Java Monitor Objects: Coordination Example Implementation

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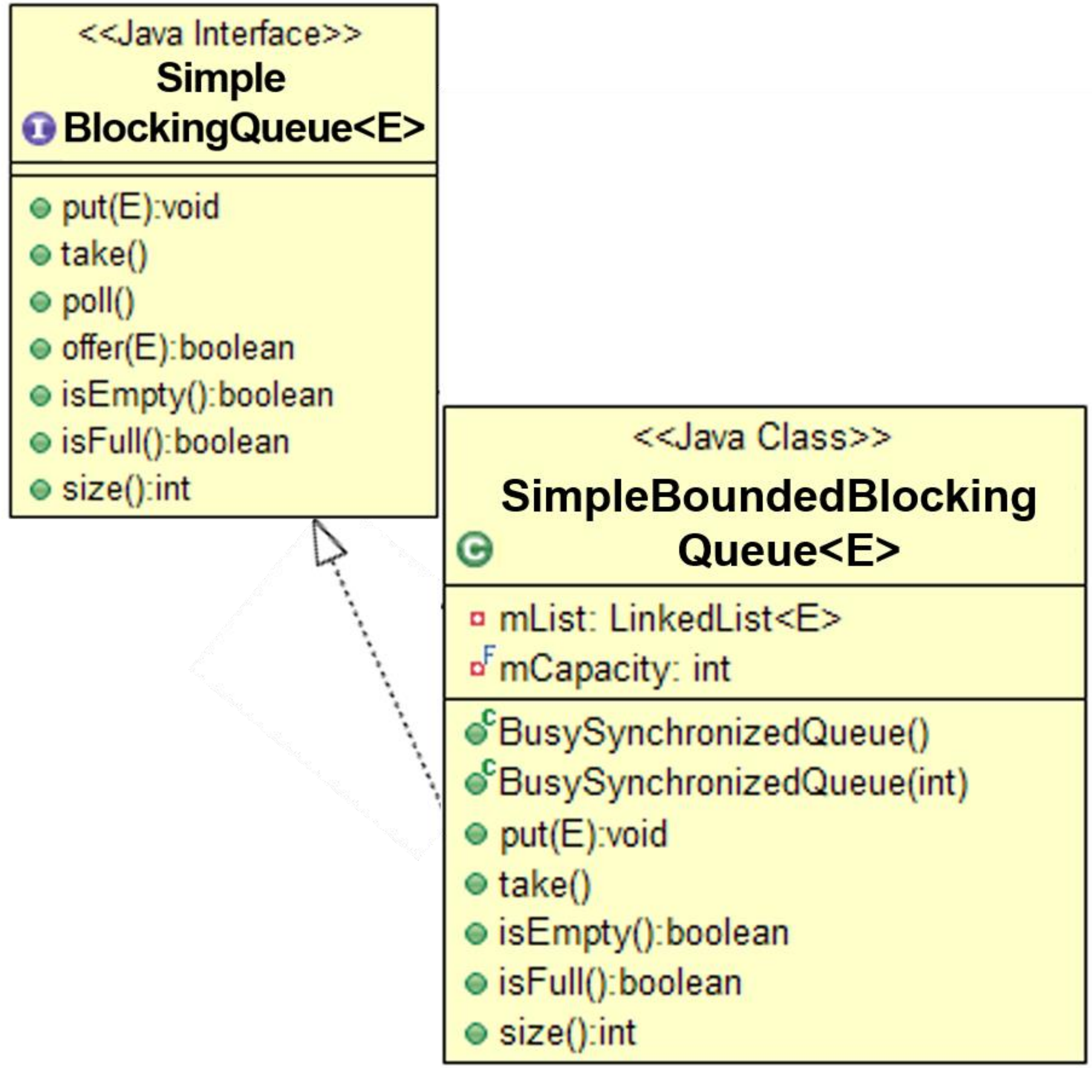
Learning Objectives in this Part of the Module

- Learn how to fix a buggy concurrent Java program using Java's wait & notify mechanisms, which provide *coordination*
- Visualize how Java monitor objects can be used to ensure mutual exclusion & coordination between threads running in a concurrent program
- Know how to program the Simple BlockingBoundedQueue in Java

Code Analysis of the SimpleBlockingBounded Queue Example

Code Analysis of SimpleBoundedBlockingQueue

- This class provides a simple synchronized blocking queue that limited to a given # of elements



See github.com/douglascraigschmidt/POSA/tree/master/ex/M3/BoundedBuffers/SimpleBoundedBlockingQueue

Code Analysis of SimpleBoundedBlockingQueue

- This class provides a simple synchronized blocking queue

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  private List<E> mList;
  private int mCapacity;

  SimpleBoundedBlockingQueue
    (int capacity)
  {
    mList = new ArrayList<E>();
    mCapacity = capacity;
  }
  ...
```

Code Analysis of SimpleBoundedBlockingQueue

- This class provides a simple synchronized blocking queue

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  private List<E> mList;
  private int mCapacity;
```

This internal state must be protected against race conditions

```
  SimpleBoundedBlockingQueue
     (int capacity)
  {
    mList = new ArrayList<E>();
    mCapacity = capacity;
  }
  ...
```

Code Analysis of SimpleBoundedBlockingQueue

- This class provides a simple synchronized blocking queue

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  private List<E> mList;
  private int mCapacity;

  SimpleBoundedBlockingQueue
    (int capacity)
  {
    mList = new ArrayList<E>();
    mCapacity = capacity;
  }
  ...
```

The constructor need not be protected against race conditions

A constructor is only called once in one thread so there won't be race conditions

Code Analysis of SimpleBoundedBlockingQueue

- A thread can "wait" for a condition in a synchronized method


```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
    while (isEmpty())
      wait();

    final E e = mList.poll();

    notifyAll();
    return e;
  }

  public synchronized boolean isEmpty(){
    return mList.isEmpty();
  }
  ...
```

See en.wikipedia.org/wiki/Guarded_suspension

Code Analysis of SimpleBoundedBlockingQueue

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    final E e = mList.poll();

    notifyAll();
    return e;
  }

  public synchronized boolean isEmpty(){
    return mList.isEmpty();
  }
  ...
```

e.g., thread T_1 calls take(), which acquires the intrinsic lock & waits while the queue is empty

Code Analysis of SimpleBoundedBlockingQueue

- A thread can "wait" for a condition in a synchronized method

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
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    final E e = mList.poll();

    notifyAll();
    return e;
  }

  public synchronized boolean isEmpty(){
    return mList.isEmpty();
  }
  ...
```

Check if the list is empty

Code Analysis of SimpleBoundedBlockingQueue

- A thread can "wait" for a condition in a synchronized method

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
    while (isEmpty())
      wait();

    final E e = mList.poll();

    notifyAll();
    return e;
  }

  public synchronized boolean isEmpty(){
    return mList.isEmpty();
  }
  ...
```

isEmpty() is synchronized via the Java monitor object "reentrant mutex" semantics

See en.wikipedia.org/wiki/Reentrant_mutex

Code Analysis of SimpleBoundedBlockingQueue

- wait() should be called in a loop that checks whether the condition is true or not

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
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    return e;
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  public synchronized boolean isEmpty(){
    return mList.isEmpty();
  }
  ...
```

See docs.oracle.com/javase/tutorial/essential/concurrency/guardmeth.html

Code Analysis of SimpleBoundedBlockingQueue

- wait() should be called in a loop that checks whether the condition is true or not
  - A thread can't assume a notification it receives is for *its* condition expression

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
    while (isEmpty())
      wait();

    final E e = mList.poll();

    notifyAll();
    return e;
  }
  ...
```

See stackoverflow.com/questions/37026/java-notify-vs-notifyall-all-over-again/3186336#3186336

Code Analysis of SimpleBoundedBlockingQueue

- wait() should be called in a loop that checks whether the condition is true or not
  - A thread can't assume a notification it receives is for *its* condition expression
  - It also can't assume the condition expression is true!

i.e., due to the inherent non-determinism of concurrency

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
    while (isEmpty())
      wait();

    final E e = mList.poll();

    notifyAll();
    return e;
  }
  ...
```

See en.wikipedia.org/wiki/Nondeterministic_algorithm

Code Analysis of SimpleBoundedBlockingQueue

- wait() should be called in a loop that checks whether the condition is true or not
  - A thread can't assume a notification it receives is for *its* condition expression
  - It also can't assume the condition expression is true!
  - Must also guard against "spurious wakeups"
    - A thread might be awoken in wait() even if no thread called notify()/notifyAll()!

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
    while (isEmpty())
      wait();

    final E e = mList.poll();

    notifyAll();
    return e;
  }
  ...
```

See en.wikipedia.org/wiki/Spurious_wakeup

Code Analysis of SimpleBoundedBlockingQueue

- A thread blocked on wait() won't continue until it's notified that the condition expression may be true

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
    while (isEmpty())
      wait();

    final E e = mList.poll();

    notifyAll();
    return e;
  }
  ...
```

Code Analysis of SimpleBoundedBlockingQueue

- A thread blocked on wait() won't continue until it's notified that the condition expression may be true

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized void put(E msg){
    ...
    while (isFull())
      wait();

    mList.add(msg);
    notifyAll();
  }

  private synchronized boolean isFull(){
    return mList.size() >= mCapacity;
  }
  ...
```

e.g., thread T_2 calls put(), which acquires the intrinsic lock & adds an item to the queue so it's no longer empty

Code Analysis of SimpleBoundedBlockingQueue

- A thread blocked on wait() won't continue until it's notified that the condition expression may be true

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized void put(E msg){
    ...
    while (isFull())
      wait();

    mList.add(msg);
    notifyAll();
  }

  private synchronized boolean isFull(){
    return mList.size() >= mCapacity;
  }
  ...
```

Assuming that thread T_1 is blocked in take() the queue won't be full!

Code Analysis of SimpleBoundedBlockingQueue

- A thread blocked on wait() won't continue until it's notified that the condition expression may be true

thread T_2 calls notifyAll(), which will wakeup thread T_1 that's blocking in wait()

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized void put(E msg){
    ...
    while (isFull())
      wait();

    mList.add(msg);
    notifyAll();
  }

  private synchronized boolean isFull(){
    return mList.size() >= mCapacity;
  }
  ...
```

Code Analysis of SimpleBoundedBlockingQueue

- A thread blocked on wait() won't continue until it's notified that the condition expression may be true

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class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized void put(E msg){
    ...
    while (isFull())
      wait();

    mList.add(msg);
    notifyAll();
  }

  private synchronized boolean isFull(){
    return mList.size() >= mCapacity;
  }
  ...
```

Again, notifyAll() is used due to a Java monitor object only having a single wait queue..

See stackoverflow.com/questions/37026/java-notify-vs-notifyall-all-over-again/3186336#3186336

Code Analysis of SimpleBoundedBlockingQueue

- Several steps occur when a waiting thread is notified

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
    while (isEmpty())
      wait();

    notifyAll();
    return mList.poll();
  }
```

Code Analysis of SimpleBoundedBlockingQueue

- Several steps occur when a waiting thread is notified
  - wakes up & obtains lock

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
    while (isEmpty())
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    notifyAll();
    return mList.poll();
  }
```

Code Analysis of SimpleBoundedBlockingQueue

- Several steps occur when a waiting thread is notified
  - wakes up & obtains lock
  - re-evaluates the condition expression

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
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    return mList.poll();
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```

Code Analysis of SimpleBoundedBlockingQueue

- Several steps occur when a waiting thread is notified
  - wakes up & obtains lock
  - re-evaluates the condition expression
  - continues after wait()

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
    while (isEmpty())
      wait();

    notifyAll();
    return mList.poll();
  }
```

Calling notifyAll() before removing/returning the front item in the queue is ok since the monitor lock is held & only one method can be in monitor

Code Analysis of SimpleBoundedBlockingQueue

- Several steps occur when a waiting thread is notified
  - wakes up & obtains lock
  - re-evaluates the condition expression
  - continues after wait()
  - releases lock when it returns

```
class SimpleBoundedBlockingQueue<E>
      implements SimpleBlockingQueue<E>
{
  ...

  public synchronized String take(){
    while (isEmpty())
      wait();

    notifyAll();
    return mList.poll();
  }
```

End of Java Monitor Objects: Coordination Example Implementation