Java ConditionObject: Example Application

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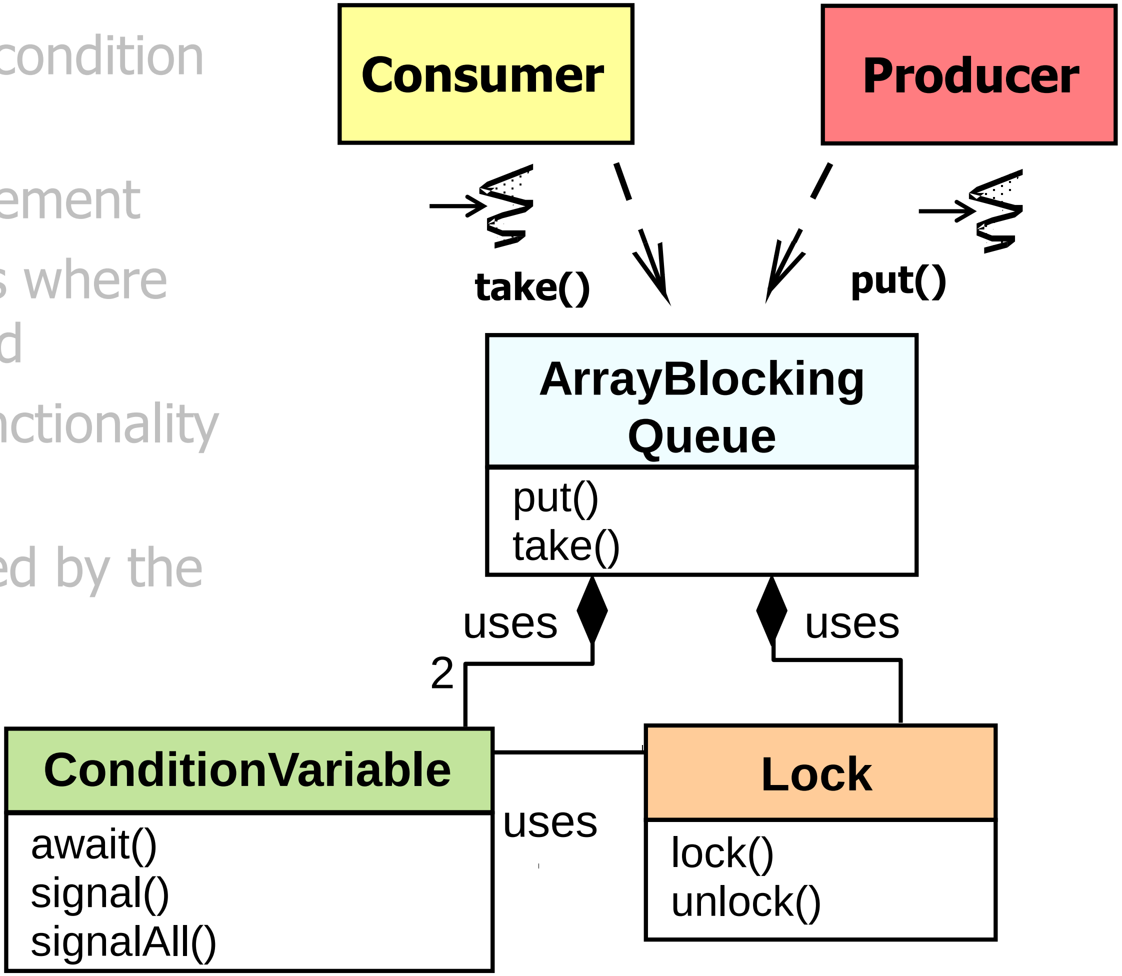
Learning Objectives in this Part of the Lesson

- Understand what condition variables are
- Note a human known use of condition variables
- Know what pattern they implement
- Recognize common use cases where condition variables are applied
- Recognize the structure & functionality of Java ConditionObject
- Know the key methods defined by the Java ConditionObject class
- Master the use of Condition Objects in practice

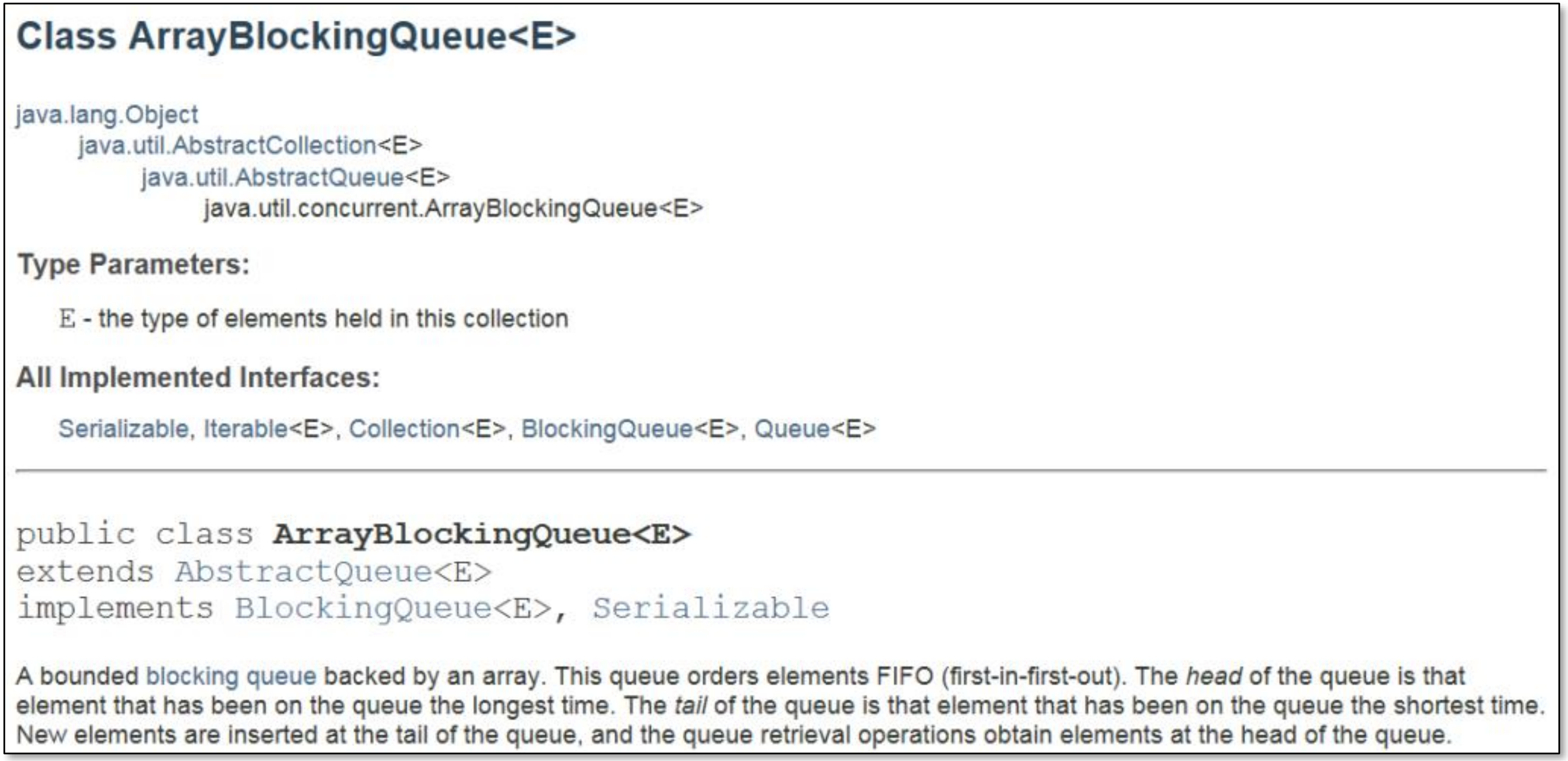


Applying Java Condition Object in Practice

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded 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:

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.

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

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue

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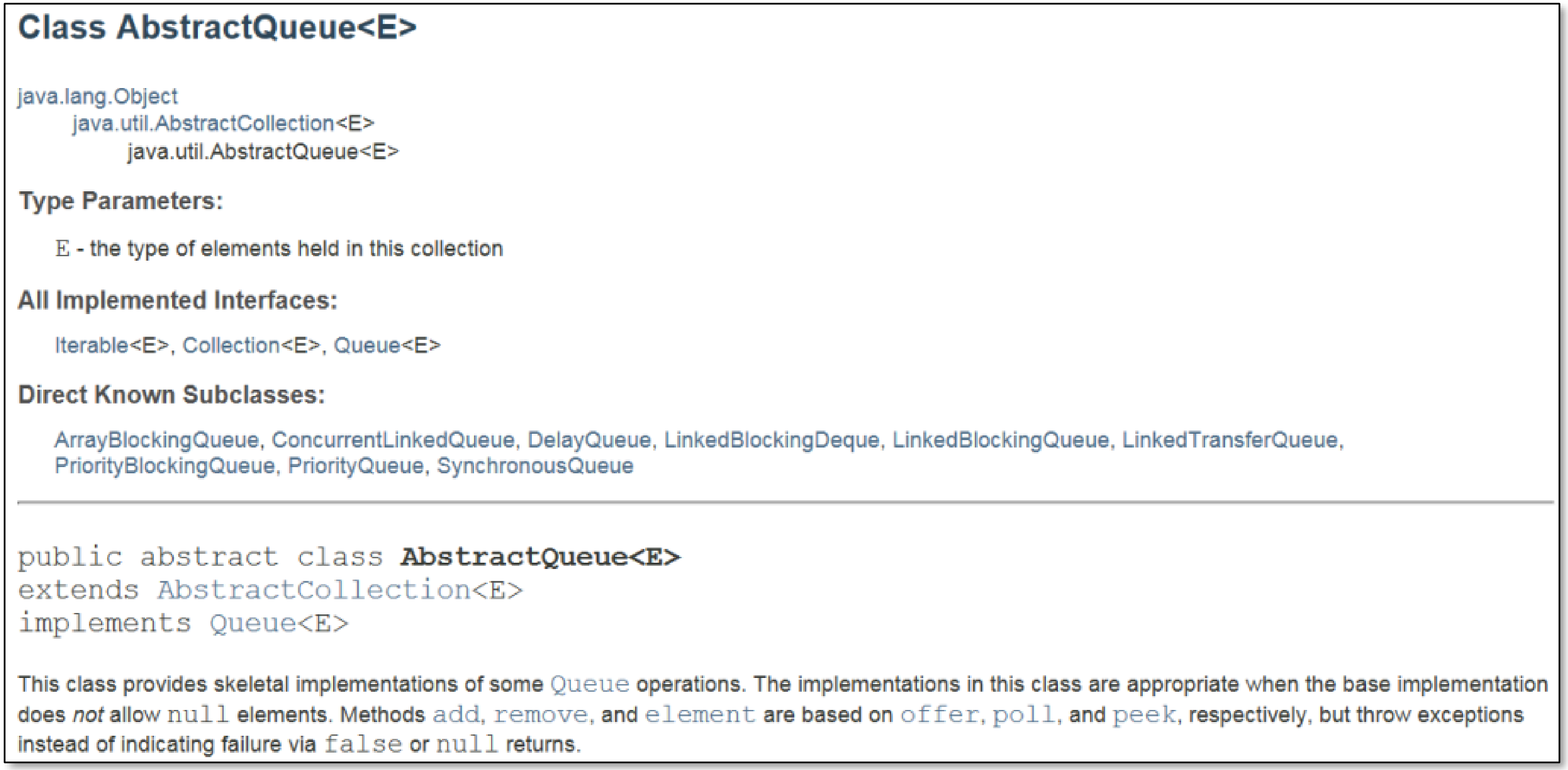
```



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>
```

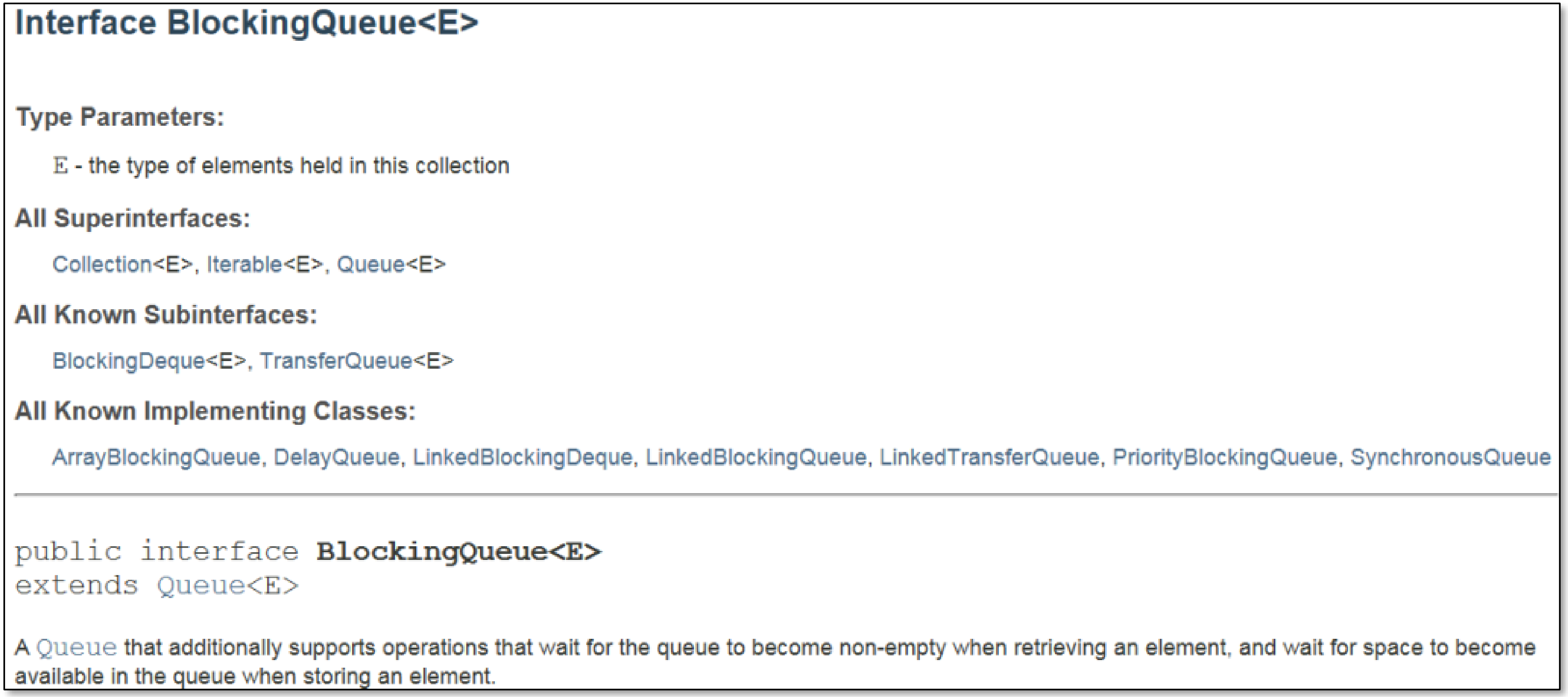
This class provides skeletal implementations of some `Queue` operations. The implementations in this class are appropriate when the base implementation does *not* allow `null` elements. Methods `add`, `remove`, and `element` are based on `offer`, `poll`, and `peek`, respectively, but throw exceptions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

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

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded 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 Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue

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

We'll focus on both the interface & implementation of ArrayBlockingQueue

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue
  - It's implemented using an dynamically sized array

```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  /** The queued items */
  final Object[] items;

  /** items index for next take,
       poll, peek or remove */
  int takeIndex;

  /** items index for next put,
      offer, or add */
  int putIndex;

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

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue
    - It's implemented using an dynamically sized array

```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
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  final Object[] items;

  /** items index for next take,
       poll, peek or remove */
  int takeIndex;

  /** items index for next put,
      offer, or add */
  int putIndex;

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

Object state that (1) must be protected from race conditions & (2) is used to coordinate concurrent put() & take() calls

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue
  - It's implemented using an dynamically sized array
  - It has a ReentrantLock & two ConditionObjects

```
public class ArrayBlockingQueue<E>
                extends AbstractQueue<E>
             implements BlockingQueue<E>,
                   java.io.Serializable {
  ...
  /** Main lock guarding access */
  final ReentrantLock lock;

  /** Condition for waiting takes */
  private final Condition notEmpty;

  /** Condition for waiting puts */
  private final Condition notFull;
  ...
```

Used to protect the object state from race conditions

See earlier lesson on "*Java ReentrantLock: Example Application*"

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue
  - It's implemented using an dynamically sized array
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public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
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  ...
  /** Main lock guarding access */
  final ReentrantLock lock;

  /** Condition for waiting takes */
  private final Condition notEmpty;

  /** Condition for waiting puts */
  private final Condition notFull;
  ...
```

Two ConditionObjects separate waiting consumers & producers, thus reducing redundant wakeups & checking

See stackoverflow.com/questions/18490636/condition-give-the-effect-of-having-multiple-wait-sets-per-object

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue
  - It's implemented using an dynamically sized array
  - It has a ReentrantLock & two ConditionObjects

```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  public ArrayBlockingQueue
          (int capacity,
           boolean fair) {
    items =
      new Object[capacity];
    lock = new ReentrantLock(fair);
    notEmpty = lock.newCondition();
    notFull =  lock.newCondition();
  }
```

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue
  - It's implemented using an dynamically sized array
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public class ArrayBlockingQueue<E>
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  ...
  public ArrayBlockingQueue
          (int capacity,
           boolean fair) {
    items =
      new Object[capacity];
    lock = new ReentrantLock(fair);
    notEmpty = lock.newCondition();
    notFull =  lock.newCondition();
  }
```

The ArrayBlockingQueue has a fixed-size capacity

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue
  - It's implemented using an dynamically sized array
  - It has a ReentrantLock & two ConditionObjects

```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  public ArrayBlockingQueue
          (int capacity,
           boolean fair) {
    items =
      new Object[capacity];
    lock = new ReentrantLock(fair);
    notEmpty = lock.newCondition();
    notFull =  lock.newCondition();
  }
```

The "fair" parameter controls the order in which a group of threads can call methods on the queue

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

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue
  - It's implemented using an dynamically sized array
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```
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           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  public ArrayBlockingQueue
          (int capacity,
           boolean fair) {
    items =
      new Object[capacity];
    lock = new ReentrantLock(fair);
    notEmpty = lock.newCondition();
    notFull =  lock.newCondition();
  }
```

If true then queue accesses for threads blocked on insertion or removal are processed in FIFO order, whereas if false access order is unspecified

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

Applying Java ConditionObject in Practice

- ArrayBlockingQueue is a blocking bounded FIFO queue
  - It's implemented using an dynamically sized array
  - It has a ReentrantLock & two ConditionObjects

```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  public ArrayBlockingQueue
          (int capacity,
           boolean fair) {
    items =
      new Object[capacity];
    lock = new ReentrantLock(fair);
    notEmpty = lock.newCondition();
    notFull =  lock.newCondition();
  }
```

Both ConditionObjects share a common ReentrantLock returned via a factory method

Visualizing the Condition Object in Action

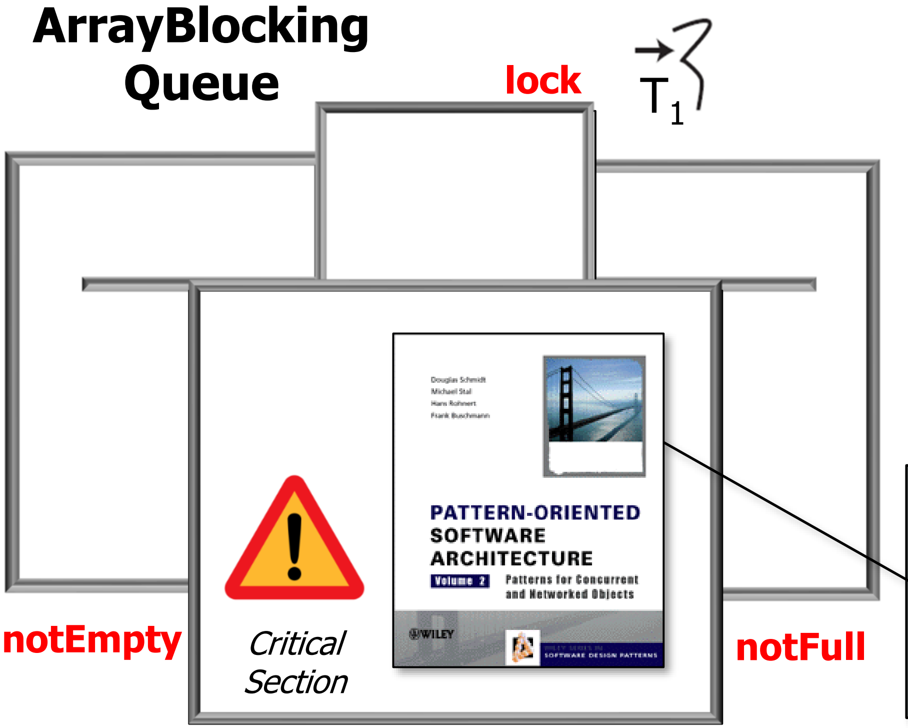
Visualizing Java ConditionObjects in Action

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
                  extends AbstractQueue<E>
               implements BlockingQueue<E>,
                     java.io.Serializable {
  ...
  /** Main lock guarding access */
  final ReentrantLock lock;

  /** Condition for waiting takes */
  private final Condition notEmpty;

  /** Condition for waiting puts */
  private final Condition notFull;
  ...
```


ArrayBlocking Queue
lock
T_1
PATTERN-ORIENTED SOFTWARE ARCHITECTURE
Volume 2
Patterns for Concurrent and Networked Objects
WILEY
notEmpty
Critical Section
notFull

This pattern synchronizes method execution to ensure only one method runs in an object at a time & allows an object's methods to cooperatively schedule their execution

See www.dre.vanderbilt.edu/~schmidt/PDF/monitor.pdf

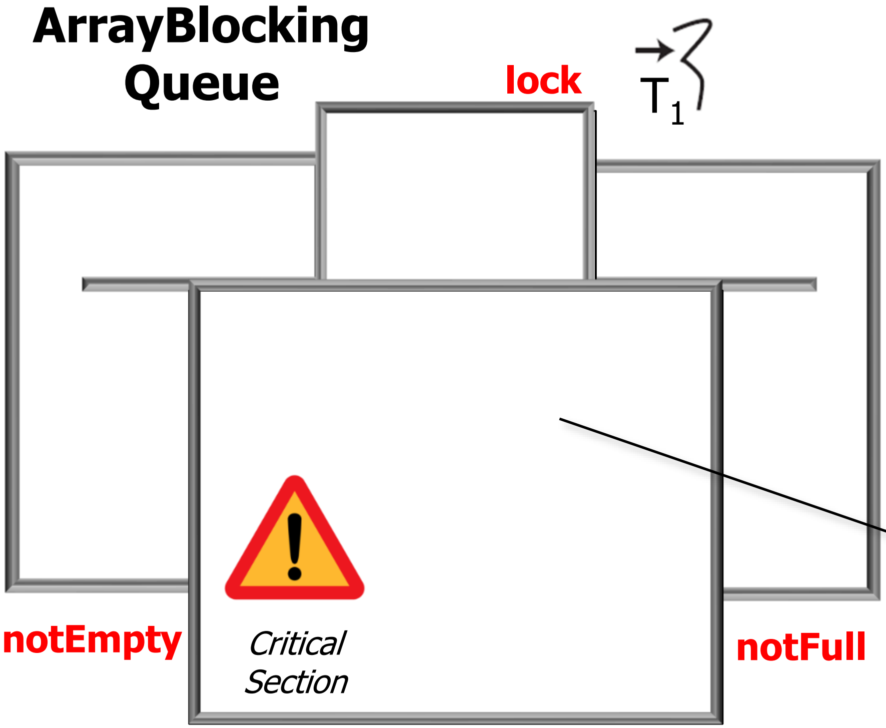
Visualizing Java ConditionObjects in Action

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  /** Main lock guarding access */
  final ReentrantLock lock;

  /** Condition for waiting takes */
  private final Condition notEmpty;

  /** Condition for waiting puts */
  private final Condition notFull;
  ...
```



The steps visualized next apply to both the Monitor Object pattern & Java condition objects

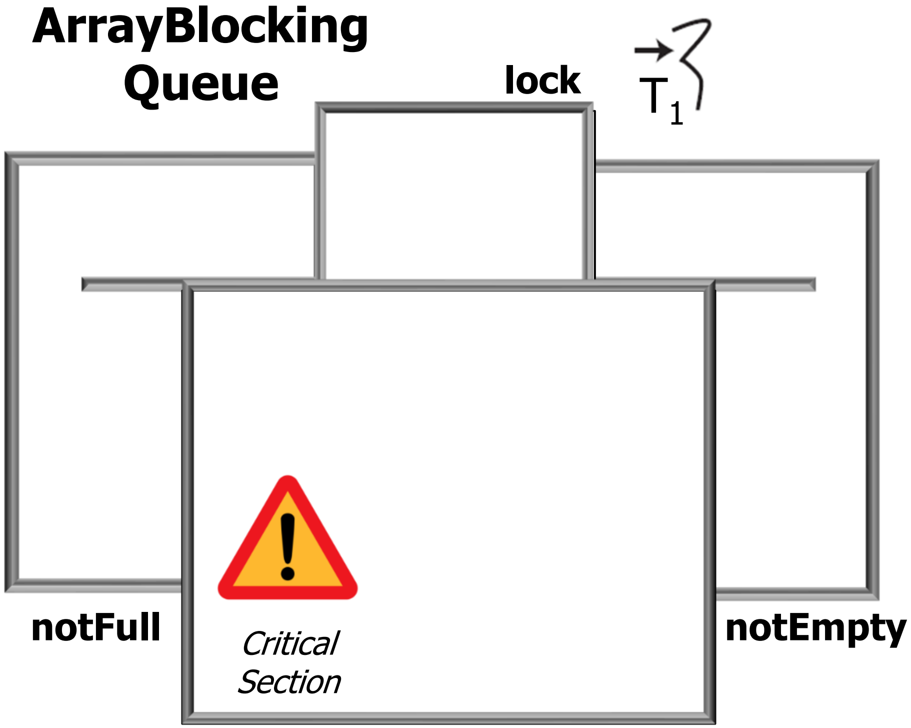
Visualizing a Java Condition Object for Take (T_1)

Visualizing a Java ConditionObject for Take (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

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

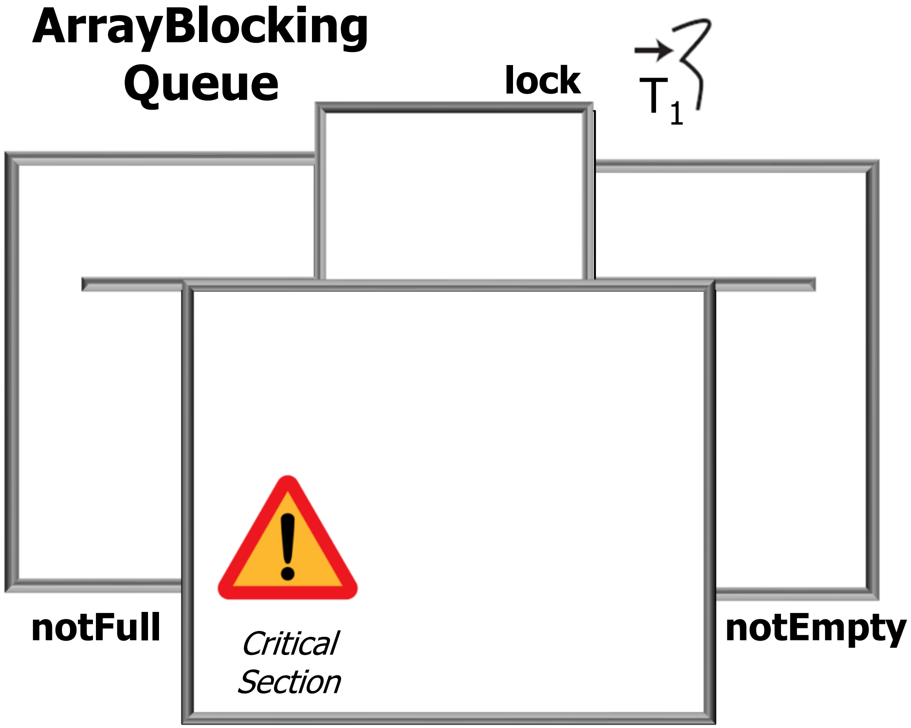
Create a bounded blocking queue with a maximum size of 10 elements



Visualizing a Java ConditionObject for Take (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

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

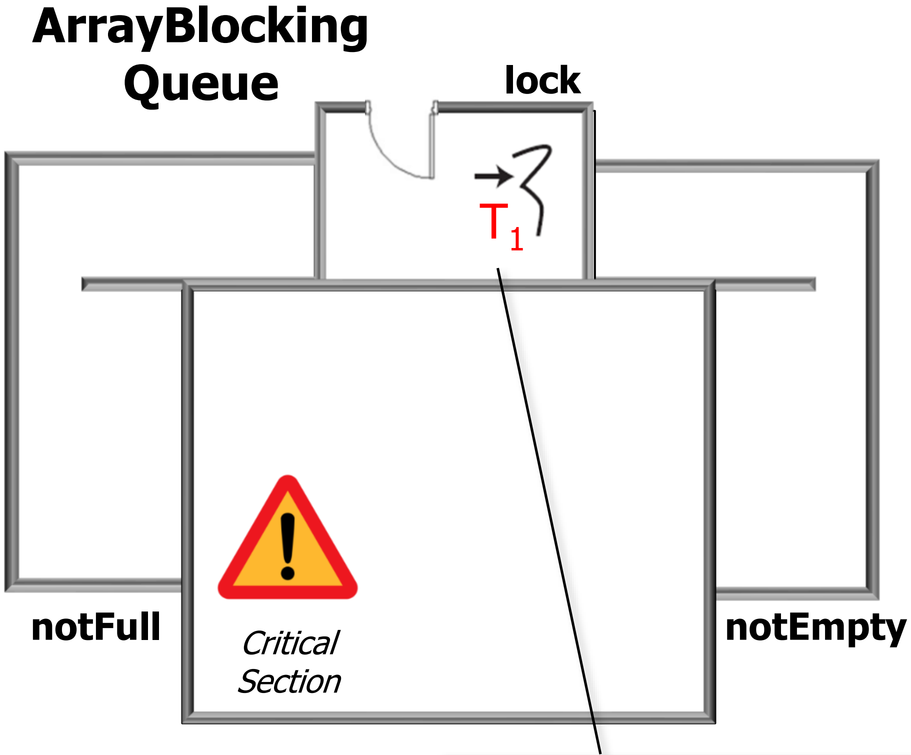


This call to the take() method blocks since the queue is initially empty

Visualizing a Java ConditionObject for Take (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
           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();
    }
  }
```

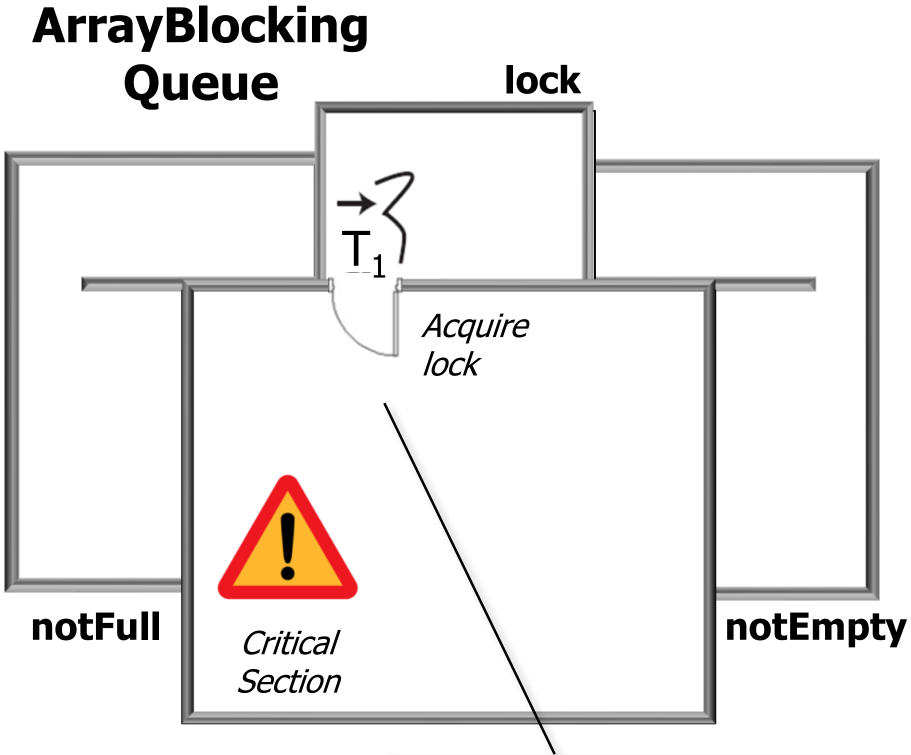


When take() is called thread T_1 enters the monitor object if there's no contention of the monitor lock

Visualizing a Java ConditionObject for Take (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
           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();
    }
  }
```

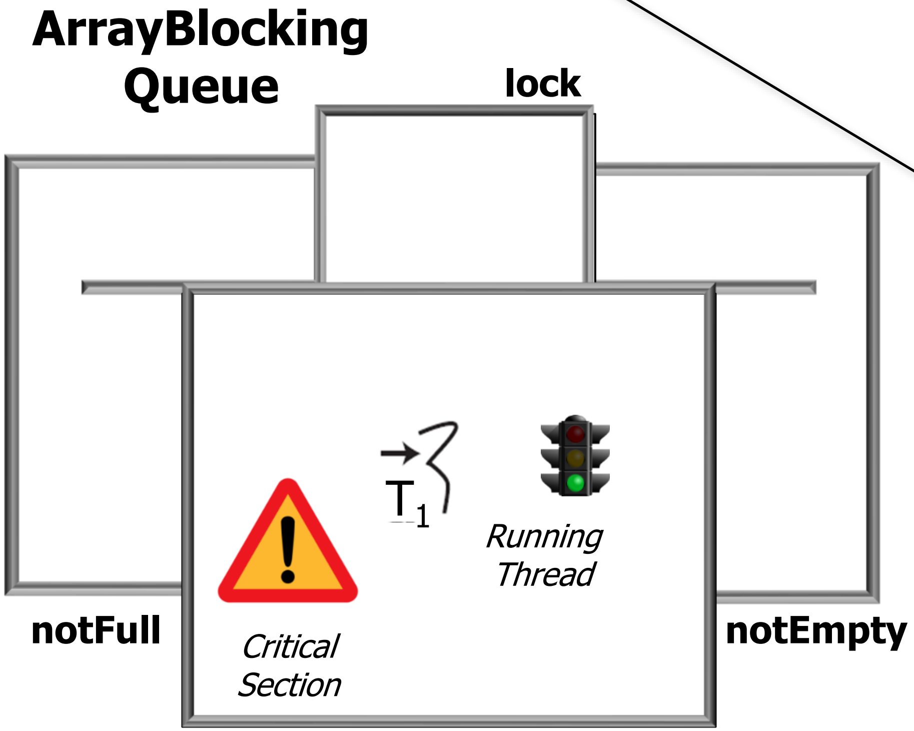


Thread T_1 then acquires the lock & enters the critical section since there's no contention from other threads

Visualizing a Java ConditionObject for Take (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

The Guarded Suspension pattern waits until the queue's not empty



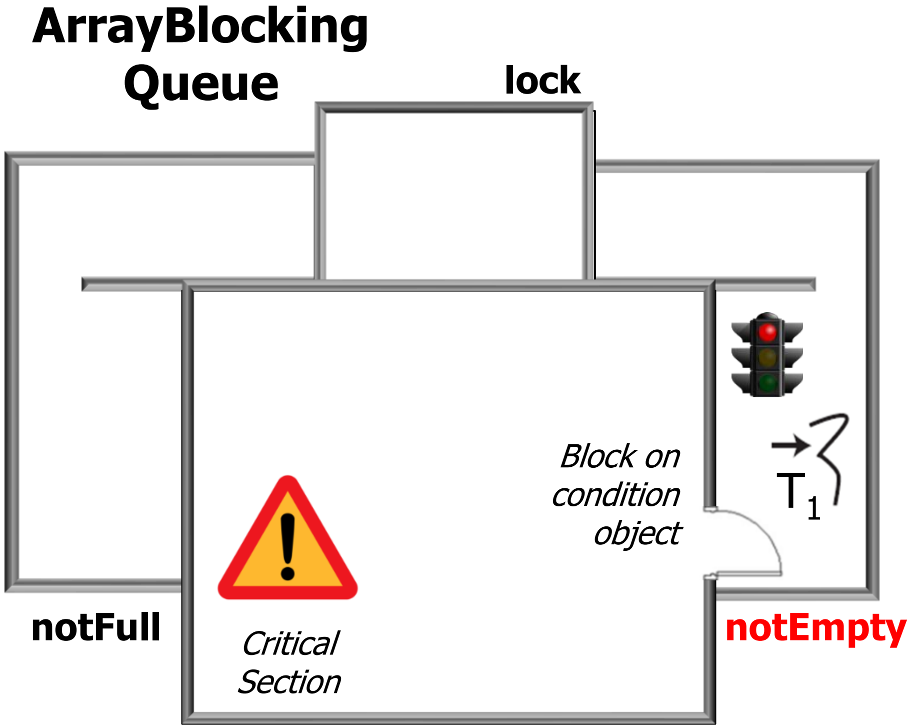
```
public class ArrayBlockingQueue<E>
                 extends AbstractQueue<E>
              implements BlockingQueue<E>,
                    java.io.Serializable {
 ...
 public E take() ... {
   final ReentrantLock lock =
     this.lock;
   lock.lockInterruptibly();
   try {
     while (count == 0)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

See en.wikipedia.org/wiki/Guarded_suspension

Visualizing a Java ConditionObject for Take (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
           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();
    }
  }
```



The call to await() atomically blocks T_1 & releases the lock

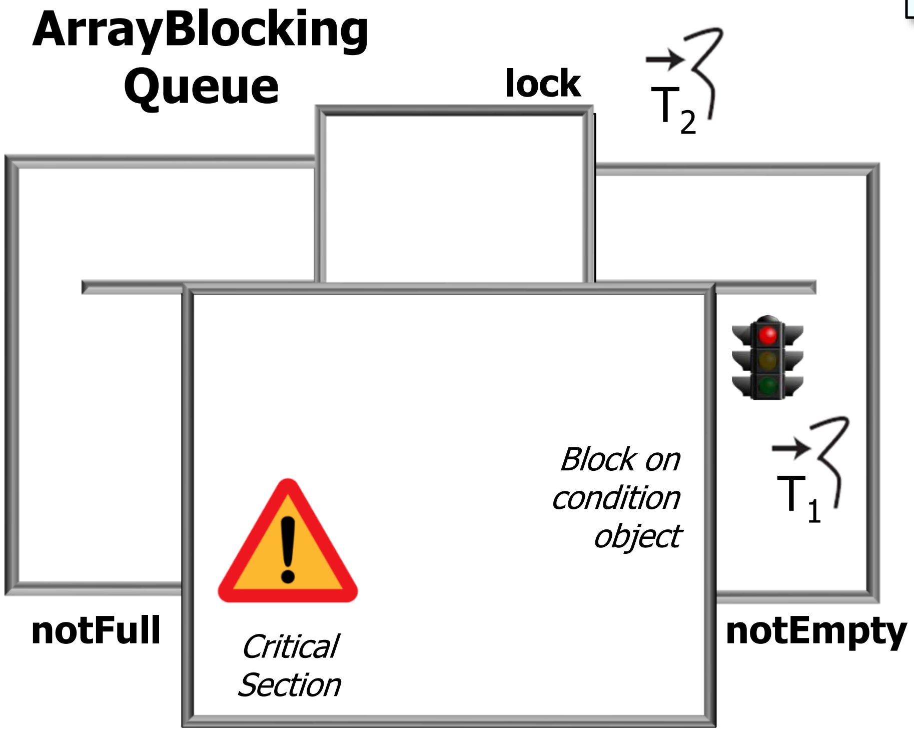
Visualizing a Java Condition Object for Put (T_2)

Visualizing a Java ConditionObject for Put (T_2)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

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

This is the same bounded blocking queue with a maximum size of 10 elements



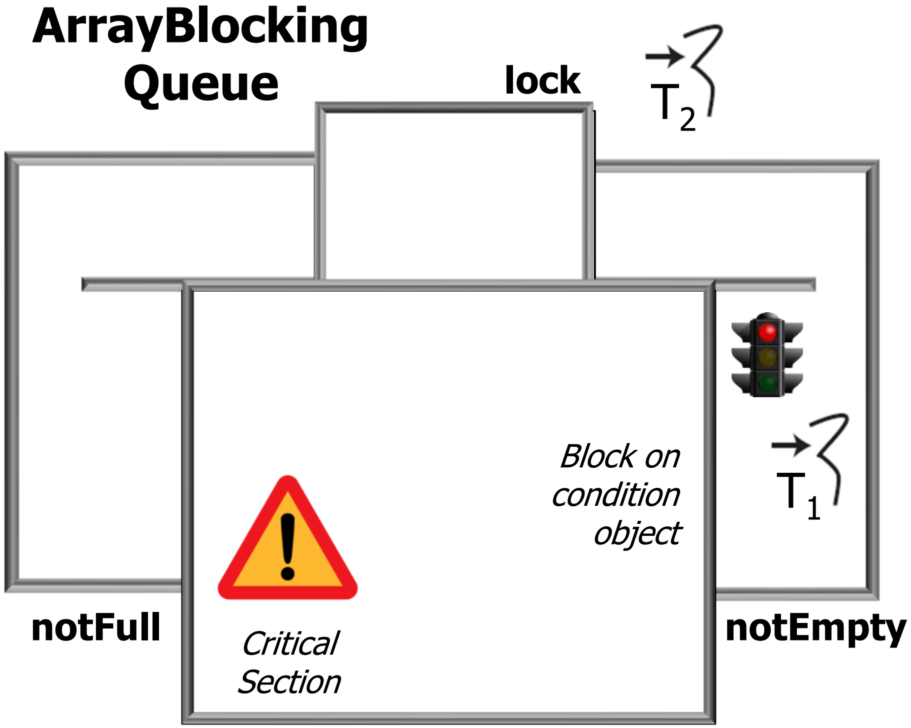
Visualizing a Java ConditionObject for Put (T_2)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

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

// Called by thread T2
String s =
  new String("...");
...

q.put(s);
...
```

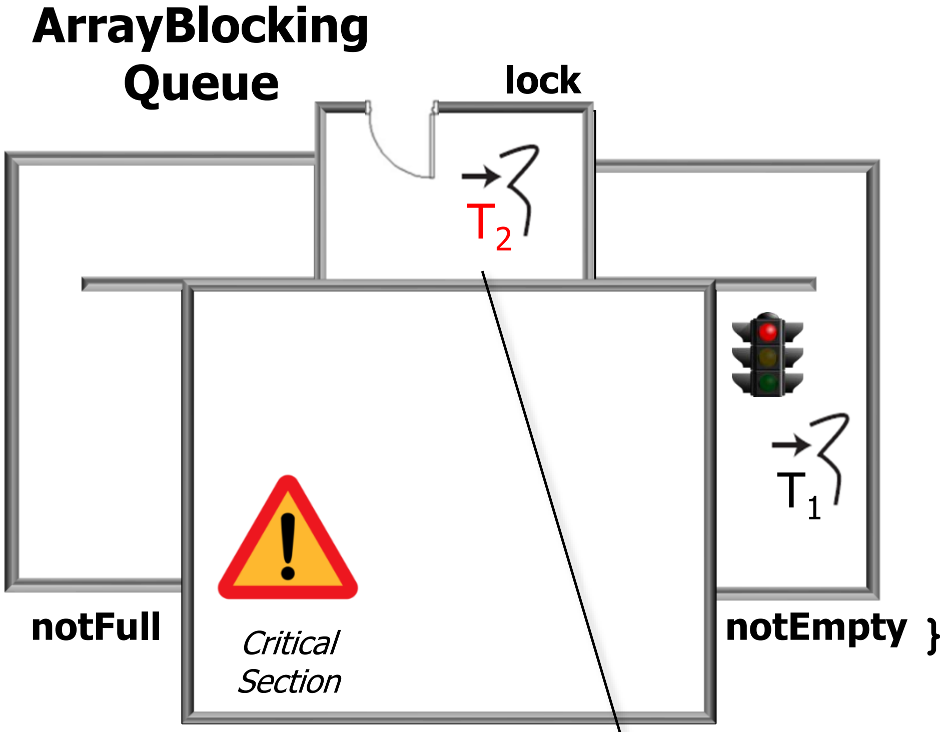


Thread T_2 puts a new string into the queue, which is currently empty & which has thread T_1 waiting on the notEmpty ConditionObject

Visualizing a Java ConditionObject for Put (T_2)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
                extends AbstractQueue<E>
            implements BlockingQueue<E>,
                       java.io.Serializable {
  ...
  public void put(E e) … {
    ...
    final ReentrantLock lock =
      this.lock;
    lock.lockInterruptibly();
    try {
      while (count == items.length)
        notFull.await();
      insert(e);
    } finally {
        lock.unlock();
    }
    }
```

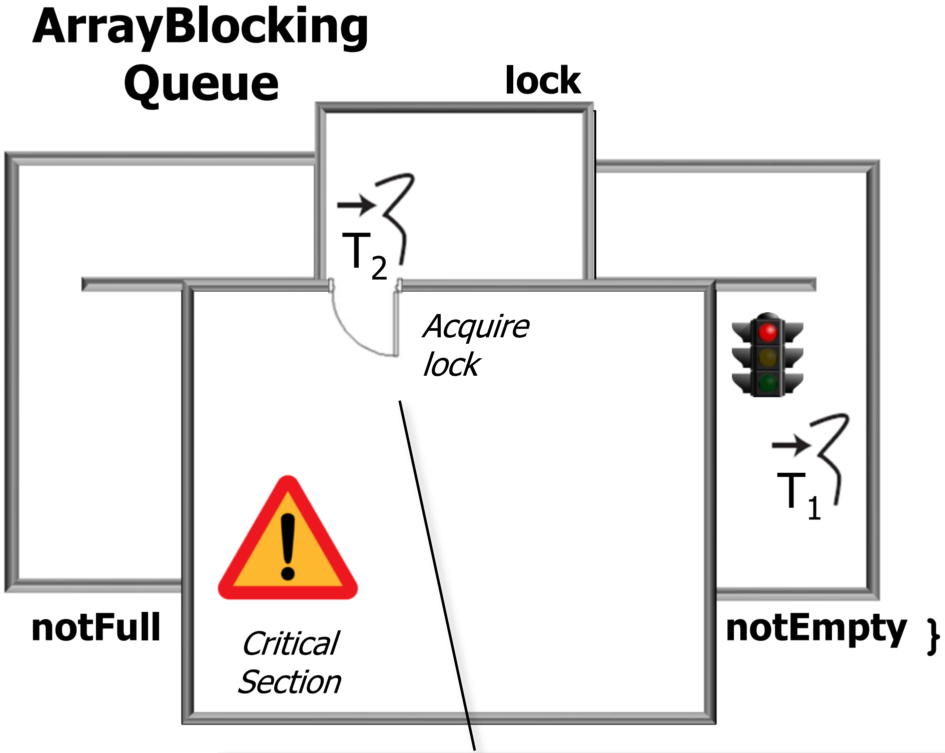


When put() is called thread T_2 enters the monitor object

Visualizing a Java ConditionObject for Put (T_2)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
                   java.io.Serializable {
  ...
  public void put(E e) … {
    ...
    final ReentrantLock lock =
      this.lock;
    lock.lockInterruptibly();
    try {
      while (count == items.length)
        notFull.await();
      insert(e);
    } finally {
        lock.unlock();
    }
}
```

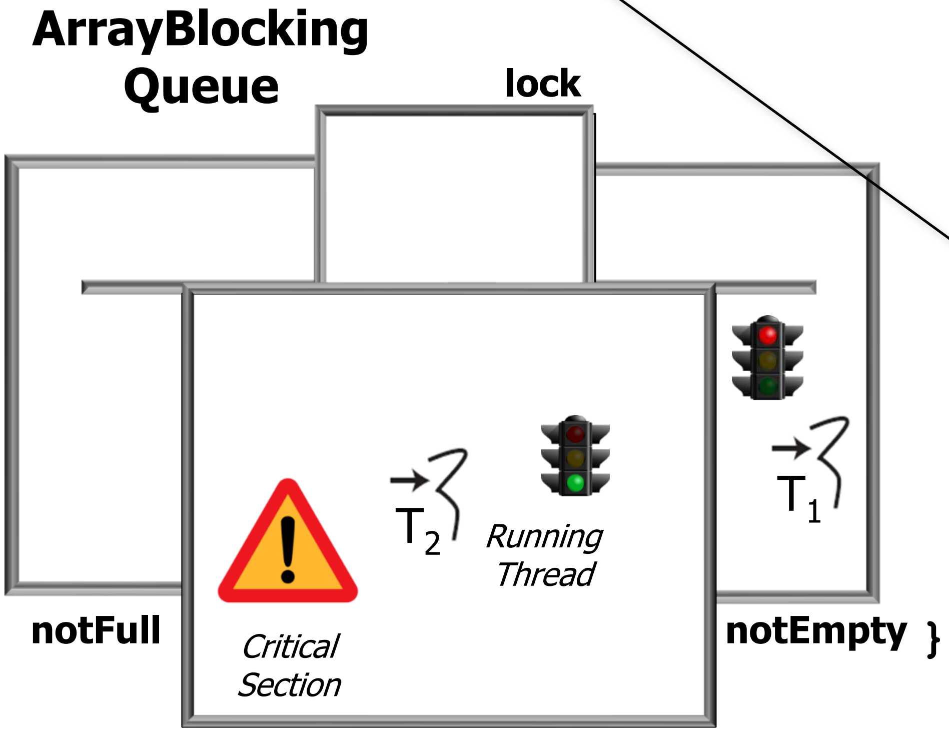


Thread T_2 acquires the monitor lock & enters the critical section since there's no contention from other threads

Visualizing a Java ConditionObject for Put (T_2)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

The Guarded Suspension pattern waits until the queue's not full

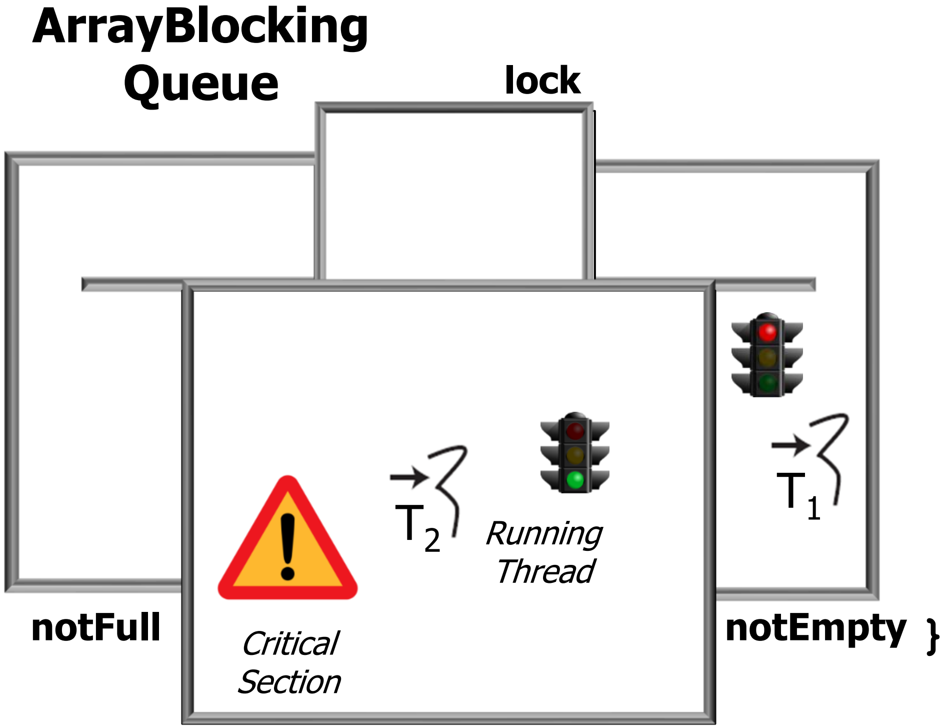


```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  public void put(E e) … {
    ...
    final ReentrantLock lock =
      this.lock;
    lock.lockInterruptibly();
    try {
      while (count == items.length)
        notFull.await();
      insert(e);
    } finally {
        lock.unlock();
    }
```

See en.wikipedia.org/wiki/Guarded_suspension

Visualizing a Java ConditionObject for Put (T_2)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern



```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  public void put(E e) … {
    ...
    final ReentrantLock lock =
      this.lock;
    lock.lockInterruptibly();
    try {
      while (count == items.length)
        notFull.await();
      insert(e);
    } finally {
        lock.unlock();
    }
  }
```

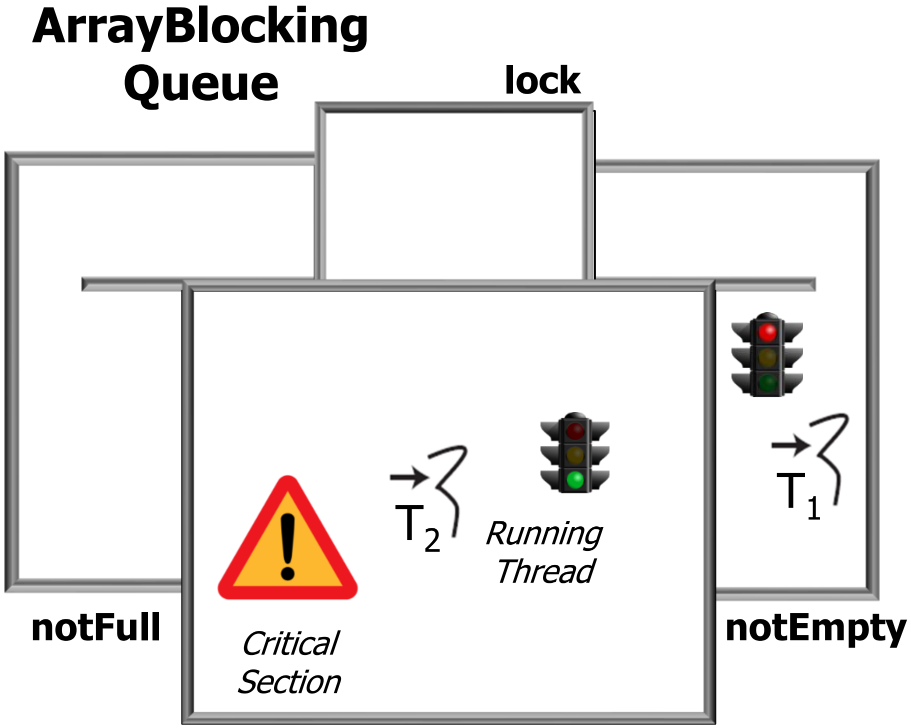
After the condition is satisfied the new element can be inserted into the queue

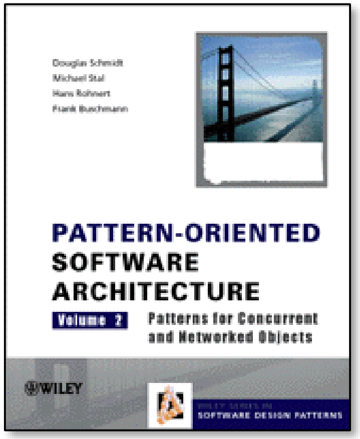
Visualizing a Java ConditionObject for Put (T_2)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
                   java.io.Serializable {
  ...
  private void insert(E x) {
    items[putIndex] = x;
    putIndex = inc(putIndex);
    ++count;
    notEmpty.signal();
  }
```

insert() is not synchronized since it must be called with the lock held





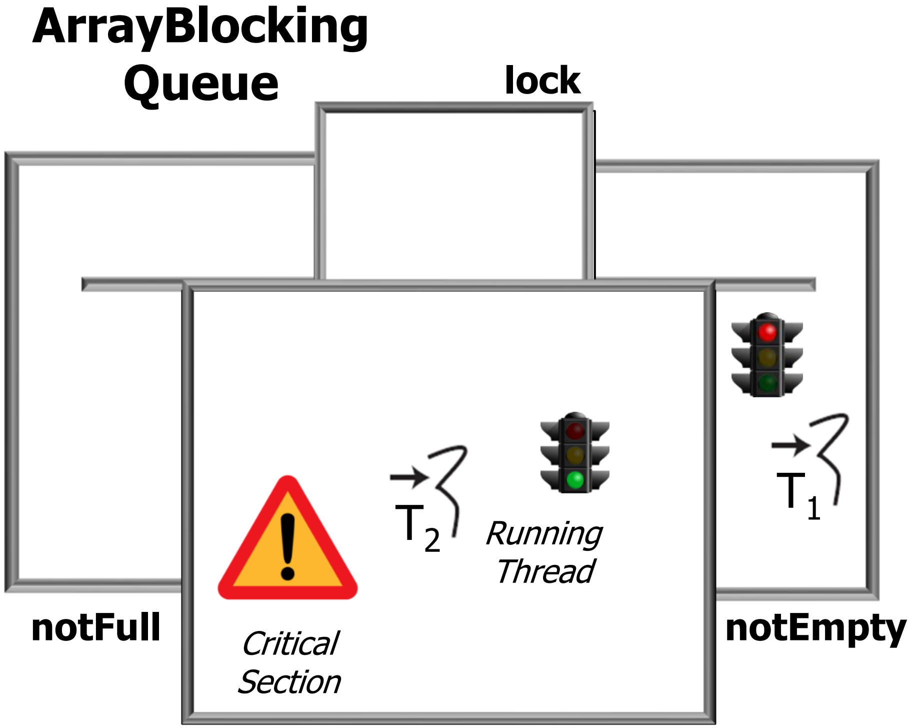
See www.dre.vanderbilt.edu/~schmidt/PDF/locking-patterns.pdf

Visualizing a Java ConditionObject for Put (T_2)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  private void insert(E x) {
    items[putIndex] = x;
    putIndex = inc(putIndex);
    ++count;
    notEmpty.signal();
  }
```

This method updates the state of the queue



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- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

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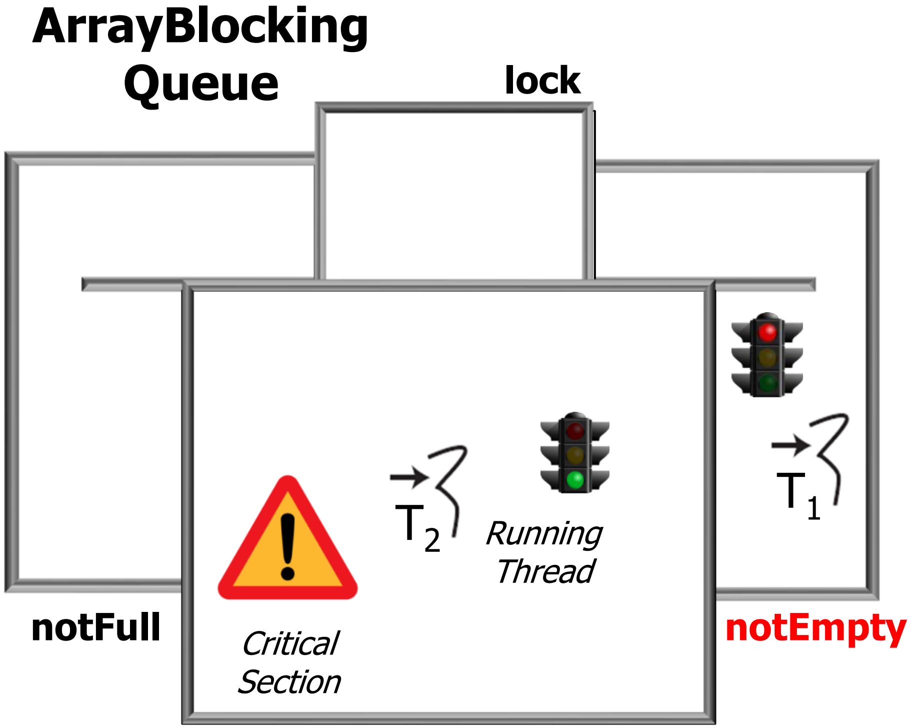
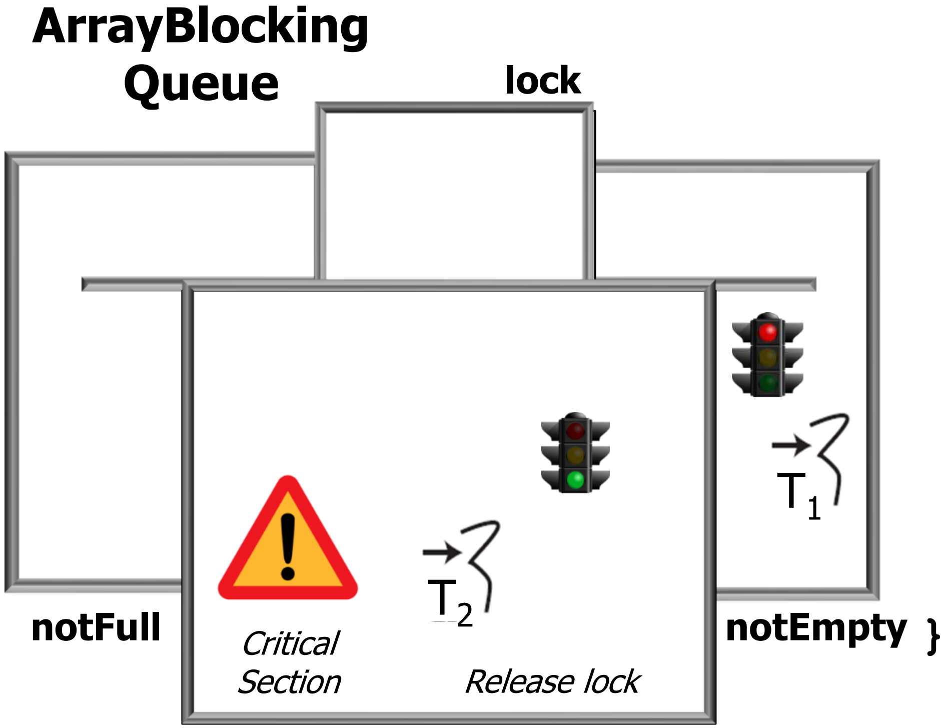
    items[putIndex] = x;
    putIndex = inc(putIndex);
    ++count;
    notEmpty.signal();
  }
```



It then signals the notEmpty condition object to indicate the queue's no longer empty

Visualizing a Java ConditionObject for Put (T_2)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern



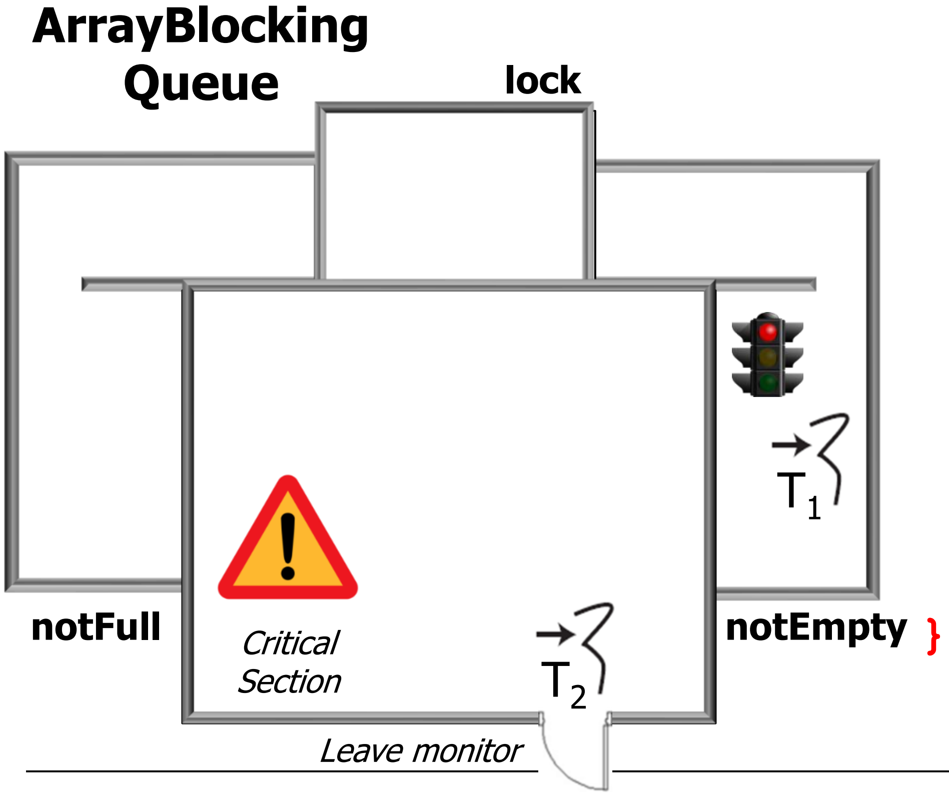
```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  public void put(E e) … {
    ...
    final ReentrantLock lock =
      this.lock;
    lock.lockInterruptibly();
    try {
      while (count == items.length)
        notFull.await();
      insert(e);
    } finally {
      lock.unlock();
    }
  }
```

The put() method then unlocks the monitor lock

Visualizing a Java ConditionObject for Put (T_2)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
                extends AbstractQueue<E>
             implements BlockingQueue<E>,
                   java.io.Serializable {
  ...
  public void put(E e) … {
    ...
    final ReentrantLock lock =
      this.lock;
    lock.lockInterruptibly();
    try {
      while (count == items.length)
        notFull.await();
      insert(e);
    } finally {
      lock.unlock();
    }
  }
```



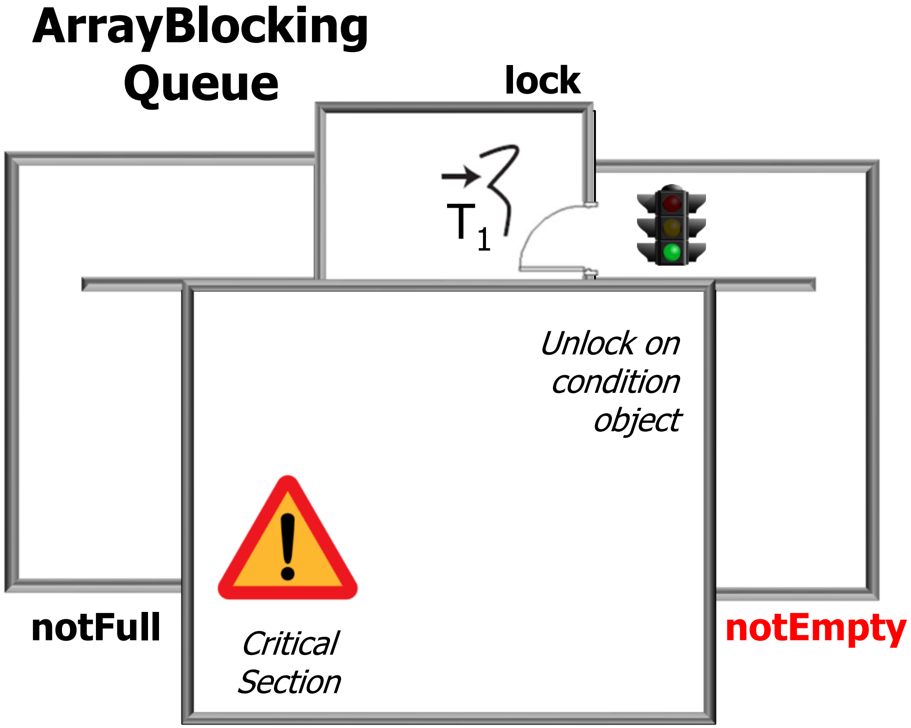
The put() method finally leaves the monitor

Visualizing a Condition Object for Take (T_1)

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
                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();
    }
  }
```

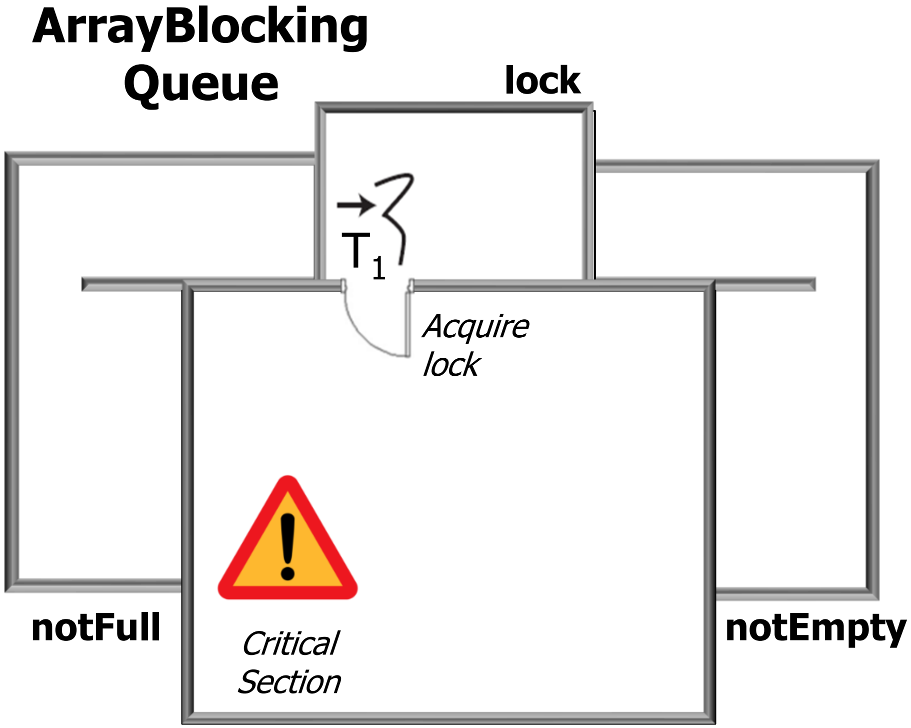


When insert() signals the notEmpty condition thread T_1 wakes up & returns in take()

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
                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();
    }
  }
```

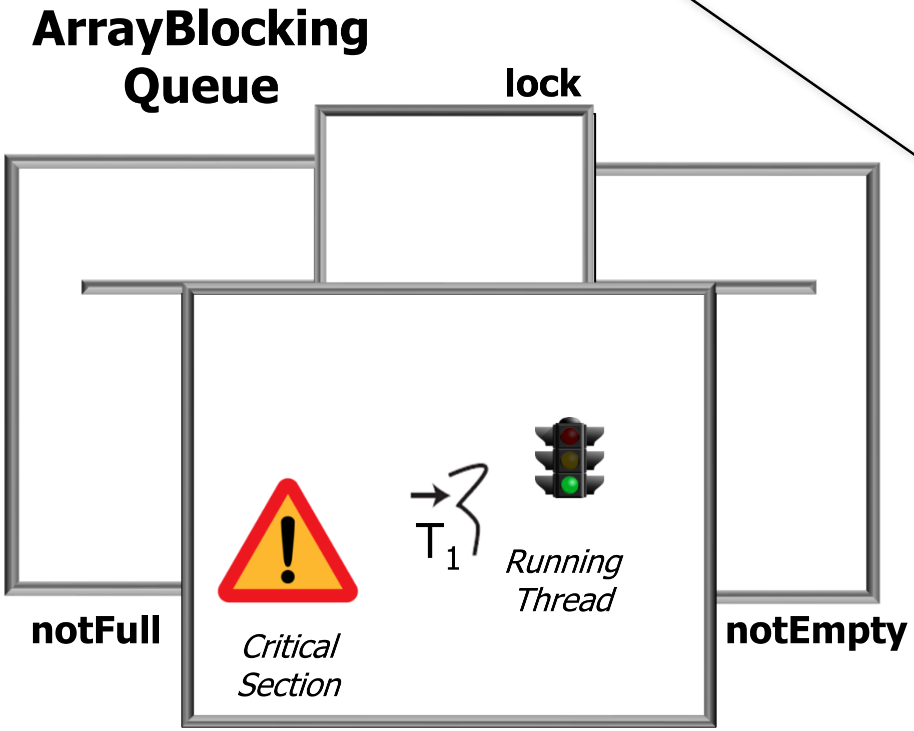


Before await() returns the monitor lock will be reacquired atomically

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

The Guarded Suspension pattern waits to see if the queue is no longer empty



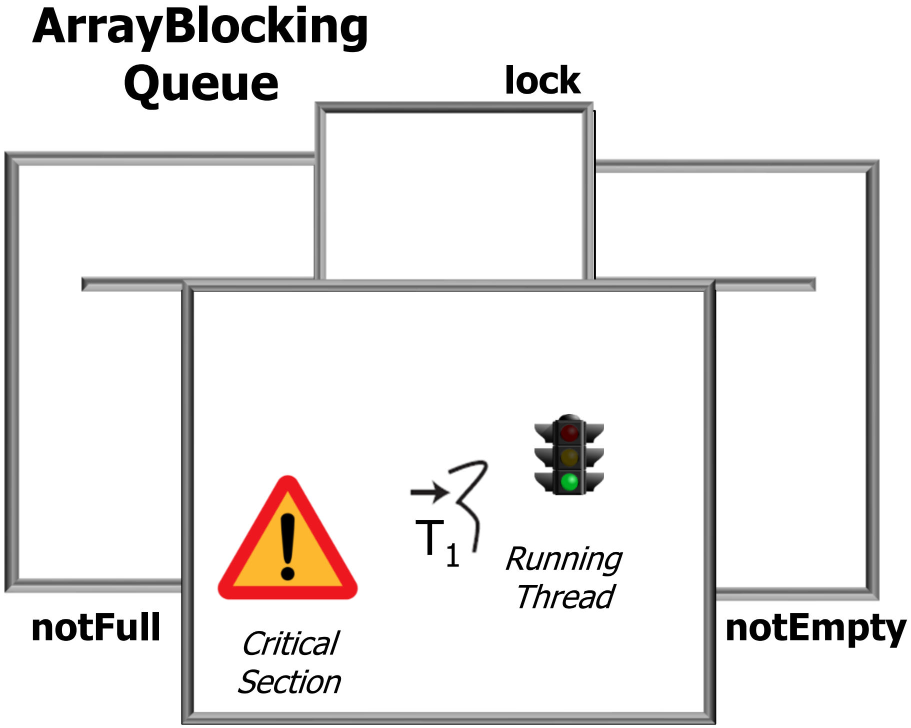
```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
...
public E take() ... {
  final ReentrantLock lock =
    this.lock;
  lock.lockInterruptibly();
  try {
    while (count == 0)
      notEmpty.await();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

See en.wikipedia.org/wiki/Guarded_suspension

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

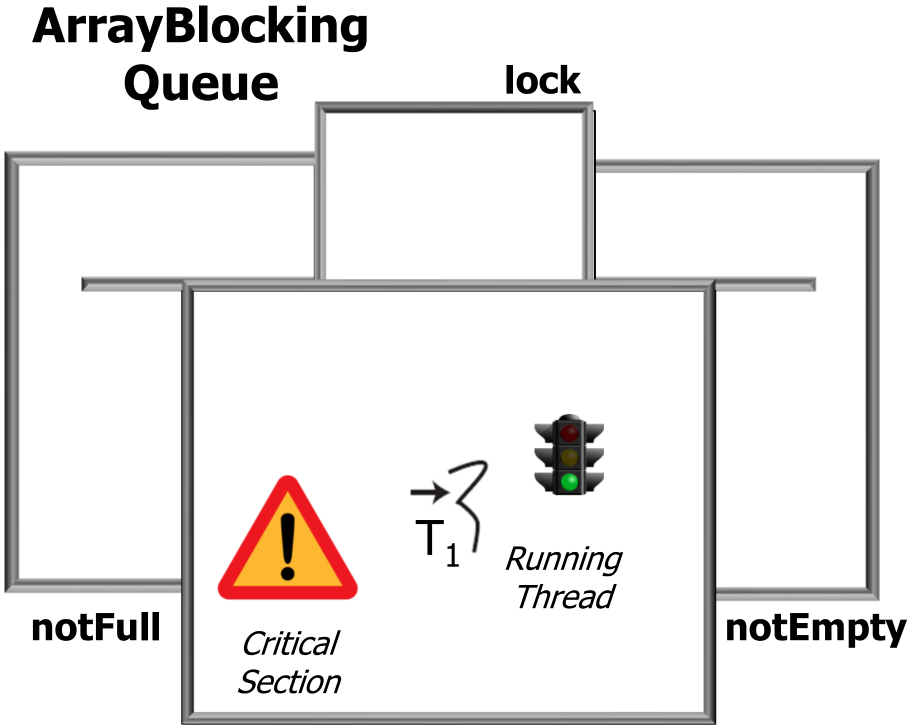
```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  public E take() ... {
    final ReentrantLock lock =
      this.lock;
    lock.lockInterruptibly();
    try {
      while (count == 0)
        notEmpty.await();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



When the condition is satisfied the extract() method is called

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern



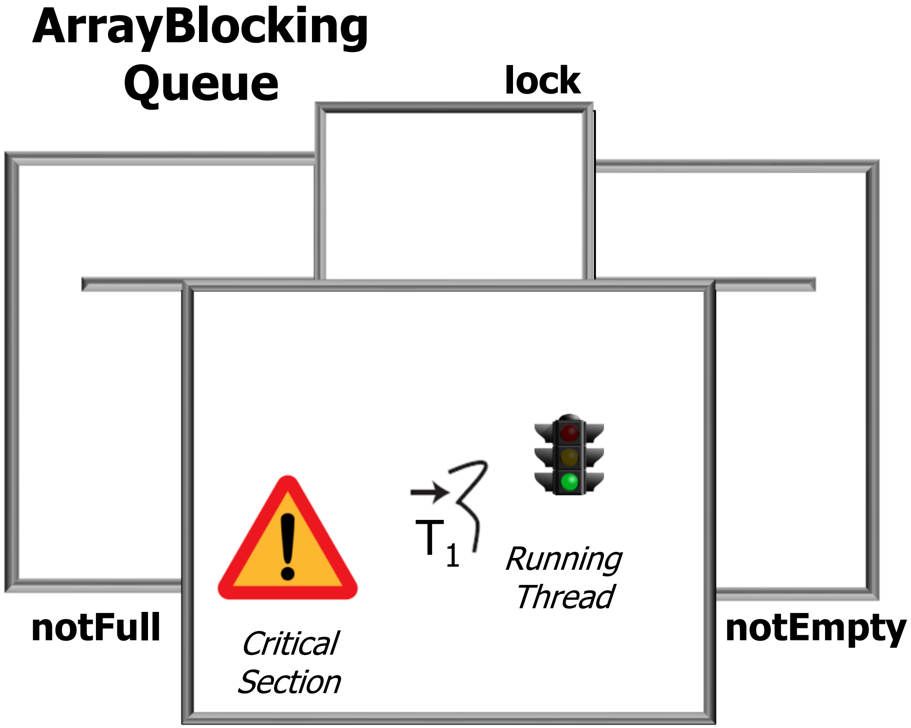
```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
              java.io.Serializable {
  ...
  private E extract() {
    final Object[] items =
      this.items;
    E x =
      this.<E>cast
        (items[takeIndex]);
    items[takeIndex] = null;
    takeIndex = inc(takeIndex);
    --count;
    notFull.signal();
    return x;
  }
```

extract() assumes it's called with the monitor lock held

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
          extends AbstractQueue<E>
       implements BlockingQueue<E>,
             java.io.Serializable {
  ...
  private E extract() {
    final Object[] items =
      this.items;
    E x =
      this.<E>cast
        (items[takeIndex]);
    items[takeIndex] = null;
    takeIndex = inc(takeIndex);
    --count;
    notFull.signal();
    return x;
  }
```

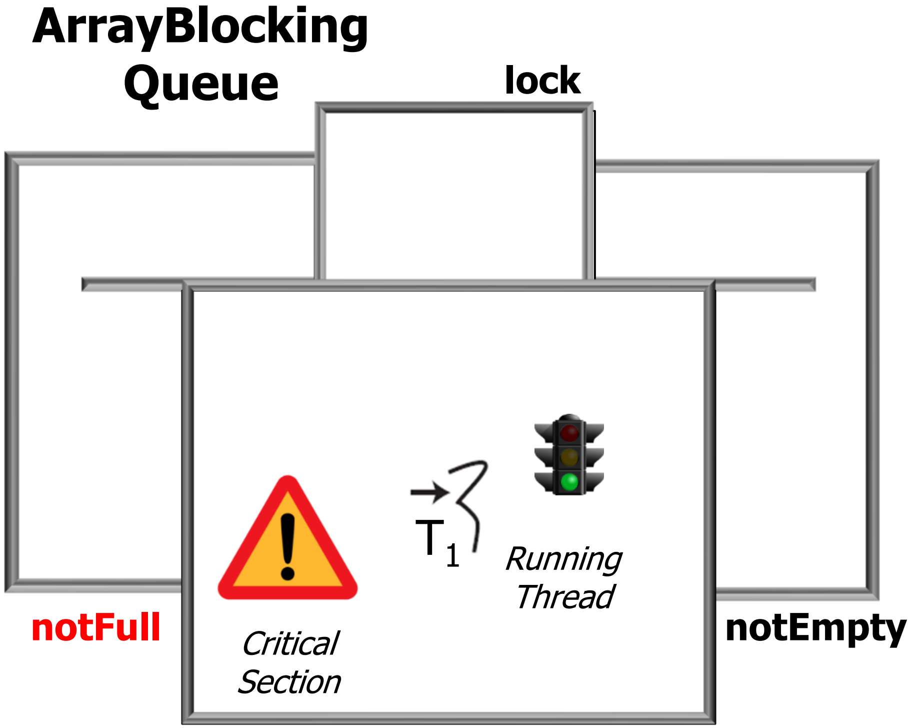


extract() updates the state of the queue to remove the front item

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
           extends AbstractQueue<E>
        implements BlockingQueue<E>,
                   java.io.Serializable {
  ...
  private E extract() {
    final Object[] items =
      this.items;
    E x =
      this.<E>cast
        (items[takeIndex]);
    items[takeIndex] = null;
    takeIndex = inc(takeIndex);
    --count;
    notFull.signal();
    return x;
  }
```

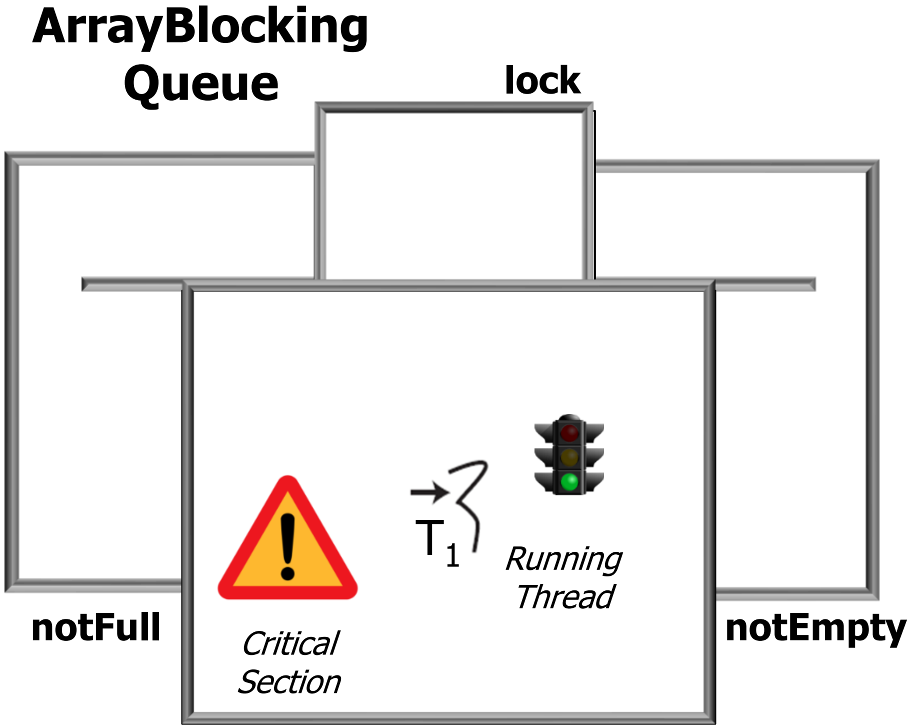


It then signals the notFull CO to alert any thread waiting in put() that the queue's not full

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

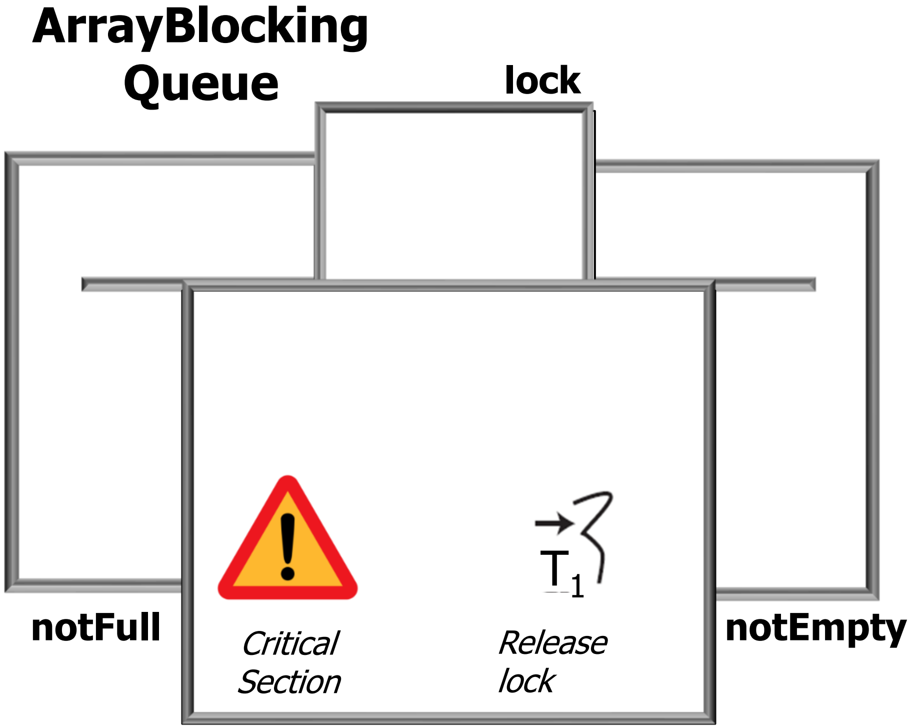
```
public class ArrayBlockingQueue<E>
                  extends AbstractQueue<E>
               implements BlockingQueue<E>,
                     java.io.Serializable {
  ...
  private E extract() {
    final Object[] items =
      this.items;
    E x =
      this.<E>cast
        (items[takeIndex]);
    items[takeIndex] = null;
    takeIndex = inc(takeIndex);
    --count;
    notFull.signal();
    return x;
  }
```



The item that's extracted is then returned to the caller of take()

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern



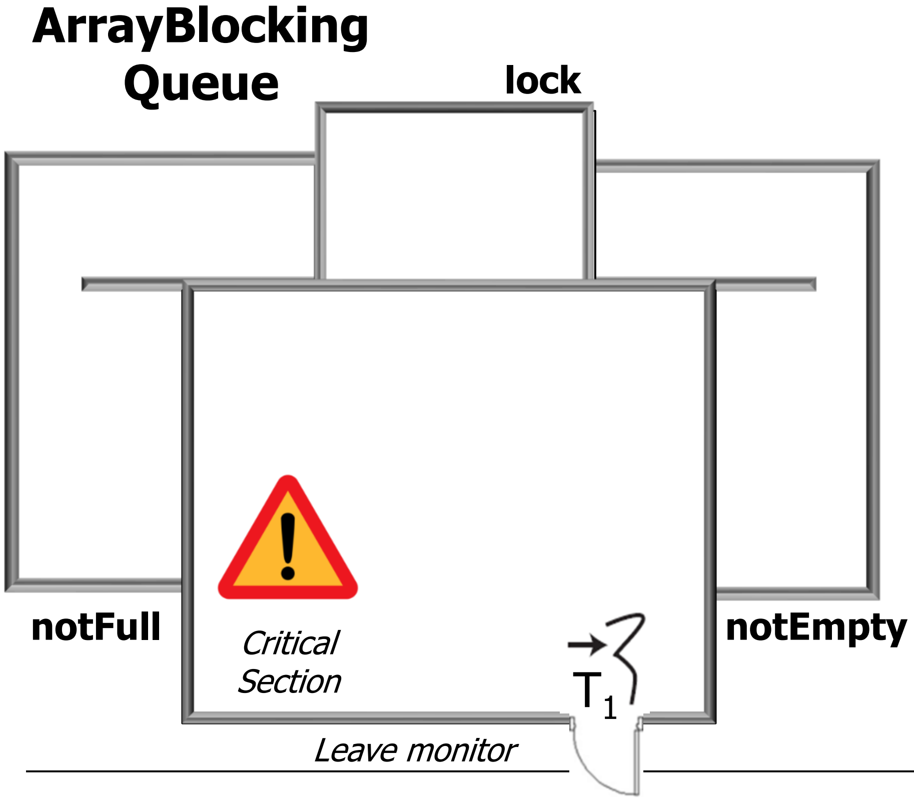
```
public class ArrayBlockingQueue<E>
            extends AbstractQueue<E>
         implements BlockingQueue<E>,
               java.io.Serializable {
  ...
  public E take() ... {
    final ReentrantLock lock =
      this.lock;
    lock.lockInterruptibly();
    try {
      while (count == 0)
     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

The take() method then unlocks the monitor lock

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
                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();
     }
   }
```

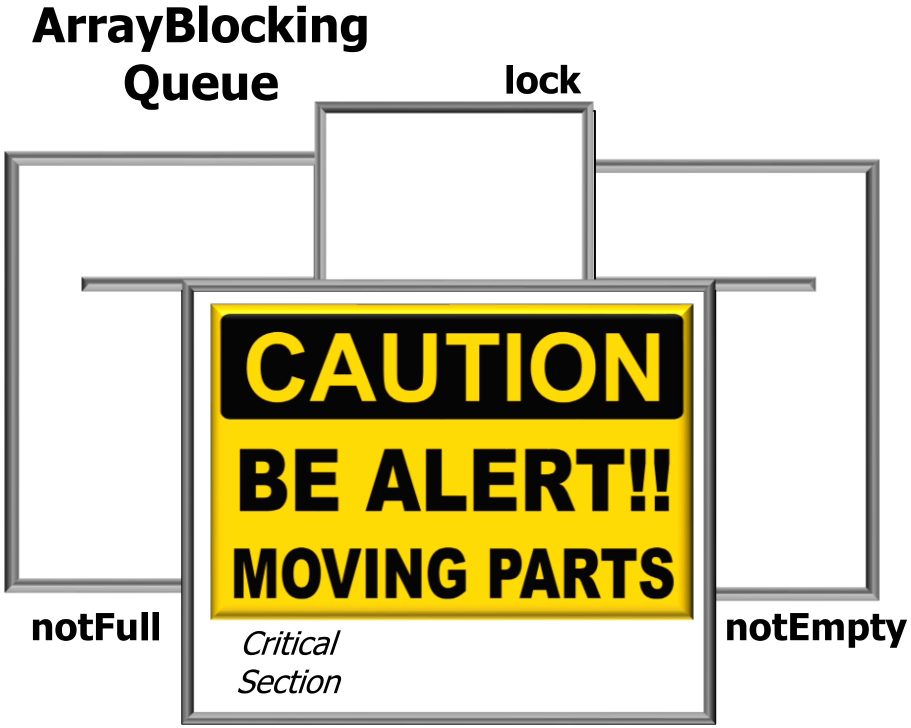


The take() method then finally leaves the monitor

Visualizing a Java ConditionObject for Put (T_1)

- ReentrantLock & Condition Objects implement the *Monitor Object* pattern

```
public class ArrayBlockingQueue<E>
                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();
    }
  }
```



This example is complex due to the concurrent coordination between threads & the "moving parts" between the lock & condition objects!

End of Java ConditionObject: Example Application