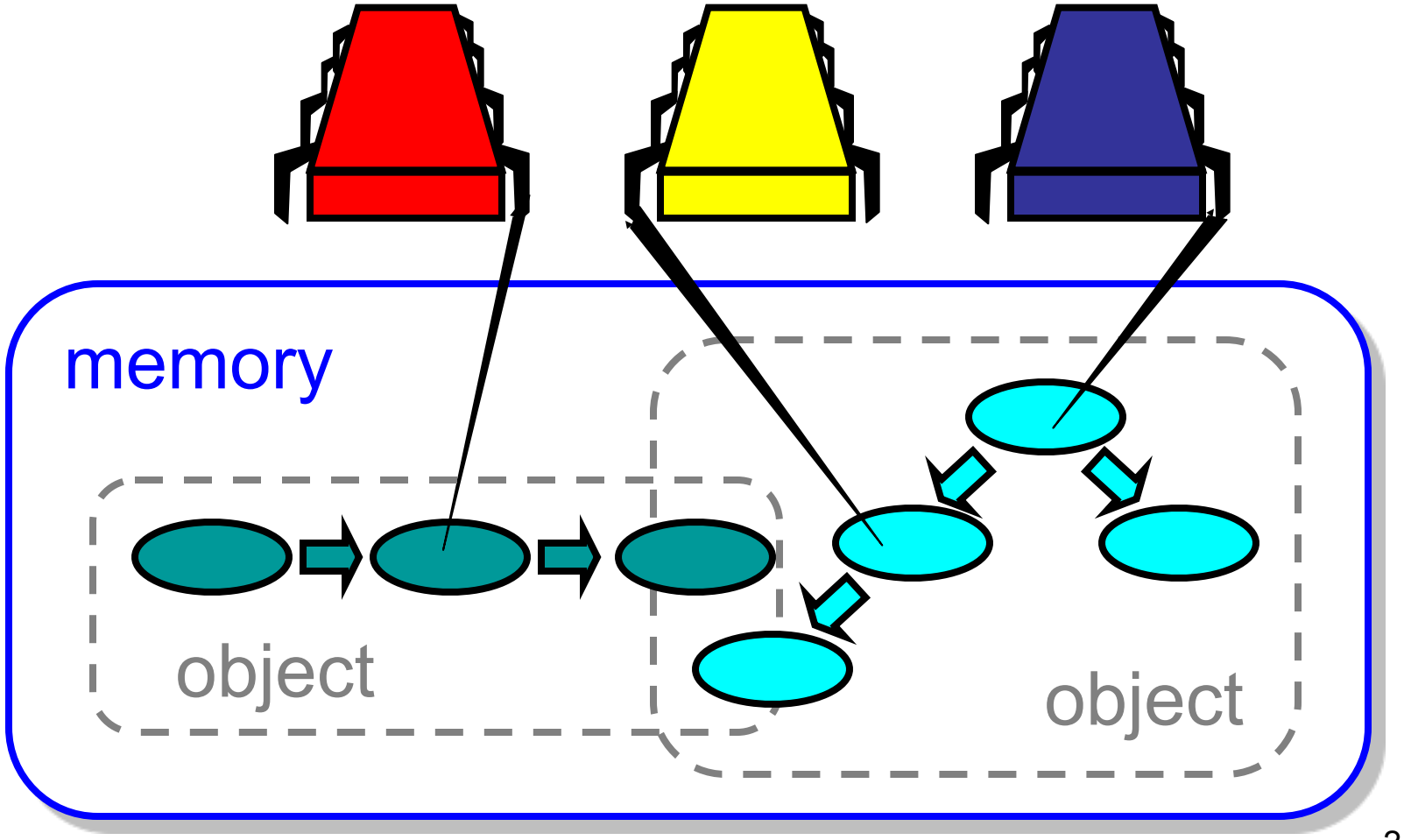
YSC3242: Parallel, Concurrent and Distributed Programming

Concurrent Objects
Part 1

Concurrent Computation



Objectivism

- What is a concurrent object?
  - How do we **describe** one?
  - How do we **implement** one?
  - How do we **tell if we're right**?

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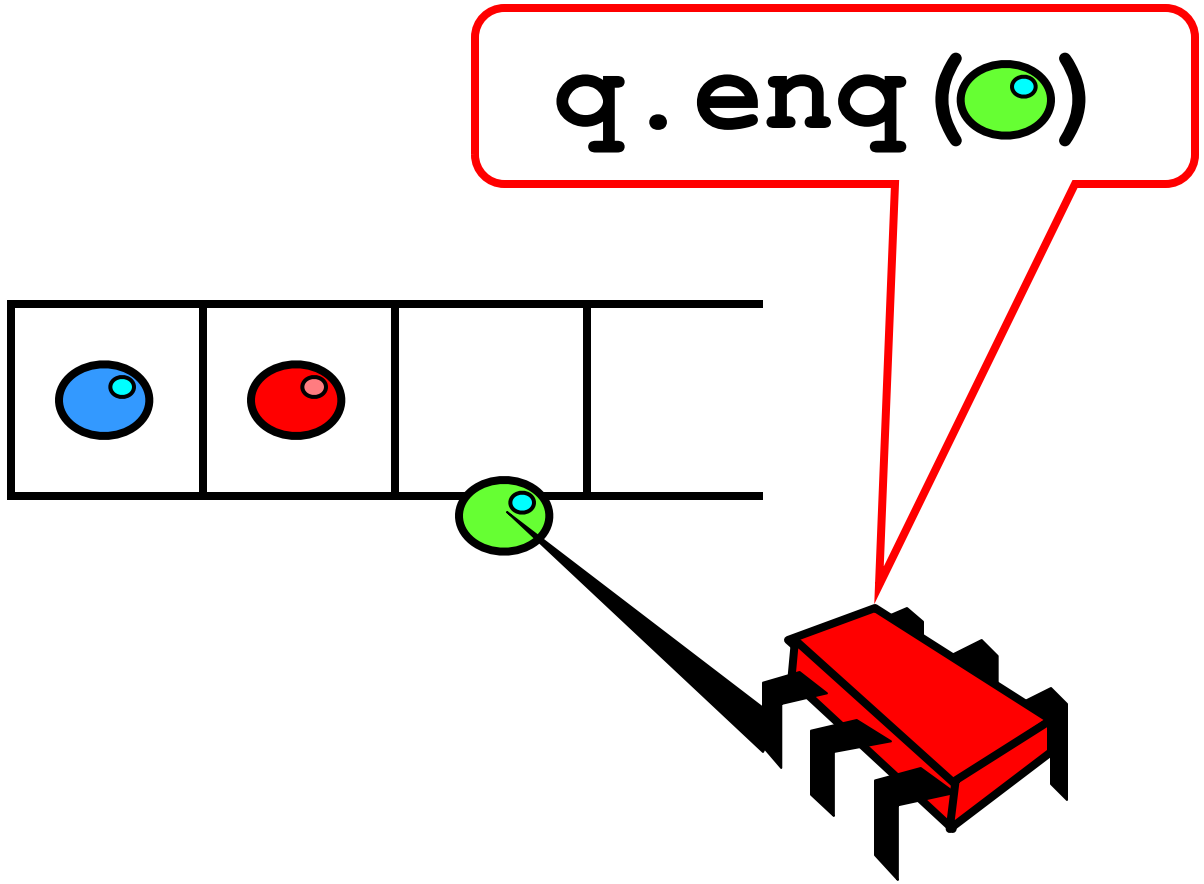
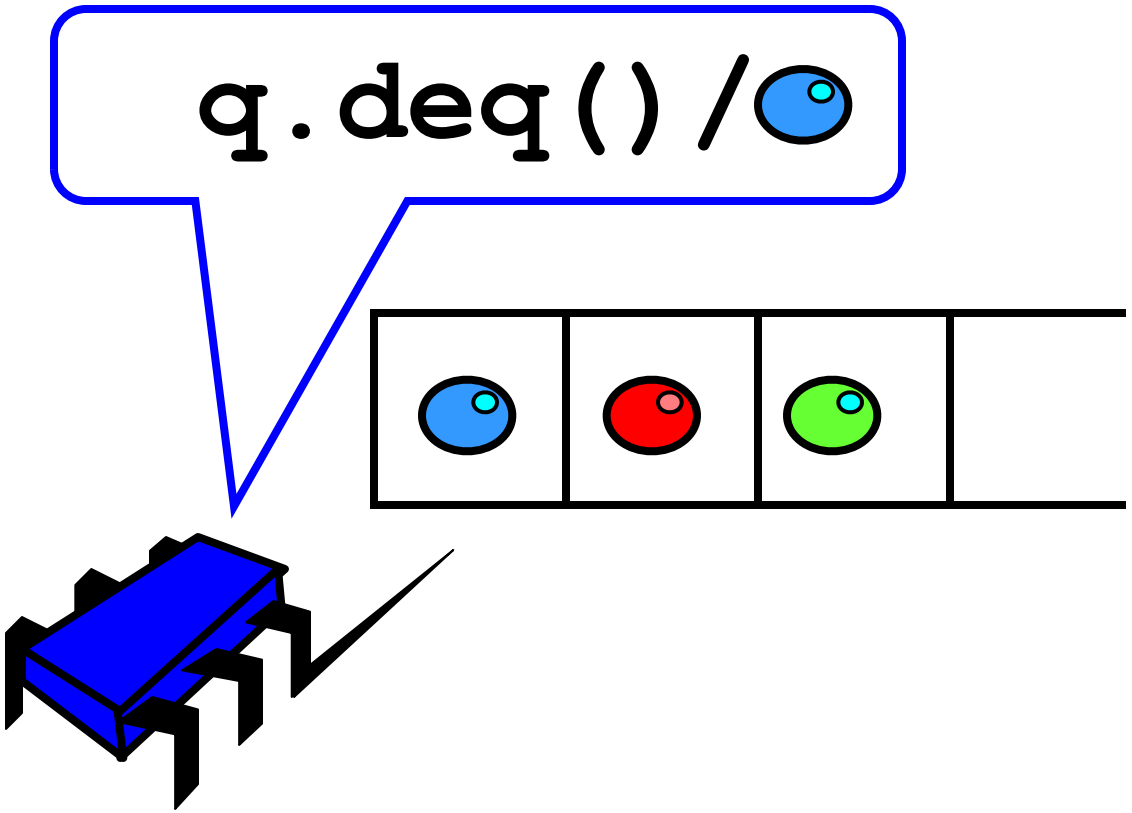
  - How do we **tell if we're right**?

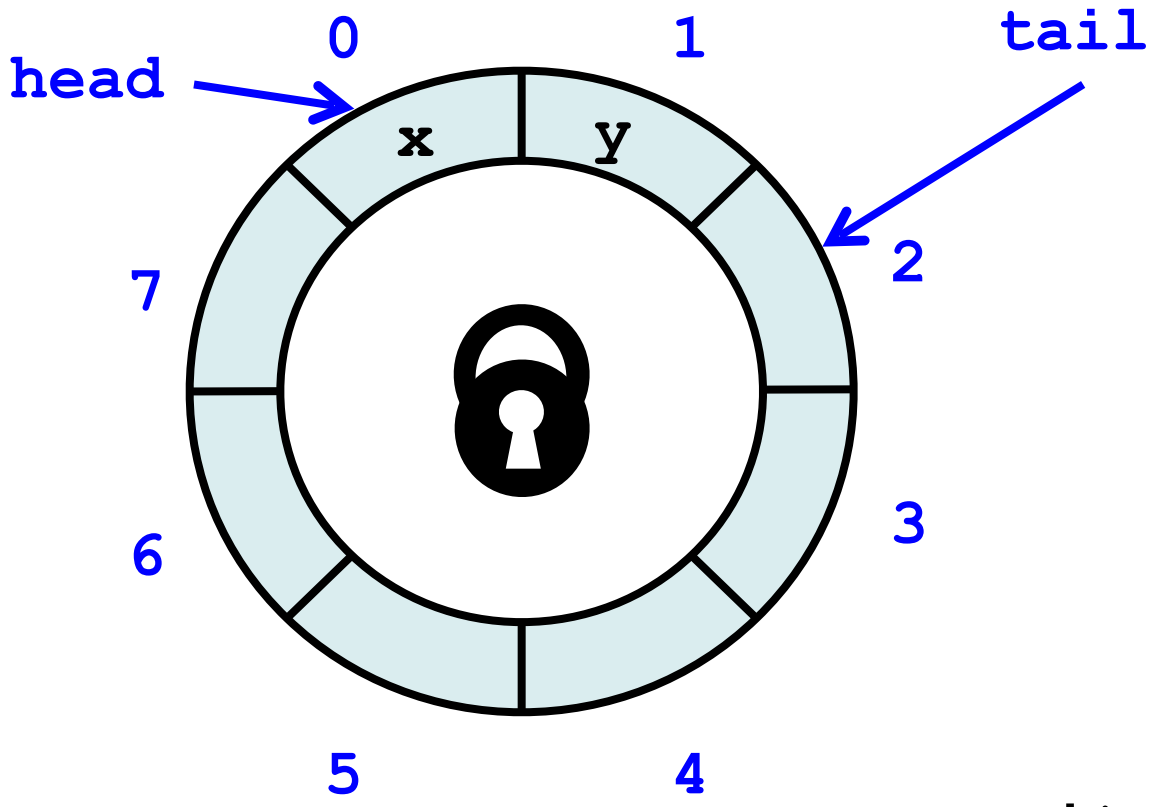
FIFO Queue: Enqueue Method



FIFO Queue: Dequeue Method

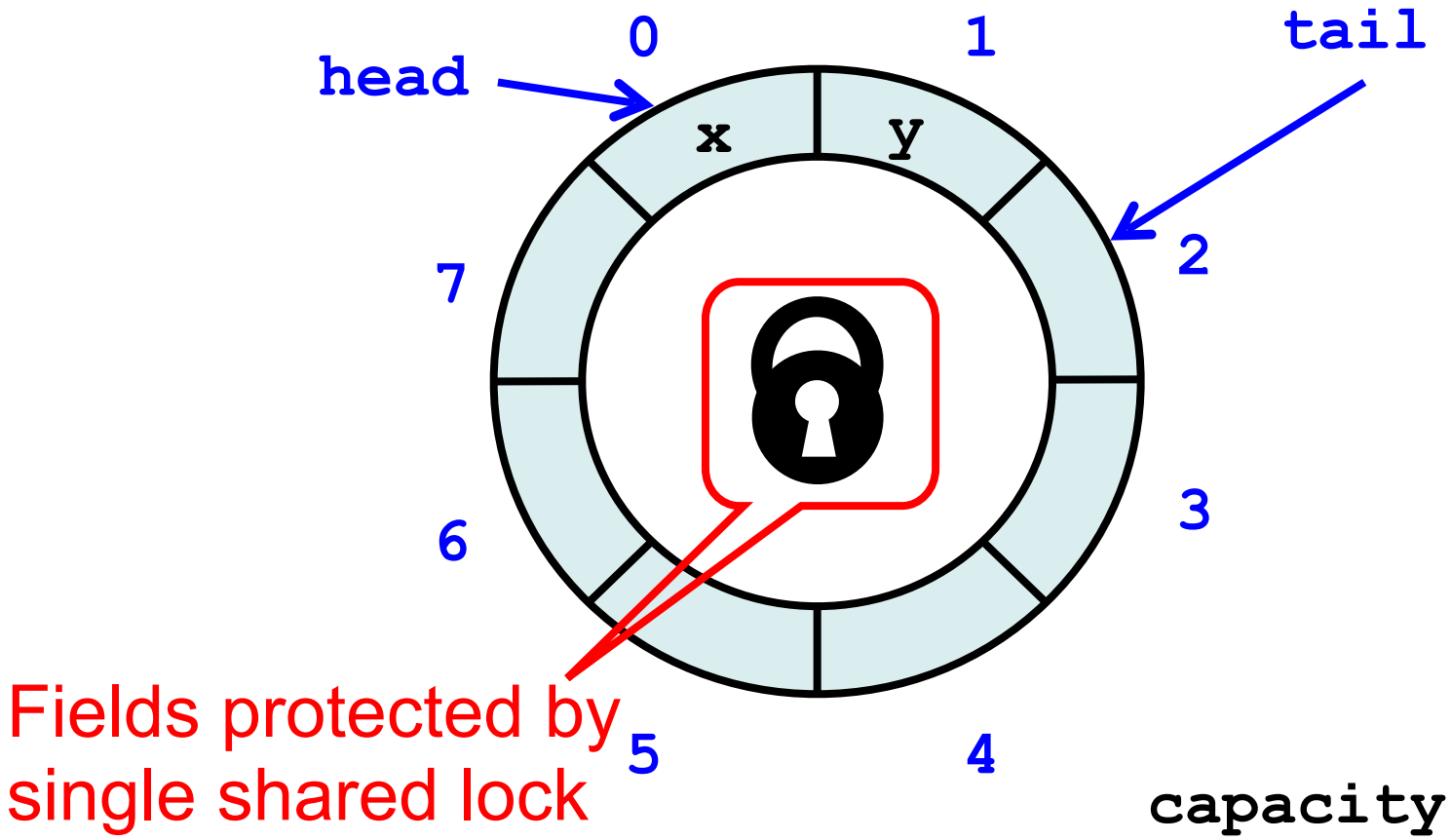


Lock-Based Queue



capacity = 8

Lock-Based Queue

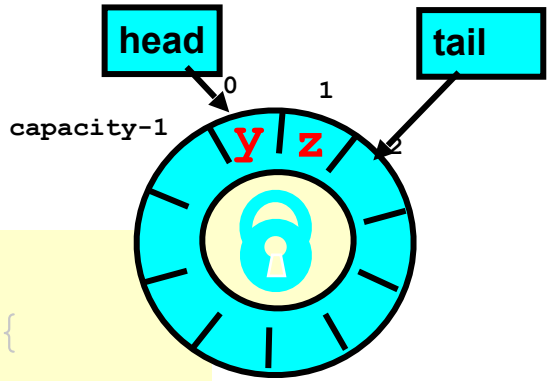


A Lock-Based Queue

```
class LockBasedQueue[T: ClassTag]
  (val capacity: Int) extends MyQueue[T] {

  private var head, tail: Int = 0
  private val items = new Array[T](capacity)
  private val myLock = new ReentrantLock()
```

A Lock-Based Queue

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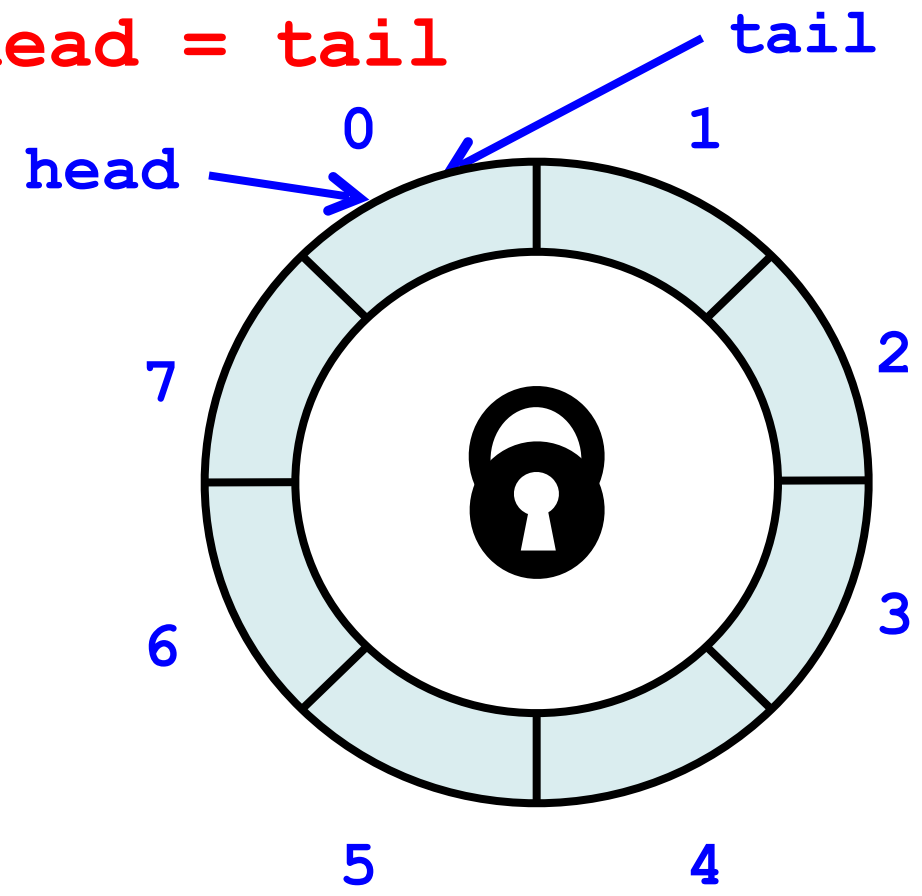
```

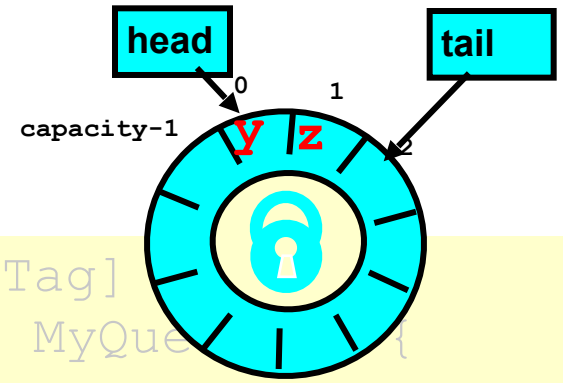
Fields protected by single shared lock

Lock-Based Queue

Initially: **`head = tail`**



Lock-Based Queue

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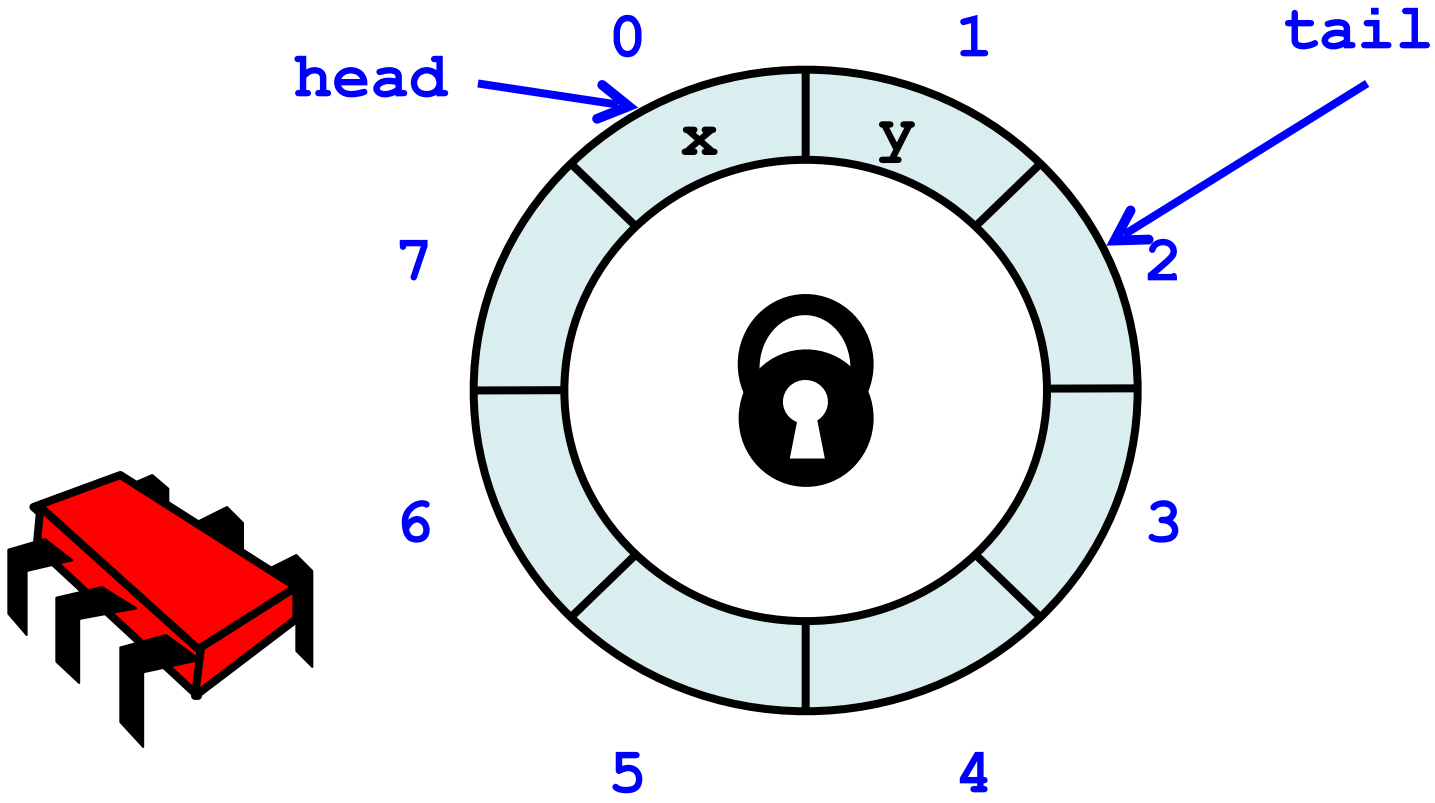
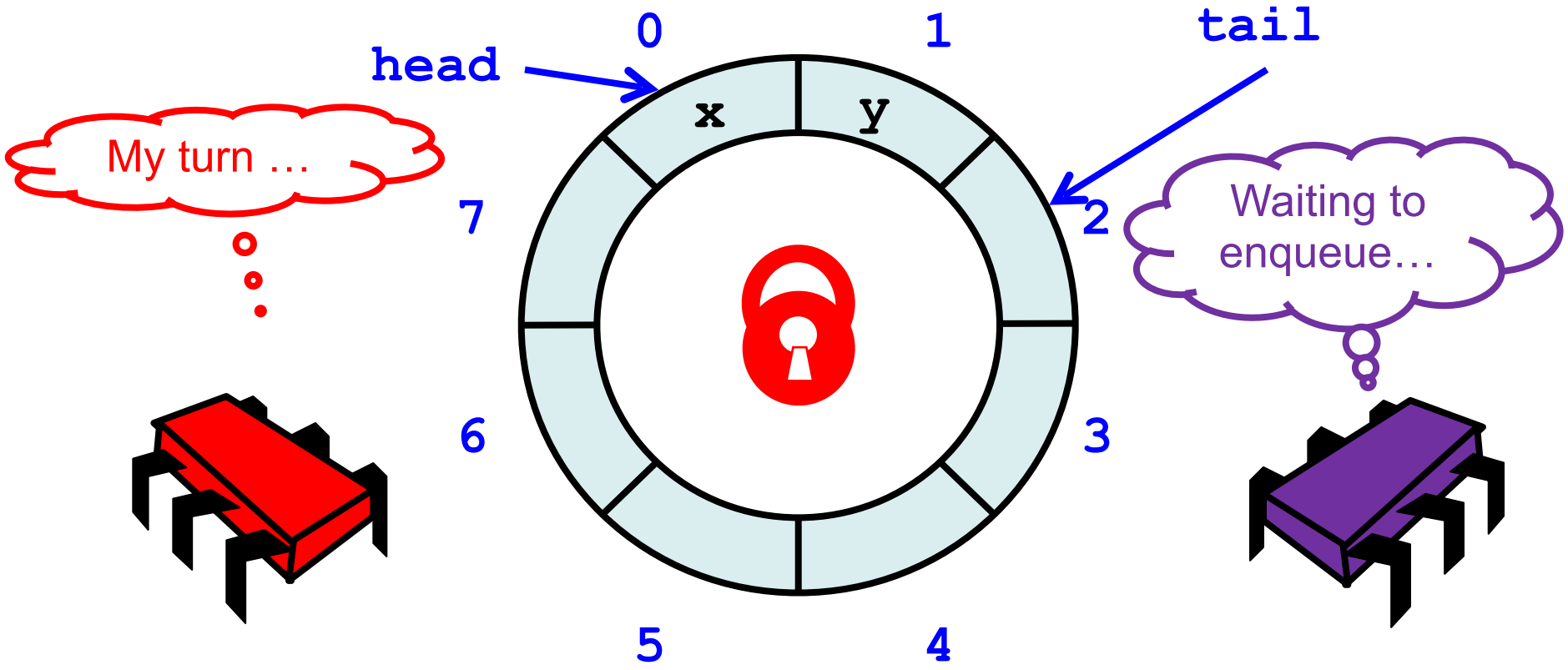
Lock-Based `deq()`



Acquire Lock



Implementation: `deq()`

```
def deq() : T = {
  myLock.lock()
  try {
    if (tail == head) {
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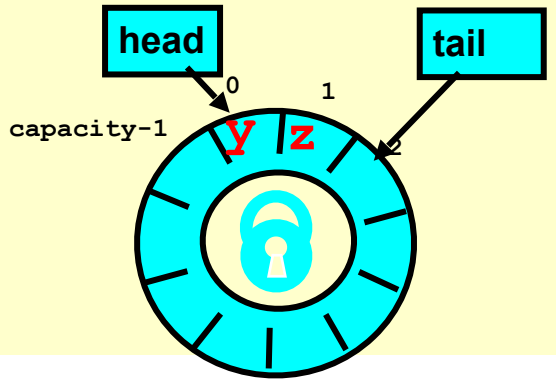
```



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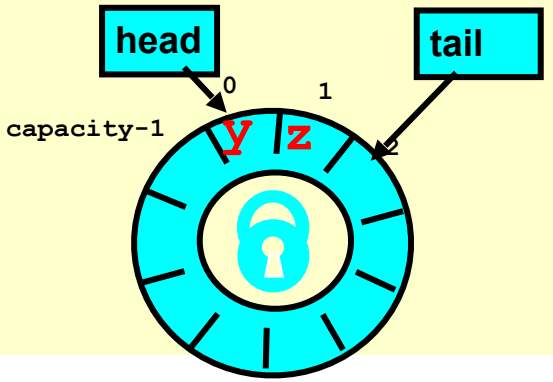
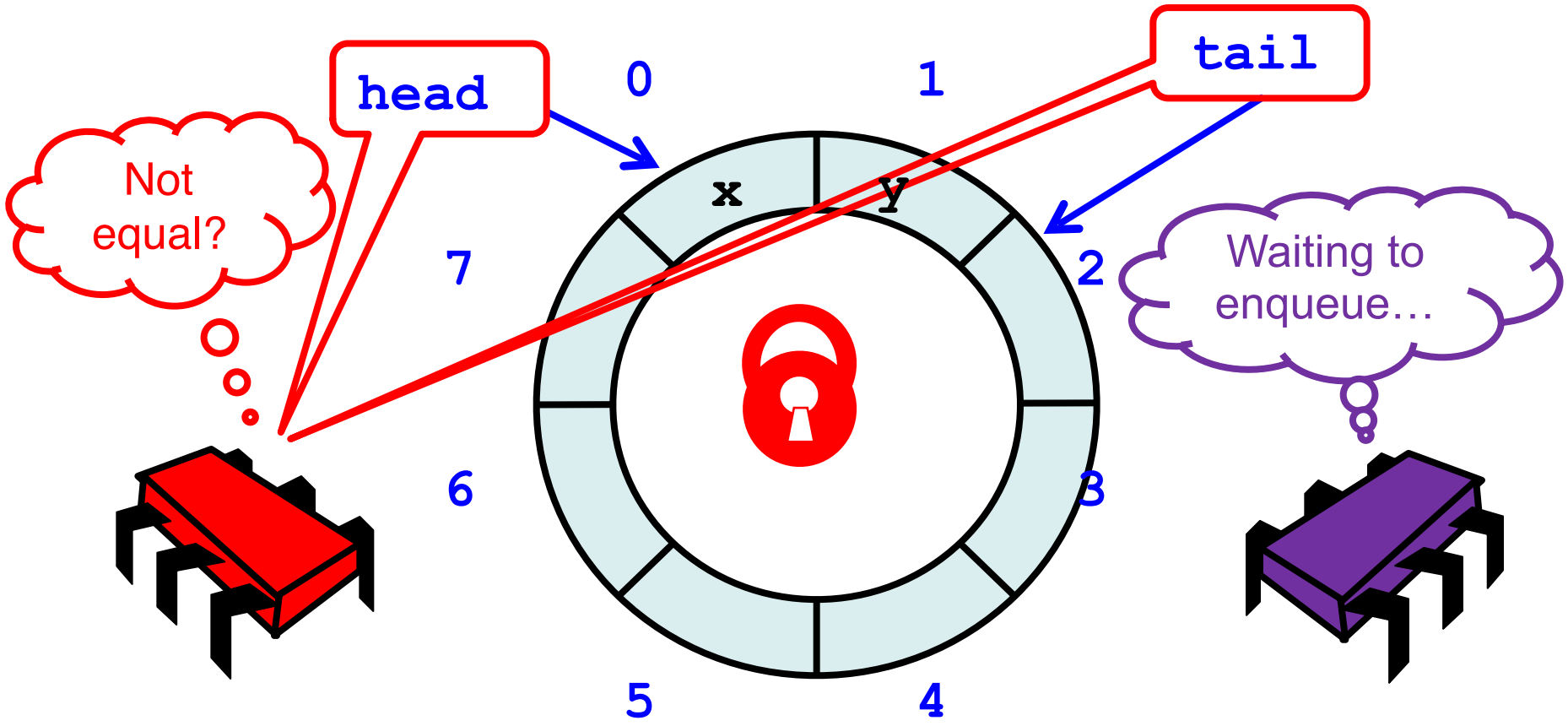
Acquire lock at method start



Check if Non-Empty



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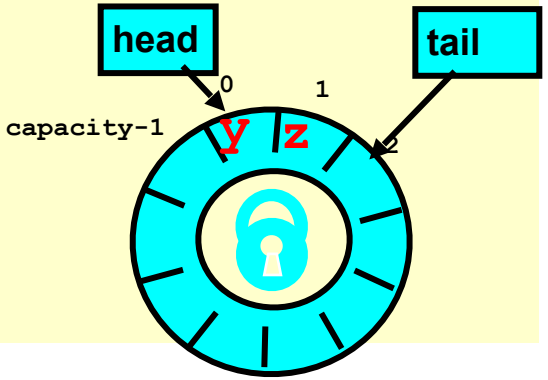
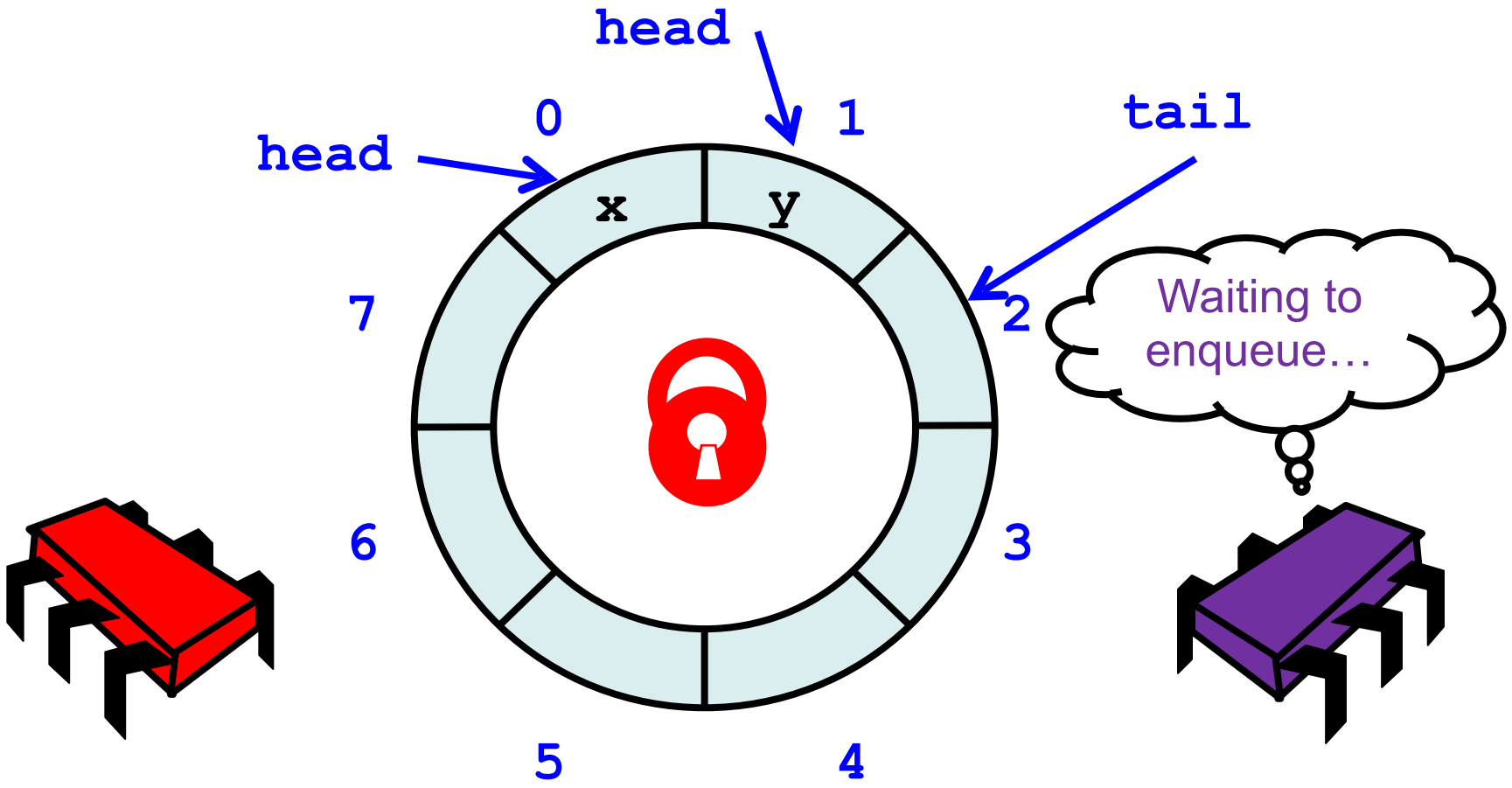
If queue empty
throw exception



Modify the Queue



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```
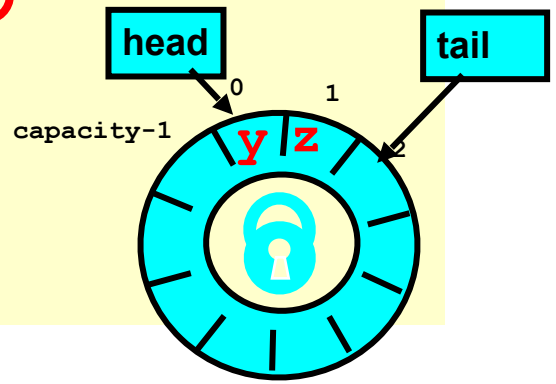

Queue not empty?

Remove item and update head



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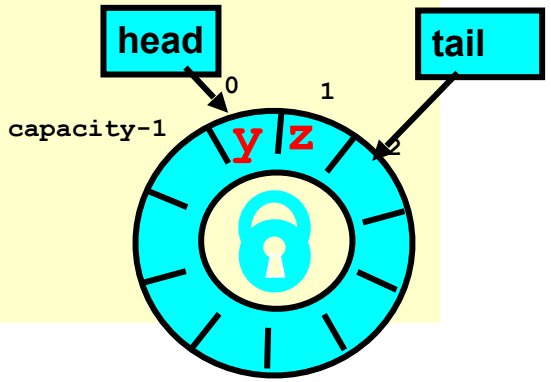
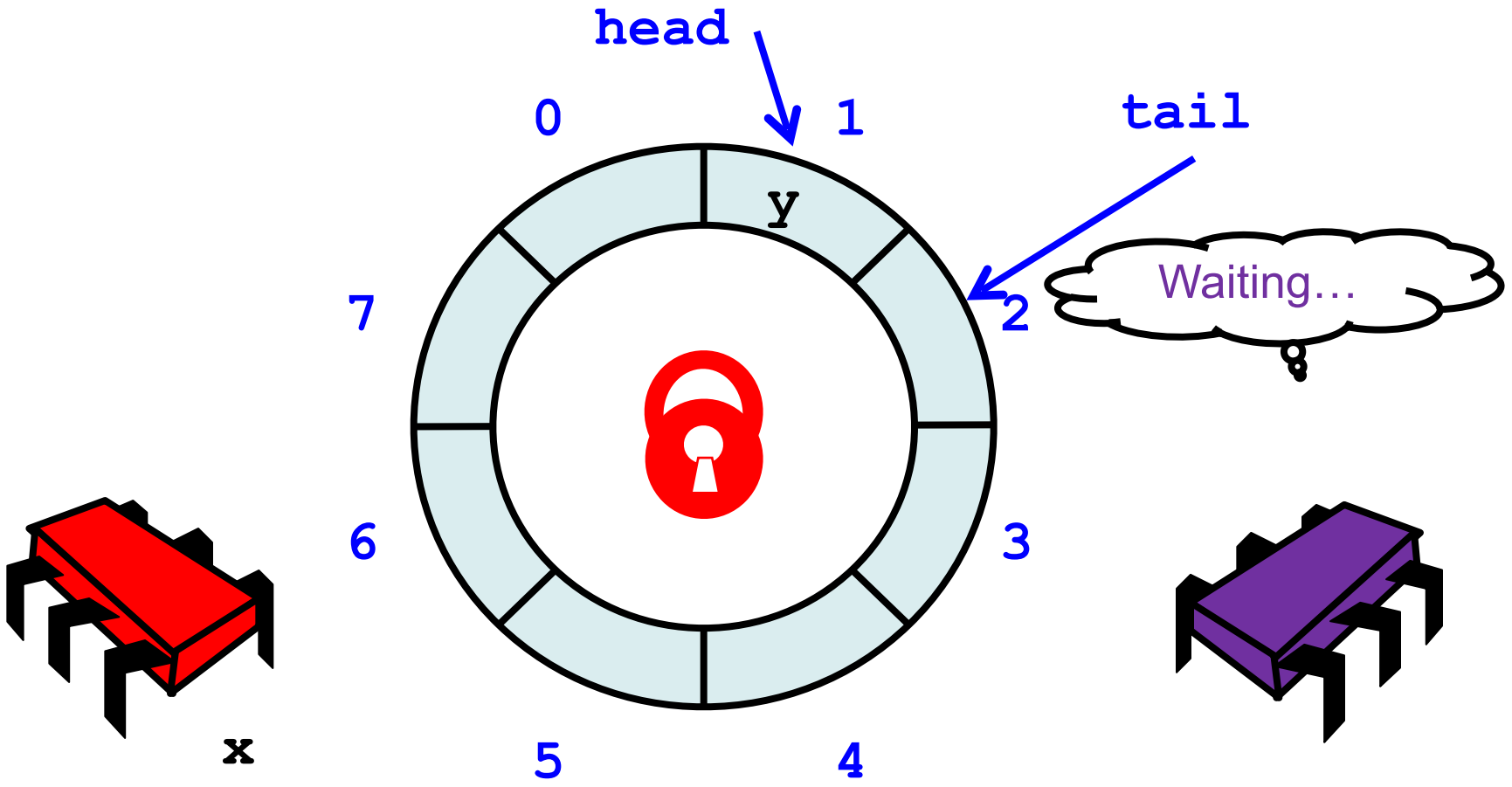
Return result



Release the Lock



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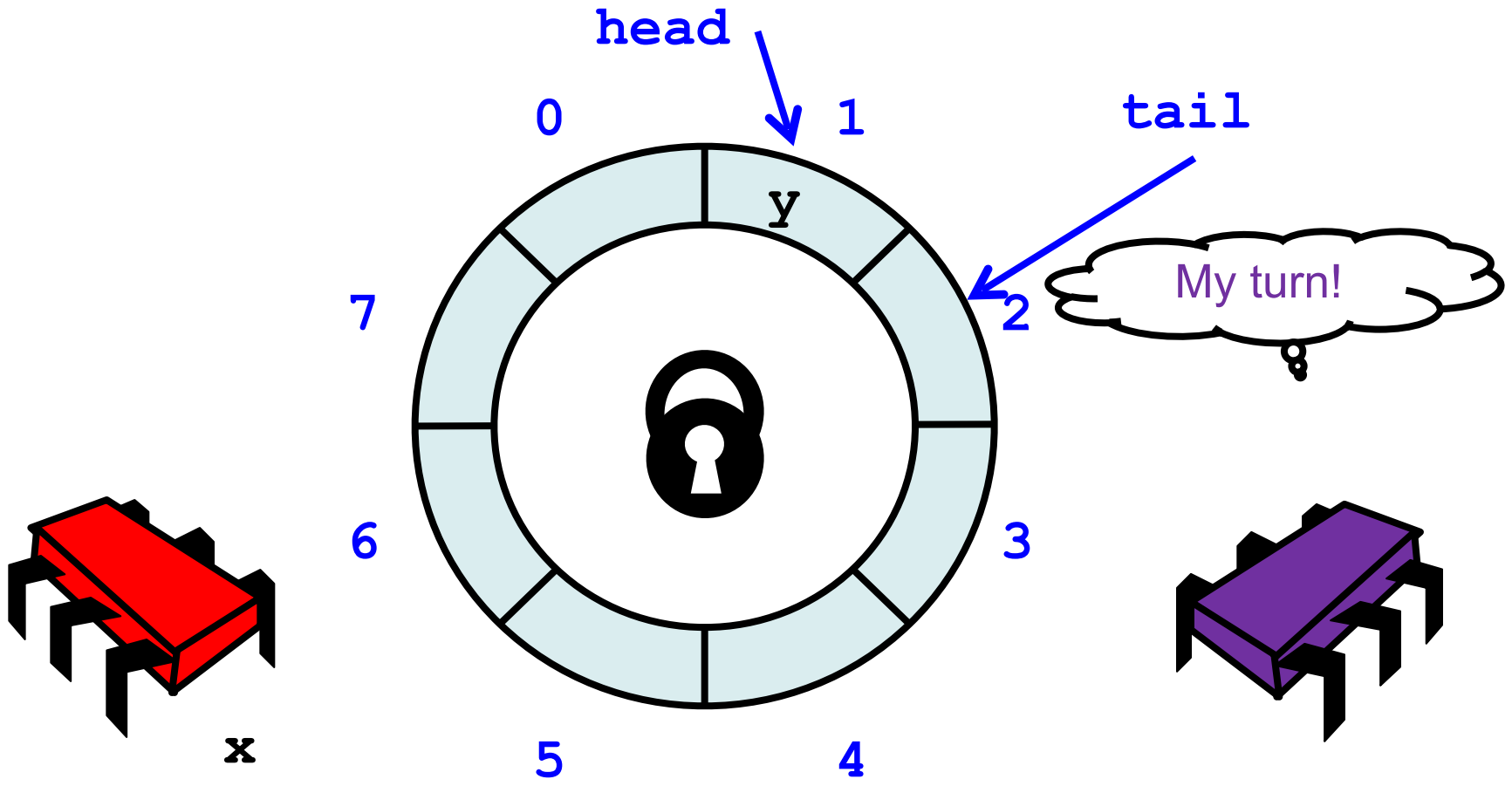

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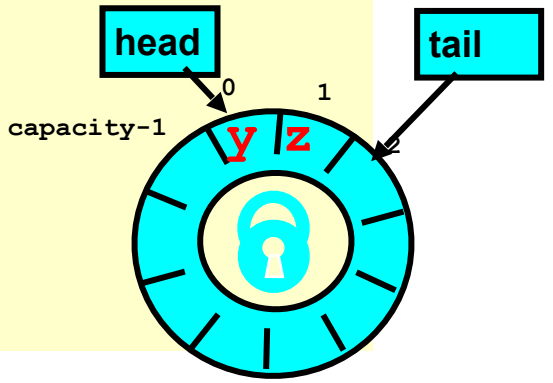
Release lock no matter what!



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  }
}
```

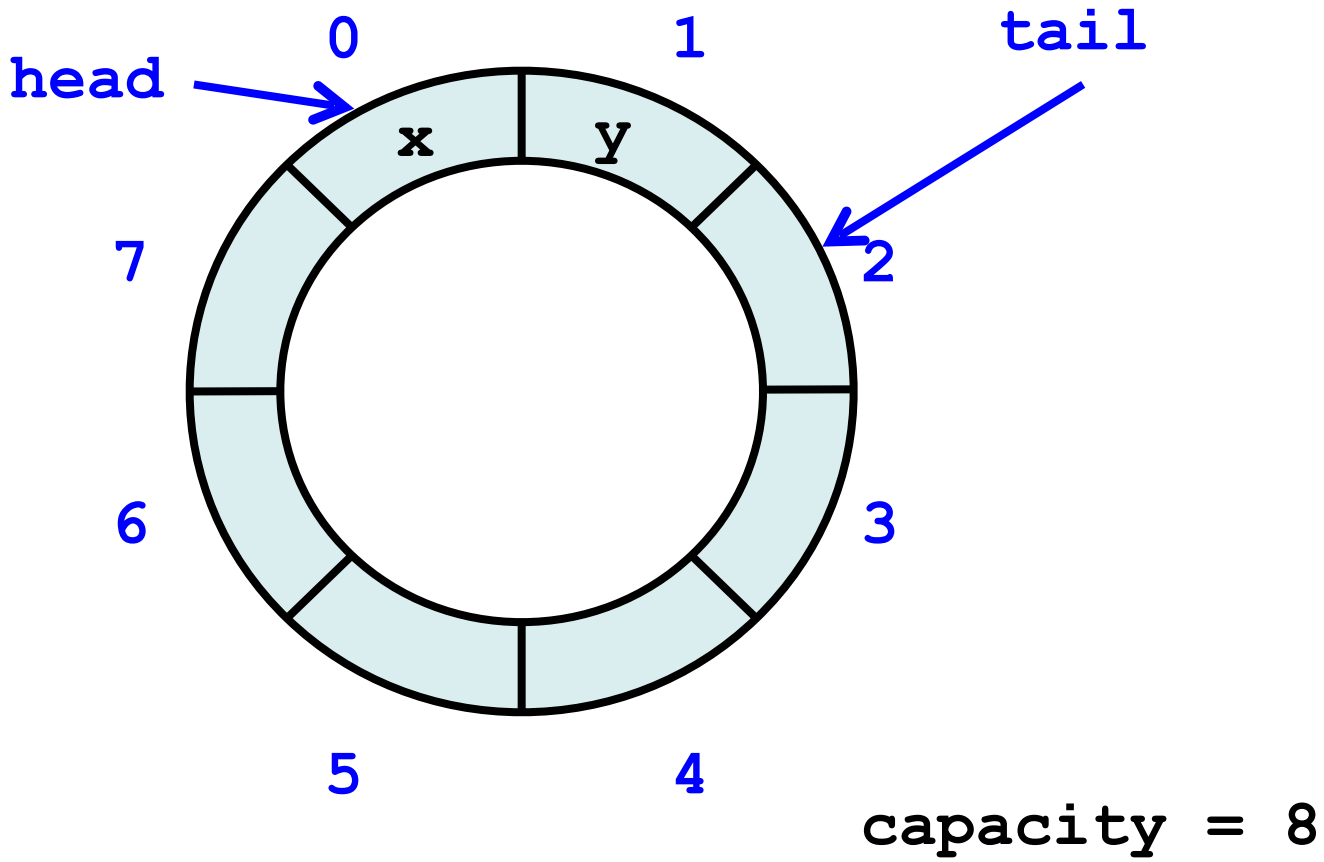
Should be correct because modifications are mutually exclusive…

Demo

Now consider the following implementation

- The same thing without mutual exclusion
- For simplicity, only two threads
  - One thread enq only
  - The other deq only

Wait-free 2-Thread Queue



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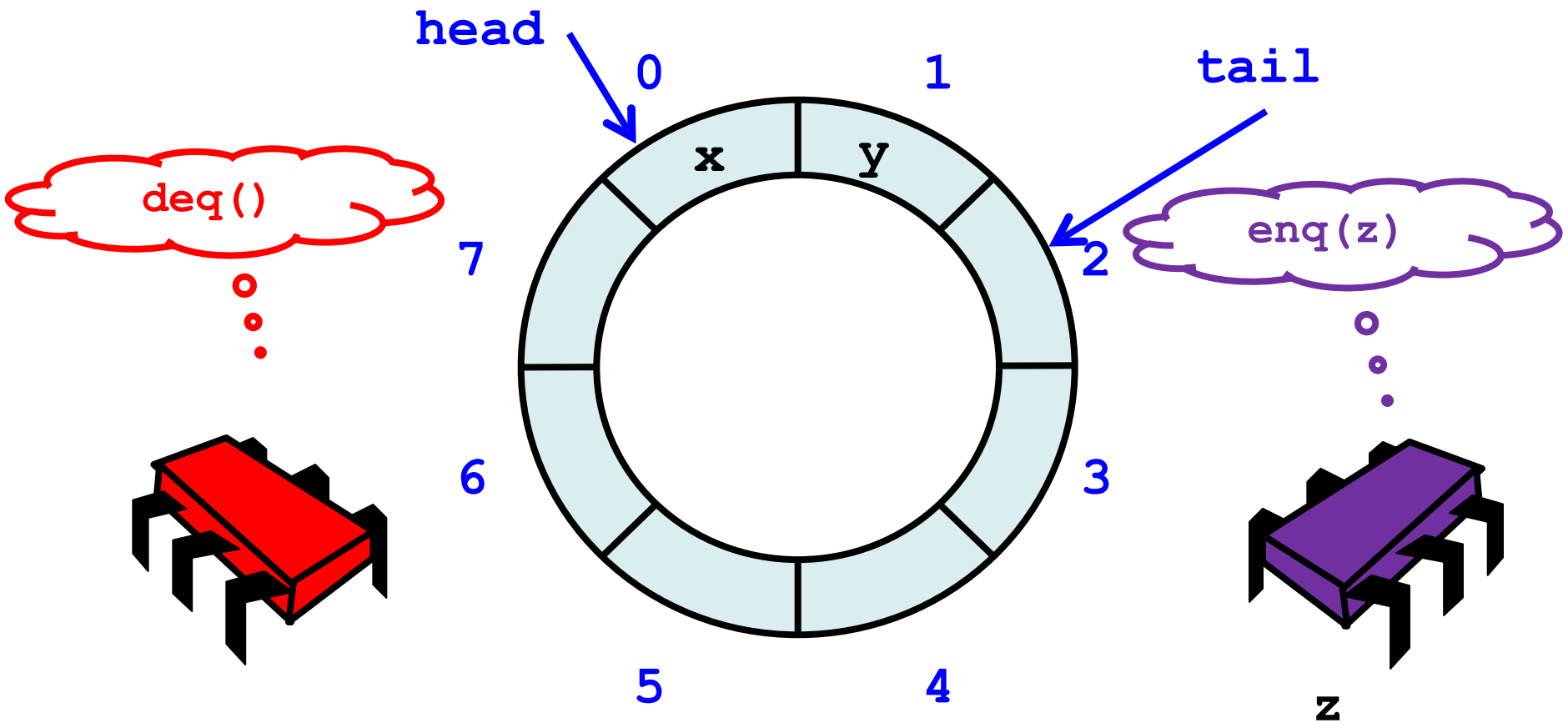

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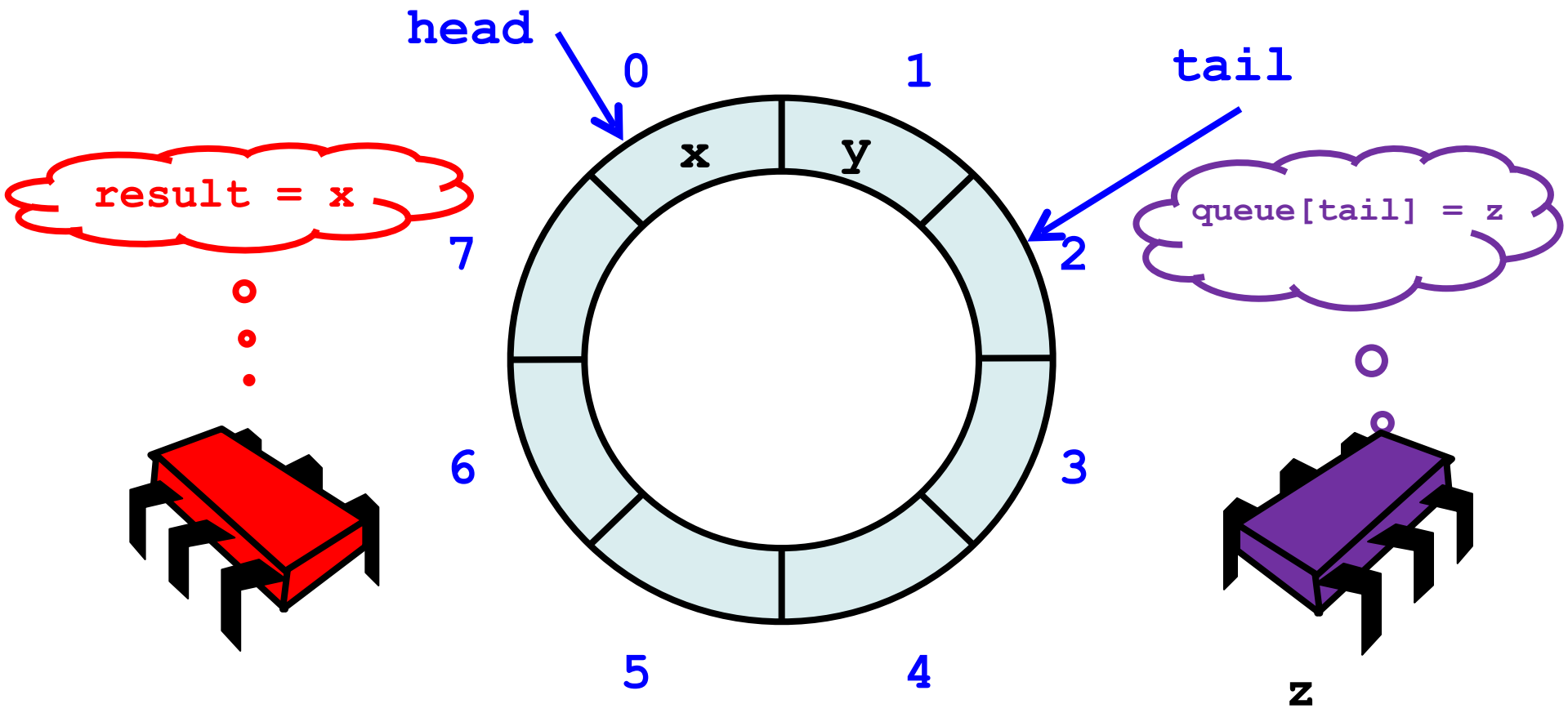

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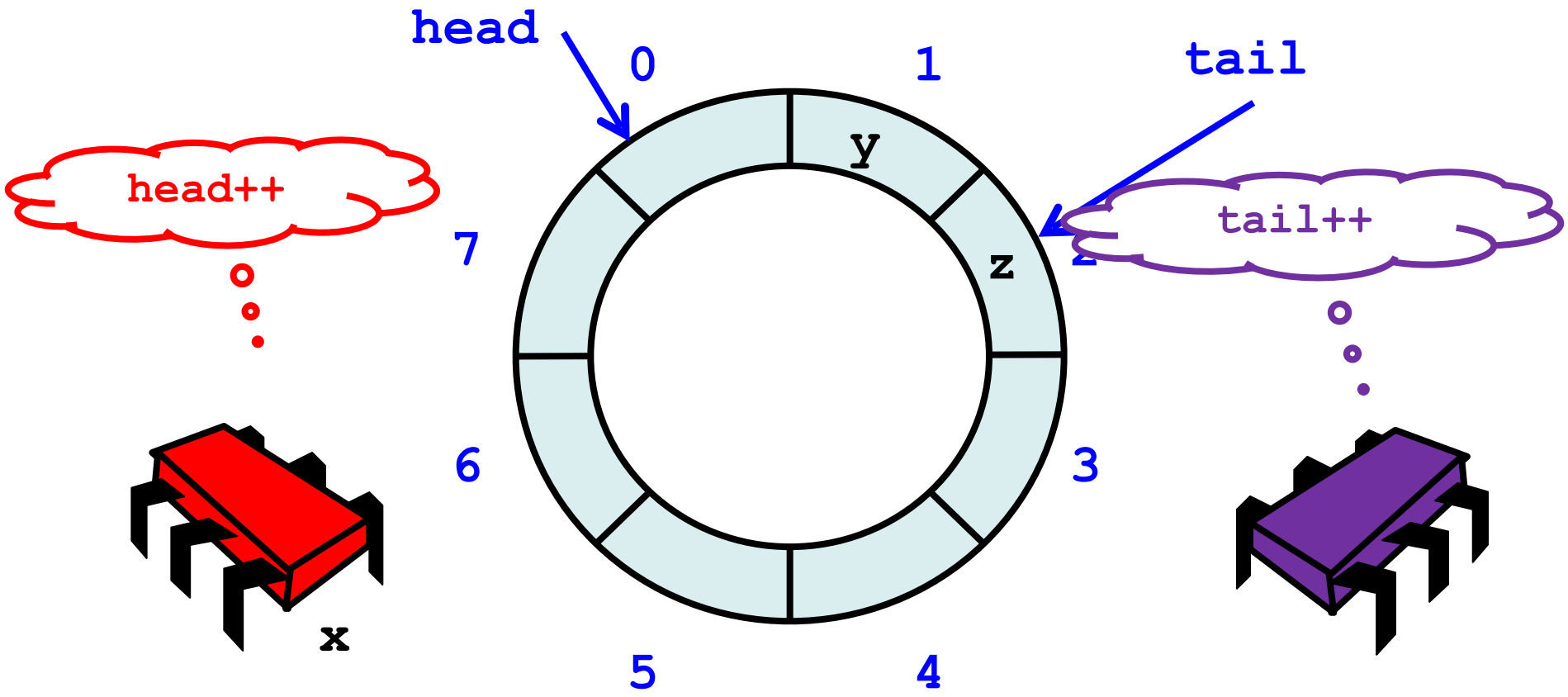

Wait-free 2-Thread Queue

```
class LockFreeQueue[T: ClassTag](val capacity: Int) {

  @volatile
  private var head, tail: Int = 0
  private val items = new Array[T](capacity)

  def enq(x: T): Unit = {
    if (tail - head == items.length) throw FullException
    items(tail % items.length) = x
    tail = tail + 1
  }

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    if (tail == head) throw EmptyException
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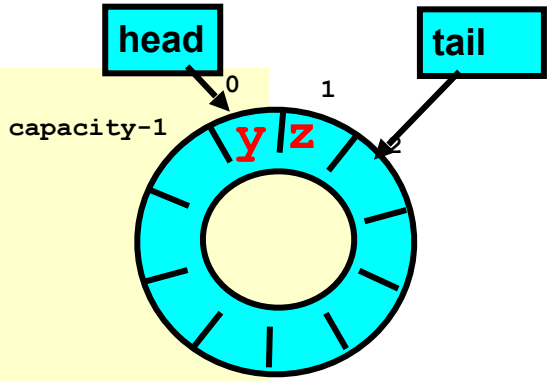

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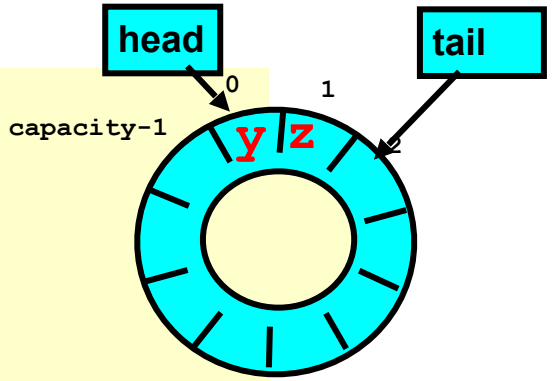


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No lock needed!

Wait-free 2-Thread Queue

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```

How do we define "correct" when modifications are not mutually exclusive?

What *is* a Concurrent Queue?

- Need a way to specify a concurrent queue object
- Need a way to prove that an algorithm implements the object's specification
- Lets talk about object specifications …

Correctness and Progress

- In a concurrent setting, we need to specify both the safety and the liveness properties of an object
- Need a way to define
  - when an implementation is correct
  - the conditions under which it guarantees progress

Lets begin with correctness

Sequential Objects

- Each object has a ***state***
  - Usually given by a set of ***fields***
  - Queue example: sequence of items
- Each object has a set of ***methods***
  - Only way to manipulate state
  - Queue example: **`enq`** and **`deq`** methods

Sequential Specifications

- If (precondition)
  - the object is in such-and-such a state
  - before you call the method,
- Then (postcondition)
  - the method will return a particular value
  - or throw a particular exception,
- and (postcondition, con't)
  - the object will be in some other state
  - when the method returns

Pre and PostConditions for Dequeue

- Precondition:
  - Queue is non-empty
- Postcondition:
  - Returns first item in queue
- Postcondition:
  - Removes first item in queue

Pre and PostConditions for Dequeue

- Precondition:
  - Queue is empty
- Postcondition:
  - Throws Empty exception
- Postcondition:
  - Queue state unchanged

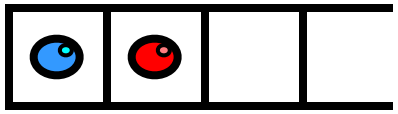
Why Sequential Specifications *Totally Rock*

- Interactions among methods captured by side-effects on object state
  - State meaningful between method calls
- Documentation size linear in number of methods
  - Each method described in isolation
- Can add new methods
  - Without changing descriptions of old methods

What About Concurrent Specifications ?

- Methods?
- Documentation?
- Adding new methods?

Methods Take Time



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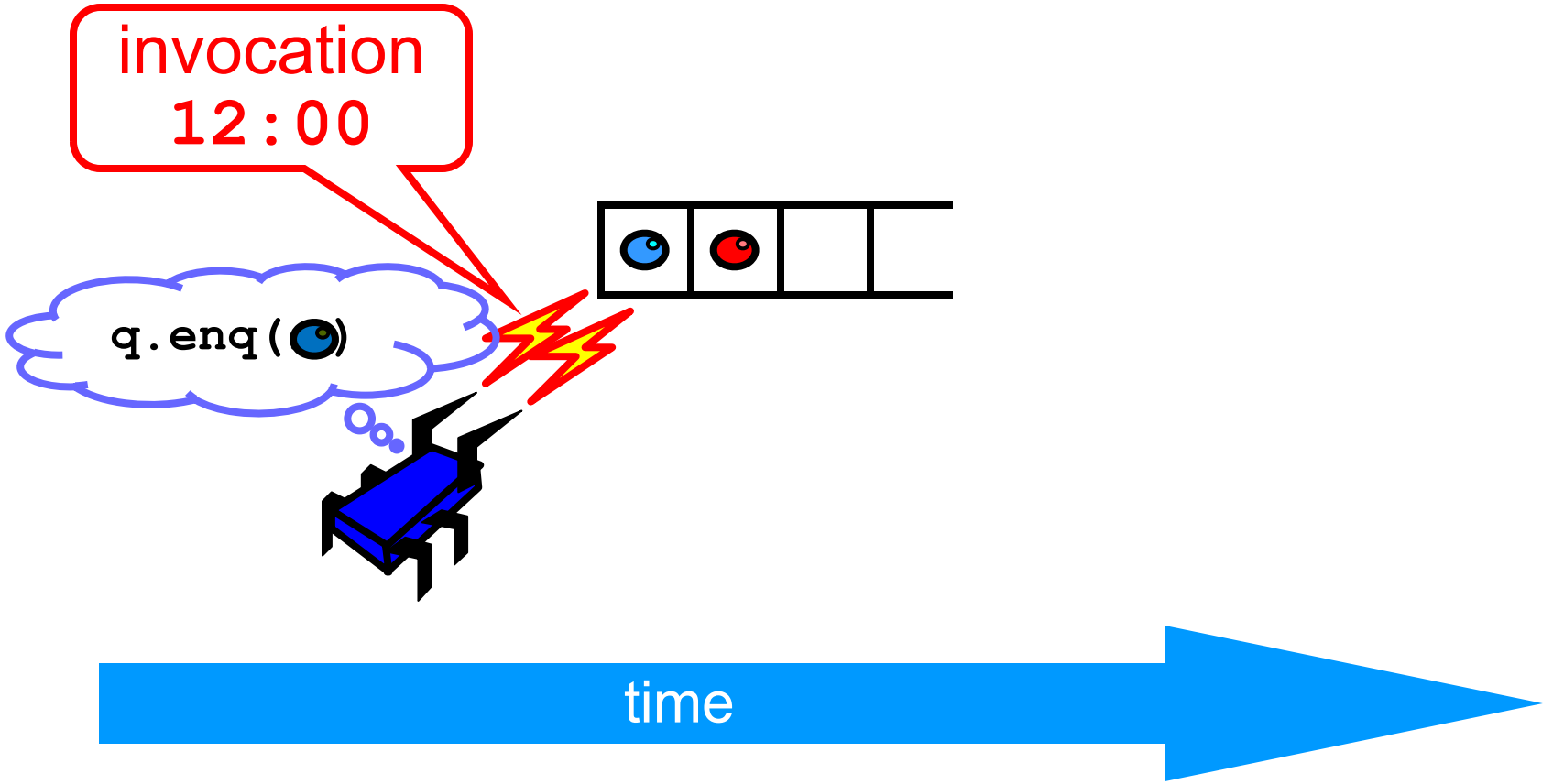

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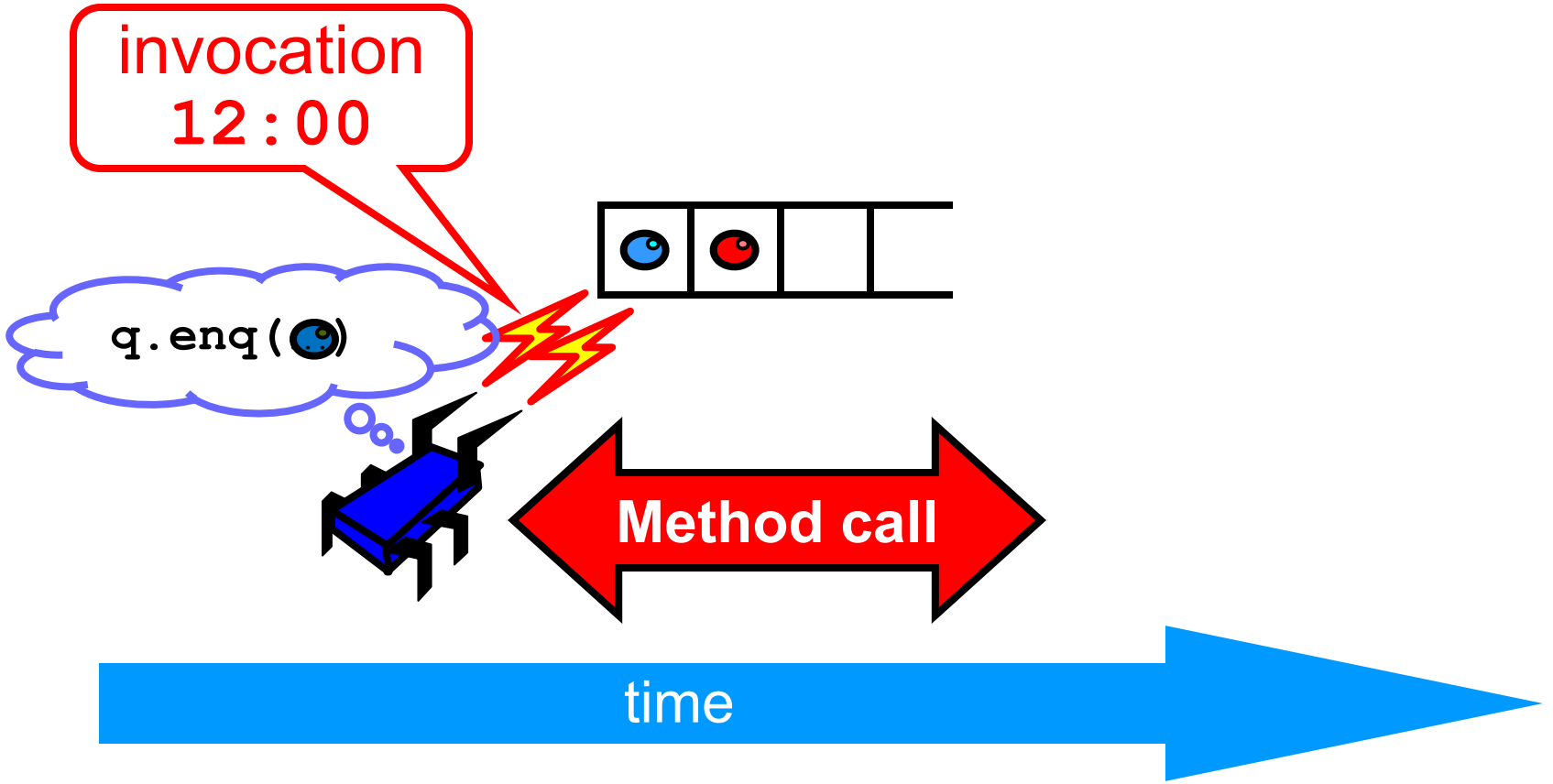

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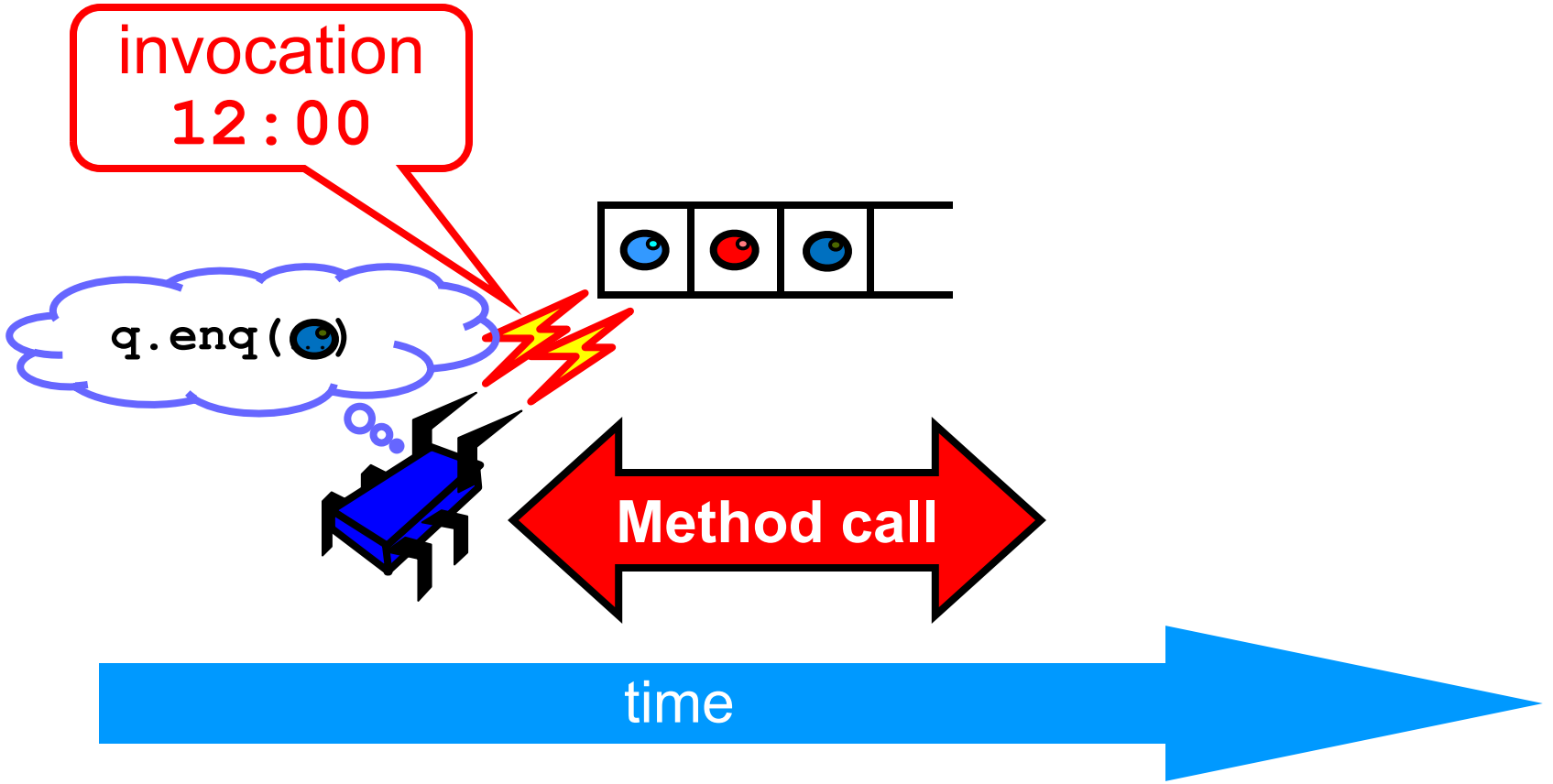

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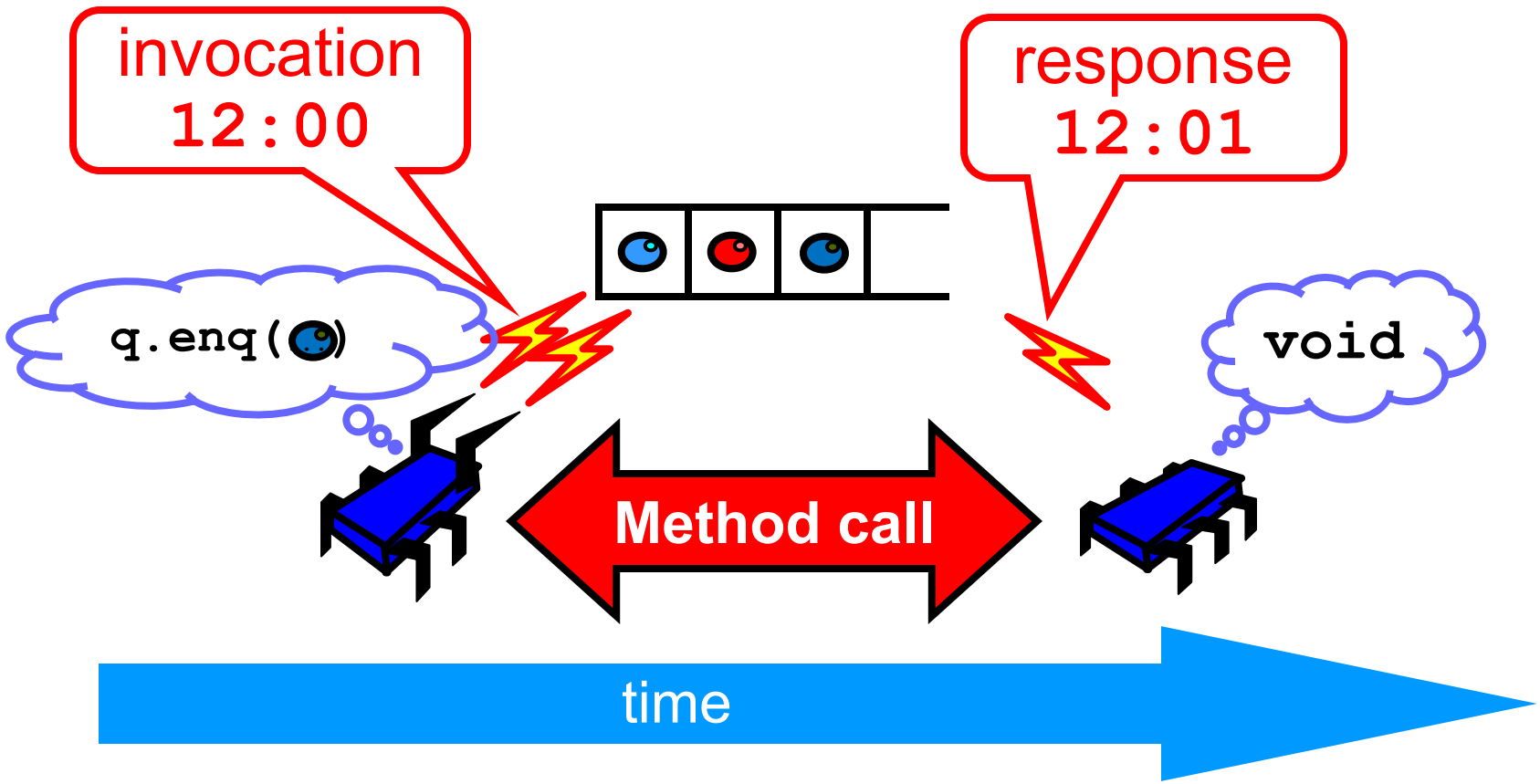
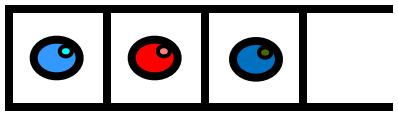


Sequential vs Concurrent

- Sequential
  - Methods take time? Who knew?
- Concurrent
  - Method call is not an event
  - Method call is a sequence of interval events.

Concurrent Methods Take Overlapping Time



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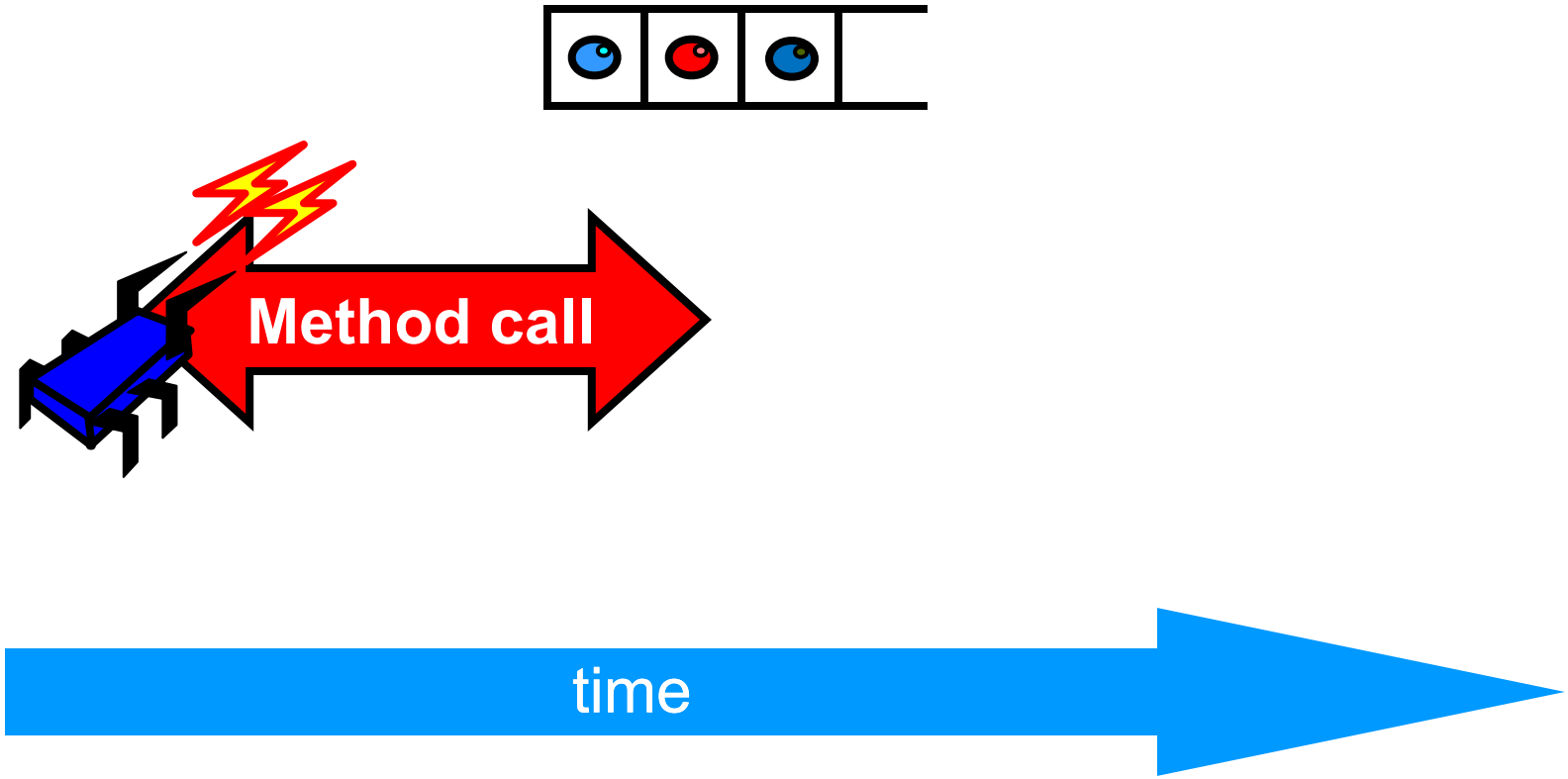

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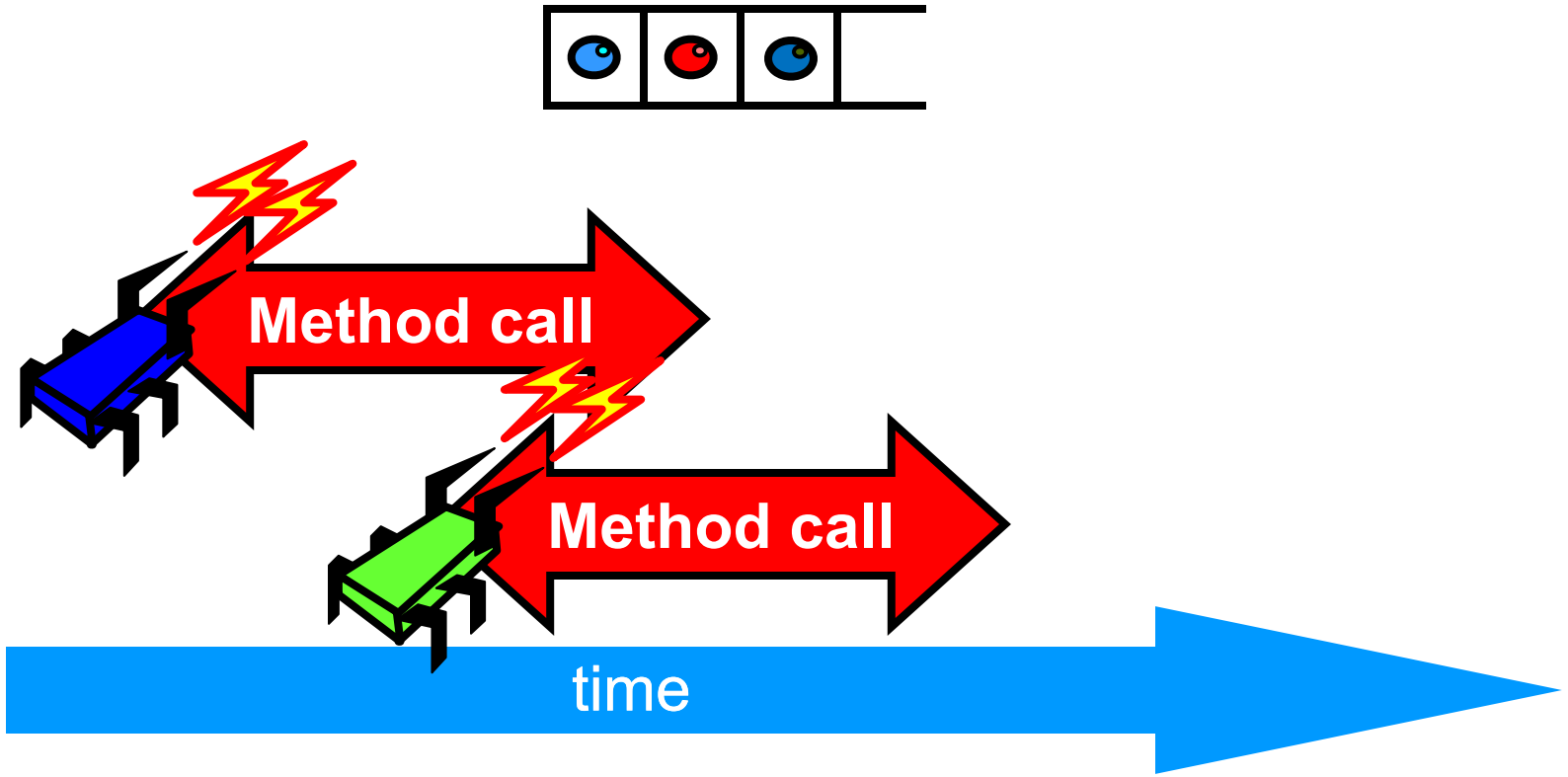

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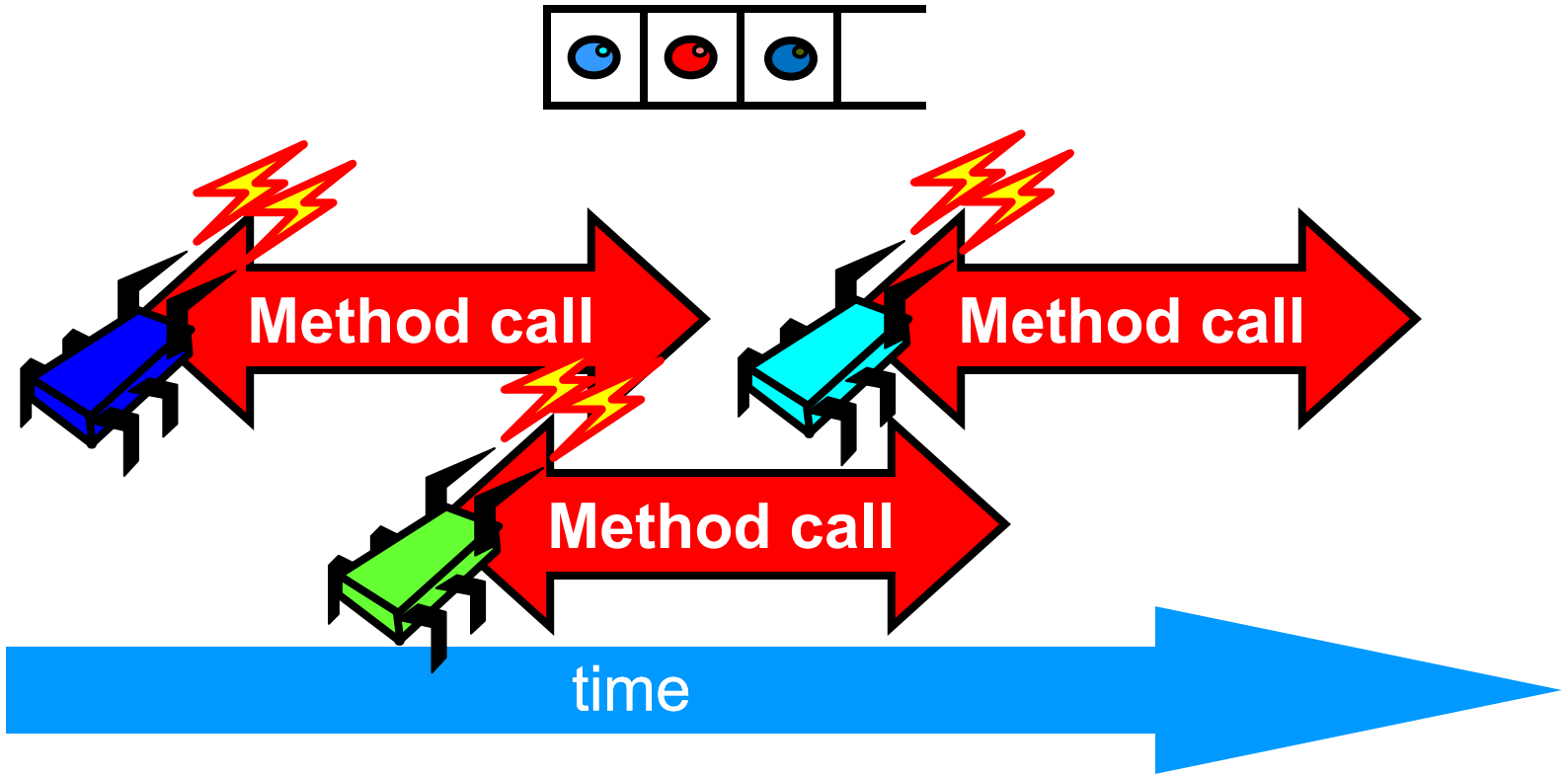

Sequential vs Concurrent

- Sequential:
  - Object needs meaningful state only ***between*** method calls
- Concurrent
  - Because method calls overlap,
    object might ***never*** be between method calls

Sequential vs Concurrent

- Sequential:
  - Each method described in isolation
- Concurrent
  - Must characterize ***all*** possible interactions with concurrent calls
    - What if two `enq()` calls overlap?
    - Two `deq()` calls? `enq()` and `deq()`? …

Sequential vs Concurrent

- Sequential:
  - Can add new methods without affecting older methods
- Concurrent:
  - Everything can potentially interact with everything else

Sequential vs Concurrent

- Sequential:
  - Can add new methods without affecting older methods
- Concurrent:
  - Everything can potentially interact with everything else

The Big Question

- What does it mean for a *concurrent* object to be correct?
  - What *is* a concurrent FIFO queue?
  - FIFO means strict temporal order
  - Concurrent means ambiguous temporal order

Intuitively…

```
def deq() : T = {
  myLock.lock()
  try {
    if (tail == head) {
      throw EmptyException
    }
    val x = items(head % items.length)
    head = head + 1
    x
  } finally {
    myLock.unlock()
  }
}
```

Intuitively…

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}
```
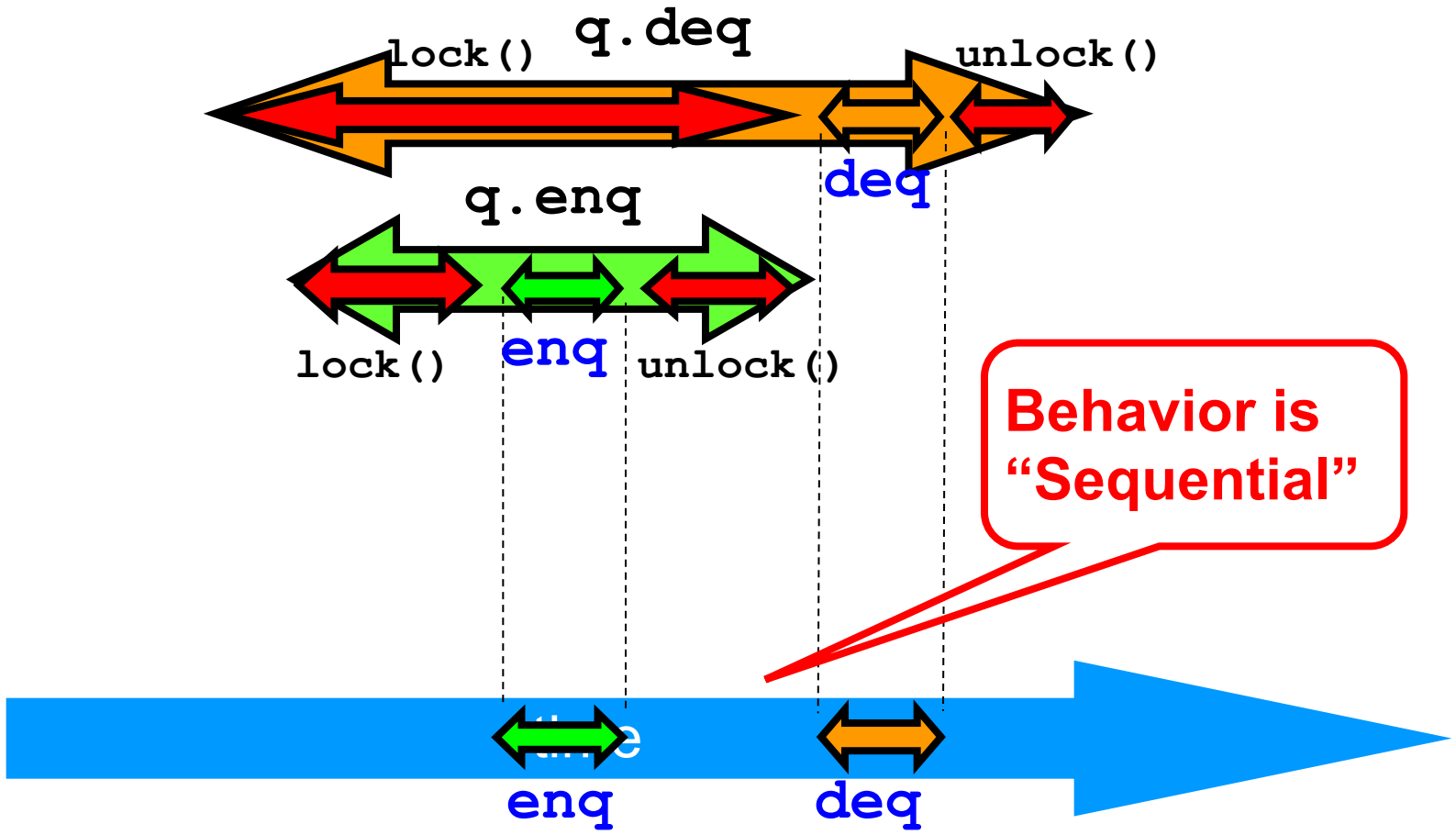

All queue modifications are mutually exclusive

Intuitively

Lets capture the idea of describing the concurrent via the sequential



Linearizability

- Each method should
  - "take effect"
  - Instantaneously
  - Between invocation and response events
- Object is correct if this "sequential" behavior is correct
- Any such concurrent object is
  - **Linearizable™**

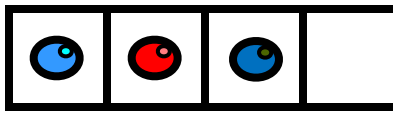
Is it really about the object?

- Each method should
  - "take effect"
  - Instantaneously
  - Between invocation and response events
- Sounds like a property of an execution…
- A linearizable object: one *all* of whose possible *executions* are linearizable

Proving execution lineearizable

- Identify “linearization points”
  - Between invocation and response events
  - Correspond to the effect of the call
  - “Justify” the whole execution
- Multiple ways to identify linearization points exist
- If none found, execution is *non-linearizable*

Example



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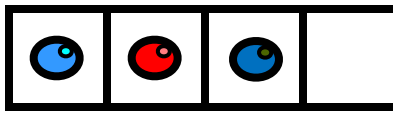

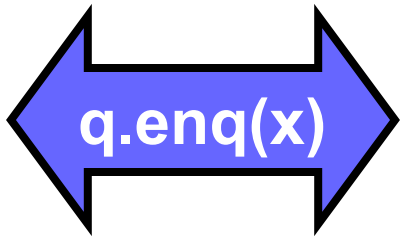

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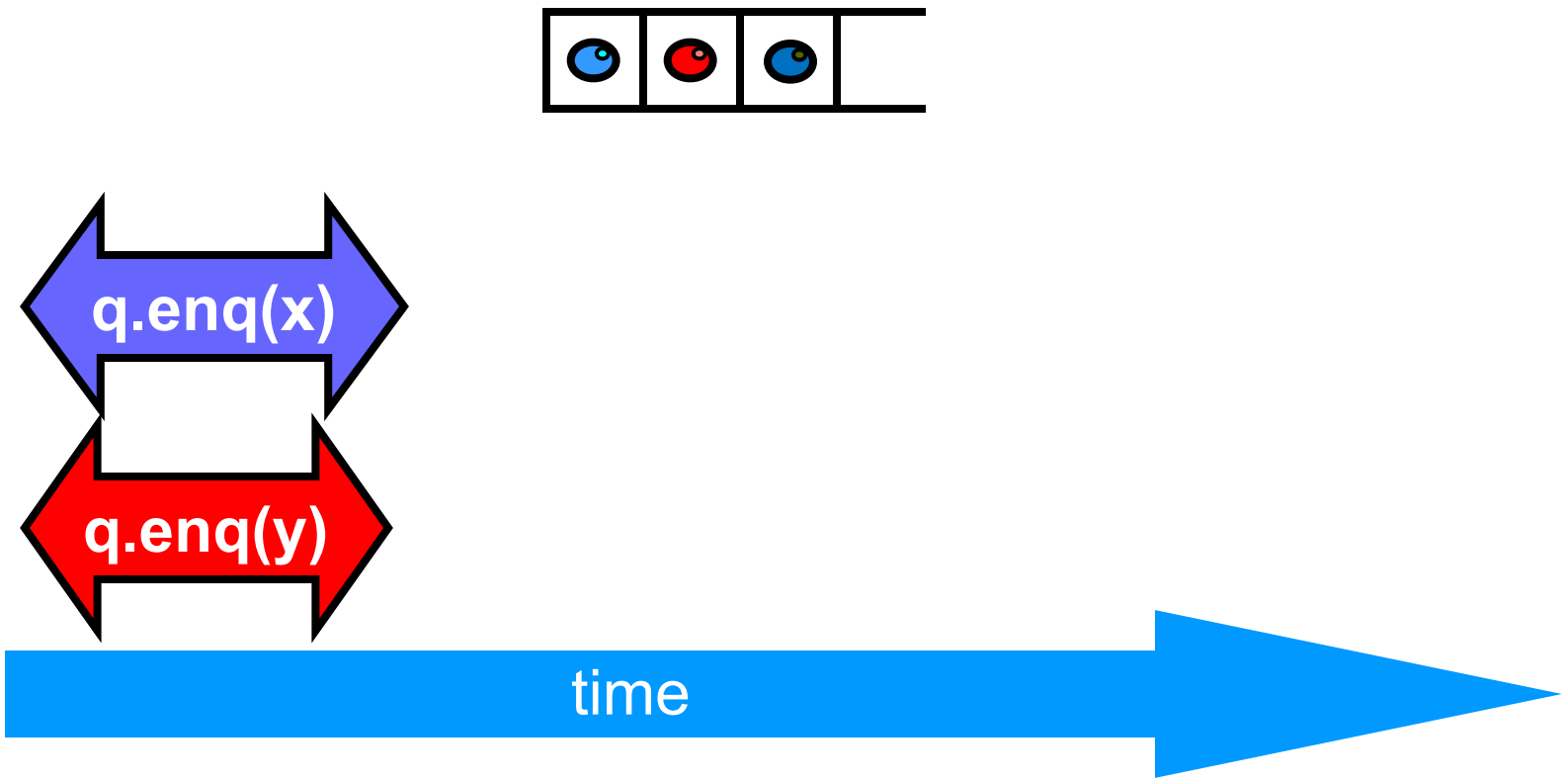

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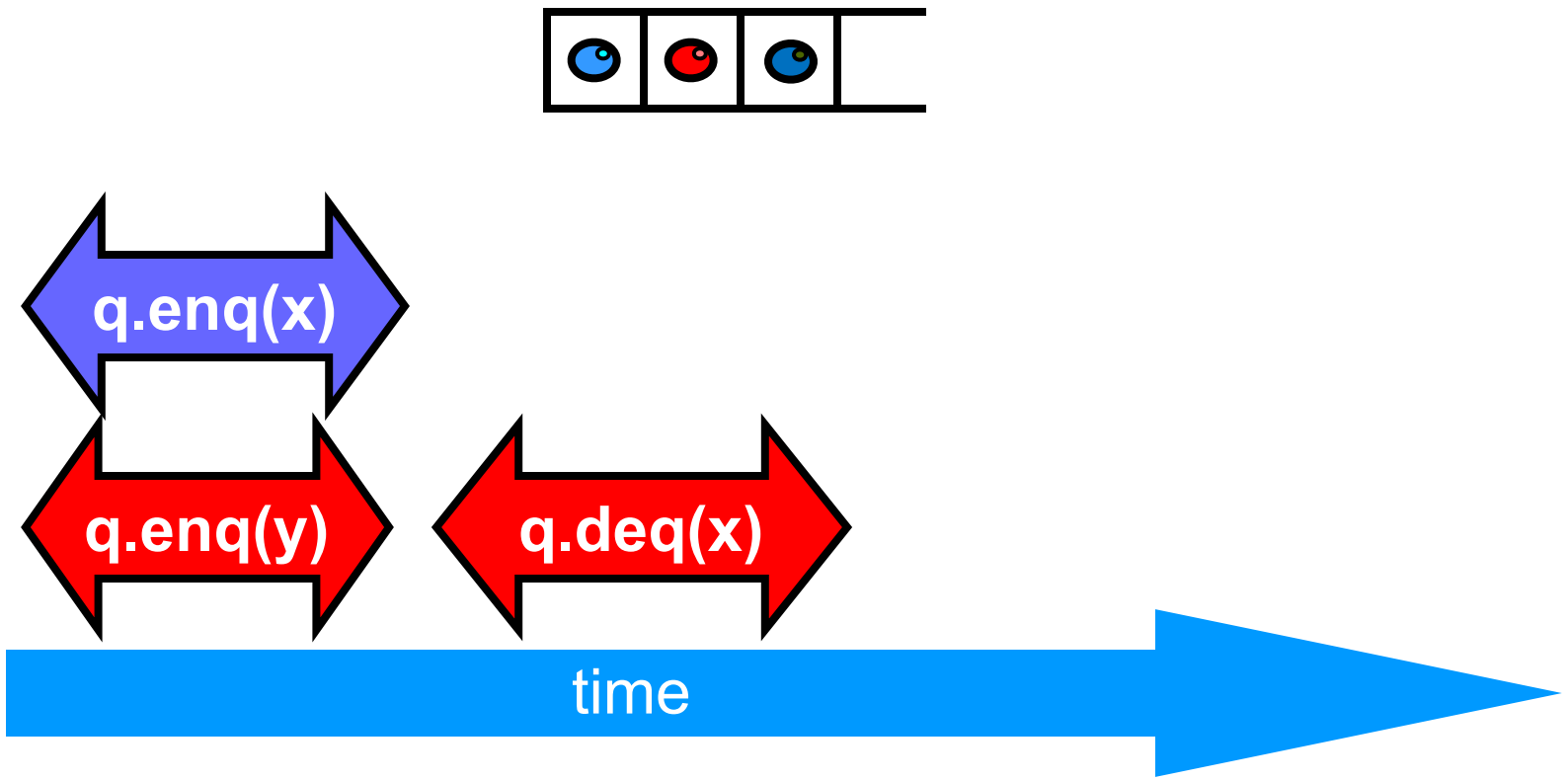

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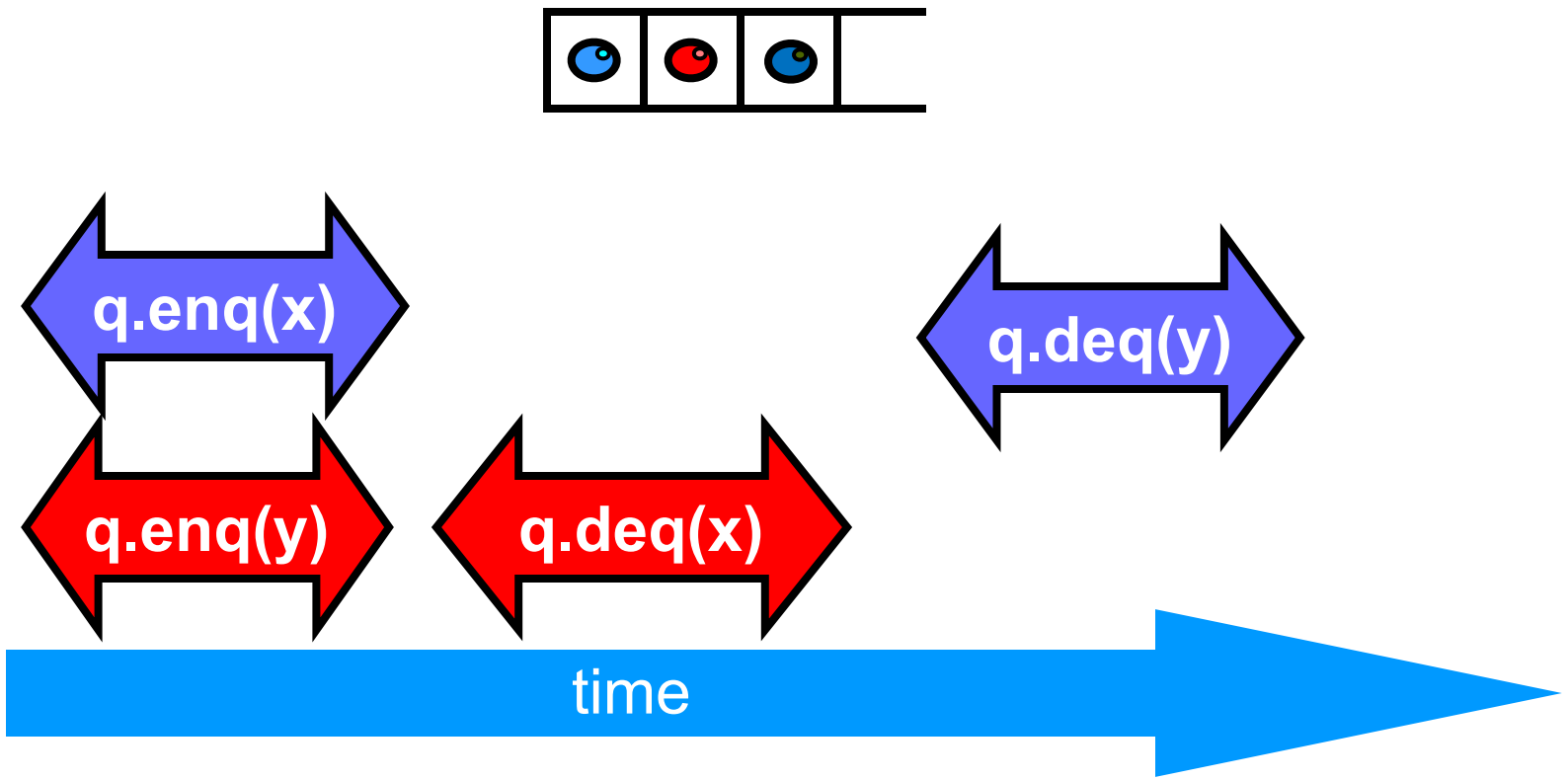

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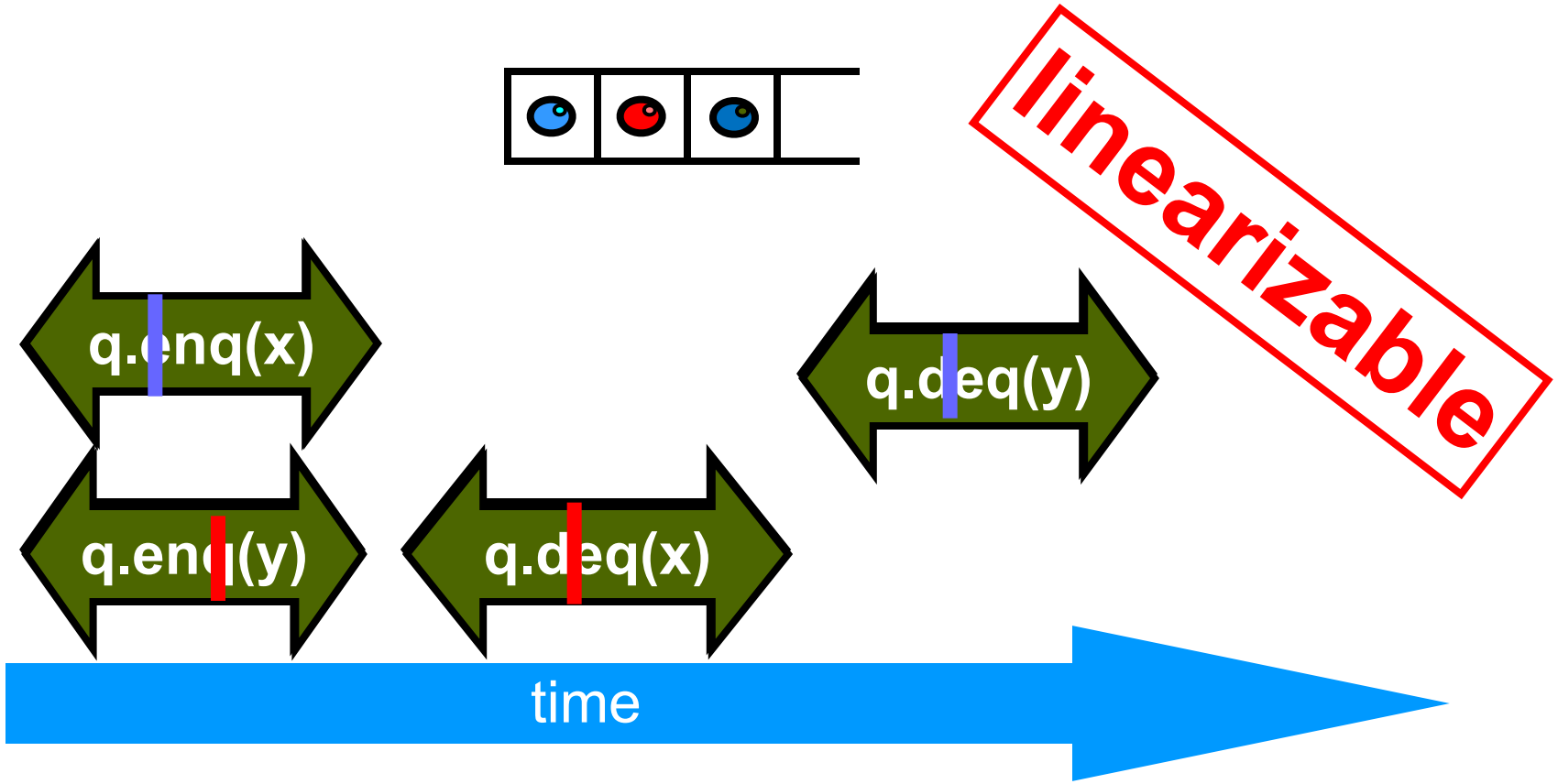

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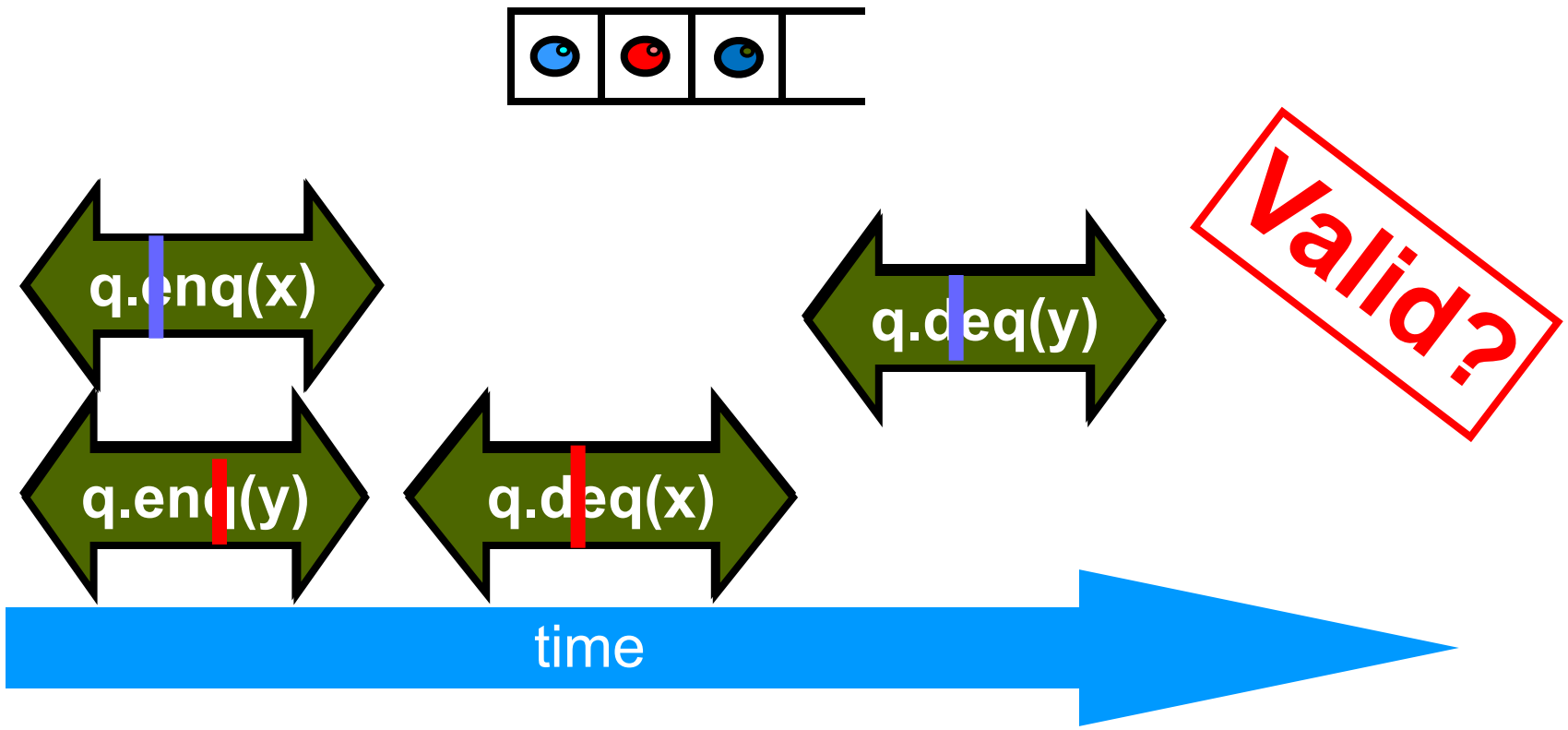

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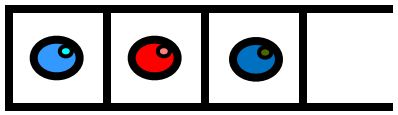

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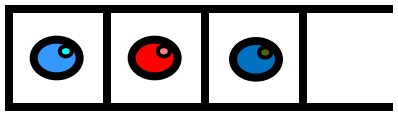

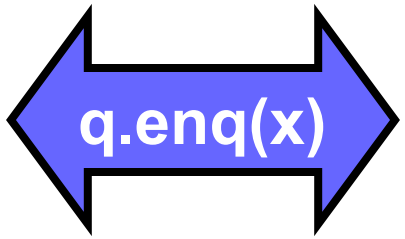

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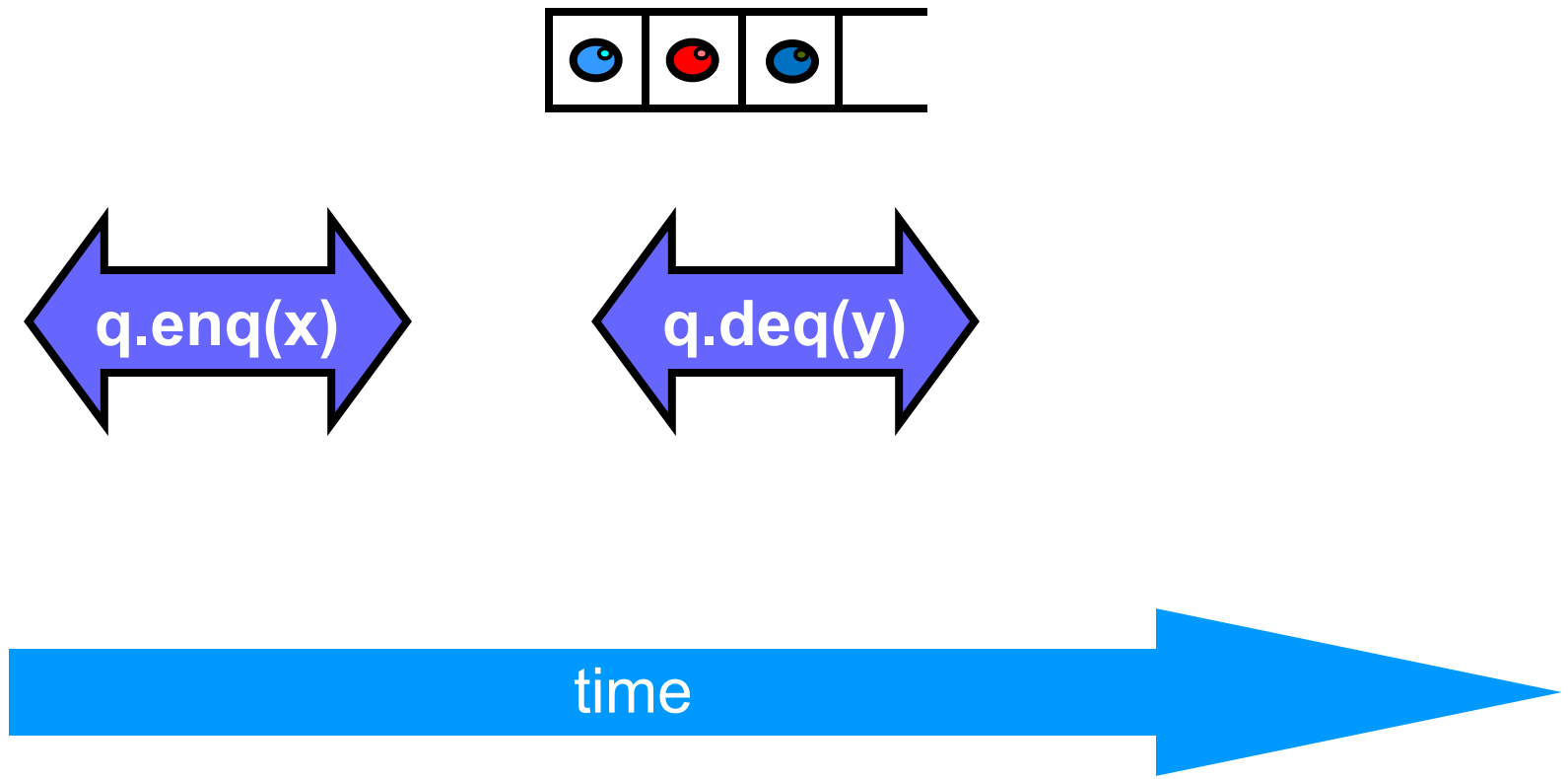

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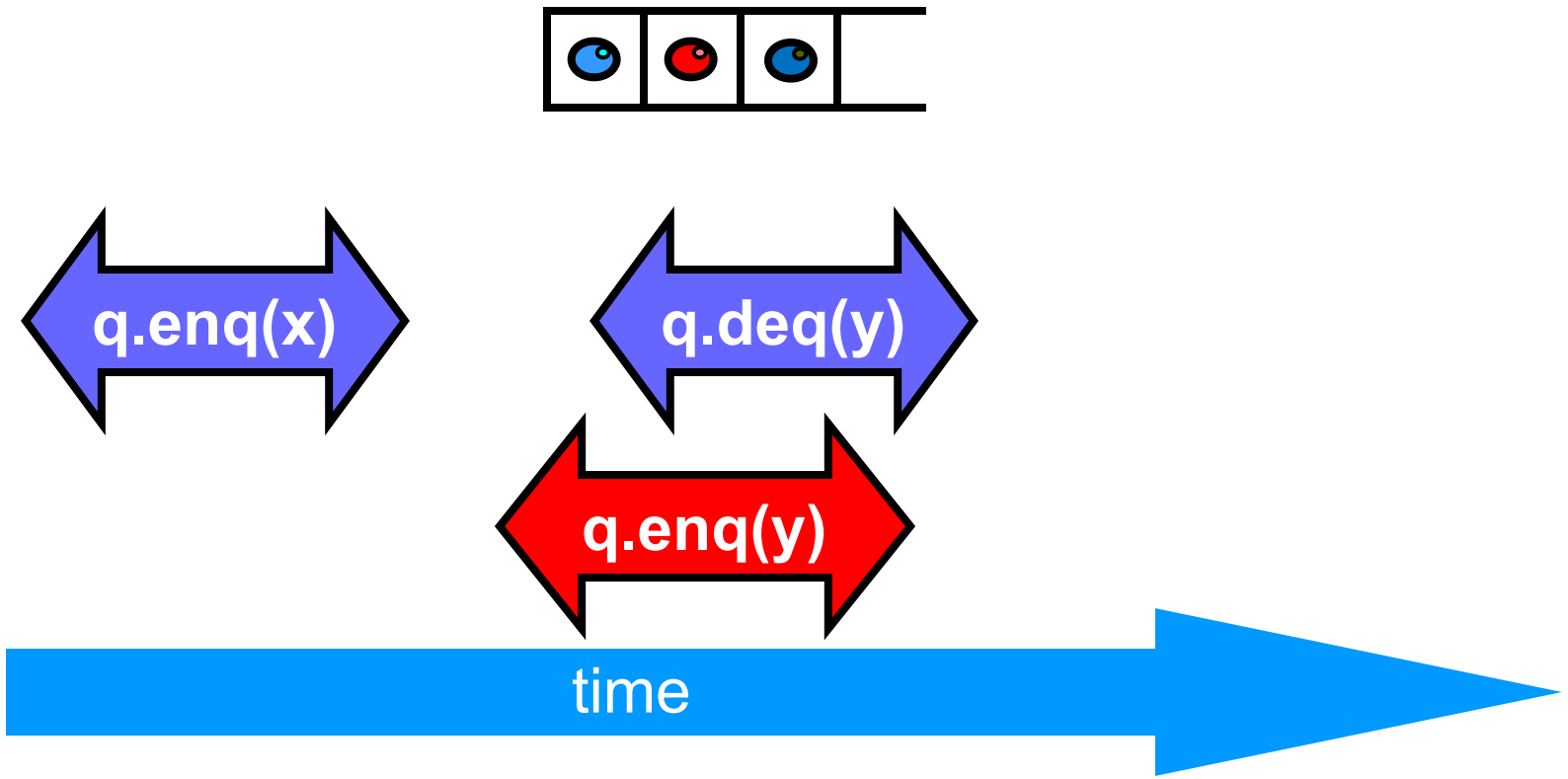

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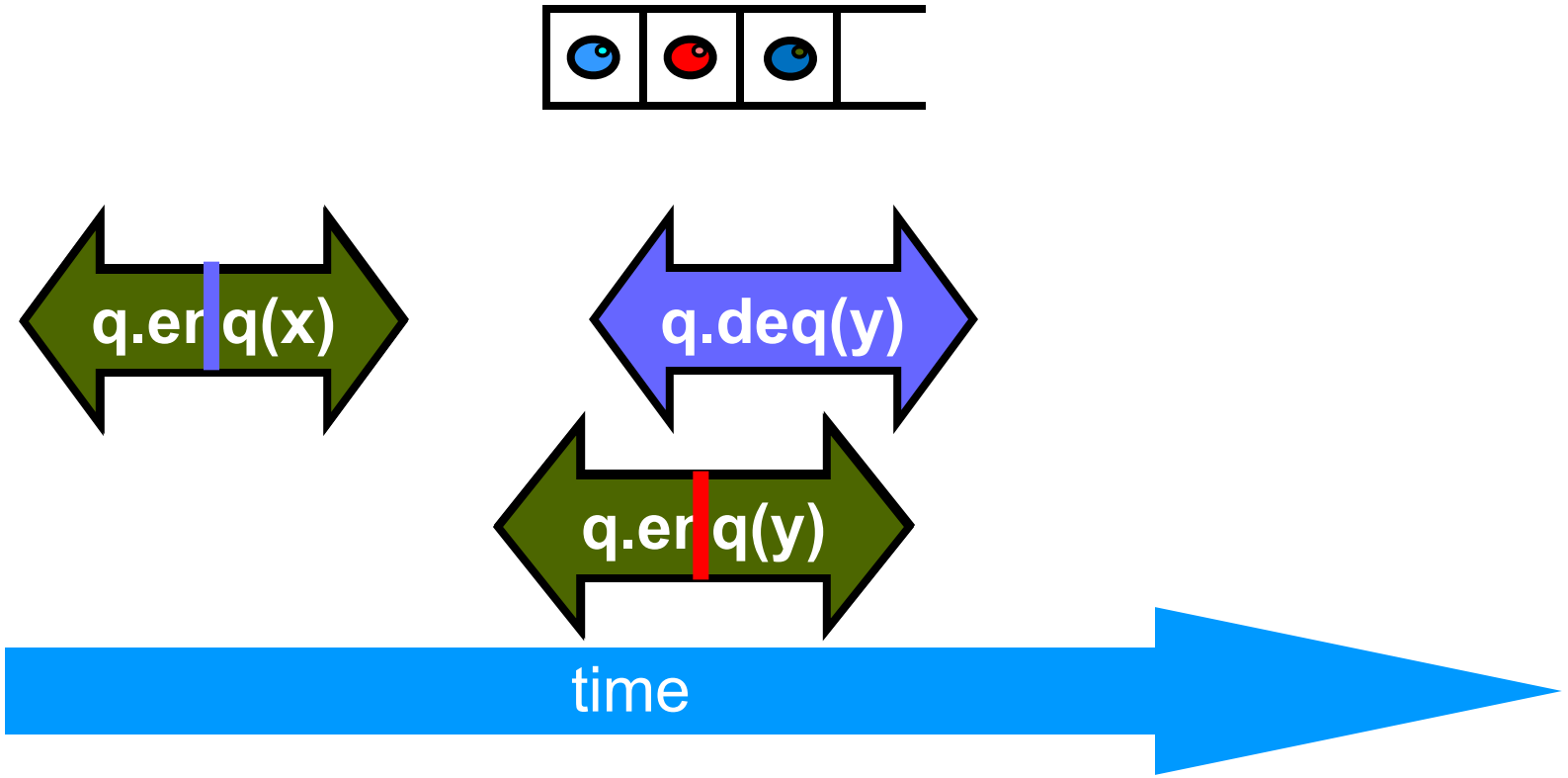

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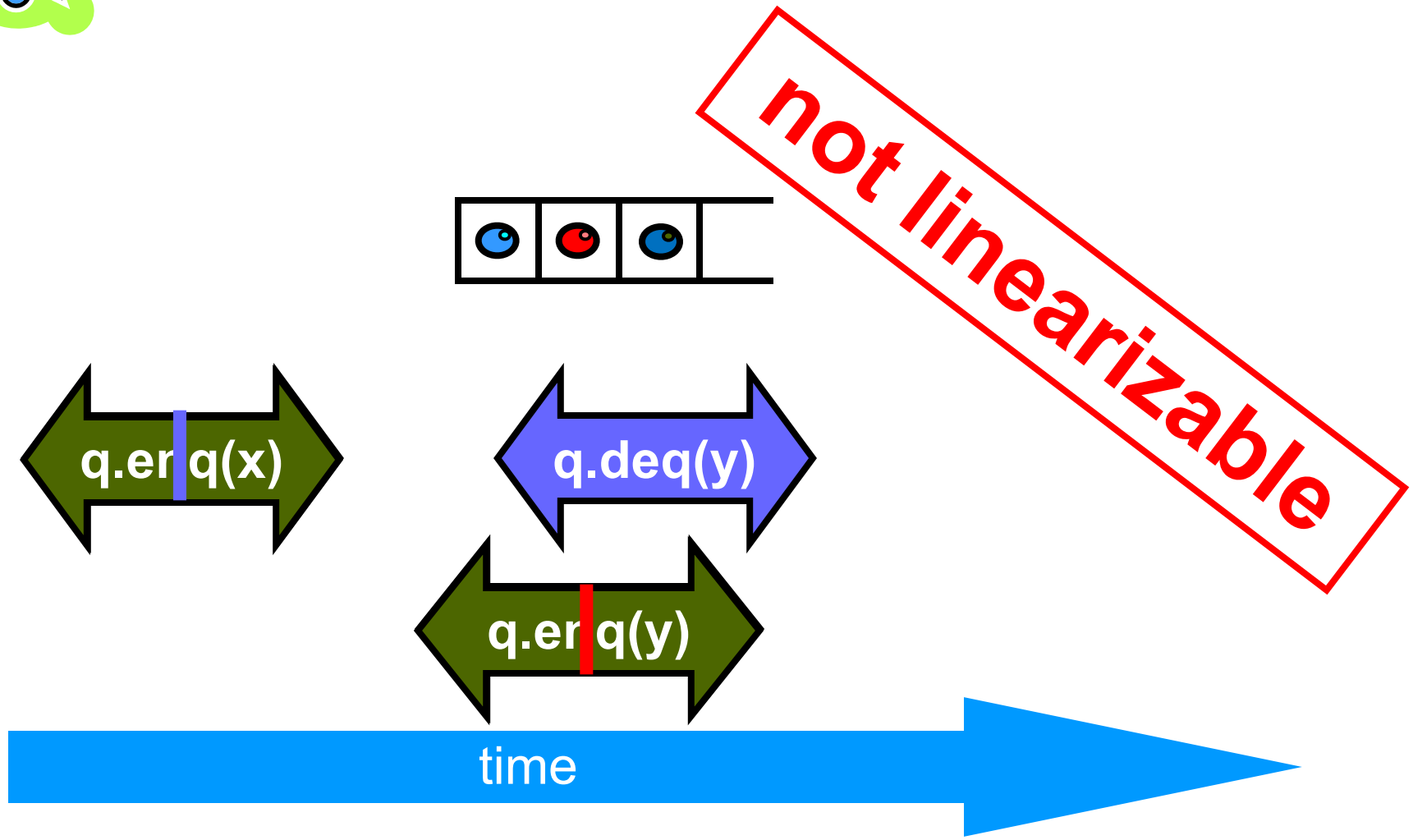

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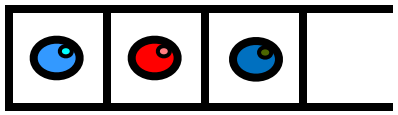

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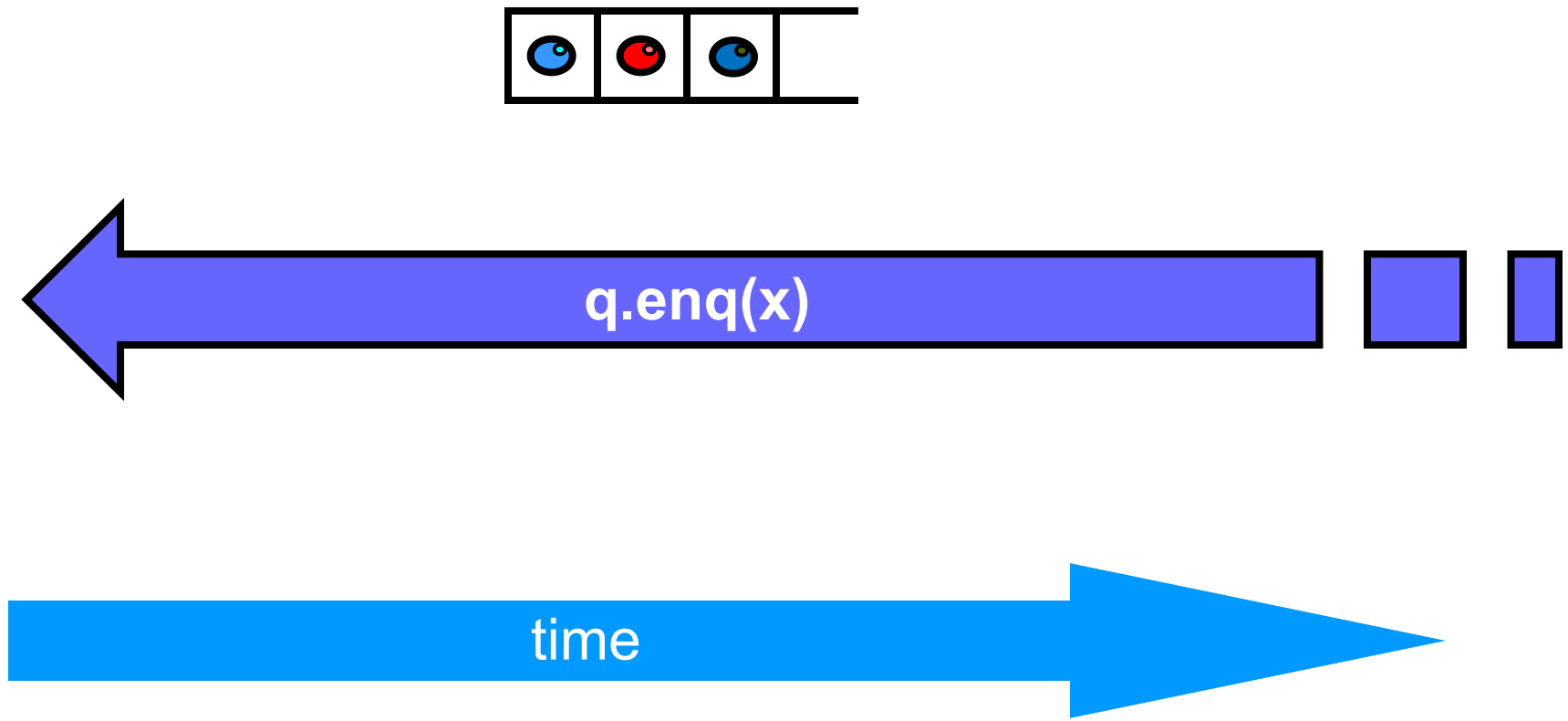

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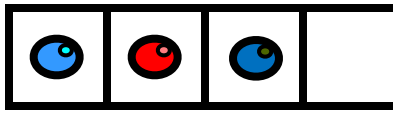

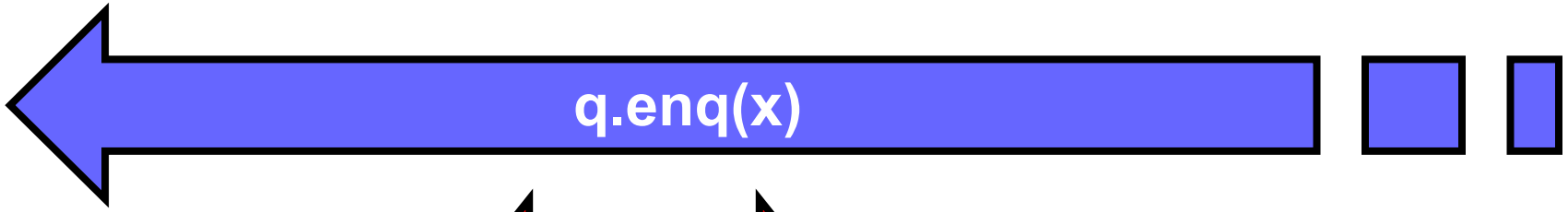

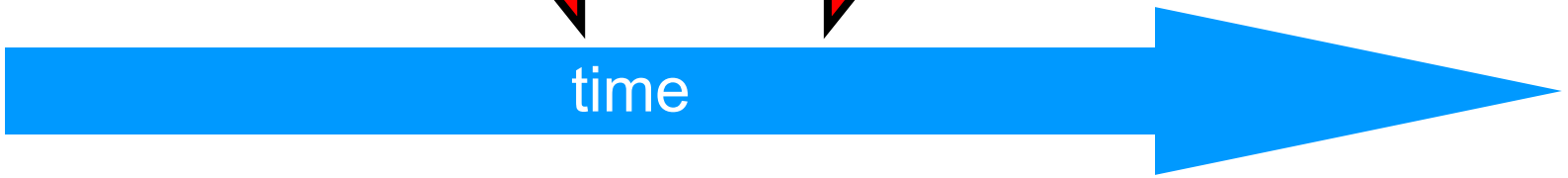

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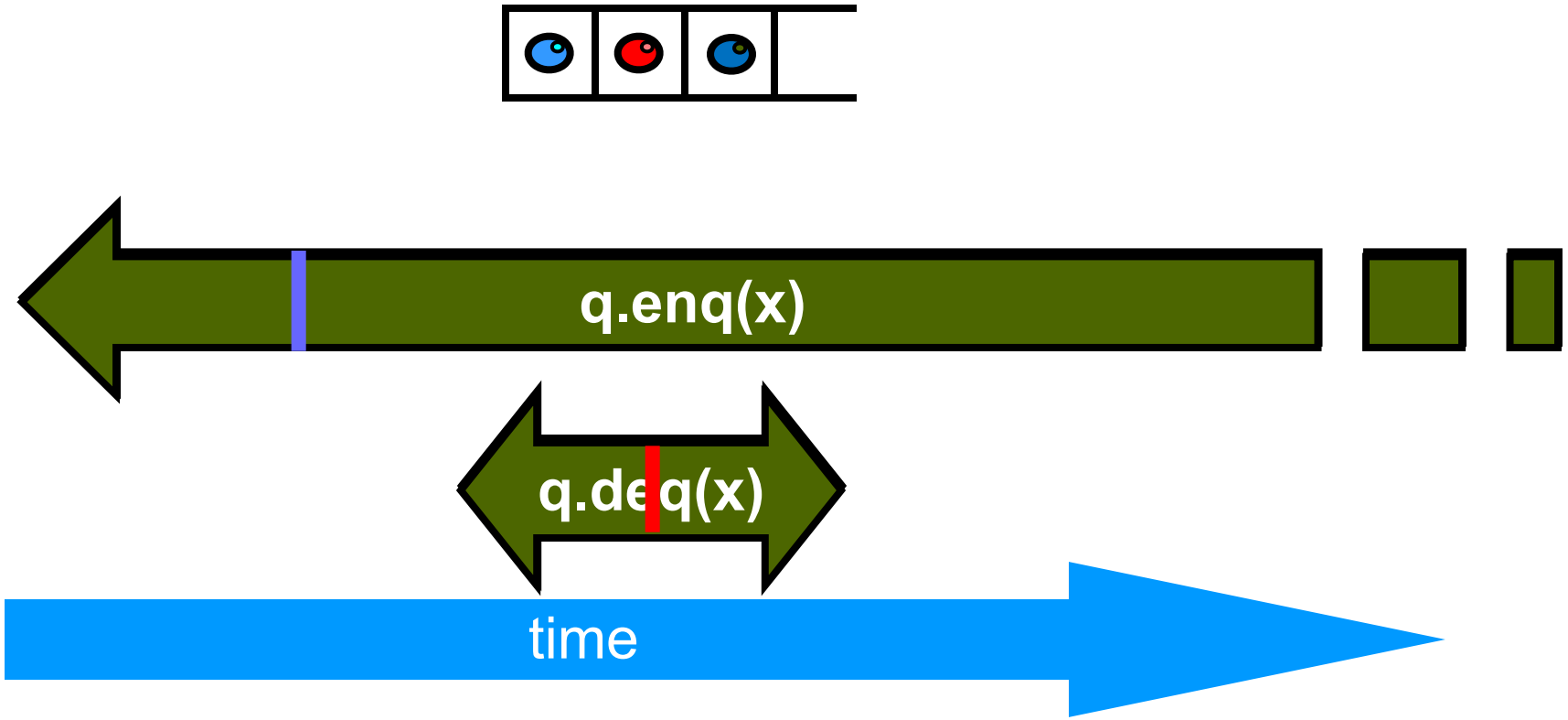

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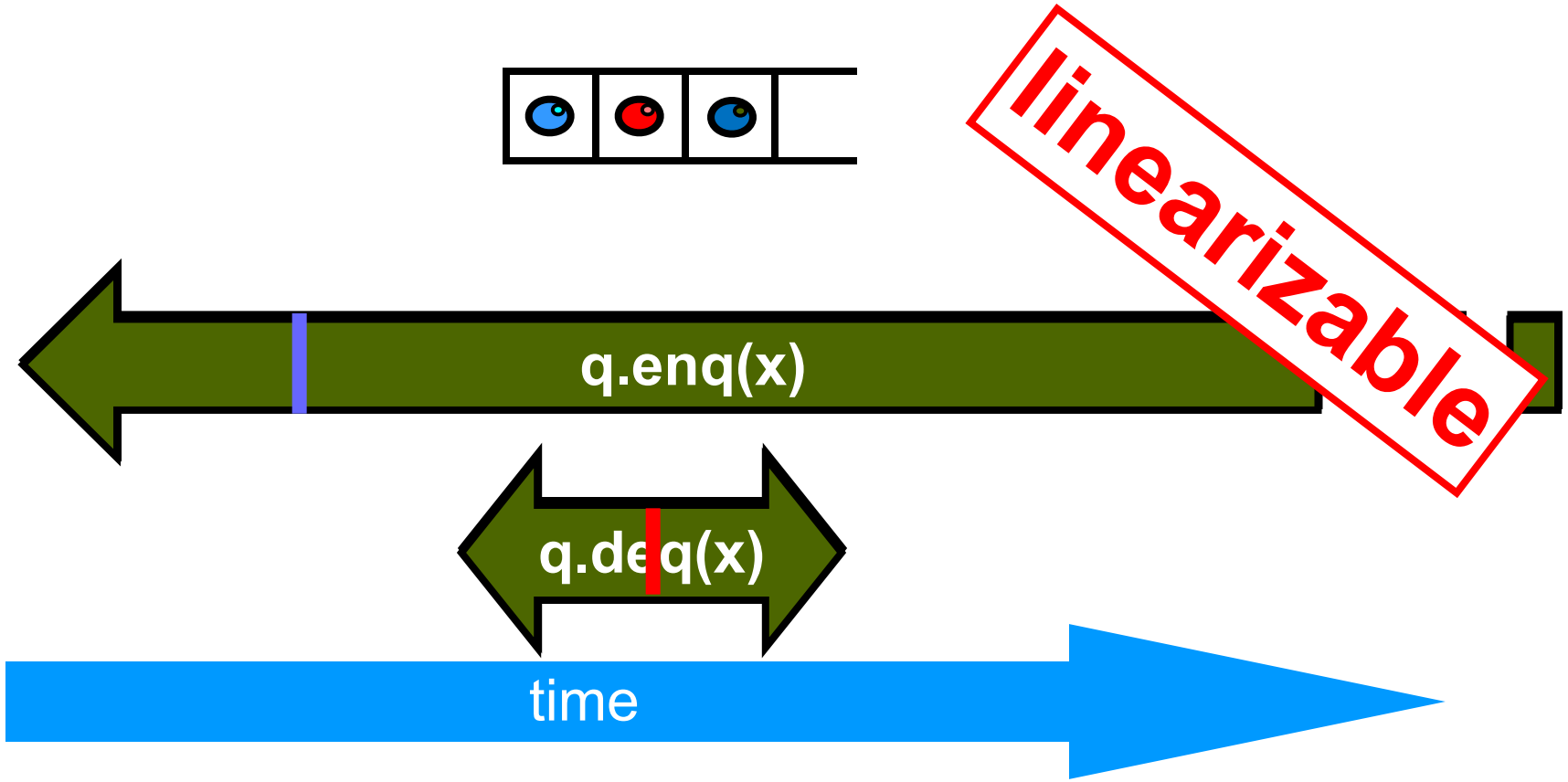

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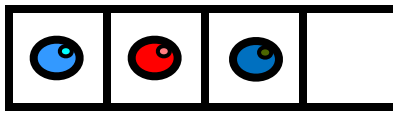

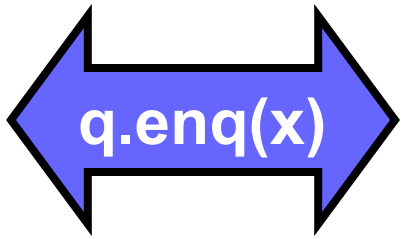

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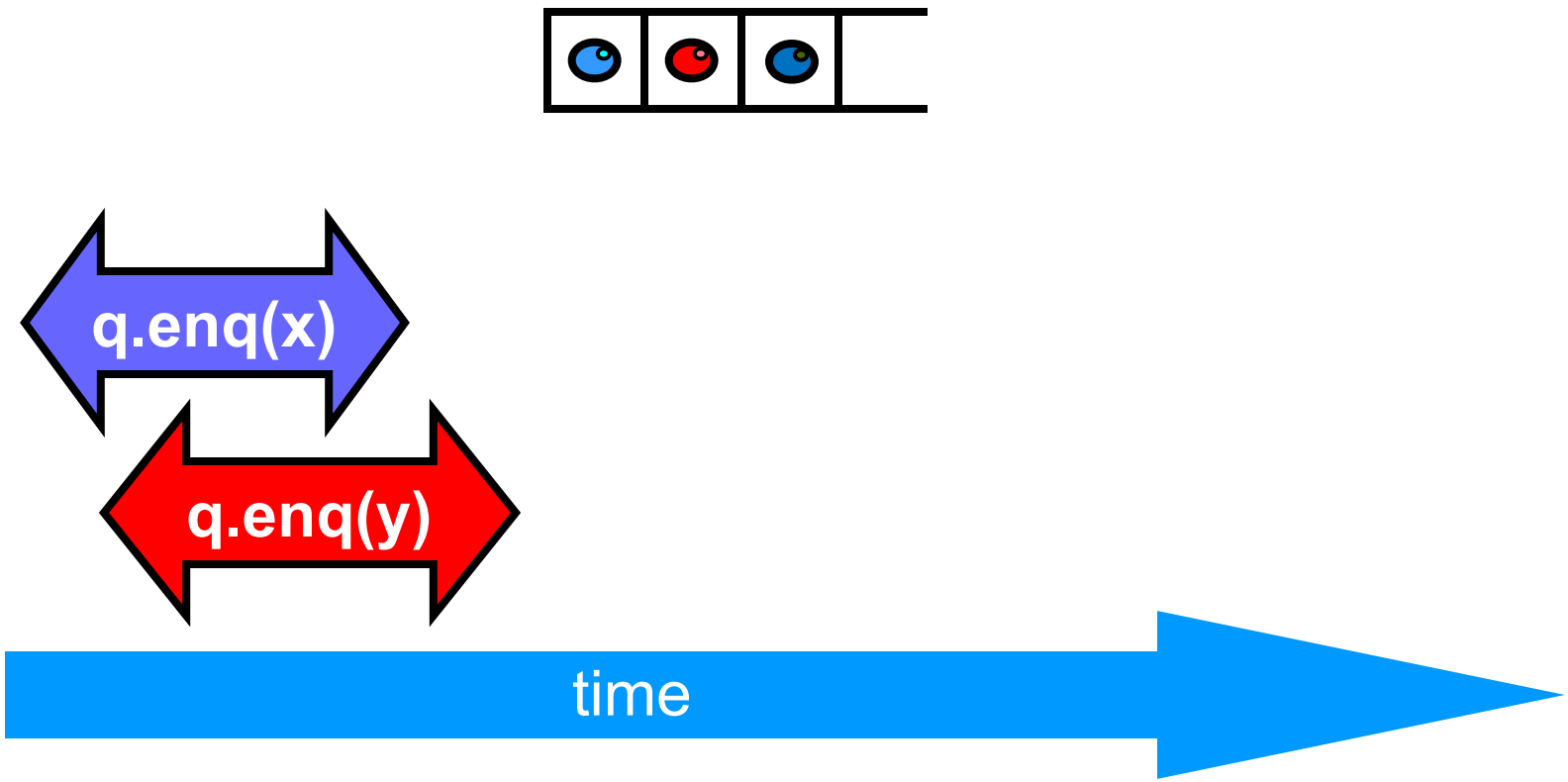

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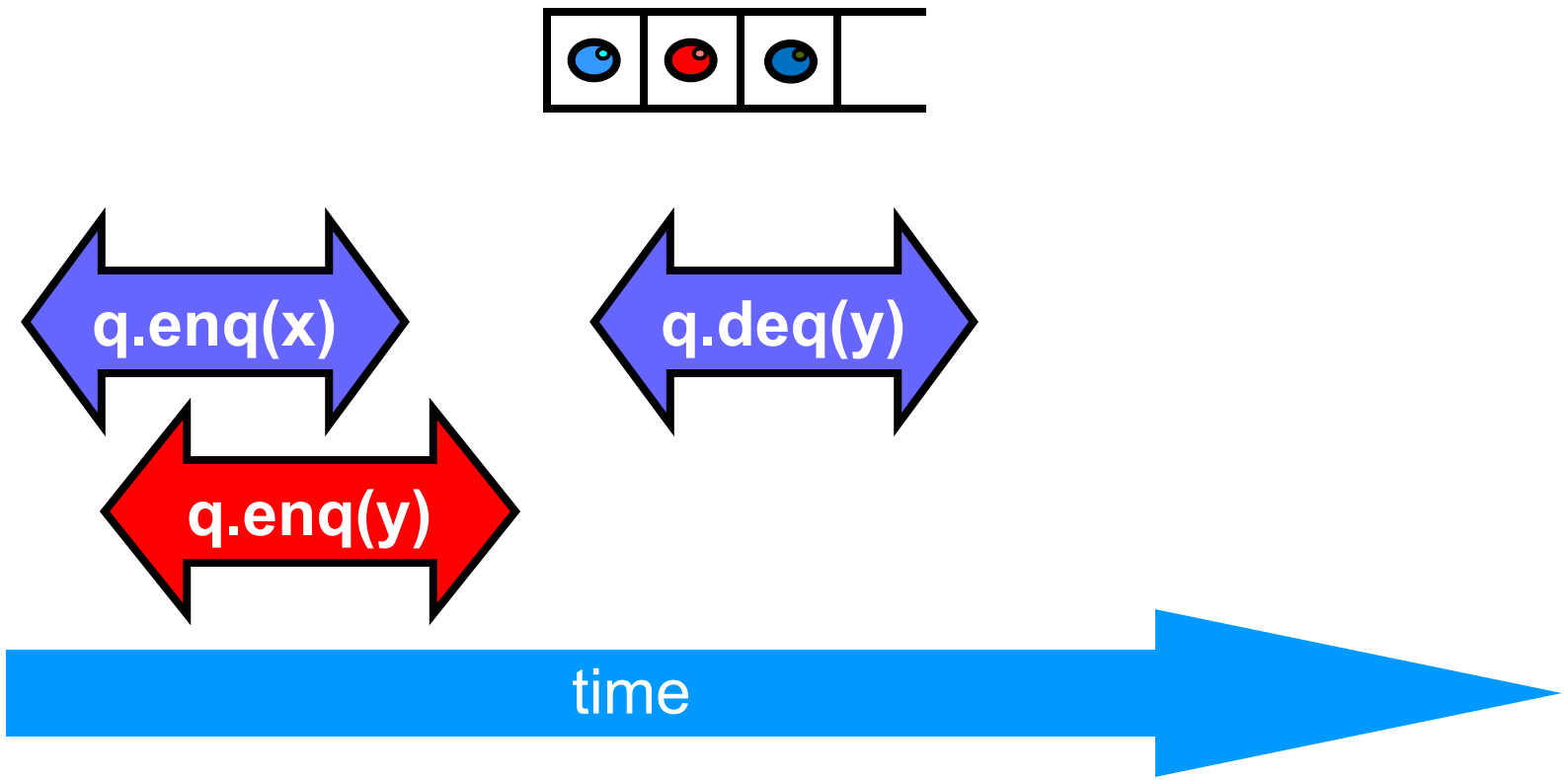

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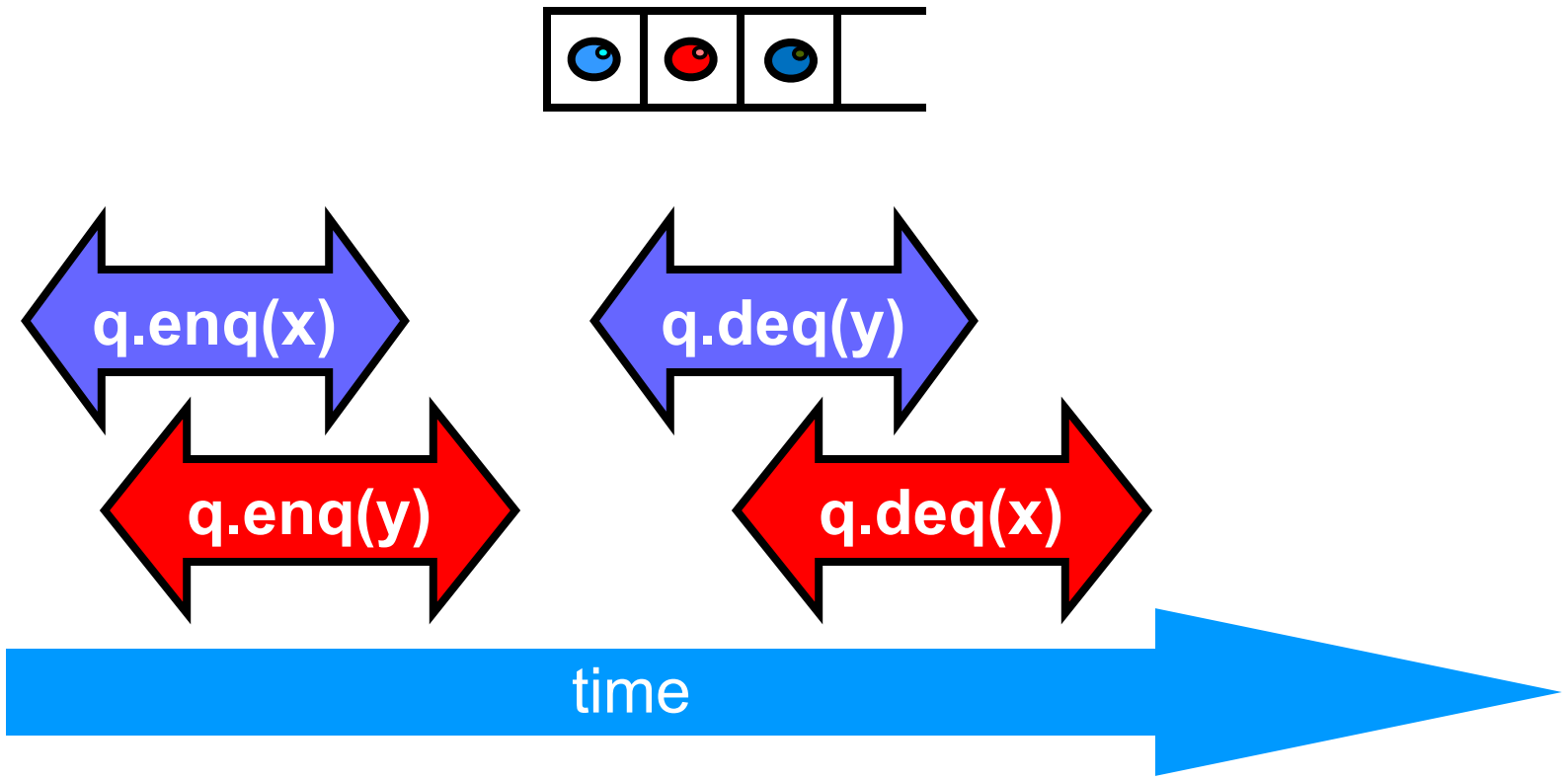

Comme ci
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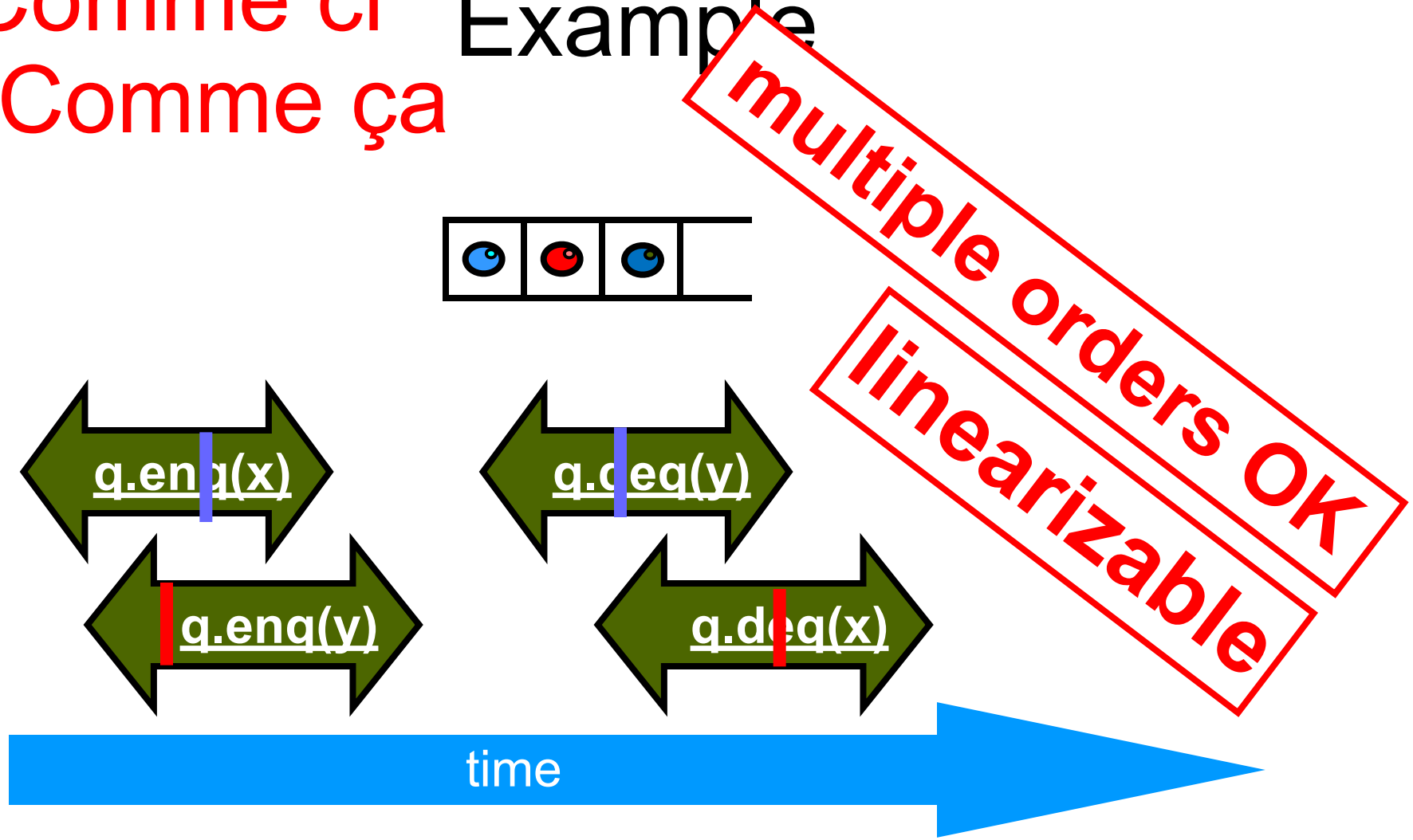
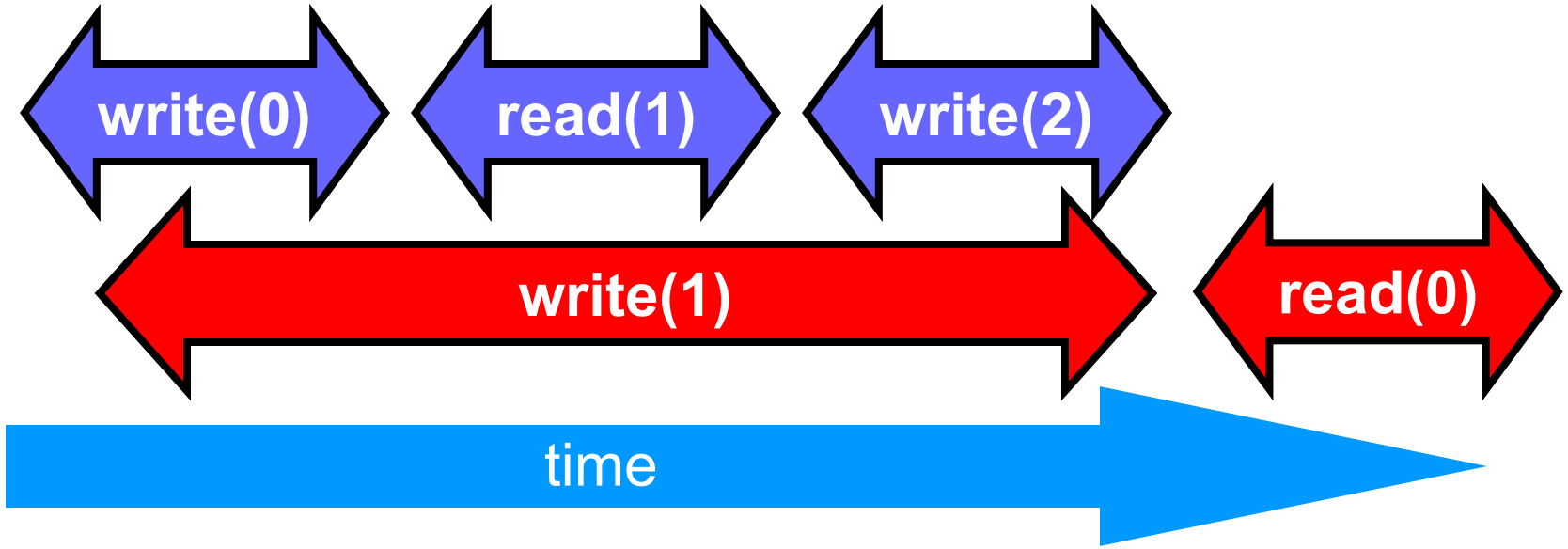
Example



Read/Write Register Example



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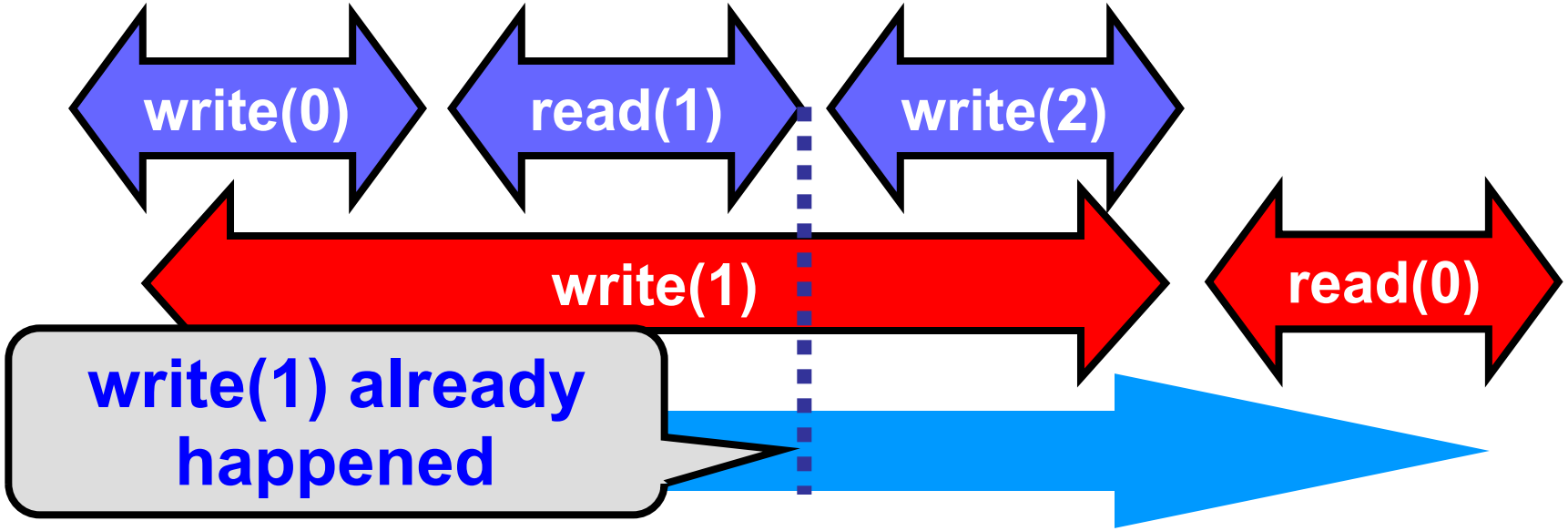

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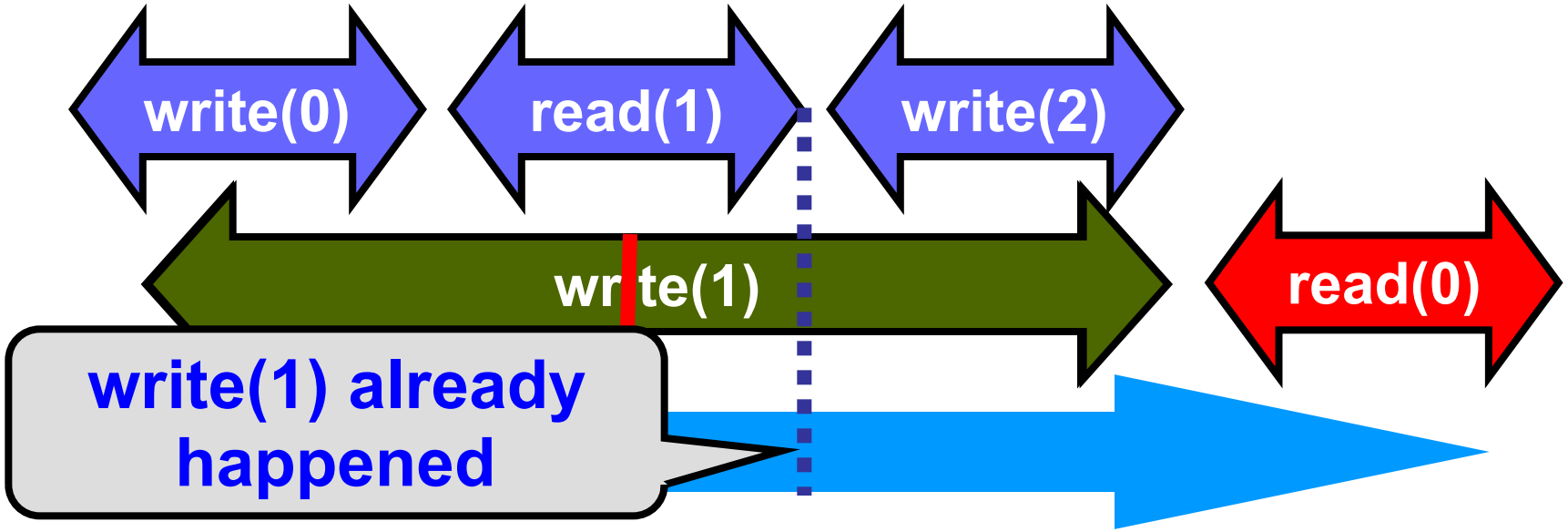

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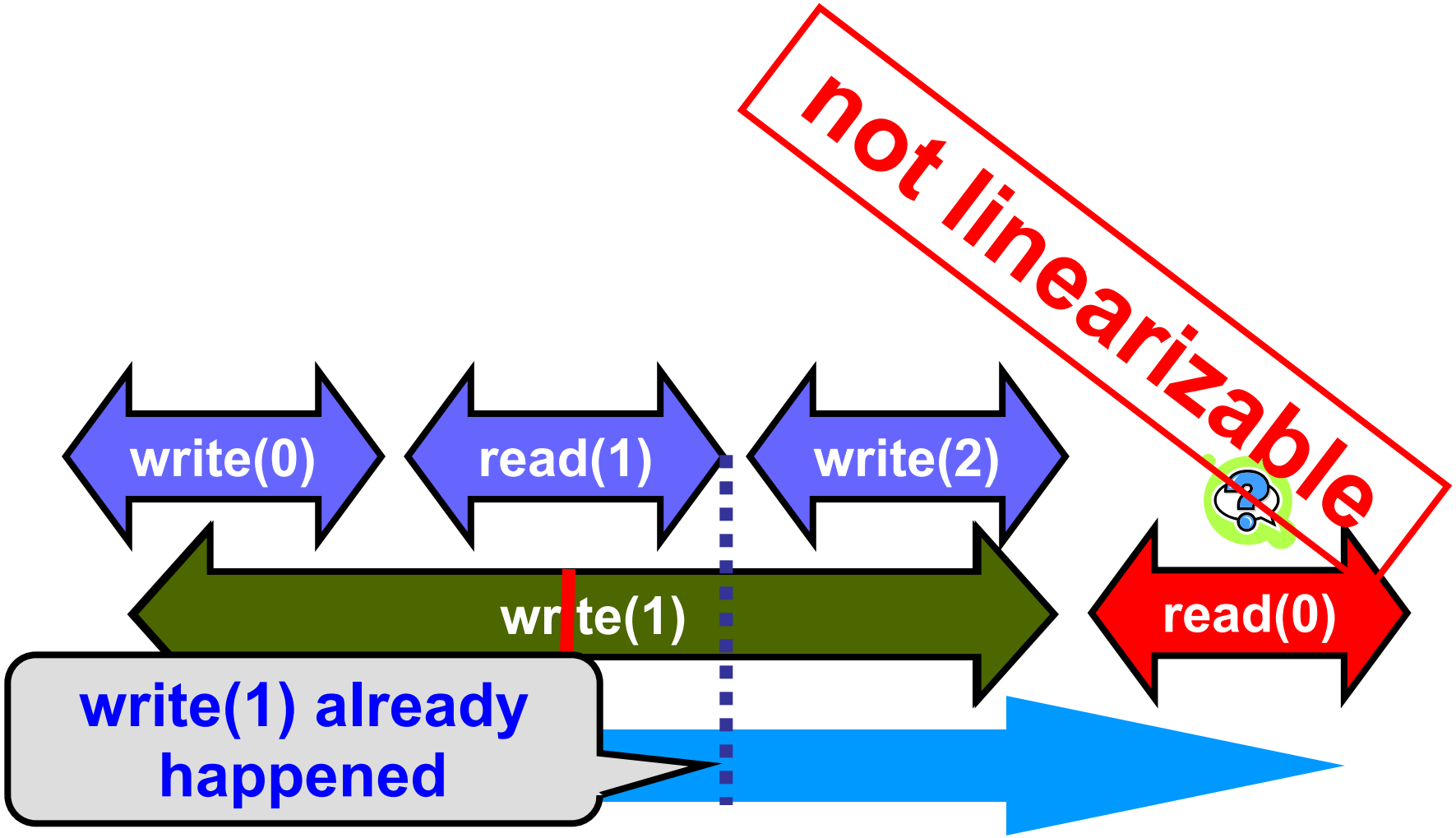

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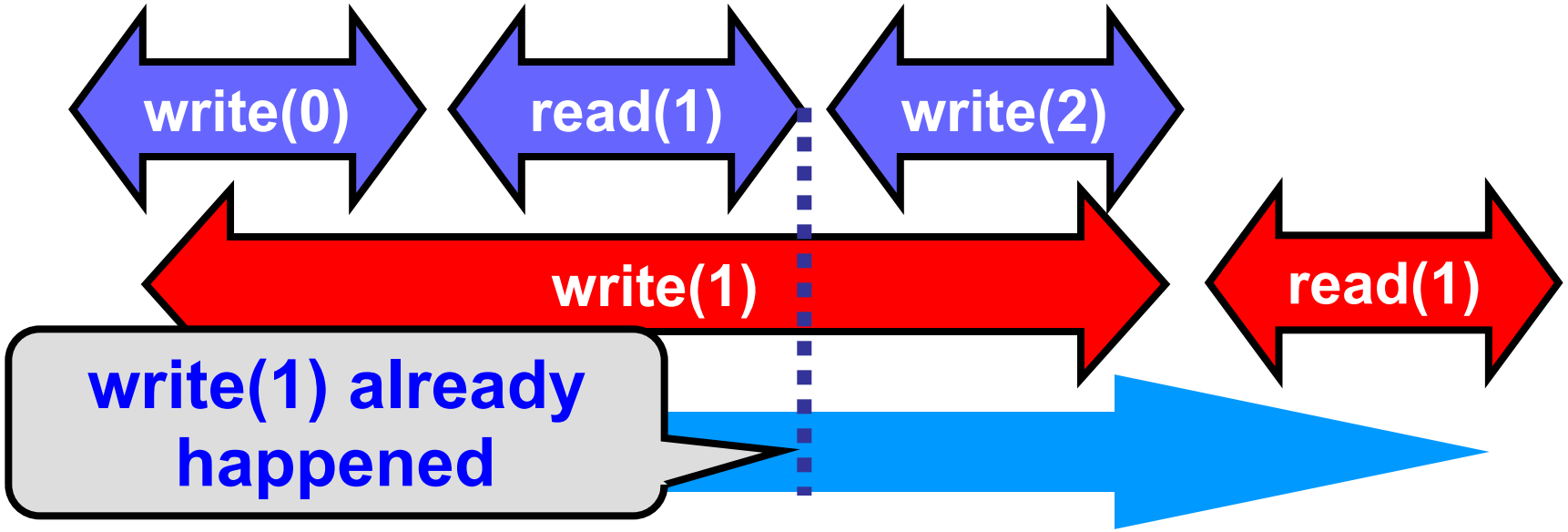

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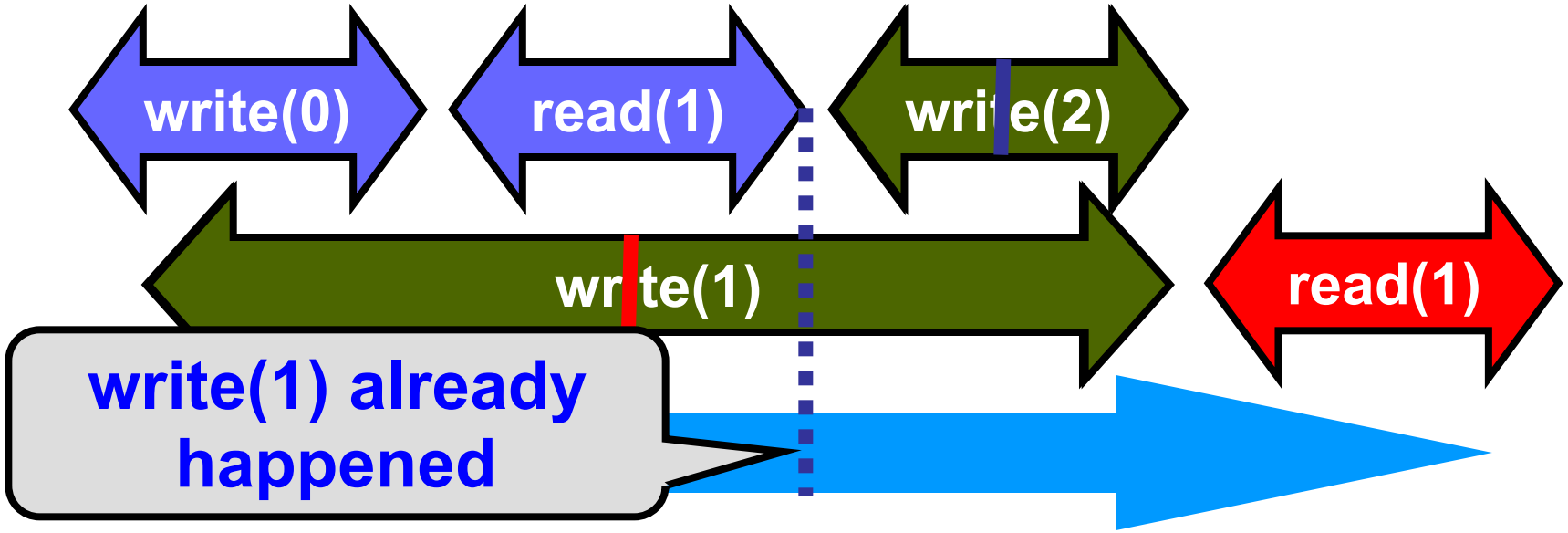

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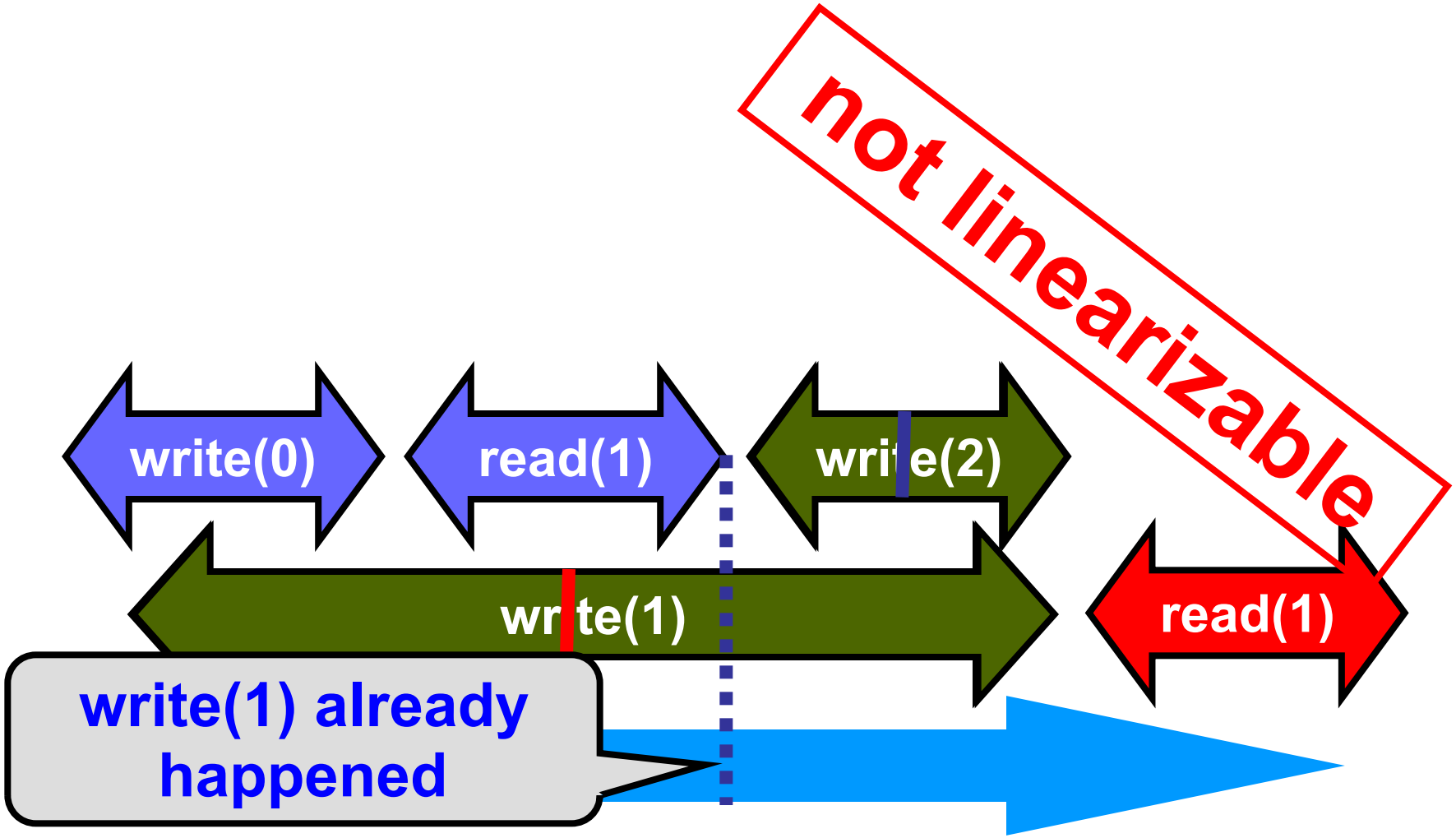

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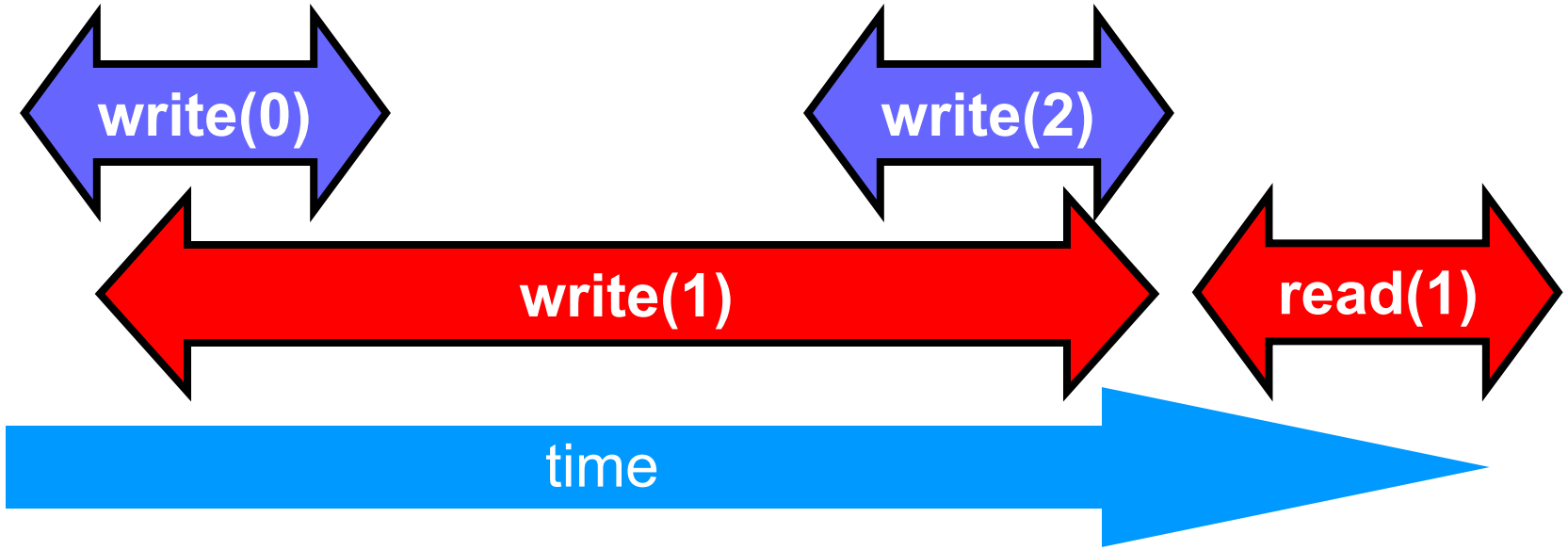

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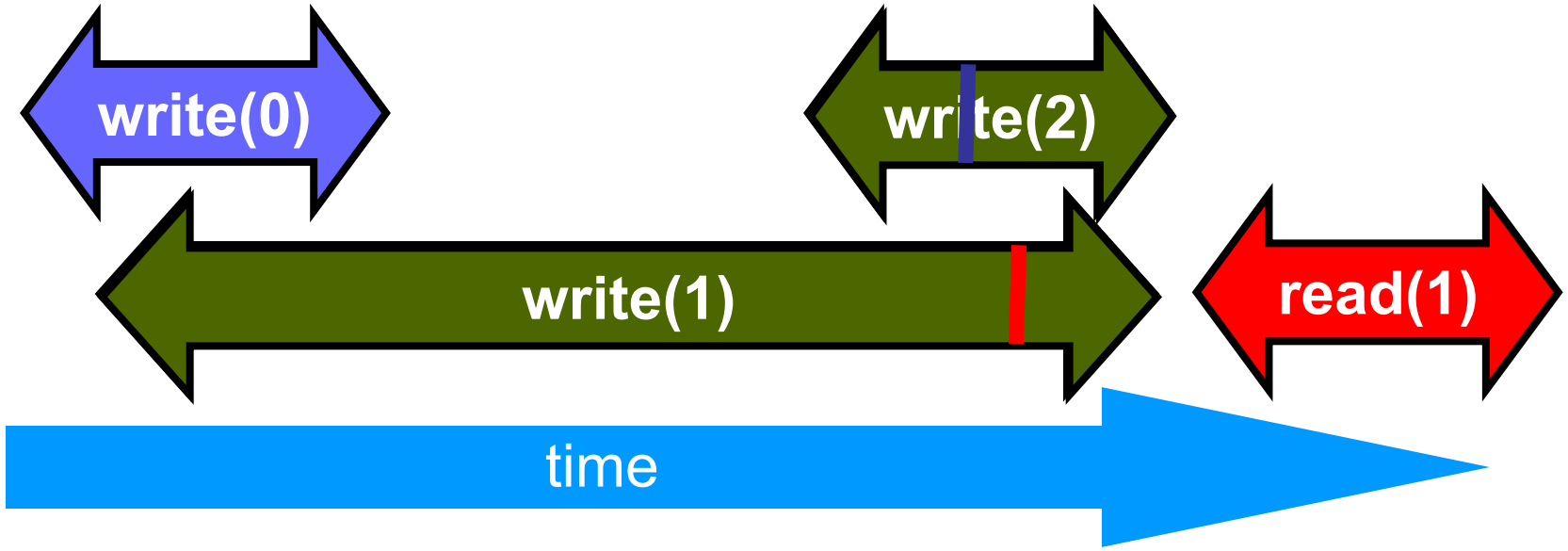

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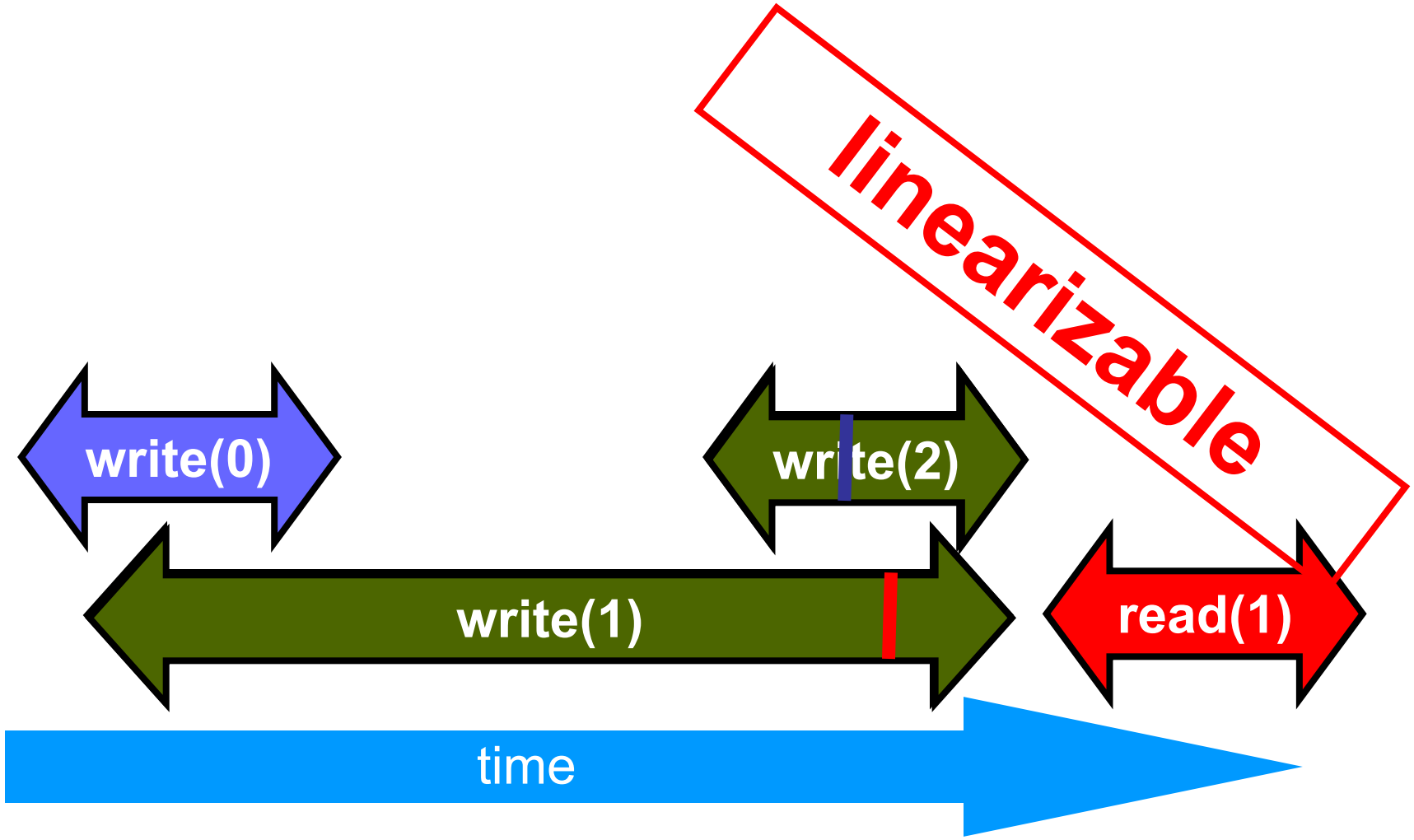

Talking About Executions

- Why?
  - Can’t we specify the linearization point of each operation without describing an execution?
- Not Always
  - In some cases, linearization point ***depends on the execution***

Let's stop here for today

Next lecture:
formal model for linearizability