SideTrack: Generalizing Dynamic Atomicity Analysis

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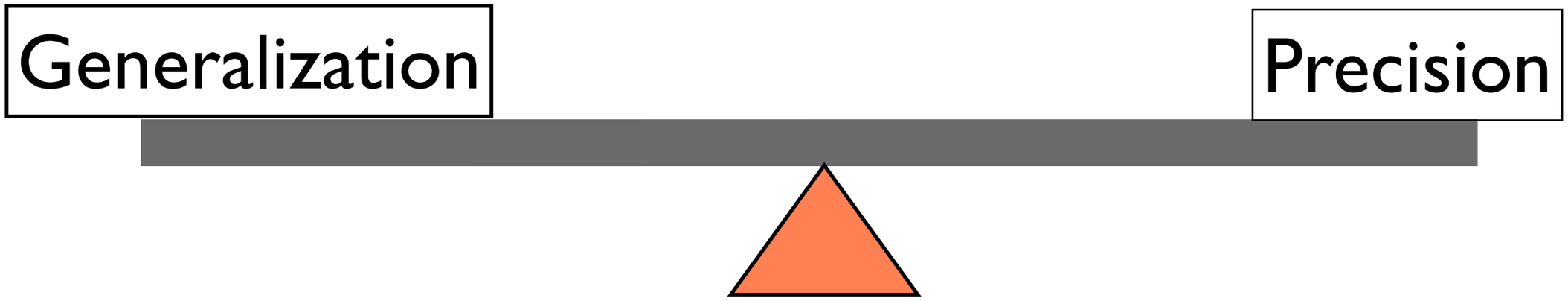
Atomicity

The effect of an atomic code block can be considered in isolation from the rest of a running program.

- enables sequential reasoning
- atomicity violations often represent synchronization errors
- most methods are atomic

Analyzing for Atomicity



- online/dynamic
- generalizes
- no false alarms

Thread 1

```
atomic{
  synchronized(n){
      tmp = bal;
  }
  synchronized(n){
      bal = tmp + 1;
  }
}
```

Thread 2

```
synchronized(m){
  newVar = 0;
}
```

Thread 1

```
begin
acquire(n)
t1 = bal
release(n)
acquire(n)
bal = t + 1
release(n)
end
```

Thread 2

```
acquire(m)
newVar = 0
release(m)
```

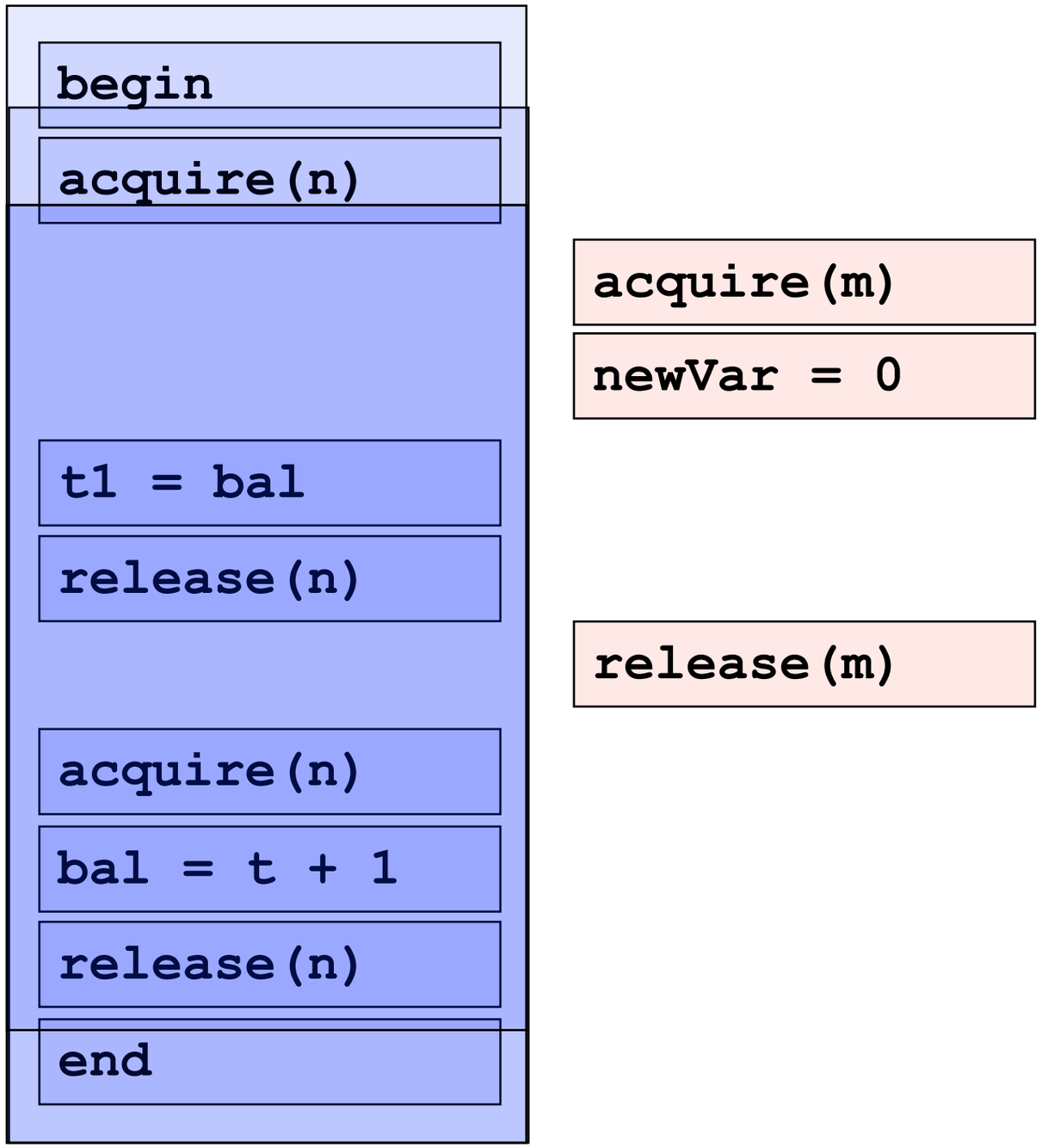
Serial Trace: Each atomic block executes contiguously

Thread 1

```
atomic{
   synchronized(n){
       tmp = bal;
   }
   synchronized(n){
       bal = tmp + 1;
   }
}
```

Thread 2

```
   synchronized(m){
      newVar = 0;
   }
```



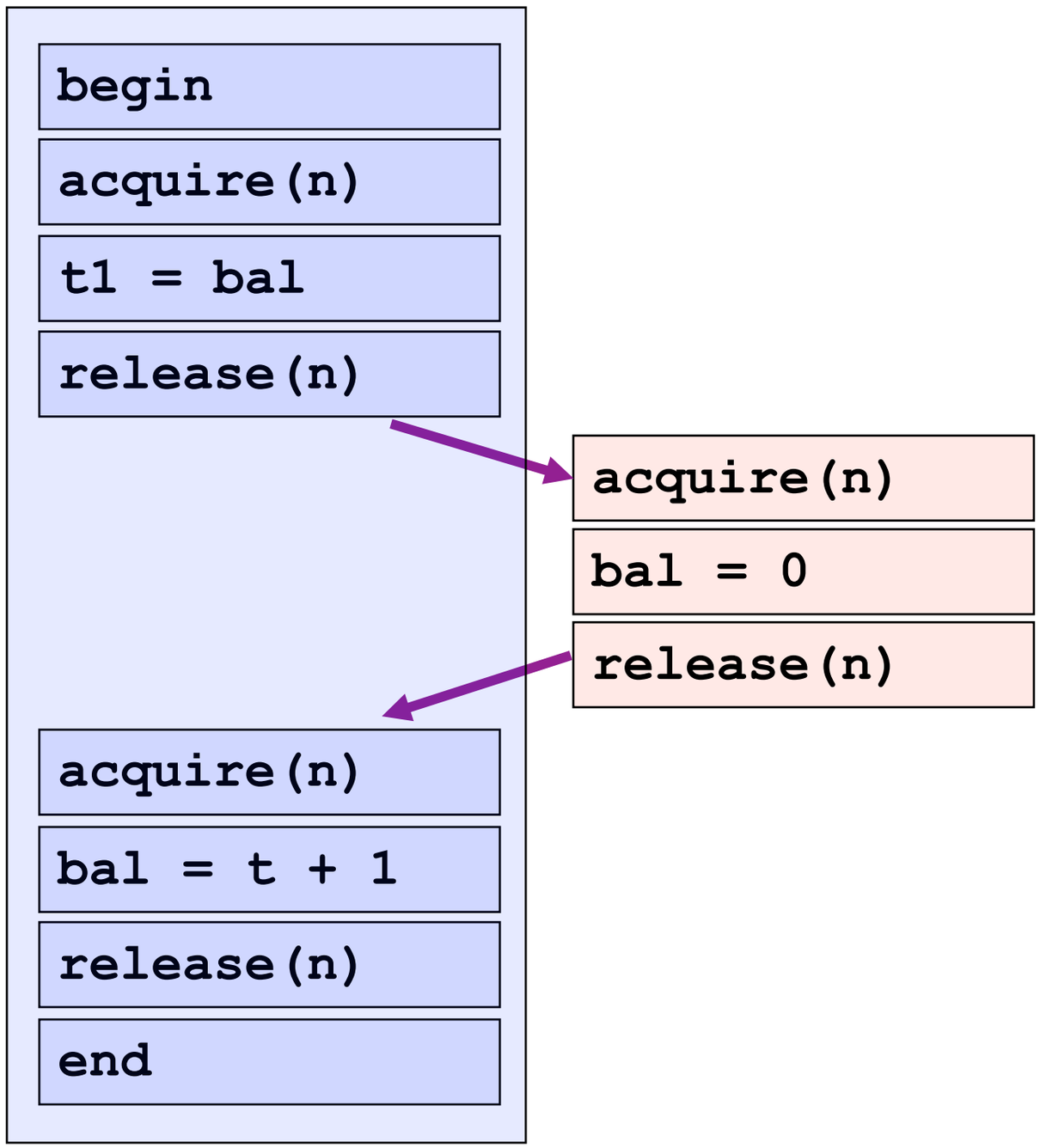
Atomicity = Serializability

Thread 1

```
atomic{
  synchronized(n){
      tmp = bal;
  }
  synchronized(n){
      bal = tmp + 1;
  }
}
```

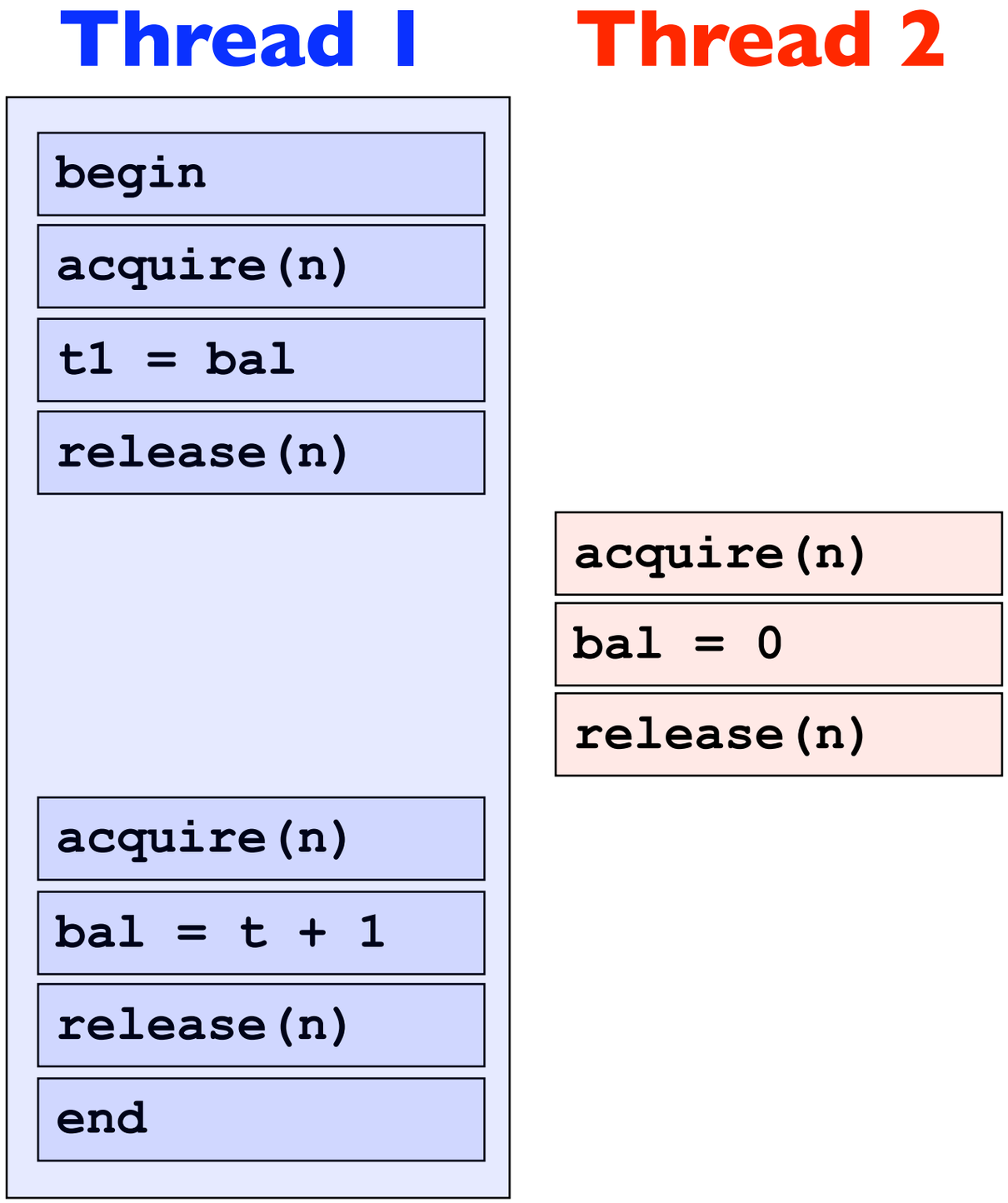
Thread 2

```
synchronized(n){
  bal = 0;
}
```



Happens-Before

Enables Relation

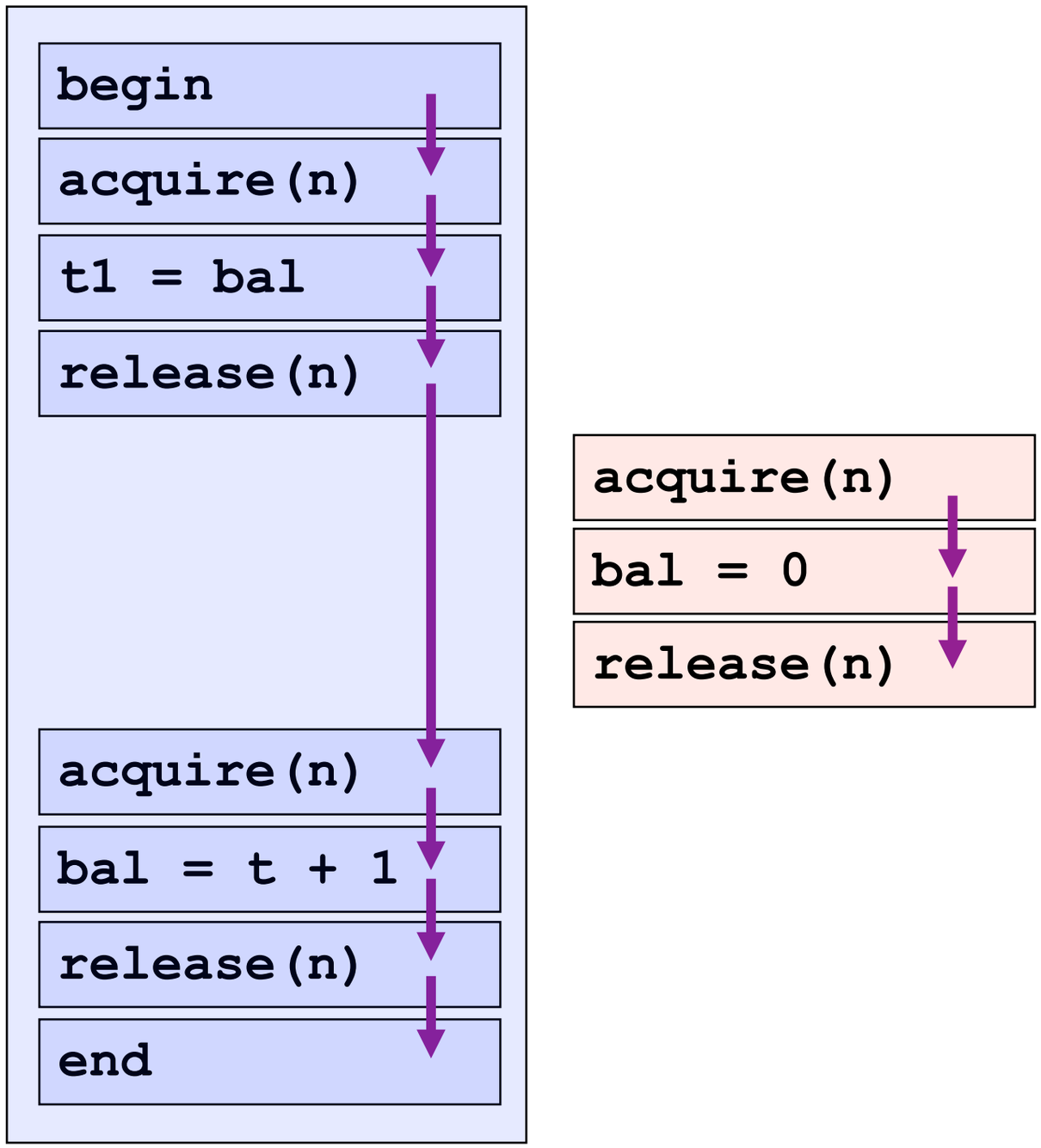


Happens-Before

- program order

Enables Relation

- program order

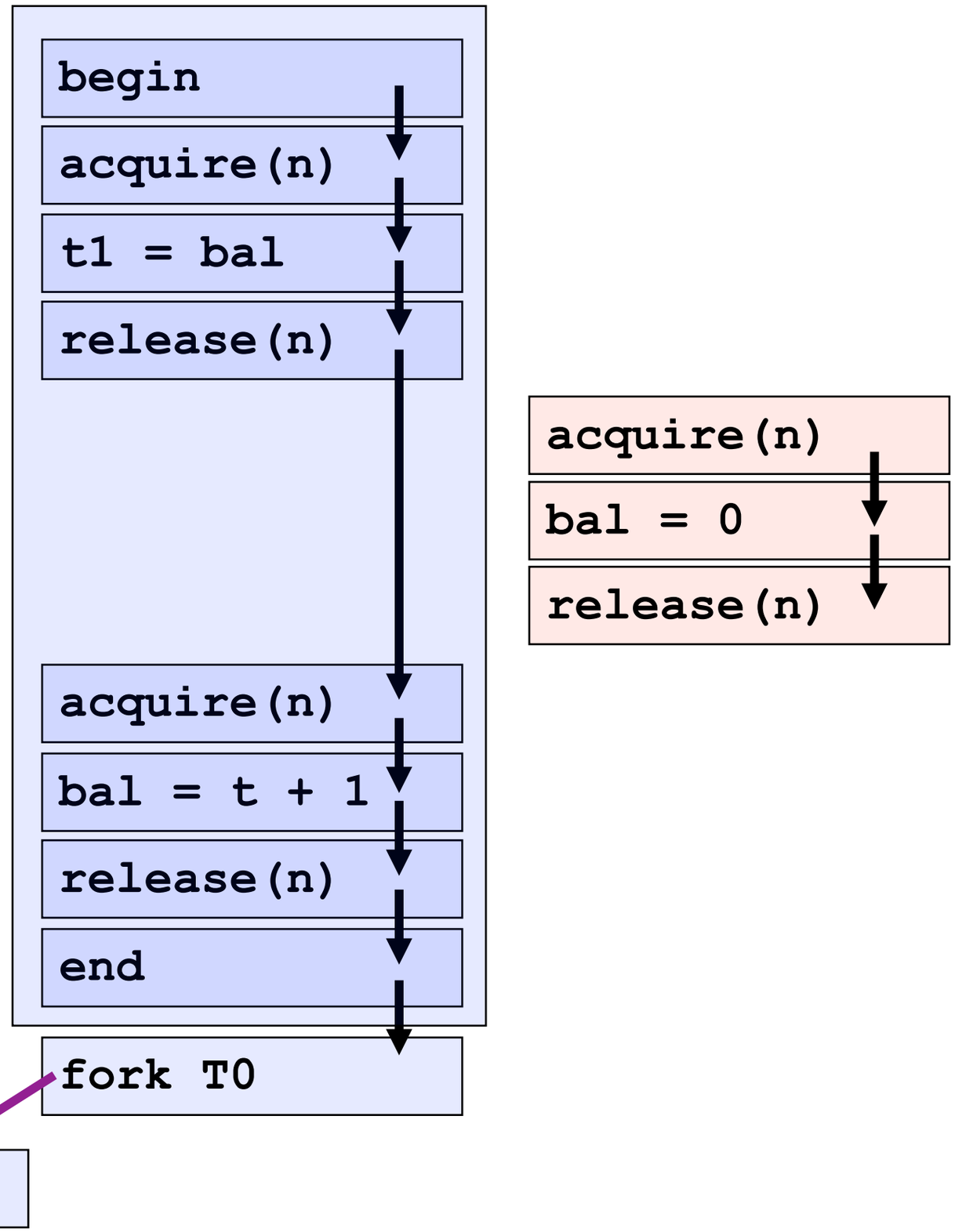


Happens-Before

- program order
- fork/join order

Enables Relation

- program order
- fork/join order

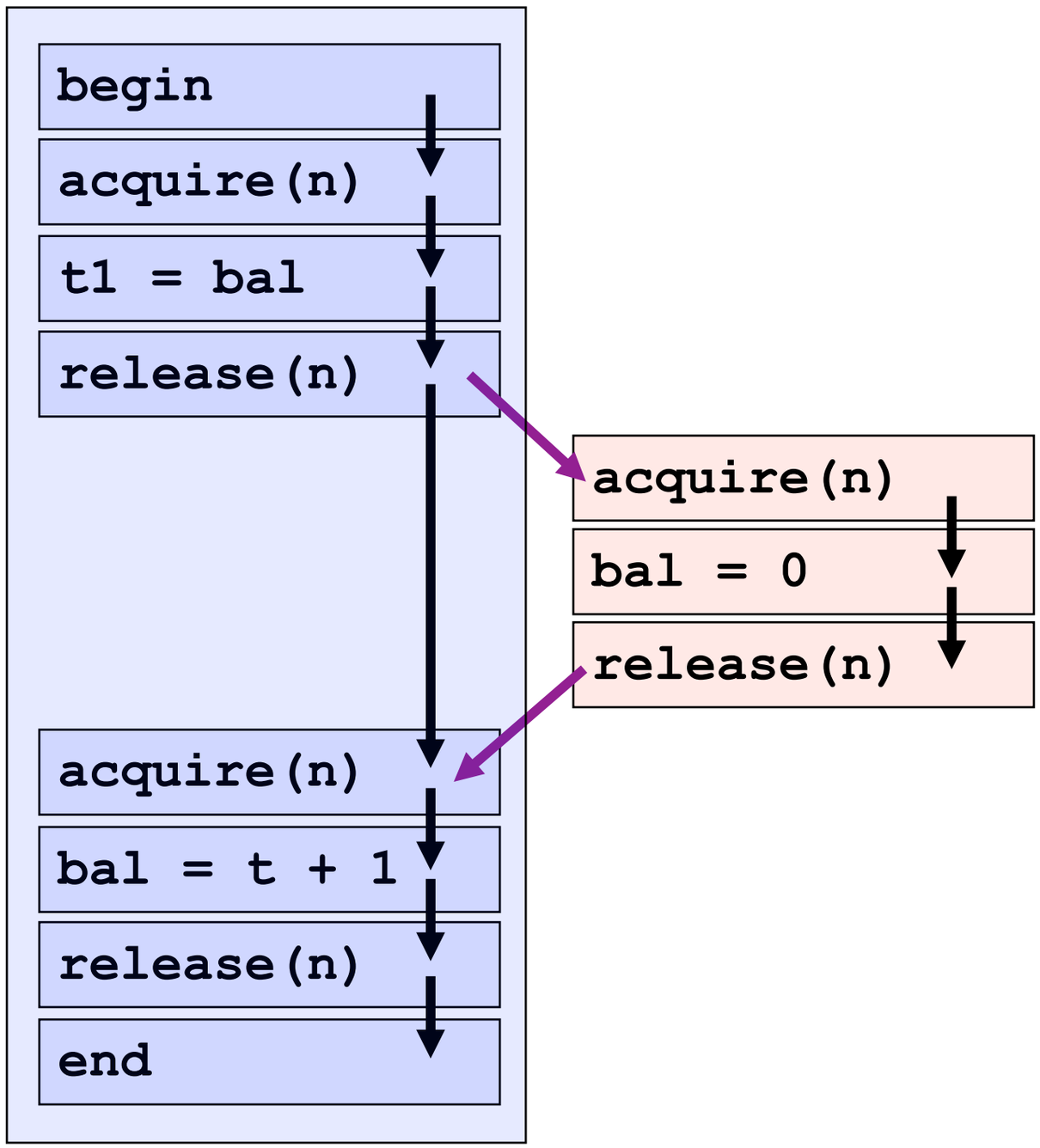


Happens-Before

- program order
- fork/join order
- synchronization order

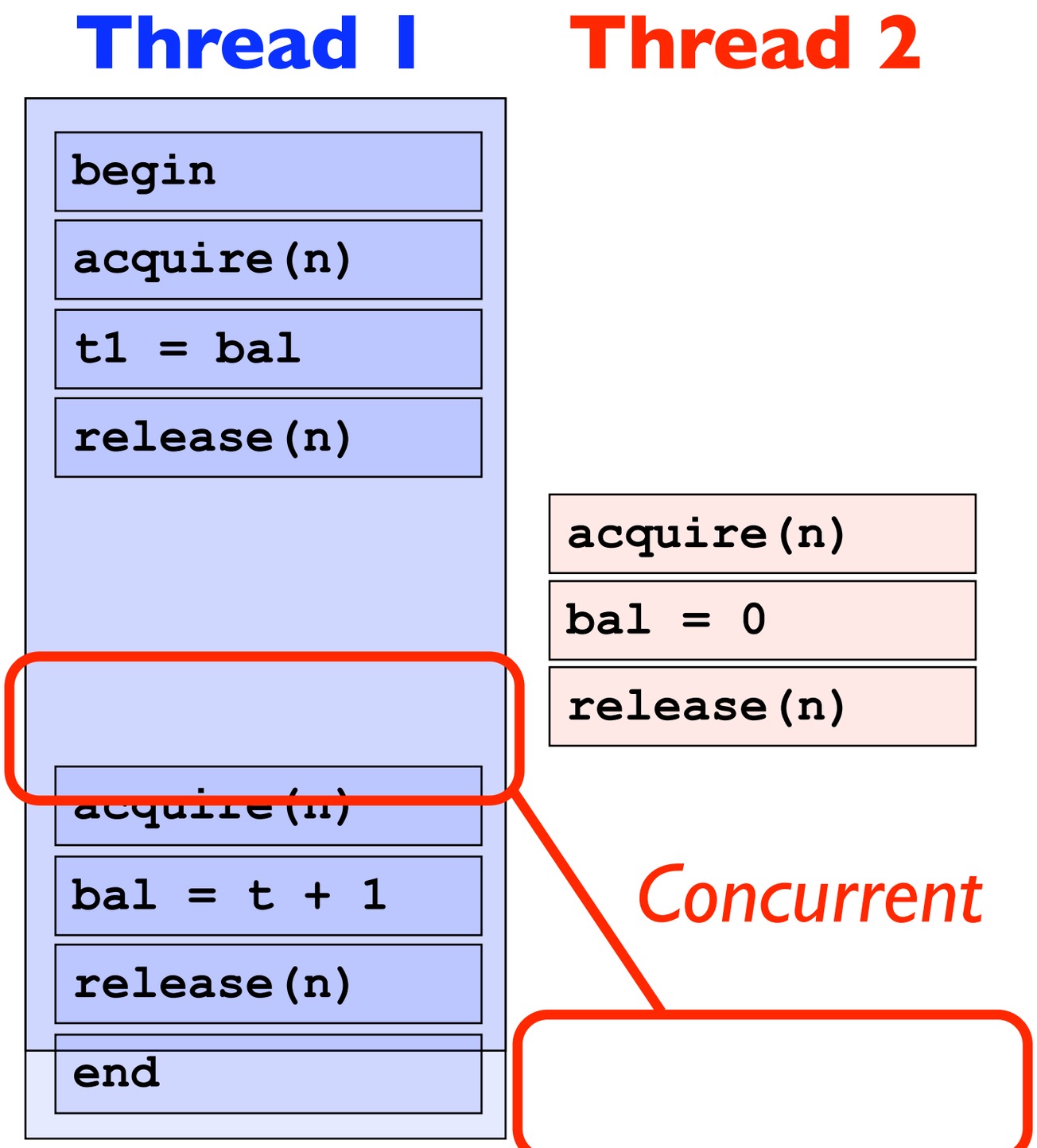
Enables Relation

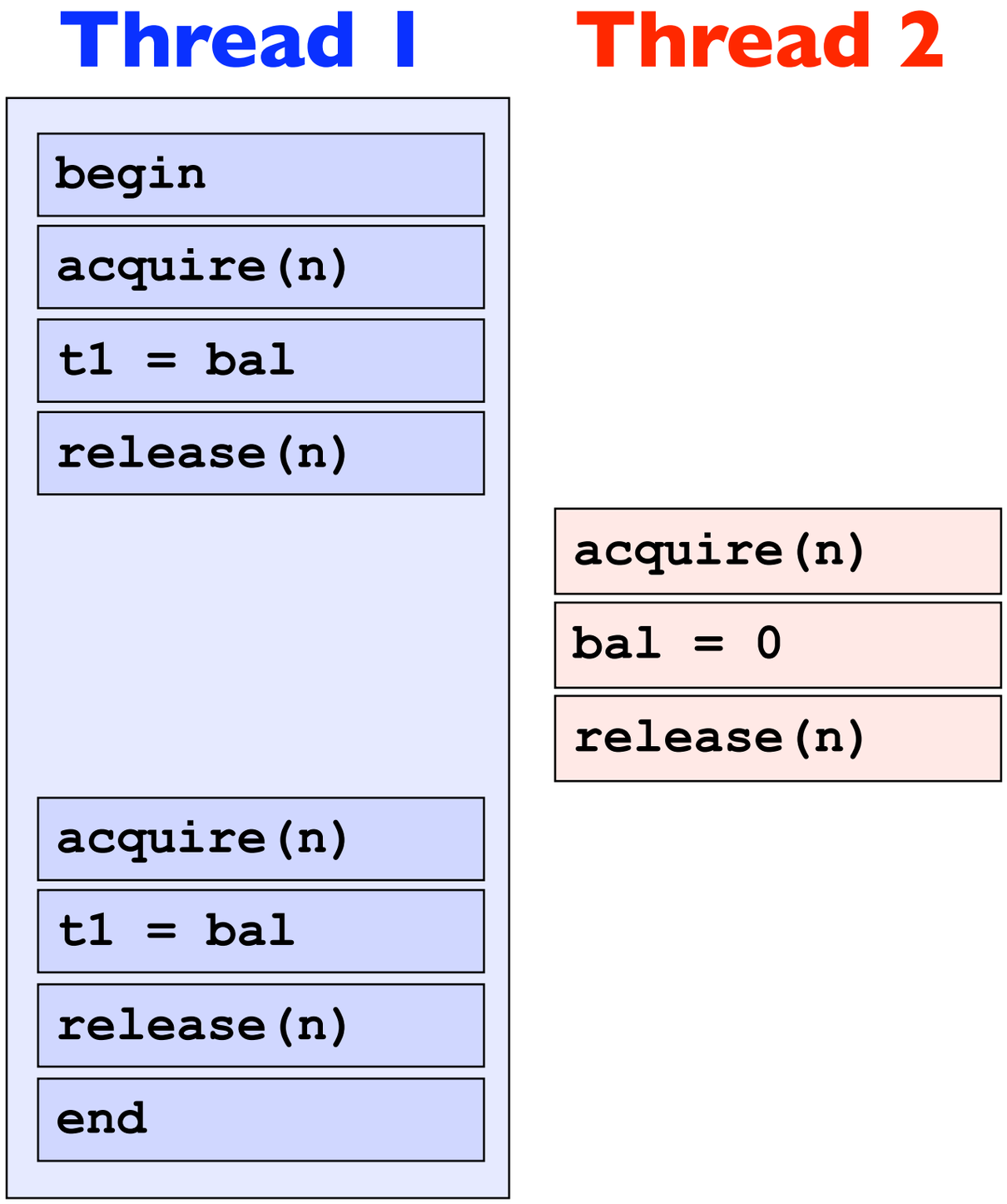
- program order
- fork/join order

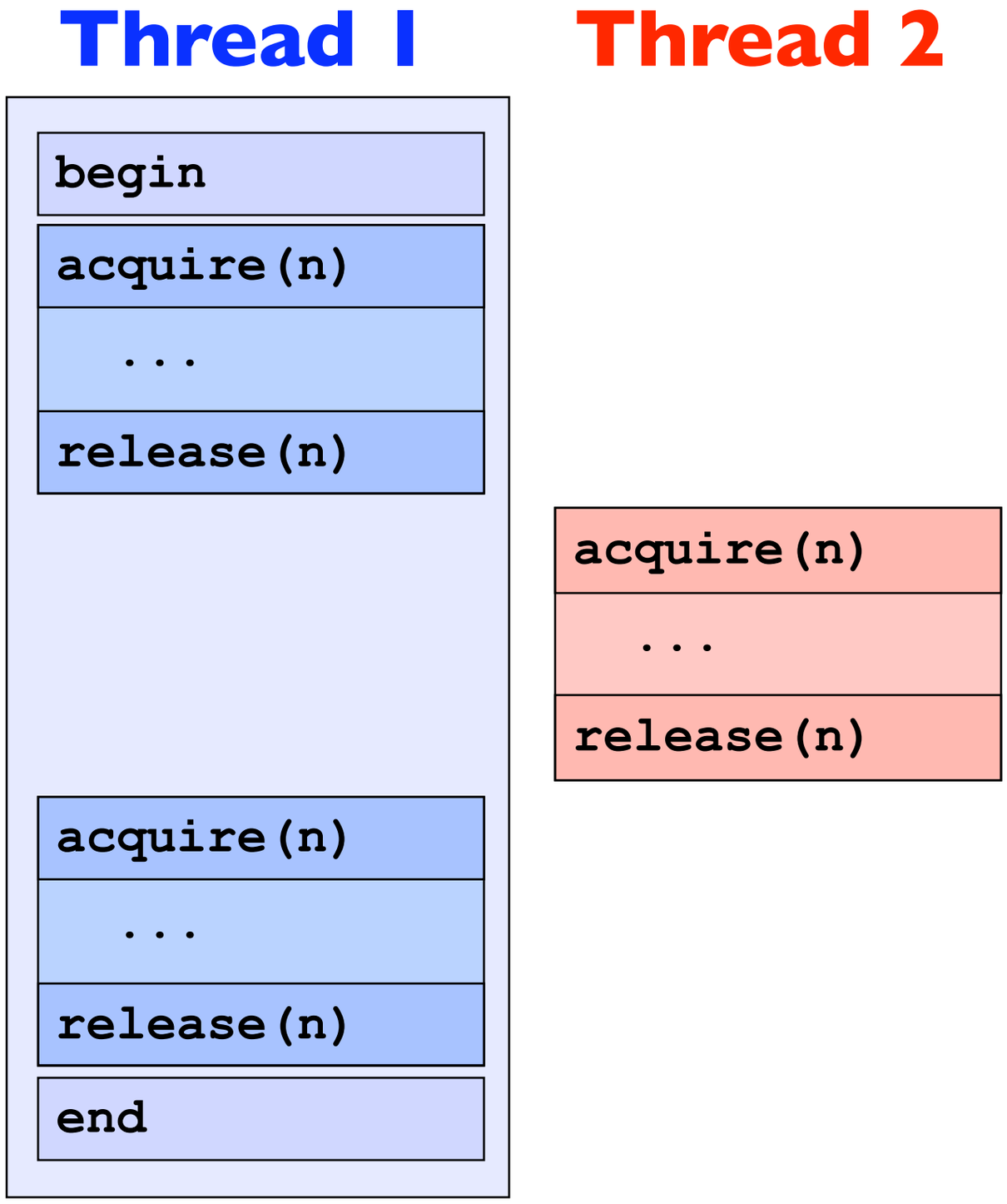


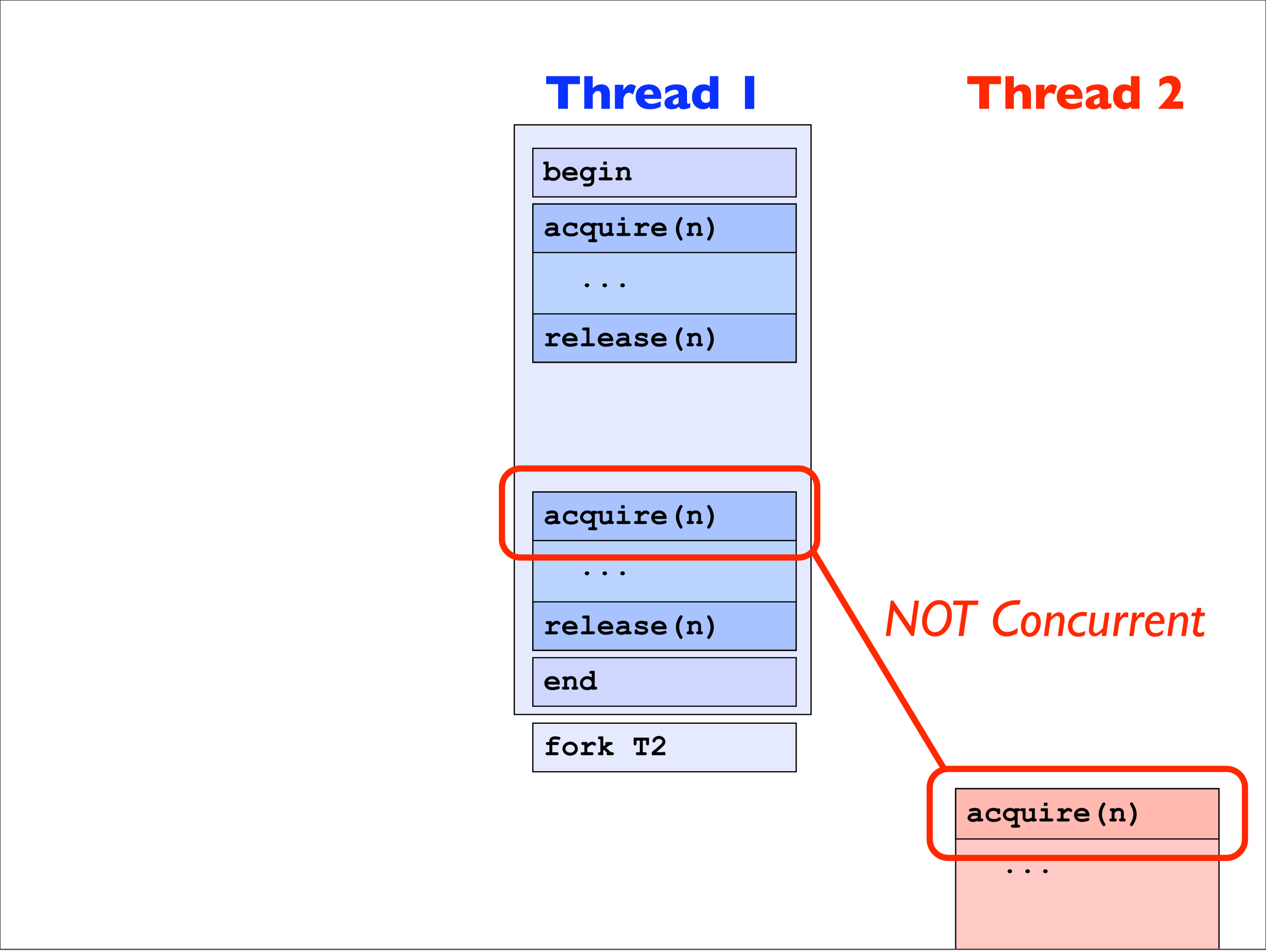
happens-before
atomicity violation

feasible
atomicity violation

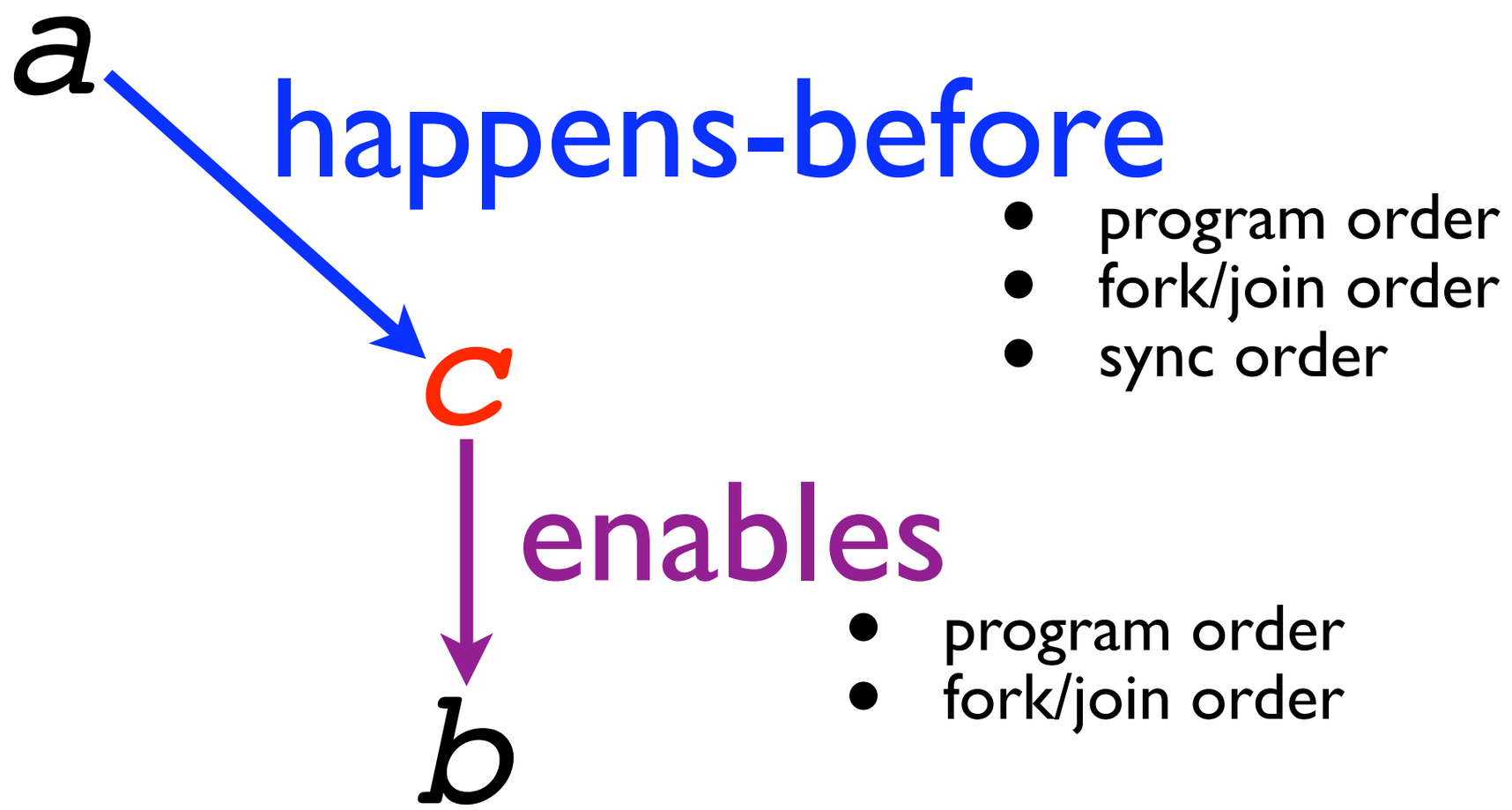



Thread 1
Thread 2
begin
acquire(n)
t1 = bal
release(n)
acquire(n)
bal = 0
release(n)
acquire(n)
t1 = bal
release(n)
end


Thread 1
Thread 2
begin
acquire(n)
...
release(n)
acquire(n)
...
release(n)
acquire(n)
...
release(n)
end

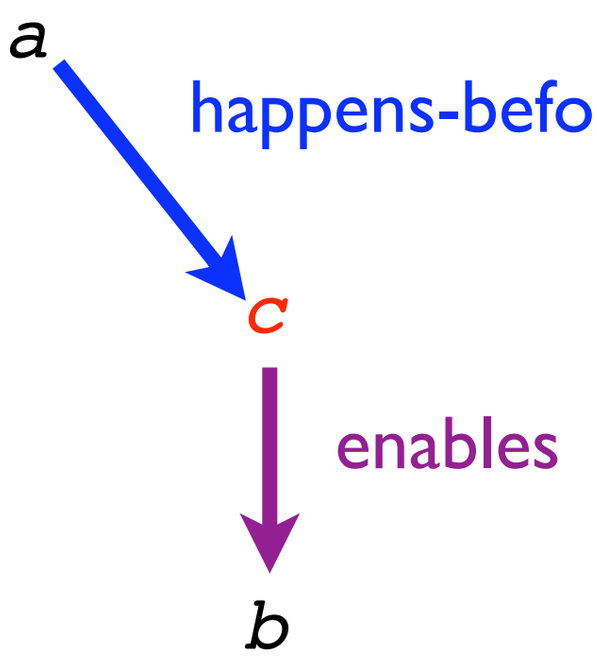

Thread 1
Thread 2
begin
acquire(n)
...
release(n)
acquire(n)
...
release(n)
end
fork T2
NOT Concurrent
acquire(n)
...

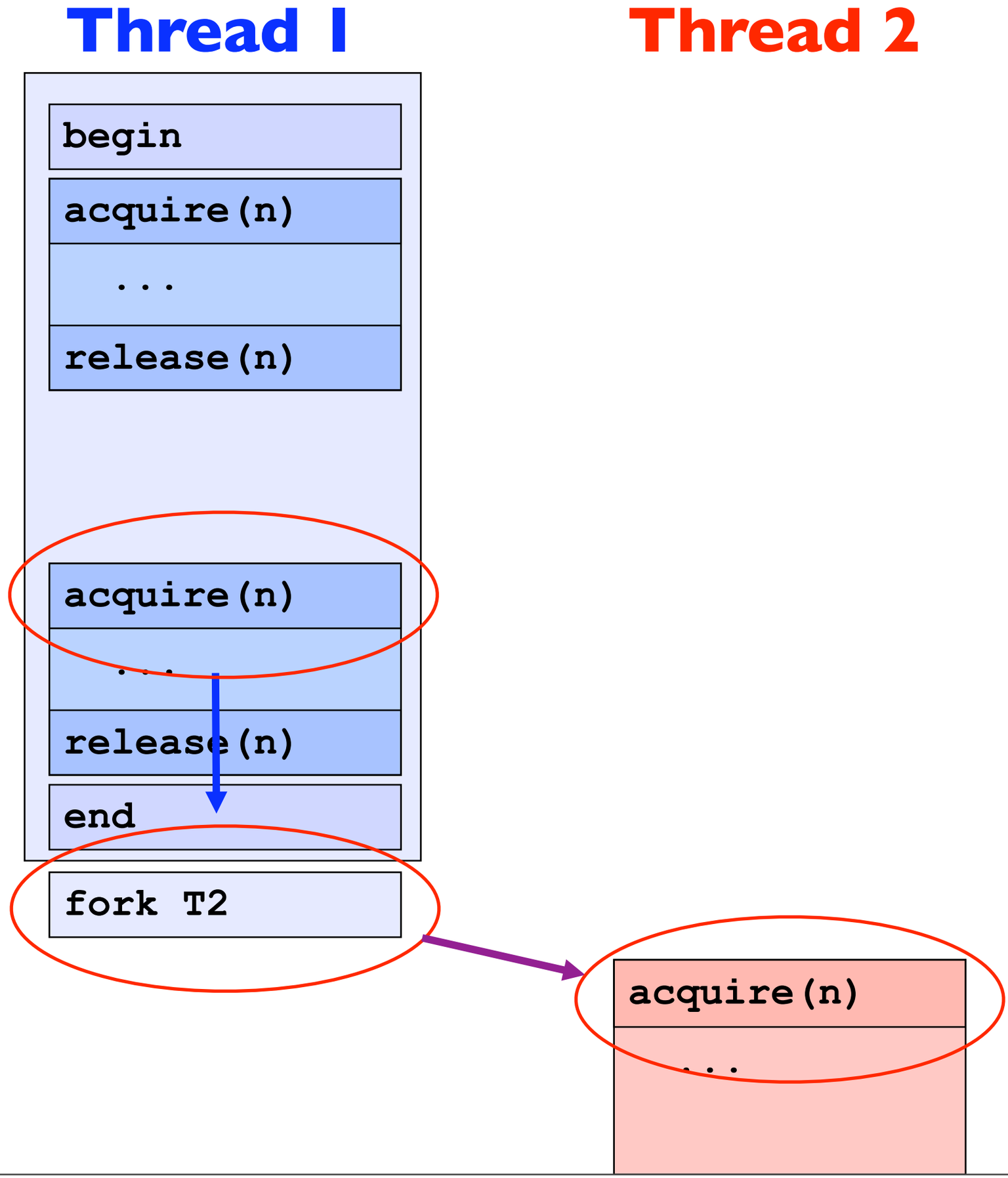
- In a trace, a lock operation *a* is *concurrent* with a later lock operation *b* if there are no intermediate operations which both enable *b* and happen-after *a*.



a and *b* not concurrent

NOT Concurrent:





no c

a

happens-before

c

enables

b

Thread 1

Thread 2

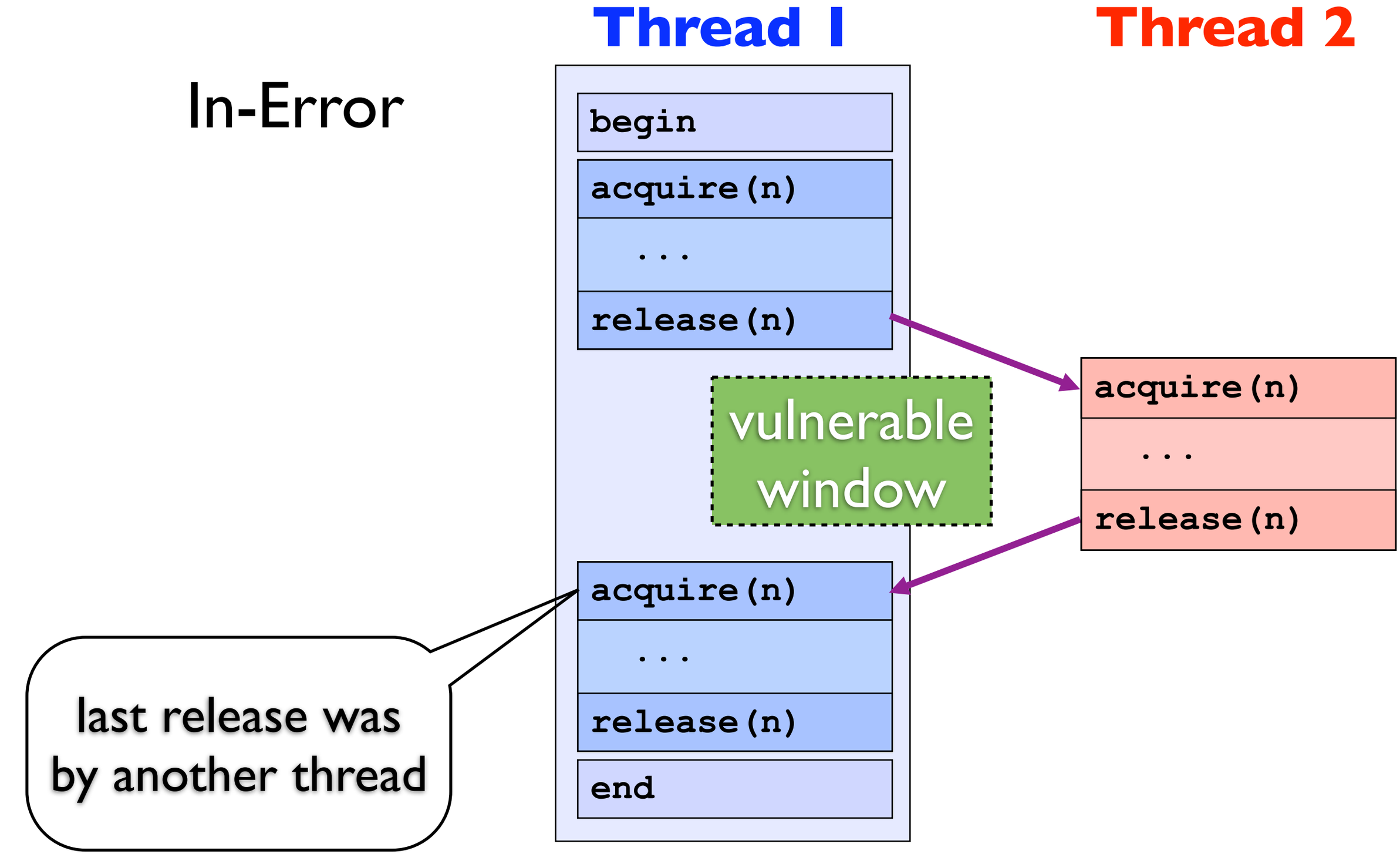
```
begin
acquire(n)
   ...
release(n)
```

```
acquire(n)
   ...
release(n)
end
```

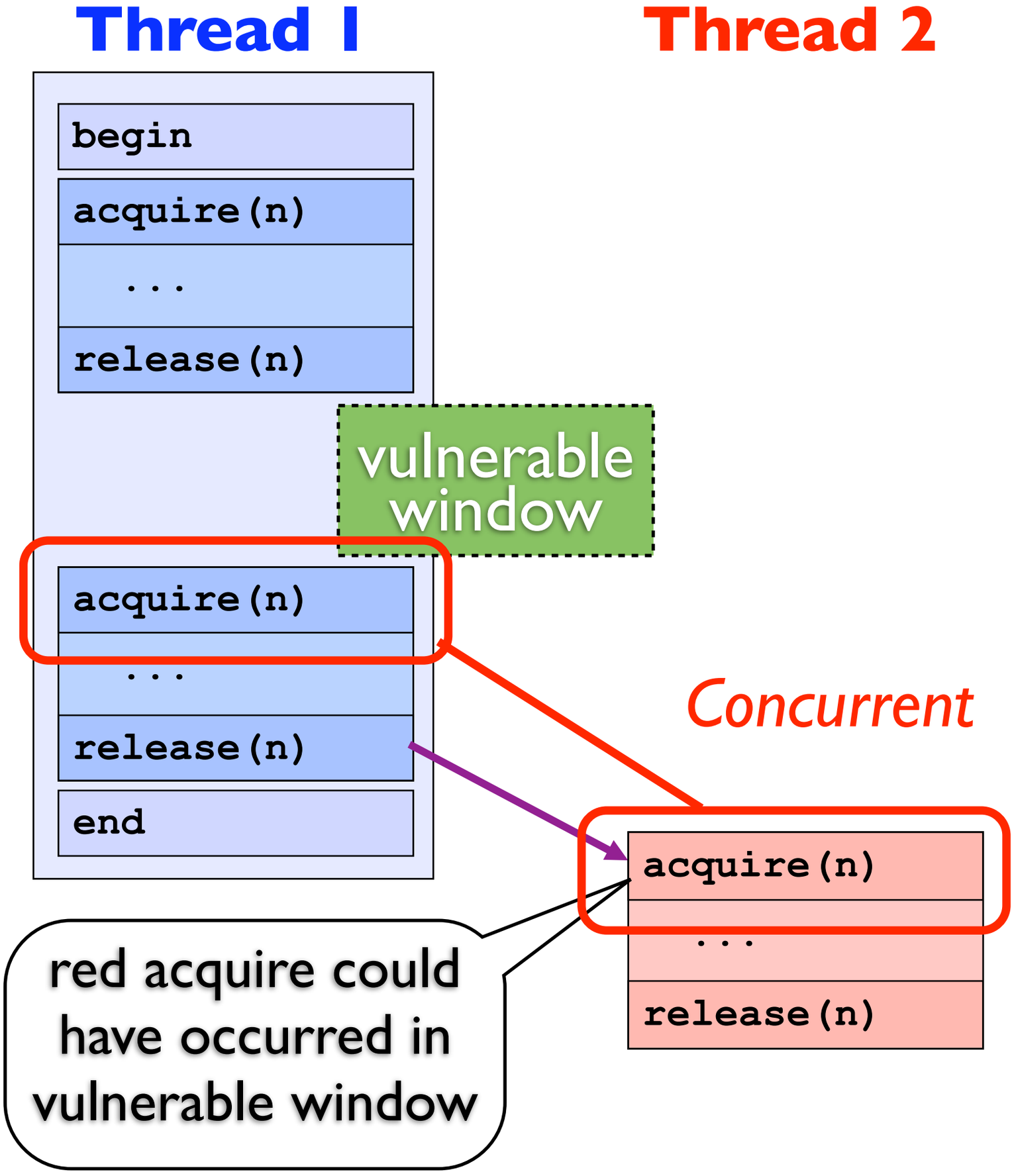
Concurrent

```
acquire(n)
   ...
release(n)
```

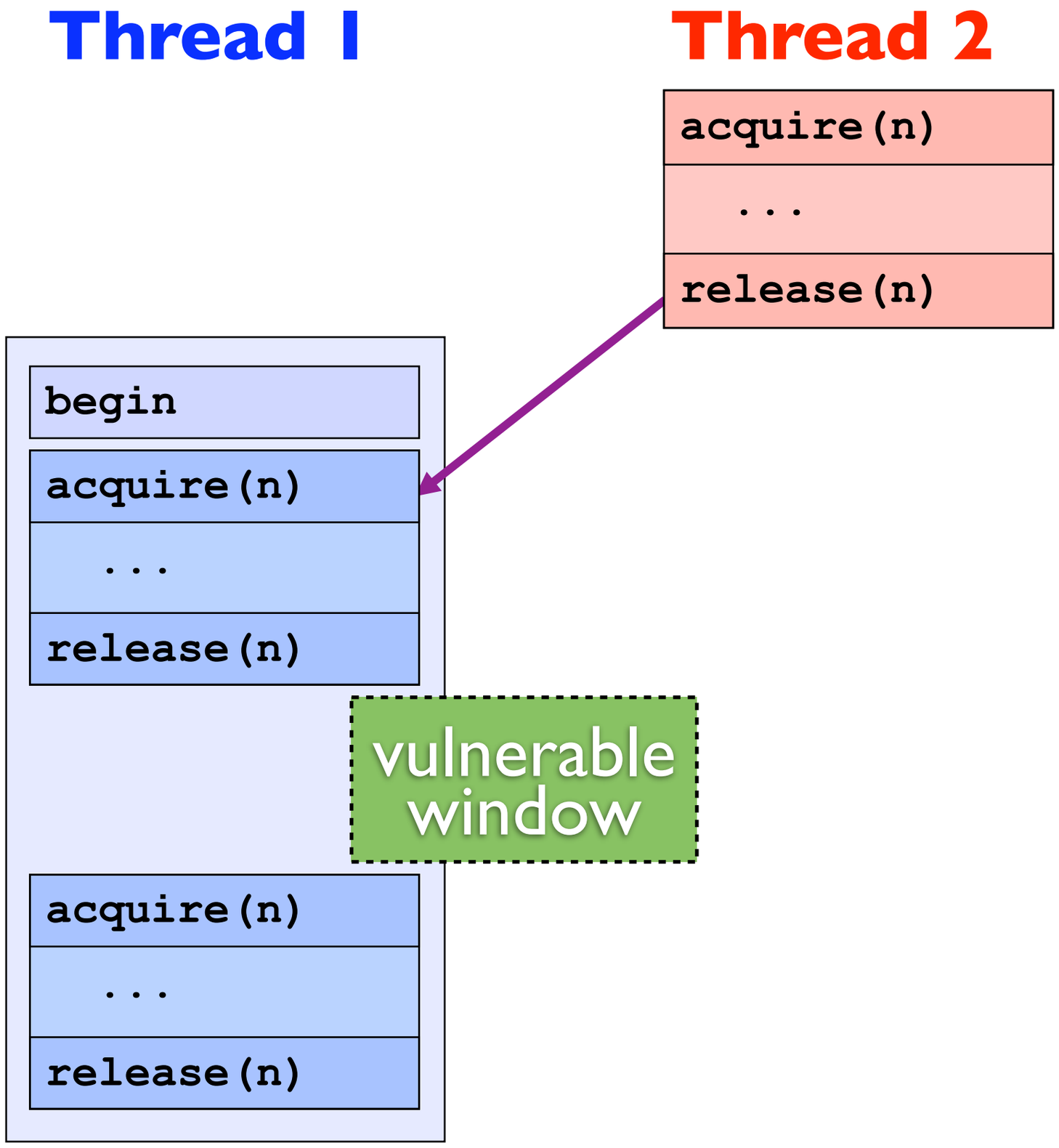
In-Error


Thread 1
Thread 2
begin
acquire(n)
...
release(n)
vulnerable window
acquire(n)
...
release(n)
acquire(n)
...
release(n)
end
last release was by another thread

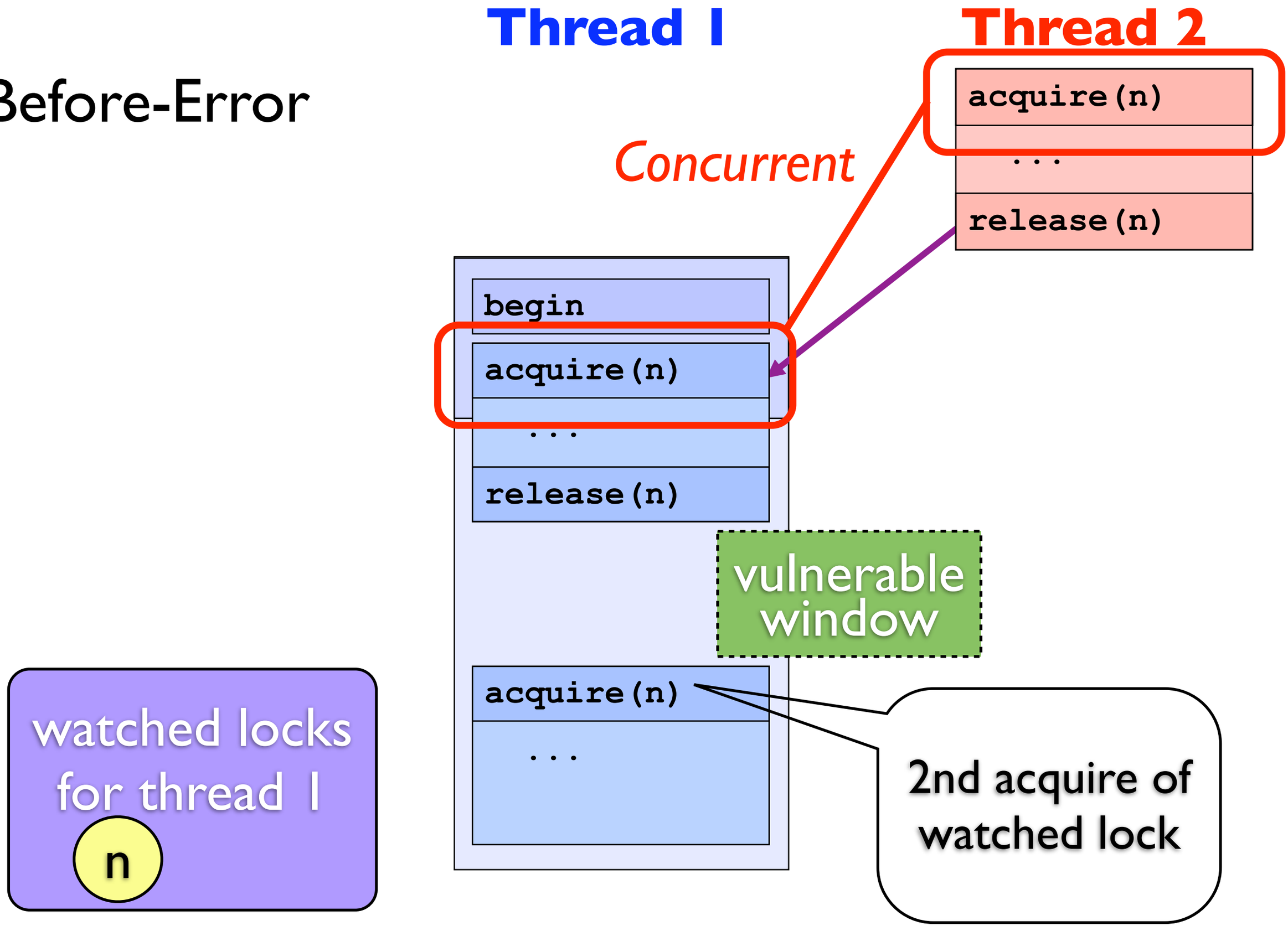
After-Error


Thread 1
Thread 2
begin
acquire(n)
...
release(n)
vulnerable window
acquire(n)
...
release(n)
end
Concurrent
acquire(n)
...
release(n)
red acquire could have occurred in vulnerable window

Before-Error



Before-Error



Blame Assignment

```
atomic b(){
  d();
  c();
}
```

Not Atomic!

```
atomic c(){
  d();
}
```

Atomic!

```
atomic d(){
  sync(m) {...}
}
```

Atomic!

Call Stack

b

b:d

b

b:c

b:c:d

Thread 1

Thread 2

Concurrent

```
enter d
acq/rel(m)
exit d
```

```
begin
enter b
enter d
acq/rel(m)
exit d
enter c
enter d
acquire(m)
```

vulnerable window

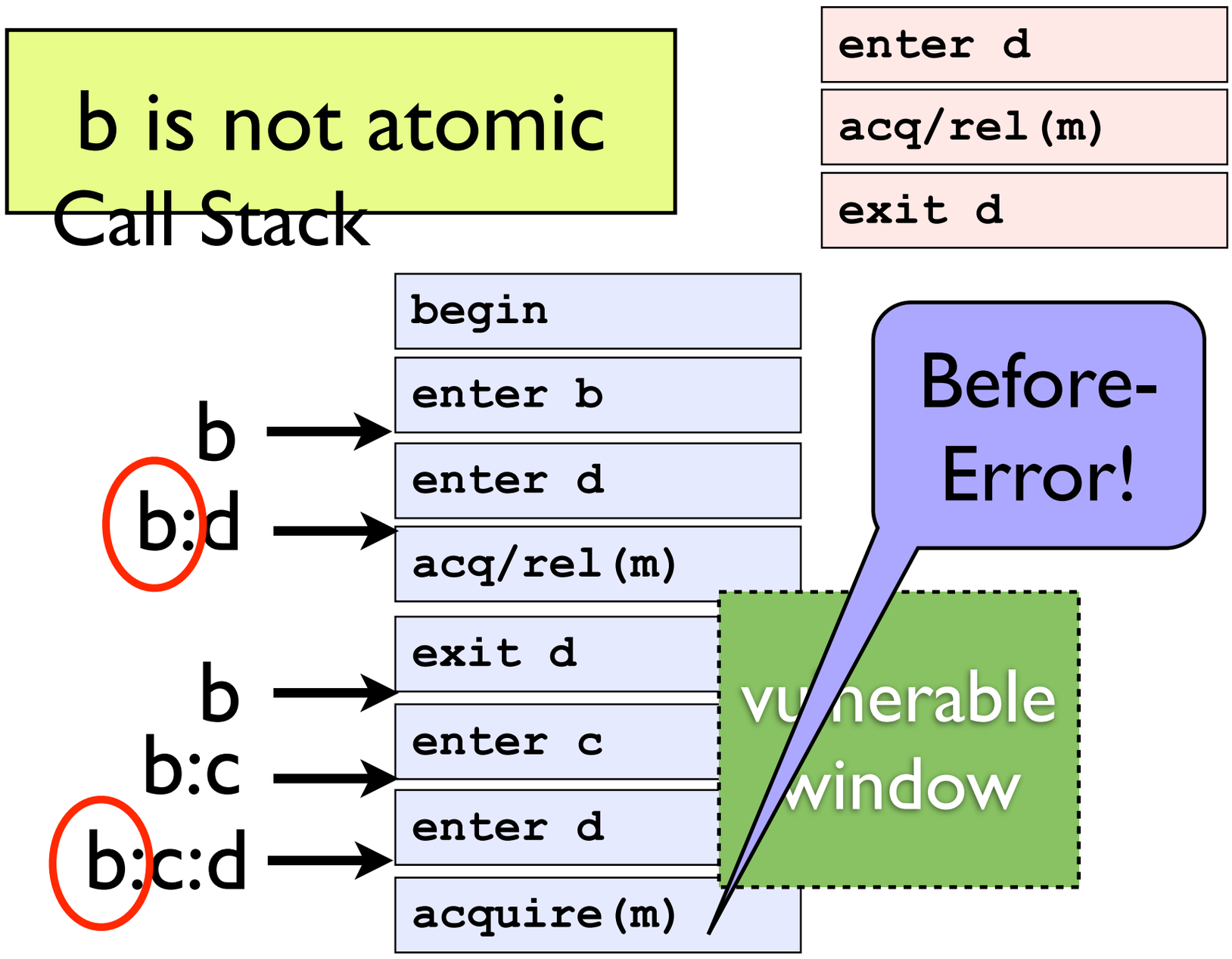
Before-Error!

Blame Assignment

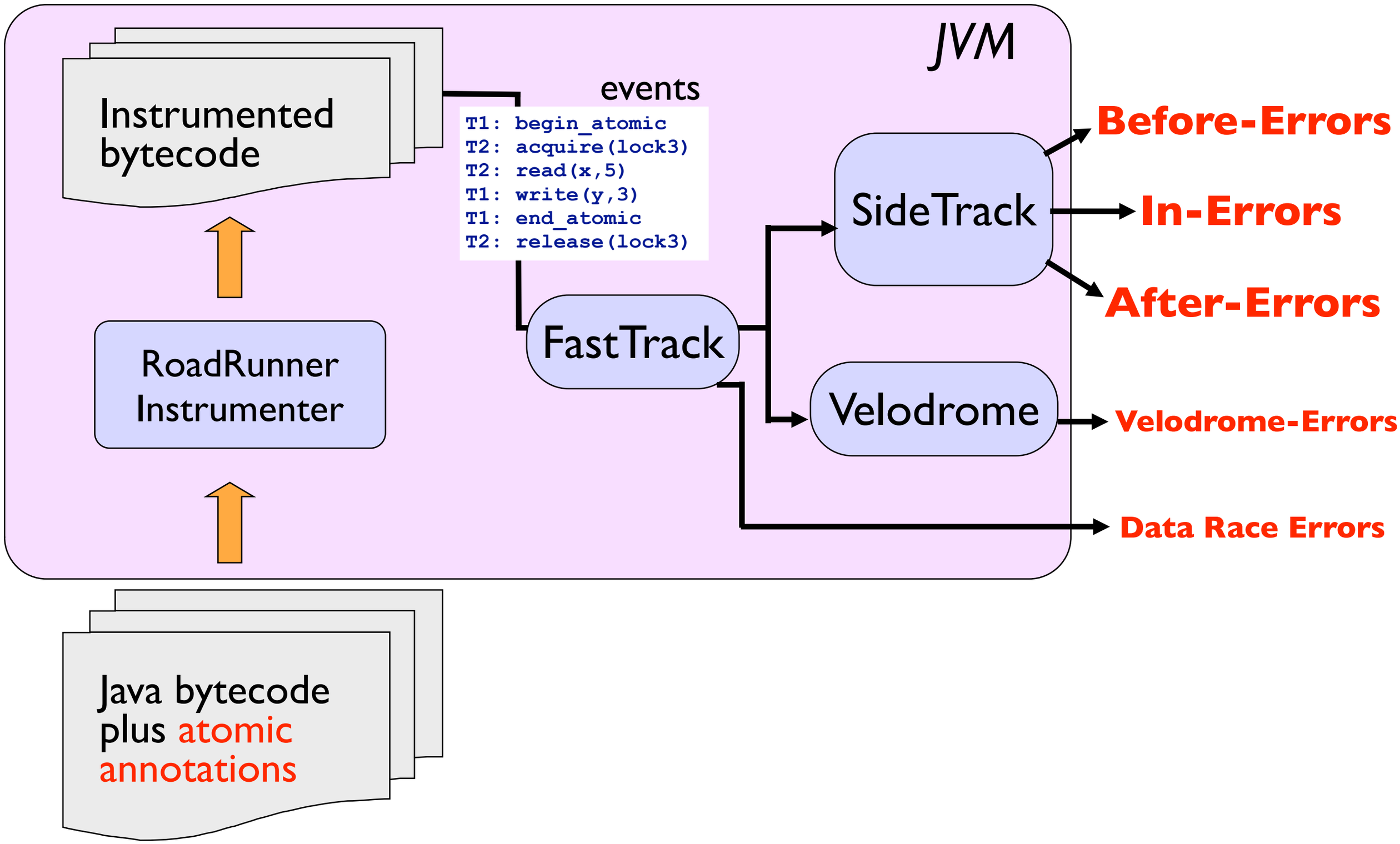
```
atomic b(){
  d();
  c();
}

atomic c(){
  d();
}

atomic d(){
  sync(m) {...}
}
```



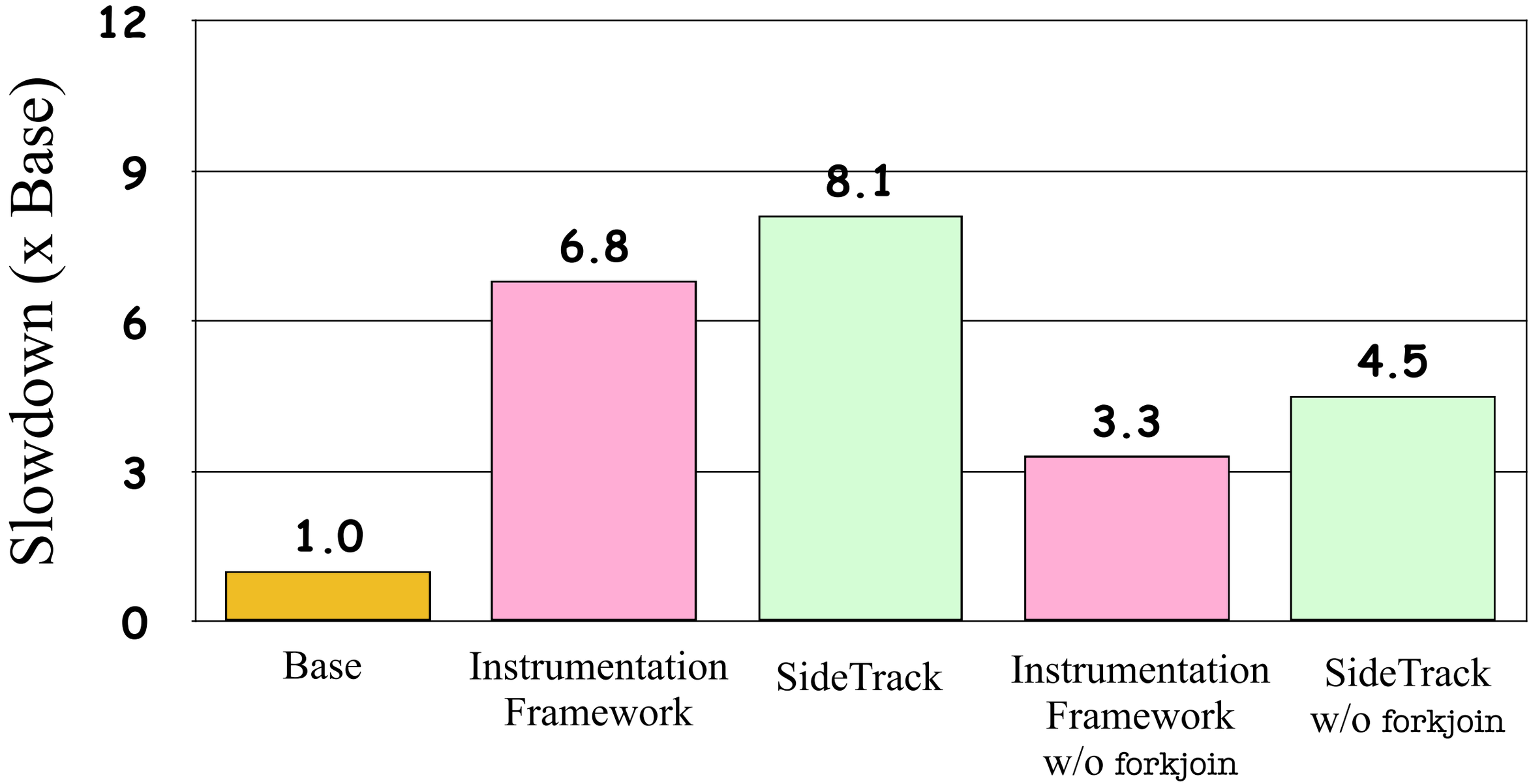
SideTrack Implementation



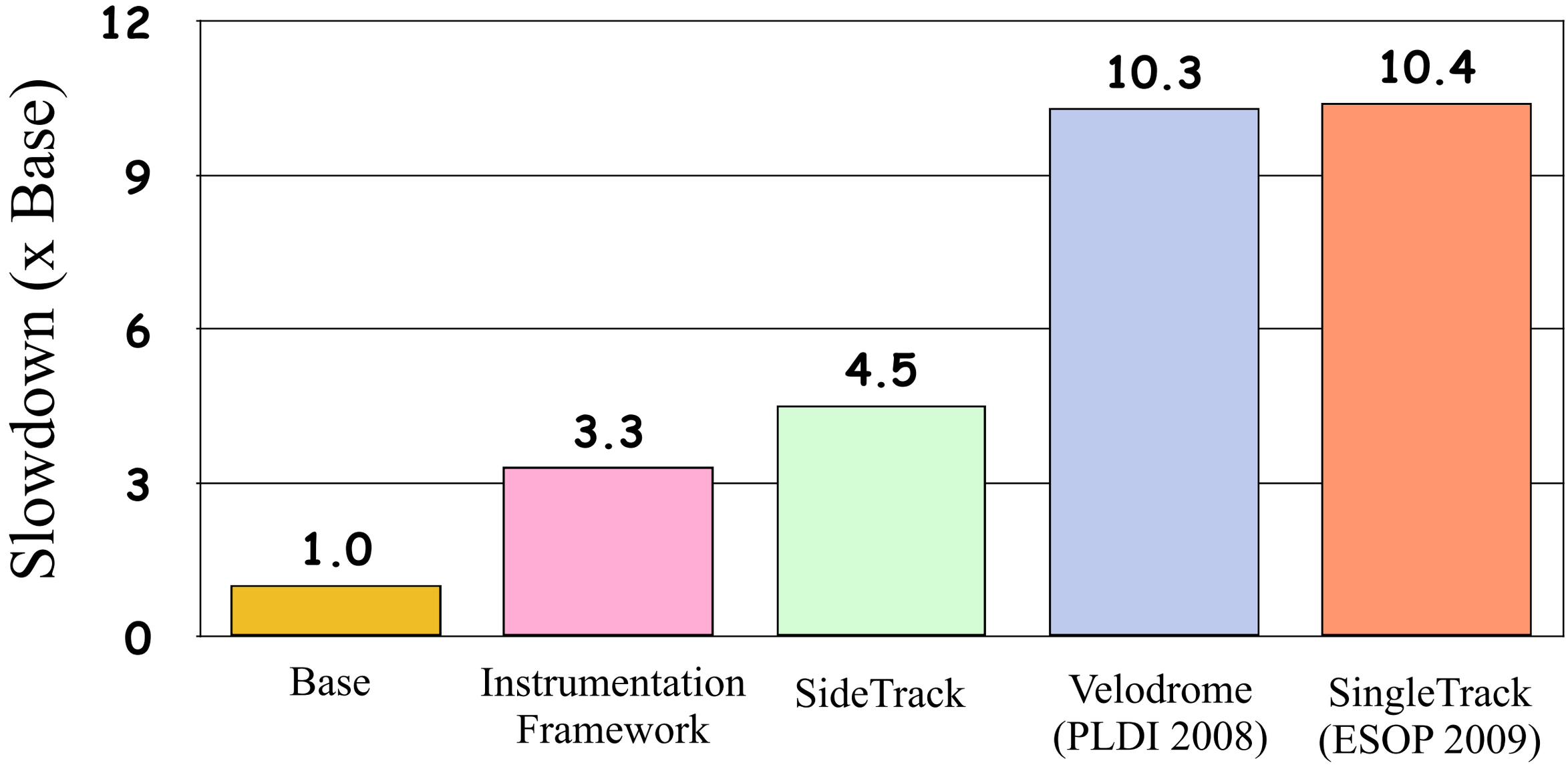
Errors Found:
40% improvement with prediction

	In-Errors	Before-Errors	After-Errors	Predicted Errors (Before ∪ After)/In
elevator	1	3	5	4
colt	7	4	9	2
jbb	5	7	10	5
hedc	4	1	4	0
barrier	1	1	1	0
philo	1	1	1	0
tsp	4	4	4	0
sync	4	4	4	0
	27	25	38	11

Experimental Results: Performance



Experimental Results: Performance



Related Work:

Predictive Approaches

- Wang & Stoller et al. (2006, 2009)
  - analyze traces offline; add static info (HAVE)
- JPredictor (Chen et al. 2008)
  - offline causality slicing, violation patterns
- Farzan & Madhusudan (2009)
  - time bounds & algorithms, no implementation
- AtomFuzzer (Sen & Park 2008)
  - drive scheduler to produce violation, probabilistic

Conclusion: SideTrack

- **no false alarms**
- predicts **feasible** atomicity violations
- **40% increase** in atomicity violations detected
- competitive performance
- chain with other tools (Velodrome, FastTrack)

SideTrack:

- no false alarms
- predicts feasible atomicity violations
- 40% increase in atomicity violations detected
- competitive performance
- chain with other tools

Future Work

- volatiles, wait/notify, barriers, etc.
- direct comparison with other tools
- more benchmarks
- formal proofs