The Specific Notification Pattern: “Fair” Semaphore Semantics

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Learning Objectives in this Part of the Lesson

- Understand the *Specific Notification* pattern
- Be aware of the semantics of “fair” semaphores

Class Semaphore

java.lang.Object
    java.util.concurrent.Semaphore

All Implemented Interfaces:

`Serializable`

```
public class Semaphore
extends Object
implements Serializable
```

A counting semaphore. Conceptually, a semaphore maintains a set of permits. Each `acquire()` blocks if necessary until a permit is available, and then takes it. Each `release()` adds a permit, potentially releasing a blocking acquirer. However, no actual permit objects are used; the `Semaphore` just keeps a count of the number available and acts accordingly.

Semaphores are often used to restrict the number of threads than can access some (physical or logical) resource. For example, here is a class that uses a semaphore to control access to a pool of items:

An Overview of Fair Semaphore Semantics

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- Threads calling acquire() on a "fair" semaphore obtain permits in "first-in, first-out" (FIFO) order

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See docs.oracle.com/javase/8/docs/api/java/util/concurrent/Semaphore.html

Overview of Fair Semaphore Semantics

- Threads calling acquire() on a "fair" semaphore obtain permits in "first-in, first-out" (FIFO) order
  - FIFO ordering applies to internal points of execution within semaphore methods

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Overview of Fair Semaphore Semantics

- Threads calling acquire() on a "fair" semaphore obtain permits in "first-in, first-out" (FIFO) order
  - FIFO ordering applies to internal points of execution within semaphore methods
    - e.g., one thread can invoke acquire() *before* another, but reach the ordering point *after* the other

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Overview of Fair Semaphore Semantics

- Threads calling acquire() on a "fair" semaphore obtain permits in "first-in, first-out" (FIFO) order
  - FIFO ordering applies to internal points of execution within semaphore methods
  - The *Specific Notification* pattern provides an effective model for implementing fair semaphore semantics

Specific Notification
for
Java Thread Synchronization

Tom Cargill
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Abstract

Java supports thread synchronization by means of monitor-like primitives. The weak semantics of Java's signaling mechanism provides little control over the order in which threads acquire resources, which encourages the use of the Haphazard Notification pattern, in which an *arbitrary* thread is selected from a set of threads competing for a resource. For synchronization problems in which such arbitrary selection of threads is unacceptable, the Specific Notification pattern may be used to designate exactly which thread should proceed. Specific Notification provides an explicit mechanism for thread selection and scheduling.

0. Introduction

To study Java's threads, I first tackled some of the classic exercises, like the "Dining Philosophers" and the "Readers and Writers." The solutions that I obtained were reasonable, but I felt uncomfortable with the degree to which I had to depend on serendipitous treatment with respect to contention for locks and notifications. The solutions were free of deadlock, but were not fair in all circumstances. I thought I might

threads could have active requests outstanding with an NNTP server. The fundamental correctness of this class depended on waiting threads being reactivated in *exactly* the right order to receive their responses from the server. In coding this class I applied the Specific Notification mechanism described below. With new insight, I returned to the earlier exercises and found that Specific Notification provided complete solutions to those problems. I therefore propose the Specific Notification pattern.

See www.dre.vanderbilt.edu/~schmidt/PDF/specific-notification.pdf (especially Listing 3)

End of the Specific Notification Pattern: Fair Semaphore Semantics

The Specific Notification Pattern: Implementing a “Fair” Semaphore

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Learning Objectives in this Part of the Lesson

- Understand the *Specific Notification* pattern
- Be aware of the semantics of "fair" semaphores
- Recognize how to implement a "fair" semaphore using the *Specific Notification* pattern

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Section 1 summarizes the semantics of Java's thread synchronization mechanisms, contrasting them with classical monitors; this section may be omitted by readers who have a detailed

[1] B. Kantor, P. Lapsley, Network News Transfer Protocol, Internic RFC 977, 1986.

1

See www.dre.vanderbilt.edu/~schmidt/PDF/specific-notification.pdf (especially Listing 3)

Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)

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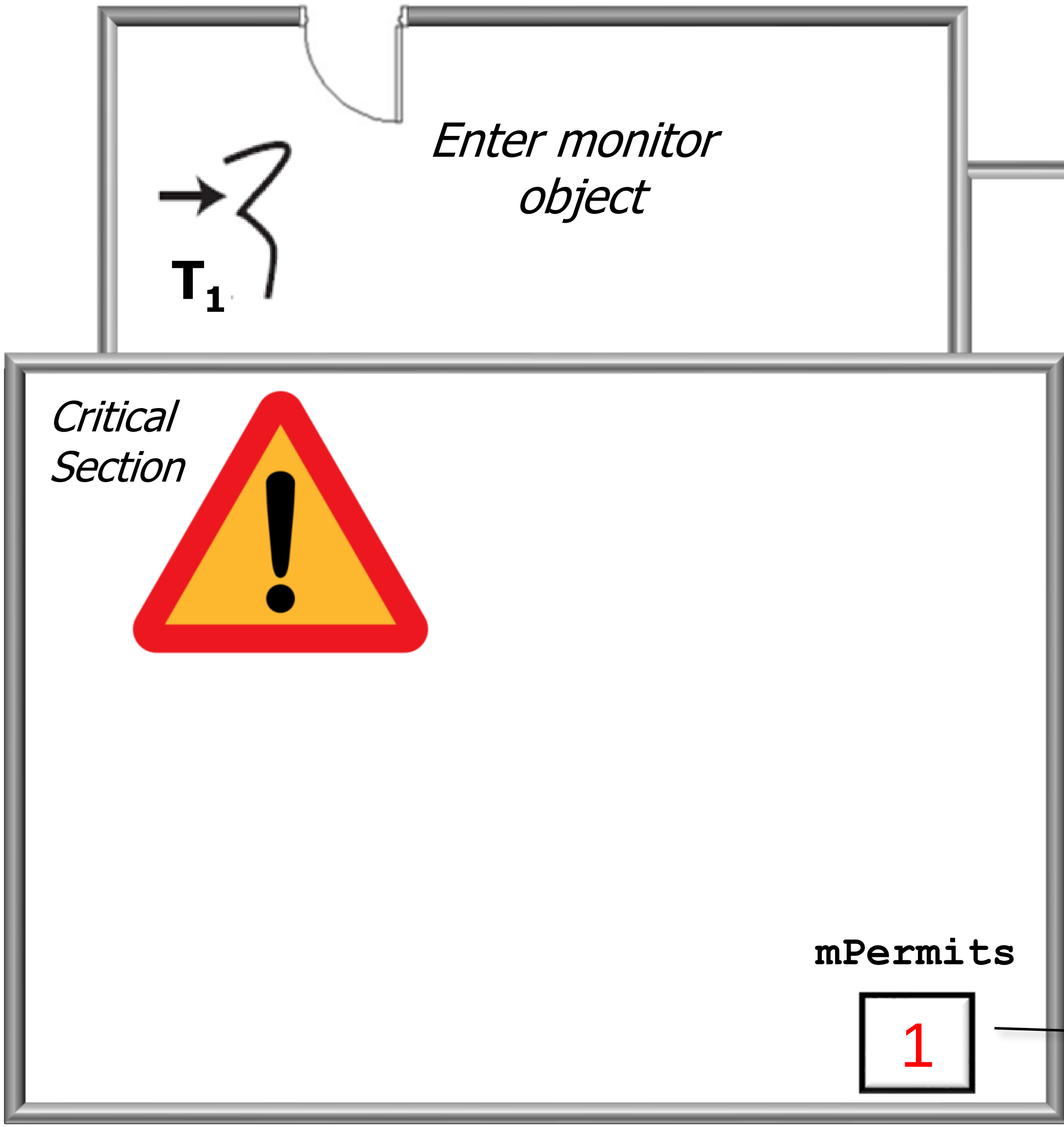
FairSemaphore

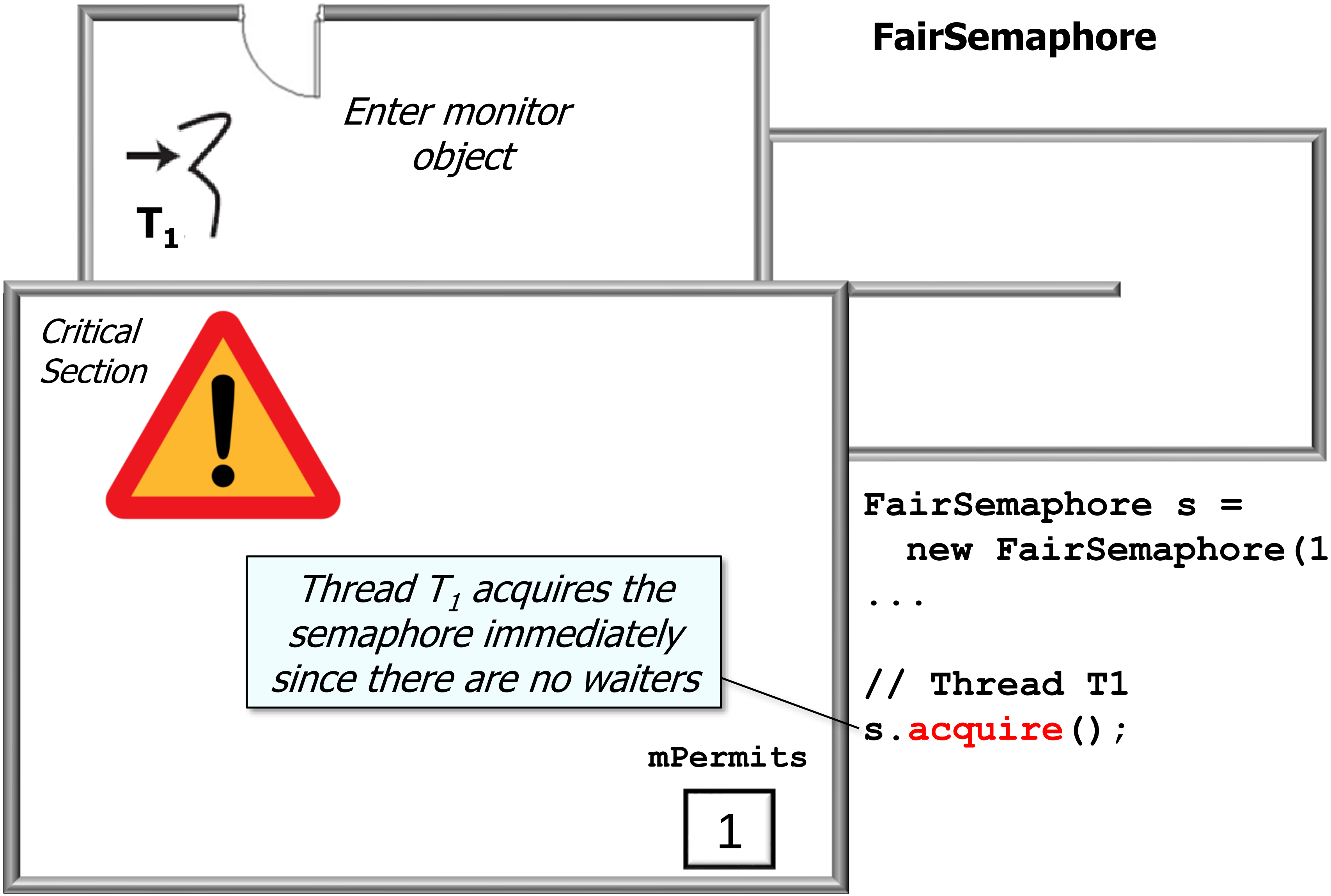



```
FairSemaphore s =
  new FairSemaphore(1);
...

// Thread T1
s.acquire();
```

Create a fair semaphore with a single permit

Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)

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...

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```

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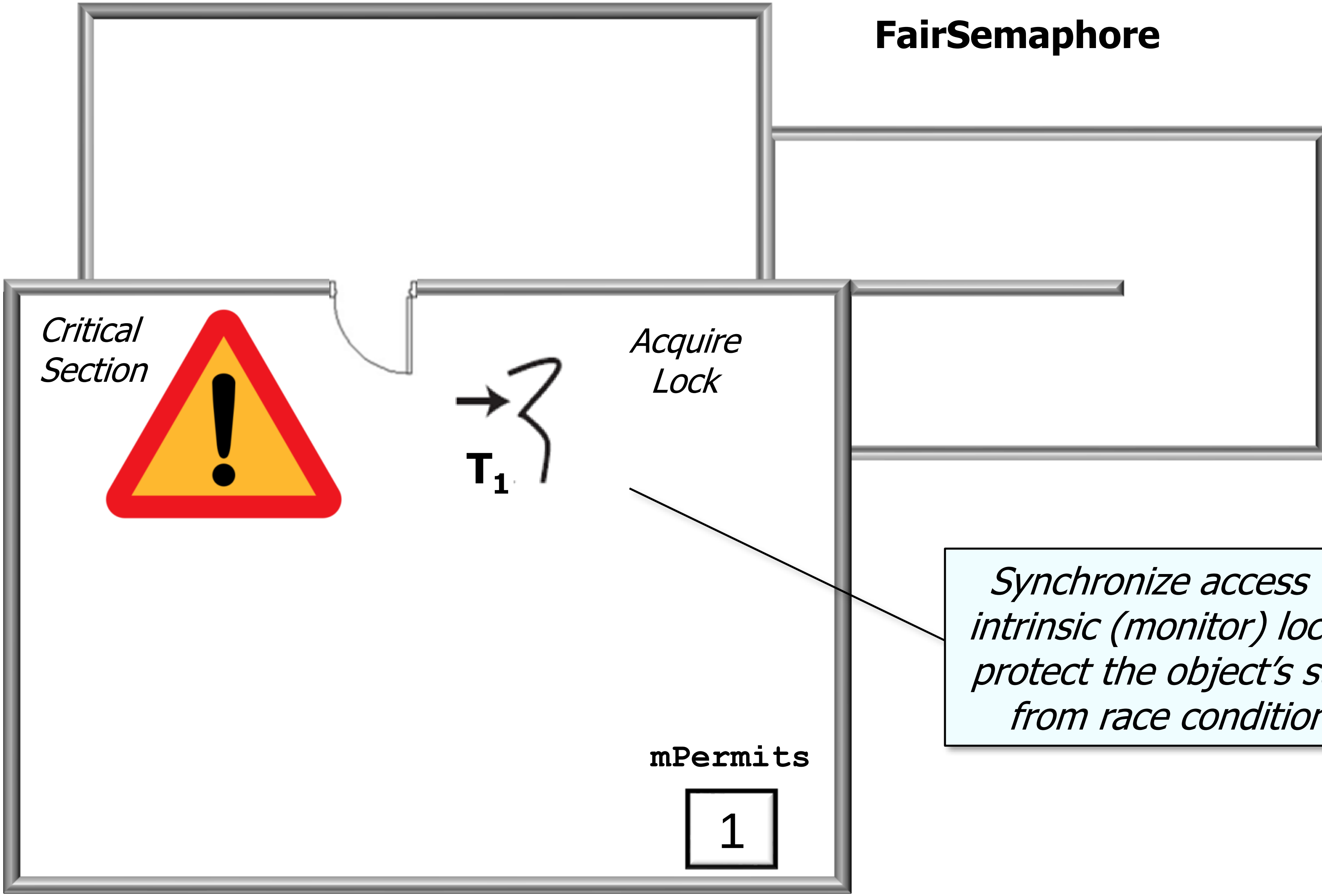
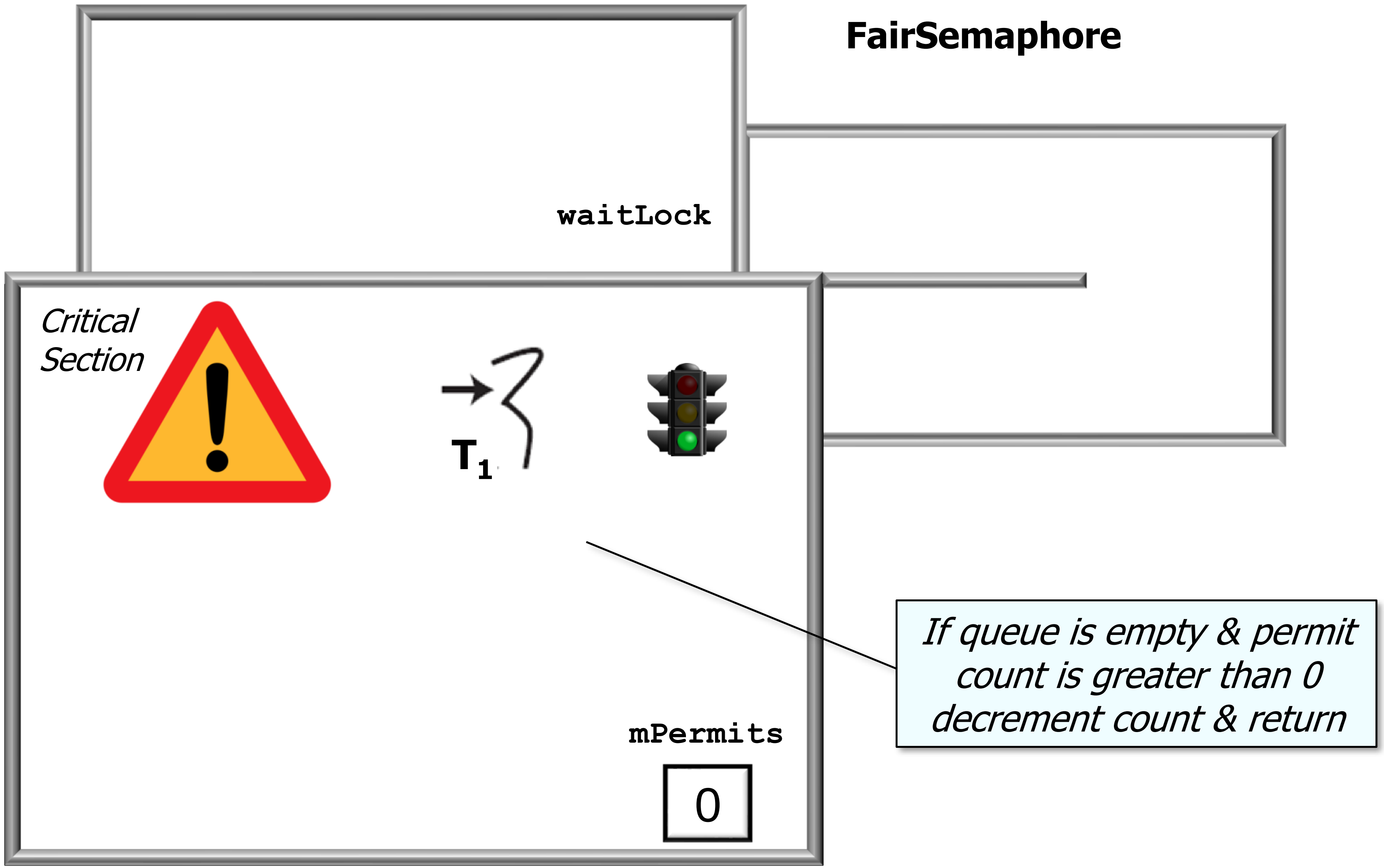


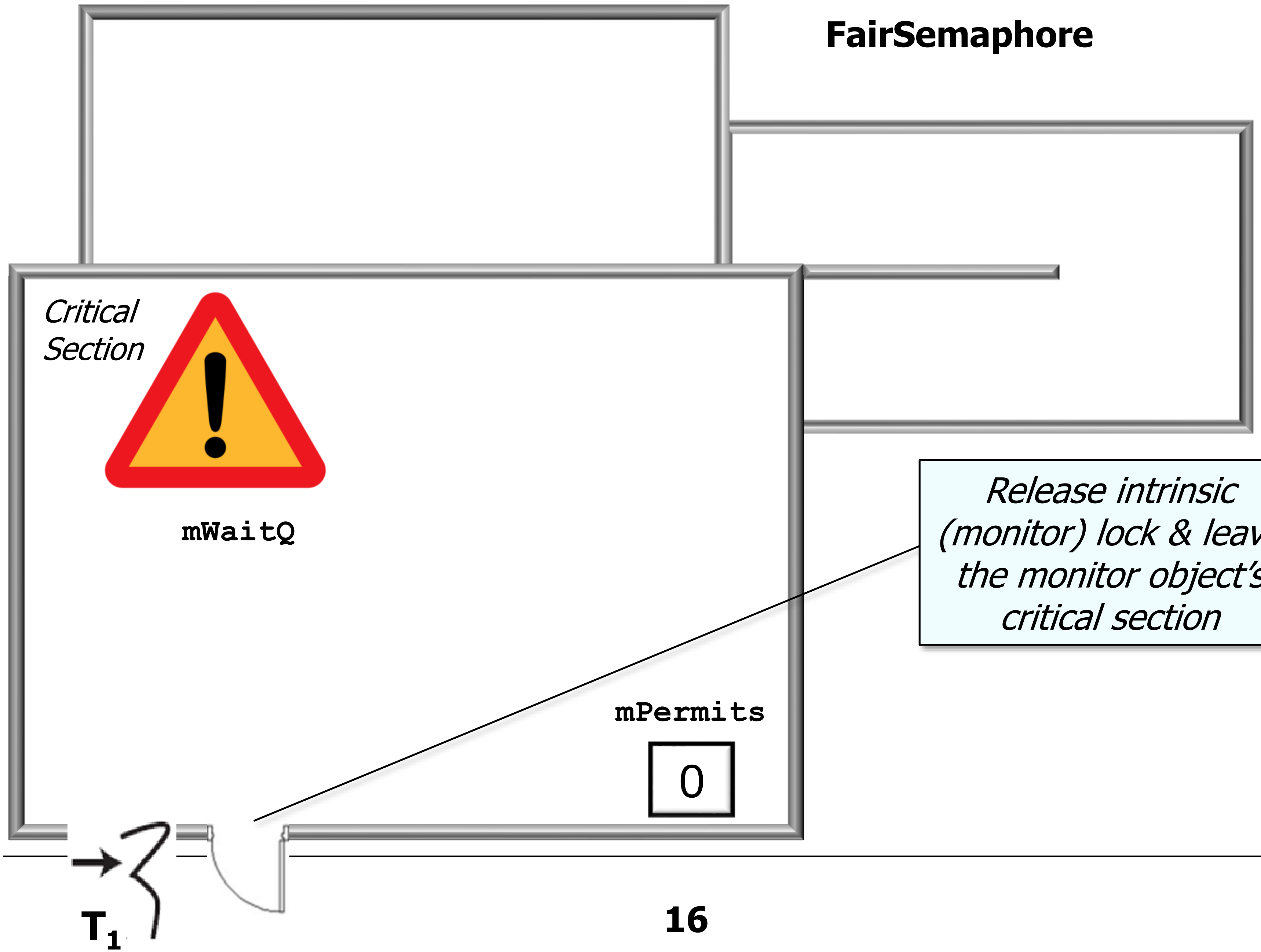
Synchronize access via intrinsic (monitor) lock to protect the object's state from race conditions

Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)



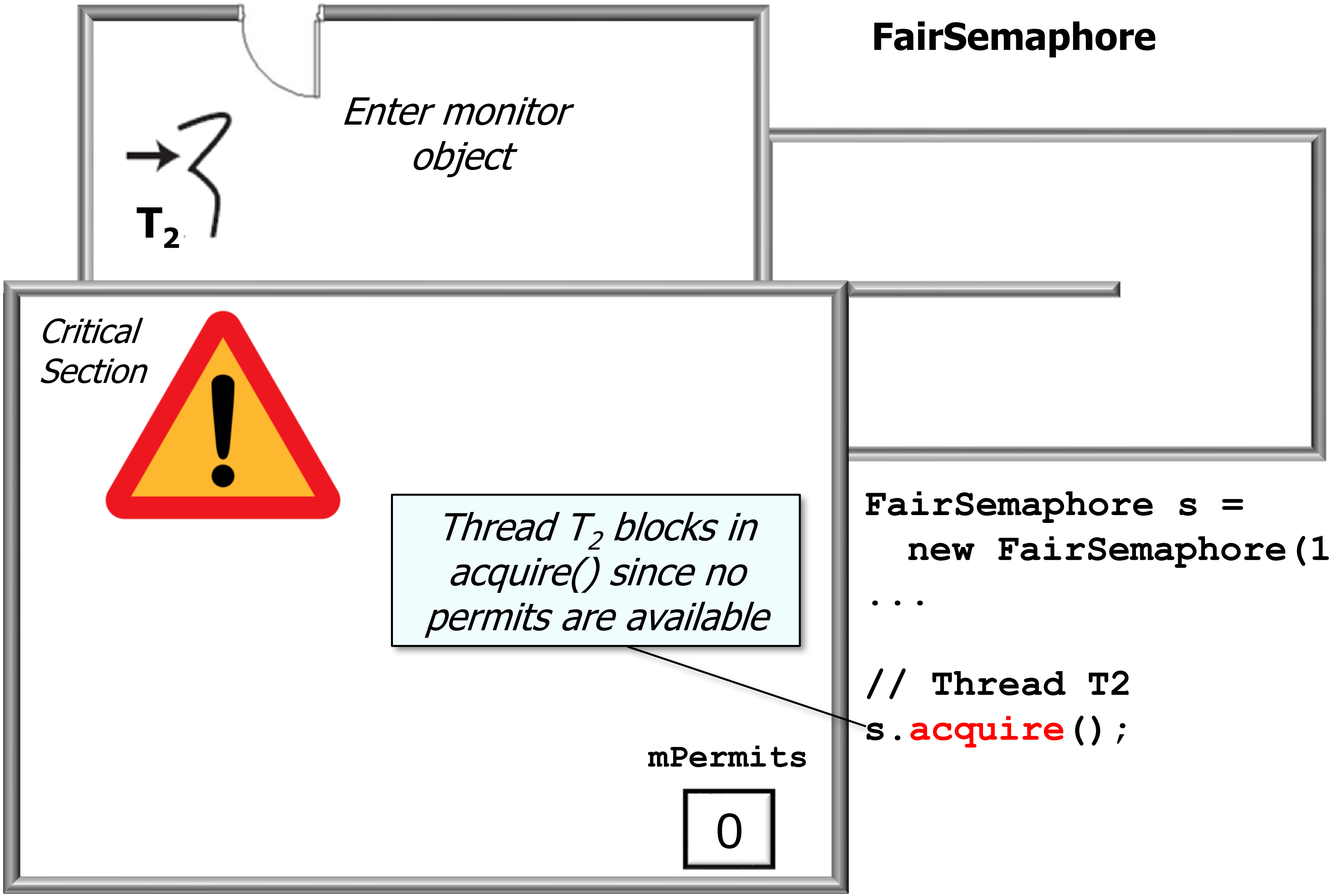
This is the "fast path"

Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)



Release intrinsic (monitor) lock & leave the monitor object's critical section

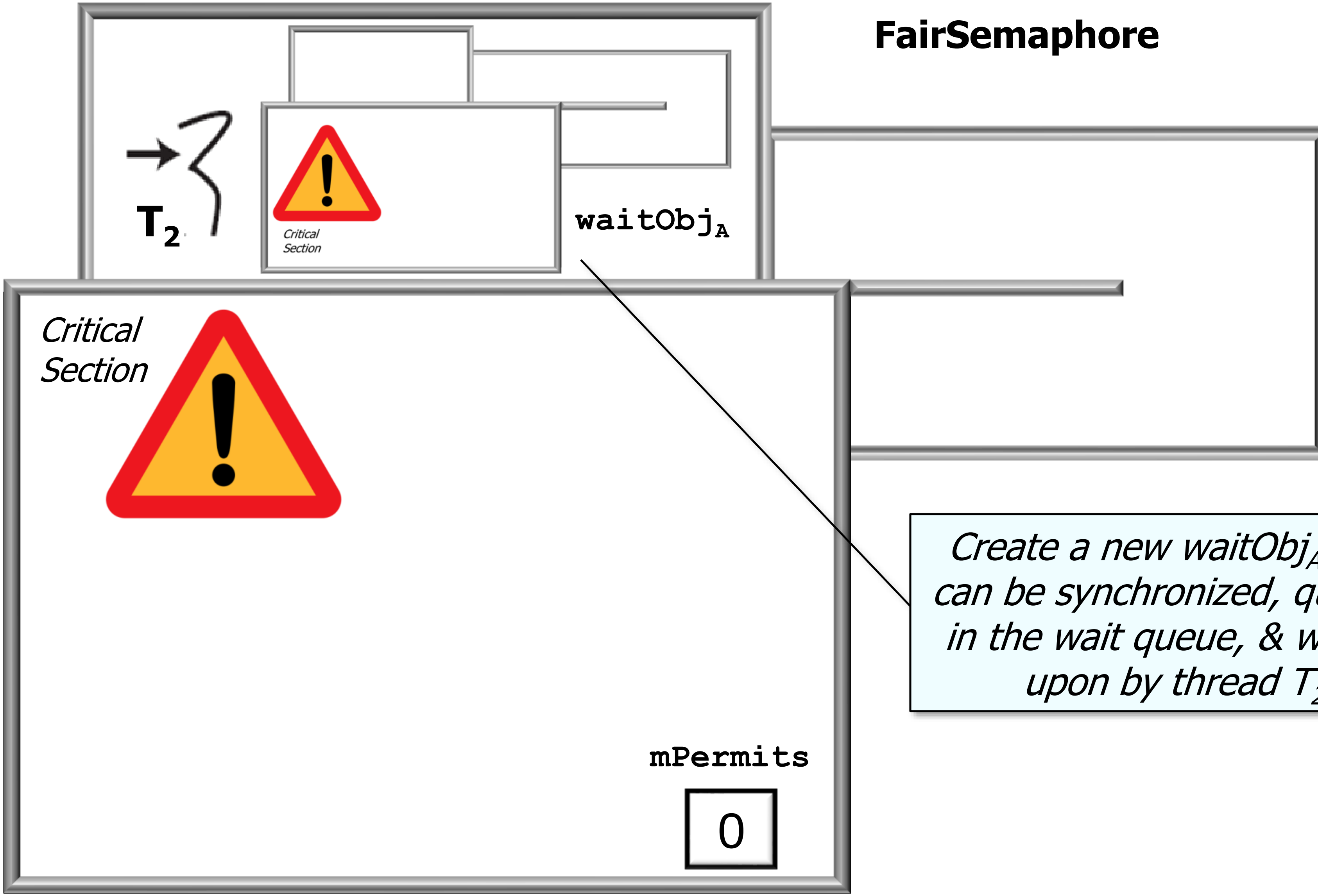
Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)




```
FairSemaphore s =
  new FairSemaphore(1);
...

// Thread T2
s.acquire();
```

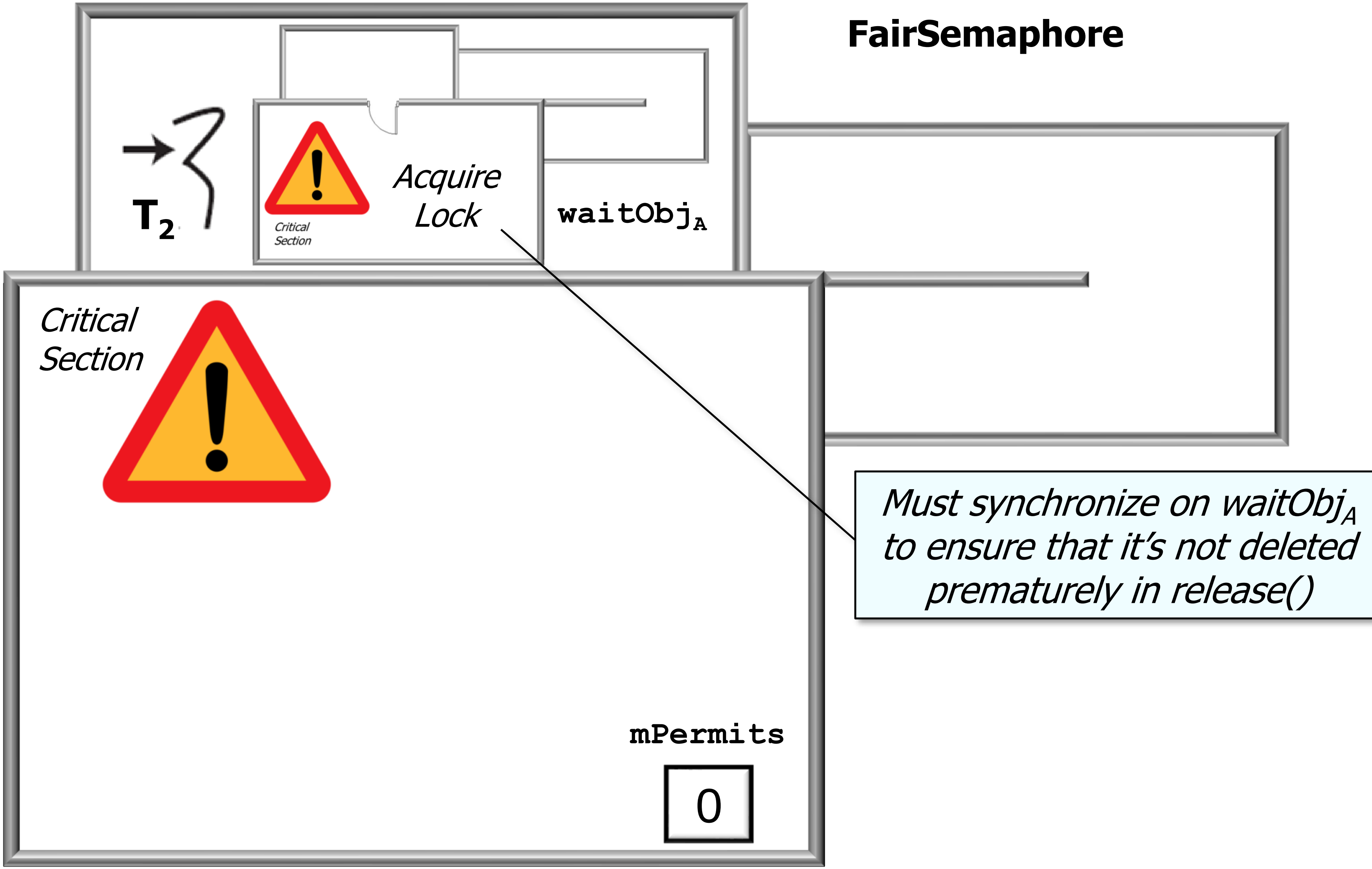
Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)



Create a new $waitObj_A$ that can be synchronized, queued in the wait queue, & waited upon by thread T_2

This waiting happens outside of the FairSemaphore's critical section

Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)



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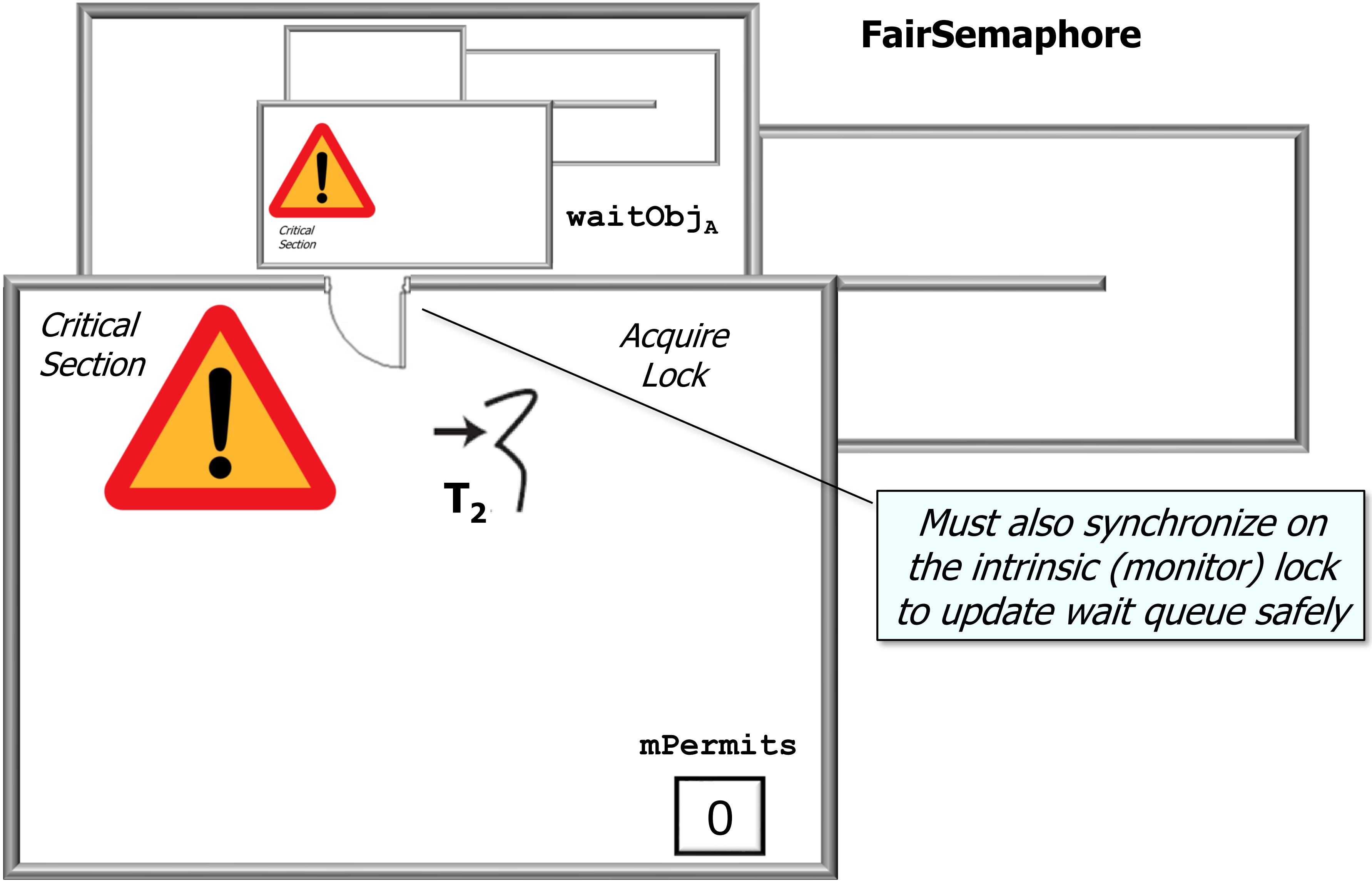

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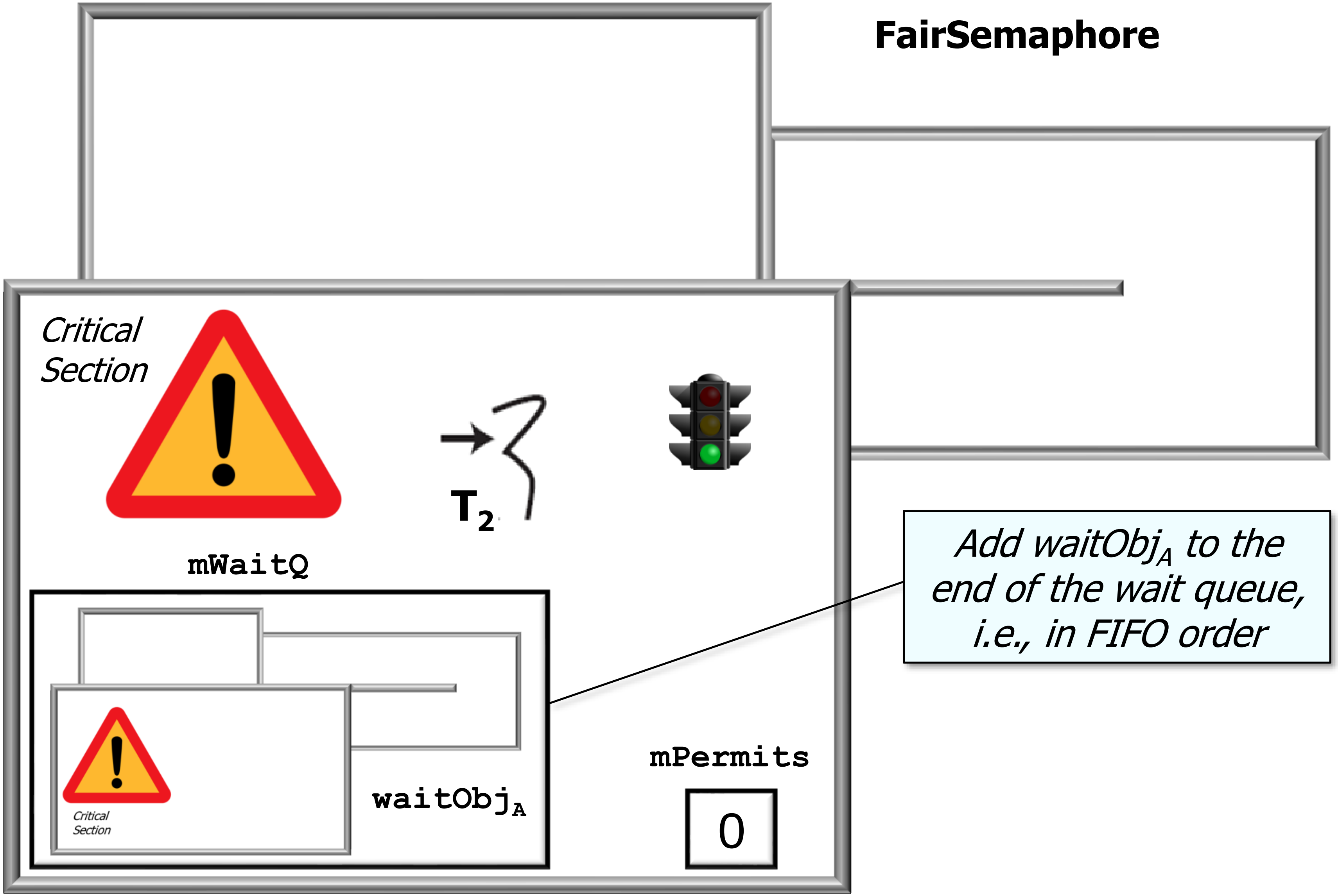

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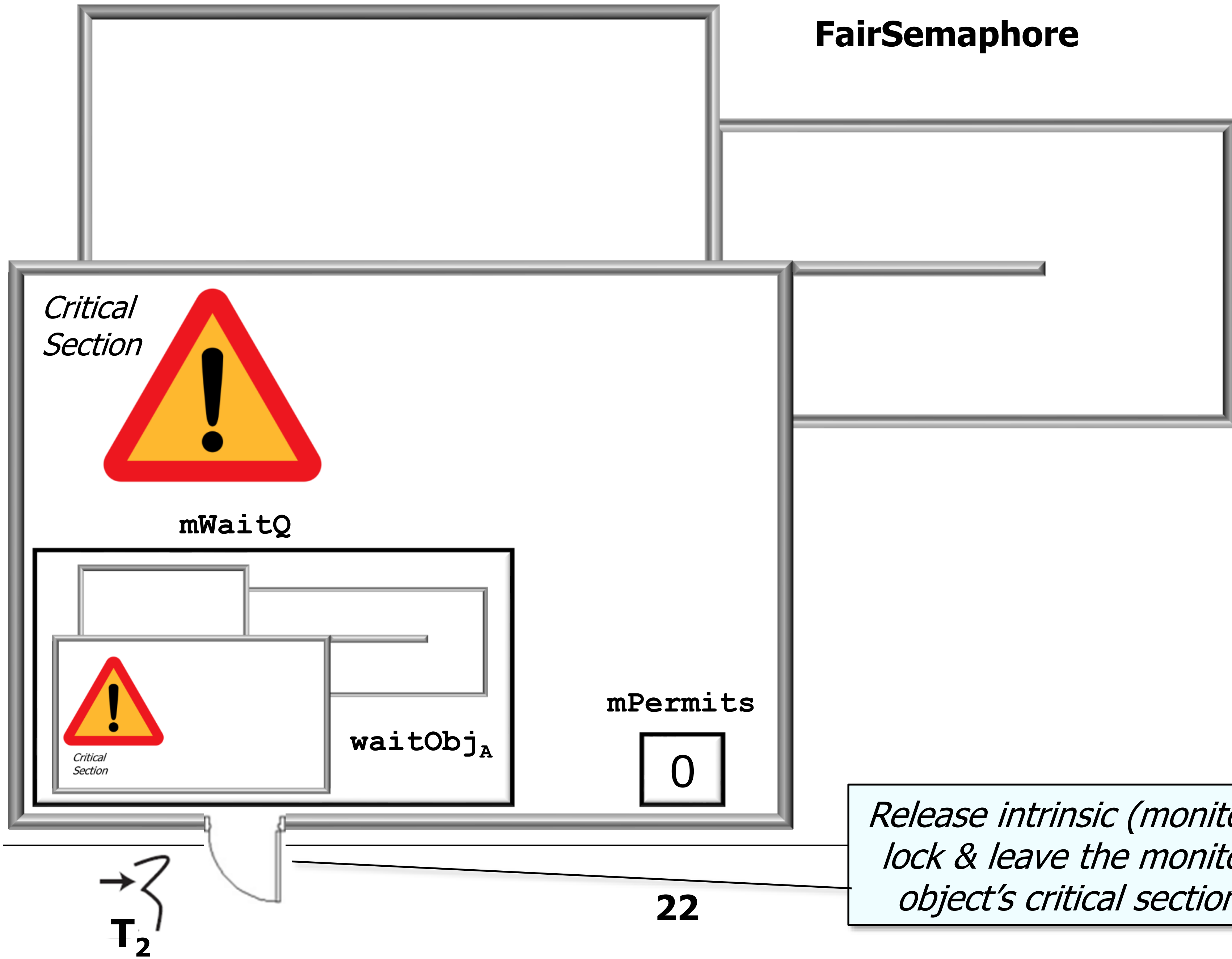

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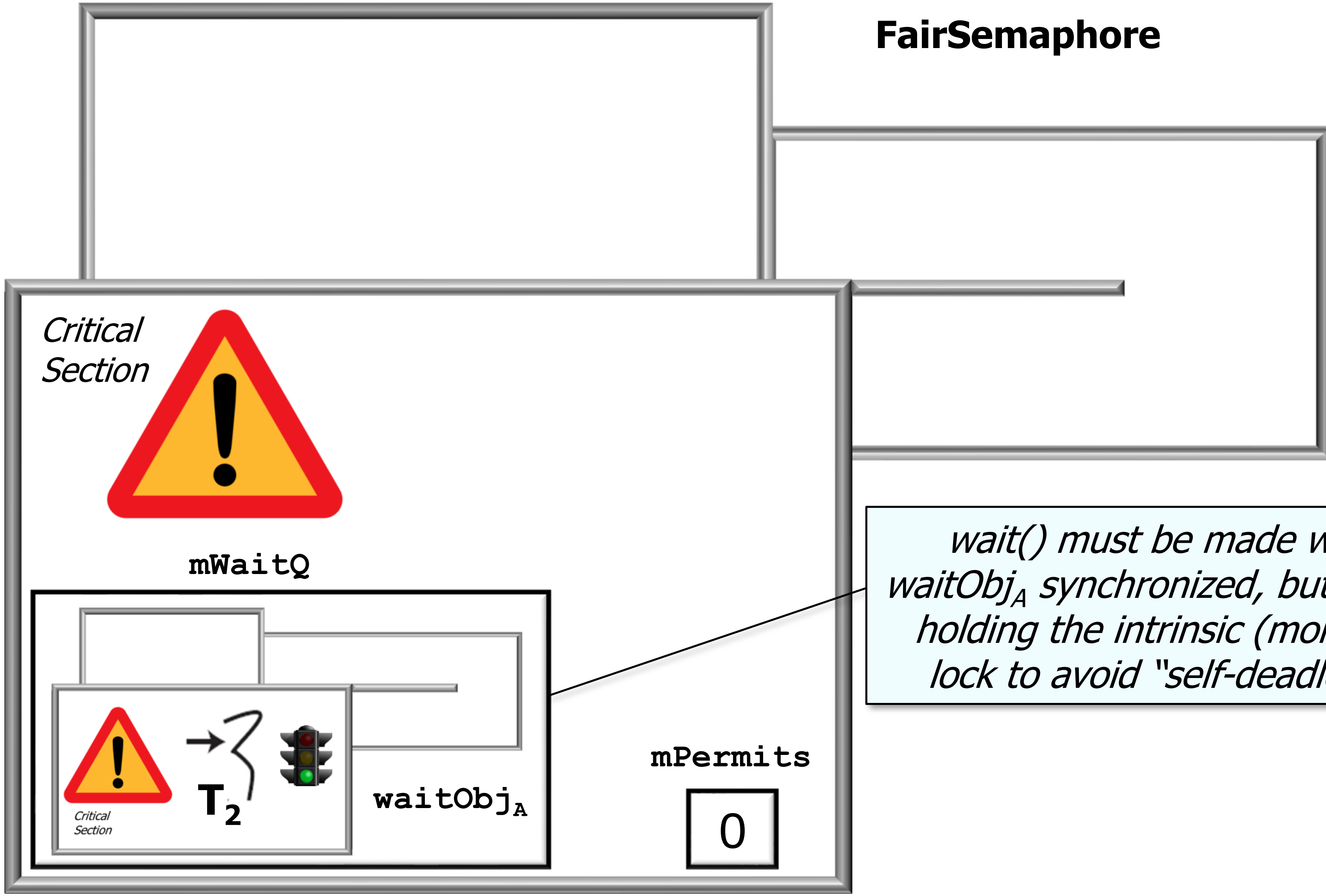
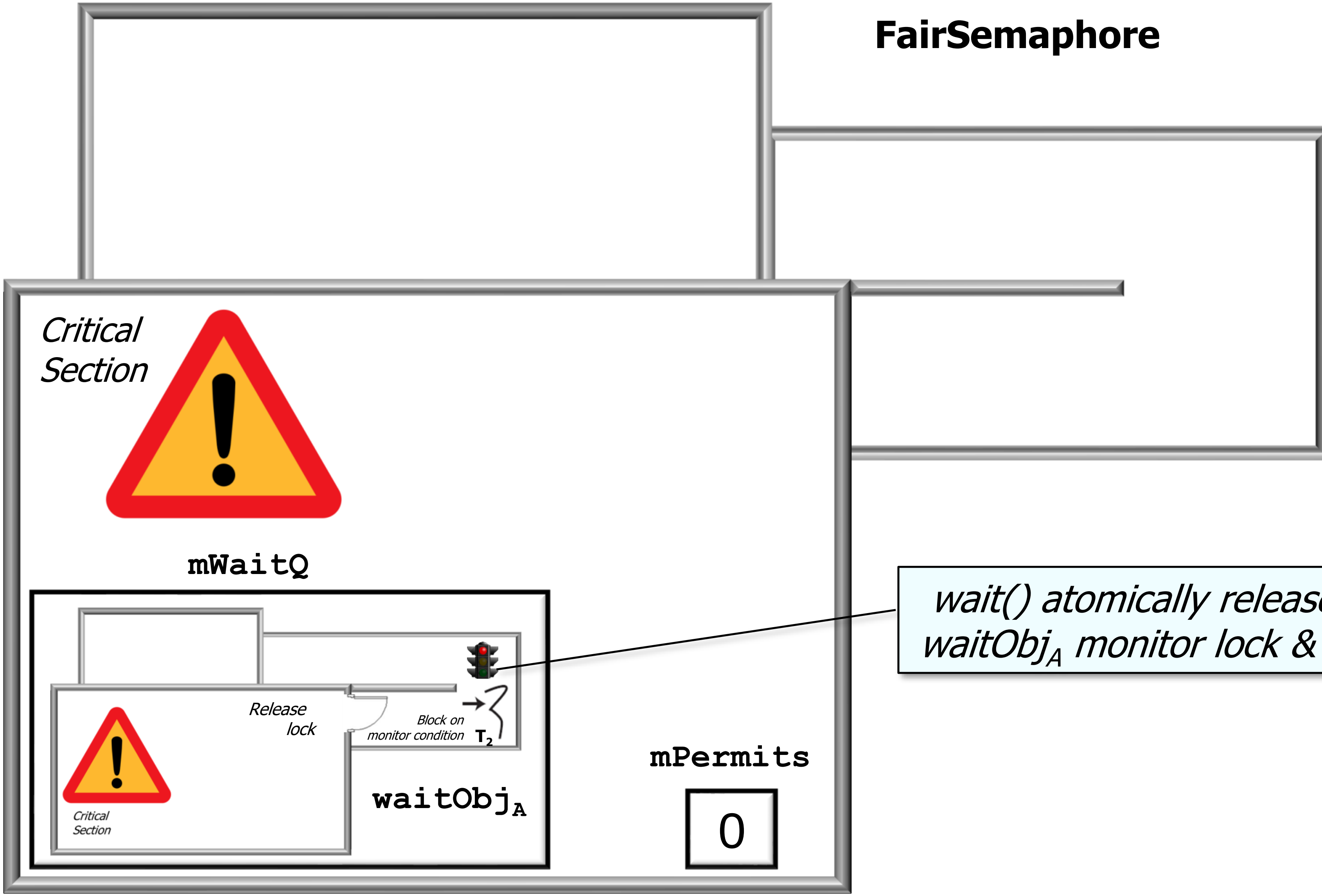


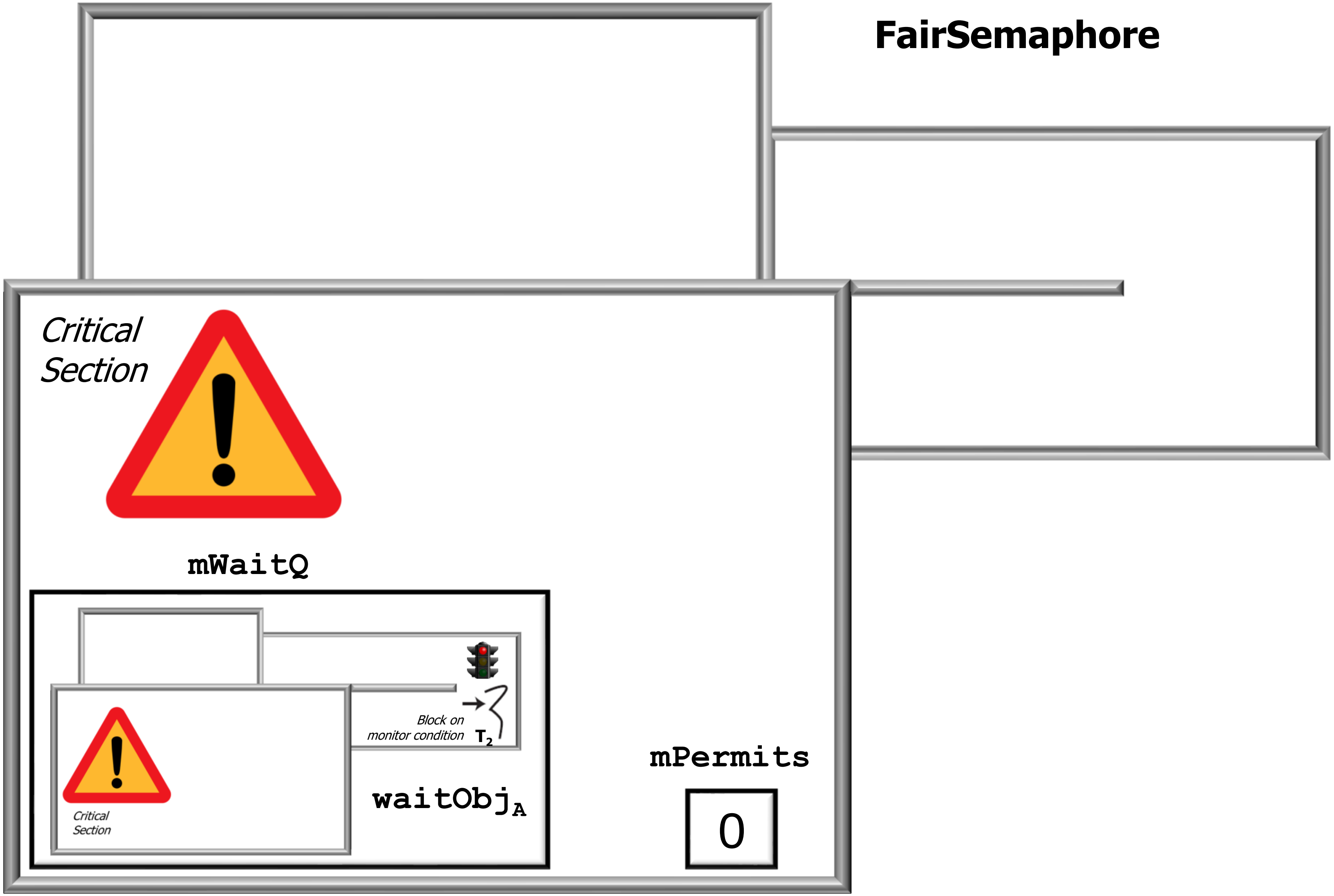
wait() must be made with waitObj$_A$ synchronized, but w/out holding the intrinsic (monitor) lock to avoid "self-deadlock"

Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)



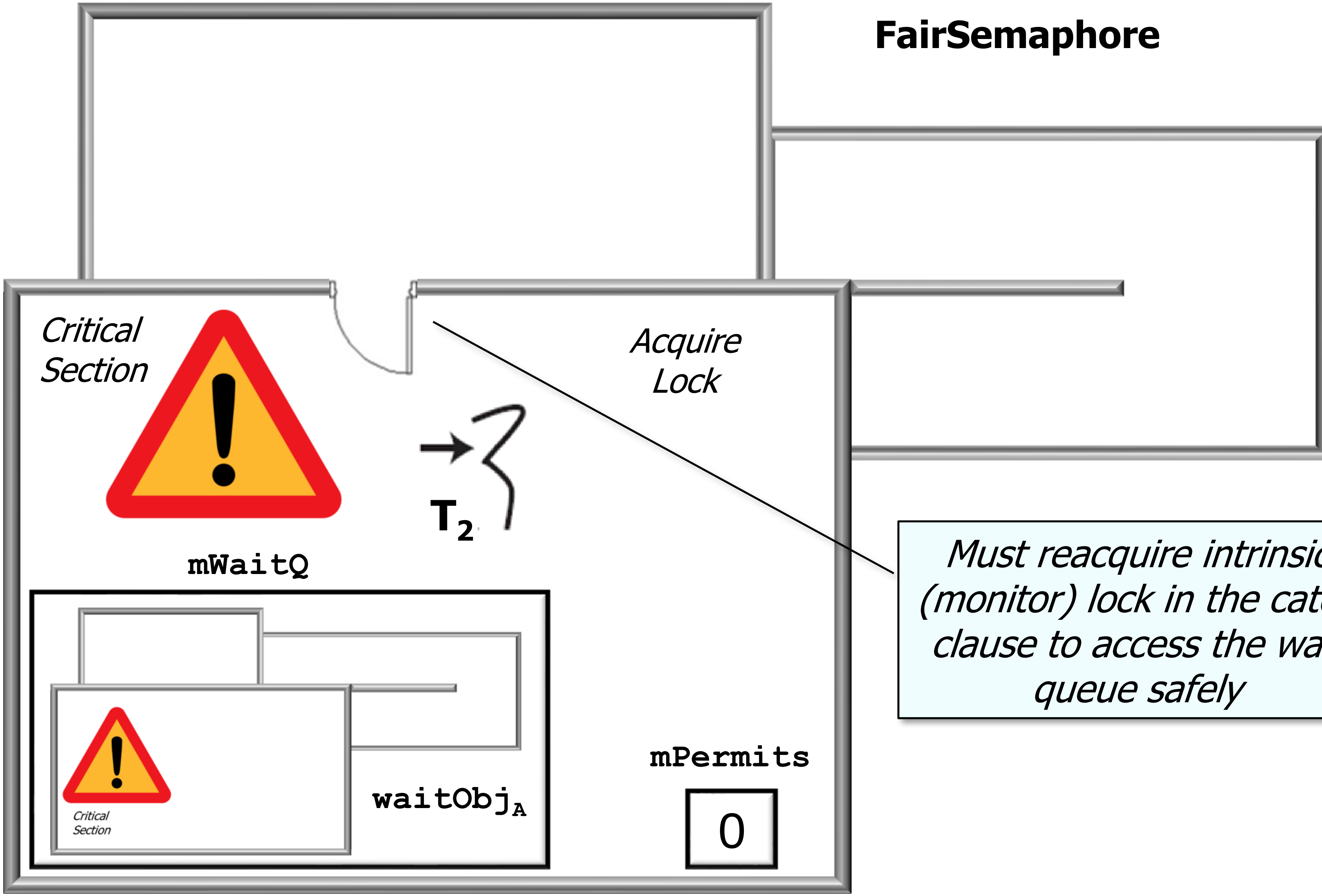
wait() atomically releases the $waitObj_A$ monitor lock & blocks

Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)



Here's what happens when a Java InterruptedException (IE) is thrown in the acquire() method during a blocking call to wait() on a waitObj

Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)



Must reacquire intrinsic (monitor) lock in the catch clause to access the wait queue safely

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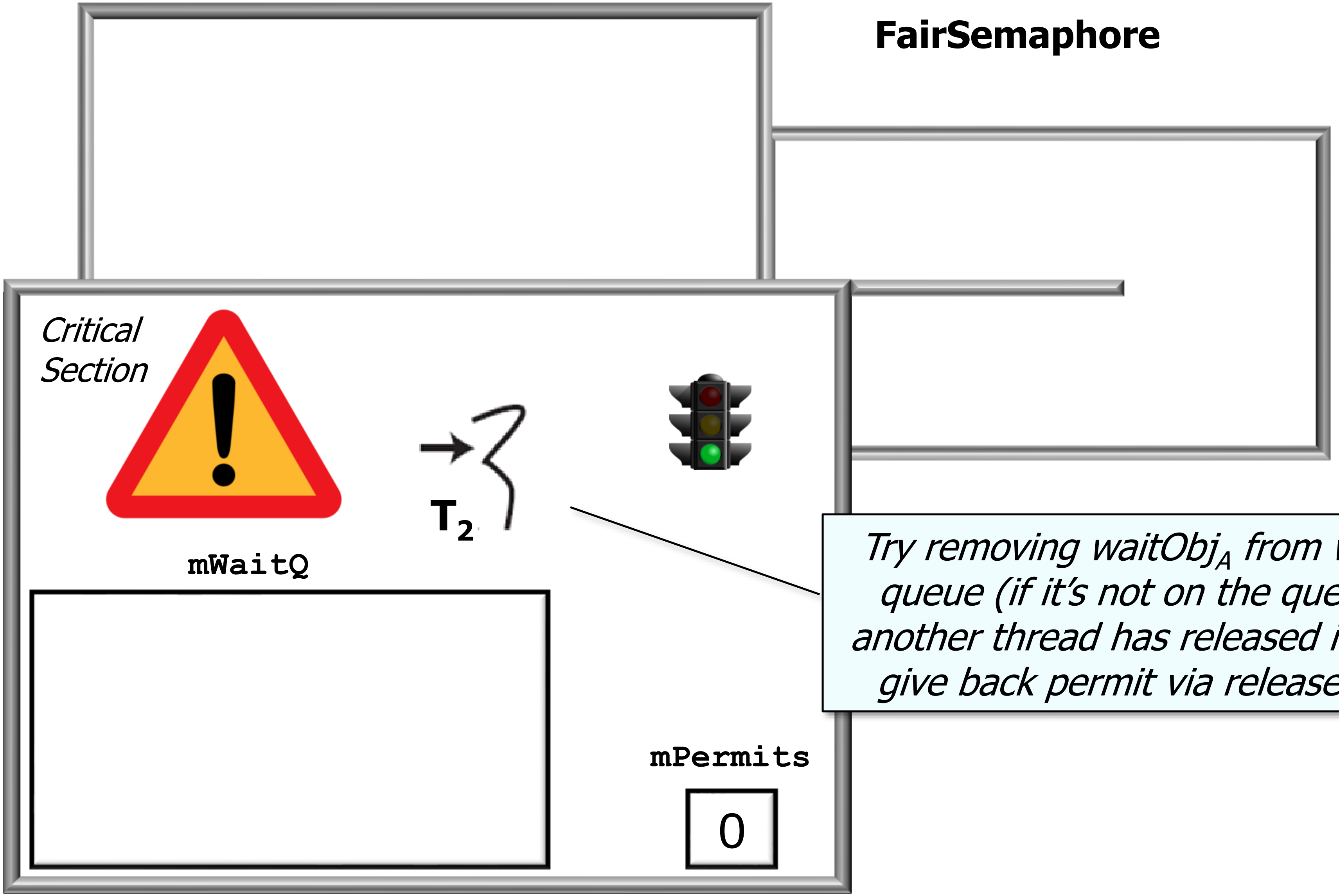
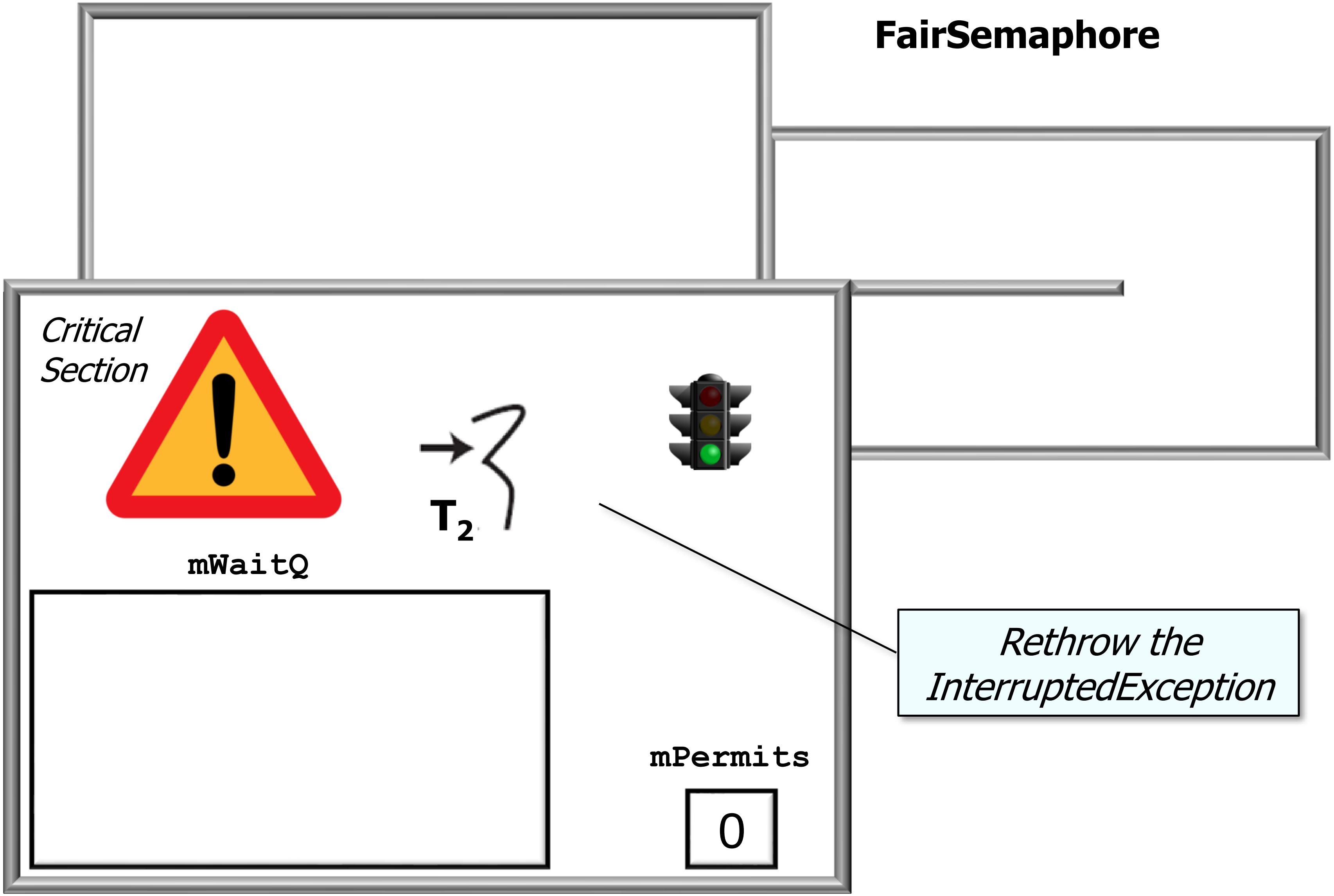


Try removing waitObj$_A$ from wait queue (if it's not on the queue another thread has released it, so give back permit via release())

Visual Analysis of Fair Semaphore Acquire (T_1 & T_2)



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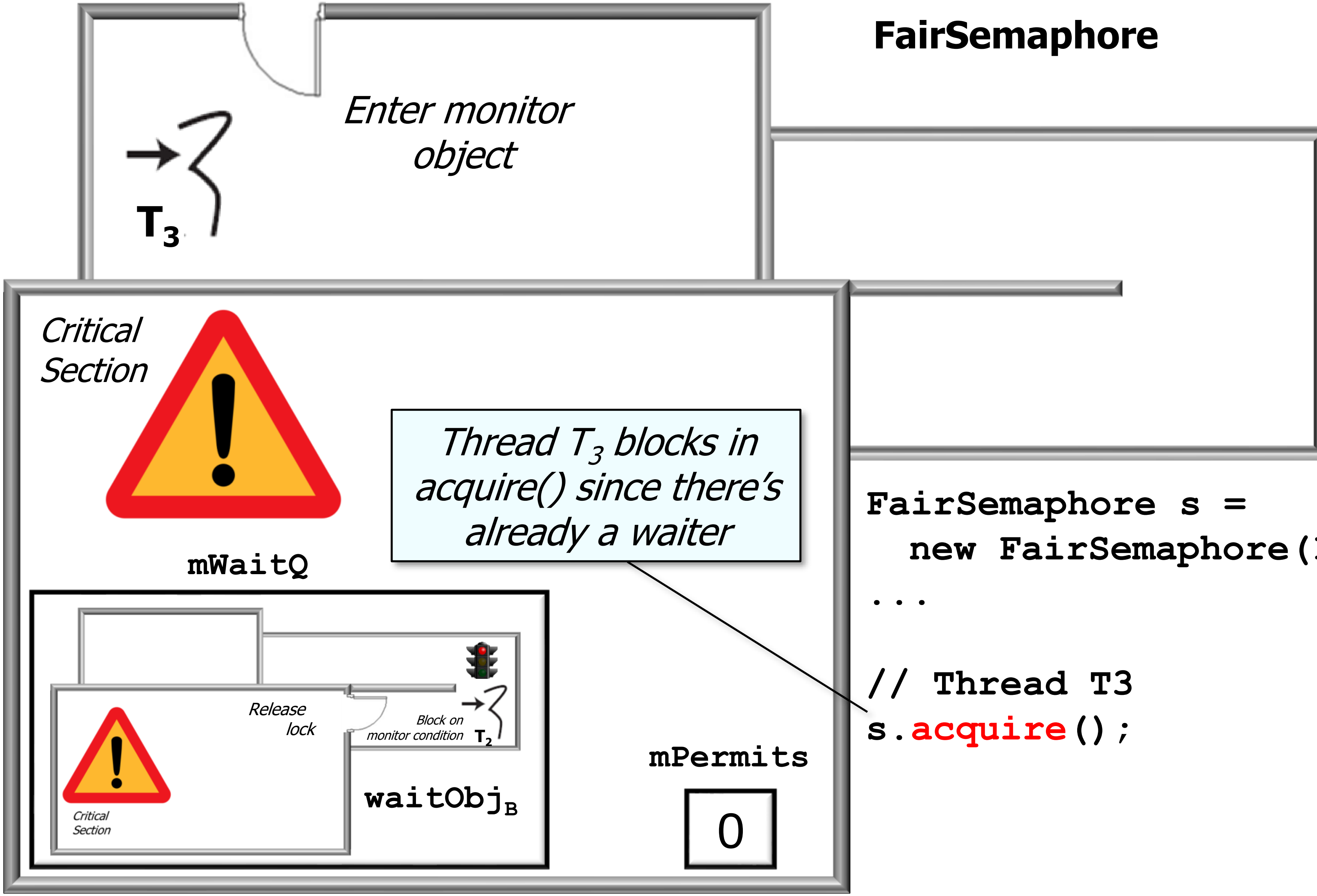


```
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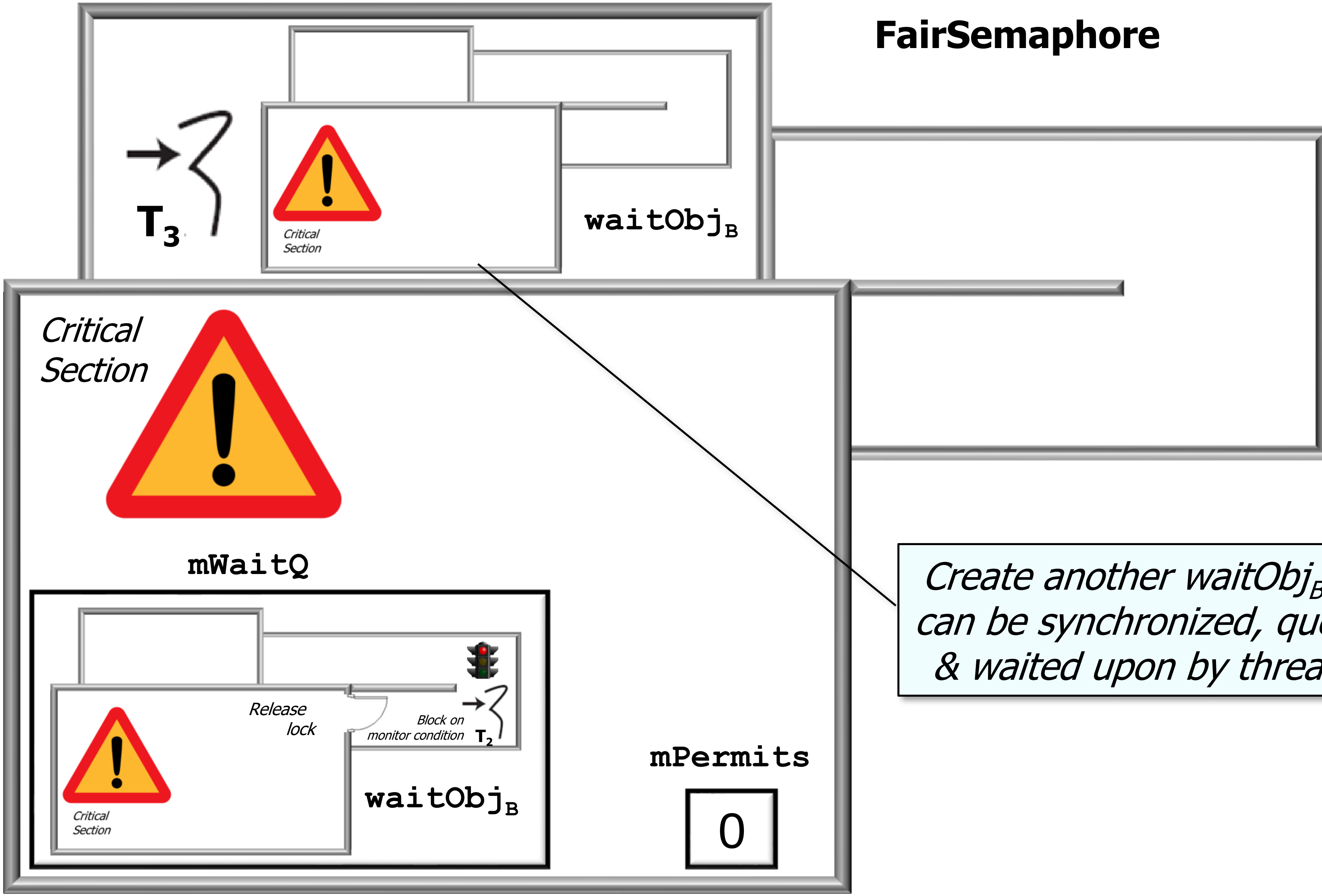
...

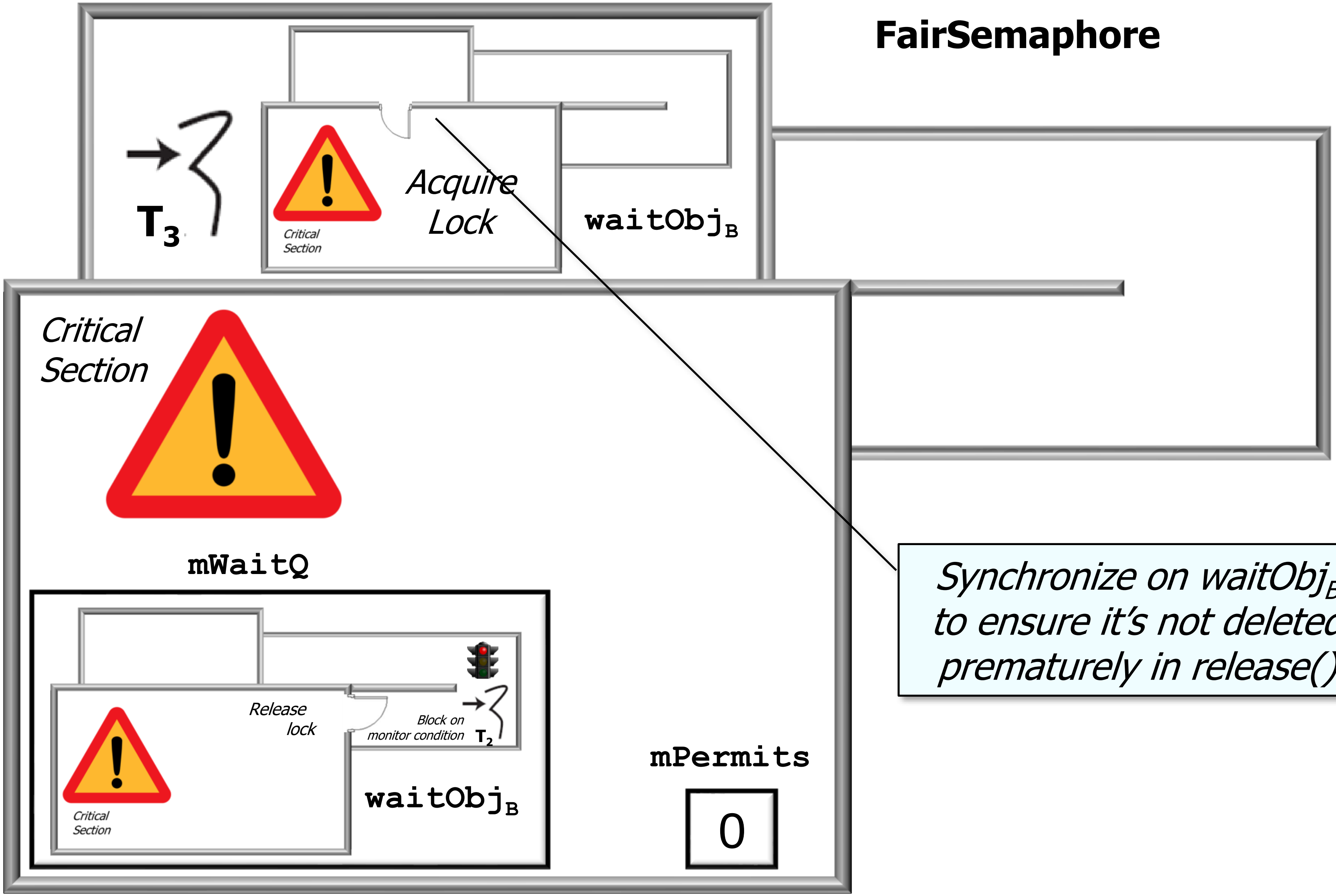
// Thread T3
s.acquire();
```

Visual Analysis of Fair Semaphore Acquire (T_3)



Create another waitObj$_B$ that can be synchronized, queued, & waited upon by thread T_3

Visual Analysis of Fair Semaphore Acquire (T_3)



Synchronize on waitObj$_B$ to ensure it's not deleted prematurely in release()

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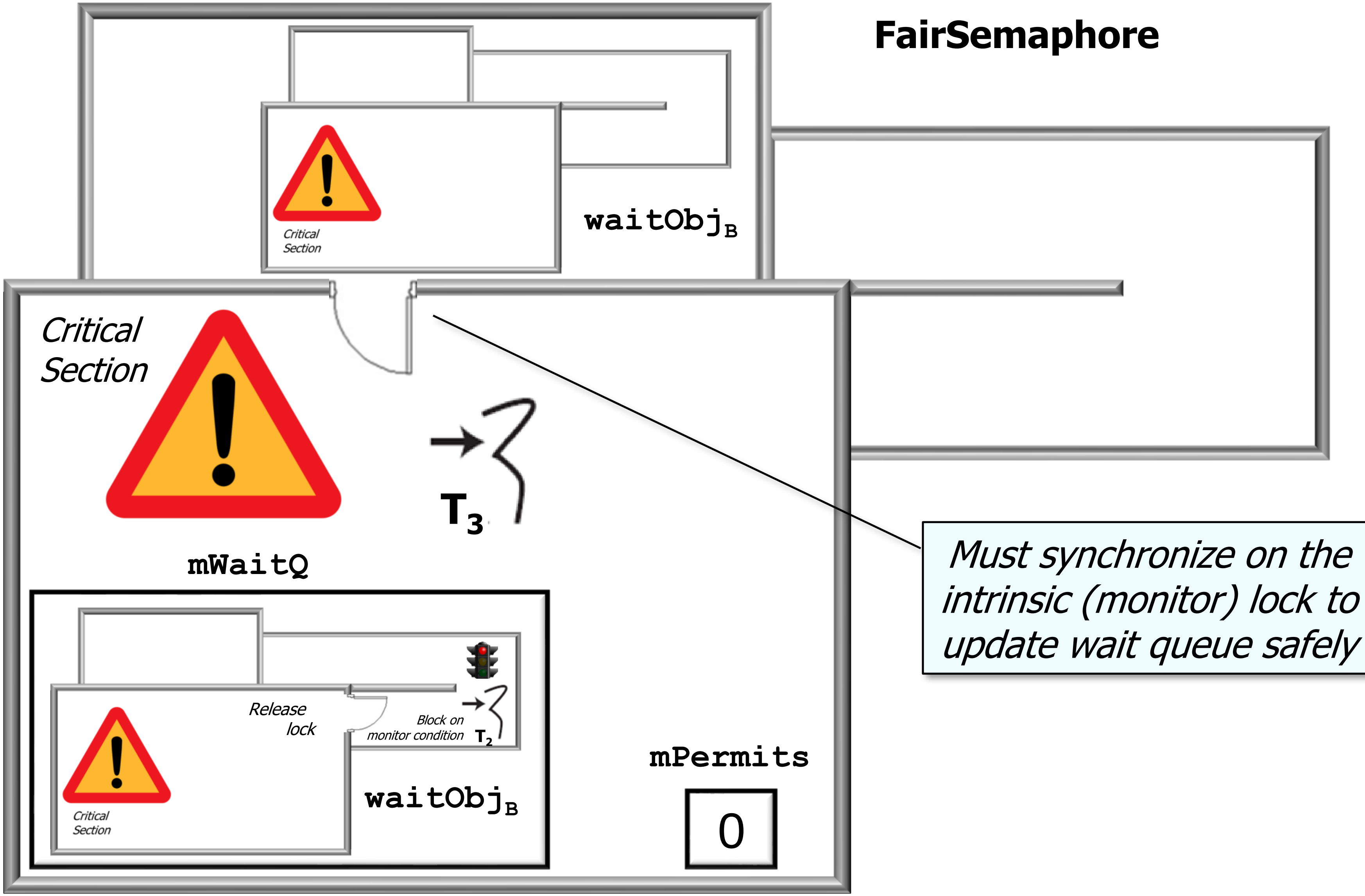

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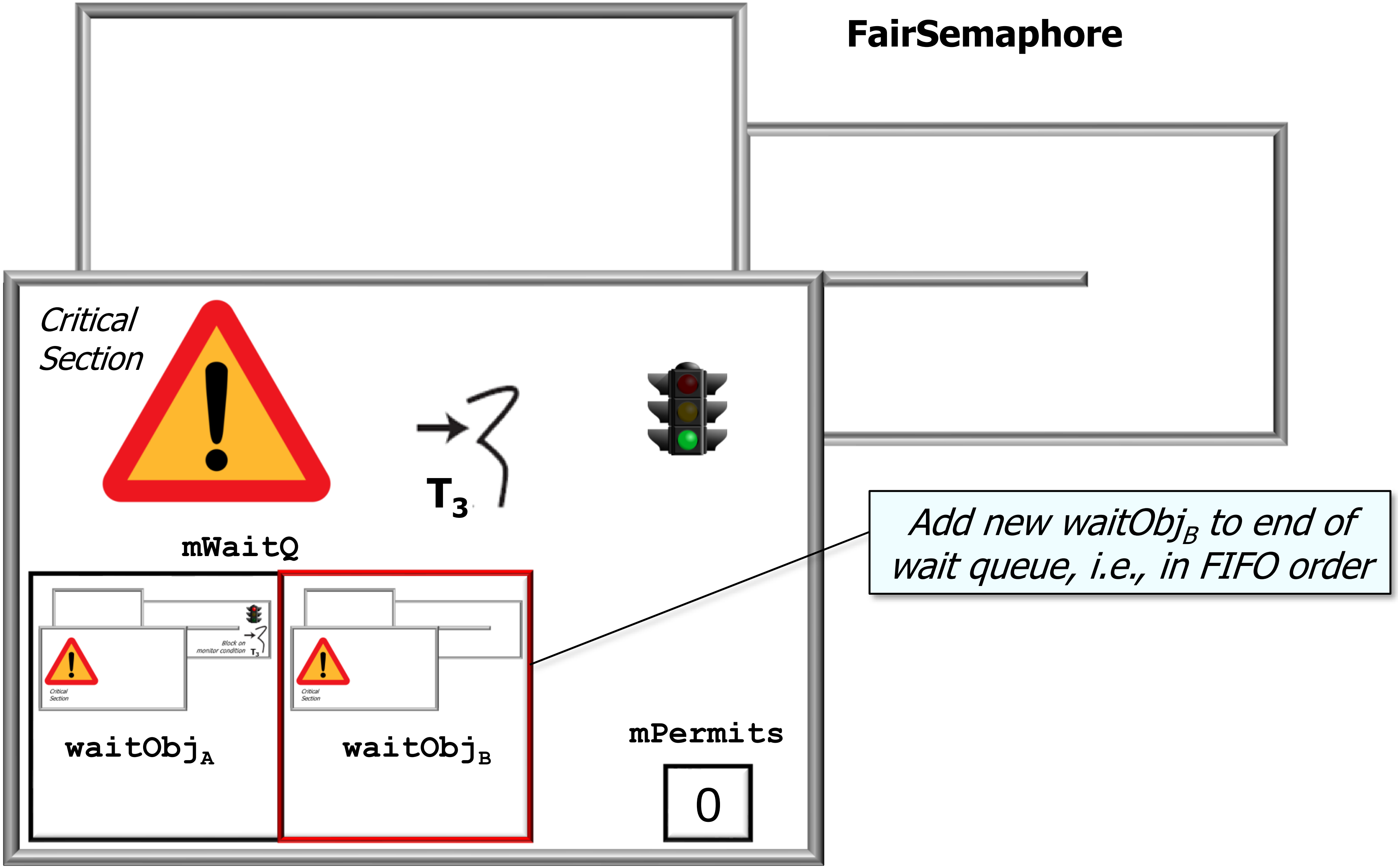

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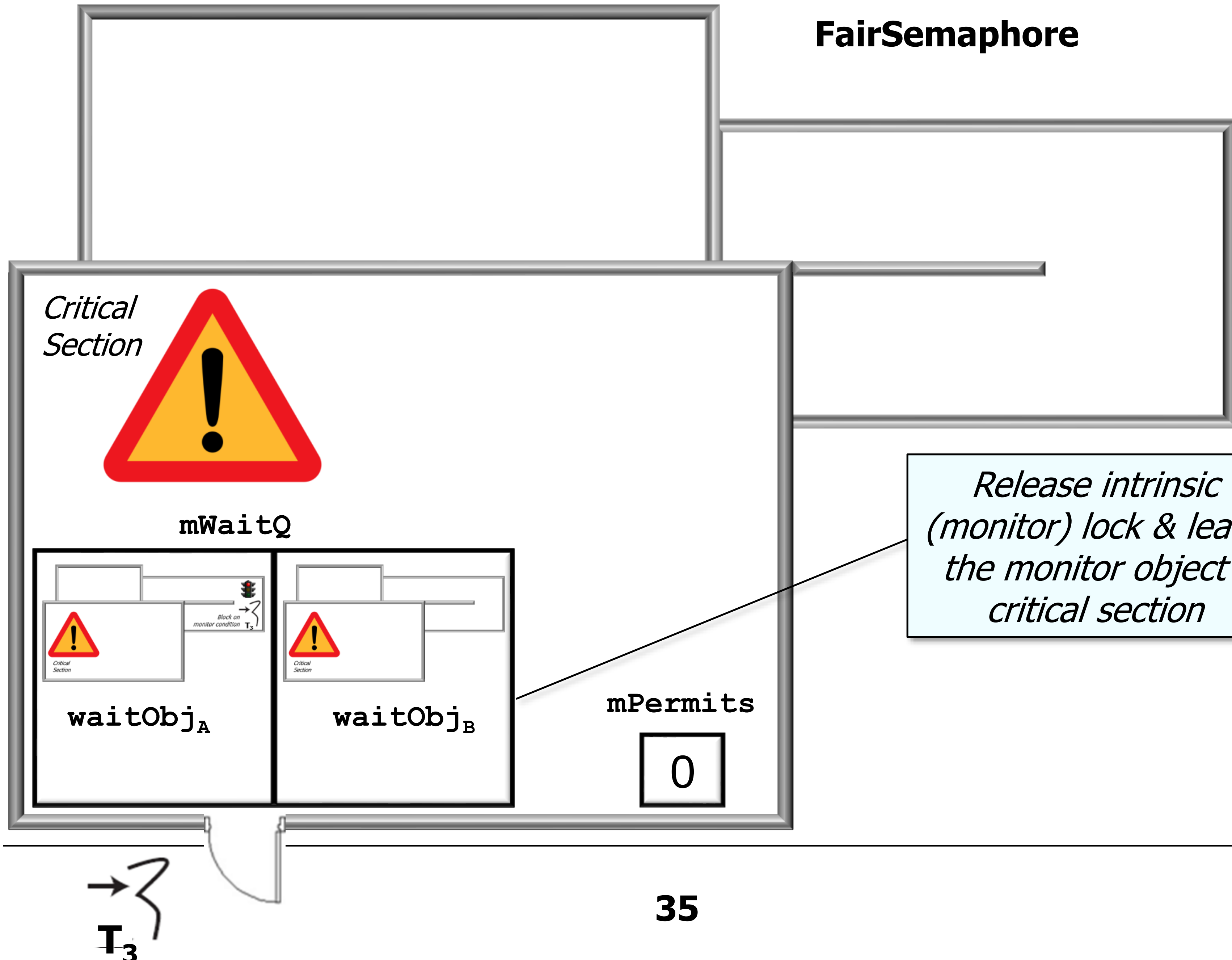

Release intrinsic (monitor) lock & leave the monitor object's critical section

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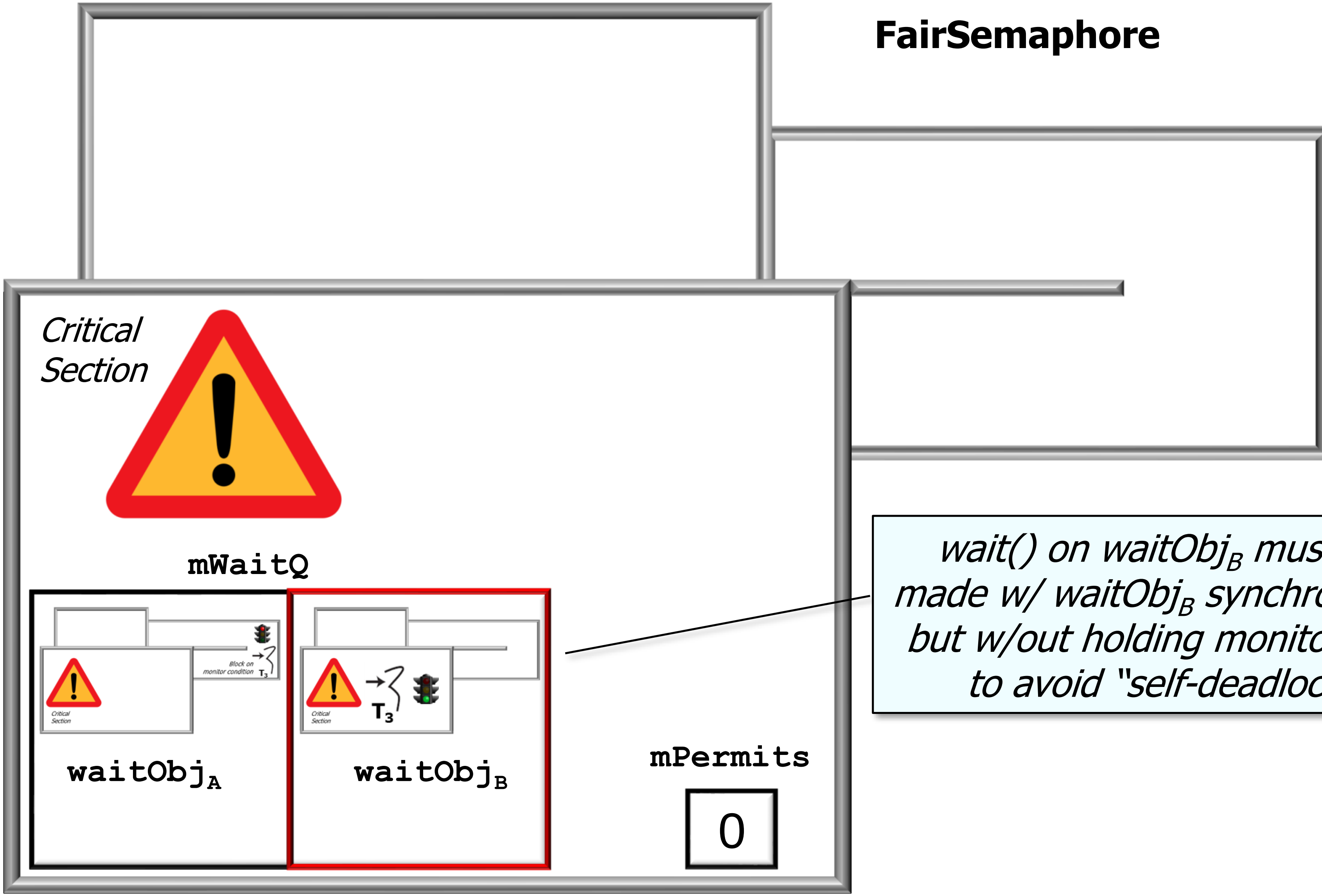

wait() on waitObj$_B$ must be made w/ waitObj$_B$ synchronized, but w/out holding monitor lock to avoid "self-deadlock"

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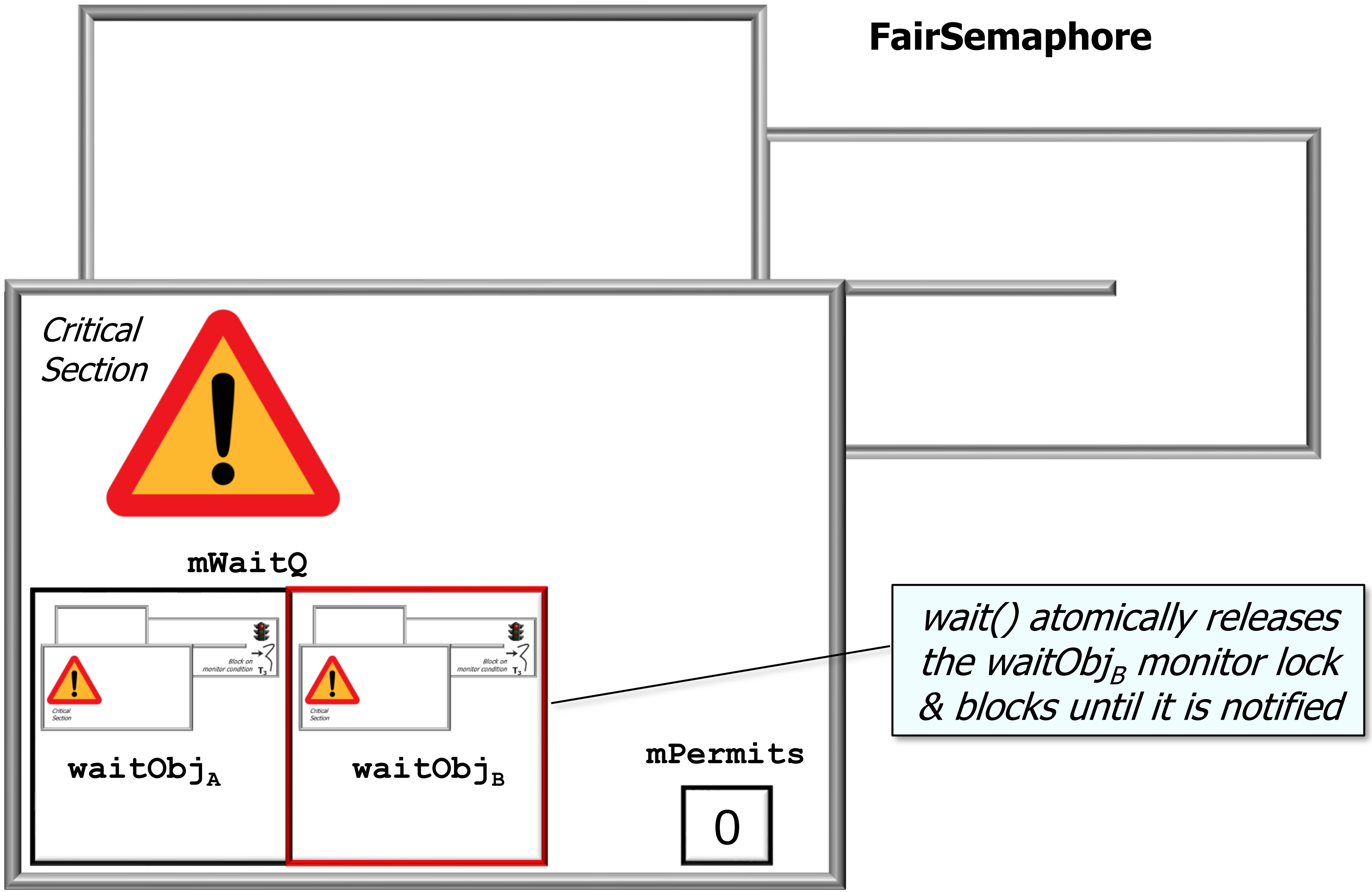

Visual Analysis of Fair Semaphore Release (T_4)

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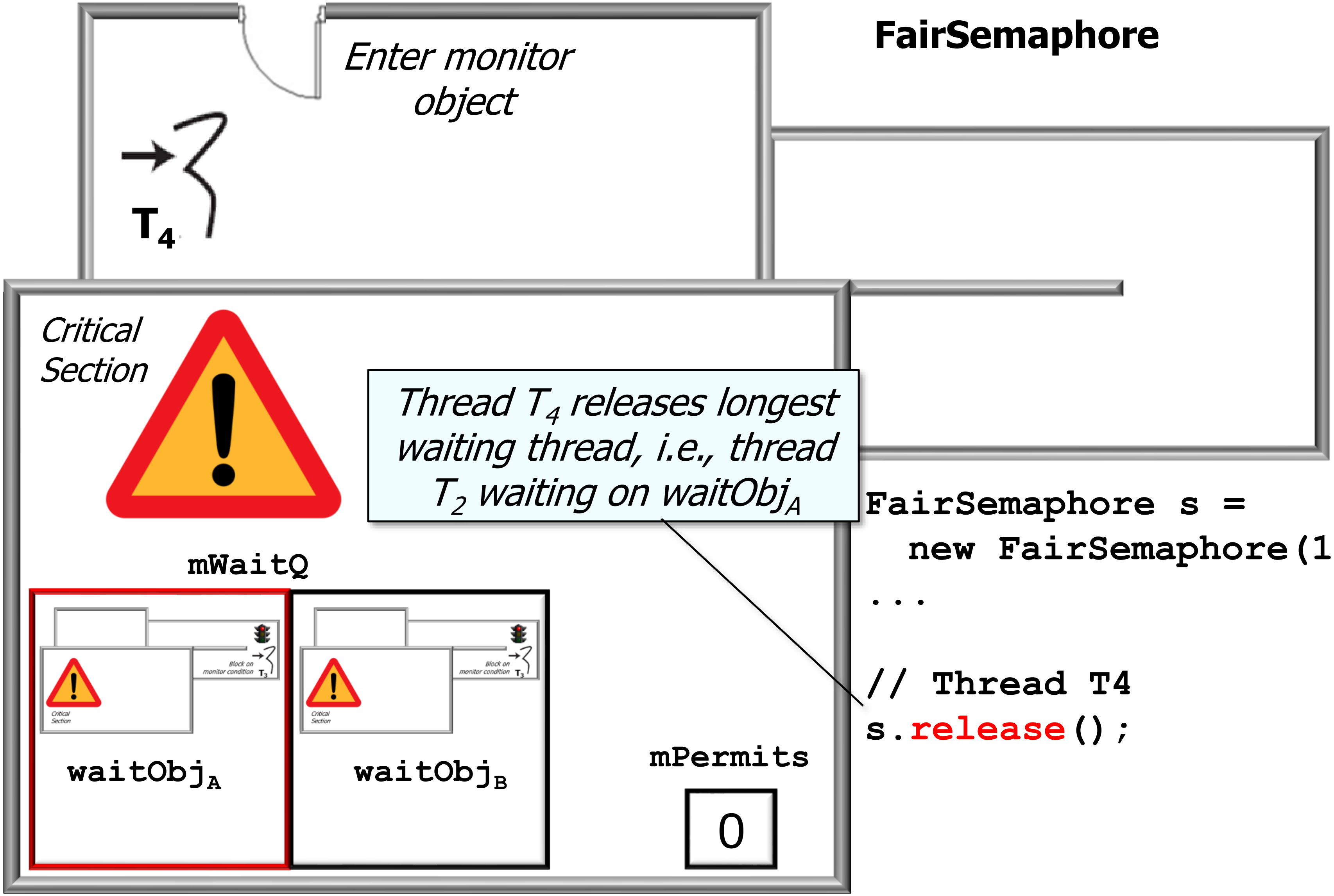


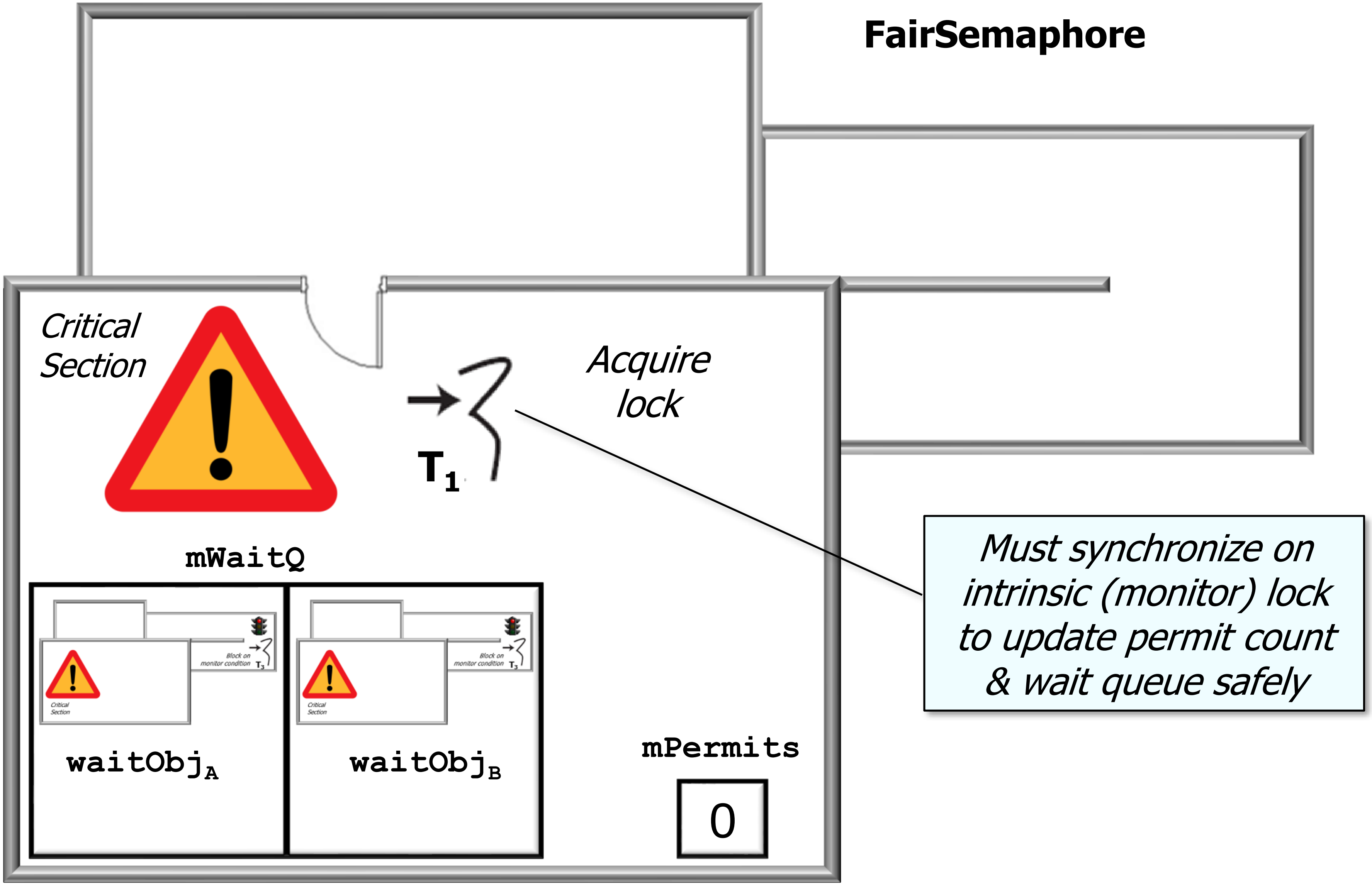
FairSemaphore

```
FairSemaphore s =
  new FairSemaphore(1);
...

// Thread T4
s.release();
```

Thread T_4 could be thread T_1 or a different thread altogether

Visual Analysis of Fair Semaphore Release (T_4)



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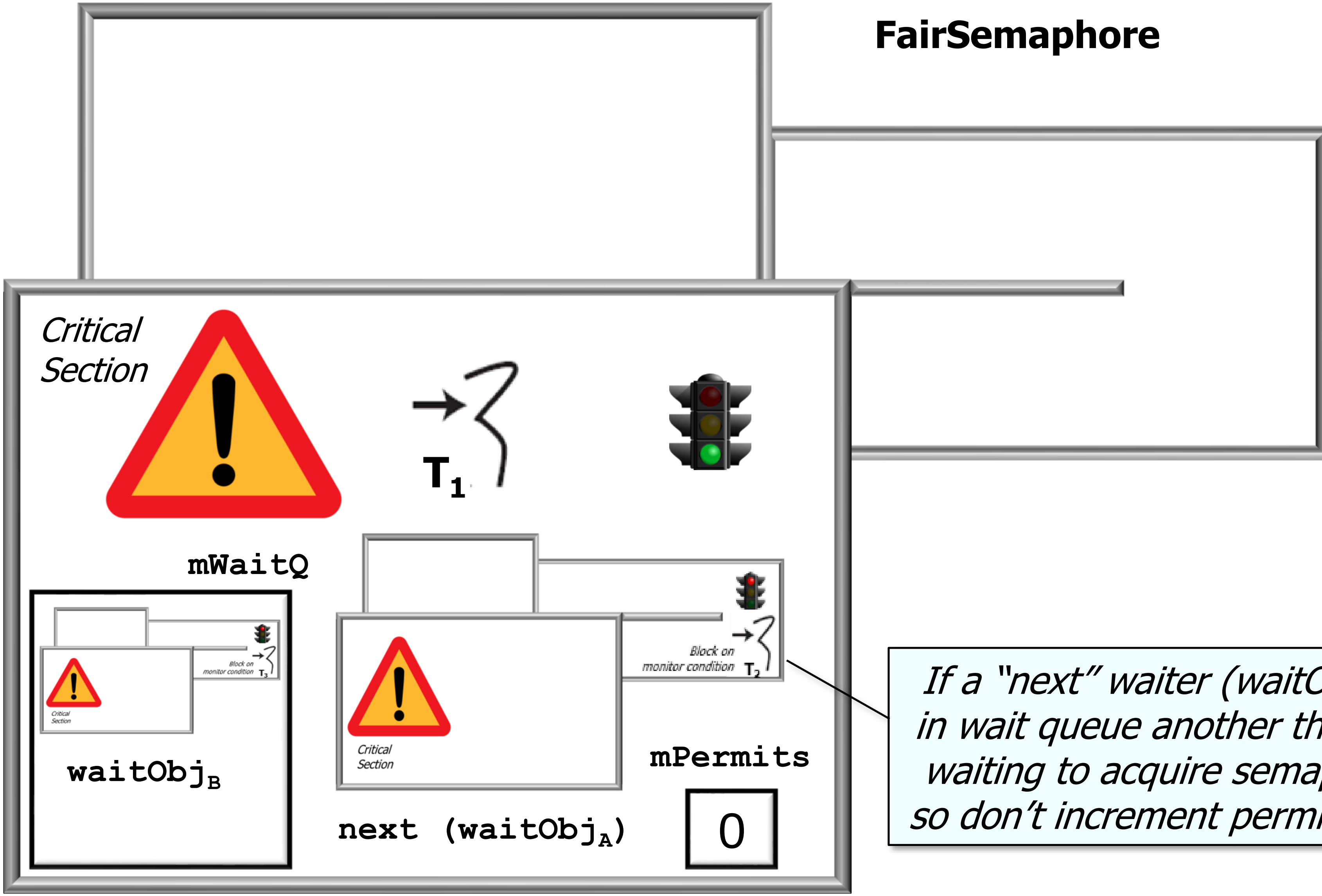
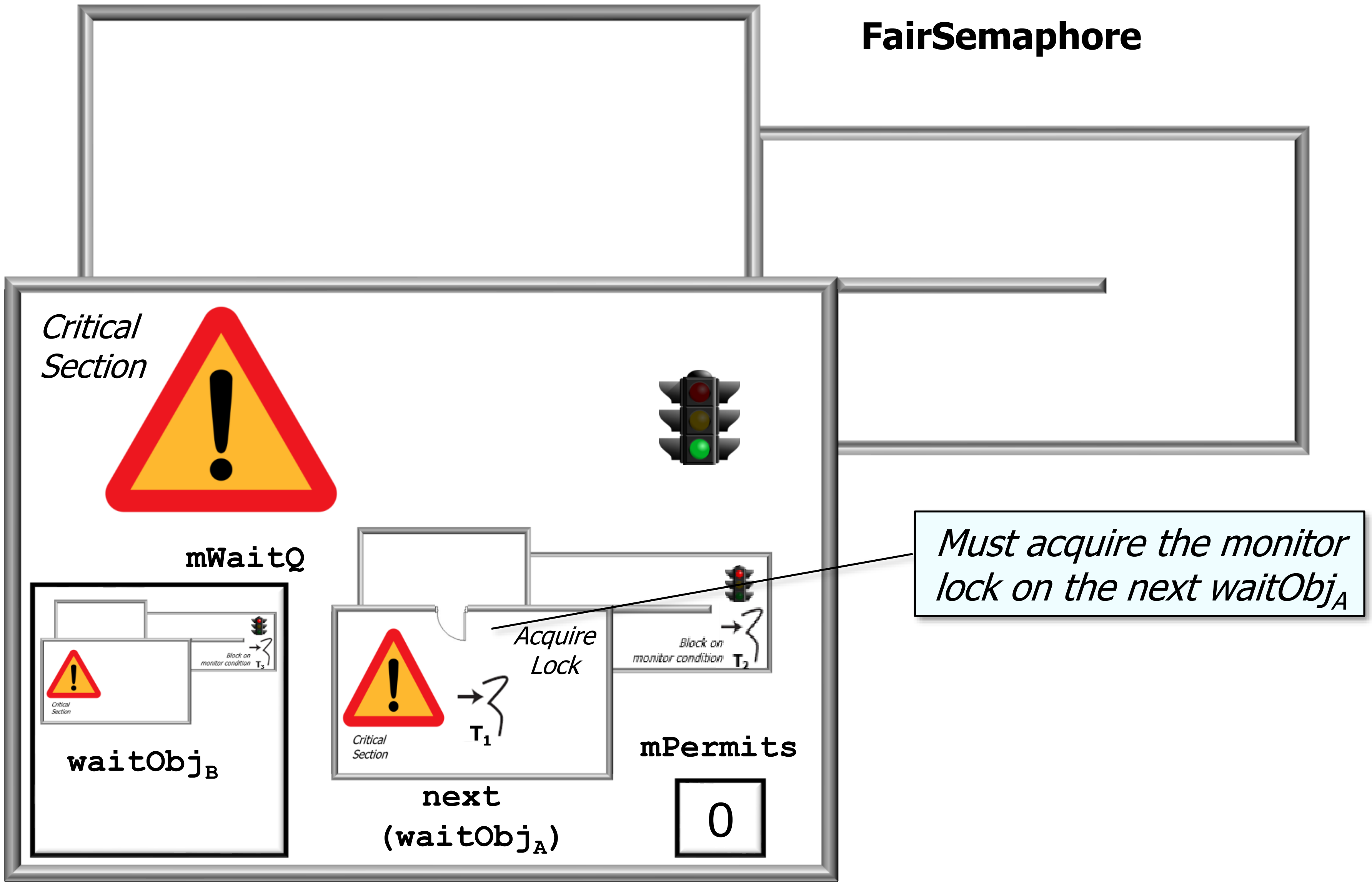


If a "next" waiter (waitObj$_A$) is in wait queue another thread is waiting to acquire semaphore, so don't increment permit count

Visual Analysis of Fair Semaphore Release (T_4)



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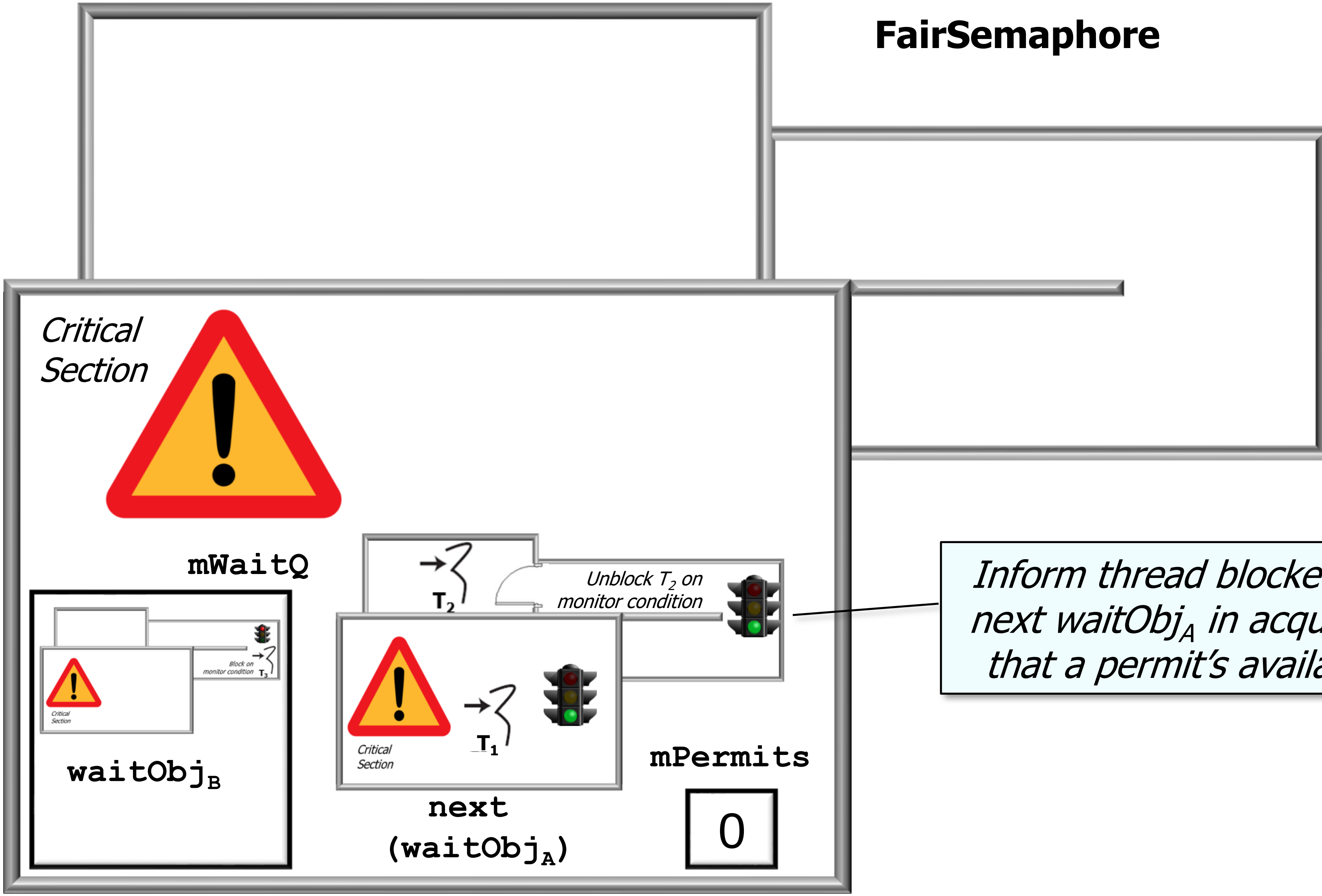
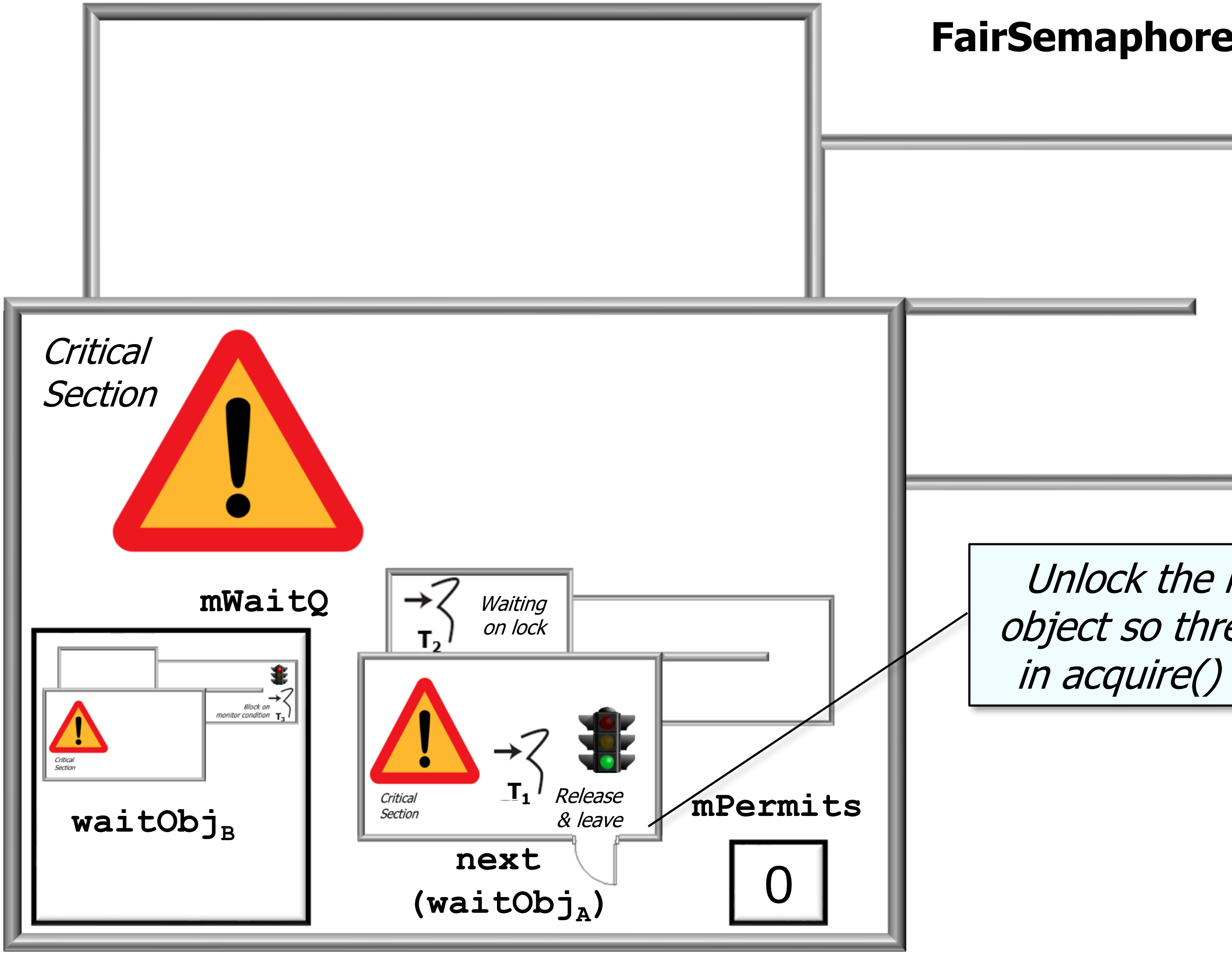


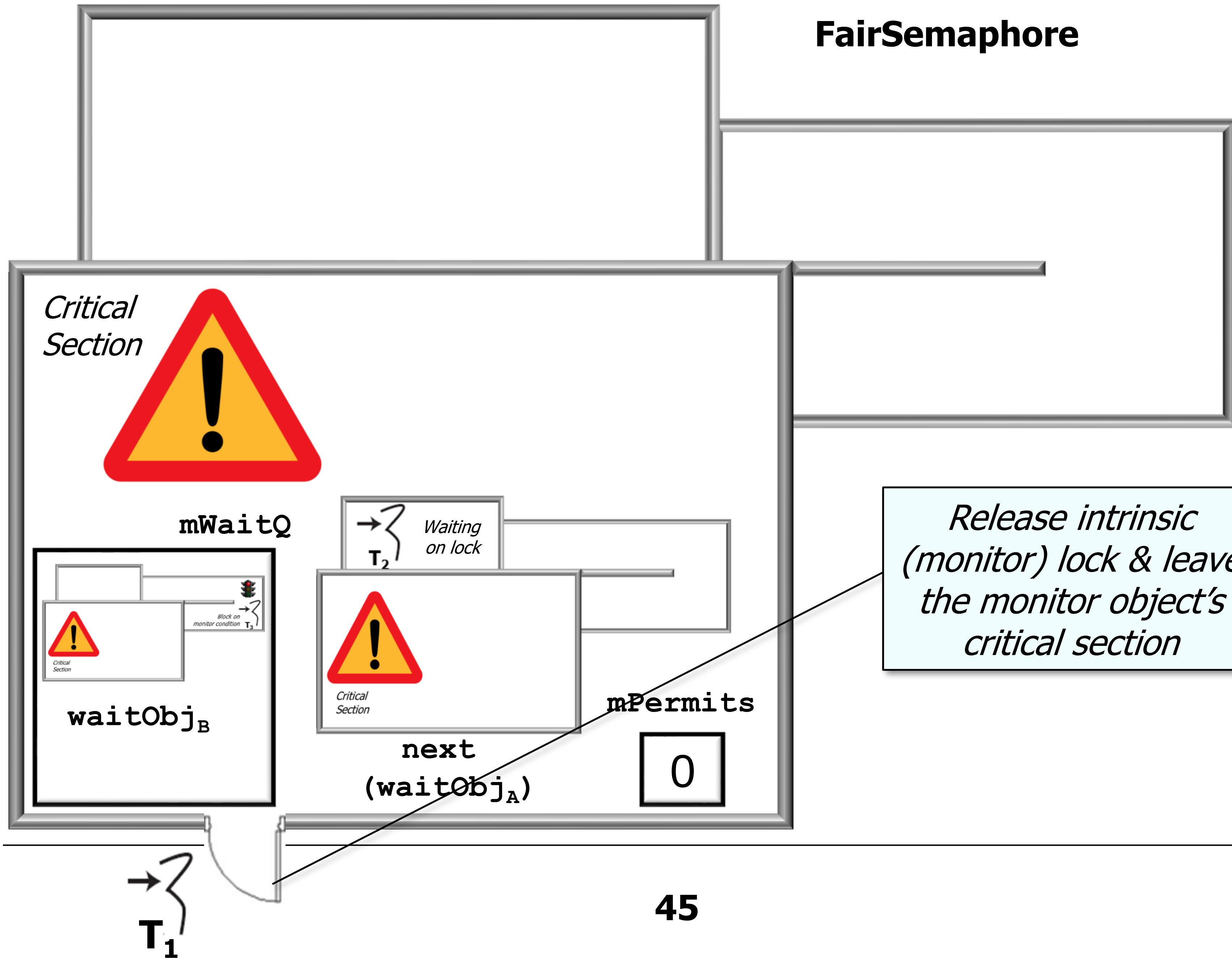
Inform thread blocked on next waitObj$_A$ in acquire() that a permit's available

Visual Analysis of Fair Semaphore Release (T_4)



Unlock the next monitor object so thread T_1 waiting in acquire() can continue

Visual Analysis of Fair Semaphore Release (T_4)



Release intrinsic (monitor) lock & leave the monitor object's critical section

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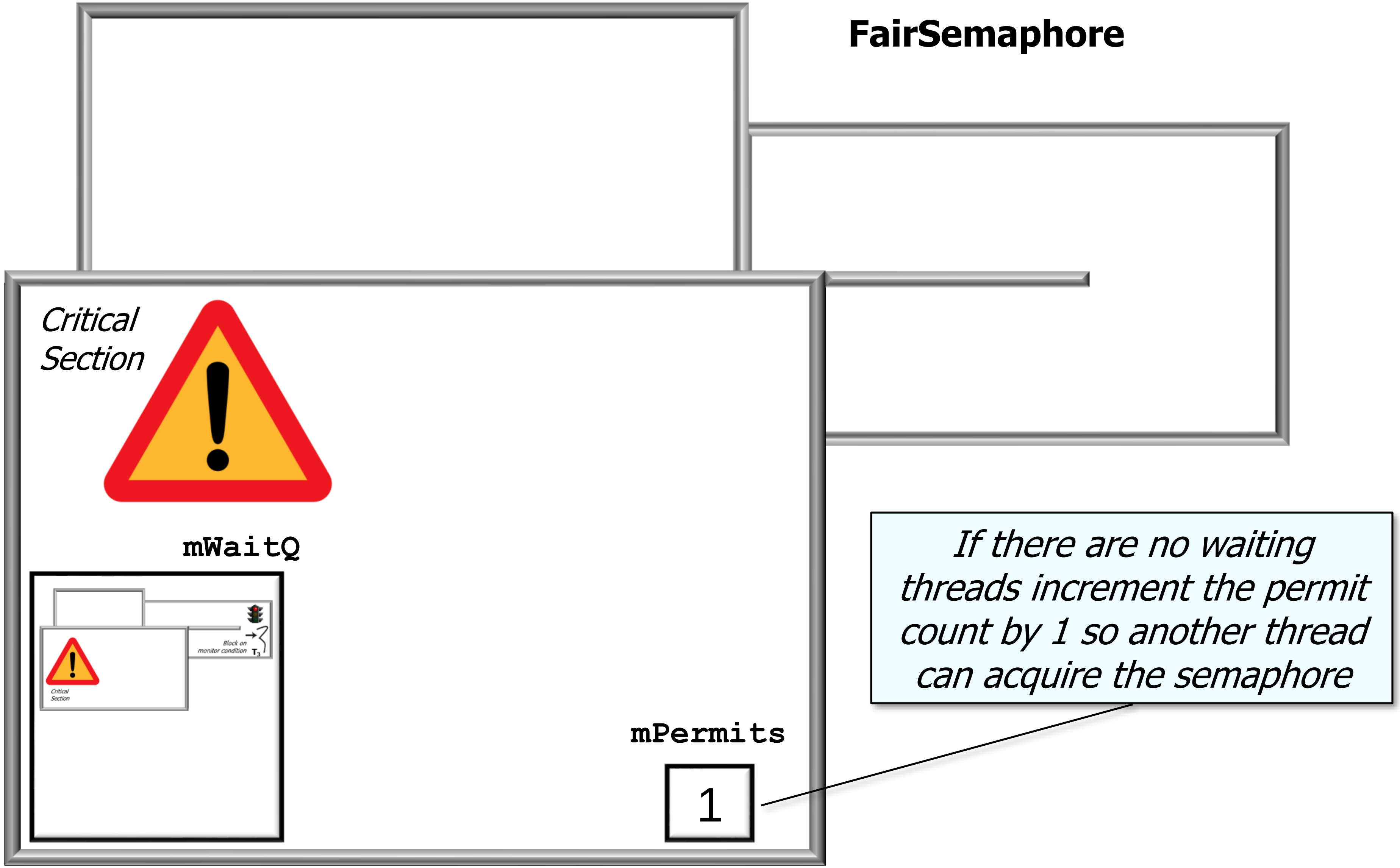

End of Implementing a Fair Semaphore with the Specific Notification Pattern