Example Application of Java ReentrantLock

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Learning Objectives in this Part of the Lesson

- Understand the concept of mutual exclusion in concurrent programs
- Note a human-known use of mutual exclusion
- Recognize the structure & functionality of Java ReentrantLock
- Be aware of reentrant mutex semantics
- Know the key methods defined by the Java ReentrantLock class
- Master how to apply ReentrantLock in practice
  - i.e., in the context of the Java ArrayBlockingQueue class

Class ArrayBlockingQueue<E>

```
java.lang.Object
    java.util.AbstractCollection<E>
        java.util.AbstractQueue<E>
            java.util.concurrent.ArrayBlockingQueue<E>
```

Type Parameters:

`E - the type of elements held in this collection`

All Implemented Interfaces:

`Serializable, Iterable<E>, Collection<E>, BlockingQueue<E>, Queue<E>`

```
public class ArrayBlockingQueue<E>
extends AbstractQueue<E>
implements BlockingQueue<E>, Serializable
```

A bounded blocking queue backed by an array. This queue orders elements FIFO (first-in-first-out). The *head* of the queue is that element that has been on the queue the longest time. The *tail* of the queue is that element that has been on the queue the shortest time. New elements are inserted at the tail of the queue, and the queue retrieval operations obtain elements at the head of the queue.

This is a classic "bounded buffer", in which a fixed-sized array holds elements inserted by producers and extracted by consumers. Once created, the capacity cannot be changed. Attempts to `put` an element into a full queue will result in the operation blocking; attempts to `take` an element from an empty queue will similarly block.

This class supports an optional fairness policy for ordering waiting producer and consumer threads. By default, this ordering is not guaranteed. However, a queue constructed with fairness set to `true` grants threads access in FIFO order. Fairness generally decreases throughput but reduces variability and avoids starvation.

Applying Reentrant Lock in Practice

Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

```
public class ArrayBlockingQueue<E>
    extends AbstractQueue<E>
    implements BlockingQueue<E>,
        java.io.Serializable {
```

Class ArrayBlockingQueue<E>

java.lang.Object
  java.util.AbstractCollection<E>
    java.util.AbstractQueue<E>
      java.util.concurrent.ArrayBlockingQueue<E>

Type Parameters:

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All Implemented Interfaces:

Serializable, Iterable<E>, Collection<E>, BlockingQueue<E>, Queue<E>

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See docs.oracle.com/javase/8/docs/api/java/util/concurrent/ArrayBlockingQueue.html

Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

```
public class ArrayBlockingQueue<E>
    extends AbstractQueue<E>
    implements BlockingQueue<E>,
        java.io.Serializable {
```

Class AbstractQueue<E>

java.lang.Object
  java.util.AbstractCollection<E>
    java.util.AbstractQueue<E>

Type Parameters:

E - the type of elements held in this collection

All Implemented Interfaces:

Iterable<E>, Collection<E>, Queue<E>

Direct Known Subclasses:

ArrayBlockingQueue, ConcurrentLinkedQueue, DelayQueue, LinkedBlockingDeque, LinkedBlockingQueue, LinkedTransferQueue, PriorityBlockingQueue, PriorityQueue, SynchronousQueue

---

```
public abstract class AbstractQueue<E>
extends AbstractCollection<E>
implements Queue<E>
```

This class provides skeletal implementations of some `Queue` operations. The implementations in this class are appropriate when the base implementation does *not* allow `null` elements. Methods `add`, `remove`, and `element` are based on `offer`, `poll`, and `peek`, respectively, but throw exceptions instead of indicating failure via `false` or `null` returns.

See docs.oracle.com/javase/8/docs/api/java/util/AbstractQueue.html

Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

```
public class ArrayBlockingQueue<E>
        extends AbstractQueue<E>
    implements BlockingQueue<E>,
        java.io.Serializable {
```

Interface BlockingQueue<E>

Type Parameters:

E - the type of elements held in this collection

All Superinterfaces:

Collection<E>, Iterable<E>, Queue<E>

All Known Subinterfaces:

BlockingDeque<E>, TransferQueue<E>

All Known Implementing Classes:

ArrayBlockingQueue, DelayQueue, LinkedBlockingDeque, LinkedBlockingQueue, LinkedTransferQueue, PriorityBlockingQueue, SynchronousQueue

---

```
public interface BlockingQueue<E>
extends Queue<E>
```

A Queue that additionally supports operations that wait for the queue to become non-empty when retrieving an element, and wait for space to become available in the queue when storing an element.

See docs.oracle.com/javase/8/docs/api/java/util/concurrent/BlockingQueue.html

Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

```
public class ArrayBlockingQueue<E>
        extends AbstractQueue<E>
    implements BlockingQueue<E>,
        java.io.Serializable {
...
```

We'll consider both the interface & implementation of ArrayBlockingQueue

Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

```
public class ArrayBlockingQueue<E>
            extends AbstractQueue<E>
        implements BlockingQueue<E>,
                java.io.Serializable {
  ...
  // Main lock guarding all access
  final ReentrantLock lock;
  ...
  // The queued items
  final Object[] items;

  // items indices for next take
  // or put calls
  int takeIndex;
  int putIndex;

  // Number of elements in the queue
  int count;
```

ReentrantLock used in lieu of Java's built-in monitor objects due to their limitations

See www.dre.vanderbilt.edu/~schmidt/C++2java.html#concurrency

Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

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    // Number of elements in the queue
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```

Object state that's being protected by the lock

Applying ReentrantLock in Practice

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public class ArrayBlockingQueue<E>
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  // or put calls
  int takeIndex;
  int putIndex;

  // Number of elements in the queue
  int count;
```

Fields needn't be defined as volatile since ReentrantLock handles all of the atomicity, visibility, & ordering issues

See docs.oracle.com/javase/8/docs/api/java/util/concurrent/locks/Lock.html

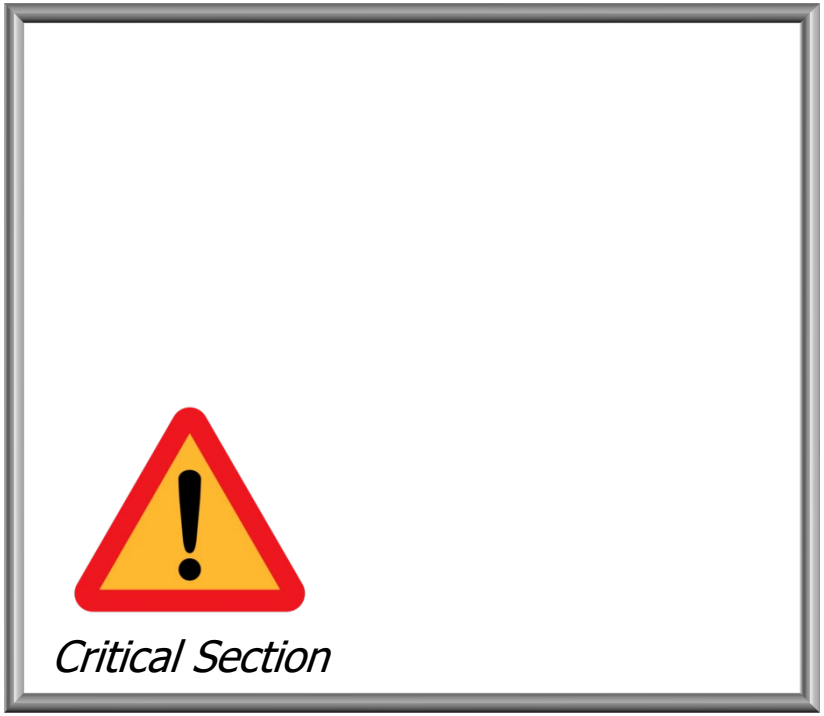
Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

```
ArrayBlockingQueue<String> q = new
  ArrayBlockingQueue<>(10);
...
```

Create a bounded blocking queue that can store up to 10 items

ArrayBlockingQueue

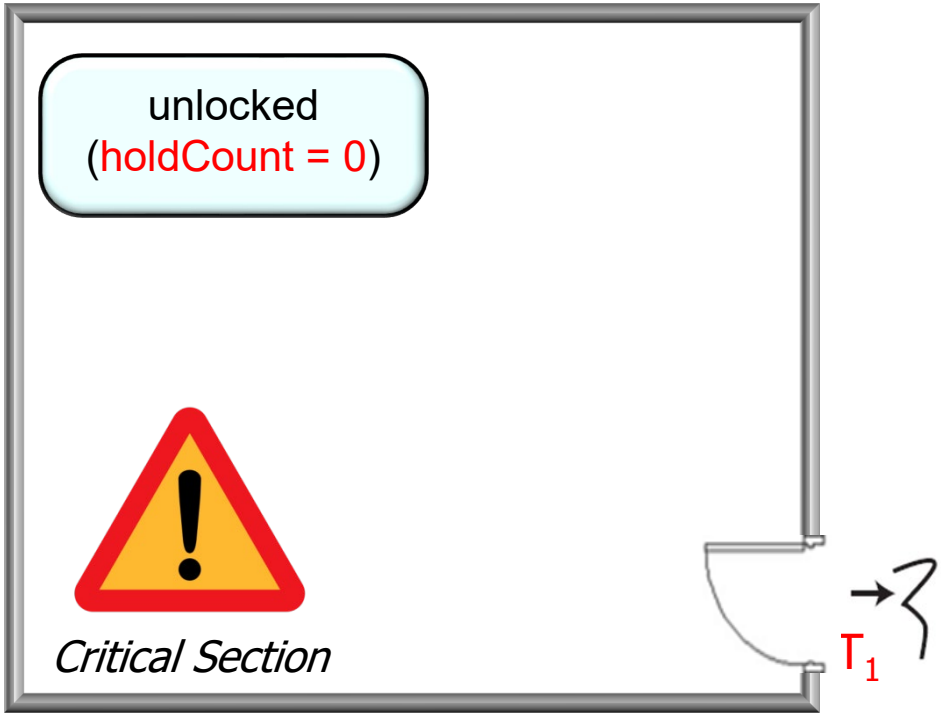


Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

```
ArrayBlockingQueue<String> q = new
  ArrayBlockingQueue<>(10);
...
// Called by thread T1
String s = q.take();
...
```

ArrayBlockingQueue



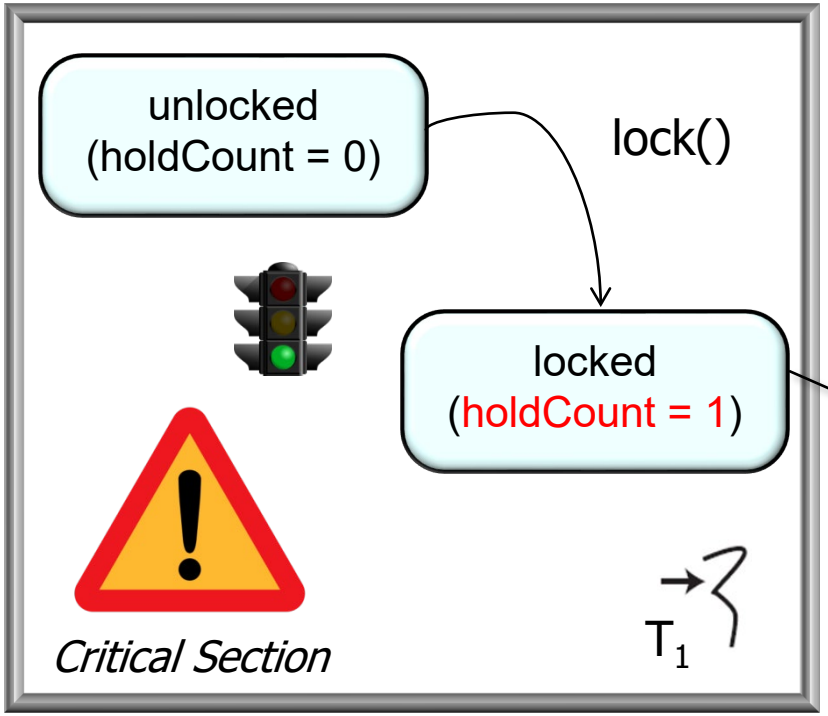
Thread T_1 acquires the lock & enters the critical section

Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

```
public class ArrayBlockingQueue<E>
            extends AbstractQueue<E>
        implements BlockingQueue<E>,
                java.io.Serializable {
  ...
  public E take() ... {
    final ReentrantLock lock
      = this.lock;
    lock.lockInterruptibly();
    ...
```

ArrayBlockingQueue



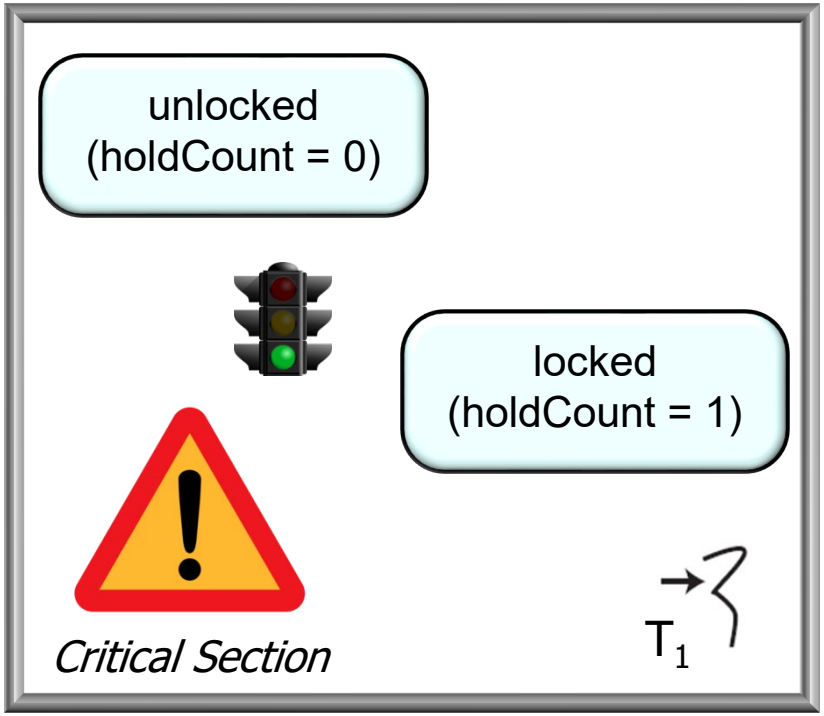
The lock's hold count is incremented by 1

Applying ReentrantLock in Practice

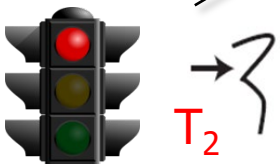
- ArrayBlockingQueue is a bounded blocking FIFO queue

```
ArrayBlockingQueue<String> q = new
  ArrayBlockingQueue<>(10);
...
// Called by thread T2
String s = q.take();
...
```

ArrayBlockingQueue



A call to take() from thread T_2 will block until thread T_1 is finished

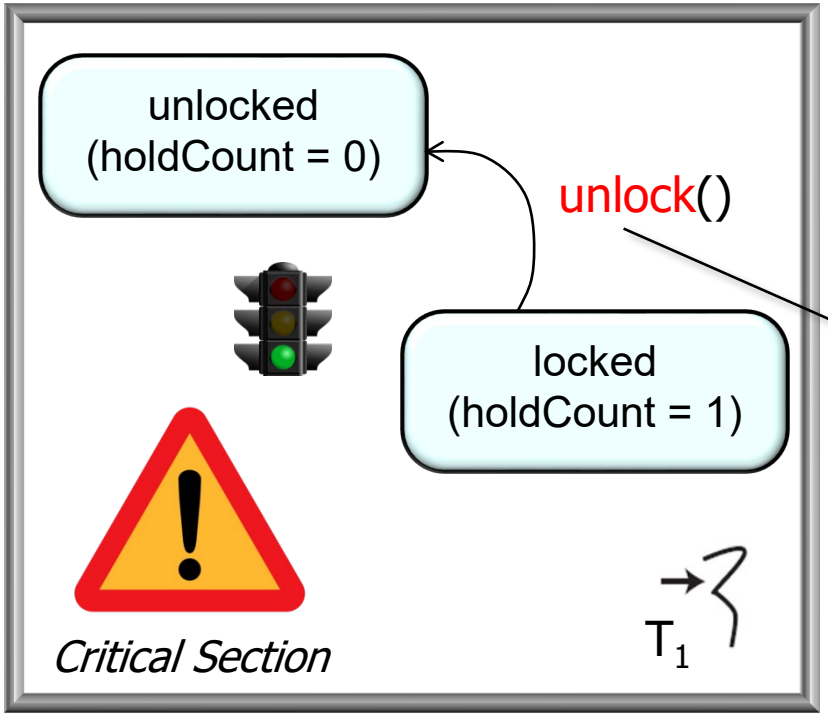


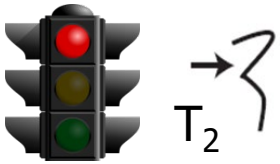
Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

```
public class ArrayBlockingQueue<E>
            extends AbstractQueue<E>
          implements BlockingQueue<E>,
                java.io.Serializable {
  ...
  public E take() ... {
    final ReentrantLock lock
      = this.lock;
    lock.lockInterruptibly();
    try { ...
    } finally {
      lock.unlock();
    }
    ...
```

ArrayBlockingQueue





When thread T_1 finishes in take() it unlocks the lock

Applying ReentrantLock in Practice

- ArrayBlockingQueue is a bounded blocking FIFO queue

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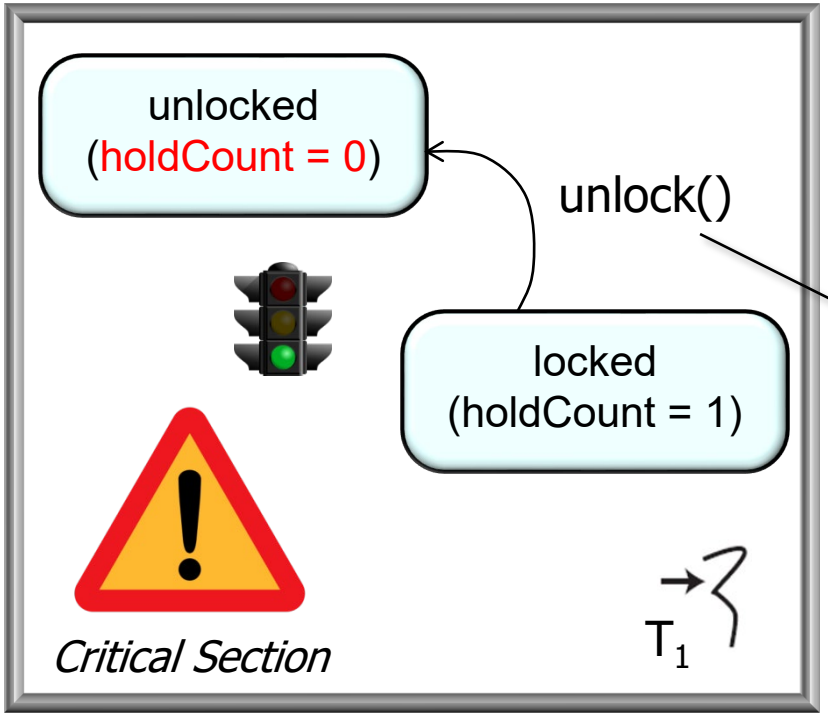
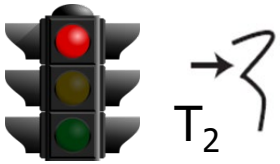
  ...
  public E take() ... {
    final ReentrantLock lock
      = this.lock;
    lock.lockInterruptibly();
    try { ...
    } finally {
      lock.unlock();
    }
    ...
```

ArrayBlockingQueue





At this point holdCount reverts back to 0

Applying ReentrantLock in Practice

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    lock.lockInterruptibly();
    try { ...
    } finally {
      lock.unlock();
    }
    ...
```
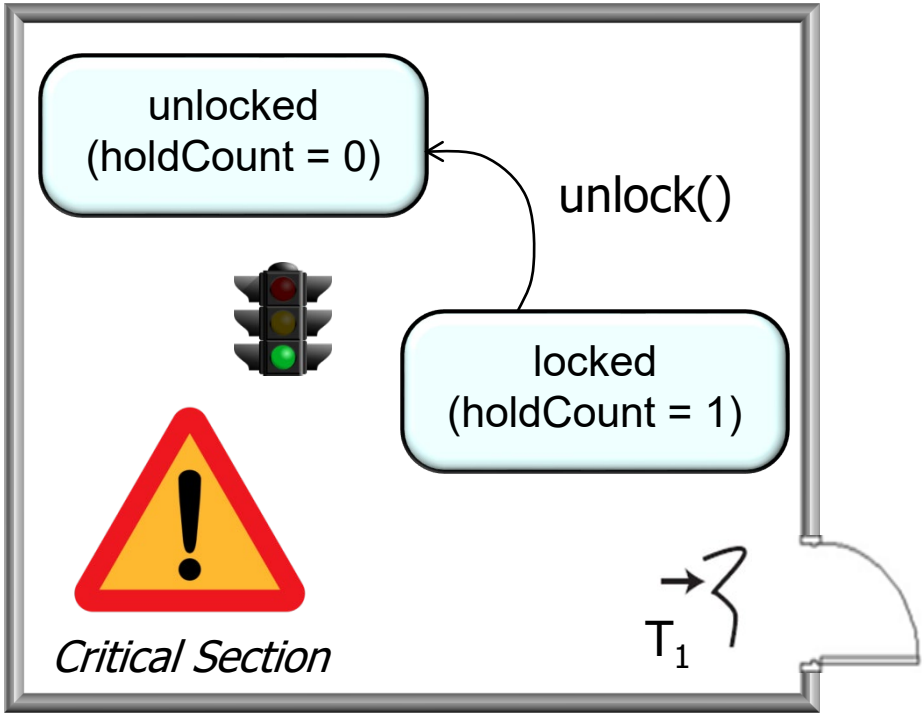

ArrayBlockingQueue



Ensure lock is always released when T_1 exits the critical section

See tutorials.jenkov.com/java-concurrency/locks.html#finally

Applying ReentrantLock in Practice

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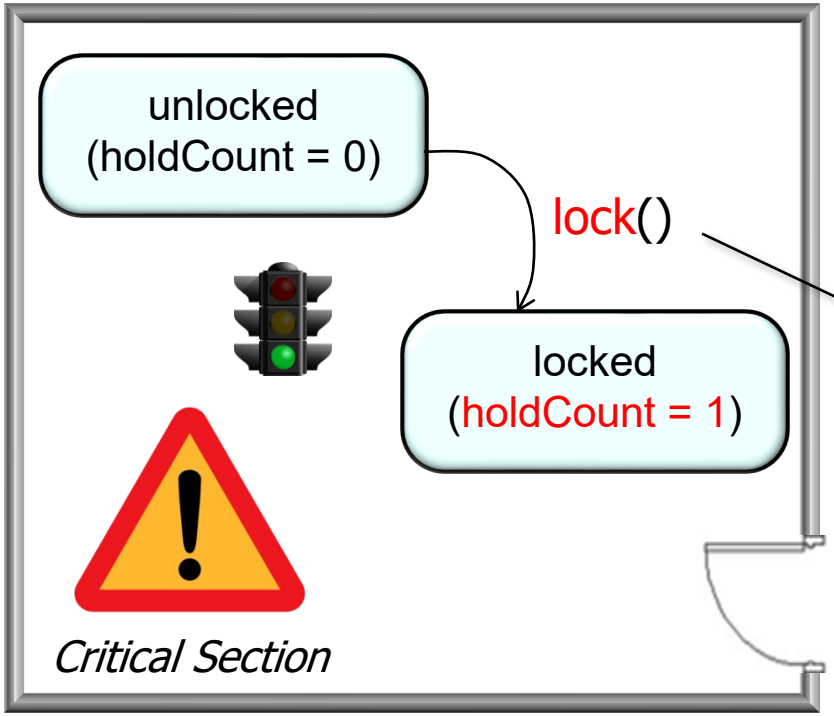
ArrayBlockingQueue

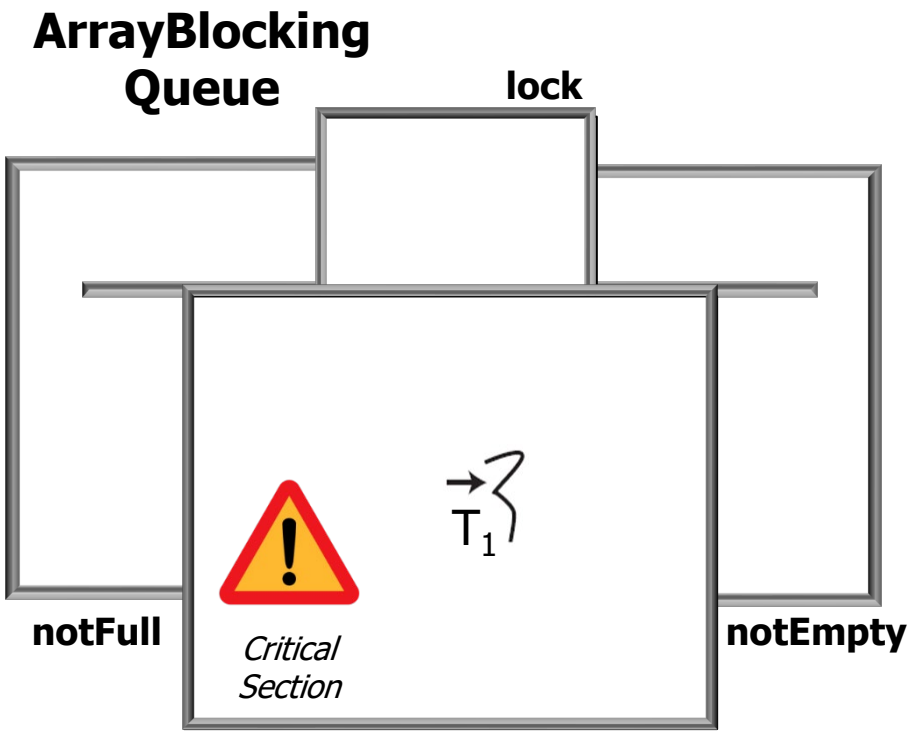


T_2

Thread T_2 can now enter the critical section of take() & start running

Applying ReentrantLock in Practice

- ArrayBlockingQueue needs to use more than ReentrantLock to implement its semantics

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                extends AbstractQueue<E>
              implements BlockingQueue<E>,
                     java.io.Serializable {
  ...
  public E take() ... {
    final ReentrantLock lock
      = this.lock;
    lock.lockInterruptibly();
    try {
      while (count == 0)
        notEmpty.await();
      return extract();
    } finally {
      lock.unlock();
    }
  }
```

A Java ConditionObject is used to coordinate multiple threads

Upcoming lesson on "*Java ConditionObject*" shows more on ArrayBlockingQueue

Applying ReentrantLock in Practice

- ArrayBlockingQueue needs to use more than ReentrantLock to implement its semantics

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  public E take() ... {
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      = this.lock;
    lock.lockInterruptibly();
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      while (count == 0)
        notEmpty.await();
      return extract();
    } finally {
      lock.unlock();
    }
  }
```

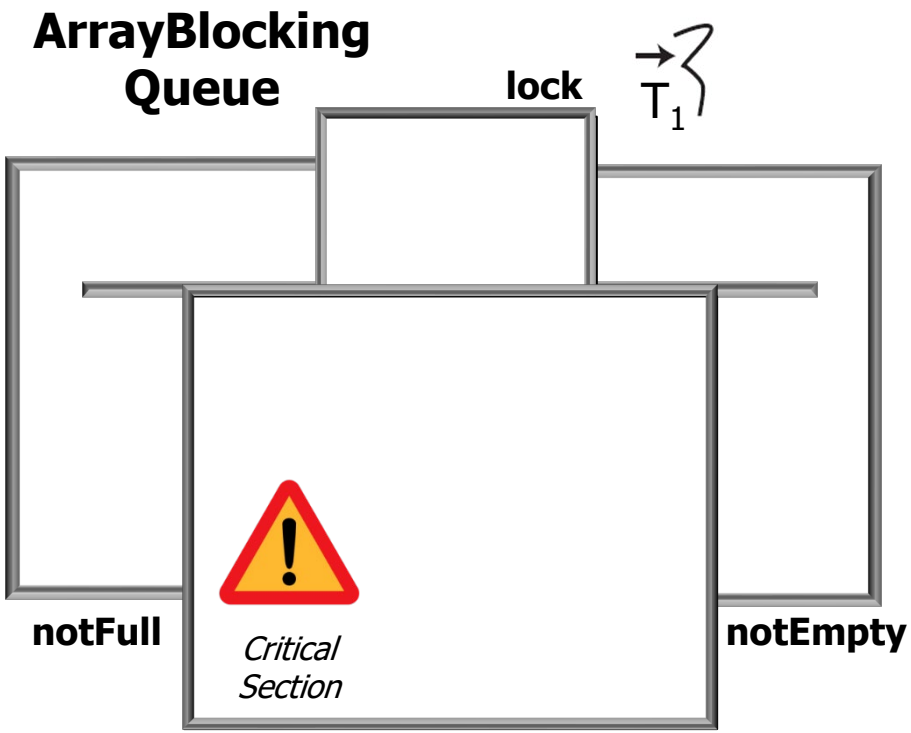

These mechanisms implement Guarded Suspension & Monitor Object patterns

See en.wikipedia.org/wiki/Guarded_suspension & www.dre.vanderbilt.edu/~schmidt/PDF/monitor.pdf

End of Example Application of Java ReentrantLock