Learning Objectives in this Part of the Lesson

• Understand what “safe publication” means in the context of Java objects running in concurrent programs

• Recognize “safe publication” techniques in Java that enable multiple threads to share an object
Safe Publication Techniques in Java
Safe Publication Techniques in Java

• To publish a properly constructed Java object safely
• The reference to the object &
• The object's state must be made visible to other threads at the same time

See flylib.com/books/en/2.558.1/safe_publication.html
Safe Publication Techniques in Java

• An object can be published safely in several ways
Safe Publication Techniques in Java

- An object can be published safely in several ways

We illustrate safe publication using the Singleton pattern

```java
If (uniqueInstance == null)
    uniqueInstance = new Singleton();
return uniqueInstance;
```

See [en.wikipedia.org/wiki/Singleton_pattern](en.wikipedia.org/wiki/Singleton_pattern)
Safe Publication Techniques in Java

- An object can be published safely in several ways
- Storing a reference to it into a field protected by a lock

```java
class Singleton {
    private static Singleton sInst;

    public static Singleton instance() {
        synchronized (Singleton.class) {
            if (sInst == null) {
                sInst = new Singleton();
            }
            return sInst;
        }
    }
}
```

*This critical section is protected by the Singleton Class instance’s intrinsic lock*

See [docs.oracle.com/javase/tutorial/essential/concurrency/locksync.html](http://docs.oracle.com/javase/tutorial/essential/concurrency/locksync.html)
Safe Publication Techniques in Java

- An object can be published safely in several ways
  - Storing a reference to it into a field protected by a lock

```java
class Singleton {
    private static Singleton sInst;

    public static Singleton instance() {
        synchronized(Singleton.class) {
            if (sInst == null) {
                sInst = new Singleton();
                return sInst;
            }
        }
    }

    ...  // more code...
}
```

This lock ensures that both the sInst reference & the Singleton’s state will be published to other threads

See [docs.oracle.com/javase/tutorial/essential/concurrency/locks.html](docs.oracle.com/javase/tutorial/essential/concurrency/locks.html)
Safe Publication Techniques in Java

- An object can be published safely in several ways
- Storing a reference to it into a field protected by a lock

```java
class Singleton {
    private static Singleton sInst;

    public static Singleton instance() {
        synchronized (Singleton.class) {
            if (sInst == null) {
                sInst = new Singleton();
            }
            return sInst;
        }
    }
}
```

*The drawback with this technique is that every call to instance() is synchronized*
An object can be published safely in several ways:

- Storing a reference to it into a field protected by a lock
- Storing a reference to it in a volatile

See flylib.com/books/en/2.558.1.25/1

```
class Singleton {
    private static volatile Singleton sInst;

    public static Singleton instance() {
        Singleton result = sInst;
        if (result == null) {
            synchronized(Singleton.class) {
                result = sInst;
                if (result == null)
                    sInst = result =
                        new Singleton();
            }
        }
        return result;
    }

    // ...
```
Safe Publication Techniques in Java

- An object can be published safely in several ways
  - Storing a reference to it into a field protected by a lock
  - Storing a reference to it in a volatile

// Singleton class

```java
class Singleton {
    private static volatile Singleton sInst;

    public static Singleton instance() {
        Singleton result = sInst;
        if (result == null) {
            synchronized(Singleton.class) {
                result = sInst;
                if (result == null)
                    sInst = result = new Singleton();
            }
        }
        return result;
    }

    // ... other methods
}
```

volatile ensures that multiple threads share the singleton instance correctly

See [en.wikipedia.org/wiki/Double-checked_locking#Usage_in_Java](en.wikipedia.org/wiki/Double-checked_locking#Usage_in_Java)
Safe Publication Techniques in Java

- An object can be published safely in several ways
- Storing a reference to it into a field protected by a lock
- Storing a reference to it in a volatile

```java
class Singleton {
    private static volatile Singleton sInst;

    public static Singleton instance() {
        Singleton result = sInst;
        if (result == null) {
            synchronized (Singleton.class) {
                result = sInst;
                if (result == null) {
                    sInst = result = new Singleton();
                }
            }
        }
        return result;
    }
    ...
}
```

*Only acquire the lock the “first time in”*
Safe Publication Techniques in Java

An object can be published safely in several ways:

• Storing a reference to it into a field protected by a lock

• Storing a reference to it in a volatile

```java
class Singleton {
    private static volatile Singleton sInst;

    public static Singleton instance() {
        Singleton result = sInst;
        if (result == null) {
            synchronized (Singleton.class) {
                result = sInst;
                if (result == null)
                    sInst = result = new Singleton();
            }
        }
        return result;
    }

    ...
}
```

Perform "lazy initialization" only the "first time in"

See [en.wikipedia.org/wiki/Lazy_initialization](en.wikipedia.org/wiki/Lazy_initialization)
Safe Publication Techniques in Java

• An object can be published safely in several ways
  • Storing a reference to it into a field protected by a lock
  • Storing a reference to it in a volatile

```java
class Singleton {
    private static volatile Singleton sInst;

    public static Singleton instance() {
        Singleton result = sInst;
        if (result == null) {
            synchronized (Singleton.class) {
                result = sInst;
                if (result == null)
                    sInst = result = new Singleton();
            }
        }
        return result;
    }
}
```

volatile avoids problems with partially constructed objects
Safe Publication Techniques in Java

• An object can be published safely in several ways
  • Storing a reference to it into a field protected by a lock
  • Storing a reference to it in a volatile

```java
class Singleton {
    private static volatile Singleton sInst;

    public static Singleton instance() {
        Singleton result = sInst;
        if (result == null) {
            synchronized (Singleton.class) {
                result = sInst;
                if (result == null) {
                    sInst = result = new Singleton();
                }
            }
        }
        return result;
    }
    ...
}
```

Return the singleton’s value
A class `Singleton` can be published safely in several ways:

- Storing a reference to it into a field protected by a lock
- Storing a reference to it in a volatile

```java
class Singleton {
    private static volatile Singleton sInst;

    public static Singleton instance()
    {
        Singleton result = sInst;
        if (result == null) {
            synchronized(Singleton.class) {
                result = sInst;
                if (result == null)
                    sInst = result = new Singleton();
            }
        }
        return result;
    }
}
```

*The drawback with this approach is that it only works with Java 1.5 or later*

See [en.wikipedia.org/wiki/Double-checked_locking#Usage_in_Java](en.wikipedia.org/wiki/Double-checked_locking#Usage_in_Java)
Safe Publication Techniques in Java

• An object can be published safely in several ways
  • Storing a reference to it into a field protected by a lock
  • Storing a reference to it in a volatile or AtomicReference

```java
class Singleton {
    private static AtomicReference sInst
        = new AtomicReference(null);

    public static Singleton instance() {
        Singleton sing = sInst.get();

        if (sing == null) {
            sing = new Singleton();
            if (!sInst.compareAndSet
                (null, sing))
                sing = sInst.get();
        }
        return sing;
    }

    ...
}
```

See day-to-day-stuff.blogspot.com/2011/06/lock-less-singleton-pattern.html
Safe Publication Techniques in Java

- An object can be published safely in several ways
  - Storing a reference to it into a field protected by a lock
  - Storing a reference to it in a volatile or AtomicReference

```java
class Singleton {
    private static AtomicReference sInst = new AtomicReference(null);

    public static Singleton instance() {
        Singleton sing = sInst.get();
        if (sing == null) {
            sing = new Singleton();
            if (!sInst.compareAndSet(null, sing))
                sing = sInst.get();
        }
        return sing;
    }
}
```

See [docs.oracle.com/javase/8/docs/api/java/util/concurrent/atomic/AtomicReference.html](docs.oracle.com/javase/8/docs/api/java/util/concurrent/atomic/AtomicReference.html)
class Singleton {
    private static AtomicReference sInst = new AtomicReference(null);

    public static Singleton instance() {
        Singleton sing = sInst.get();
        if (sing == null) {
            sing = new Singleton();
            if (!sInst.compareAndSet(null, sing))
                sing = sInst.get();
        }
        return sing;
    }
}

// Safe Publication Techniques in Java

• An object can be published safely in several ways
  • Storing a reference to it into a field protected by a lock
  • Storing a reference to it in a volatile or AtomicReference
An object can be published safely in several ways:

- Storing a reference to it into a field protected by a lock
- Storing a reference to it in a volatile or AtomicReference

```java
class Singleton {
    private static AtomicReference sInst = new AtomicReference(null);

    public static Singleton instance() {
        Singleton sing = sInst.get();
        if (sing == null) {
            sing = new Singleton();
            if (!sInst.compareAndSet(null, sing))
                sing = sInst.get();
        }
        return sing;
    }

    ... // Further implementation
}
```

Allocate Singleton & atomically CAS with sInst
An object can be published safely in several ways:

- Storing a reference to it into a field protected by a lock
- Storing a reference to it in a volatile or AtomicReference

```java
class Singleton {
    private static AtomicReference sInst = new AtomicReference(null);

    public static Singleton instance() {
        Singleton sing = sInst.get();
        if (sing == null) {
            sing = new Singleton();
            if (!sInst.compareAndSet(null, sing))
                sing = sInst.get();
        }
        return sing;
    }
    ...
}
```

*Update this local value if sInst was already set*
Safe Publication Techniques in Java

- An object can be published safely in several ways
  - Storing a reference to it into a field protected by a lock
  - Storing a reference to it in a volatile or AtomicReference

```
class Singleton {
    private static AtomicReference sInst
        = new AtomicReference(null);

    public static Singleton instance() {
        Singleton sing = sInst.get();

        if (sing == null) {
            sing = new Singleton();
            if (!sInst.compareAndSet(null, sing))
                sing = sInst.get();
        }

        return sing;
    }

    ...
}
```

Return the singleton’s value
An object can be published safely in several ways:

- Storing a reference to it into a field protected by a lock
- Storing a reference to it in a volatile or AtomicReference

The drawback is that singleton’s constructor can be called multiple times.

```java
class Singleton {
    private static AtomicReference sInst = new AtomicReference(null);

    public static Singleton instance() {
        Singleton sing = sInst.get();
        if (sing == null) {
            sing = new Singleton();
            if (!sInst.compareAndSet(null, sing))
                sing = sInst.get();
        }
        return sing;
    }
}
```
An object can be published safely in several ways:

- Storing a reference to it into a field protected by a lock
- Storing a reference to it in a volatile or AtomicReference
- Initializing an object reference from a static initializer

```java
class Singleton {
    private Singleton() {}

    private static class LazyHolder {
        private static final Singleton sInst = new Singleton();
    }

    public static Singleton instance() {
        return LazyHolder.sInst;
    }
}
```

This idiom relies on the initialization phase of execution within the Java execution environment (e.g., JVM).

See [en.wikipedia.org/wiki/Initialization-on-demand_holder_idiom](en.wikipedia.org/wiki/Initialization-on-demand_holder_idiom)
Safe Publication Techniques in Java

• An object can be published safely in several ways
  • Storing a reference to it into a field protected by a lock
  • Storing a reference to it in a volatile or AtomicReference
  • Initializing an object reference from a static initializer

```java
class Singleton {
    private Singleton() {} 

    private static class LazyHolder {
        private static final Singleton sInst =
            new Singleton();
    }

    public static Singleton instance() {
        return LazyHolder.sInst;
    }
}
```

LazyHolder is only initialized when the static method instance is invoked on the class Singleton, which triggers the JVM to load & initialize the LazyHolder class

See [en.wikipedia.org/wiki/Initialization-on-demand_holder_idiom](en.wikipedia.org/wiki/Initialization-on-demand_holder_idiom)
Safe Publication Techniques in Java

- An object can be published safely in several ways
  - Storing a reference to it into a field protected by a lock
  - Storing a reference to it in a volatile or AtomicReference
  - Initializing an object reference from a static initializer
  - Storing a reference to it into a final field

```java
class A {
    long mNotFinal = 1;
    final long mFinal = 2;
    ...
}
...
```

An object can be published safely in several ways:

- Storing a reference to it into a field protected by a lock
- Storing a reference to it in a volatile or AtomicReference
- Initializing an object reference from a static initializer
- Storing a reference to it into a final field

Final fields can be safely accessed without some form of synchronization.

```java
class A {
    long mNotFinal = 1;
    final long mFinal = 2;
    ...
}

// Thread T1
A a = new A();

// Thread T2
long l1 = a.mFinal;
long l2 = a.mNotFinal;
```

*mFinal is guaranteed to be initialized by the time thread T2 gets a reference to object a.*

Safe Publication Techniques in Java

- An object can be published safely in several ways
  - Storing a reference to it into a field protected by a lock
  - Storing a reference to it in a volatile or AtomicReference
  - Initializing an object reference from a static initializer
  - Storing a reference to it into a final field
  - Final fields can be safely accessed without some form of synchronization

```java
class A {
    long mNotFinal = 1;
    final long mFinal = 2;
    ...
}

// Thread T1
A a = new A();

// Thread T2
long l1 = a.mFinal;
long l2 = a.mNotFinal;

mNotFinal is not guaranteed to be initialized by the time thread T2 gets a reference to object a.
Safe Publication Techniques in Java

- An object can be published safely in several ways
  - Storing a reference to it into a field protected by a lock
  - Storing a reference to it in a volatile or AtomicReference
  - Initializing an object reference from a static initializer
  - Storing a reference to it into a final field
    - Final fields can be safely accessed without some form of synchronization
    - Immutable objects in Java contain only final fields and/or only accessor methods

```java
final class String {
    private final char value[];
    ...

    public String(String s) {
        value = s;
        ...
    }

    public int length() {
        return value.length;
    }
    ...
}
```

See docs.oracle.com/javase/tutorial/essential/concurrency/immutable.html
Safe Publication Techniques in Java

• An object can be published safely in several ways
  • Storing a reference to it into a field protected by a lock
  • Storing a reference to it in a volatile or AtomicReference
  • Initializing an object reference from a static initializer
  • Storing a reference to it into a final field
  • Final fields can be safely accessed without some form of synchronization
  • Immutable objects in Java contain only final fields and/or only accessor methods

```java
final class String {
    private final char value[];
    ...

    public String(String s) {
        value = s;
        ...
    }

    public int length() {
        return value.length;
    }
    ...
}
```

An object can be published safely in several ways:

- Storing a reference to it into a field protected by a lock
- Storing a reference to it in a volatile or AtomicReference
- Initializing an object reference from a static initializer
- Storing a reference to it into a final field

Final fields can be safely accessed without some form of synchronization.

If a final field refers to a mutable object, synchronization is needed to access the state of the referenced object.

```java
class A {
    final String[] QBs = new String[]{
        "Brady", "Favre", "Newton", ...
    };
    ...
};

A a = new A();

// Thread T1
synchronized(m) {
    a.QBs[1] = "Manning";
}

// Thread T2
synchronized(m) {
    a.QBs[1] = "Montana";
}
```

Safe Publication Techniques in Java

- An object can be published safely in several ways
  - Storing a reference to it into a field protected by a lock
  - Storing a reference to it in a volatile or AtomicReference
  - Initializing an object reference from a static initializer
  - Storing a reference to it into a final field
    - Final fields can be safely accessed without some form of synchronization
    - If a final field refers to a mutable object, synchronization is needed to access the state of the referenced object

```java
class A {
    final String[] QBs = new String[]{
        "Brady", "Favre", "Newton", ...
    };
    ...
}

A a = new A();

// Thread T1
synchronized(m) {
    a.QBs[1] = "Manning";
}

// Thread T2
synchronized(m) {
    a.QBs[1] = "Montana";
}

QBs is final, but its contents are mutable
```
Safe Publication Techniques in Java

• An object can be published safely in several ways
  • Storing a reference to it into a field protected by a lock
  • Storing a reference to it in a volatile or AtomicReference
  • Initializing an object reference from a static initializer
  • Storing a reference to it into a final field
    • Final fields can be safely accessed without some form of synchronization
  • If a final field refers to a mutable object, synchronization is needed to access the state of the referenced object

```java
class A {
    final String[] QBs = new String[] {
        "Brady", "Favre", "Newton", ...
    };
    ...
}

A a = new A();

// Thread T1
synchronized (m) {
    a.QBs[1] = "Manning";
}

// Thread T2
synchronized (m) {
    a.QBs[1] = "Montana";
}
```

Access to QBs contents must be synchronized
End of Safe Publication Techniques in Java