ and thus start executing ‘withdraw()’. It is simply put into a *blocking state*, and cannot continue until the lock is released!

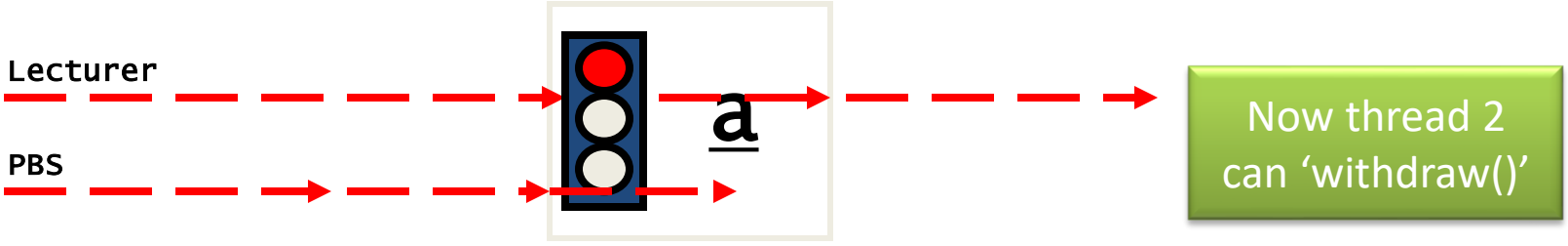
Thread State



AARHUS UNIVERSITET

And next…





AARHUS UNIVERSITET

Monitor/Synchronized

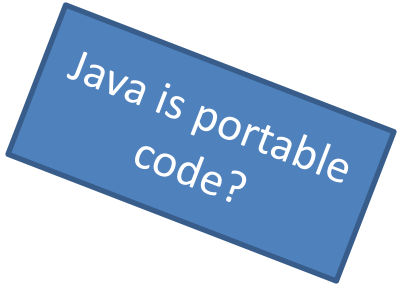
- A *Monitor* is a class whose methods are *all* associated with a lock/semaphore/”lysregulering”
  - Not available in Java
- In Java it is more fine-grained: **synchronized**
- Only methods with the **synchronized** keyword will respect the lock
- **There is only one lock per object !!!**
  - Not one per method!!!

Synchronized

- Synchronized methods = whole method is a critical sect.

```
public synchronized void add(int value){
    this.count += value;
}
```

- *Do not make too much code a critical section!*
  - It slows a program down if all threads have to wait for the lock
- Rule:
  - Only **writing** needs to be guarded
- Rule 2:
  - Oh yeah – and **reads** of items more than N bits
    - N = 16, 32, 64 - Depending upon your processor !!!
    - Corollary: Reading **objects must be a critical region**



AARHUS UNIVERSITET

Synchronized Section

- You can simply state the object you want to sync on, on a smaller portion of the code!

```
public void add(int value){

  synchronized(this){
     this.count += value;
  }
}
```

AARHUS UNIVERSITET

Example again:

- Exercise: What should be **synchronized**?

```
class Counter {
  private Integer count = new Integer(0);

  public void incrementCount() {
    count++;
  }
  public int getCount() {
    return count;
  }
}
```

```
d:\proj\frsproject\concurrency>javac CounterTest.java

d:\proj\frsproject\concurrency>java CounterTest
Count    : 10000000
Expected: 10000000

d:\proj\frsproject\concurrency>java CounterTest
Count    : 10000000
Expected: 10000000

d:\proj\frsproject\concurrency>java CounterTest
Count    : 10000000
Expected: 10000000
```

AARHUS UNIVERSITET

Server Side and Client Side

- So far, the object itself has stated its synchronization.
- Often, this is not ok.
- Consider this ATM code:
  - *Account.debit() is* ***synchronized***
- *What is the problem???*

```
long available = account.getBalance();
if(available > 0){
    System.out.print("You have "+available+
        " available, how much do you want? ");
   long amount = keyboard.nextLong();
    if(amount <= 0){
        System.out.println("The amount must be positive.");
    }
    else if(amount > available){
        System.out.println("That is too much.");
    }
    else{
        // This should be ok, but ...
        if(!account.debit(amount)){
            System.out.println("The ATM debit failed!");
        }
    }
}
```

AARHUS UNIVERSITET

Server Side and Client Side

- *What is the problem???*

```
long available = account.getBalance();
if(available > 0){
    System.out.print("You have "+available+
        " available, how much do you want? ");
   long amount = keyboard.nextLong();
    if(amount <= 0){
        System.out.println("The amount must be positive.");
    }
    else if(amount > available){
        System.out.println("That is too much.");
    }
    else{
        // This should be ok, but ...
        if(!account.debit(amount)){
            System.out.println("The ATM debit failed!");
        }
    }
}
```

AARHUS UNIVERSITET

Client Side Synchronization

- Synchronized takes the object as parameter, thus

```
synchronized(account) {
  <<<ATM code here>>>
}
```

- Will solve it – it is executed atomically using the lock of the account…

MiniDraw Client Side Sync

- MiniDraw, by default, does not lock the ‘Drawing’ during figure manipulation, but offers *client-side* synchronization via ‘locks’

```
public void updateStats() {
  writeLock().lock();
  try {
    attackText.setText("" + associatedCard.getAttack());
    healthText.setText("" + associatedCard.getHealth());
  } finally {
    writeLock().unlock();
  }
}
```

Reentrance

- Hey – did we not miss a thing here???
  - Thread starts ‘deposit()’
    - Acquire the lock
  - Then calls ‘setBalance()’
    - But the lock is taken???

synch

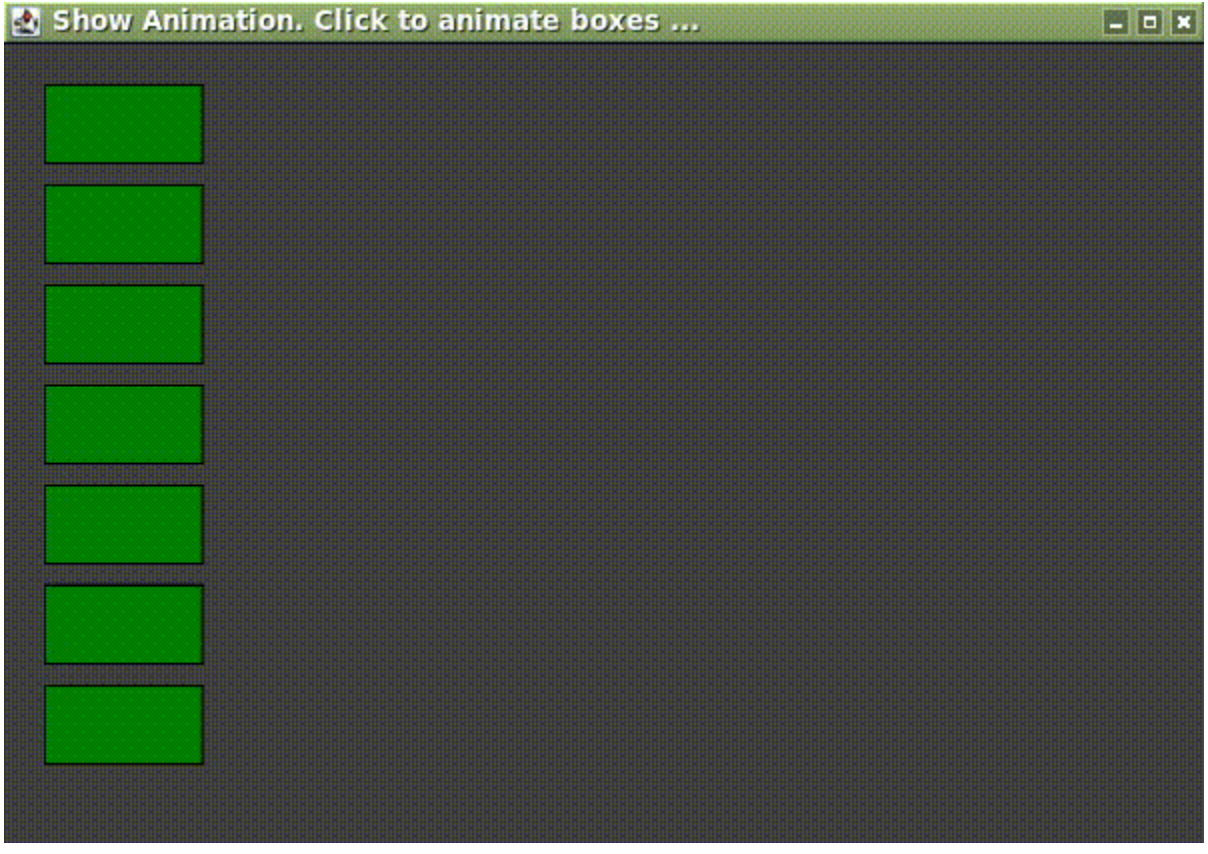
```
public boolean deposit(long amount){
  if(amount >= 0){
     return setBalance(getBalance()+amount);
  }
  else {
     return false;
  }
}
```

- **Reentrant critical sections**
  - If a thread ‘t’ has acquired the lock on object ‘a’, then it is free to invoke all other synchronized methods in ‘a’
    - Reentrance: The thread may *reenter* in locked methods
      - Recursion !

AARHUS UNIVERSITET

Example: MiniDraw Animation

- Treating ‘dirty rectangles’ as critical region
- Single writer
- Multi reader



And – moving on…

Java 5

- Java 5 onwards introduced ‘java.util.concurrent’ because the old ‘synchronized’ was way too simple…
  - A lot of concurrent data structures
  - An fine-grained ‘synchronized’ object: **Lock**

Main Differences Between Locks and Synchronized Blocks

The main differences between a `Lock` and a synchronized block are:

- A synchronized block makes no guarantees about the sequence in which threads waiting to entering it are granted access.
- You cannot pass any parameters to the entry of a synchronized block. Thus, having a timeout trying to get access to a synchronized block is not possible.
- The synchronized block must be fully contained within a single method. A `Lock` can have it's calls to `lock()` and `unlock()` in separate methods.

ReentrantLock

- Instead of ‘synchronized’ on incrementCount()

```
class Counter {

  private int count = 0;
  private final ReentrantLock lock = new ReentrantLock();

  public void incrementCount() {
    lock.lock();
    try {
      count++;
    } finally { lock.unlock(); }
  }

  public int getCount() {
    return count;
  }
}
```

- Note:
  - Explicit lock object!
  - Not on ‘this’…
- Can have more locks in play in same object!

The idiom

- Or
  - tryLock(100 ms)
  - Will time out waiting to get the lock
  - Avoid indefinite waiting for a lock that a frozen thread has taken!

```
lock.lock();
try {
   // critical region
} finally {
   lock.unlock();
}
```

- Liability
  - *Code readability suffers greatly!*
  - *Some day you will forget the finally clause ☹*

AARHUS UNIVERSITET

Deadlocks

Availability AntiPattern:
Blocked Threads

Deadlock

- ***Deadlock***
  - *A thread waits infinitely for an event that will never happen*

- That is
  - T1, is in synchronized method in A, call sync. method in B
  - T2, has acquired lock on B, and waits for lock on C
  - …
  - T4 waits for lock on A – which T1 has !
- Result
  - Utterly nothing!!!

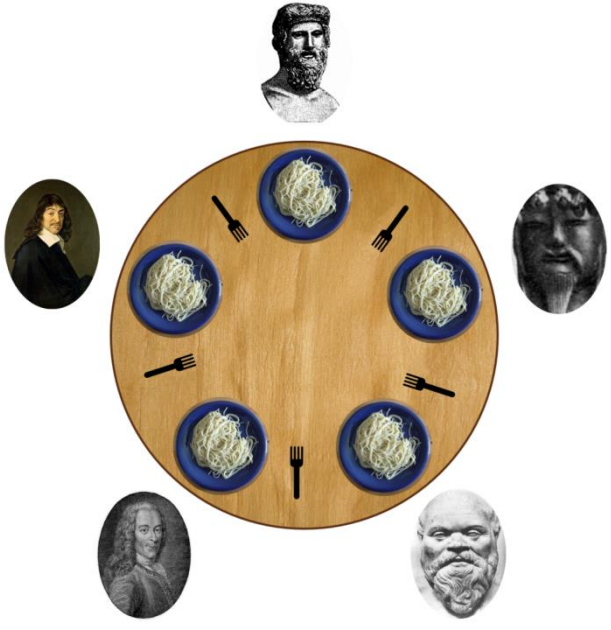
```
Thread 1  locks A, waits for B
Thread 2  locks B, waits for C
Thread 3  locks C, waits for D
Thread 4  locks D, waits for A
```

AARHUS UNIVERSITET

A Classic

- Edger Dijkstra, 1965: Dining Philosophers Problem
  - *Eat or think*
  - *To eat you need two forks*

- Design an algorithm that does not deadlock…



[By Benjamin D. Esham / Wikimedia Commons, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=56559]

AARHUS UNIVERSITET

The General Rules of Thumb

- *Always acquire the locks in the same order*
  - Example: A, then B, then C

Note – does not work for the Philosophers!

```
Thread 1:

  lock A
  lock B


Thread 2:

   wait for A
   lock C (when A locked)


Thread 3:

   wait for A
   wait for B
   wait for C
```

- Only works if you know the order ahead of time

- *Use timeouts on locks*
  - *If timeout: free all locks, wait, and retry…*