Parallel Programming Exercise Session 4

Spring 2020

Feedback: Exercise 3

Counter

Let’s count number of times a given event occurs

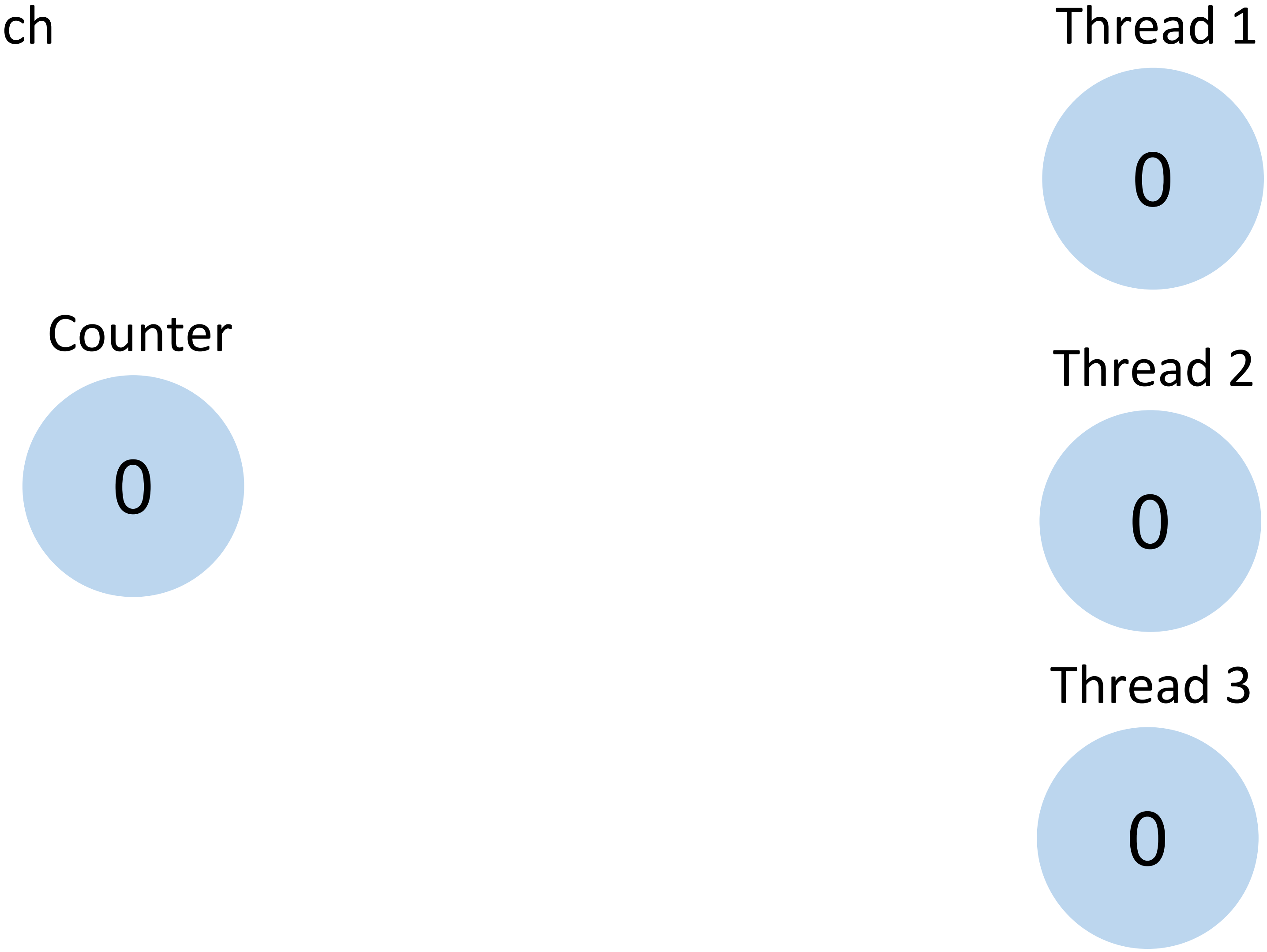
```java
public interface Counter {
  public void increment();
  public int value();
}
```

```java
// background threads
for (int i = 0; i < numIterations; i++) {
  // perform some work

  counter.increment();
}

// progress thread
while (isWorking) {
  System.out.println(counter.value());
}
```

10 iterations each



Counter

0

Thread 1

0

Thread 2

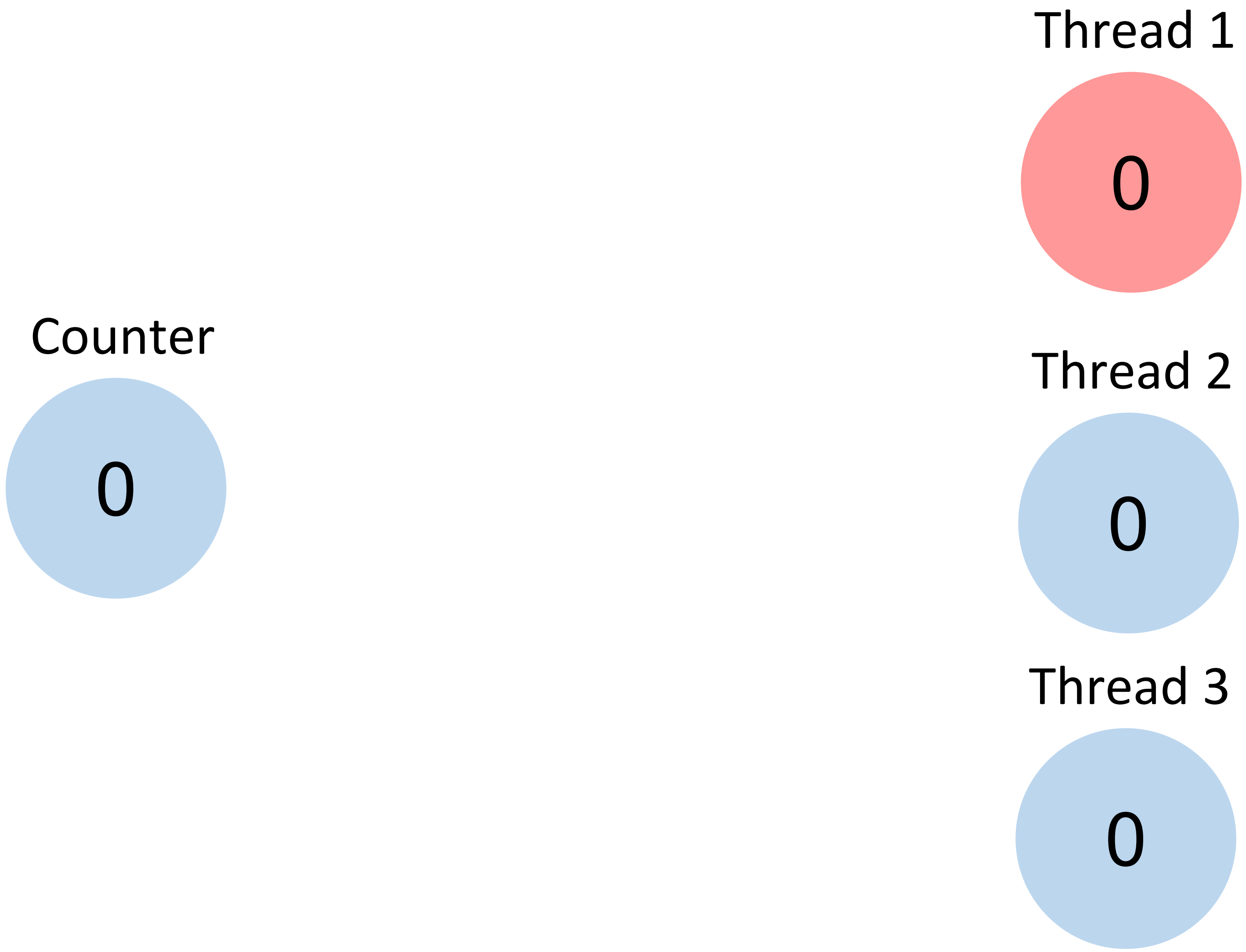
0

Thread 3

0

value of the
shared Counter

number of times
`increment()` is called



Counter

0

Thread 1

0

Thread 2

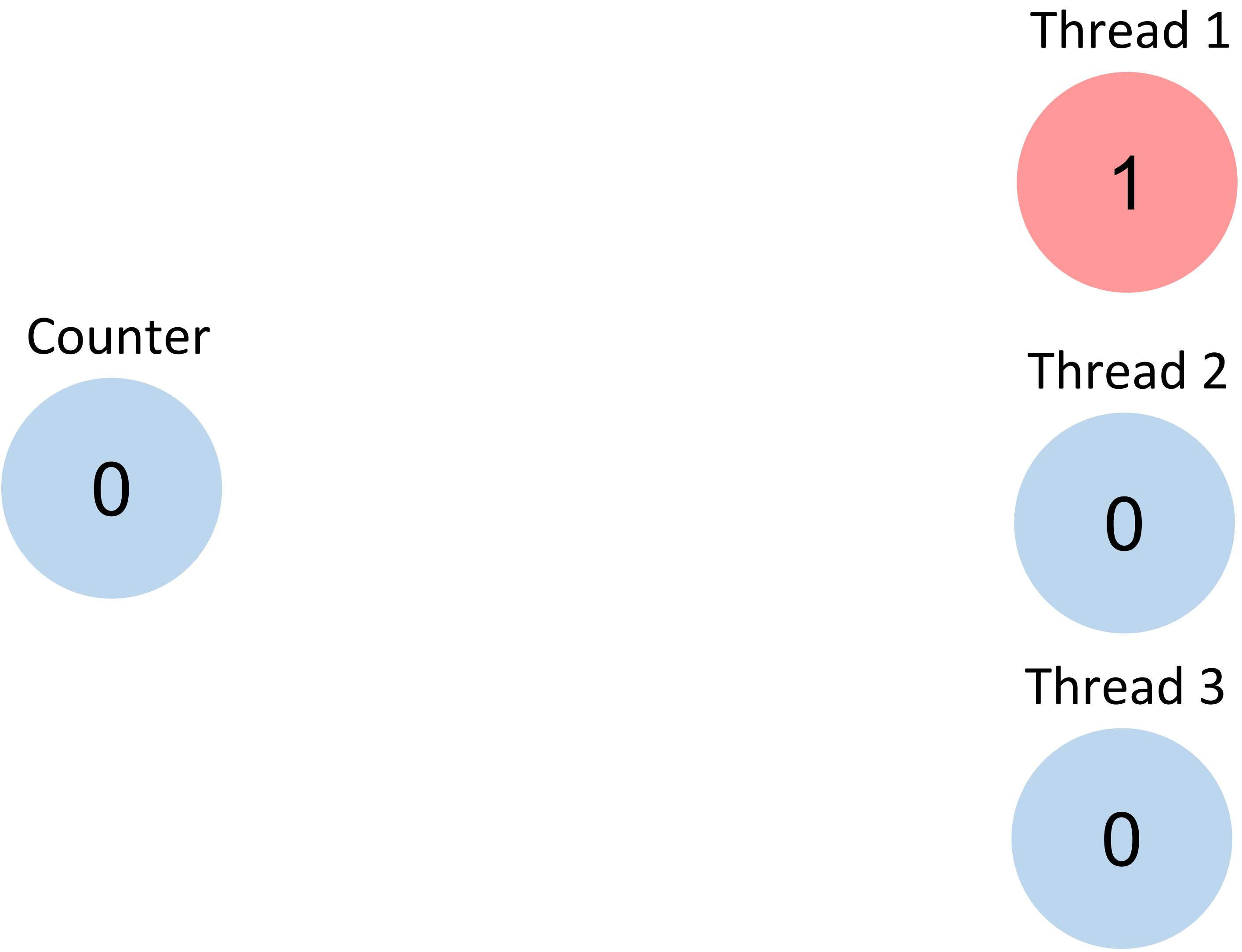
0

Thread 3

0

value of the
shared Counter

number of times
`increment()` is called



Counter

0

Thread 1

1

Thread 2

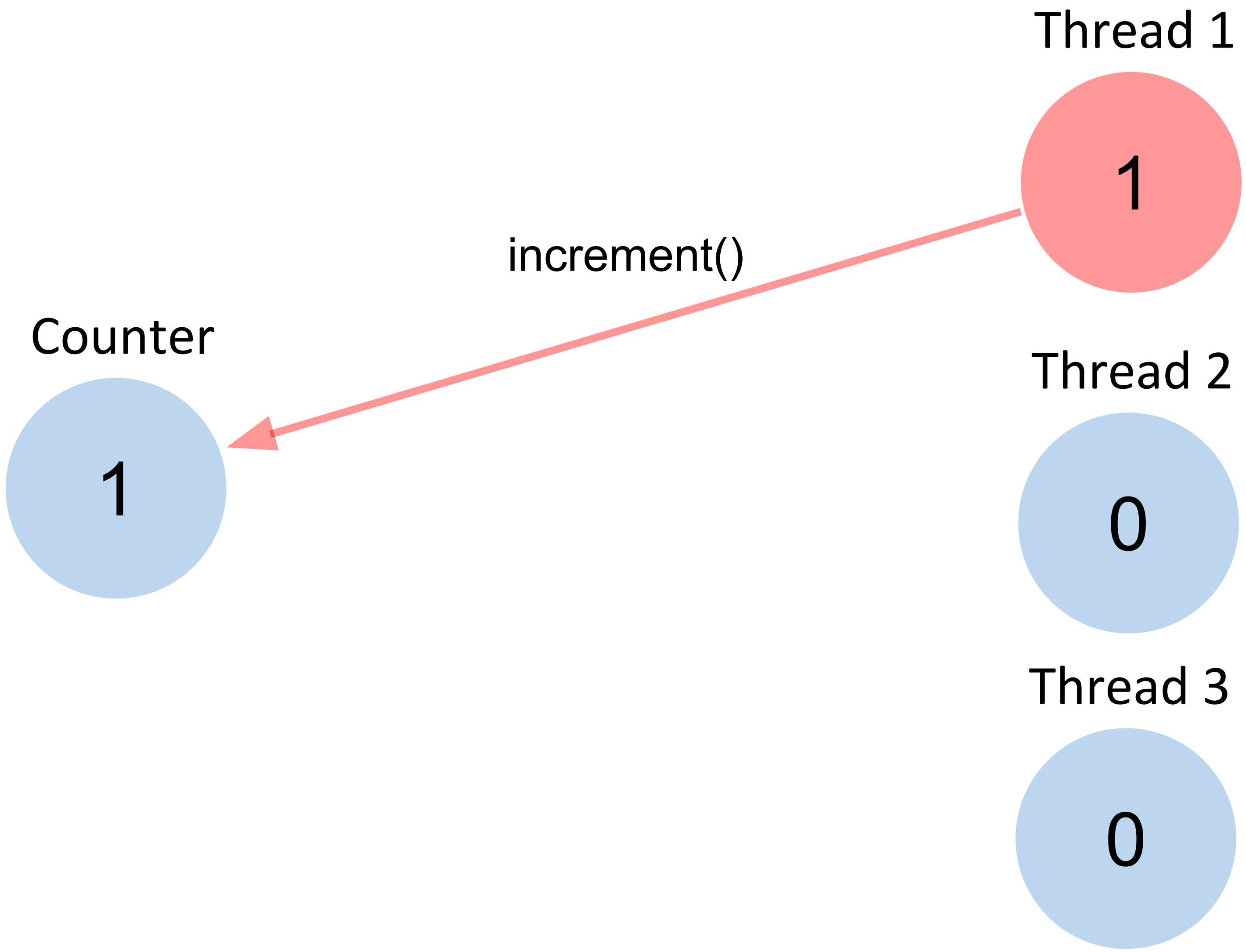
0

Thread 3

0

value of the
shared Counter

number of times
`increment()` is called



Thread 1

1

increment()

Counter

1

Thread 2

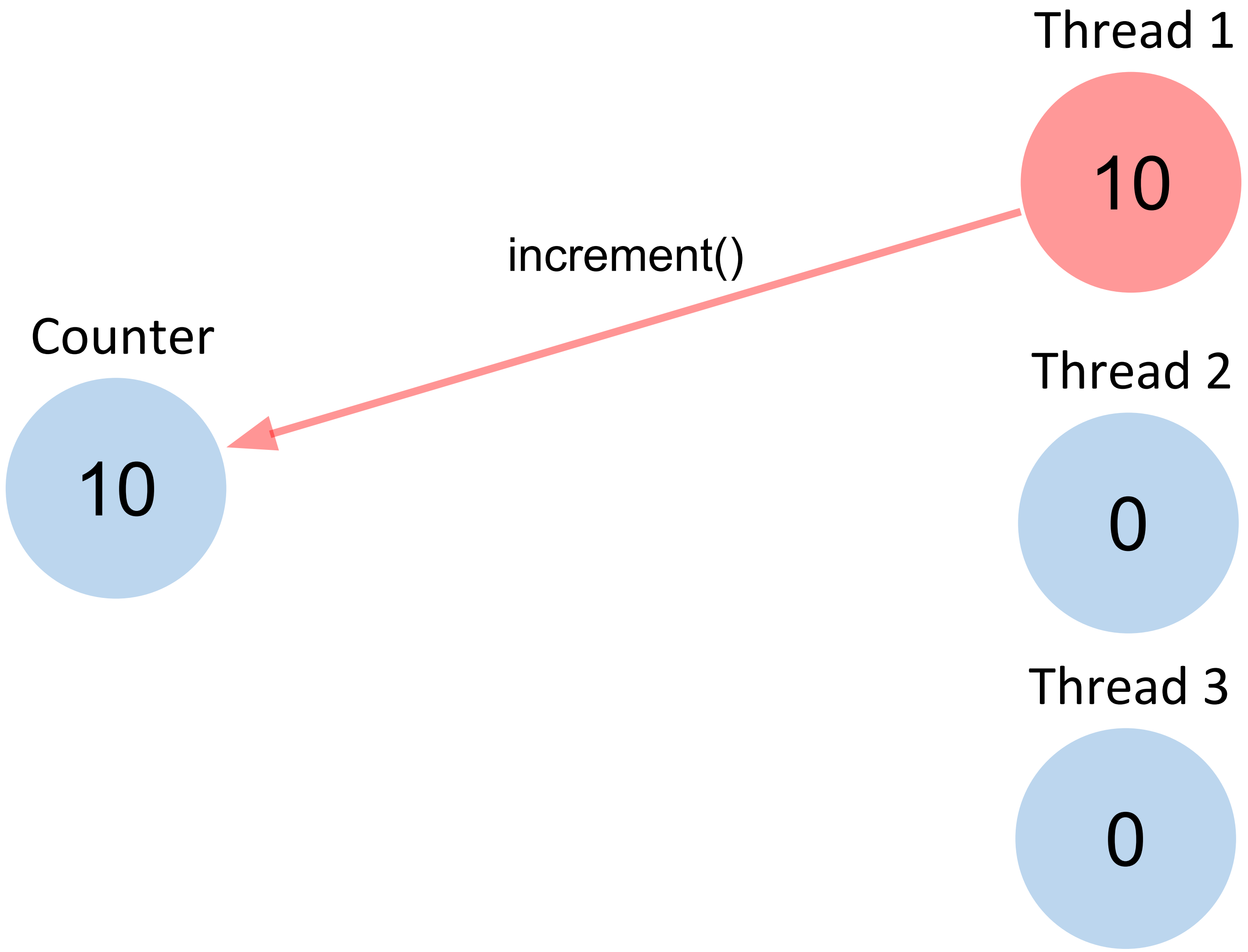
0

Thread 3

0

value of the
shared Counter

number of times
`increment()` is called



Thread 1

10

increment()

Counter

10

Thread 2

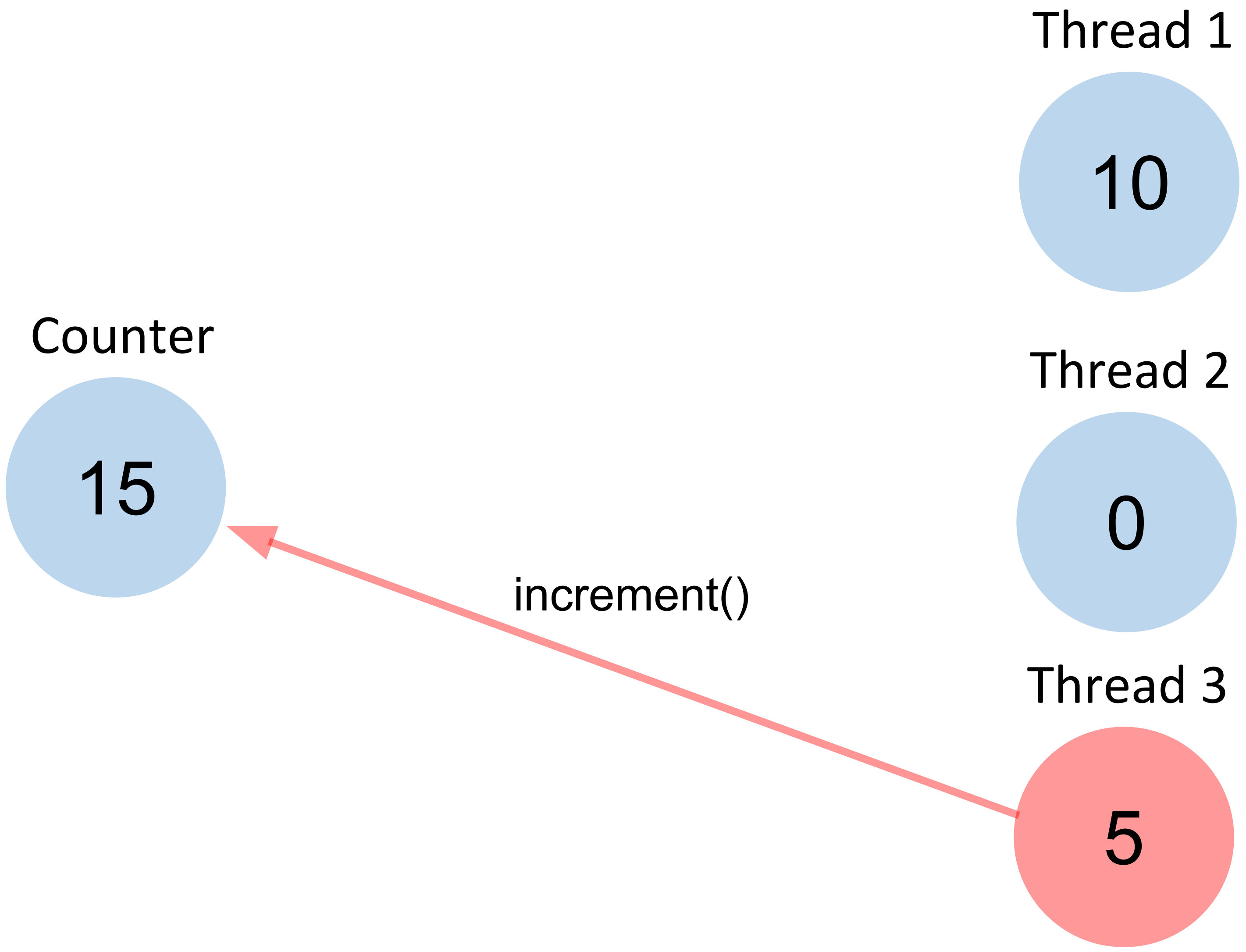
0

Thread 3

0

value of the
shared Counter

number of times
`increment()` is called



Counter

15

increment()

Thread 1

10

Thread 2

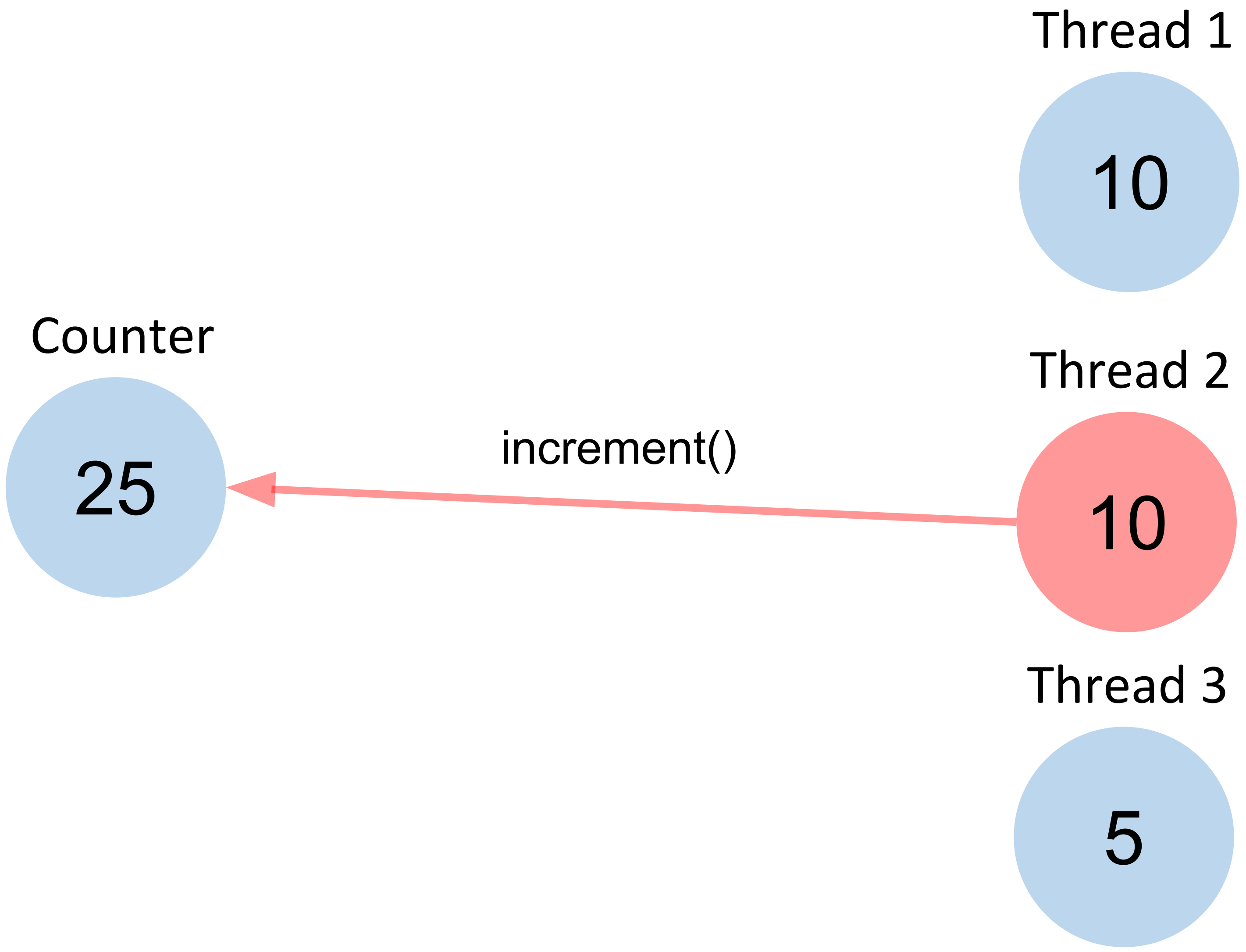
0

Thread 3

5

value of the
shared Counter

number of times
`increment()` is called



Thread 1

10

Counter

25

increment()

Thread 2

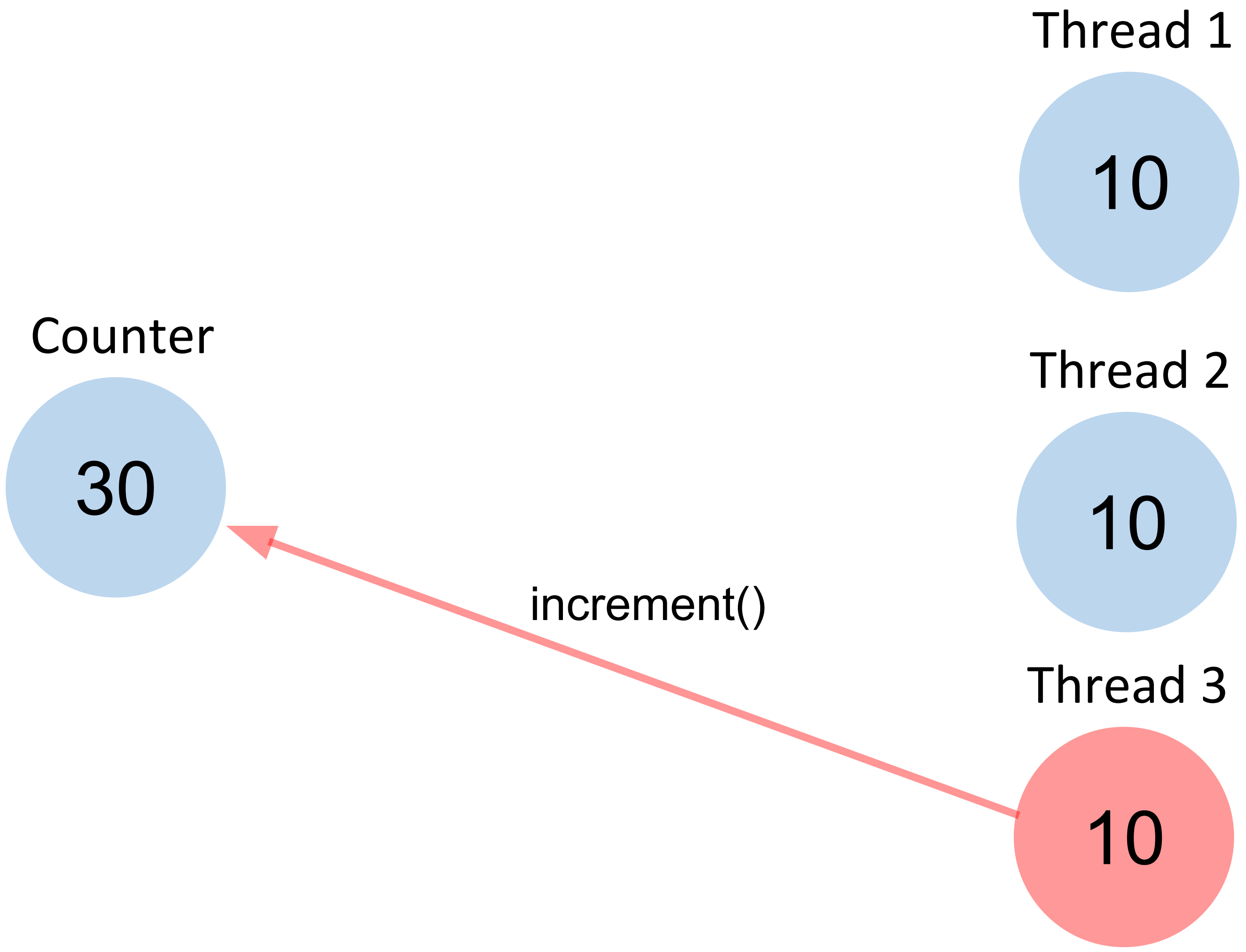
10

Thread 3

5

value of the
shared Counter

number of times
`increment()` is called



Thread 1

10

Counter

30

Thread 2

10

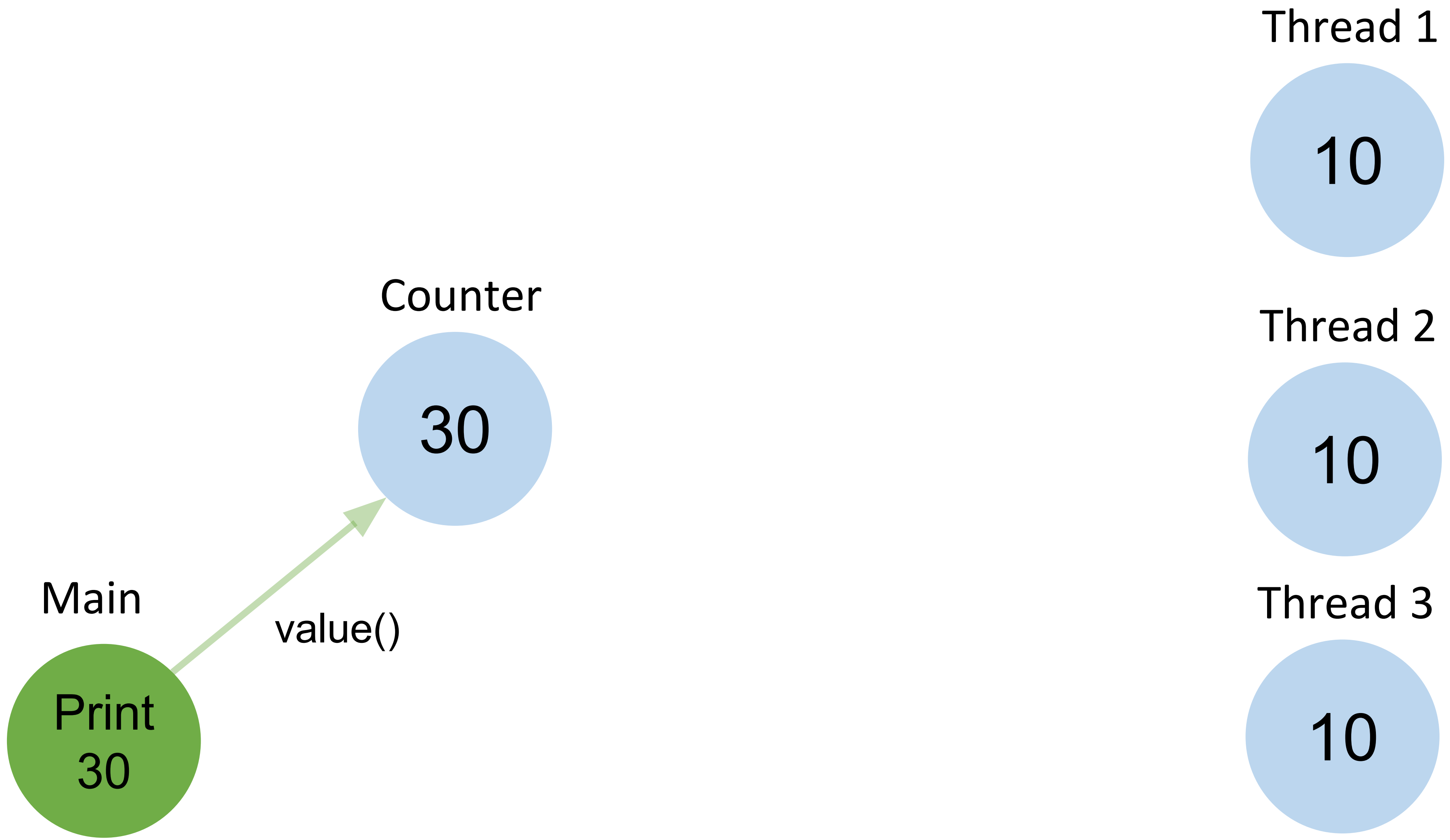
increment()

Thread 3

10

value of the
shared Counter

number of times
`increment()` is called



Thread 1

10

Thread 2

10

Thread 3

10

Counter

30

Main

value()

Print
30

read the
Counter value

value of the
shared Counter

number of times
`increment()` is called

Task A: SequentialCounter

```
public class SequentialCounter implements Counter {


    public void increment() {
        ??
    }

    public int value() {
        ??
    }
}
```

Task A: SequentialCounter

```
public class SequentialCounter implements Counter {
    private int c = 0;

    public void increment() {
        c++;
    }

    public int value() {
        return c;
    }
}
```

Task A: SequentialCounter

Thread 1

0

Counter

0

Thread 2

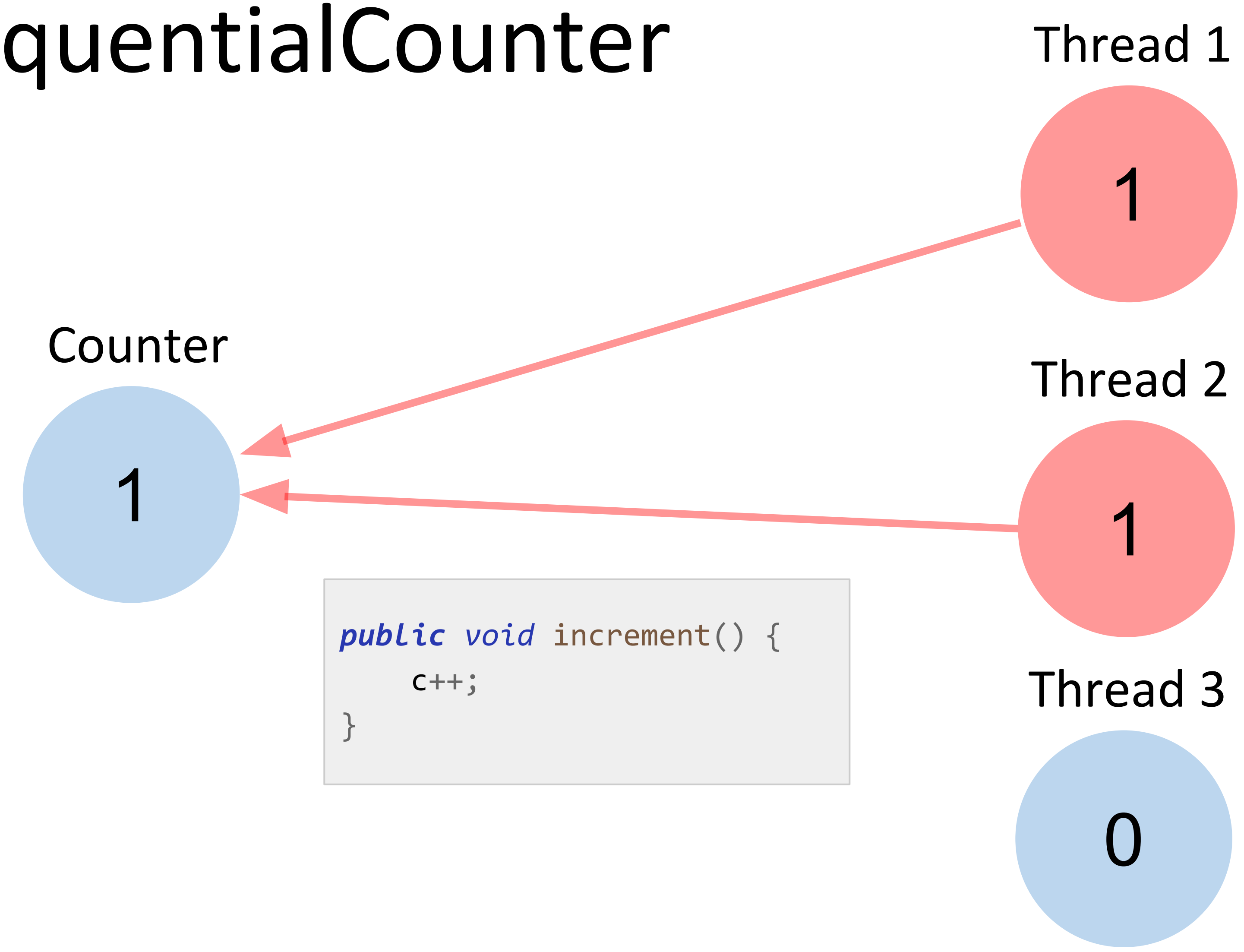
0

```
public void increment() {
    c++;
}
```

Thread 3

0

Task A: SequentialCounter



conflicting access!

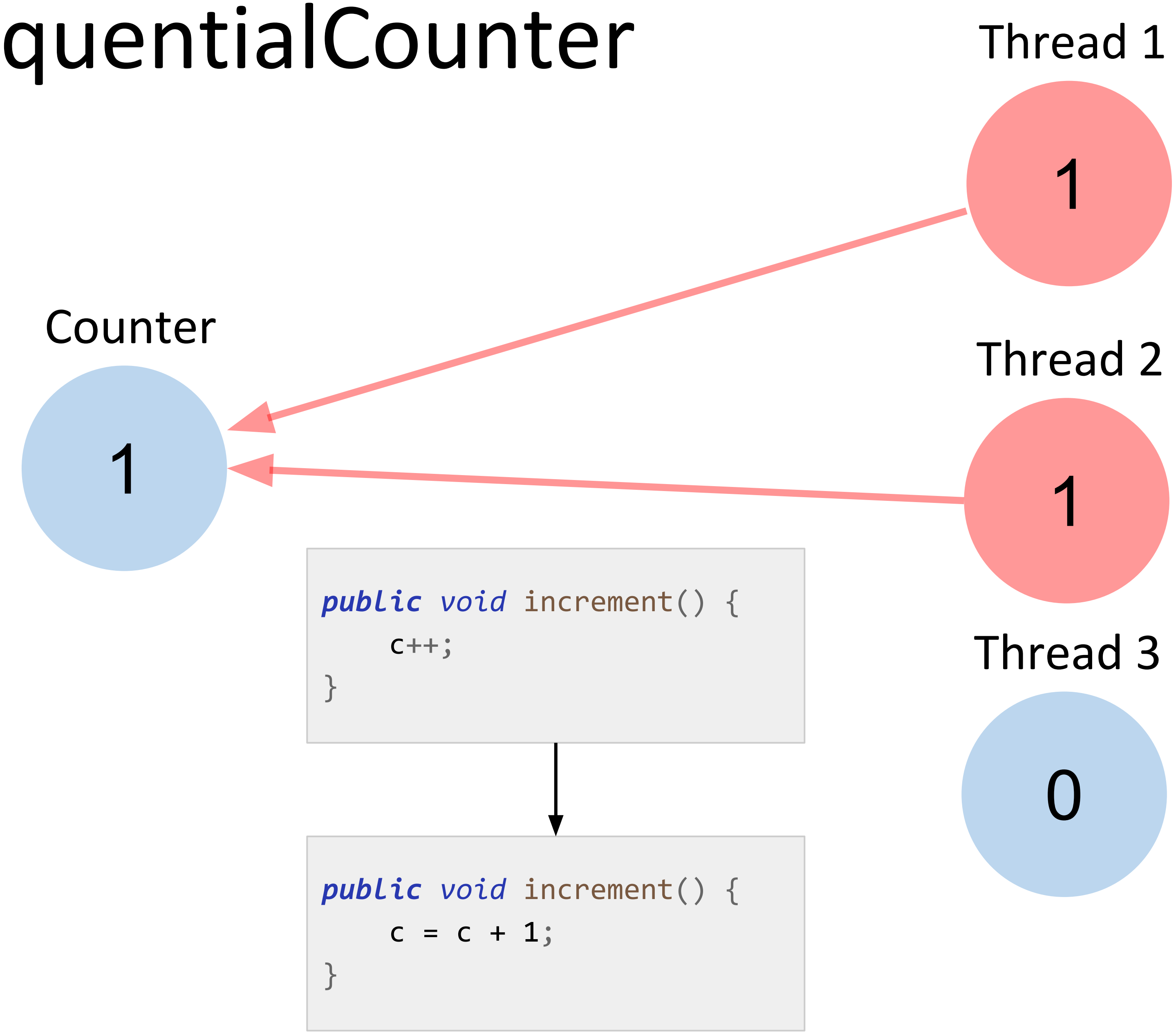
How is this possible?

```
public void increment() {
    c++;
}
```

Task A: SequentialCounter

conflicting access!

How is this possible?



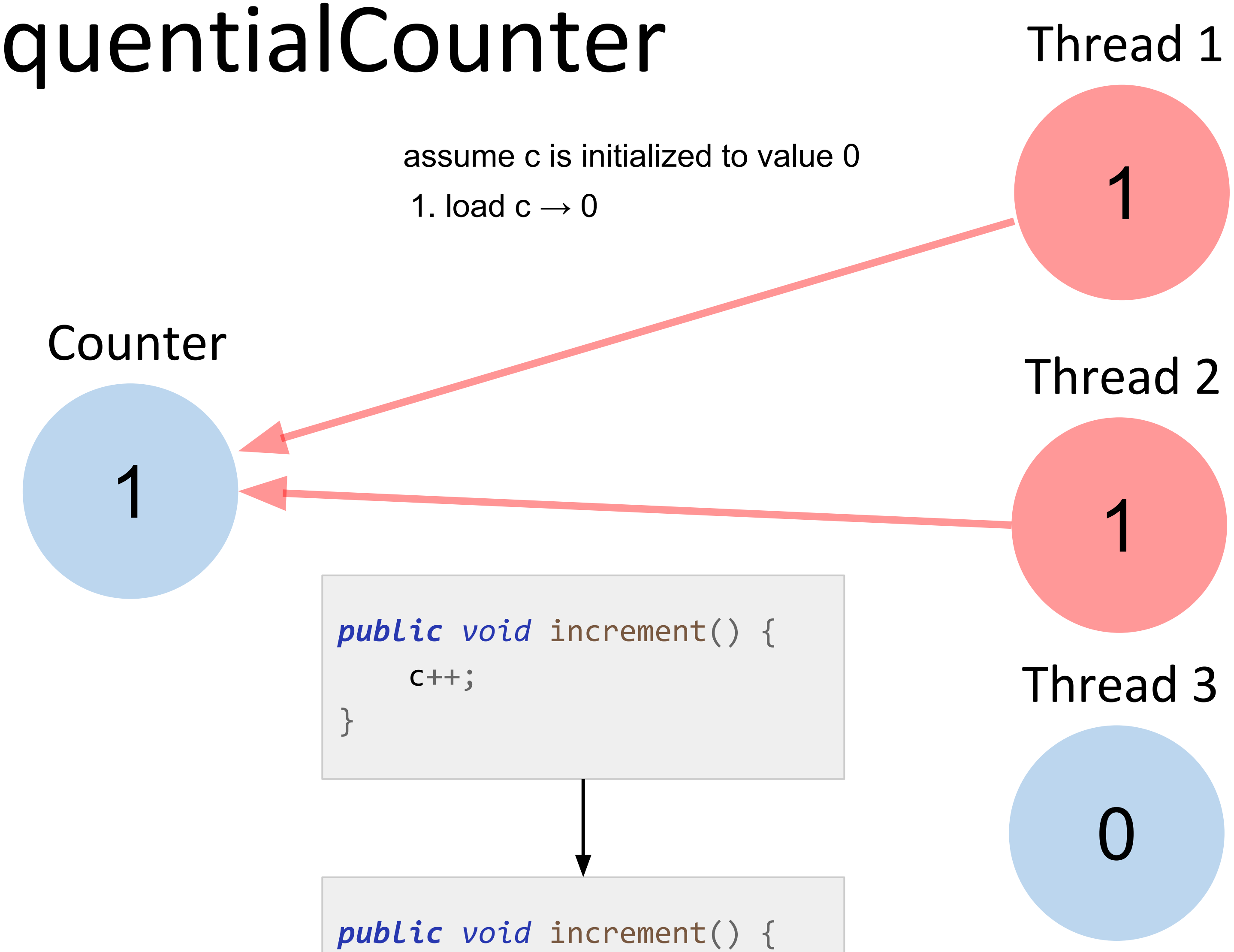
```
public void increment() {
    c++;
}
```

```
public void increment() {
    c = c + 1;
}
```

Task A: SequentialCounter

conflicting access!

How is this possible?



assume c is initialized to value 0

1. load c → 0

```
public void increment() {
    c++;
}
```

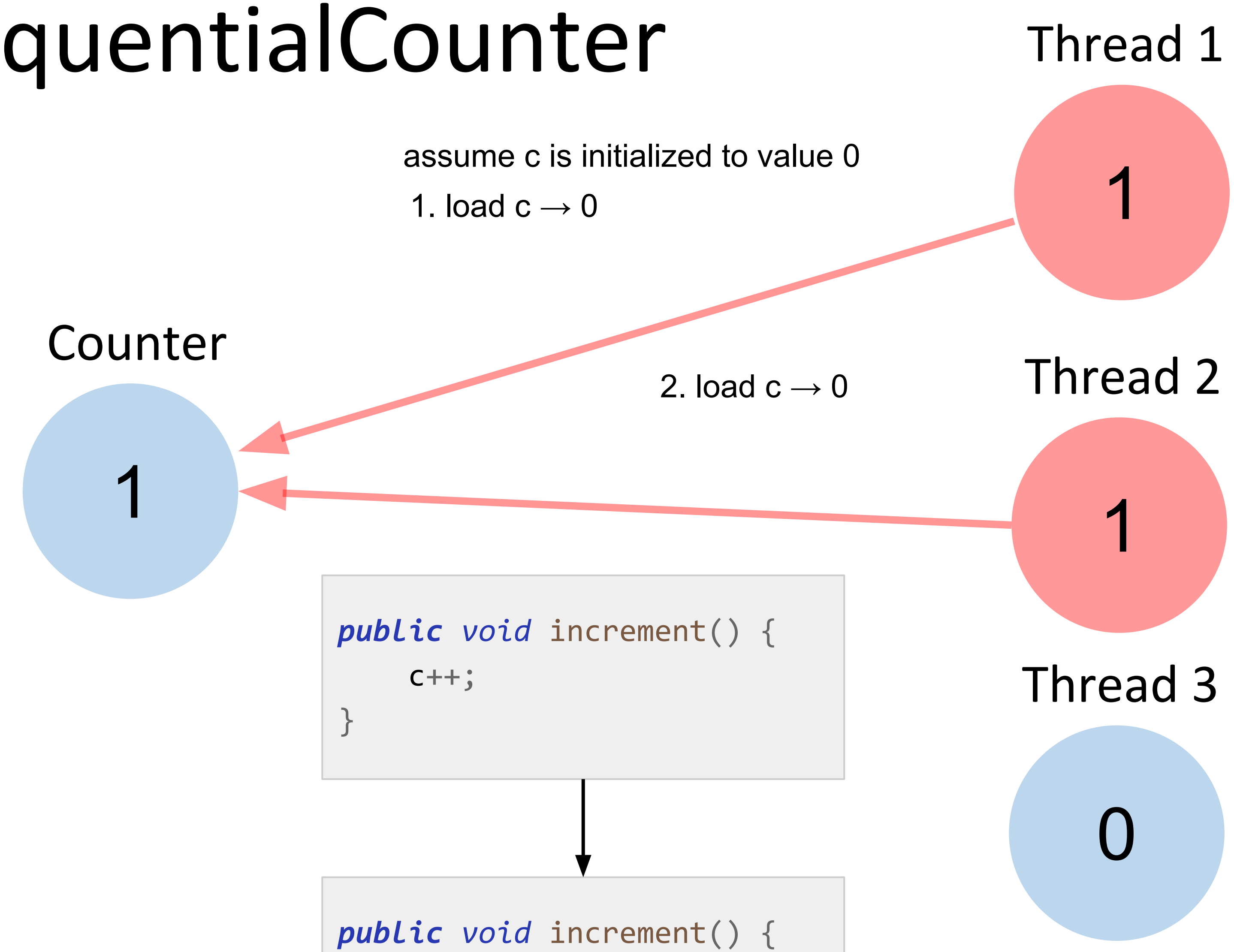
↓

```
public void increment() {
    c = c + 1;
}
```

Task A: SequentialCounter

conflicting access!

How is this possible?



Thread 1

1

assume c is initialized to value 0

1. load c → 0

Counter

1

2. load c → 0

Thread 2

1

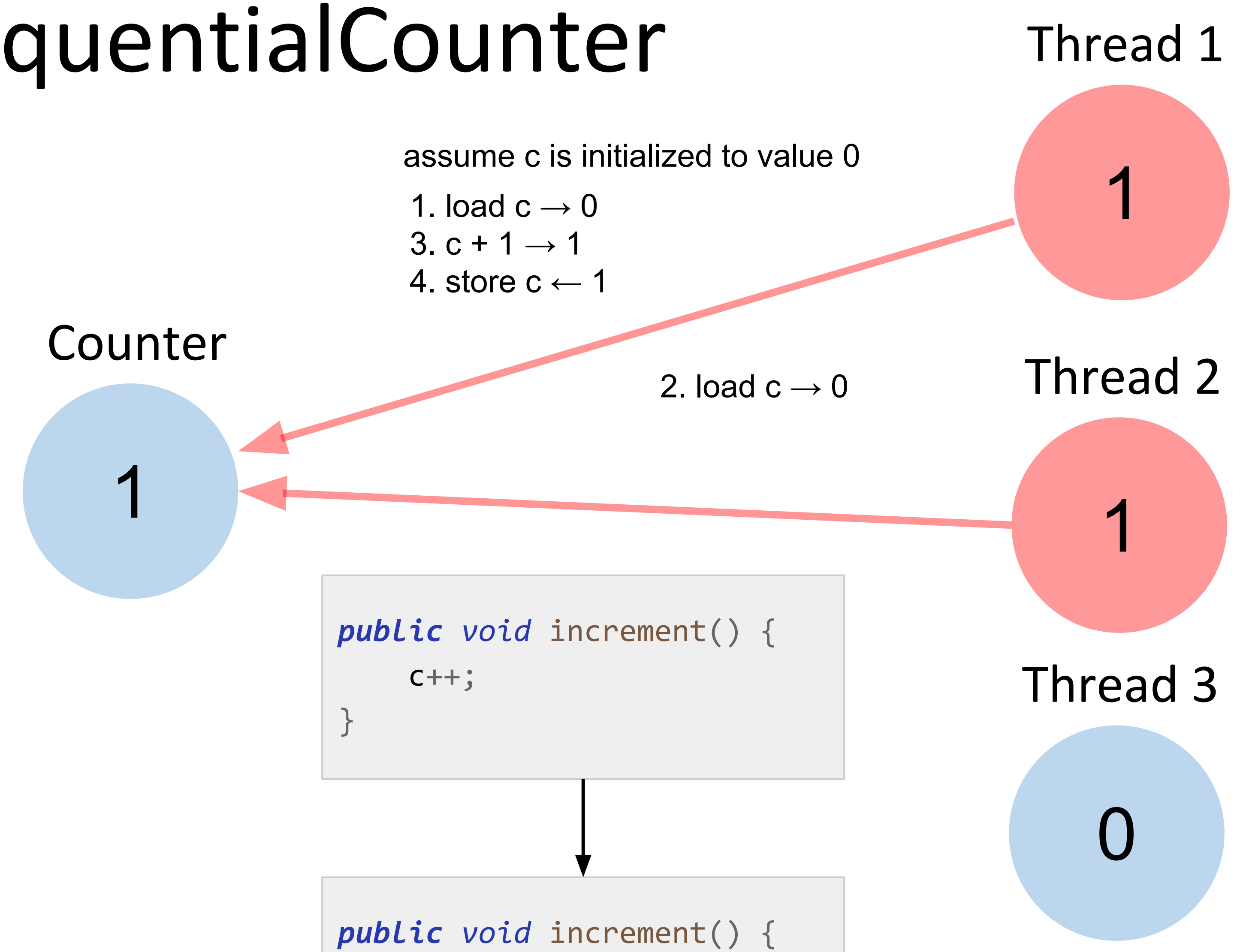
Thread 3

0

```
public void increment() {
    c++;
}
```

```
public void increment() {
    c = c + 1;
}
```

Task A: SequentialCounter



assume c is initialized to value 0

1. load c → 0
3. c + 1 → 1
4. store c ← 1

2. load c → 0

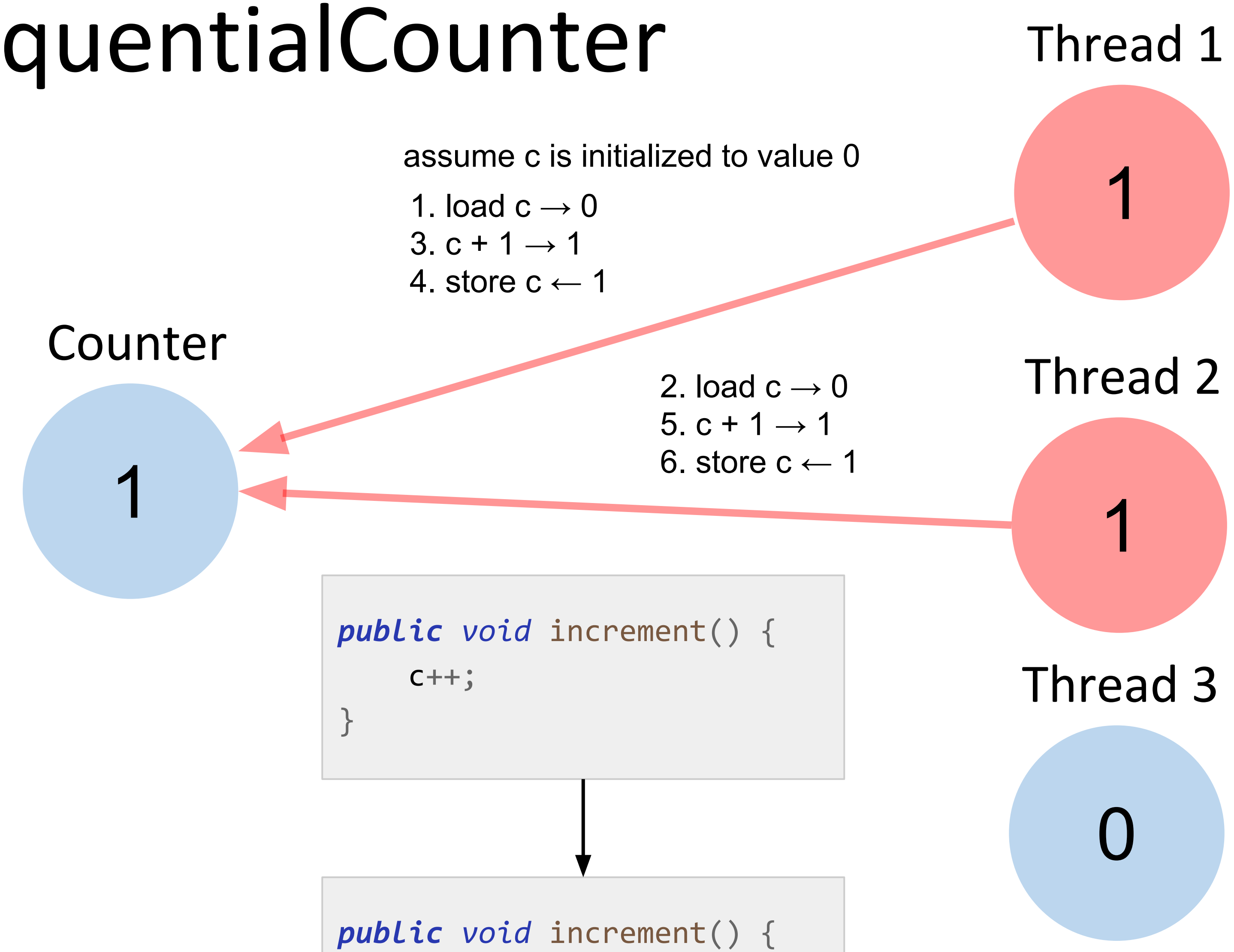
conflicting access!

How is this possible?

```
public void increment() {
    c++;
}
```

```
public void increment() {
    c = c + 1;
}
```

Task A: SequentialCounter



assume c is initialized to value 0

1. load c → 0
3. c + 1 → 1
4. store c ← 1

2. load c → 0
5. c + 1 → 1
6. store c ← 1

conflicting access!

How is this possible?

```java
public void increment() {
    c++;
}
```

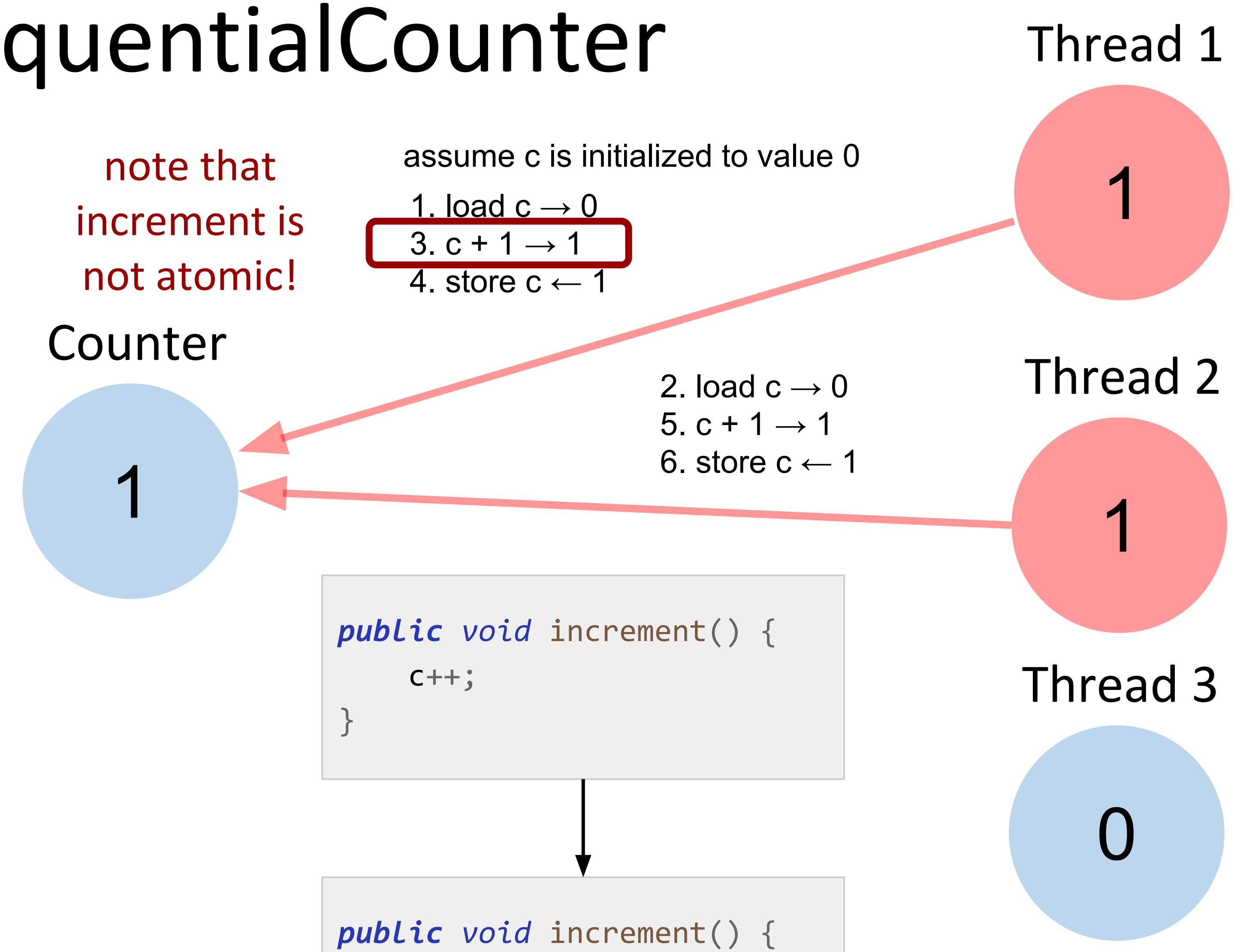
```java
public void increment() {
    c = c + 1;
}
```

Task A: SequentialCounter

note that increment is not atomic!

conflicting access!

How is this possible?



assume c is initialized to value 0

1. load c → 0
3. c + 1 → 1
4. store c ← 1

2. load c → 0
5. c + 1 → 1
6. store c ← 1

```
public void increment() {
    c++;
}
```

```
public void increment() {
    c = c + 1;
}
```

Task B: SynchronizedCounter

```java
public class SynchronizedCounter implements Counter {


    public void increment() {
       ??
    }

    public int value() {
       ??
    }
}
```

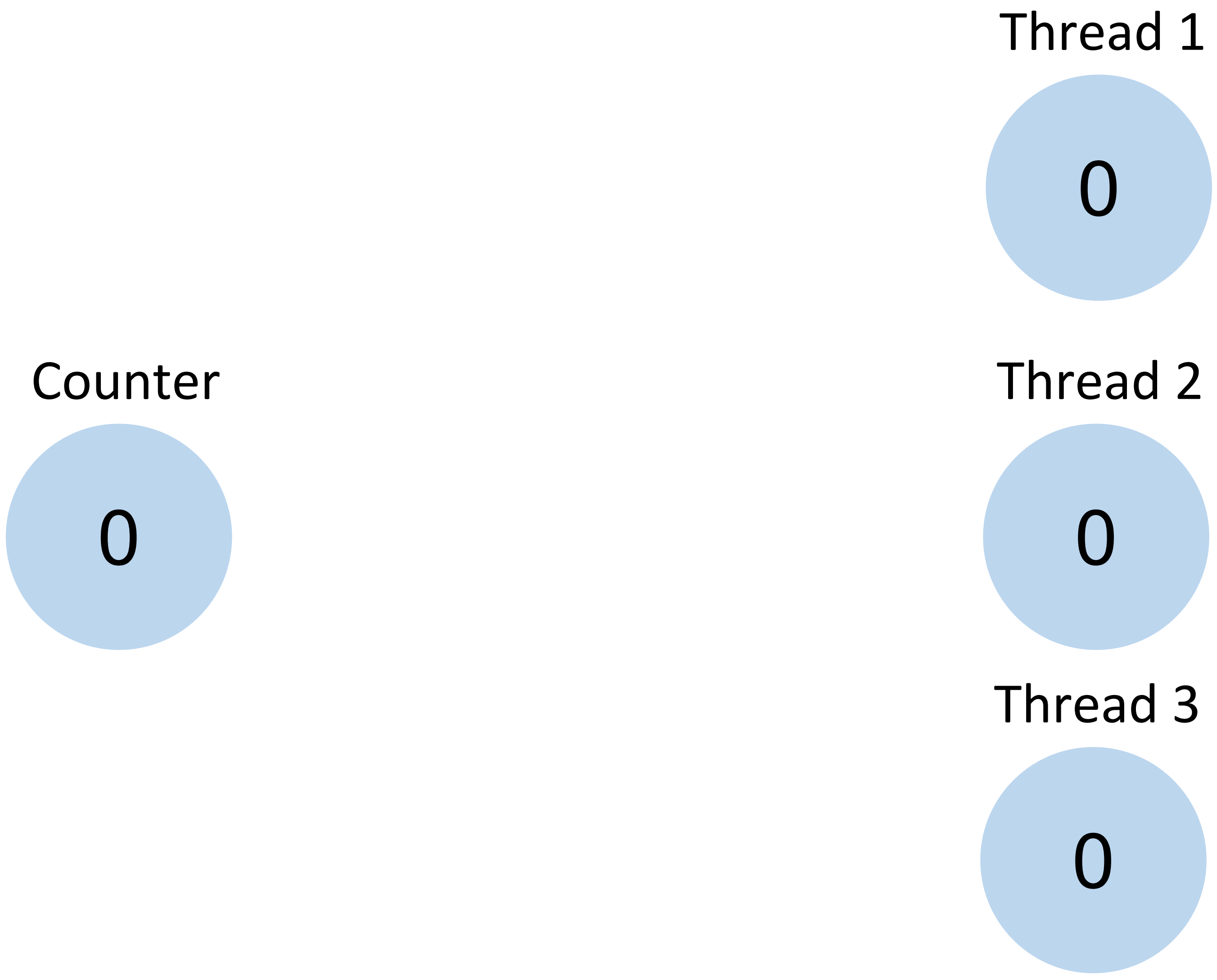
Task B: SynchronizedCounter

```java
public class SynchronizedCounter implements Counter {
    private int c = 0;

    public synchronized void increment() {
        c++;
    }

    public synchronized int value() {
        return c;
    }
}
```

Task B: SynchronizedCounter



Thread 1

0

Counter

0

Thread 2

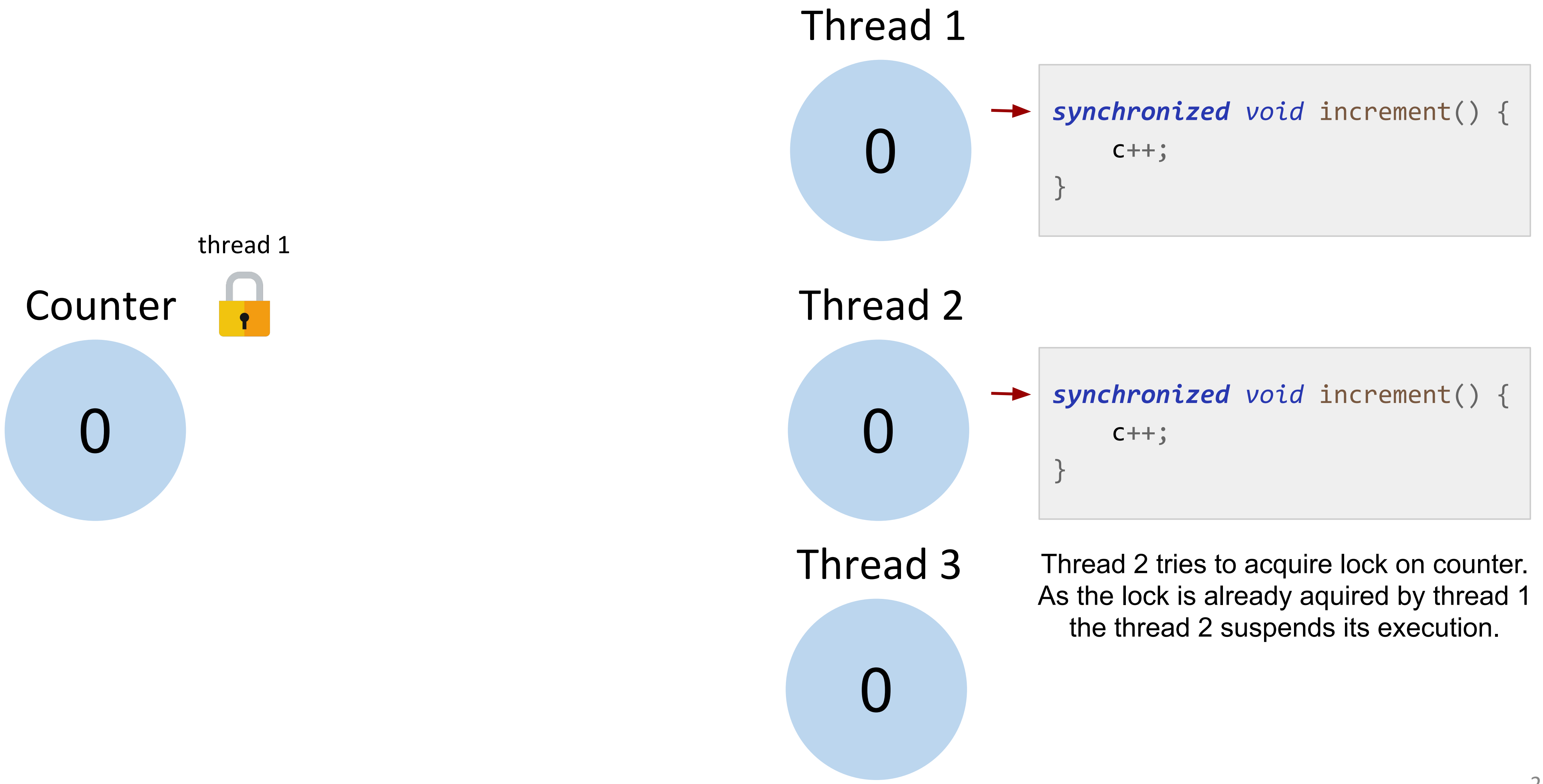
0

Thread 3

0

```
synchronized void increment() {
    c++;
}
```

Task B: SynchronizedCounter

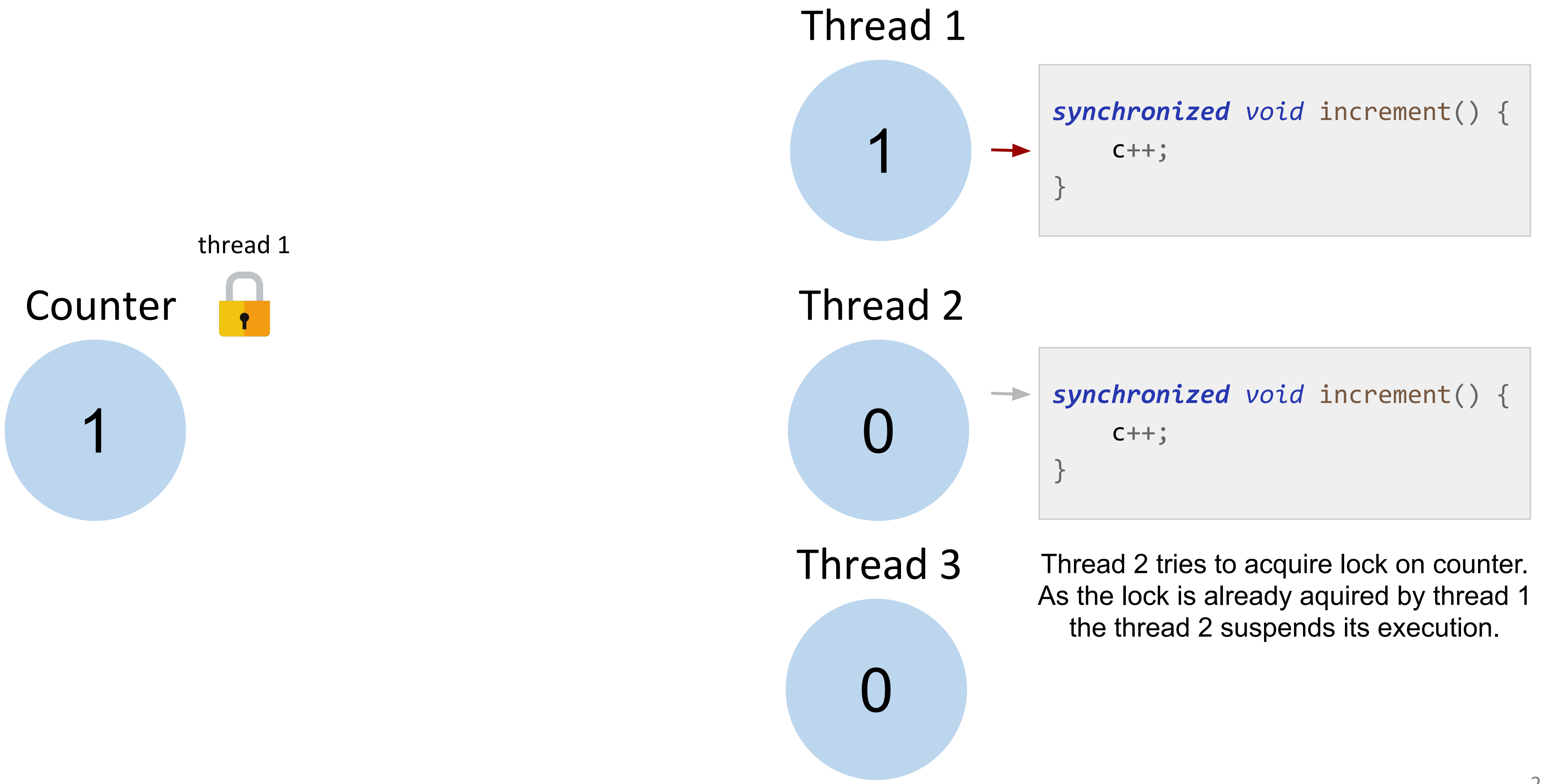


```
synchronized void increment() {
    c++;
}
```

```
synchronized void increment() {
    c++;
}
```

Thread 2 tries to acquire lock on counter.
As the lock is already aquired by thread 1
the thread 2 suspends its execution.

Task B: SynchronizedCounter

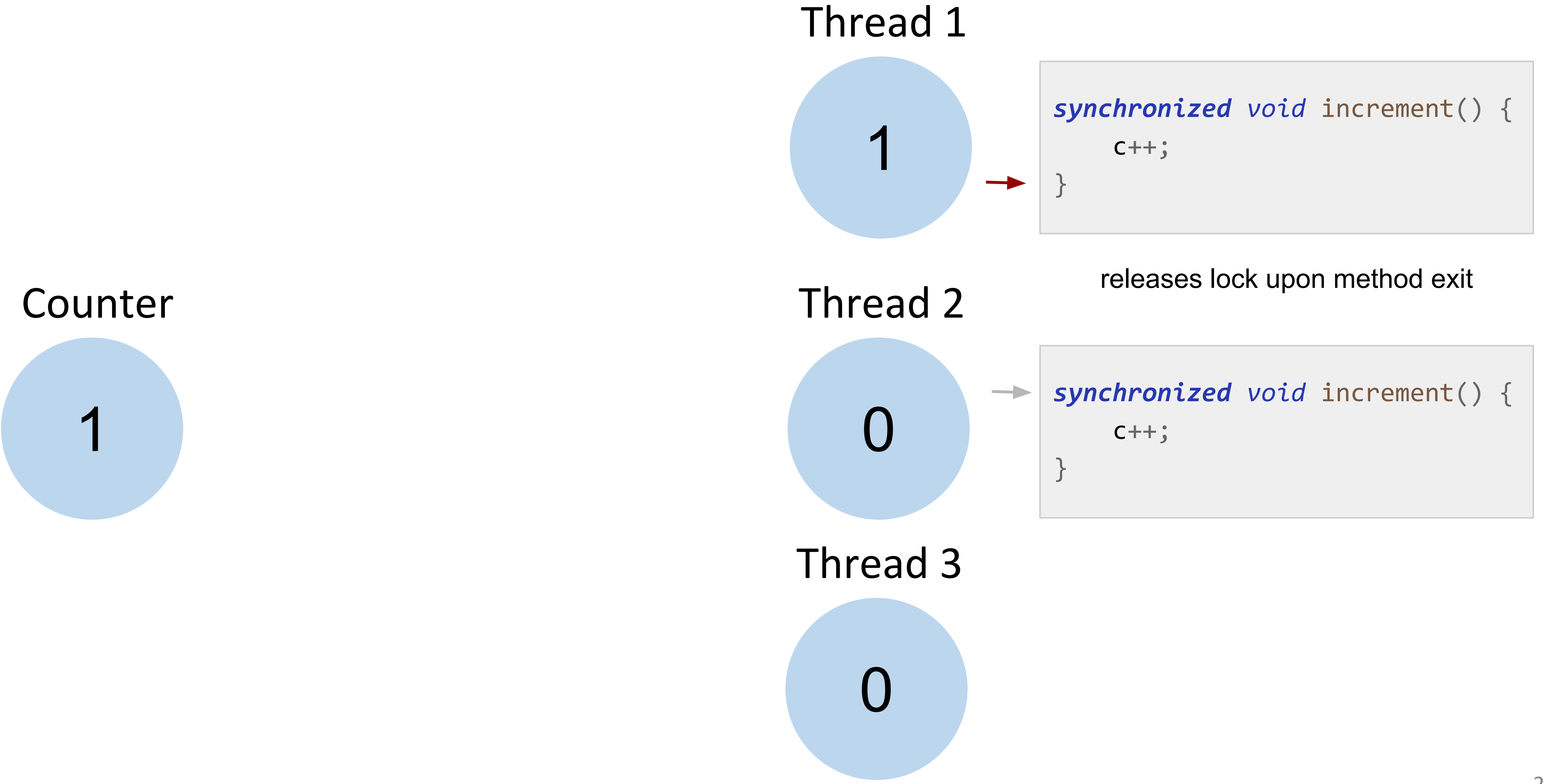


```
synchronized void increment() {
    c++;
}
```

```
synchronized void increment() {
    c++;
}
```

Thread 2 tries to acquire lock on counter. As the lock is already aquired by thread 1 the thread 2 suspends its execution.

Task B: SynchronizedCounter



Thread 1

1

```
synchronized void increment() {
    c++;
}
```

releases lock upon method exit

Counter

1

Thread 2

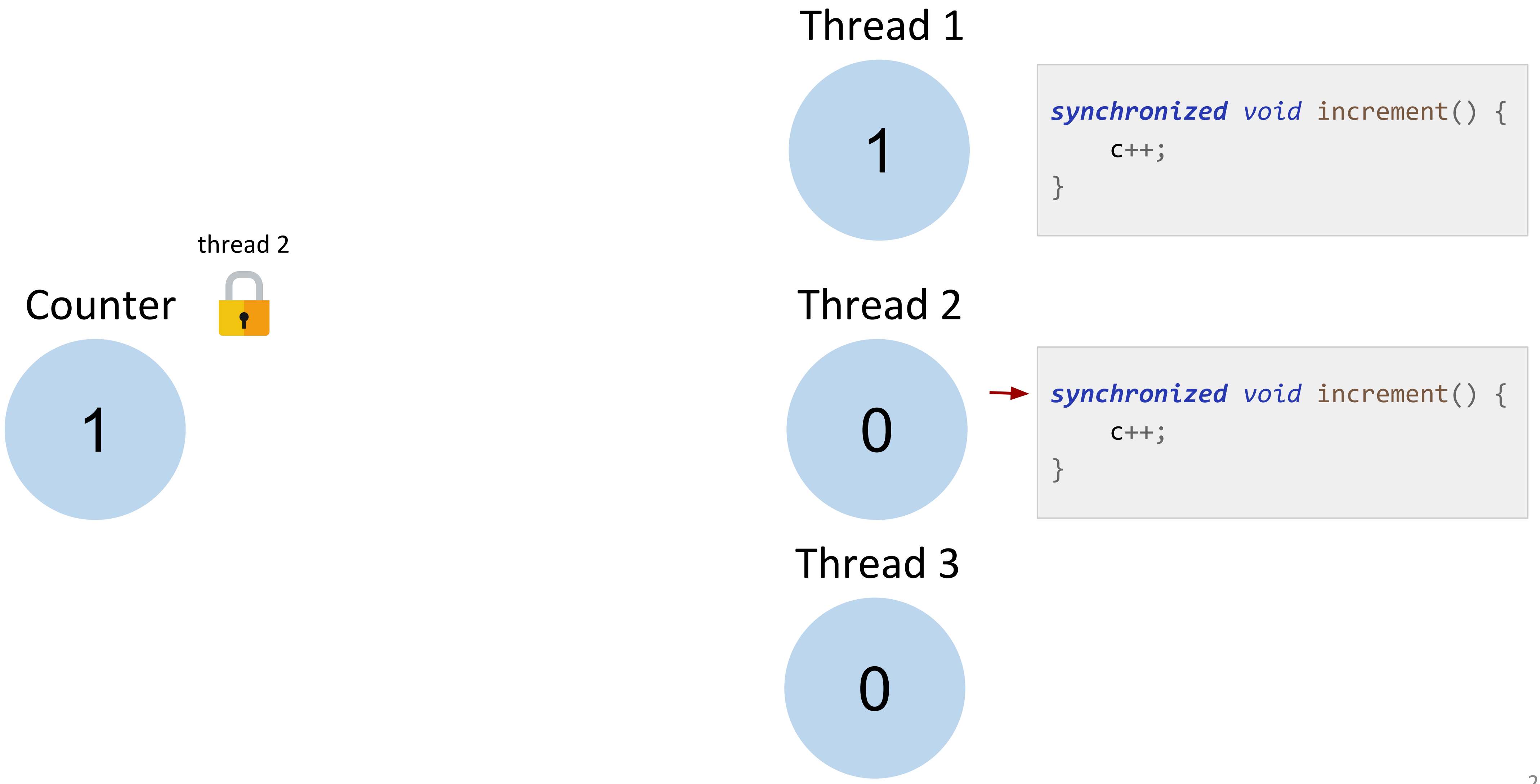
0

```
synchronized void increment() {
    c++;
}
```

Thread 3

0

Task B: SynchronizedCounter



Thread 1

1

```
synchronized void increment() {
    c++;
}
```

thread 2

Counter

1

Thread 2

0

```
synchronized void increment() {
    c++;
}
```

Thread 3

0

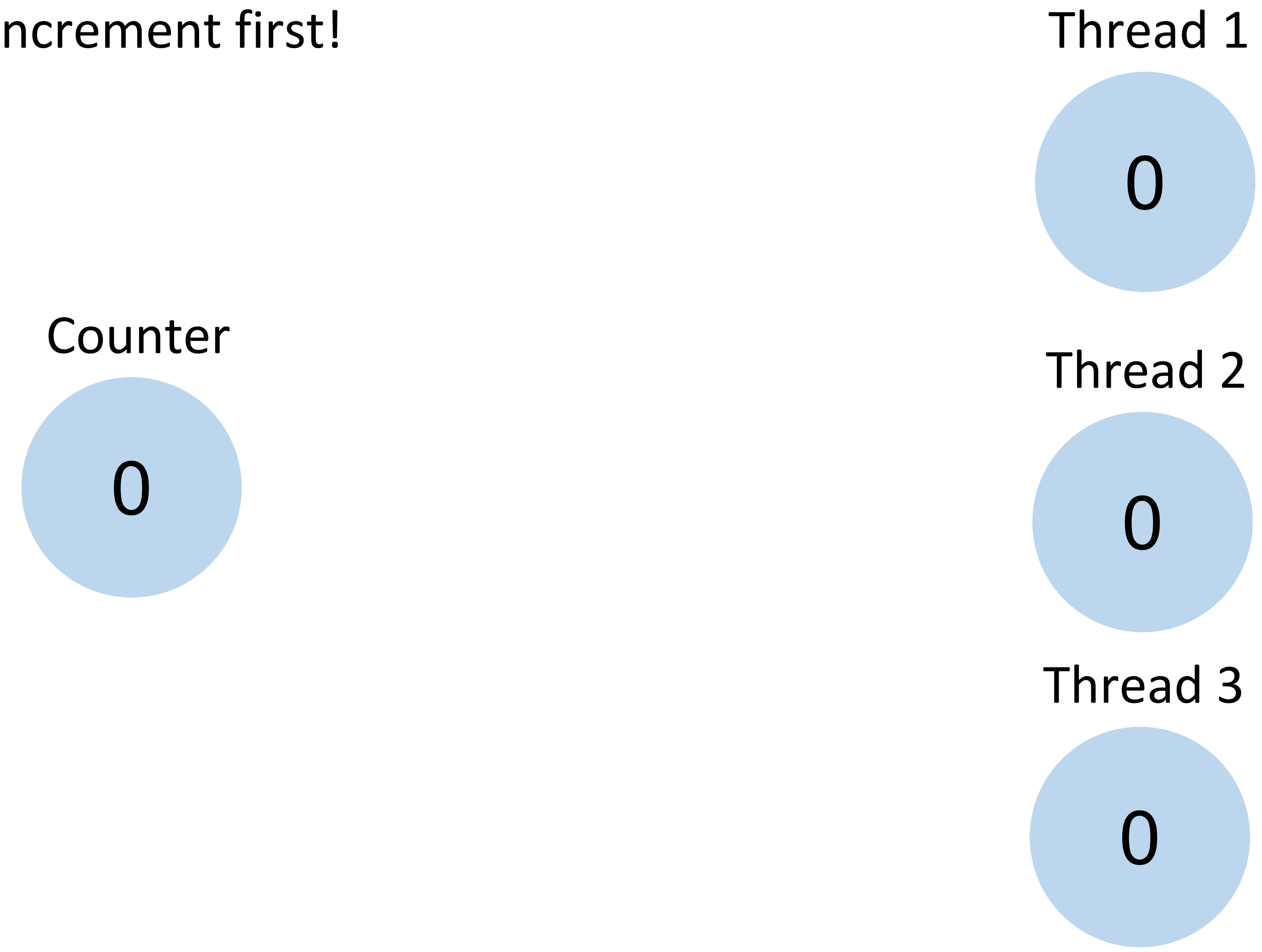
Task D

- Implement a FairThreadCounter that ensures that different threads increment the Counter in an round-robin fashion. That is, two threads with ids 1 and 2 would increment the value in the following order 1, 2, 1, 2, 1, 2, etc. You should implement the scheduling using the wait and notify methods.
- Can you think of implementation that does not use wait and notify methods?
- (Optional) Extend your implemenation to work with arbitrary number of threads (instead of only 2) that increment the counter in round-robin fashion.

Wait and Notify Recap

- Object provides wait() and notify() methods
- To call wait() on an object thread must own its lock
- Thread releases the lock and is added to the “waiting list” for that object
- Thread waits until a notify method is called on the object
- notify() removes one (arbitrary) thread from the object’s “waiting list”
- notifyAll() removes all the threads

Thread 1 must increment first!



Counter

0

Thread 1

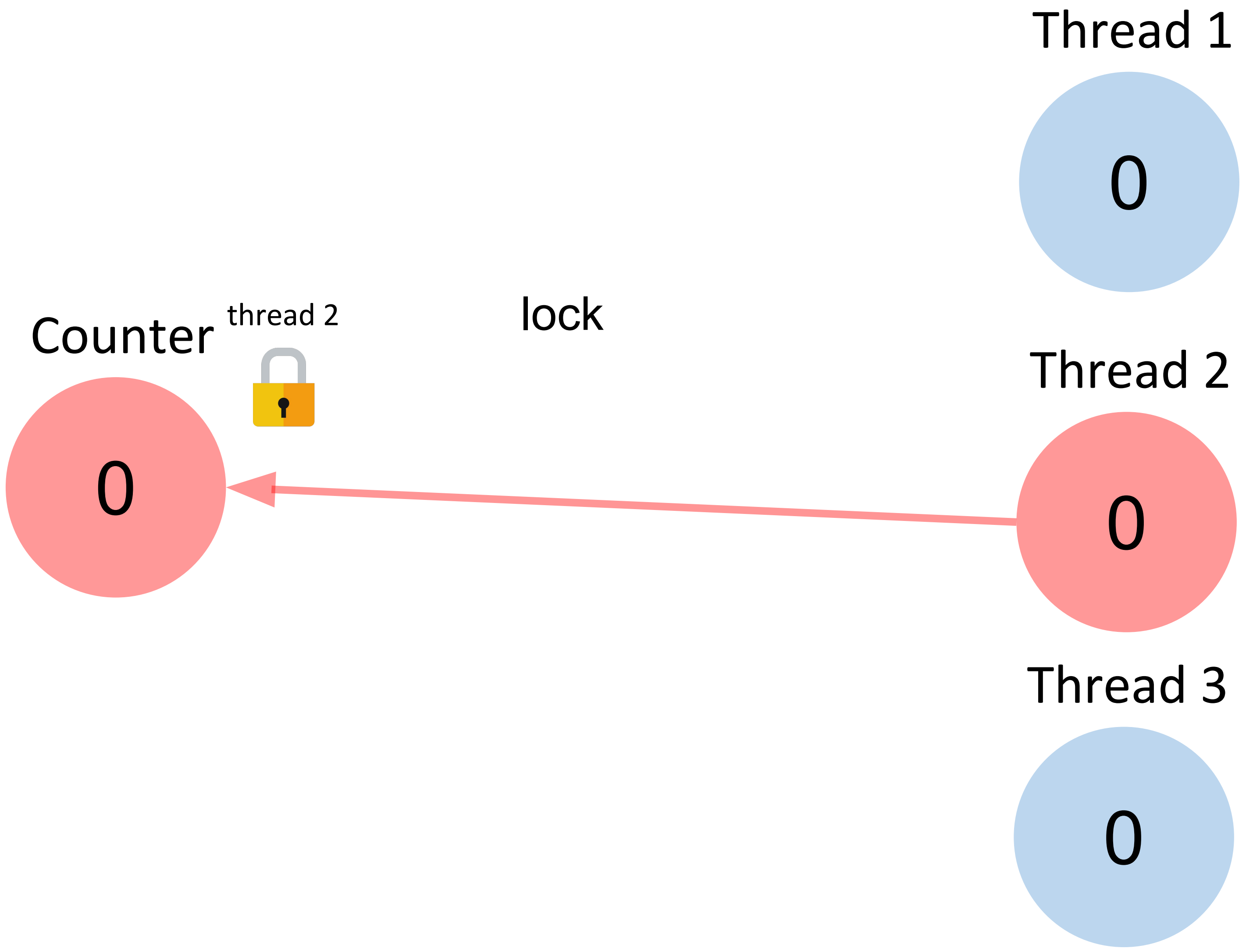
0

Thread 2

0

Thread 3

0



Thread 1

0

Counter

thread 2

lock

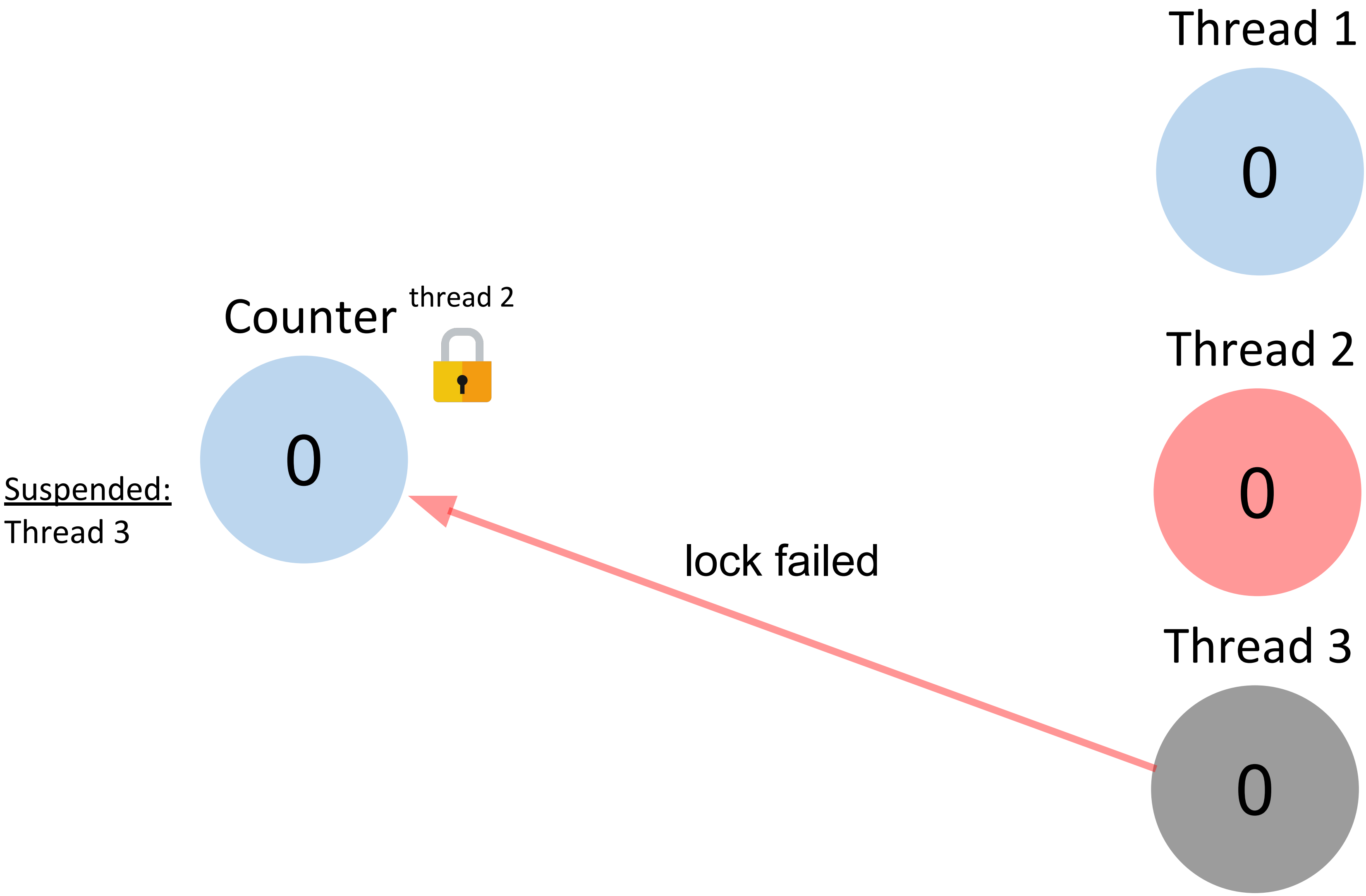
Thread 2

0

0

Thread 3

0



Thread 1

0

Counter

thread 2

0

Suspended:

Thread 3

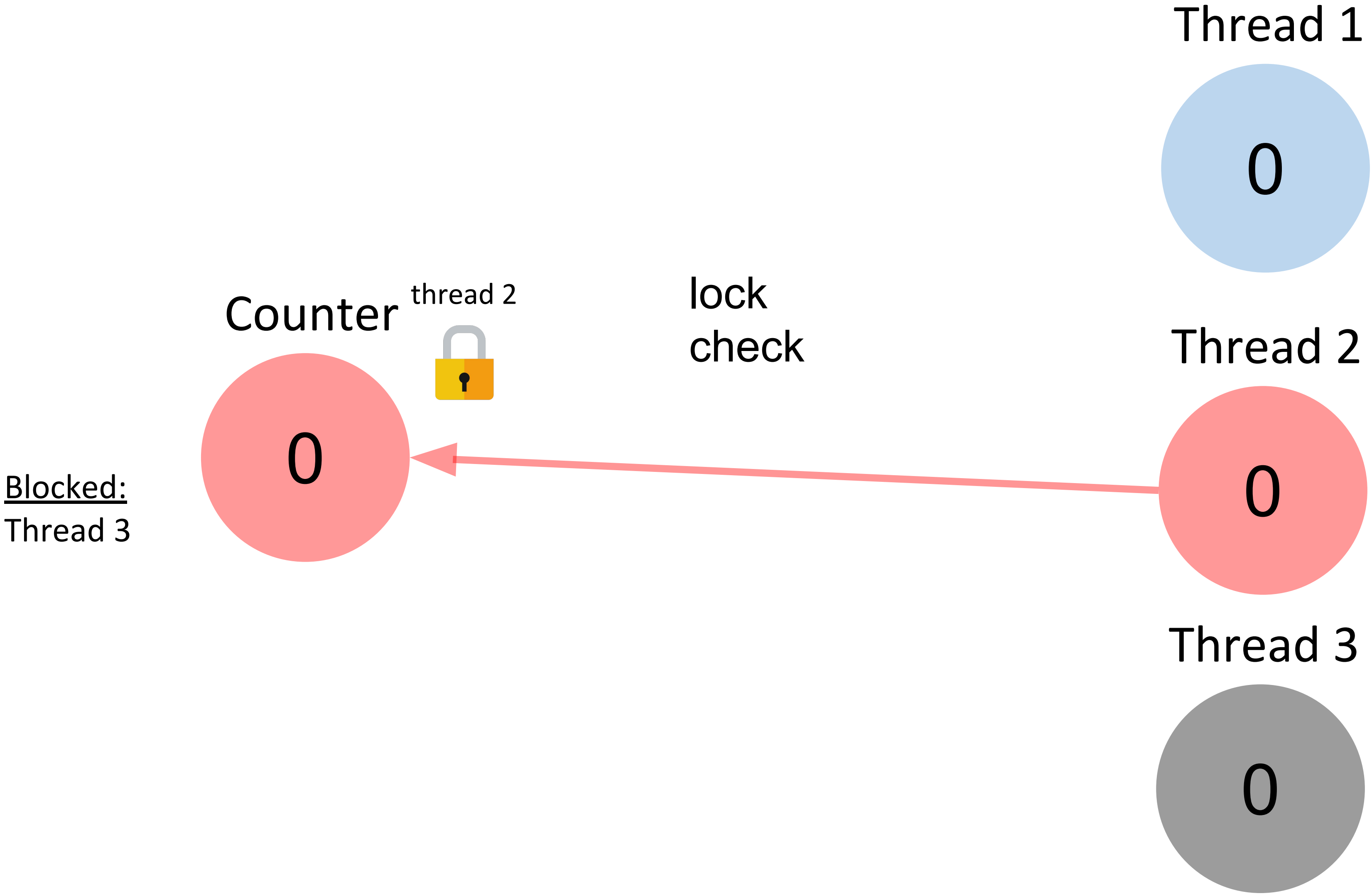
Thread 2

0

lock failed

Thread 3

0



Thread 1

0

Counter

thread 2

lock

check

Thread 2

0

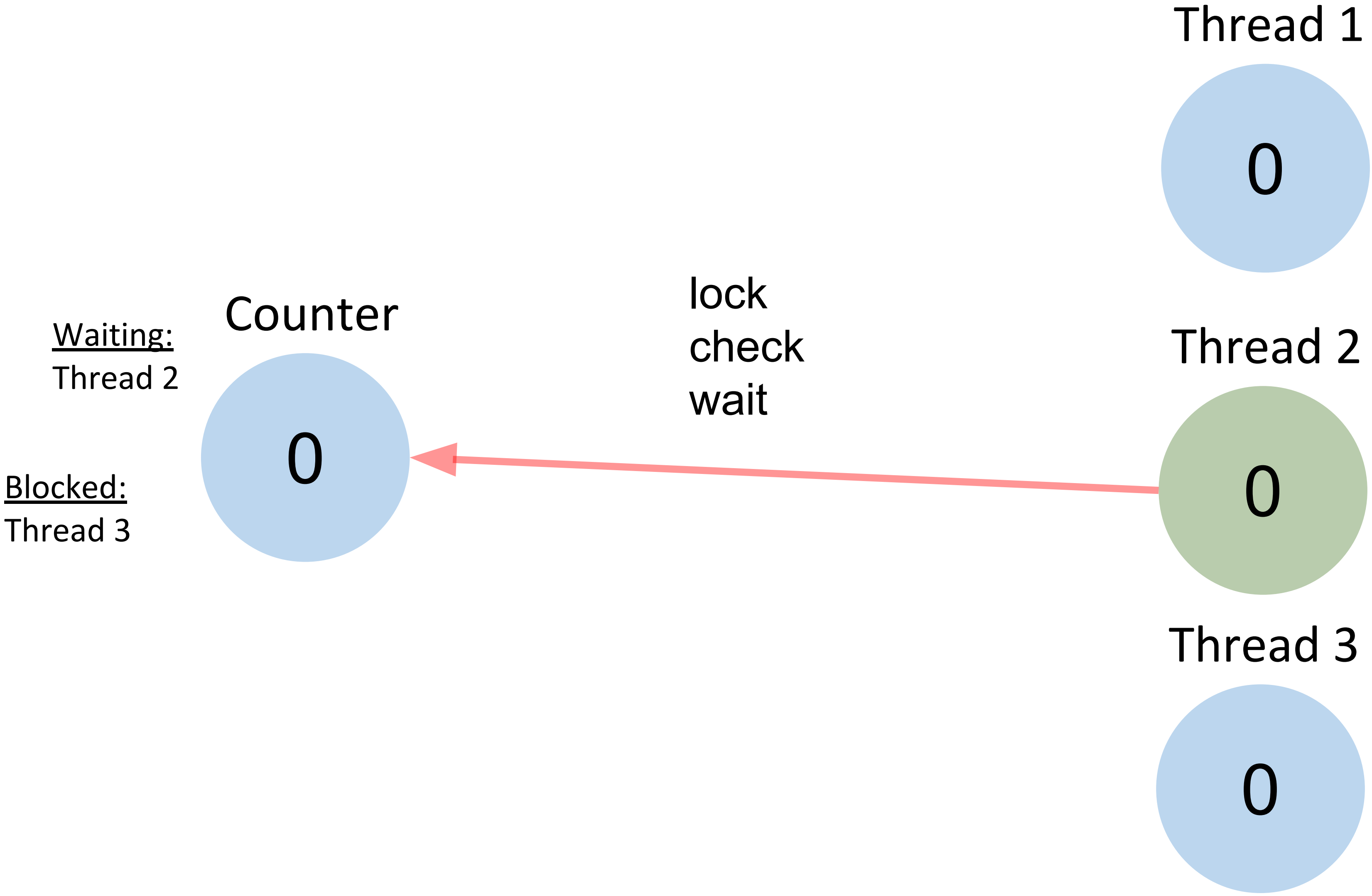
Blocked:

Thread 3

0

Thread 3

0



Waiting:
Thread 2

Blocked:
Thread 3

Counter

0

lock
check
wait

Thread 1

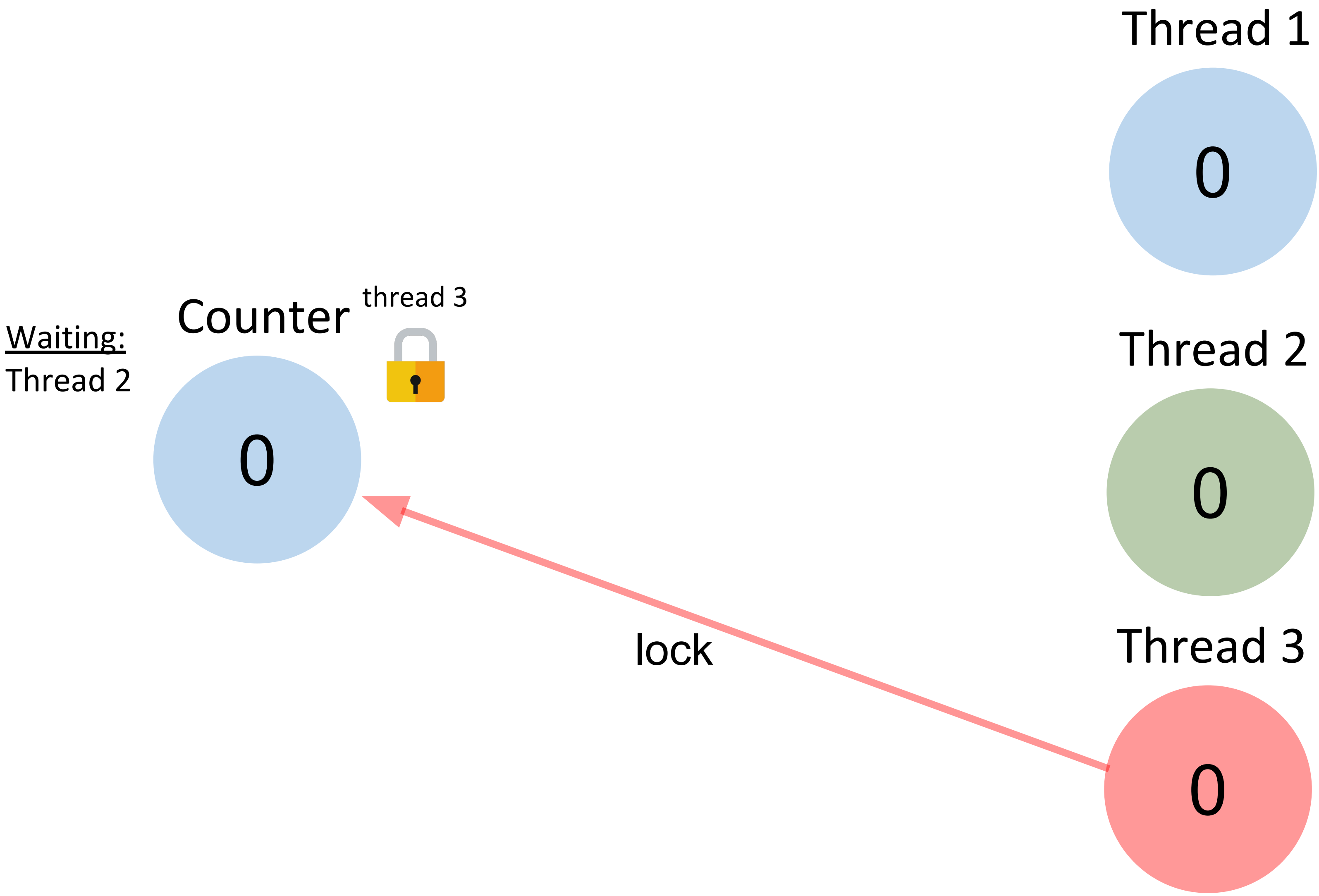
0

Thread 2

0

Thread 3

0



Thread 1

0

Waiting:

Thread 2

Counter

thread 3

0

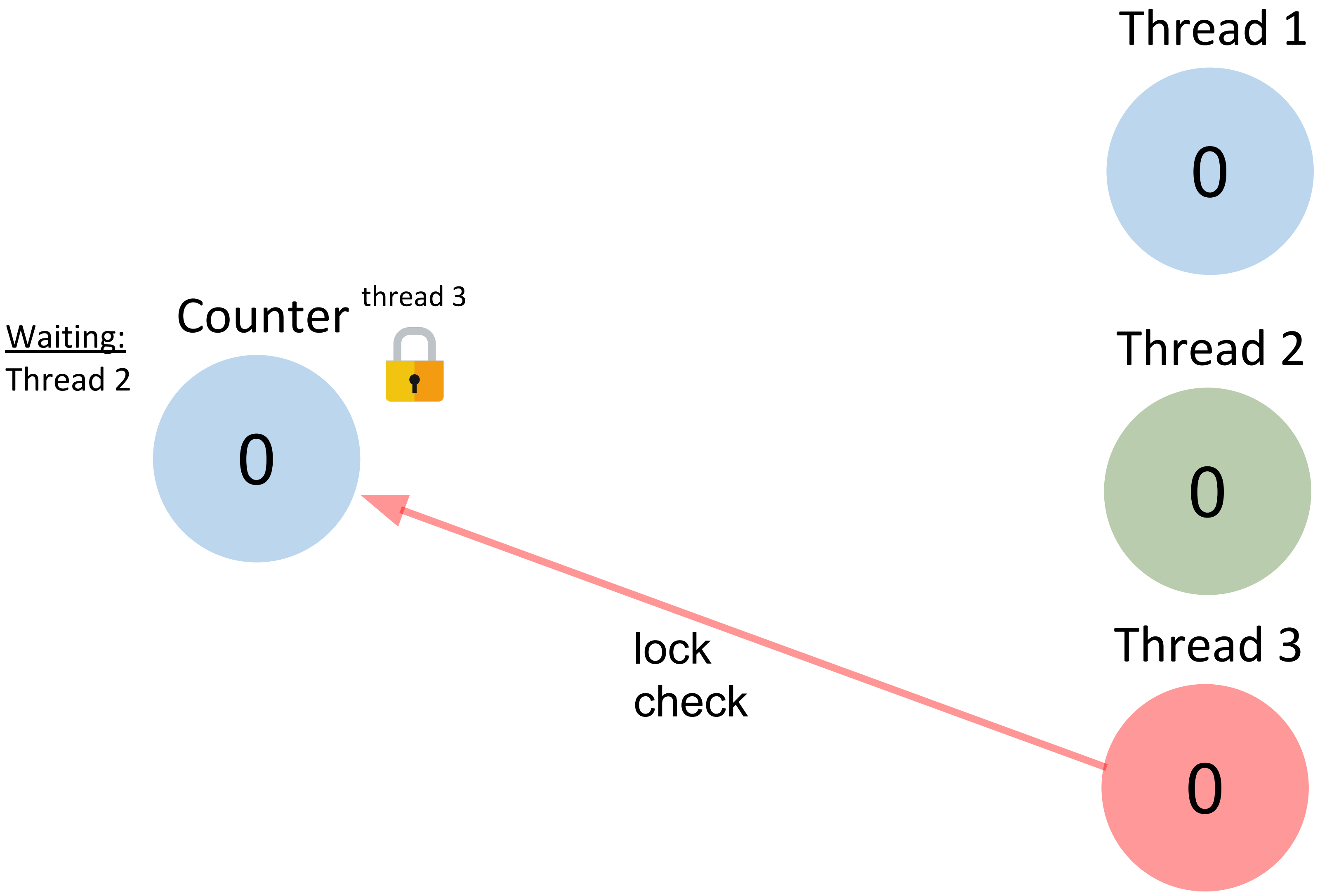
Thread 2

0

lock

Thread 3

0



Thread 1

0

Waiting:

Thread 2

Counter

thread 3

0

Thread 2

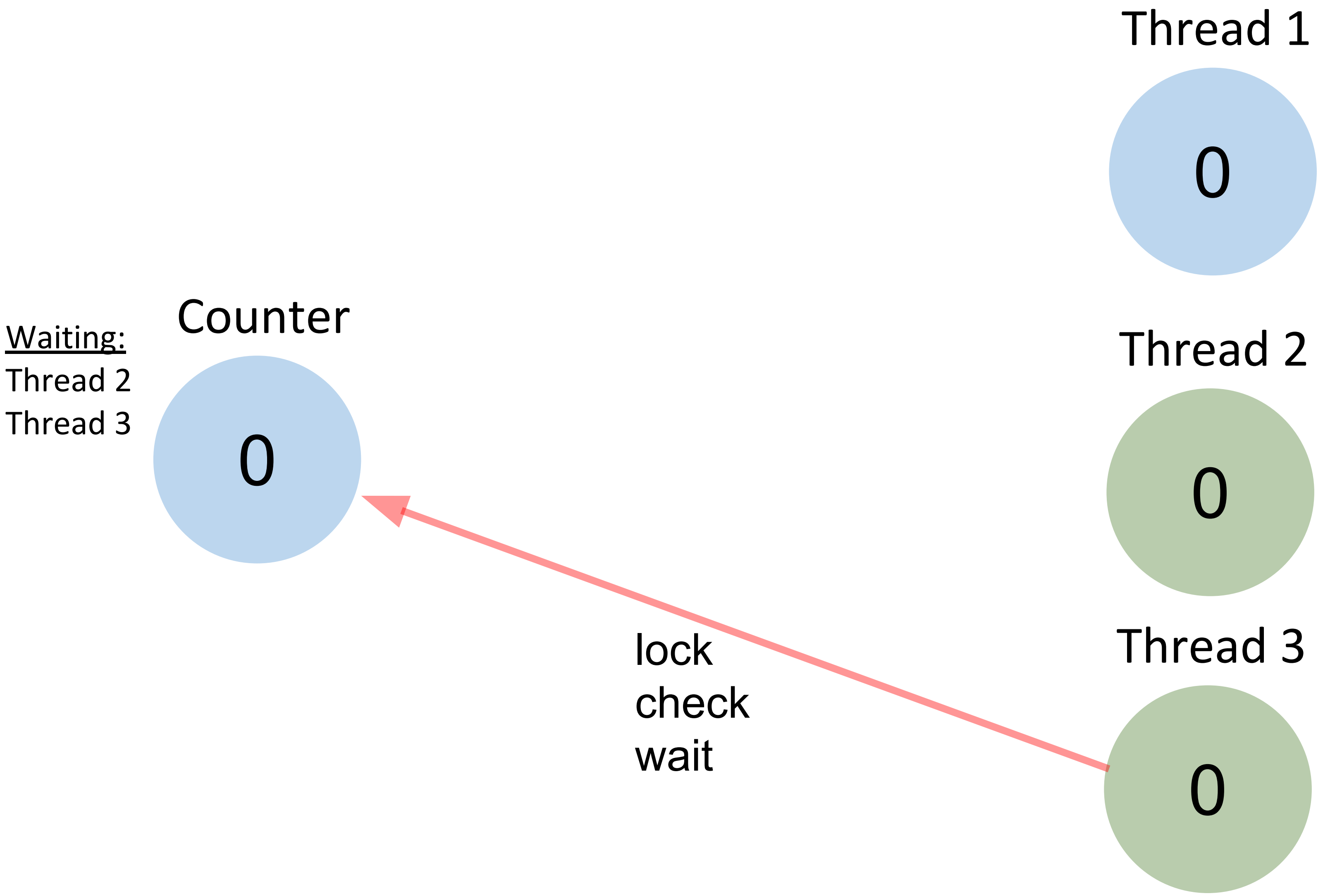
0

lock

check

Thread 3

0



Thread 1

0

Waiting:

Thread 2

Thread 3

Counter

0

Thread 2

0

lock

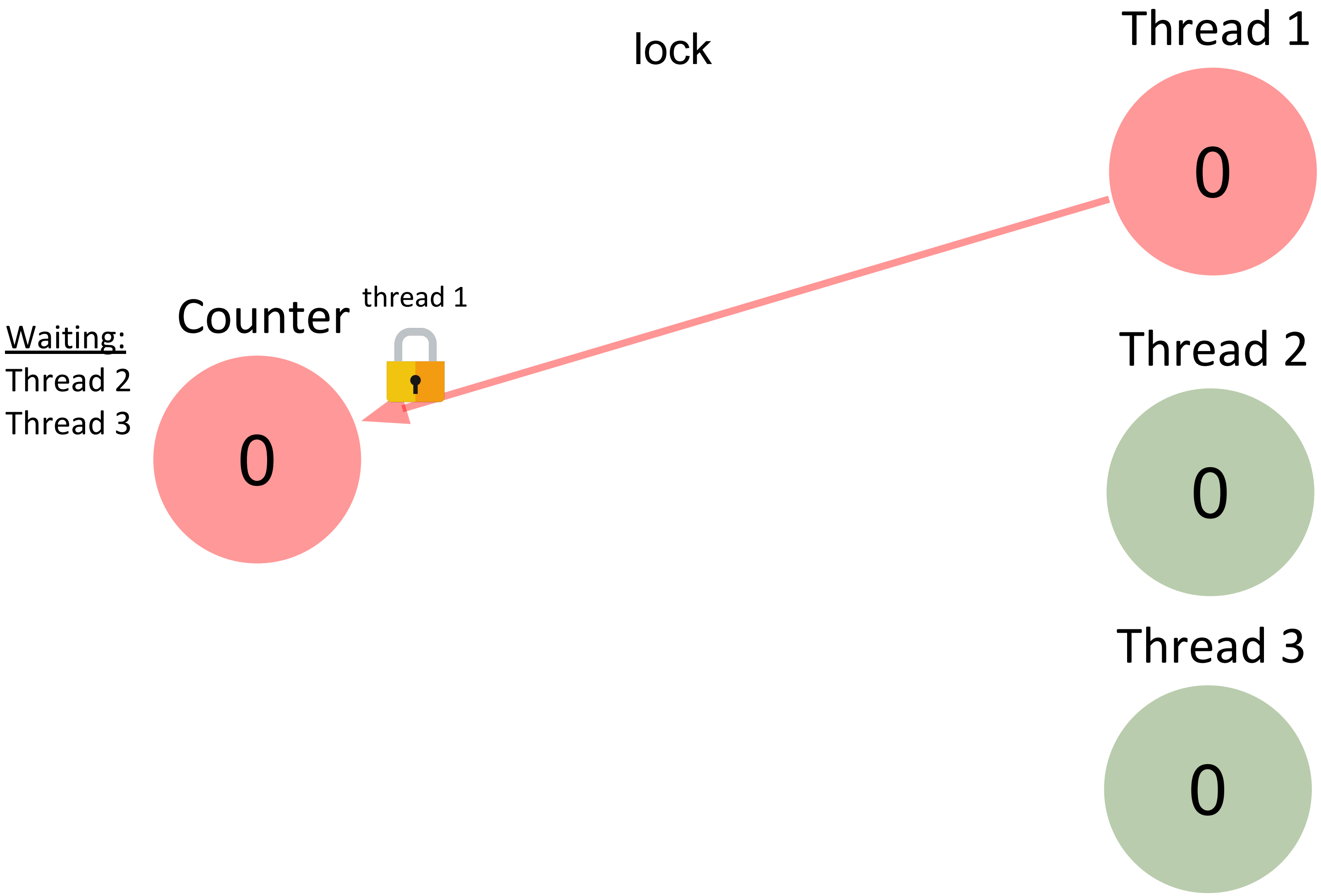
check

wait

Thread 3

0

lock



Thread 1

0

Thread 2

0

Thread 3

0

Counter

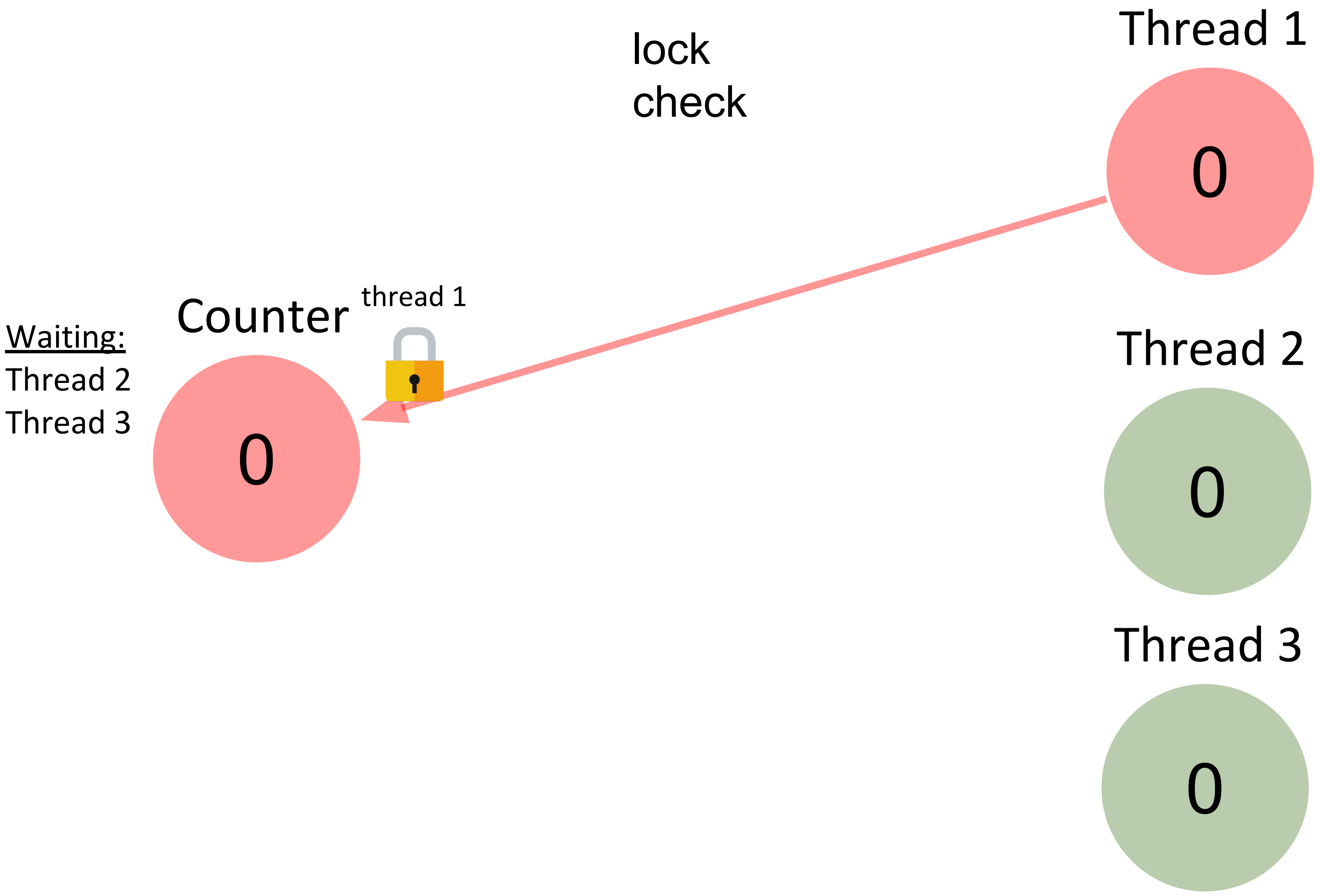
0

thread 1

Waiting:

Thread 2

Thread 3



lock
check

Thread 1

0

Counter

thread 1

Waiting:
Thread 2
Thread 3

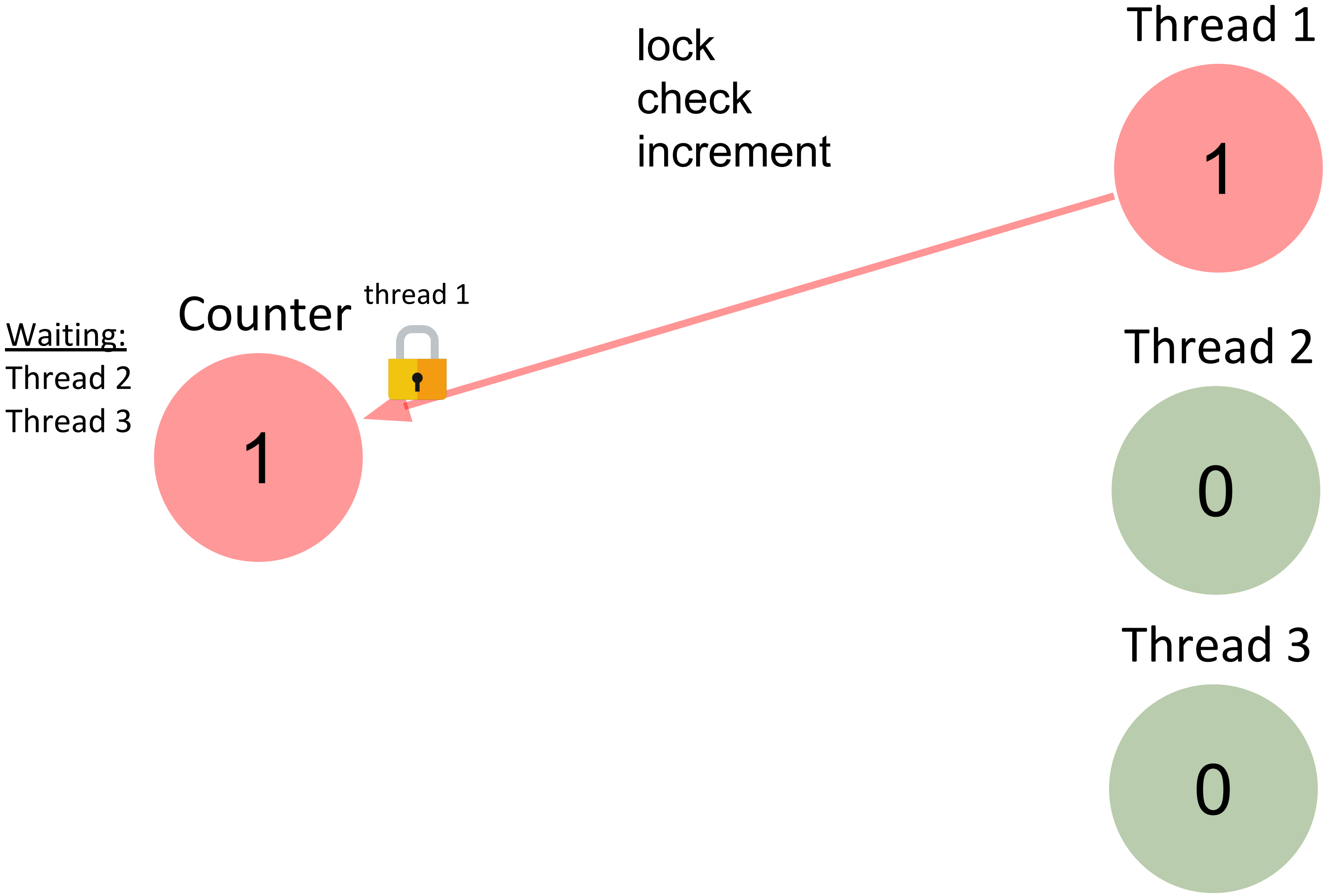
0

Thread 2

0

Thread 3

0



lock
check
increment

Thread 1

1

Counter

thread 1

<u>Waiting:</u>
Thread 2
Thread 3

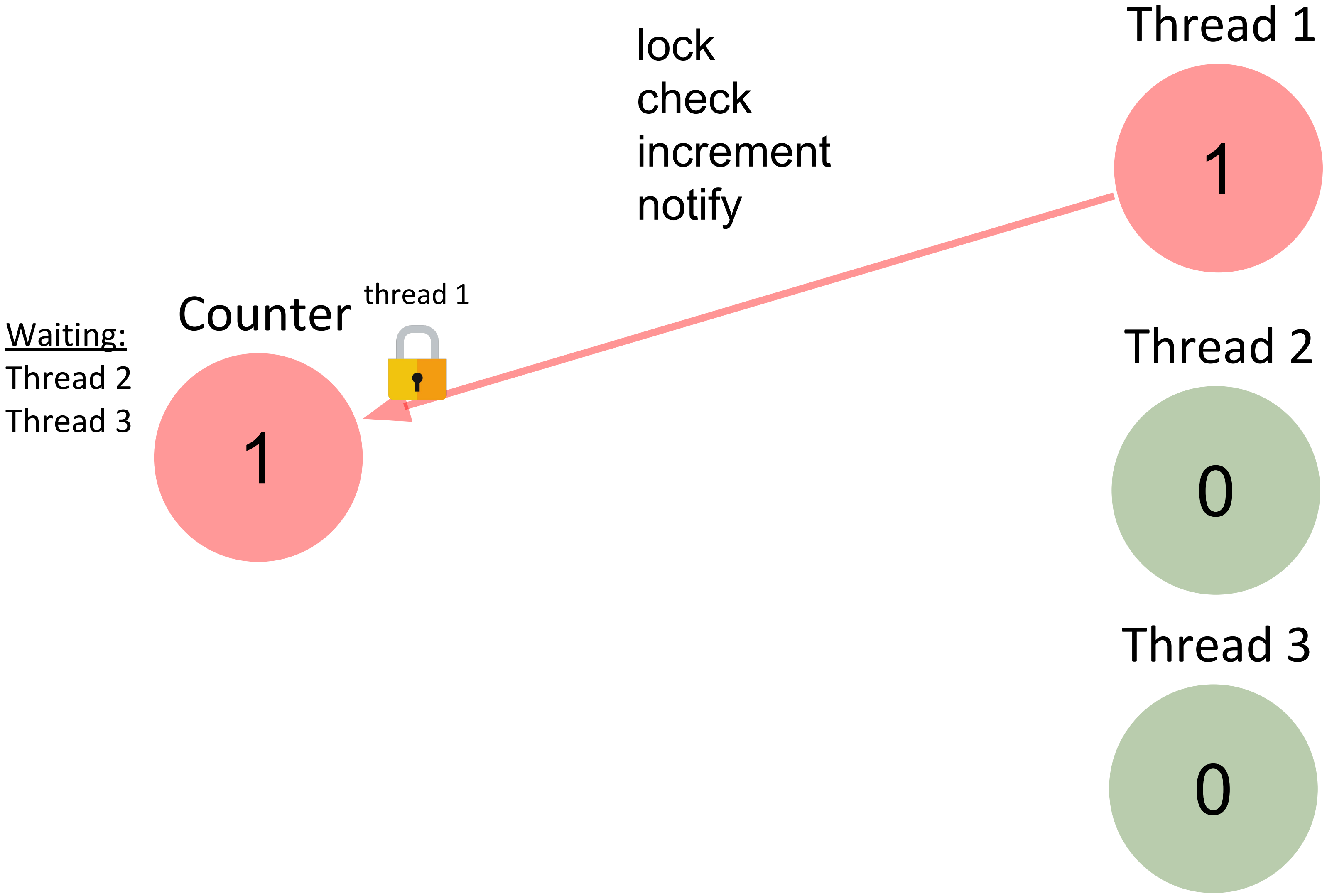
1

Thread 2

0

Thread 3

0



lock
check
increment
notify

Thread 1

1

Counter

thread 1

1

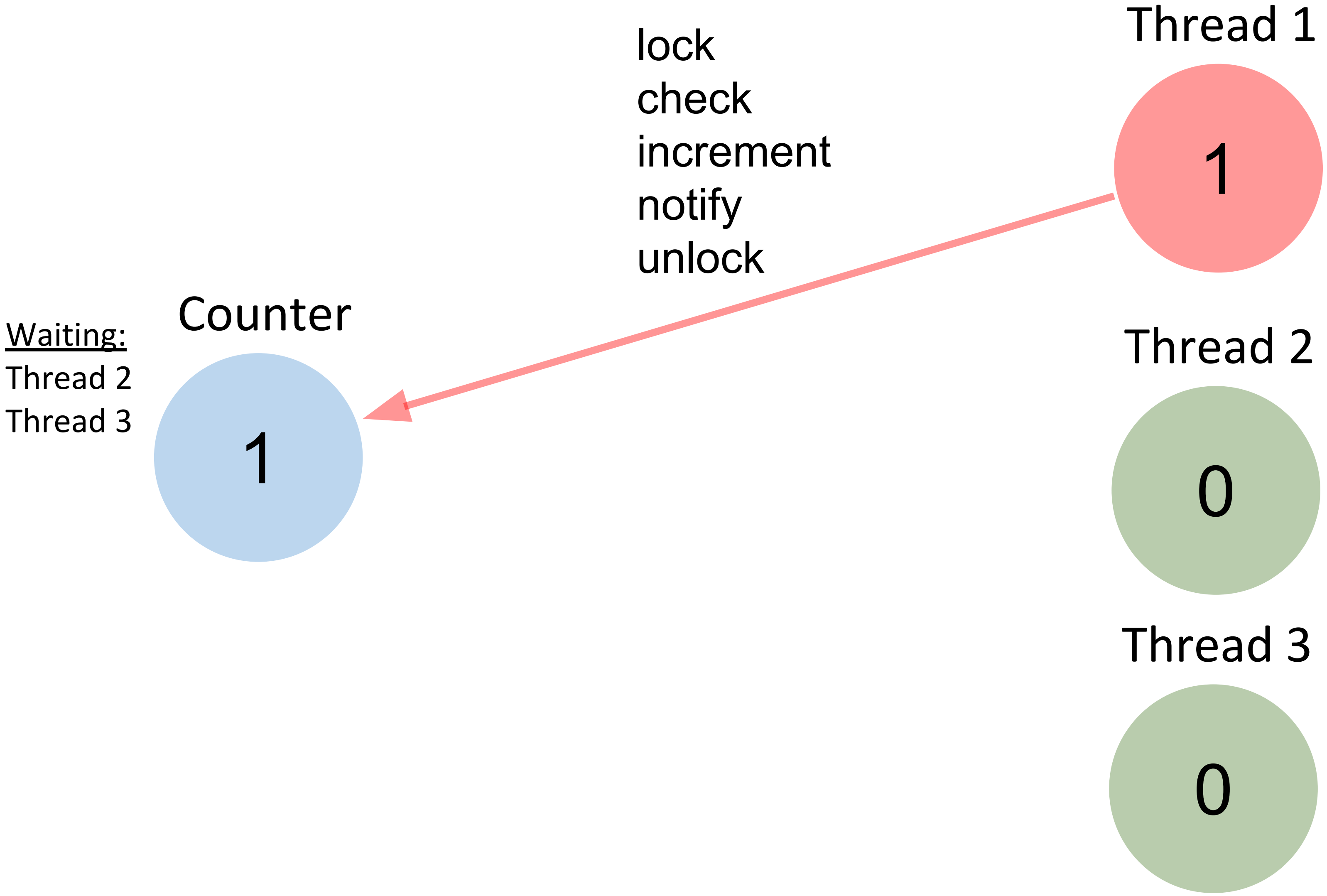
Waiting:
Thread 2
Thread 3

Thread 2

0

Thread 3

0



lock
check
increment
notify
unlock

Thread 1

1

Waiting:
Thread 2
Thread 3

Counter

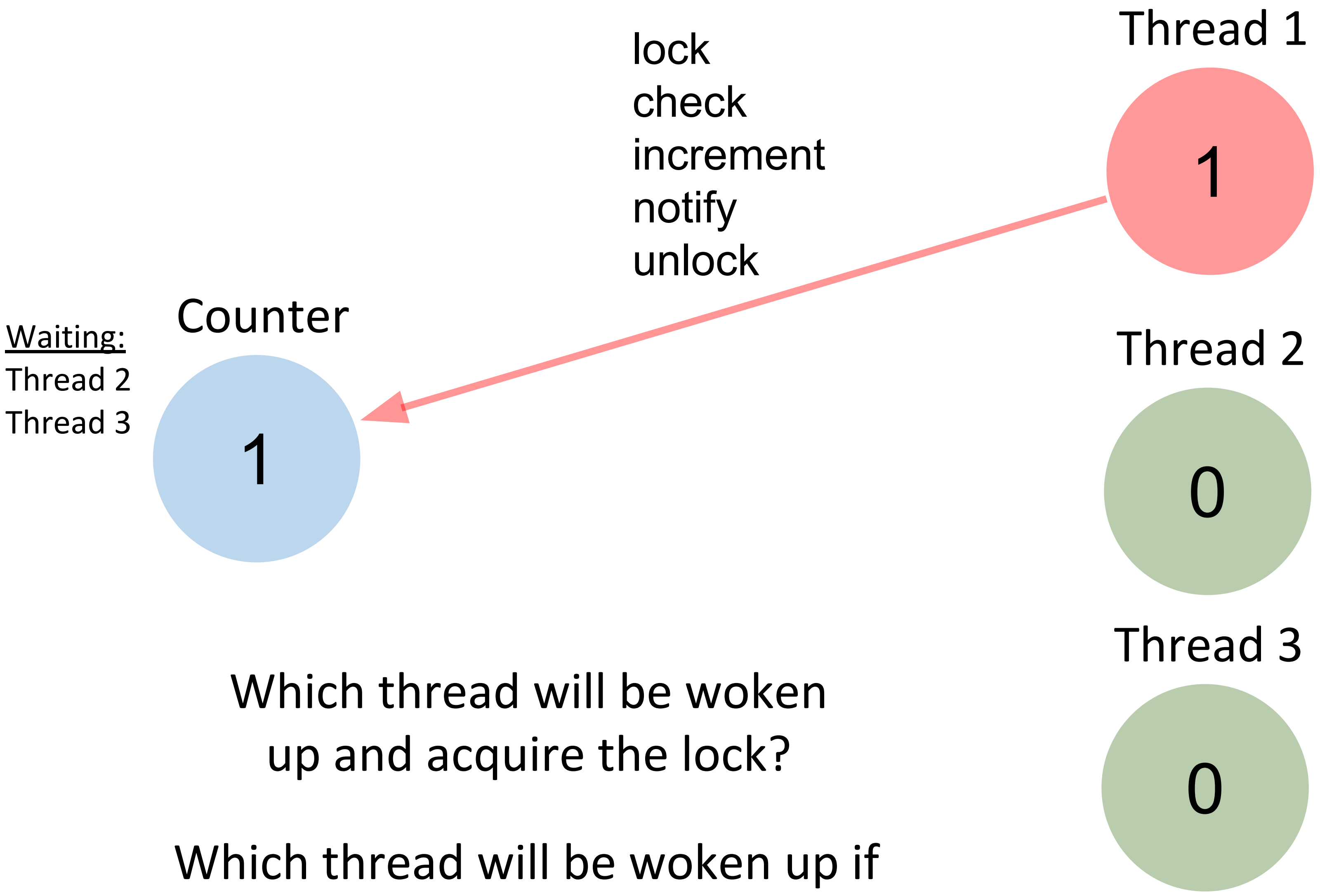
1

Thread 2

0

Thread 3

0



lock
check
increment
notify
unlock

Thread 1

1

Counter

Waiting:
Thread 2
Thread 3

1

Thread 2

0

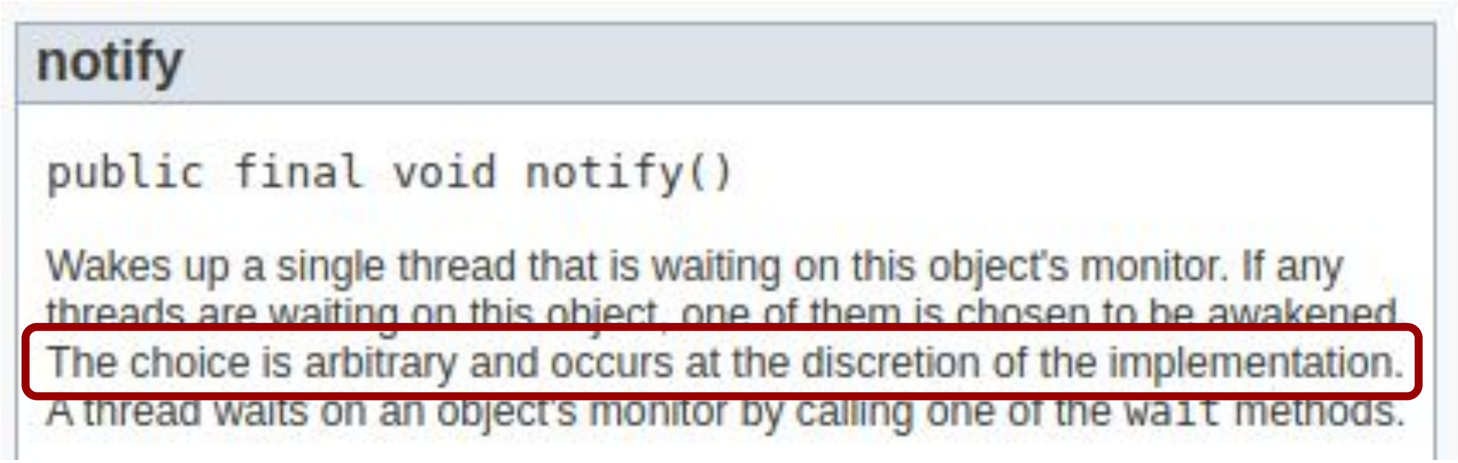
Thread 3

0

Which thread will be woken up and acquire the lock?

Which thread will be woken up if we use notifyAll instead of notify?

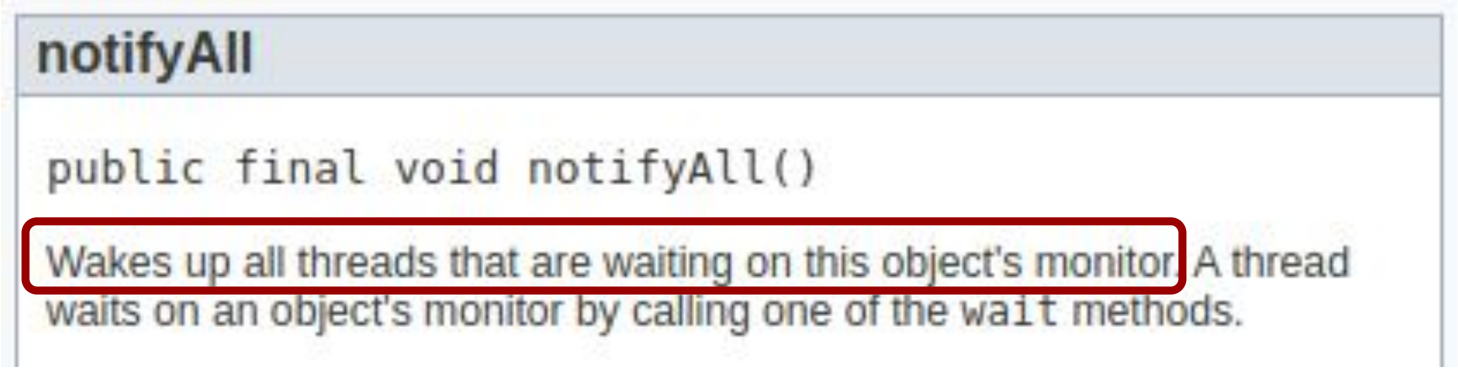
How to find the difference between notify vs notifyAll?



notify

```
public final void notify()
```

Wakes up a single thread that is waiting on this object's monitor. If any threads are waiting on this object, one of them is chosen to be awakened. The choice is arbitrary and occurs at the discretion of the implementation. A thread waits on an object's monitor by calling one of the `wait` methods.



notifyAll

```
public final void notifyAll()
```

Wakes up all threads that are waiting on this object's monitor. A thread waits on an object's monitor by calling one of the `wait` methods.

https://docs.oracle.com/javase/7/docs/api/java/lang/Object.html

Task E: AtomicCounter (Optional)

```java
public class AtomicCounter implements Counter {


    public void increment() {
        ??
    }

    public int value() {
        ??
    }
}
```

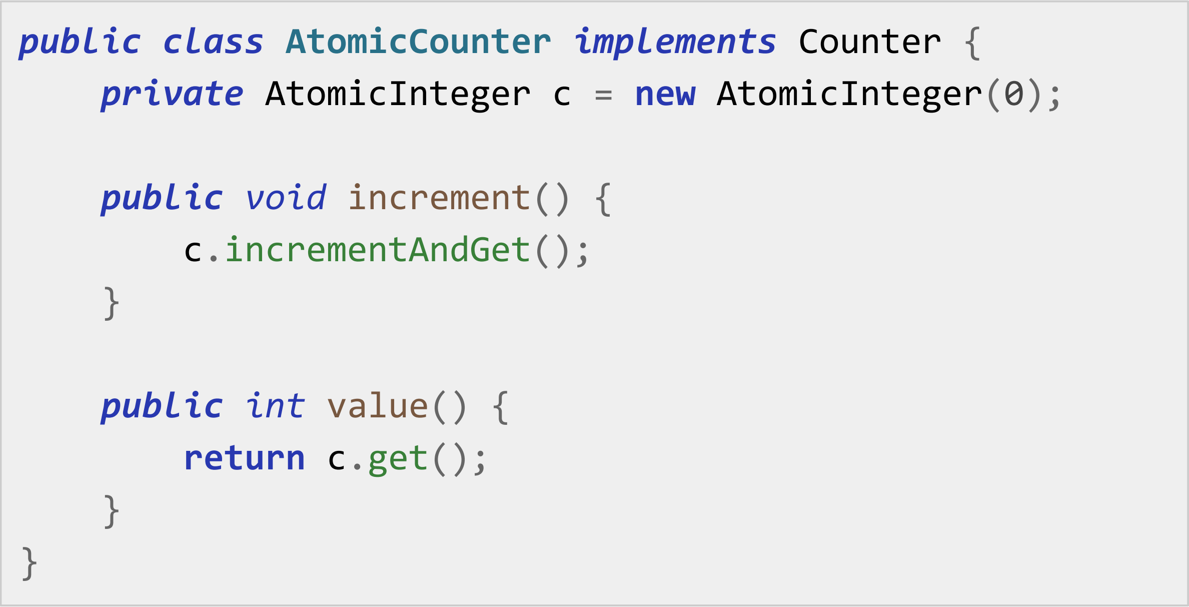
Task E: AtomicCounter (Optional)

```
public class AtomicCounter implements Counter {
    private AtomicInteger c = new AtomicInteger(0);

    public void increment() {
        c.incrementAndGet();
    }

    public int value() {
        return c.get();
    }
}
```

Task E: AtomicCounter (Optional)



```java
public class AtomicCounter implements Counter {
    private AtomicInteger c = new AtomicInteger(0);

    public void increment() {
        c.incrementAndGet();
    }

    public int value() {
        return c.get();
    }
}
```

What is the difference?

`int`	`AtomicInteger`
`c++;`	`c.incrementAndGet();`

Task E: AtomicCounter (Optional)

```java
public class AtomicCounter implements Counter {
    private AtomicInteger c = new AtomicInteger(0);

    public void increment() {
        c.incrementAndGet();
    }

    public int value() {
        return c.get();
    }
}
```

An operation is atomic if no other thread can see it partly executed. Atomic as in “appears indivisible”. However does not mean it’s implemented as single instruction.

What is the difference?

`int`

1. load c → 0
2. c + 1 → 1
3. store c ← 1

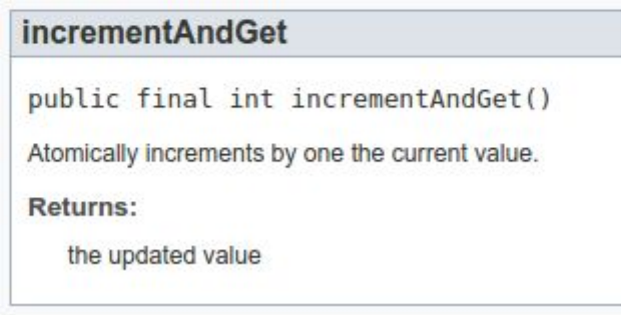
← `c++;`

not atomic

`AtomicInteger`

`c.incrementAndGet();` →

atomic



incrementAndGet

`public final int incrementAndGet()`

Atomically increments by one the current value.

Returns:

the updated value

Exercise 4: Pipelining Recap

Pipelining: Main Concepts Recap

Latency

Throughput

Balanced/Unbalanced Pipeline

Pipelining: Main Concepts Recap

Latency

time needed to perform a given computation
(e.g., process a customer)

Throughput

Balanced/Unbalanced Pipeline

Pipelining: Main Concepts Recap

Latency

time needed to perform a given computation
(e.g., process a customer)

Throughput

amount of work that can be done by a system in a given period of time
(e.g., how many customers can be processed in one minute)

Balanced/Unbalanced Pipeline

Pipelining: Main Concepts Recap

Latency

time needed to perform a given computation
(e.g., process a customer)

Throughput

amount of work that can be done by a system in a given period of time
(e.g., how many customers can be processed in one minute)

Balanced/Unbalanced Pipeline

a pipeline is balanced if it has constant latency

Library

Over at UZH the law students have been tasked with writing a legal essay about the philosophy of Swiss law. In order to write the essay, each student needs to read four different books on the subject, denoted as A, B, C and D (in this order).

This exercise is created by Lasse Meinen and part of the unofficial VIS Prüfungsvorbereitungsworkshop Skripts available at:

https://vis.ethz.ch/de/services/pvw-scripts/

Every student takes the exact same amount of time to read a book, concretely:

1) Reading book **A** takes 80 minutes

2) Reading book **B** takes 40 minutes

3) Reading book **C** takes 120 minutes

4) Reading book **D** takes 40 minutes

Library

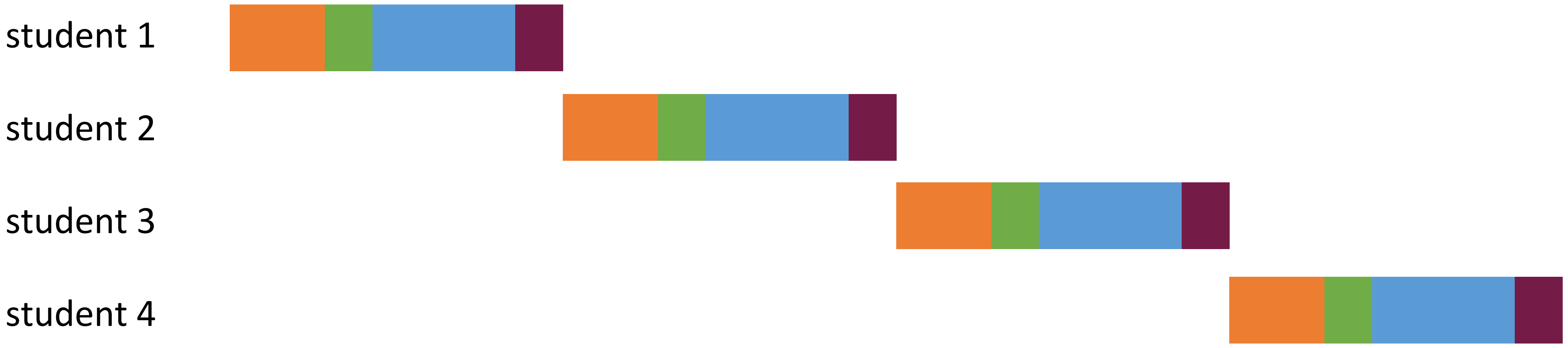
Over at UZH the law students have been tasked with writing a legal essay about the philosophy of Swiss law. In order to write the essay, each student needs to read four different books on the subject, denoted as A, B, C and D (in this order).

Question 1: Let's assume all law students are a bit too competitive and don't return any books before they're done reading all of them. How long will it take for 4 students until all of them have started writing their essays?

Every student takes the exact same amount of time to read a book, concretely:

1) Reading book **A** takes 80 minutes
2) Reading book **B** takes 40 minutes
3) Reading book **C** takes 120 minutes
4) Reading book **D** takes 40 minutes

Library



Question 1: Let’s assume all law students are a bit too competitive and don’t return any books before they’re done reading all of them. How long will it take for 4 students until all of them have started writing their essays?

Every student takes the exact same amount of time to read a book, concretely:

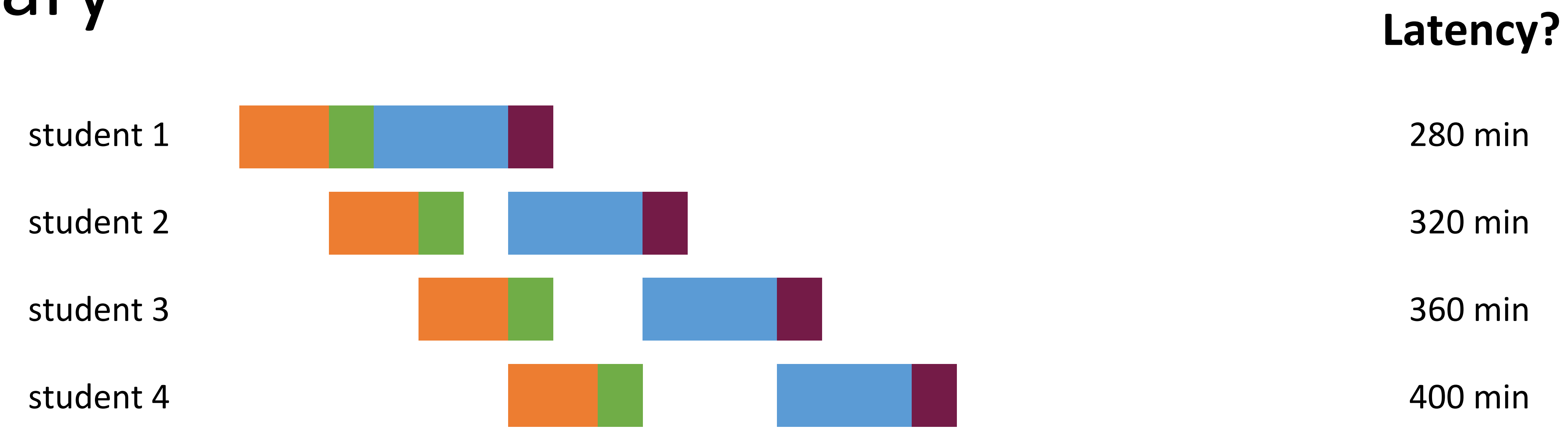
1) Reading book **A** takes 80 minutes

2) Reading book **B** takes 40 minutes

3) Reading book **C** takes 120 minutes

4) Reading book **D** takes 40 minutes

Library



Question 2: The library introduces a ”one book at a time” policy, i.e. the students have to return a book before they can start on the next one. How long will it now take for 4 students until all of them have started writing their essays?

Every student takes the exact same amount of time to read a book, concretely:

1) Reading book **A** takes 80 minutes

2) Reading book **B** takes 40 minutes

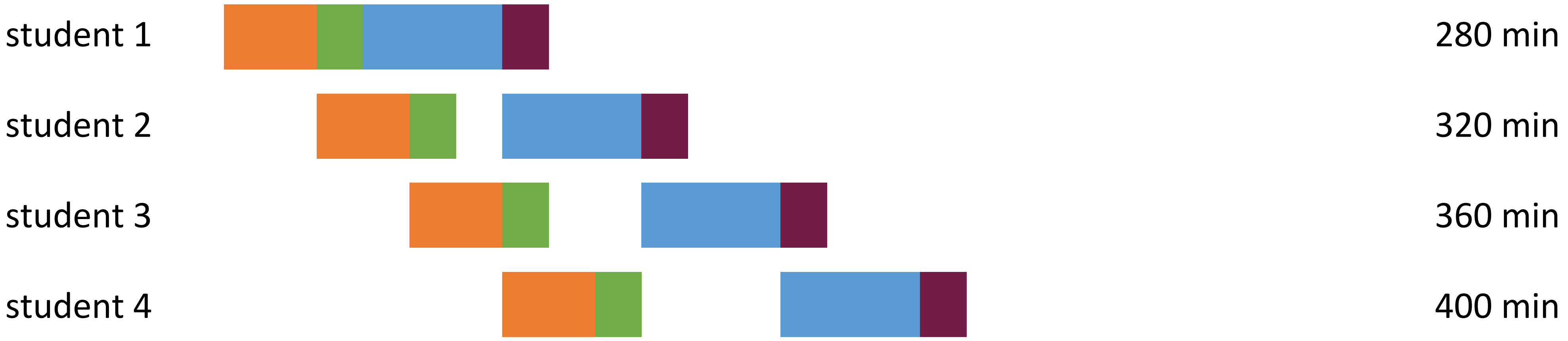
3) Reading book **C** takes 120 minutes

4) Reading book **D** takes 40 minutes

Library

For this pipeline, latency makes sense only if asked for a particular student, not for the whole pipeline.

Latency?



Question 2: The library introduces a ”one book at a time” policy, i.e. the students have to return a book before they can start on the next one. How long will it now take for 4 students until all of them have started writing their essays?

Every student takes the exact same amount of time to read a book, concretely:

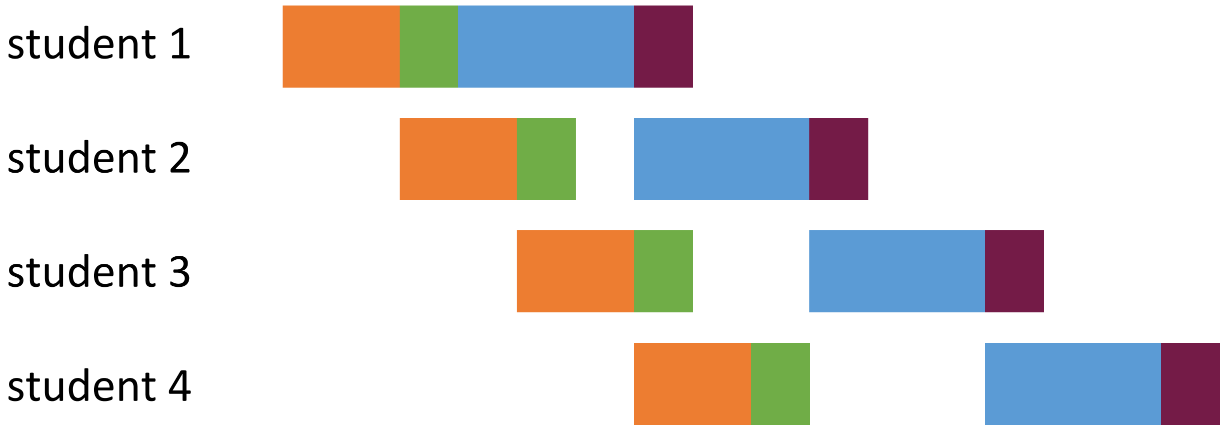
1) Reading book **A** takes 80 minutes

2) Reading book **B** takes 40 minutes

3) Reading book **C** takes 120 minutes

4) Reading book **D** takes 40 minutes

Library



Balanced?	Throughput?	Latency?
	1 student	280 min
	per 120 minutes	320 min
		360 min
		400 min

Question 2: The library introduces a ”one book at a time” policy, i.e. the students have to return a book before they can start on the next one. How long will it now take for 4 students until all of them have started writing their essays?

Every student takes the exact same amount of time to read a book, concretely:

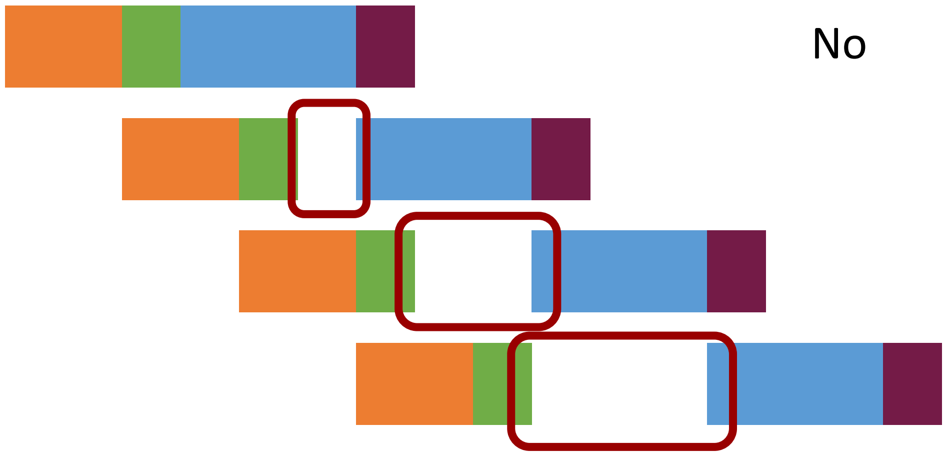
1) Reading book **A** takes 80 minutes

2) Reading book **B** takes 40 minutes

3) Reading book **C** takes 120 minutes

4) Reading book **D** takes 40 minutes

Library



	Balanced?	Throughput?	Latency?
student 1	No	1 student	280 min
student 2		per 120 minutes	320 min
student 3			360 min
student 4			400 min

The pipeline is not balanced
since the latency is not constant

Every student takes the exact same amount of time to read a book, concretely:

1) Reading book A takes 80 minutes

2) Reading book B takes 40 minutes

3) Reading book C takes 120 minutes

4) Reading book D takes 40 minutes

Exercise 4

Task 1 - Pipelining

Bob, Mary, John and Alice

50 min

90 min

15 min

a) Laundry time using sequential order

b) Design a strategy with better laundry time

c) How would the laundry time improve if they bought a new dryer?

Task 2 - Pipelining II

Assume a processor that can each cycle issue either:

- one multiplication instruction with latency 6 cycles
- one addition instruction with latency 3 cycles

How many cycles are required to execute following loops?

```
for (int i = 0; i < data.length; i++) {
    data[i] = data[i] * data[i];
}
```

```
for (int i = 0; i < data.length; i += 2) {
    j = i + 1;
    data[i] = data[i] * data[i];
    data[j] = data[j] * data[j];
}
```

```
for (int i = 0; i < data.length; i += 4) {
    j = i + 1;
    k = i + 2;
    l = i + 3;
    data[i] = data[i] * data[i];
    data[j] = data[j] * data[j];
    data[k] = data[k] * data[k];
    data[l] = data[l] * data[l];
}
```

Task 3 - Identify Potential Parallelization

Can we parallelize following two loops using parallel for construct?

```
for (int i=1; i<size; i++) {    // for loop: i from 1 to (size-1)
    if (data[i-1] > 0)          // If the previous value is positive
        data[i] = (-1)*data[i]; // change the sign of this value
}                               // end for loop
```

```
for (int i=0; i<size; i++) {      // for loop: i from 0 to (size-1)
    data[i] = Math.sin(data[i]);  // calculate sin() of the value
}                                 // end for loop
```