Parallel Programming Practice

Sharing Objects

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Publication

An object is *published* when

- It has been made available outside of its current scope

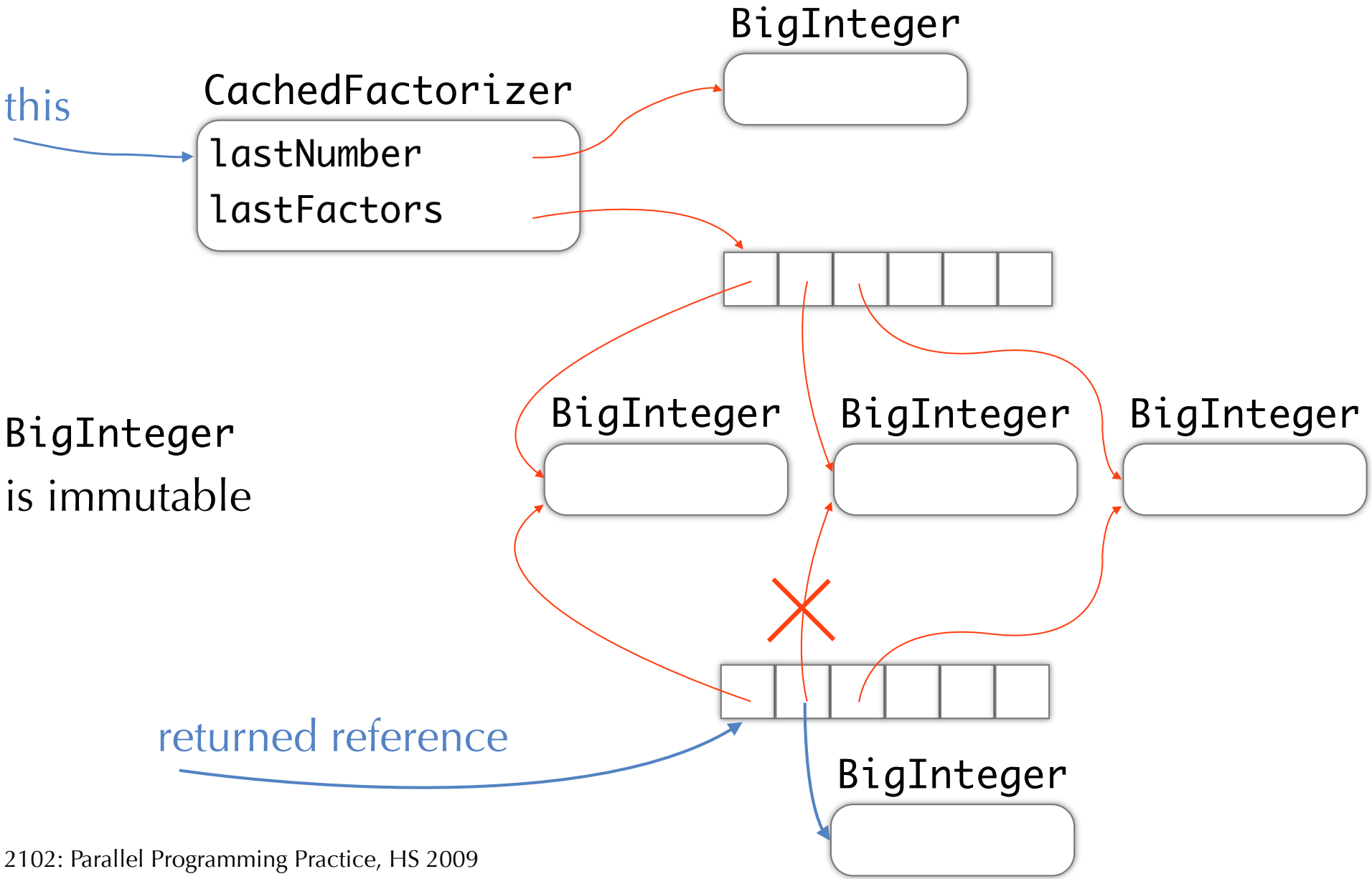
How?

- Store a reference where other code can access it
- Return a reference from a non-private method
- Pass a reference to a method in another class

```
@ThreadSafe
public class CachedFactorizer implements Servlet {
    @GuardedBy("this") private BigInteger lastNumber;
    @GuardedBy("this") private BigInteger[] lastFactors;
    public void service(ServletRequest req, ServletResponse resp) {
        BigInteger i = extractFromRequest(req);
        BigInteger[] factors = null;
        synchronized (this) {
            if (i.equals(lastNumber)) factors = lastFactors.clone();
        }
        if (factors == null) {
            factors = factor(i);
            synchronized (this) {
                lastNumber = i;
                lastFactors = factors.clone();
            }
        }
        encodeIntoResponse(resp, factors);
    }
}
```

http://java.sun.com/javaee/5/docs/api/javax/servlet/Servlet.html

Object graph of `CachedFactorizer`



`BigInteger` is immutable

Problems with escaped objects

An object is *escaped* when

- It is published and should not have been published

Consequences

- Any caller can modify object

Proper construction

Object is *not* properly constructed if `this` escapes during construction

- Consistent state only after constructor returns

Do not

- Start a thread in the constructor
- Call a overridable method in the constructor

How to prevent escape

Thread confinement

Immutability

Safe publication

Thread confinement

Thread confinement

Avoid escaping of objects by *not* sharing

Thread confinement

- A single thread accesses data ⇒ thread safe

Kinds

- Ad-hoc thread confinement
- Stack confinement
- `ThreadLocal`

1 Ad-hoc thread confinement

Implementation is responsible

- Fragile

Special case: volatile variables

- Ensure that only one thread writes the volatile variable
- Remember visibility guarantees of volatile writes

2 Stack confinement

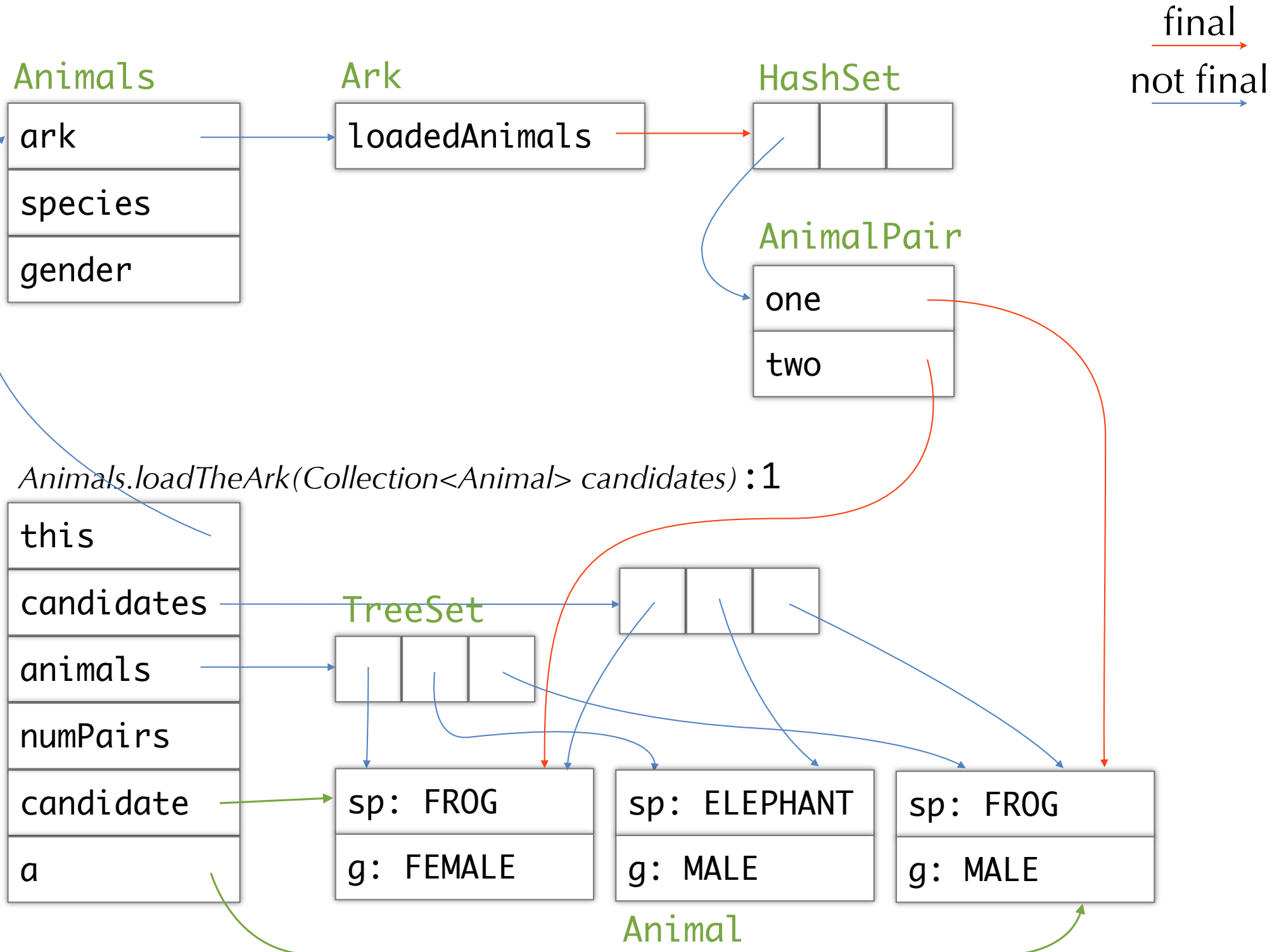
Object is reachable only through local variables

- Local variables exist only on stack
- Stack accessible only to current thread

Enforcement

- Obvious for primitive types (no reference)
- References: Programmer must take care and not publish reference

```
public int loadTheArk(Collection<Animal> candidates) {
    SortedSet<Animal> animals =
        new TreeSet<Animal>(new SpeciesGenderComparator());
    animals.addAll(candidates);
    int numPairs = 0;
    Animal candidate = null;
    for (Animal a : animals) {
        if (candidate == null || !candidate.isPotentialMate(a))
            candidate = a;
        else {
            ark.load(new AnimalPair(candidate, a));
            numPairs++;
            candidate = null;
        }
    }
    return numPairs;
}
```


final
not final
Animals
ark
species
gender
Ark
loadedAnimals
HashSet
AnimalPair
one
two
Animals.loadTheArk(Collection<Animal> candidates) :1
this
candidates
animals
numPairs
candidate
a
TreeSet
sp: FROG
g: FEMALE
sp: ELEPHANT
g: MALE
sp: FROG
g: MALE
Animal

3 ThreadLocal

Associate a per-thread value with an object

- Separate copy of a value for each thread
- Conceptual: `Map<Thread, T>`

Examples

- Mutable singletons, global variables

ThreadLocal API

java.lang.ThreadLocal<T>

`T get()`	Value of the current thread's copy. `if value == null: return initialValue()`
`T initialValue()`	Typically overridden (default: `return null;`)
`void remove()`	Remove value of copy of current thread.
`void set(T value)`	Set copy of current thread to `value`.

Corrected ThreadLocal example

```
public class UniqueThreadIdGenerator {
    private static final AtomicInteger uniqueId =
        new AtomicInteger(0);
    private static final ThreadLocal<Integer> uniqueNum =
        new ThreadLocal<Integer>() {
            protected Integer initialValue() {
                return uniqueId.getAndIncrement();
            }
        };
    public static int getCurrentThreadId() {
        return uniqueNum.get();
    }
}
```

See also: *http://bugs.sun.com/bugdatabase/view_bug.do?bug_id=6475885*

Immutability

Immutability

An object is immutable if

- Its state cannot be modified after construction and
- All its fields are `final` and
- It is properly constructed
  - (`this` reference does not escape during construction)

Immutable objects are *always* thread-safe

- No synchronization needed

Attention 1

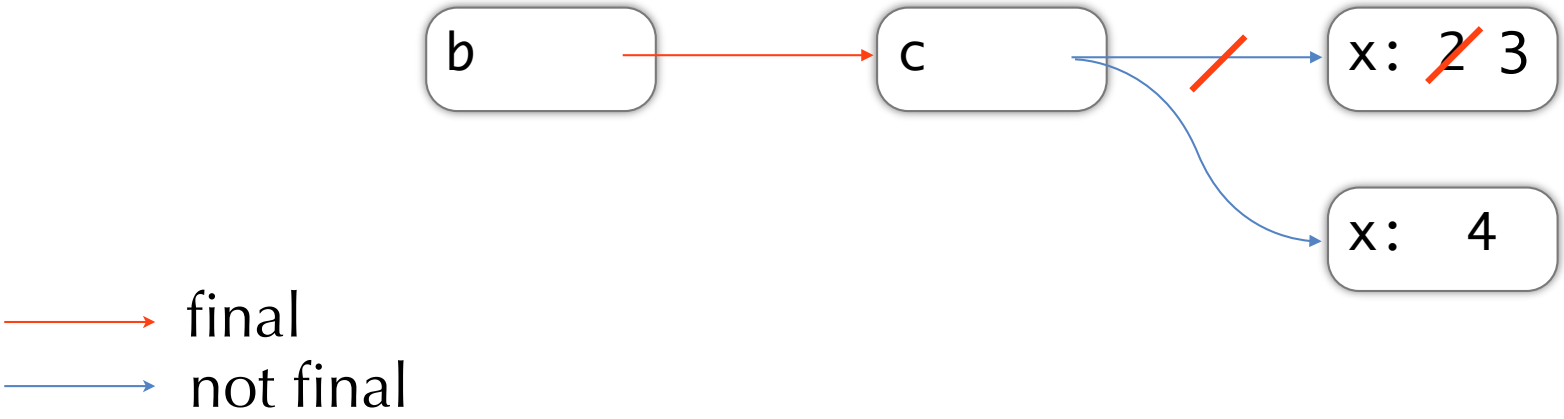
Immutability ≠ declare all fields `final`

- Final fields can hold references to mutable objects
- An object with final fields can still be mutable

```
class A {
  final B b;
}
```

```
class B {
  C c;
}
```

```
class C {
  int x;
}
```

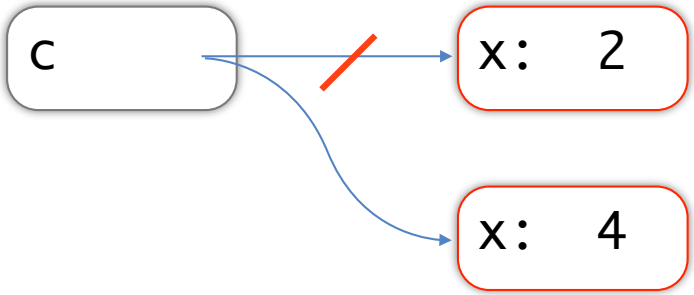


Attention 2

Reference is immutable ≠ object is immutable

```
class B {
  C c;
}
```

```
class C {
  final int x;
}
```



final

not final

Immutable example

```
@Immutable
public final class ThreeFriends {
    private final Set<String> friends = new HashSet<String>();

    public ThreeFriends() {
        friends.add("Moe");
        friends.add("Larry");
        friends.add("Curly");
    }

    public boolean isFriend(String name) {
        return friends.contains(name);
    }
}
```

Set is mutable but `ThreeFriends` *is* designed *not to be mutable*

Update state with replacing old object with a new one

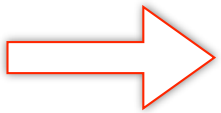
Definition of immutability revisited

An object is immutable if

- all `public` fields are `final`,
- all `public` final reference fields refer to other immutable objects, and
- constructors and methods do not publish references to any internal state which is potentially mutable by the implementation.

Weak atomicity for immutable objects

```
@ThreadSafe
public class VolatileCachedFactorizer implements Servlet {
    private volatile OneValueCache cache =
        new OneValueCache(null, null);
    public void service(ServletRequest req, ServletResponse resp) {
        BigInteger i = extractFromRequest(req);
        BigInteger[] factors = cache.getFactors(i);
        if (factors == null) {
            factors = factor(i);
            cache = new OneValueCache(i, factors);
        }
        encodeIntoResponse(resp, factors);
    }
}
```



Immutable holder class for atomic data

```
@Immutable
public class OneValueCache {
    private final BigInteger lastNumber;
    private final BigInteger[] lastFactors;
    public OneValueCache(BigInteger i, BigInteger[] factors) {
        lastNumber = i;
        lastFactors = Arrays.copyOf(factors, factors.length);
    }
    public BigInteger[] getFactors(BigInteger i) {
        if (lastNumber == null || !lastNumber.equals(i))
            return null;
        else
            return Arrays.copyOf(lastFactors, lastFactors.length);
    }
}
```

Publishing immutable objects

Immutable objects can be used without synchronization

But

- When final fields refer to mutable objects, synchronization must be used to access those objects

JMM: Initialization safety

Properly constructed *immutable* objects can be shared across threads without synchronization

All threads will see correct values set in the constructor of

- Final fields and any variables reachable through a final field
- If the object was properly constructed object

For objects with final fields, no reordering of

- Writes in the constructor to final fields
- Writes to variables reachable through these final fields
- With initial load of a reference of a reference to that object

⇒ Values become “frozen” when constructor completes

Initialization safety for immutable objects

```
@ThreadSafe
public class SafeStates {
    private final Map<String, String> states;

    public SafeStates() {
        states = new HashMap<String, String>();
        states.put("alaska", "AK");
        states.put("alabama", "AL");
        /*...*/
        states.put("wyoming", "WY");
    }
    public String getAbbreviation(String s) {
        return states.get(s);
    }
}
```

String is immutable

values that are reachable through final fields at the time the constructor finishes

Safe publication

Unsafe publication

```
@NotThreadSafe                                          No happens-
public class UnsafeLazyInitialization {                 before ordering
    private static Resource resource;

    public static Resource getInstance() {
        if (resource == null)
            resource = new Resource(); // unsafe publication
        return resource;
    }
}
```

Other threads might see

- Stale value for holder (null or older value)
- Up-to-date value for holder, but stale values for the state of holder

Safe publication

Objects that are not immutable must be safely published

- Synchronization of both the publishing and consuming thread

Establish a happens-before ordering between publishing and consuming thread

- To ensure visibility

Synchronization is required if the object can be modified after publication

Safe publication patterns

Reference *and* state of the object must be made visible at the same time

Consider a properly constructed object

- Initialize the reference with a static initializer
- Store the reference into a `volatile` field or `AtomicReference`
- Store the reference into a `final` field of a properly constructed object
- Store the reference into a field that is properly guarded by a lock

Eager safe initialization

```
@ThreadSafe
public class SafeEagerInitialization {
    private static Resource resource = new Resource();

    public static Resource getInstance() {
        return resource;
    }
}
```

Static initializers

- Run after class loading but before class is used by any threads
- Writes are visible to all threads automatically

Consider also factory implementation

Safe lazy initialization

```
@ThreadSafe
public class SafeLazyInitialization {
    private static Resource resource;

    public synchronized static Resource getInstance() {
        if (resource == null)
            resource = new Resource();
        return resource;
    }
}
```

Double-checked locking

```
@NotThreadSafe
public class DoubleCheckedLocking {
    private static Resource resource;

    public static Resource getInstance() {
        if (resource == null) {
            synchronized (DoubleCheckedLocking.class) {
                if (resource == null)
                    resource = new Resource();
            }
        }
        return resource;
    }
}
```

Corrected double-checked locking

```
@ThreadSafe
public class DoubleCheckedLocking {
    private volatile static Resource resource;

    public static Resource getInstance() {
        if (resource == null) {
            synchronized (DoubleCheckedLocking.class) {
                if (resource == null)
                    resource = new Resource();
            }
        }
        return resource;
    }
}
```

Better: `SafeLazyInitialization` with factory *(see Slide 33)*

Publishing and sharing

Immutable objects

- Can be published through any mechanism
- Shared without synchronization

Effectively immutable objects

- == mutable objects that are not modified (e.g. `Date`)
- Must be safely published
- Shared without synchronization

Mutable objects

- Must be safely published *and*
- Must be either thread-safe or guarded by a lock

Document accessibility of objects

Thread-confined

- Owed by and confined to thread
- Can be modified only by owning thread

Shared read-only

- Cannot be modified
- Access without synchronization

Shared thread-safe

- Internal synchronization
- Threads can use without synchronization using public interface

Guarded

- Accessed only with specific lock

Package net.jcip.annotations

Annotation	Target	Description
`@ThreadSafe`	Class	No synchronization needed by client. No interleaving of accesses puts object in invalid state.
`@NotThreadSafe`	Class	
`@Immutable`	Class	State cannot be seen to change by callers. Implies `@ThreadSafe`.
`@GuardedBy("lock")`	Field, method	`lock` must be used to access field/ method.

http://www.javaconcurrencyinpractice.com/annotations/doc/index.html

Study Goals