Implementing the Java Monitor
Object Coordination Example

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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 \textit{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.

Code Analysis of SimpleBoundedBlockingQueue

- This class provides a simple synchronized blocking queue

```java
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

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

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

This internal state must be protected against race conditions
This class provides a simple synchronized blocking queue

```
// A constructor is only called once in one thread so there won't be race conditions
SimpleBoundedBlockingQueue<br>}</p>

```

```java
class SimpleBoundedBlockingQueue<E> implements SimpleBlockingQueue<E> {
  private List<E> mList;
  private int mCapacity;
  SimpleBoundedBlockingQueue(int capacity) {
    mList = new ArrayList<E>();
    mCapacity = capacity;
  }
  ...
}
```
A thread can “wait” for a condition in a synchronized method

```java
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](en.wikipedia.org/wiki/Guarded_suspension)
• 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();
    }

    ...
}

\textit{e.g., thread }T_1 \textit{ calls take(), which acquires the intrinsic lock & waits while the queue is empty}
• A thread can “wait” for a condition in a synchronized method

```java
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();
    }
    ...  
}
```

_Check if the list is empty_
Code Analysis of SimpleBoundedBlockingQueue

- A thread can “wait” for a condition in a synchronized method.

```java
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](en.wikipedia.org/wiki/Reentrant_mutex)
• wait() should be called in a loop that checks whether the condition is true or not

```java
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 [docs.oracle.com/javase/tutorial/essential/concurrency/guardmeth.html](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

```java
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!

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

    final E e = mList.poll();

    notifyAll();
    return e;
}
```

*See en.wikipedia.org/wiki/Nondeterministic_algorithm*

\[i.e., \text{due to the inherent non-determinism of concurrency}\]
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()!

```java
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](en.wikipedia.org/wiki/Spurious_wakeup)
A thread blocked on `wait()` won’t continue until it’s notified that the condition expression may be true.

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

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

        final E e = mList.poll();

        notifyAll();
        return e;
    }

    ...
}
```
A thread blocked on `wait()` won’t continue until it’s notified that the condition expression may be true.

**Code Analysis of SimpleBoundedBlockingQueue**

```java
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.
A thread blocked on wait() won’t continue until it’s notified that the condition expression may be true.

Assuming that thread $T_1$ is blocked in take() the queue won’t be full!
A thread blocked on `wait()` won’t continue until it’s notified that the condition expression may be true.

```java
public synchronized void put(E msg){
    ... 
    while (isFull())
        wait();
    mList.add(msg);
    notifyAll();
}
```

Thread $T_2$ calls `notifyAll()`, which will wake up thread $T_1$ that’s blocking in `wait()`.
Code Analysis of SimpleBoundedBlockingQueue

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

```java
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](https://stackoverflow.com/questions/37026/java-notify-vs-notifyall-all-over-again/3186336#3186336)
Several steps occur when a waiting thread is notified.

```java
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

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

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

        notifyAll();
        return mList.poll();
    }
```
Several steps occur when a waiting thread is notified:

- wakes up & obtains lock
- re-evaluates the condition expression

Code Analysis of `SimpleBoundedBlockingQueue` class:

```java
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
  - re-evaluates the condition expression
  - continues after wait()

```java
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

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

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

        notifyAll();
        return mList.poll();
    }
}
```
End of Implementing the Java Monitor Object Coordination Example