

Threadsafe design

Confinement (revisited)

Java monitor pattern

Delegating thread safety

Threadsafe design

The design process for a threadsafe class should include three basic elements:

- Identify the variables (members) that form the object's state;
- Identify the invariants that constrain the state variables;
- Establish a policy for managing concurrent access to the objects state.

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A threadsafe class

```
@ThreadSafe
public final class Counter {
    @GuardedBy("this") private long value = 0;

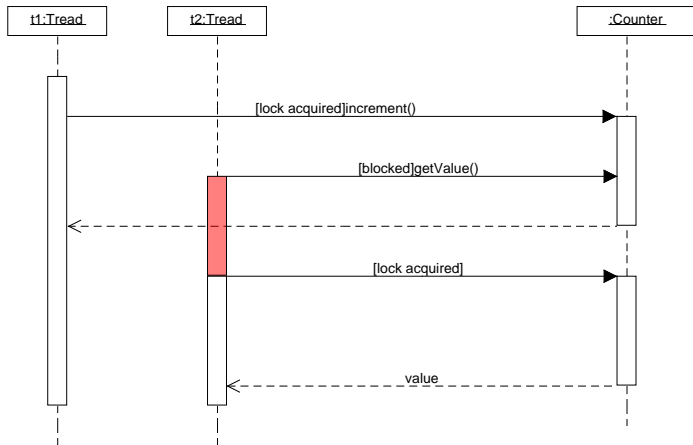
    public synchronized long getValue() {
        return value;
    }

    public synchronized long increment() {
        if (value == Long.MAX_VALUE)
            throw new IllegalStateException("counter_overflow");
        return ++value;
    }
}
```

Counter object used as monitor

Threadsafe design

- Confinement (revisited)
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- Delegating thread safety



Synchronisation requirements

- You **cannot** ensure threadsafety without understanding an object's invariants and postconditions. Constraints on the valid values or state transitions for state variables can create atomicity and encapsulation requirements.
- E.g. the Counter class:
 - the state is determined by the value of `value`.
 - Counter has a constraint: `value` is not negative.
 - `increment()` has a postcondition: the only valid state is that `value` is indeed incremented by 1.

Confinement revisited

- Encapsulating data within an object confines access to the data to the object's methods, making it easier to ensure the data is always accessed with the appropriate lock held.

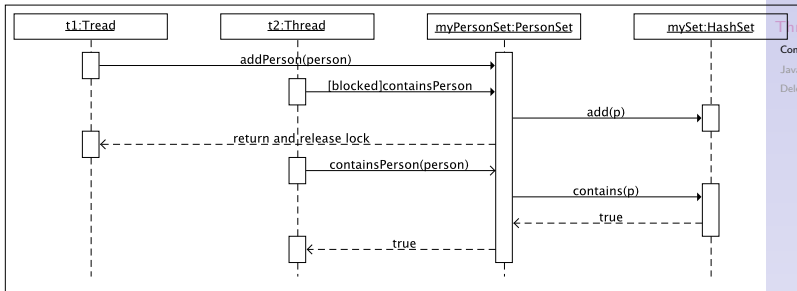
```
@ThreadSafe
public class PersonSet {
    @GuardedBy("this")
    private final Set<Person> mySet = new HashSet<Person>();

    public synchronized void addPerson(Person p) {
        mySet.add(p);
    }

    public synchronized boolean containsPerson(Person p) {
        return mySet.contains(p);
    }
}

interface Person {
}
```

PersonSet object used as monitor



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Confinement makes threadsafeness easier

- The state of class `PersonSet` is managed by a `HashSet` which is not threadsafe, but `mySet` is private and not allowed to escape: *confinement*.
- Access methods `addPerson` and `containsPerson` acquire a lock on the `PersonSet`. Therefore `PersonSet` is *threadsafe*.
- Confinement makes it easier to build thread-safe classes because a class that confines its state can be analyzed for thread safety without having to examine the whole program.

Monitor programming model

- The monitor as defined by Hoare is similar but not the same as the Java model.
 - Hoare's monitor makes, in Java terms, all methods in a class `synchronized`. In the Java variant, locking is reentrant (by the same Thread).
- In the Java monitor pattern, all the object's state is encapsulated by the object and guarded by the object's own intrinsic lock.
- This is the lock you use when you make a method `synchronized`. As an example: see the Counter class.

Using a auxiliary object as lock

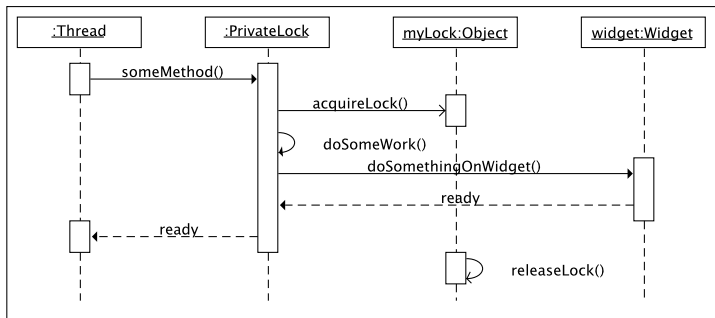
The instance myLock of type Object is used as a lock. This is a typical Java idiom or 'Pattern'.

```
public class PrivateLock {
    private final Object myLock = new Object();
    @GuardedBy("myLock") Widget widget;

    void someMethod() {
        synchronized (myLock) {
            // Access or modify the state of widget
        }
    }
}
```

There is a pattern here! *The java Monitor-pattern.*

PrivateLock



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Delegating thread safety

Monitor-based vehicle tracker implementation: thread safety although MutablePoint is not thread-safe.

@ThreadSafe

```
public class MonitorVehicleTracker {
    @GuardedBy("this")
    private final Map<String, MutablePoint> locations;

    public MonitorVehicleTracker(Map<String,
                                MutablePoint> locations) {
        this.locations = deepCopy(locations);
    }

    public synchronized Map<String, MutablePoint> getLocation
        return deepCopy(locations);
    }

    public synchronized MutablePoint getLocation(String id)
        MutablePoint loc = locations.get(id);
        return loc == null ? null : new MutablePoint(loc);
    }
}
```

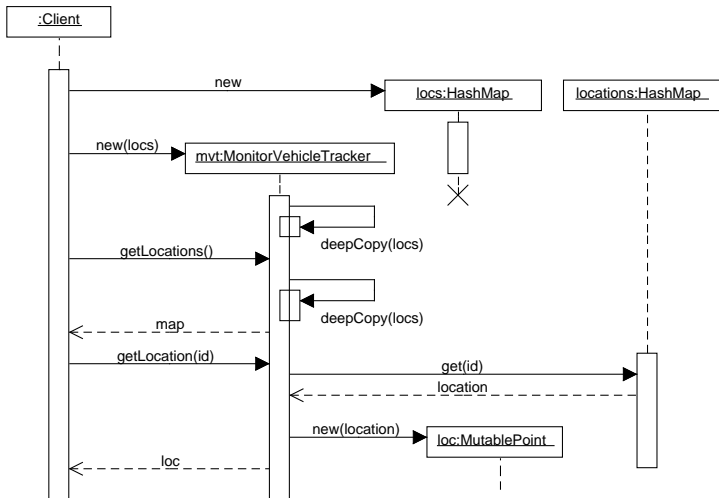
MonitorVehicleTracker sequence diagram

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Immutable Point class: Mwha!

```
@NotThreadSafe
public class MutablePoint {
    public int x, y;

    public MutablePoint() {
        x = 0;
        y = 0;
    }

    public MutablePoint(MutablePoint p) {
        this.x = p.x;
        this.y = p.y;
    }
}
```

Immutable Point

If the components of our class are already thread safe, do we need an additional layer of thread safety?

```
@Immutable
public class Point {
    public final int x, y;

    public Point(int x, int y) {
        this.x = x;
        this.y = y;
    }
}
```

See next slide for the `DelegatingVehicleTracker` which uses a thread-safe (immutable) `Point` class and a thread-safe `Map` implementation to store the locations using immutable points.

Delegating thread safety

Method `getLocations()` returns a 'live' view of the vehicle locations.

If thread A calls `getLocations()` and thread B later modifies the location of some of the points, those changes are reflected in the Map returned earlier to thread A.

`@ThreadSafe`

```
public class DelegatingVehicleTracker {
    private final ConcurrentMap<String, Point> locations;
    private final Map<String, Point> unmodifiableMap;

    public DelegatingVehicleTracker(Map<String, Point> points) {
        locations = new ConcurrentHashMap<String, Point>(points);
        unmodifiableMap = Collections.unmodifiableMap(locations);
    }

    public Map<String, Point> getLocations() {
        return unmodifiableMap;
    }
}
```

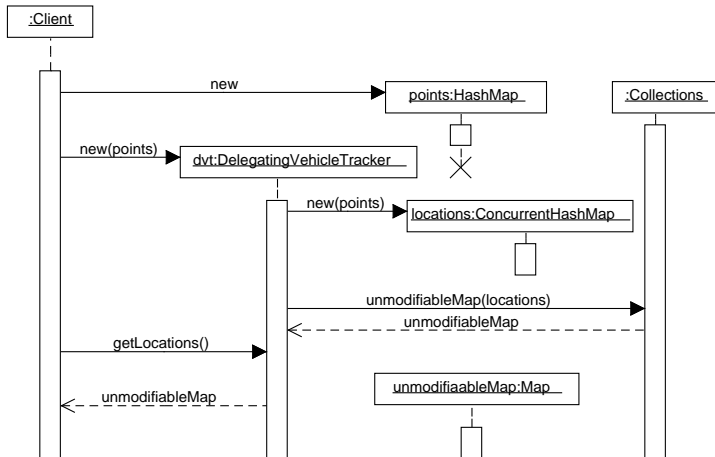

DelegatingVehicleTracker sequence diagram

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Independent state variables

Delegation to more state variables is possible if these are independent. See the `VisualComponent` class with two `List`'s: one for `KeyListener`s and one for `MouseListener`s.

```
public class VisualComponent {
    private final List<KeyListener> keyListeners
        = new CopyOnWriteArrayList<KeyListener>();
    private final List<MouseListener> mouseListeners
        = new CopyOnWriteArrayList<MouseListener>();

    public void addKeyListener(KeyListener listener) {
        keyListeners.add(listener);
    }

    public void addMouseListener(MouseListener listener) {
        mouseListeners.add(listener);
    }
}
```

Placing an object in a `CopyOnWriteArrayList`, safely publishes it to any thread that receives it from the collection.



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Two atomic integers with an additional constraint:

```
public class NumberRange {
    // INVARIANT: lower <= upper
    private final AtomicInteger lower = new AtomicInteger(0);
    private final AtomicInteger upper = new AtomicInteger(0);

    public void setLower(int i) {
        // Warning — unsafe check-then-act
        if (i > upper.get())
            throw new IllegalArgumentException(
                "can't set lower to " + i + " > upper");
        lower.set(i);
    }

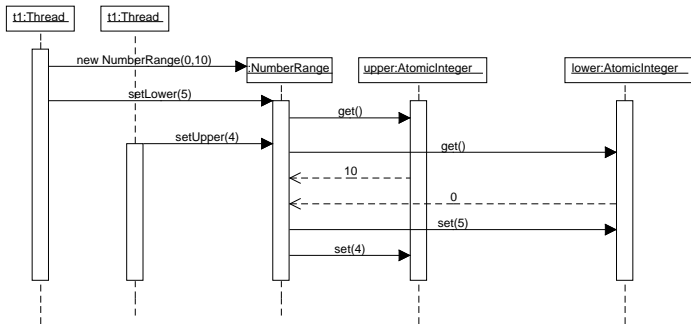
    public void setUpper(int i) {
        // Warning — unsafe check-then-act
```

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Delegating thread safety



When delegation fails

Delegation threadsafety to two thread-safe variables:
invariant is not preserved!

How could we make `NumberRange` thread-safe?

- Use locking to maintain the invariants by guarding upper and lower by a single lock

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- avoid publishing lower and upper to avoid ruining it's invariants.

When delegation fails

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How could we make `NumberRange` thread-safe?

- Use locking to maintain the invariants by guarding upper and lower by a single lock
- avoid publishing lower and upper to avoid ruining it's invariants.

Definition

If a class is composed of multiple *independent* thread-safe state variables and has no operations that have any invalid state transitions, then it can delegate thread safety to the underlying state variables.

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- Making the state variable `value` of the `Counter` class `public` (=publishing!) clients could change it into an invalid value.
- Don't publish if you don't need to!
- If there aren't any constraints, you can publish without compromising thread safety.

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- Making the state variable `value` of the `Counter` class **public** (=publishing!) clients could change it into an invalid value.
- Don't publish if you don't need to!
- If there aren't any constraints, you can publish without compromising thread safety.

Definition

If a state variable is thread-safe, does not participate in any invariants that constrain its value, and has no prohibited state transitions for any of its operations, then it can safely be published.

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A SafePoint class

```
@ThreadSafe
public class SafePoint {
    @GuardedBy("this") private int x, y;

    private SafePoint(int[] a) {
        this(a[0], a[1]);
    }

    public SafePoint(SafePoint p) {
        this(p.get());
    }

    public SafePoint(int x, int y) {
        this.x = x;
        this.y = y;
    }

    public synchronized int[] get() {
        return new int[] {x, y};
    }

    public synchronized void set(int x, int y) {
        this.x = x;
        this.y = y;
    }
}
```

The PublishingVehicleTracker class

- SafePoint returns both x and y values at once by returning an array without undermining thread safety.
- Note the use of a private constructor in SafePoint!

@ThreadSafe

```
public class PublishingVehicleTracker {
    private final Map<String, SafePoint> locations;
    private final Map<String, SafePoint> unmodifiableMap;

    public PublishingVehicleTracker(Map<String, SafePoint> locations) {
        this.locations =
            new ConcurrentHashMap<String, SafePoint>(locations);
        this.unmodifiableMap =
            Collections.unmodifiableMap(this.locations);
    }

    public Map<String, SafePoint> getLocations() {
        return unmodifiableMap;
    }

    public SafePoint getLocation(String id) {
        return locations.get(id);
    }
}
```

The PublishingVehicleTracker class

- Delegation to the underlying ConcurrentHashMap secures thread safety in PublishingVehicleTracker.
- `getLocations()` returns an unmodifiable copy of the underlying map.
- A caller of `getLocations()` could change the locations of the vehicles but cannot add or remove vehicles themselves.
- If there are additional constraints on the valid values of vehicle locations `PublishingVehicleTracker` is not thread safety anymore.

Adding functionality

- We have a thread-safe class!!
- We want to add a new operation without undermining its threadsafety.
- Example: put-if-absent operation. Should be atomic.
- You do not own the Vector code, so use subclassing.

@ThreadSafe

```
public class BetterVector <E> extends Vector<E> {
    // When extending a serializable class,
    // you should redefine serialVersionUID
    static final long serialVersionUID = -3963416950630760754L;

    public synchronized boolean putIfAbsent(E x) {
        boolean absent = !contains(x);
        if (absent)
            add(x);
        return absent;
    }
}
```

Client-side locking

- What if you don't know your collection type?
- E.g. by using the `Collections.synchronizedList` wrapper.
- Then use a "helper" class:

```
@NotThreadSafe
class BadListHelper <E> {
    public List<E> list =
        Collections.synchronizedList(new ArrayList<E>());

    public synchronized boolean putIfAbsent(E x) {
        boolean absent = !list.contains(x);
        if (absent)
            list.add(x);
        return absent;
    }
}
```



Client-side locking - 2

- Why doesn't this work?
- `putIfAbsent` is synchronized!
- It uses the *wrong lock!* (*illusion of synchronization*)
- Use the same lock that the list uses ..!
- 'Check-then-act' also here:
- The documentation on `Vector` and on synchronized wrapper classes shows that they support client-side locking.

Client-side locking - 3

- OK now.

@ThreadSafe

```
class GoodListHelper <E> {  
    public final List<E> list =  
        Collections.synchronizedList(new ArrayList<E>());  
  
    public boolean putIfAbsent(E x) {  
        synchronized (list) {  
            boolean absent = !list.contains(x);  
            if (absent)  
                list.add(x);  
            return absent;  
        }  
    }  
}
```

Composition

- Delegation instead of subclassing: often a better approach.
- It is assumed that the client after having constructed the `ImprovedList` will access the underlying list only through the `ImprovedList`.
- Uses the java monitor pattern.

@ThreadSafe

```
public class ImprovedList<T> implements List<T> {  
    private final List<T> list;  
  
    public ImprovedList(List<T> list) { this.list = list; }  
  
    public synchronized boolean putIfAbsent(T x) {  
        boolean contains = list.contains(x);  
        if (contains)  
            list.add(x);  
        return !contains;  
    }  
}
```