Parallele Programmierung FS25

Exercise Session 10

Jonas Wetzel

Plan für heute

- Organisation
- Nachbesprechung Assignment 9
- Theory
- Intro Assignment 10
- Exam questions
- Kahoot

Organisation

- Mein Name ist Jonas Wetzel
- Meine Website (Materialien und Inhalt der Übungen): n.ethz.ch/~jwetzel
- Meine Email: jwetzel@ethz.ch
- Discord: @jonas.too

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- Feedback zur Session: https://forms.gle/qiDnqkfSP2NUQGvc9

Organisation

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- Falls ihr Feedback möchtet kommt bitte zu mir

Organisation

- Wo sind wir jetzt?

Semaphores
Barriers
Monitors
Conditional Locks

Plan für heute

- Organisation
- **Nachbesprechung Assignment 9**
- Theory
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Feedback: Assignment 9

Recap: Critical Section Properties

- **Mutual exclusion**: No more then one process executing in the critical section
- **Progress**: When no process is in the critical section, any process that requests entry must be permitted without delay
- **No starvation (bounded wait)**: If any process tries to enter its critical section then that process must eventually succeed.

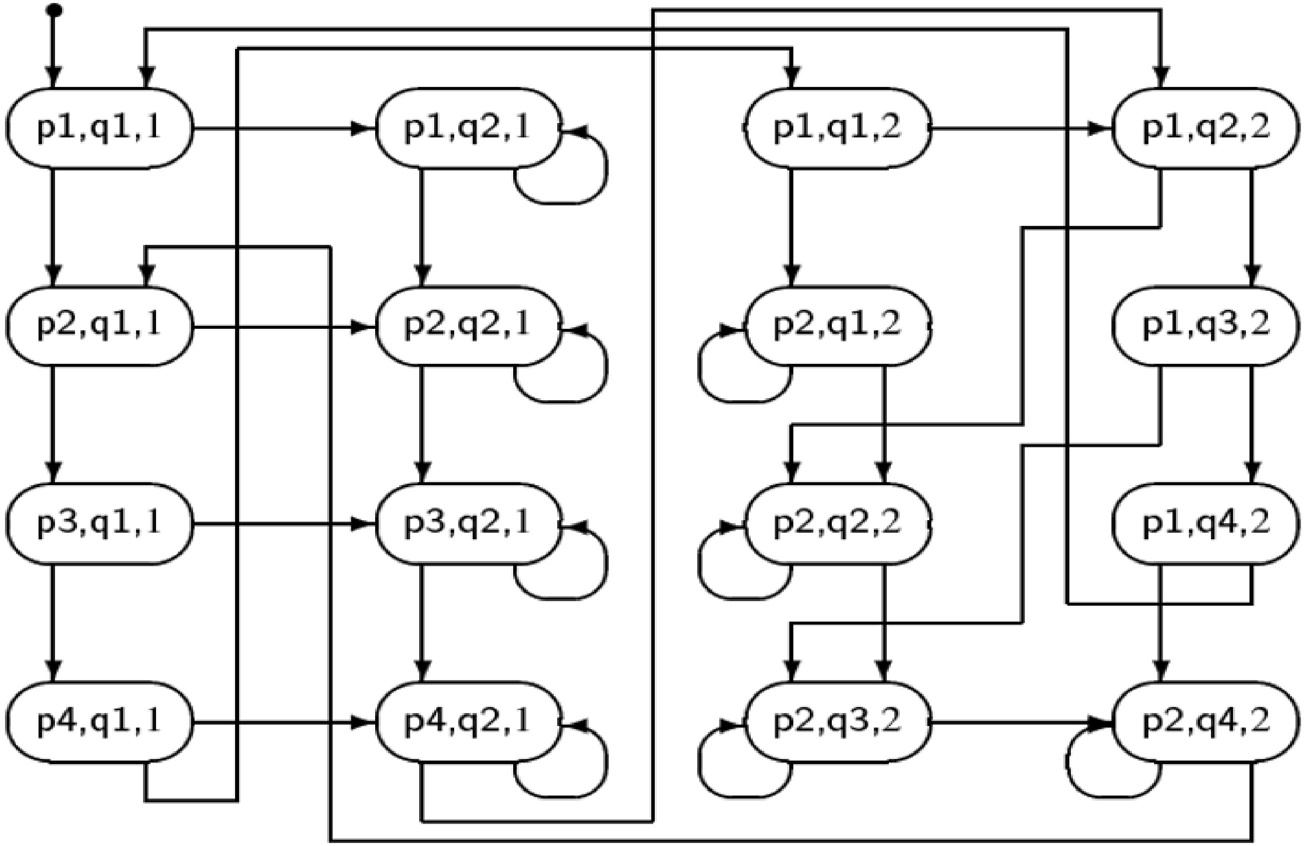
P

```
p1:   Non-critical section P
p2:   while turn != 1
p3:   Critical section
p4:   turn = 2
```

turn = 1

Q

```
q1:   Non-critical section Q
q2:   while turn != 2
q3:   Critical section
q4:   turn = 1
```



- **Mutual exclusion**: E.g. State (p3,q3,_) is not reachable
- **Progress**: E.g. There exists a path for P such that state (P3, _ , _) is reachable from (P2,_,_). Typical couterexamples: deadlocks and livelocks
- **No starvation (bounded wait)**: Possible starvation reveals itself as cycles in the state diagram.

P

p1: Non-critical section P

p2: while turn != 1

p3: Critical section

p4: turn = 2

turn = 1

Q

q1: Non-critical section Q

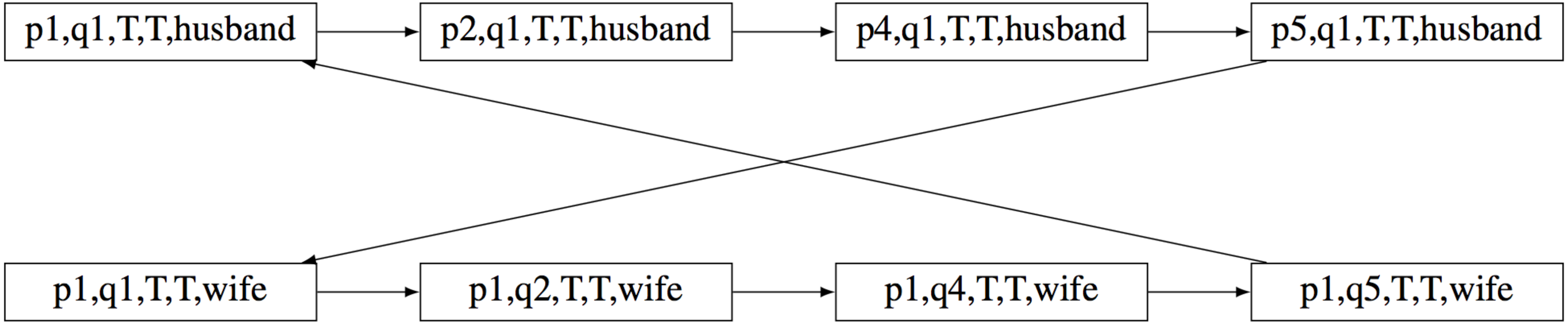
q2: while turn != 2

q3: Critical section

q4: turn = 1

Feedback for Assignment 9

owner			
husband.hungry = true			
wife.hungry = true			
husband		wife	
p1:	while hungry	q1:	while hungry
p2:	owner != me	q2:	owner != me
p3:	sleep	q3:	sleep
p4:	spouse == hungry	q4:	spouse == hungry
p5:	owner = spouse	q5:	owner = spouse
p6:	CR	q6:	CR
p7:	hungry = false	q7:	hungry = false
p8:	owner = spouse	q8:	owner = spouse



Feedback for Assignment 9

- One way to solve the livelock problem is to impose an ordering when acquiring the lock on the shared resource.

- Or one of the spouses can actually take the spoon after certain number of retries

Feedback for Assignment 9

Optimistic vs Pessimistic concurrency control

```
@Override
public int nextInt() {
    // get the current seed value
    long next;
    synchronized (this) {
        long orig = state;
        // using recurrence equation to generate next
        next = (a * orig + c) & (~0L >>> 16);
        // store the updated seed
        state = next;
    }
    return (int) (next >>> 16);
}
```

```
@Override
public int nextInt() {
    while (true) {
        // get the current seed value
        long orig = state.get();
        // using recurrence equation to generate next seed
        long next = (a * orig + c) & (~0L >>> 16);
        // store the updated seed
        if (state.compareAndSet(orig, next)) {
            return (int) (next >>> 16);
        }else{
            try {
                Thread.sleep(1);
            } catch (InterruptedException e) {

            }
        }
    }
}
```

Plan für heute

- Organisation
- Nachbesprechung Assignment 9
- **Theory**
  - **Recap last week**
- Intro Assignment 10
- Exam questions
- Kahoot

Wieso ist das TAS lock so langsam?

Locks with atomics

- Now we can implement locks for n threads using a single variable:

    - Lock: while (!TAS(l)) {}
    - Unlock: mem[l] = 0

Lets build a spinlock using RMW operations

Test and Set (TAS)

Init (lock)

```
lock = 0;
```

Acquire (lock)

```
while !TAS(lock); // wait
```

Release (lock)

```
lock = 0;
```

In Java...

```java
public class TASLock implements Lock {
  AtomicBoolean state = new AtomicBoolean(false);

  public void lock() {
    while(state.getAndSet(true)) {
      //do nothing
    }
  }

  public void unlock() {
    state.set(false);
  }

}
```

TAS Spinlock scales horribly, why?

TAS
n = 1, elapsed= 224, normalized= 224
n = 2, elapsed= 719, normalized= 359
n = 3, elapsed= 1914, normalized= 638
n = 4, elapsed= 3373, normalized= 843
n = 5, elapsed= 4330, normalized= 866
n = 6, elapsed= 6075, normalized= 1012
n = 7, elapsed= 8089, normalized= 1155
n = 8, elapsed= 10369, normalized= 1296
n = 16, elapsed= 41051, normalized= 2565
n = 32, elapsed= 156207, normalized= 4881
n = 64, elapsed= 619197, normalized= 9674

Bus Contention

- TAS/CAS are read-modify-write operations:
  - Processor assumes we modify the value even if we fail!
  - Need to invalidate cache
  - Threads serialize to read the value while spinning

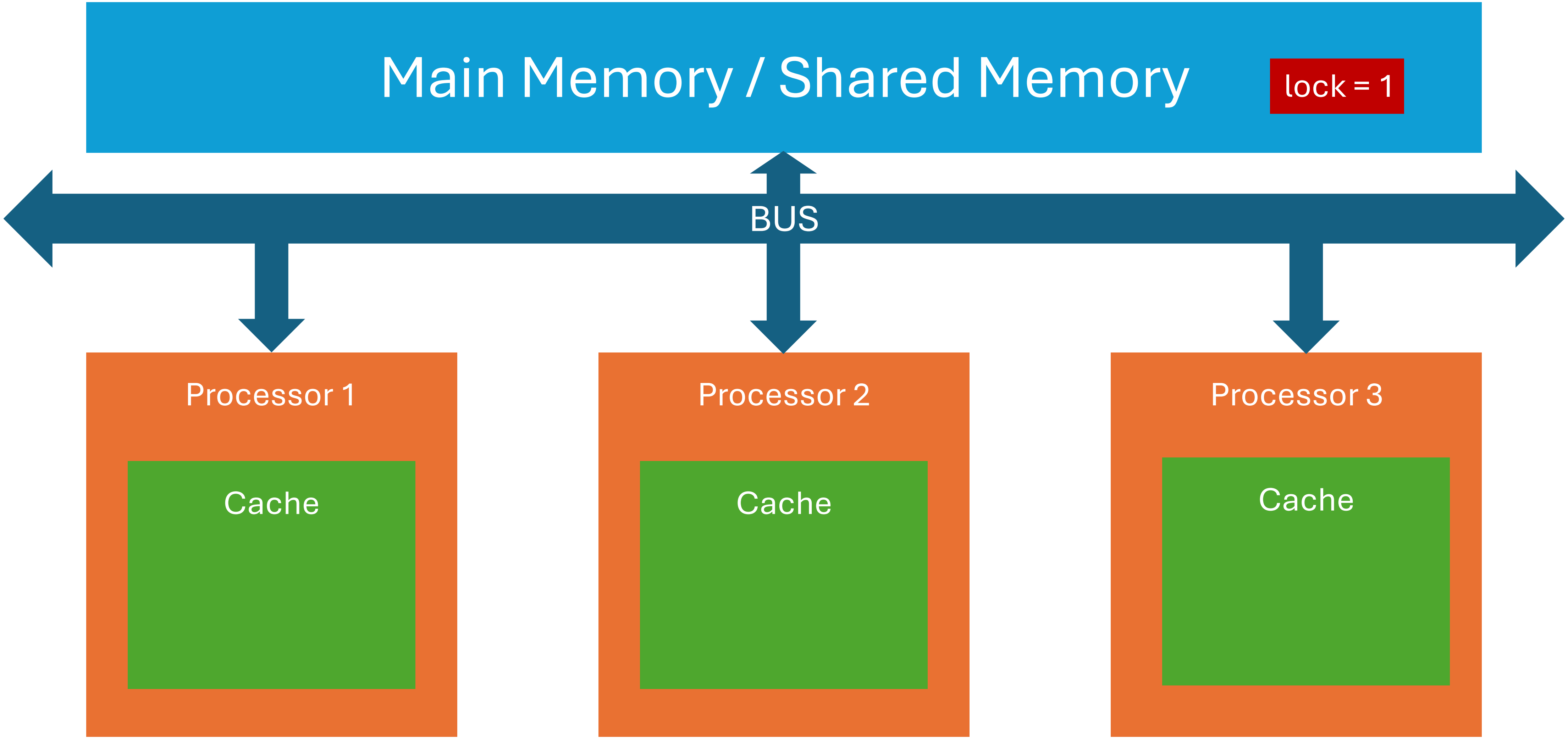
Cache Coherency Protocol ☹

We have a sequential bottleneck!

Each call to getAndSet() invalidates cached copies! => Threads need to access memory via Bus => Bus Contention!

“[…] the getAndSet() call forces other processors to discard their own cached copies of the lock, so every spinning thread encounters a cache miss almost every time, and must use the bus to fetch the new, but unchanged value.” - The Art of Multiprocessor Programming

Let’s visualize this



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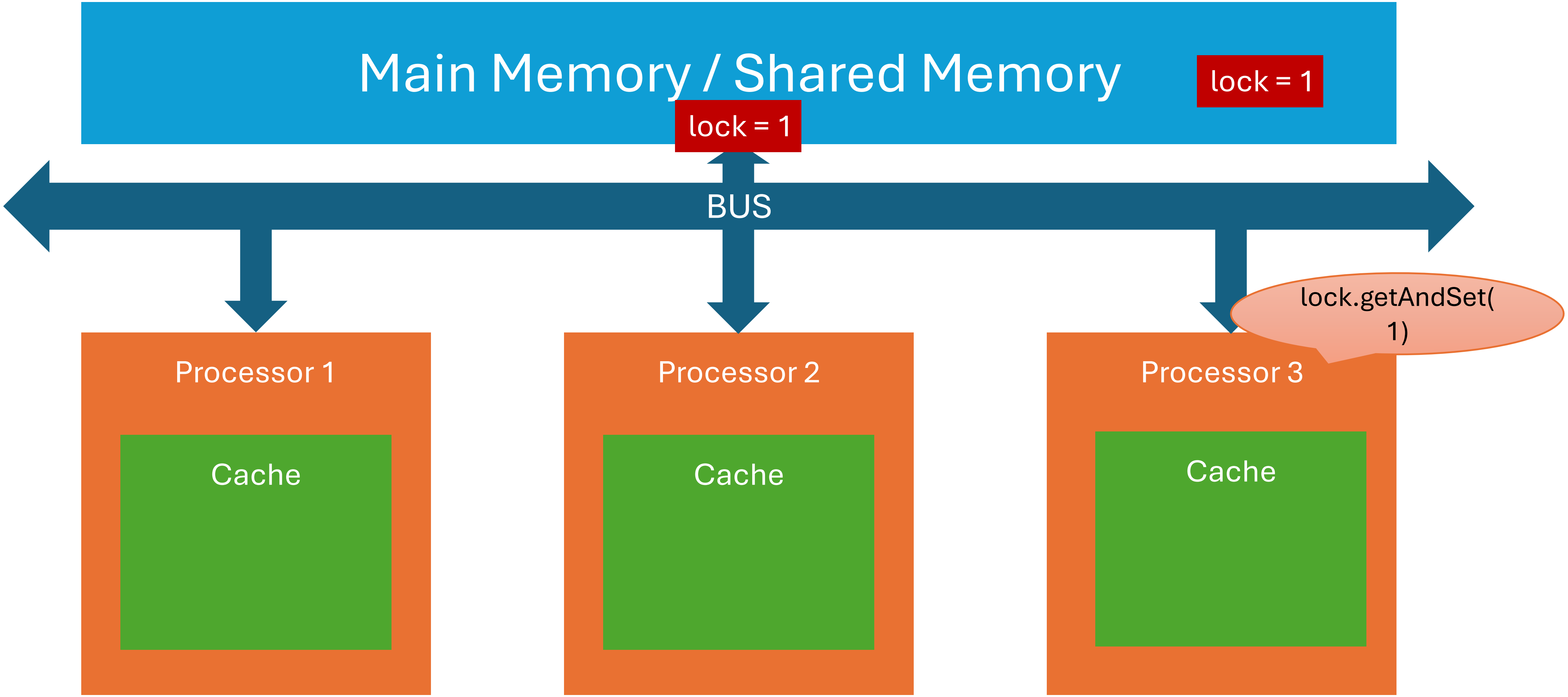

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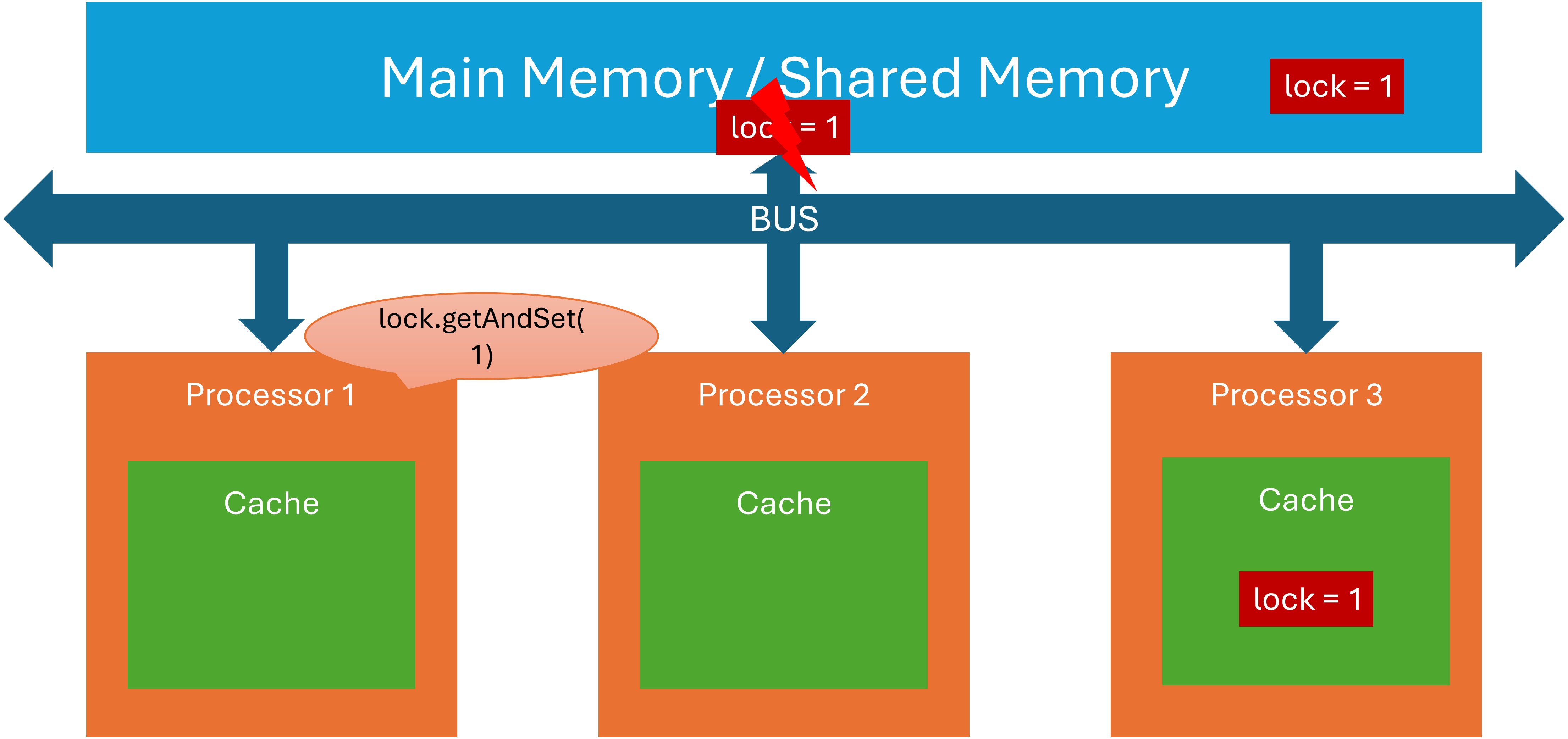

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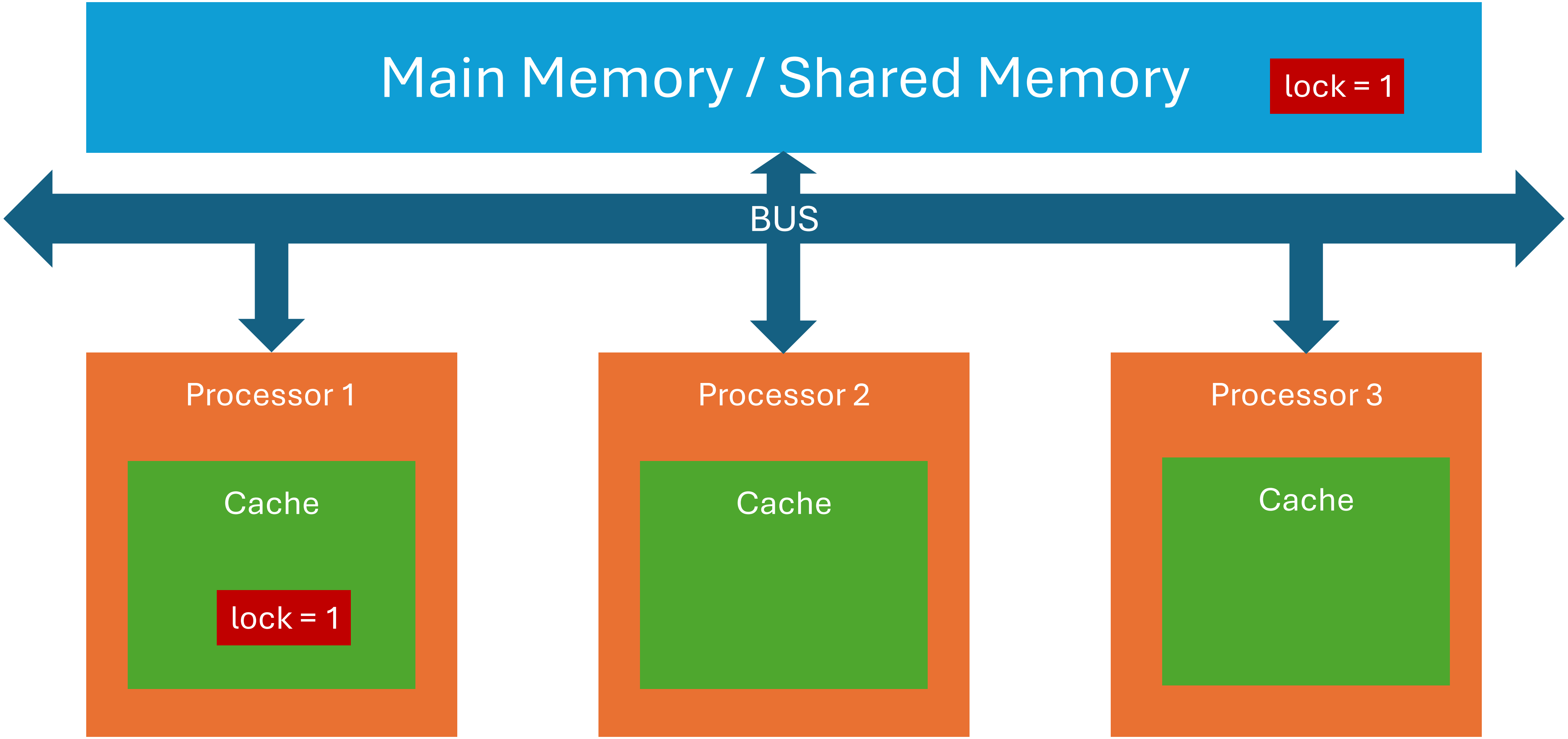


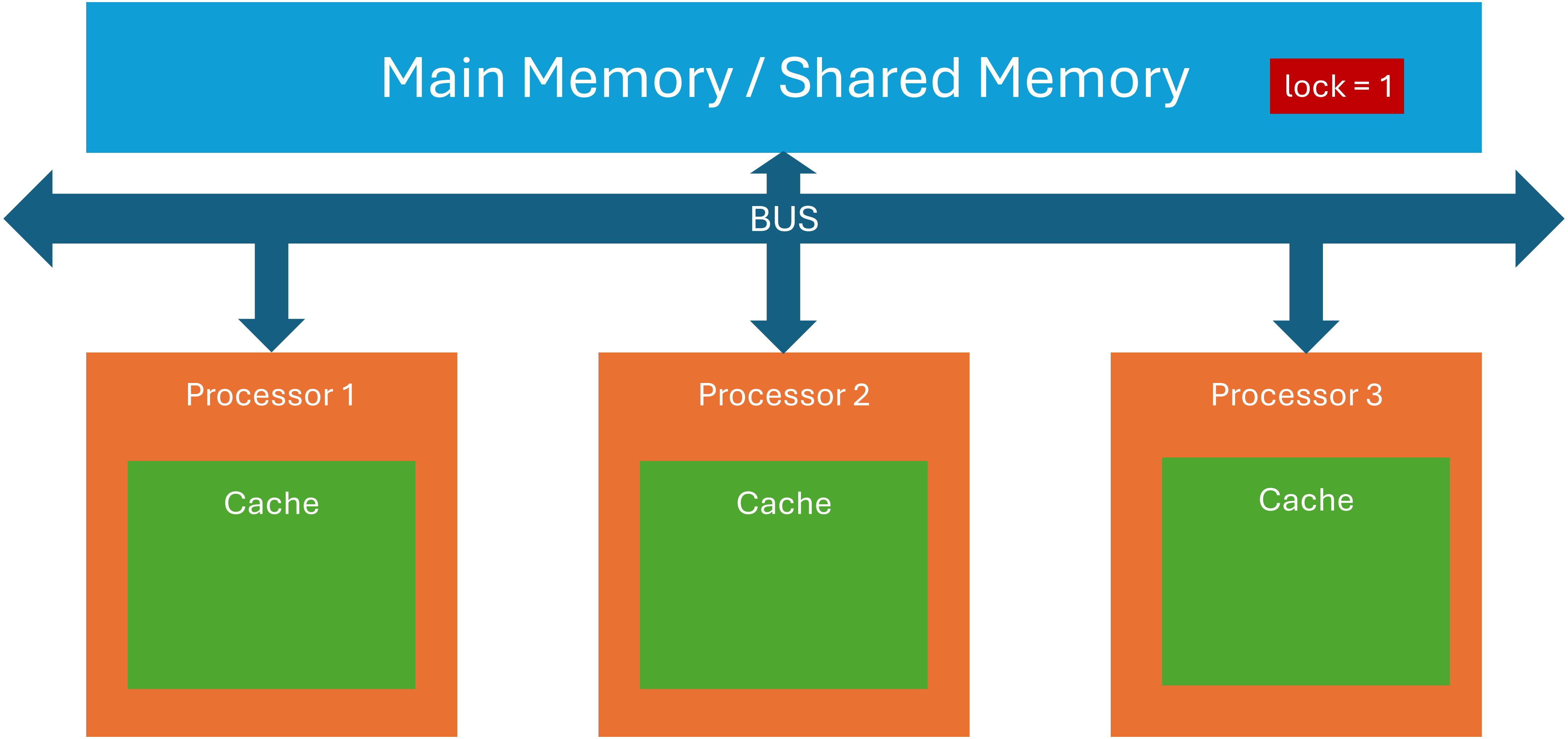
TATAS

- Idea: Use normal operation to read first, try TAS only if first read returns 0

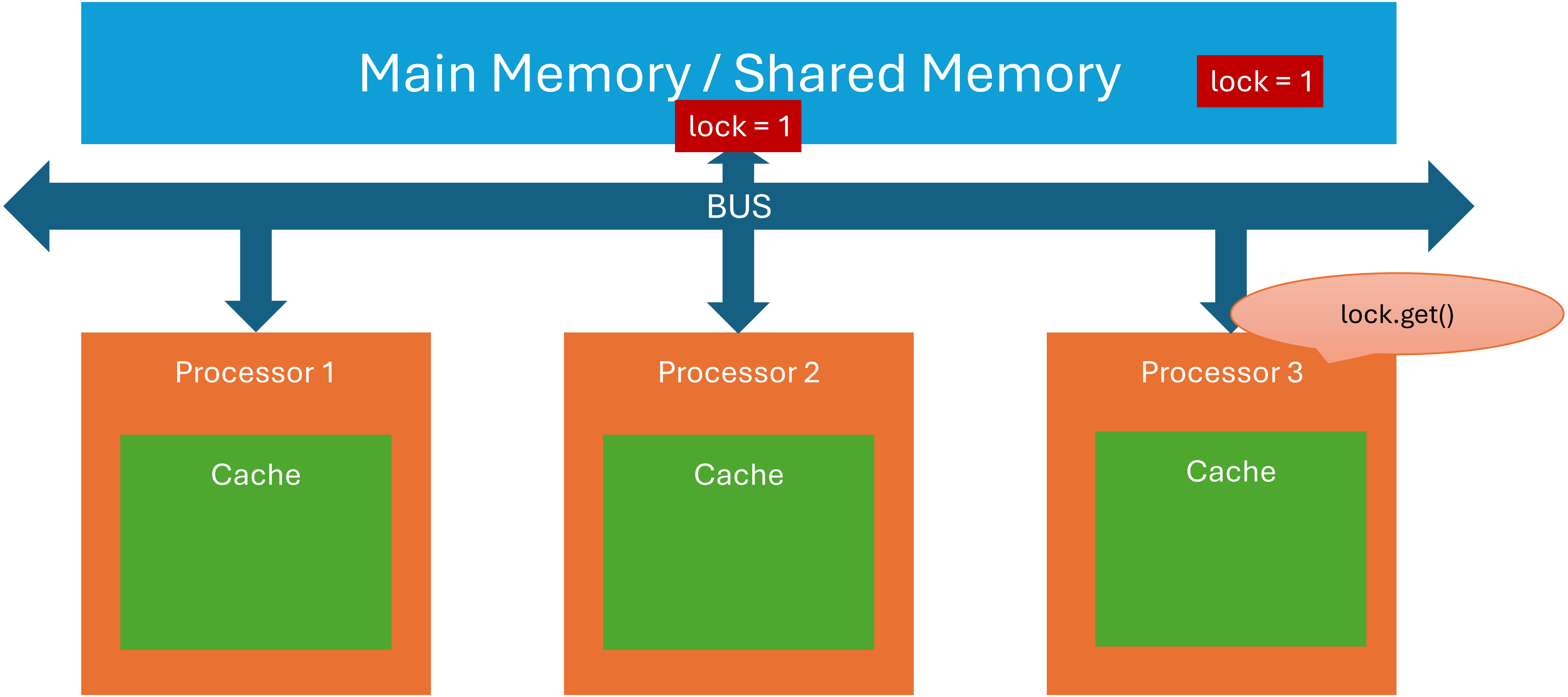
Lets try spinning on local cache

```
public class TASLock implements Lock {
  AtomicBoolean state = new AtomicBoolean(false);

  public void lock() {
    do
      while (state.get() == true) //spins on local cache
    while(!state.compareAndSet(false, true)) {}
  }

  public void unlock() {
    state.set(false);
  }

}
```

Lets visualize this



Lets visualize this



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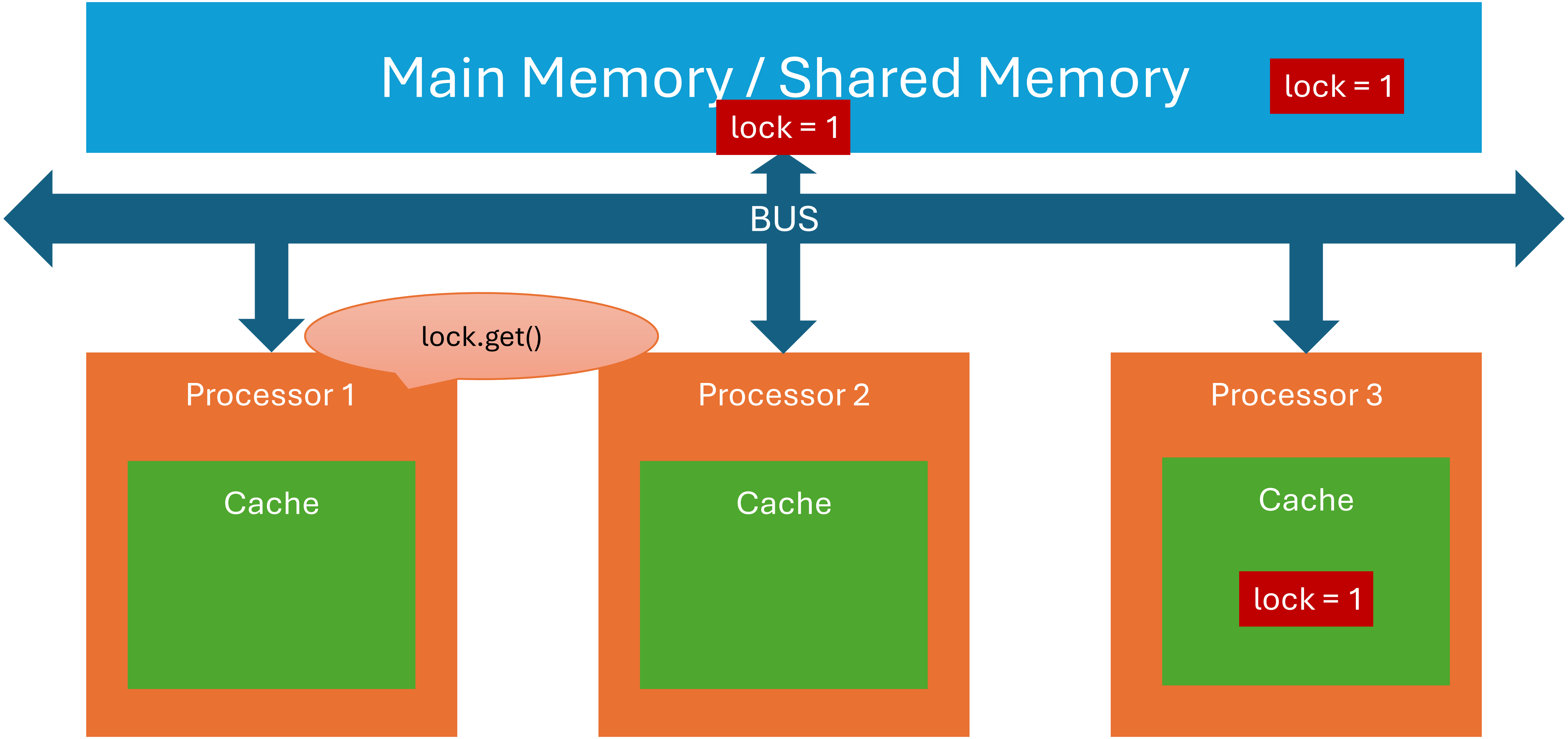

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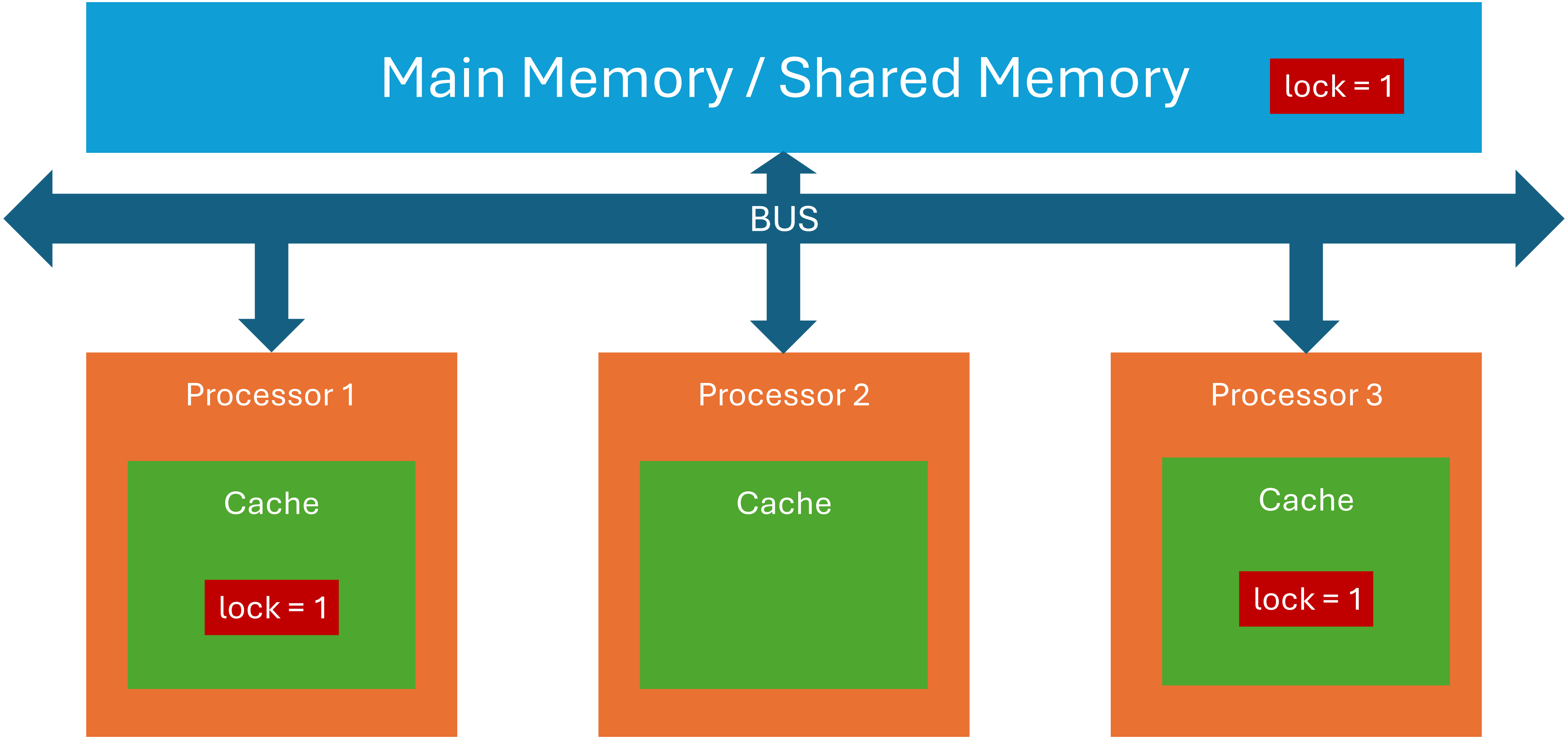
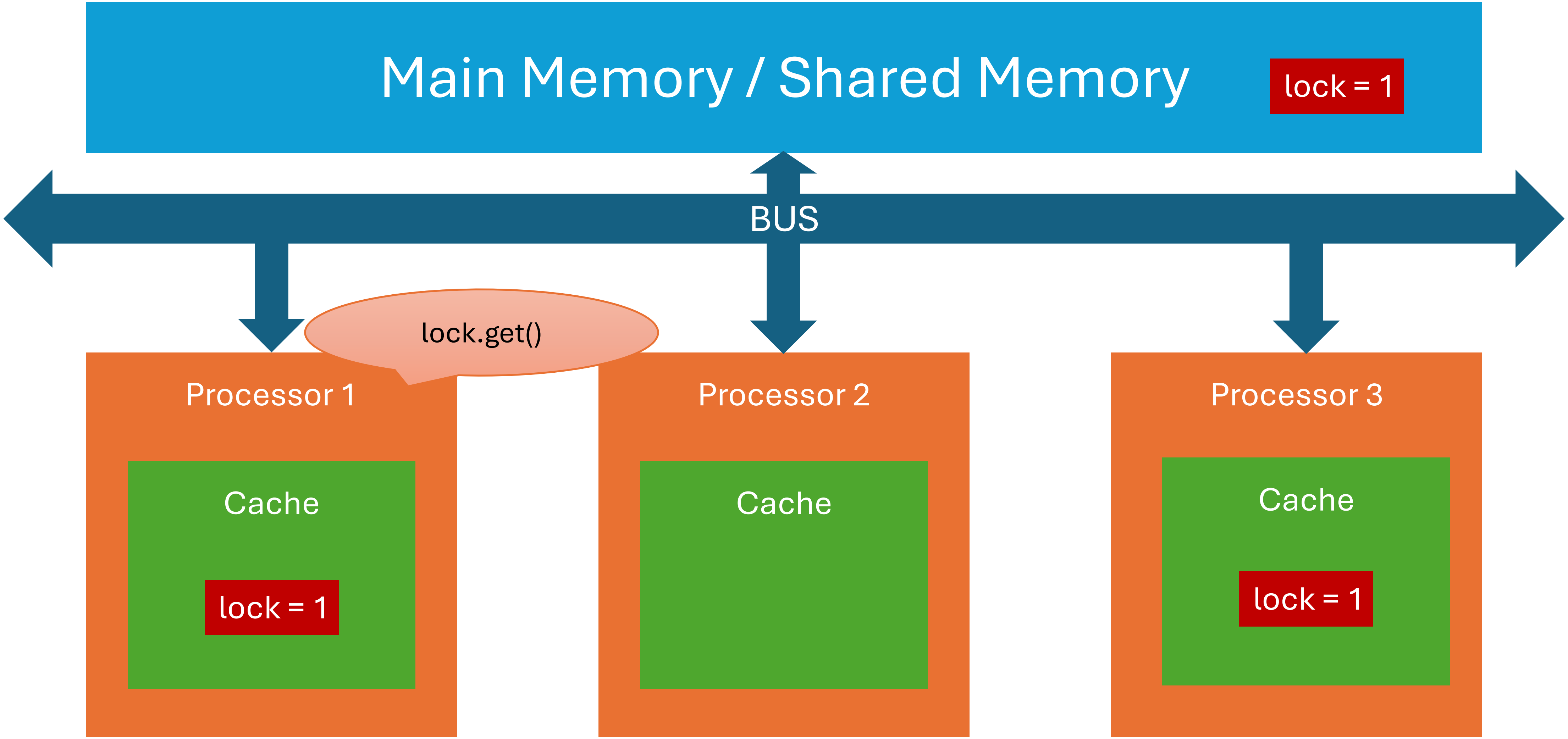
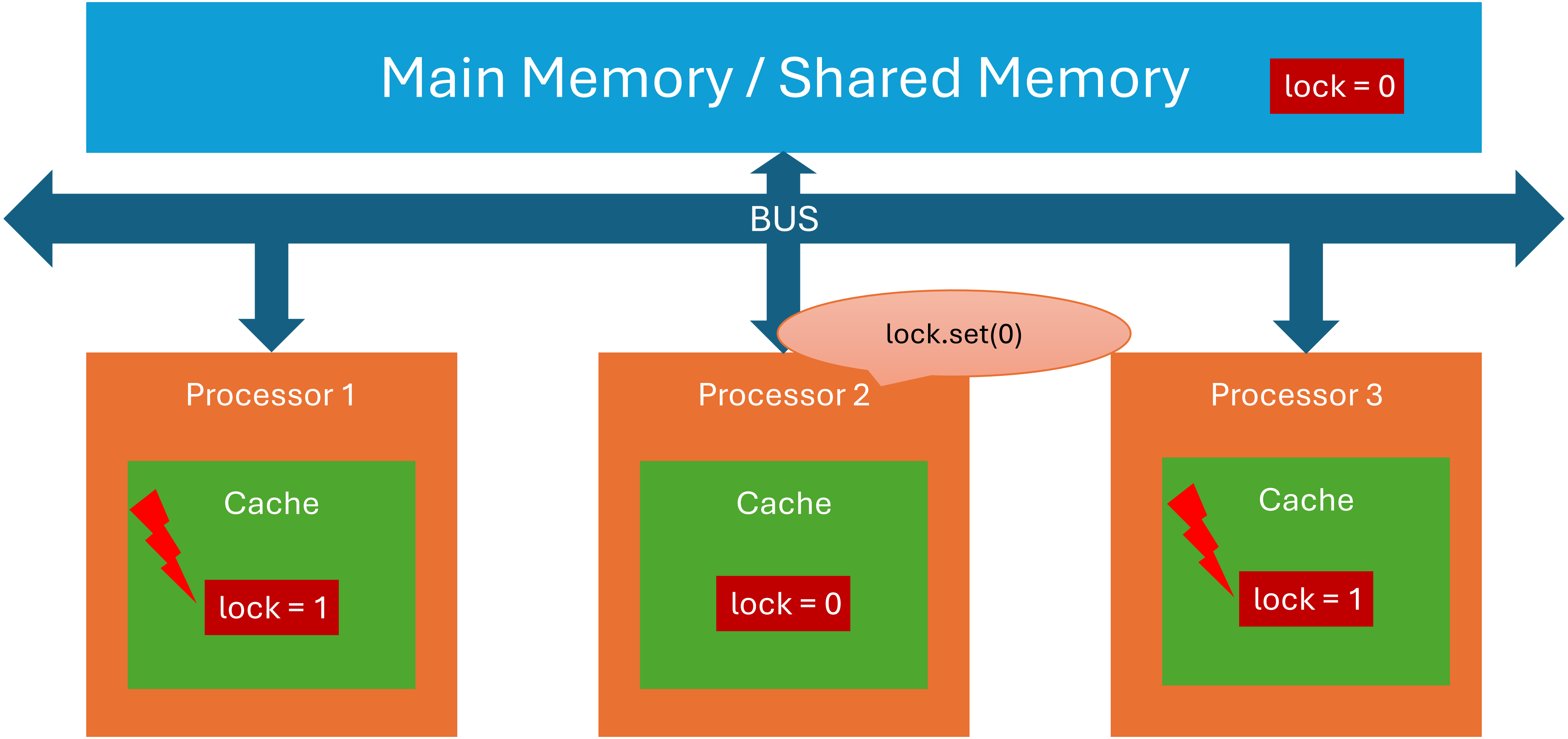


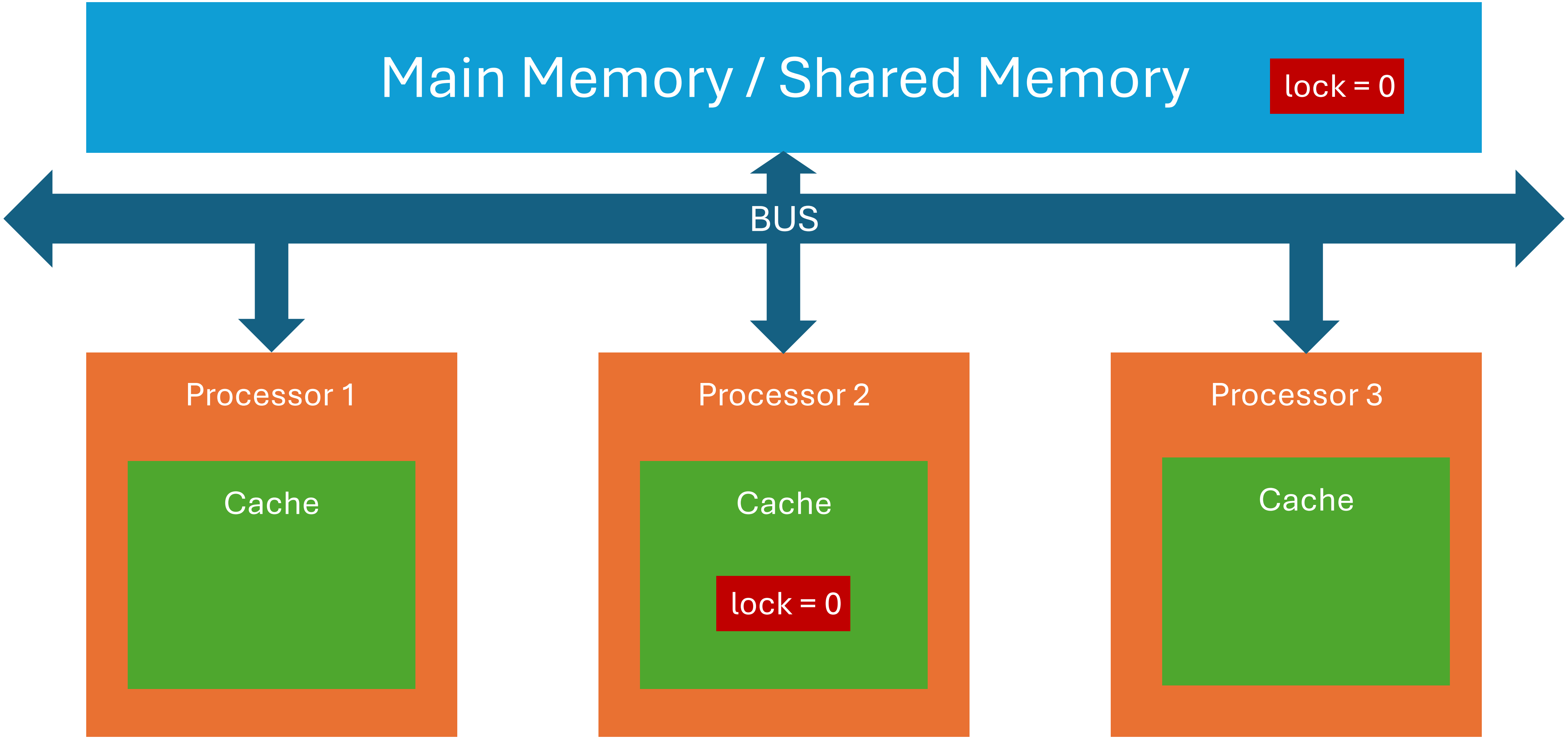
Lets visualize this



Lets visualize this

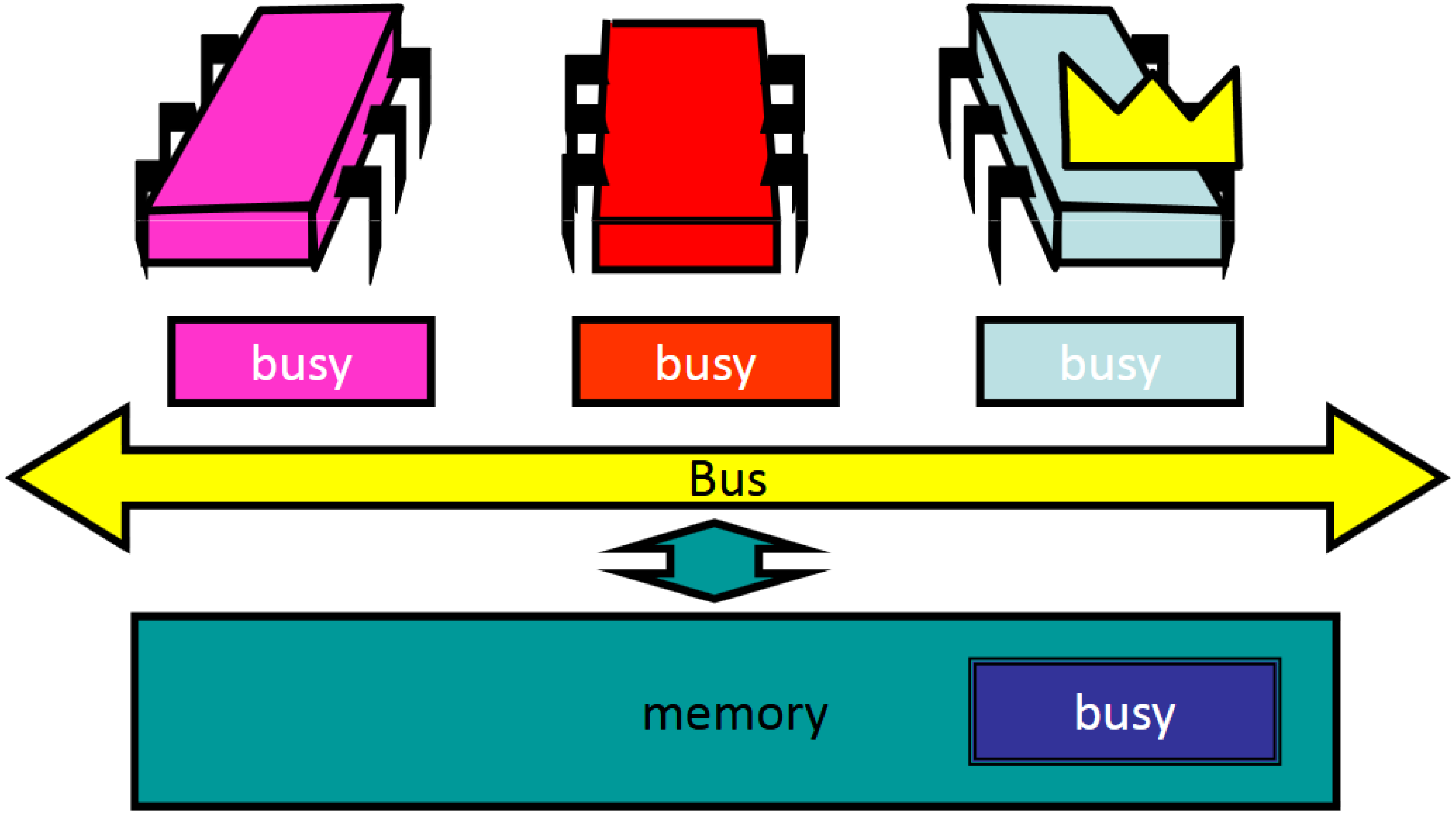


Now the whole problem repeats



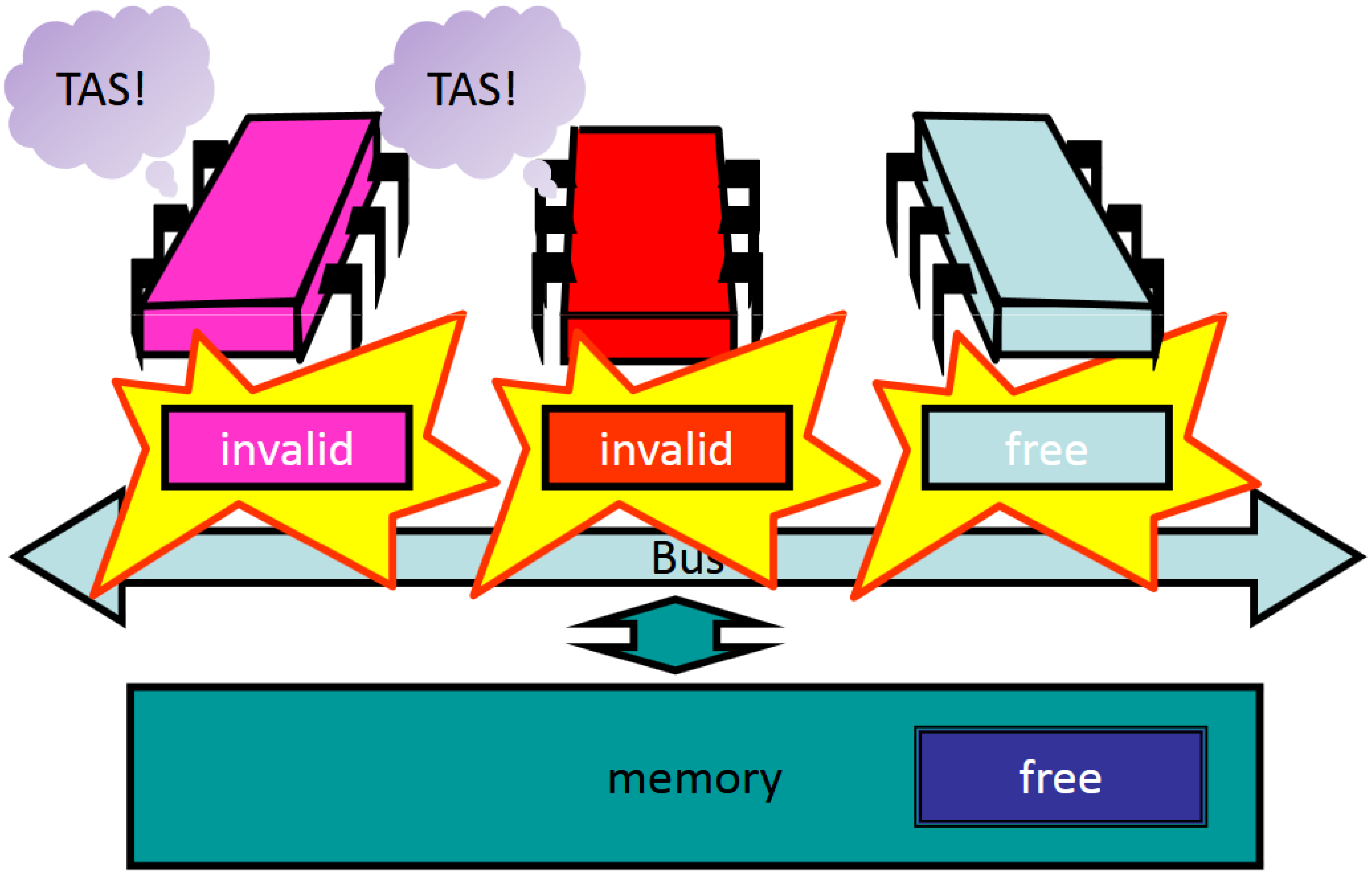
Local Spinning while Lock is Busy

- While the lock is held, all contenders spin in their caches, rereading cached data without causing any bus traffic



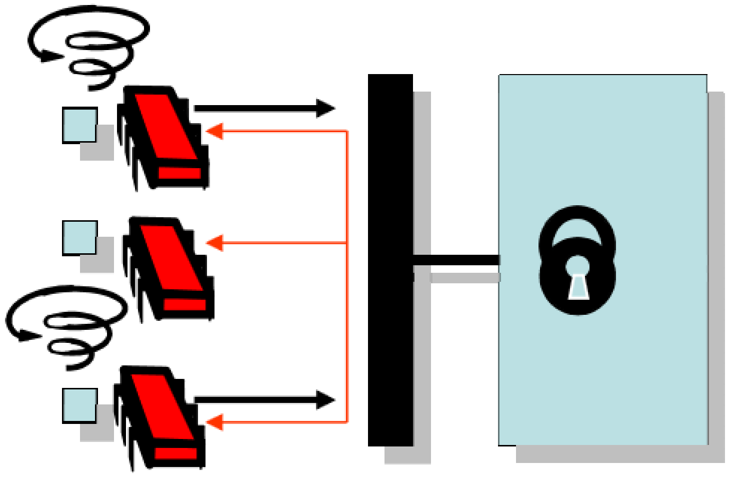
On Release

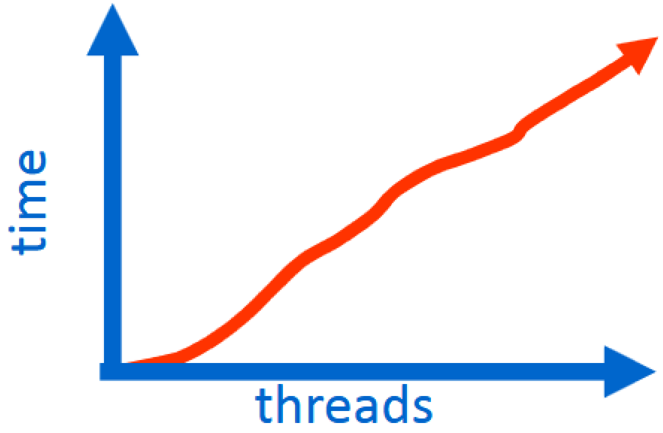
- The lock is released. All spinners take a cache miss and call Test&Set!



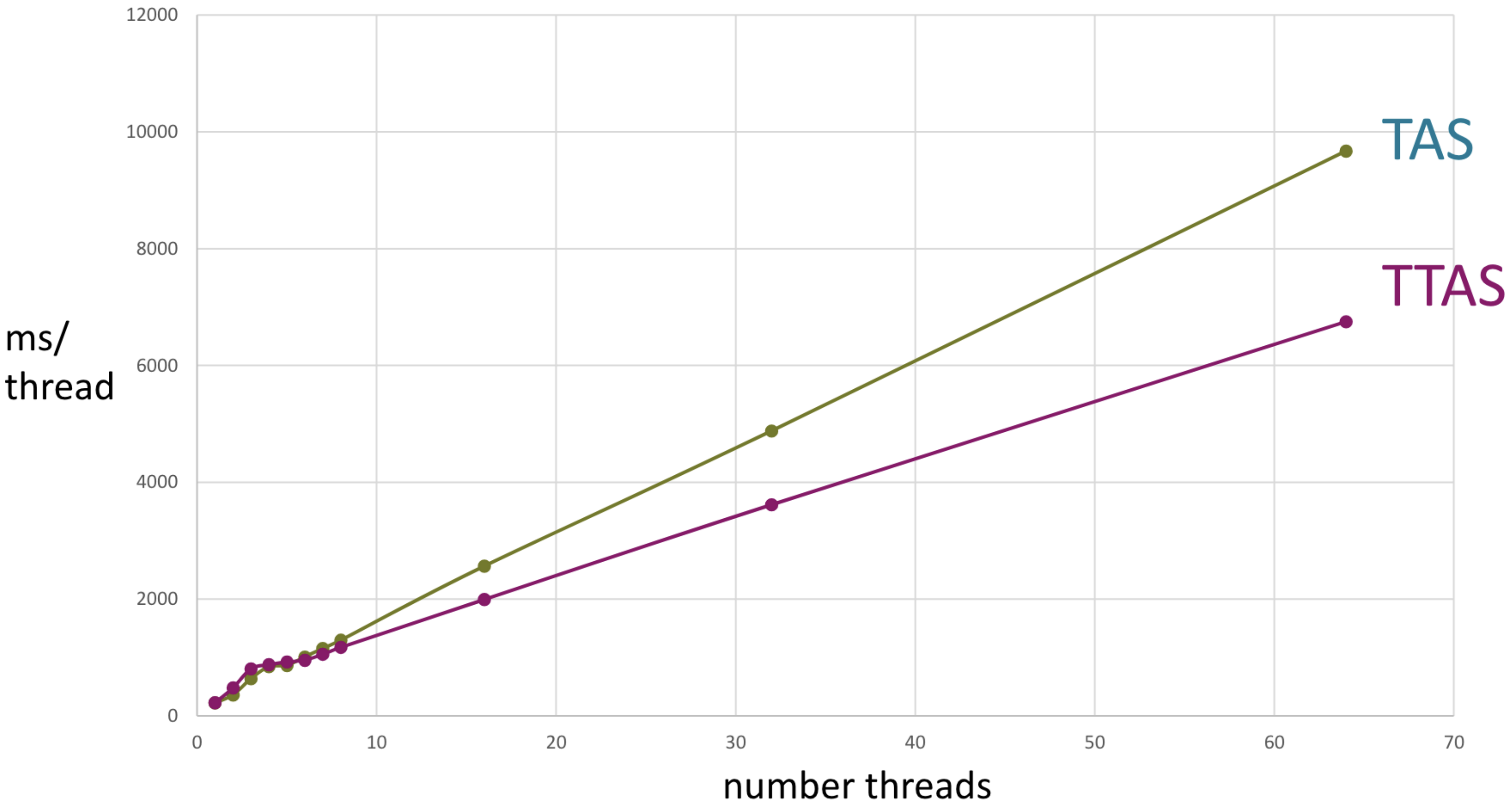
Time to Quiescence

- Every process experiences a cache miss
  - All state.get() satisfied sequentially
- Every process does TAS
  - Caches of other processes are invalidated
- Eventual quiescence ("silence") after acquiring the lock
- The time to quiescence increases linearly with the number of processors for a bus architecture!





It only helped a little bit



TAS vs. TTAS

- TAS invalidates cache lines
- Spinners
  - Always go to bus
- Thread wants to release lock
  - delayed behind spinners!!!

- TTAS waits until lock “looks” free
  - Spin on local cache
  - No bus use while lock busy
- Problem: when lock is released
  - Invalidation storm …

This is why TAS performs so poorly…

What we learned

- (too) many threads fight for access to the same resource
- slows down progress globally and locally
- **CAS/TAS: Processor assumes we modify the value even if we fail!**

Solution? Exponential Backoff

Idea: Each time TAS fails, wait longer until you re-try

- Backoff must be random!

Exponential Backoff

Essential

- Idea: Each time TAS fails, wait longer until you re-try

Exponential Backoff Lock

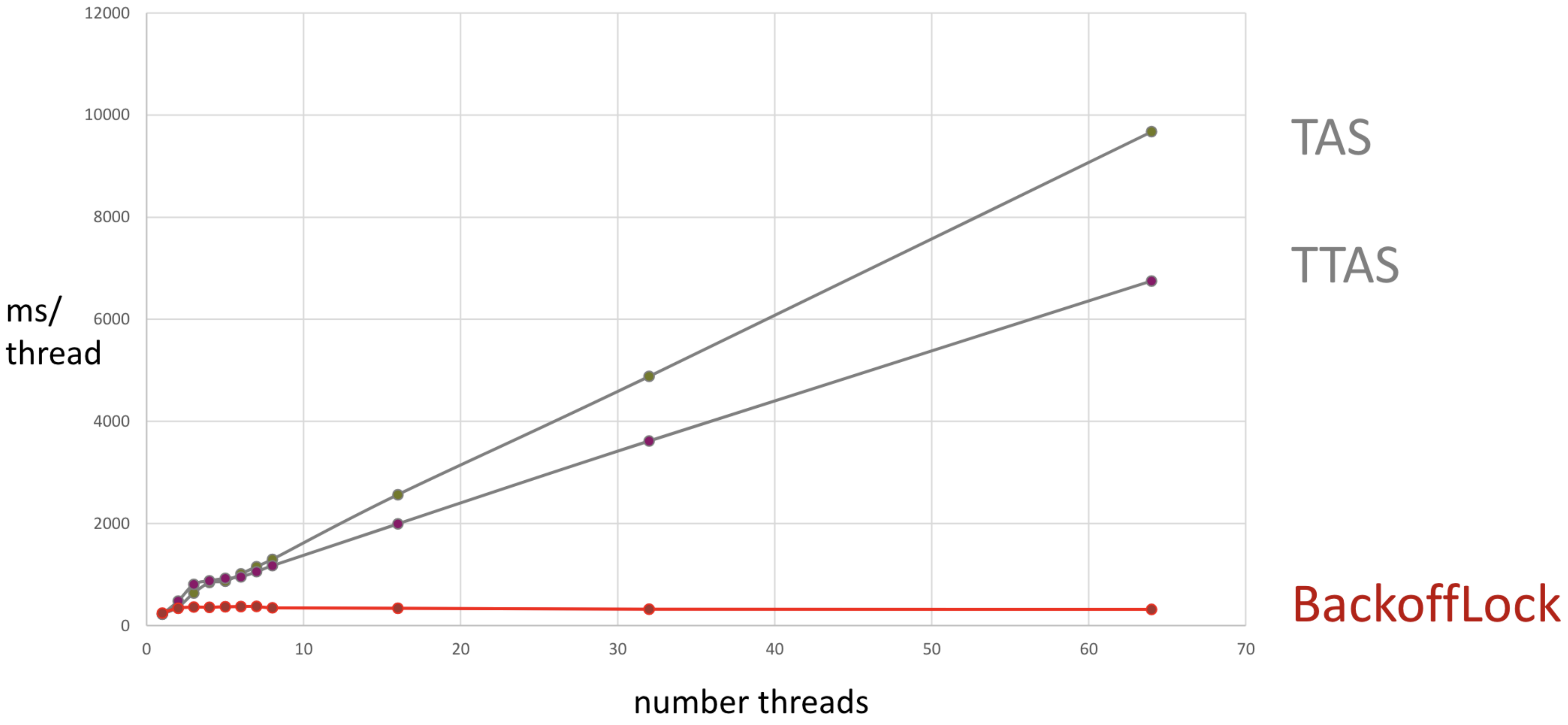
```
public class Backoff implements Lock {
  AtomicBoolean state = new AtomicBoolean(false);

  public void lock() {
    int delay = MIN_DELAY;
    while (true) {
      while(state.get()) {}
      if (!lock.getAndSet())
        return;
      sleep(random() % delay);
      if (delay < MAX_DELAY)
        delay = 2 * delay;
    }
  }

  // unlock() remains the same

}
```

Fix minimum delay

Back off for random duration

Double maximum delay until an upper bound is reached

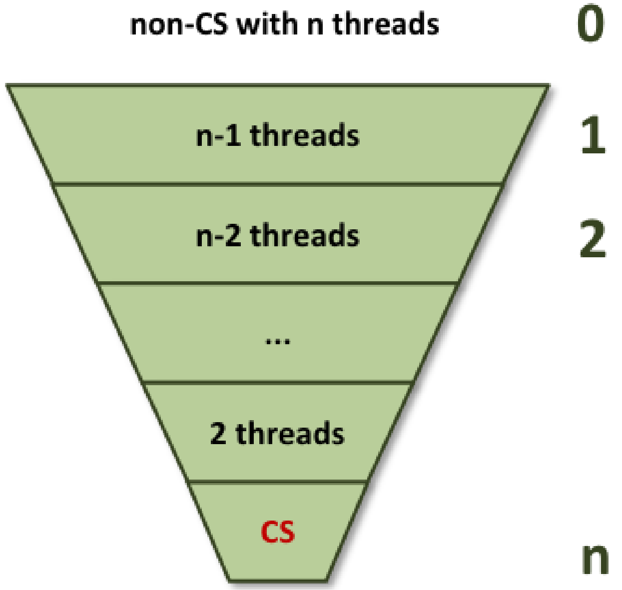
Nice!



12000
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
ms/
thread
number threads
TAS
TTAS
BackoffLock

Locks für n Threads

Filter Lock




```
int[] level(#threads), int[] victim(#threads)

lock(me) {
  for (int i=1; i<n; ++i) {
    level[me] = i;
    victim[i] = me;
    while (∃k ≠ me: level[k] >= i && victim[i] == me) {};
  }
}

unlock(me) {
  level[me] = 0;
}
```

Other threads are at same or higher level

And I have to wait

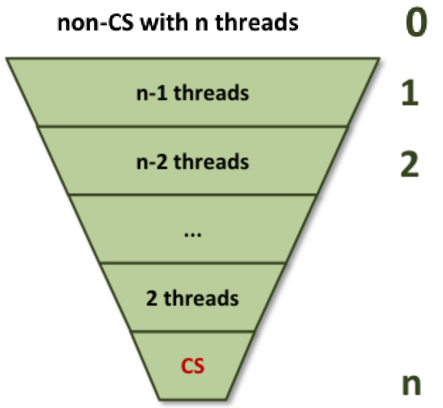
Filter Lock

- Ist das Filter Lock fair (first come first served)?

```
int[] level(#threads), int[] victim(#threads)


lock(me) {
  for (int i=1; i<n; ++i) {
    level[me] = i;
    victim[i] = me;
    while (∃k ≠ me: level[k] >= i && victim[i] == me) {};
  }
}

unlock(me) {
  level[me] = 0;
}
```

Other threads are at same or higher level

And I have to wait



Bakery Lock

```
integer array[0..n-1] label = [0, ..., 0]
boolean array[0..n-1] flag =  [false, ..., false]
```

SWMR «ticket number»

SWMR «I want the lock»

```
lock(me):
   flag[me] = true;
   label[me] = max(label[0], ... , label[n-1]) + 1;
   while (∃k ≠ me: flag[k] && (k,label[k]) <l (me, label[me])) {};

unlock(me):
   flag[me] = false;
```

$$(k, l_k) <_l (j, l_j) \Leftrightarrow l_k < l_j \text{ or } (l_k = l_j \text{ and } k < j)$$

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Semaphores

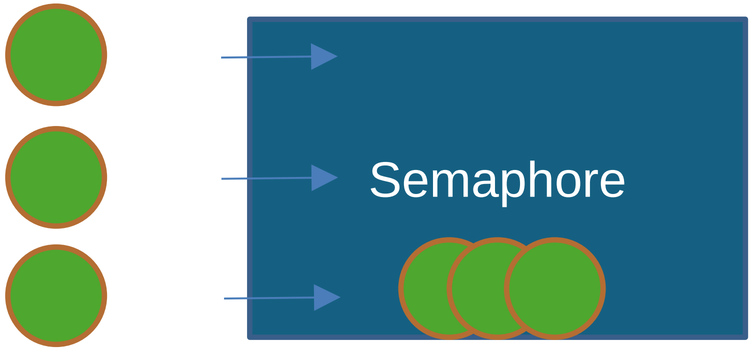
and Barriers

Lecture Recap: Semaphores

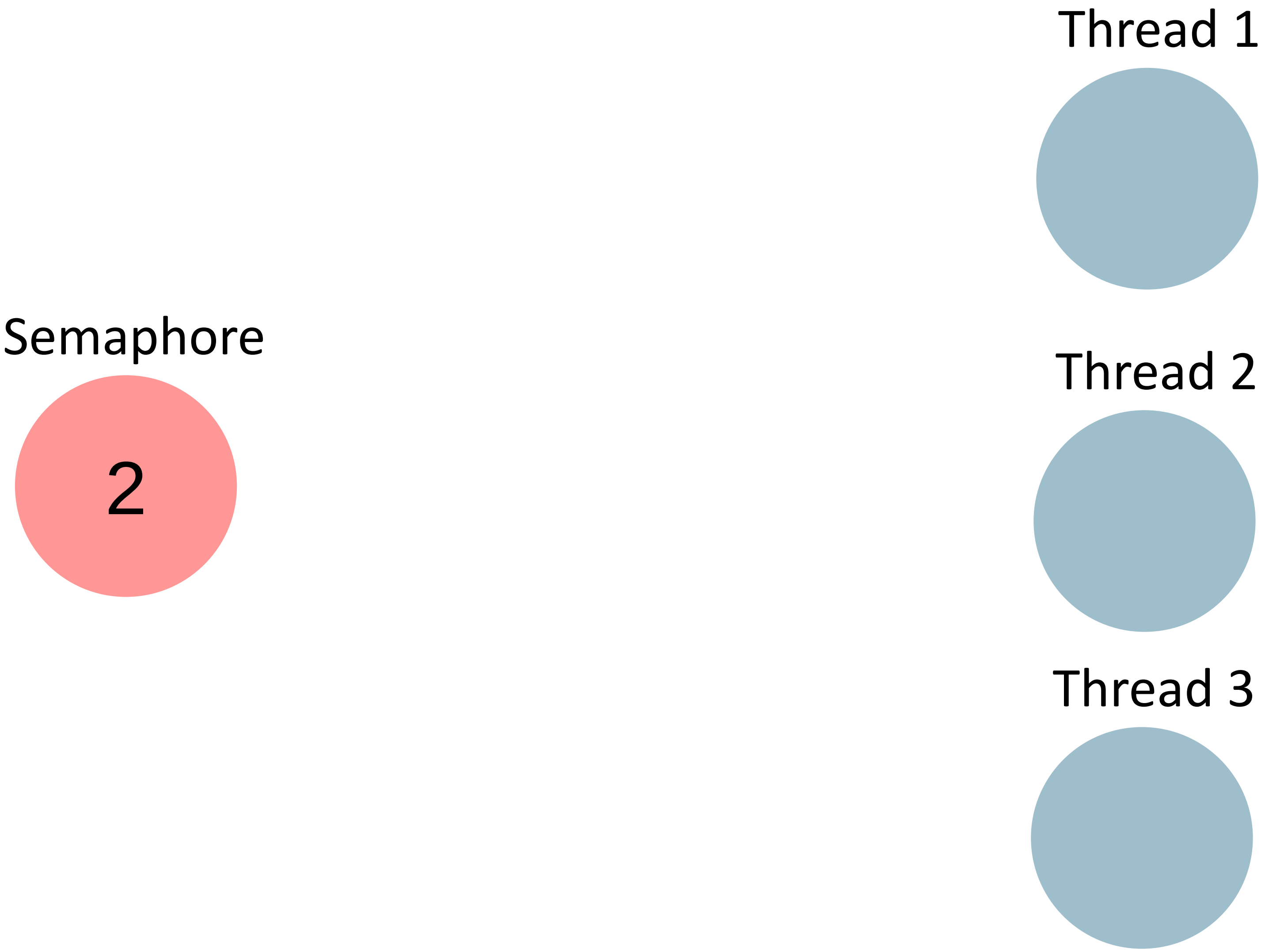
Used to restrict the number of threads that can access a specific resource.

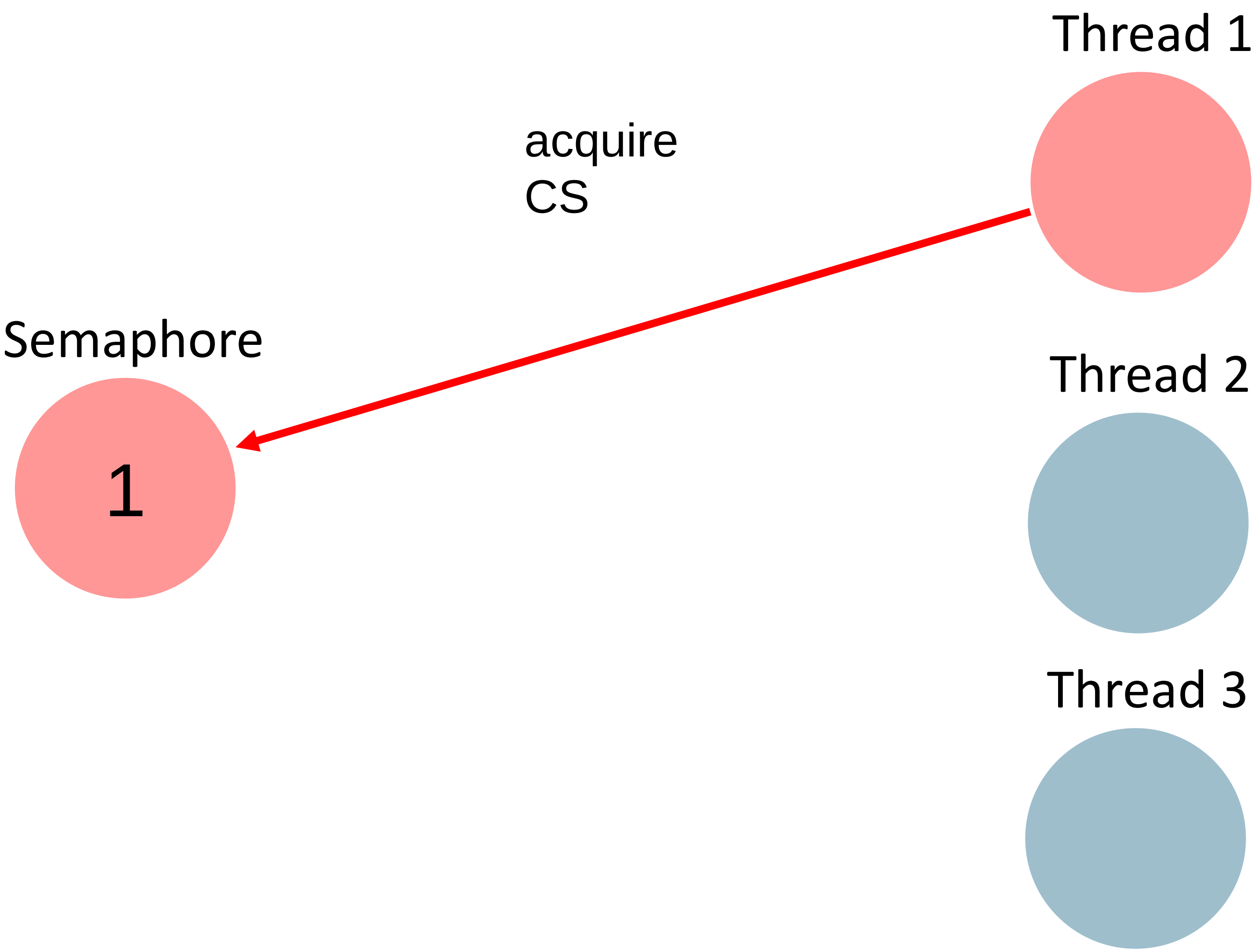
- acquire() gets a permit, if no permit available block
- release() gives up permit, releases a blocking acquirer

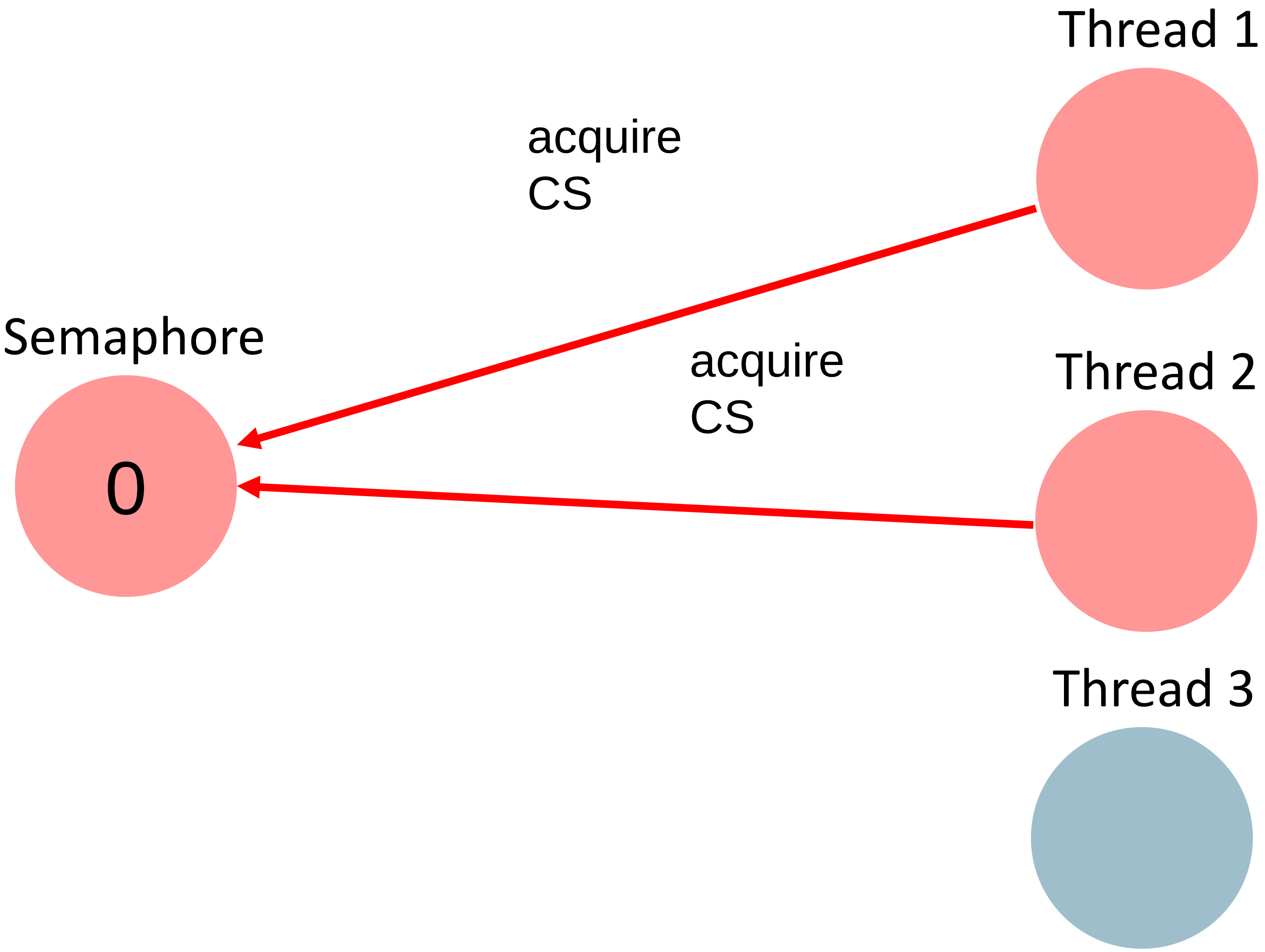
Lecture Recap: Semaphores

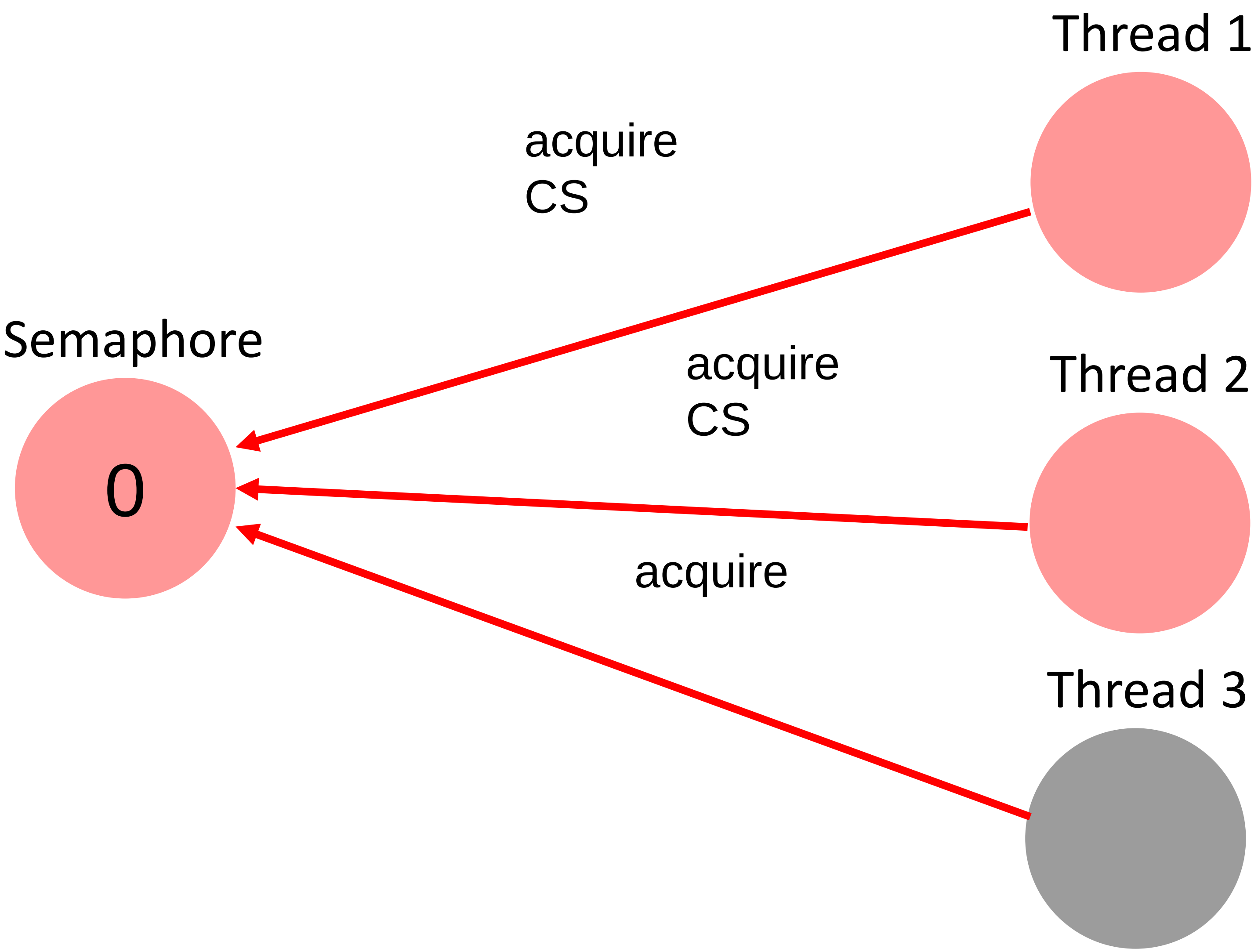


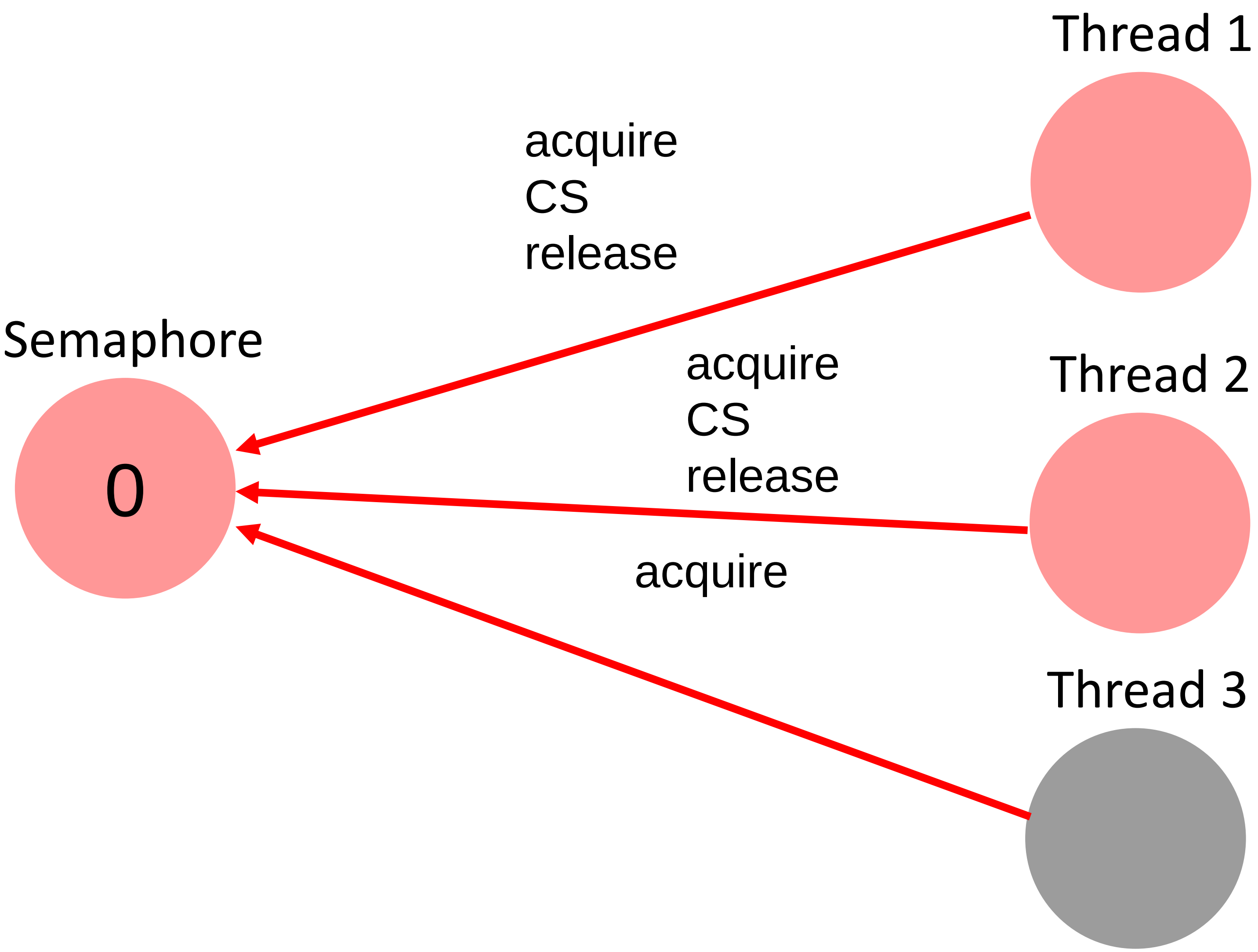
N Threads have permit to a semaphore,
others will wait (blocked) until someone leaves the semaphore

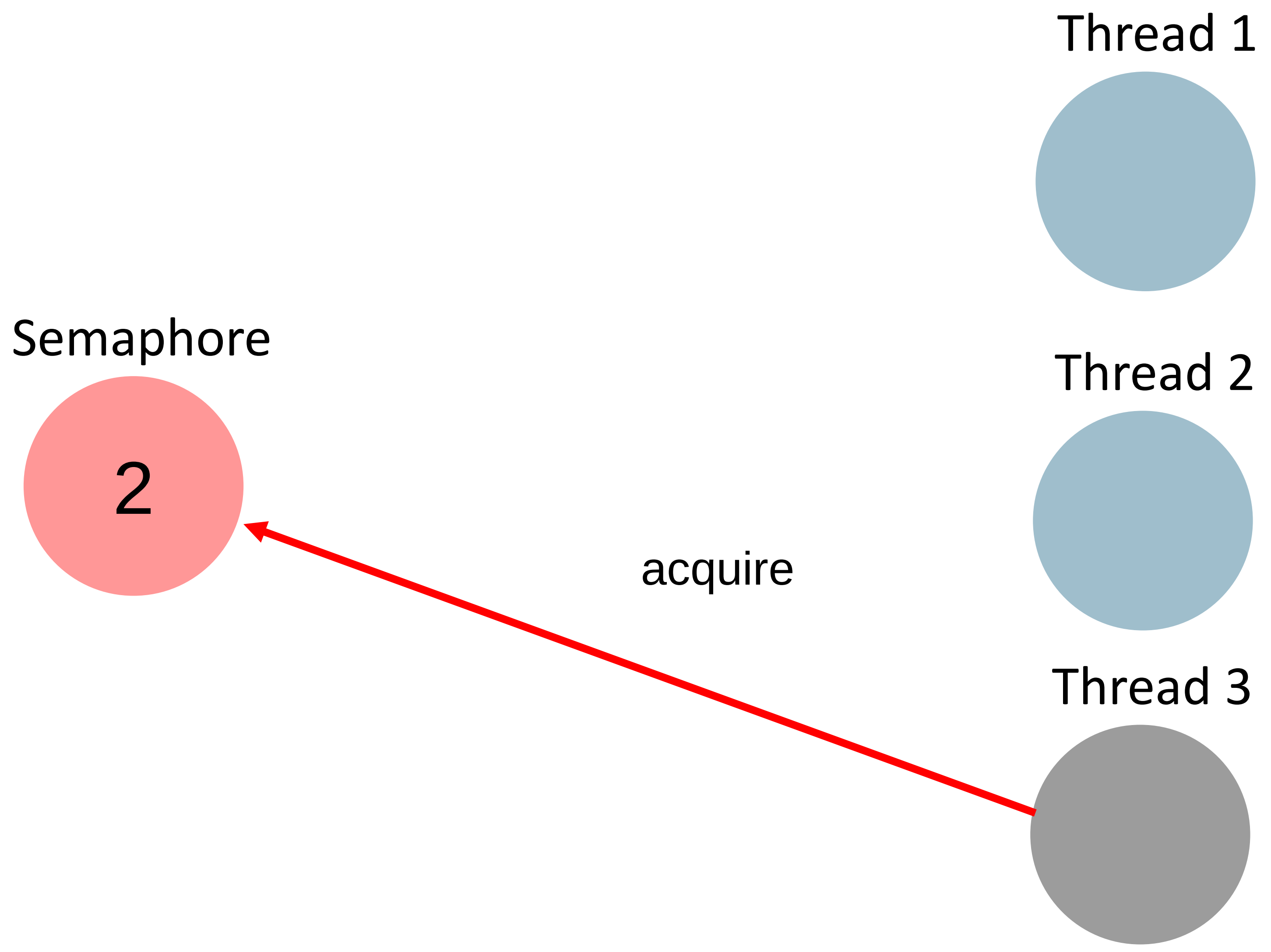

Thread 1
Semaphore
2
Thread 2
Thread 3

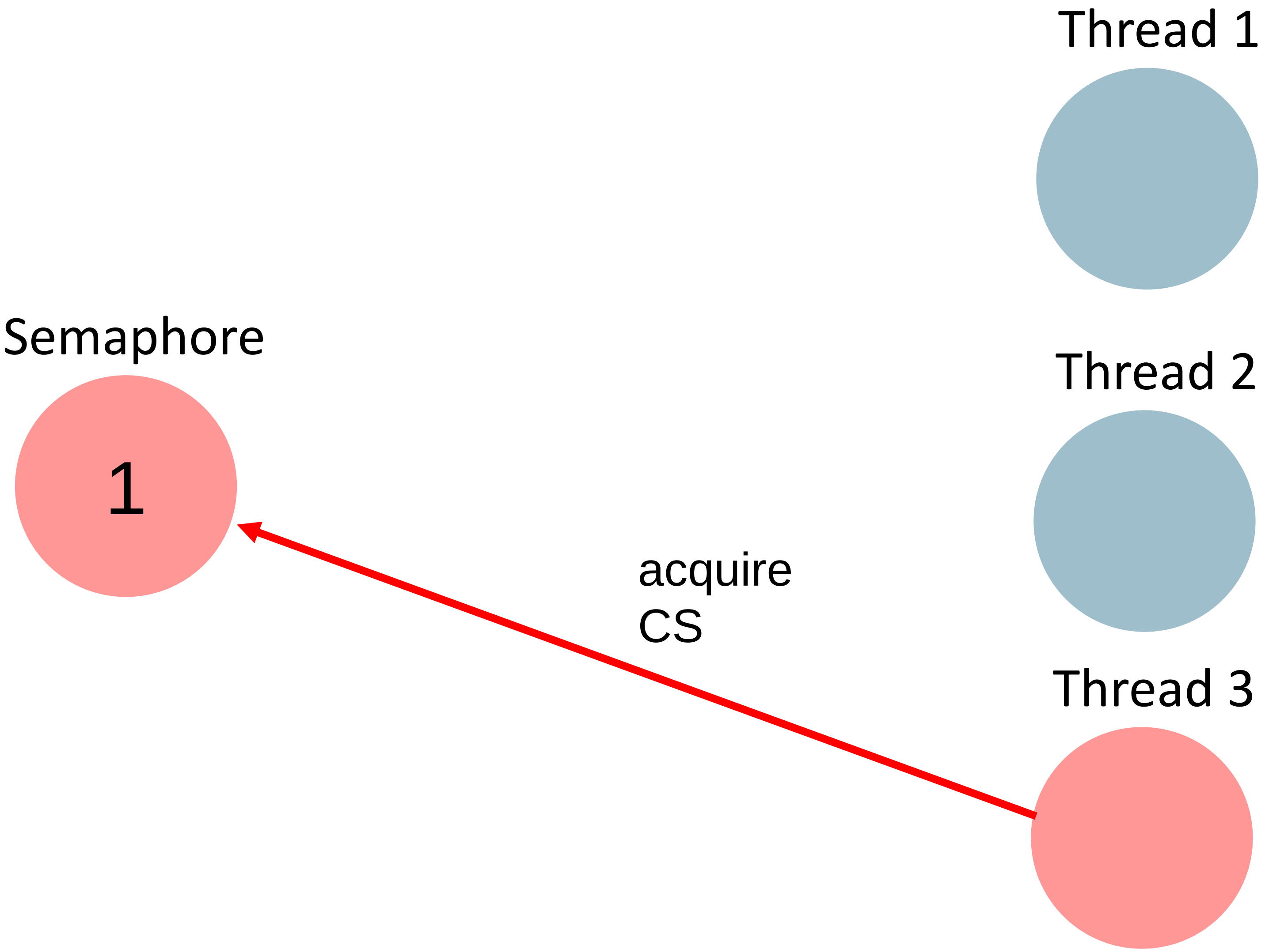

Thread 1
acquire
CS
Semaphore
1
Thread 2
Thread 3


Thread 1
acquire
CS
Semaphore
acquire
CS
Thread 2
0
Thread 3


Thread 1
acquire
CS
Semaphore
0
acquire
CS
Thread 2
acquire
Thread 3


Thread 1
acquire
CS
release
Semaphore
0
acquire
CS
release
Thread 2
acquire
Thread 3


Thread 1
Semaphore
2
Thread 2
acquire
Thread 3



Think of semaphores as bike rentals

Semaphores: Implementation

Semaphore: integer-valued abstract data type S with some initial value s≥0 and the following **atomic** operations:

```
acquire(S) {
	wait until S > 0
	dec(S)
}

release(S) {
	inc(S)
}
```

Semaphores: Implementation

Semaphore: integer-valued abstract data type S with some initial value s≥0 and the following **atomic** operations:

```
acquire(S) {
       wait until S > 0
       dec(S)
}

release(S) {
       inc(S)
}
```

What is the difference between a Lock and a Semaphore?

Building a lock with Semaphores

mutex = Semaphore(1);

lock mutex := mutex.acquire()

only one thread is allowed into the critical section

unlock mutex := mutex.release()

one other thread will be let in

Semaphore number:

1 → unlocked

0 → locked

x>0 → x threads will be let into "critical section"

Semaphores aren’t Locks!

- We can build Locks with Semaphores
- Some key differences:
  - More than one Thread can be in critical section!
  - How many depends on the number of permits
  - **Threads can release() a Semaphore without accquiring before!**
  - The is no notion of “holding” a Semaphore as we have with ”holding” Locks

Semaphores: Implementation

Semaphore: integer-valued abstract data type S with some initial value s≥0 and the following **atomic** operations:

```
acquire(S) {
       wait until S > 0
       dec(S)
}

release(S) {
       inc(S)
}
```

When would you use a semaphore?

Semaphores

- Locks provide means to enforce atomicity via mutual exclusion
- They lack the means for threads to communicate about changes
- We need something stronger to coordinate threads (e.g. to implement rendezvous)

Semaphores: Usage example

```
class Pool {
        private static final int MAX_AVAILABLE = 100;
        private final Semaphore available = new Semaphore(MAX_AVAILABLE, true);

        public Object getItem() throws InterruptedException {
          available.acquire();
          return getNextAvailableItem();
        }

        public void putItem(Object x) {
          if (markAsUnused(x))
            available.release();
        }

        //...
```

Semaphores: Usage example

```
  protected Object[] items = new Object[MAX_AVAILABLE];
  protected boolean[] used = new boolean[MAX_AVAILABLE];

  protected synchronized Object getNextAvailableItem() {
    for (int i = 0; i < MAX_AVAILABLE; ++i) {
      if (!used[i]) {
         used[i] = true;
         return items[i];
      }
    }
    return null; // not reached
  }

  protected synchronized boolean markAsUnused(Object item) {
    for (int i = 0; i < MAX_AVAILABLE; ++i) {
      if (item == items[i]) {
         if (used[i]) {
           used[i] = false;
           return true;
         } else
           return false;
      }
    }
    return false;
  }
}
```

Semaphores

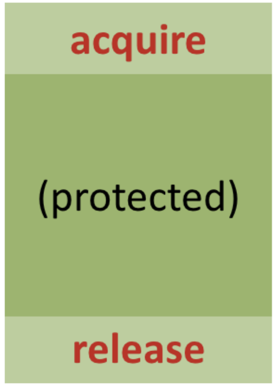
S = new Semaphore(n) - create a new semaphore with n permits

atomic

```
acquire(S)
{
   wait until S > 0
   dec(S)
}
```

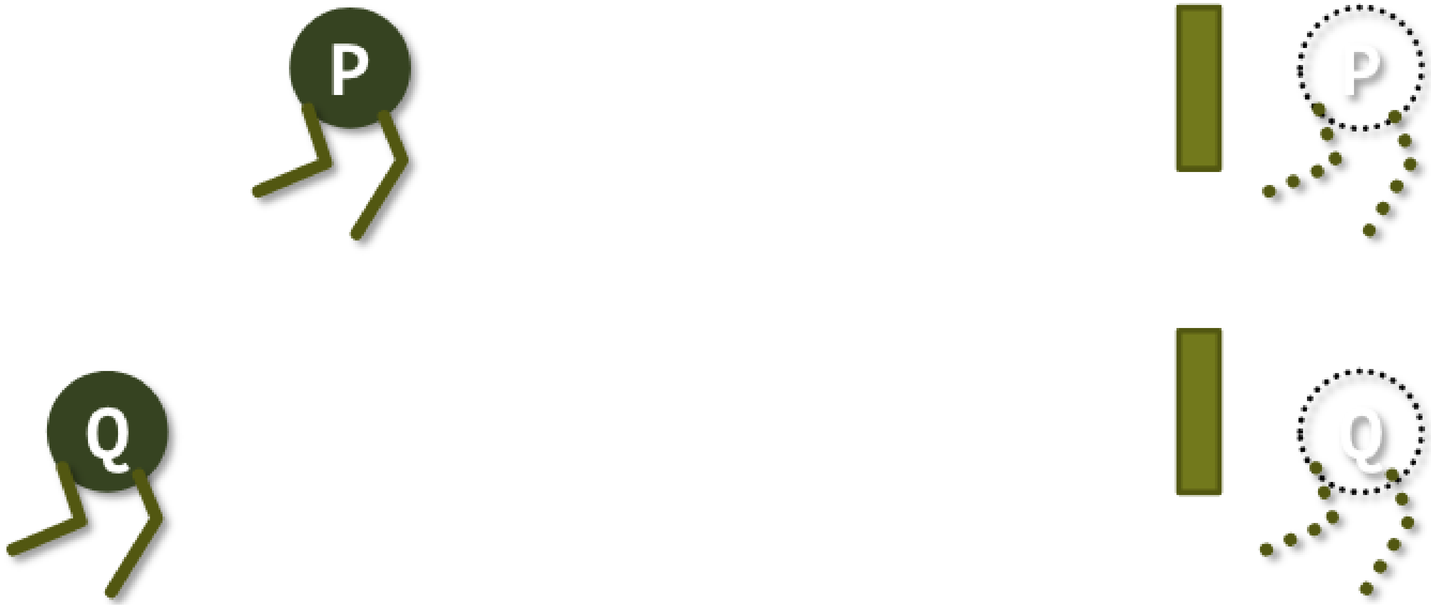
atomic

```
release(S)
{
   inc(S)
}
```



Rendezvous with Semaphores

- Two processes P and Q execute code
- Rendezvous: locations in code, where P and Q wait for the other to arrive. Synchronize P and Q.



First attempt, whats wrong?

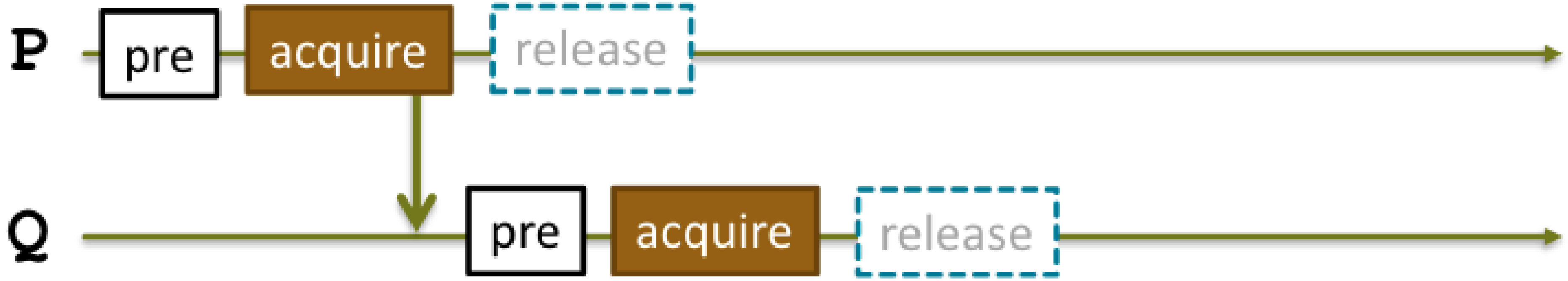
Synchronize Processes P and Q at one location (Rendezvous)

Semaphores `P_Arrived` and `Q_Arrived`

	P	Q
init	P_Arrived=0	Q_Arrived=0
pre	...	...
rendezvous	acquire(Q_Arrived) release(P_Arrived)	acquire(P_Arrived) release(Q_Arrived)
post	...	...

Deadlock :(

We are never able to release! Both P and Q wait endlessly for each other ☹



Attempt two, better?

Synchronize Processes P and Q at one location (Rendezvous)

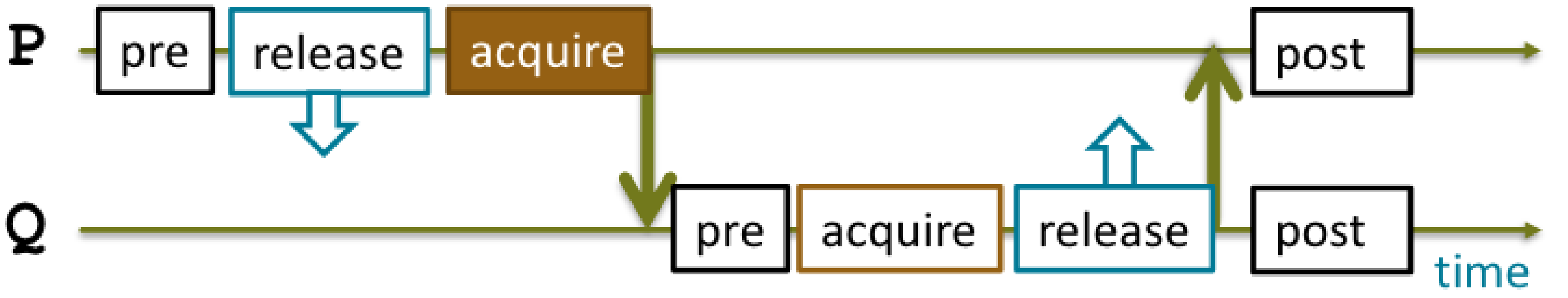
Assume Semaphores P_Arrived and Q_Arrived

	P	Q
init	P_Arrived=0	Q_Arrived=0
pre	...	...
rendezvous	release(P_Arrived) acquire(Q_Arrived)	acquire(P_Arrived) release(Q_Arrived)
post	...	..

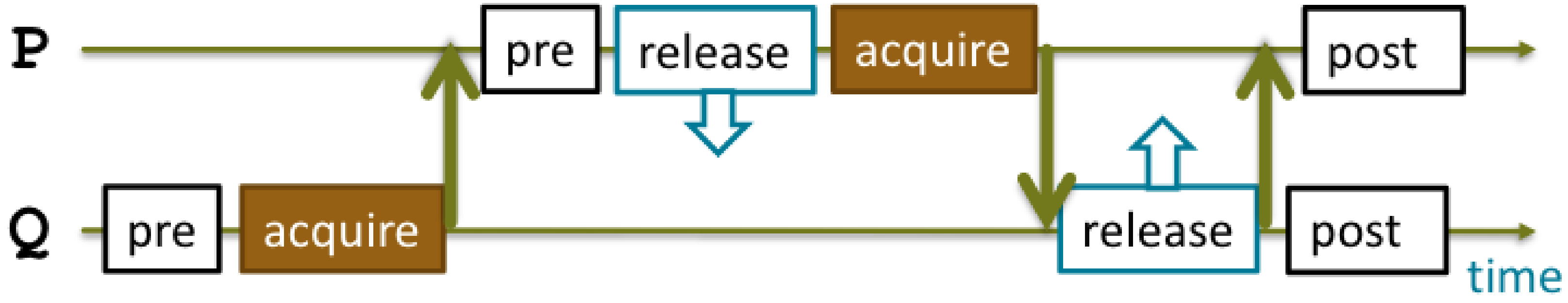
Yes, that works!

	P	Q
init	`P_Arrived=0`	`Q_Arrived=0`
pre	`...`	`...`
rendezvous	`release(P_Arrived)` `acquire(Q_Arrived)`	`acquire(P_Arrived)` `release(Q_Arrived)`
post	`...`	`..`

P first



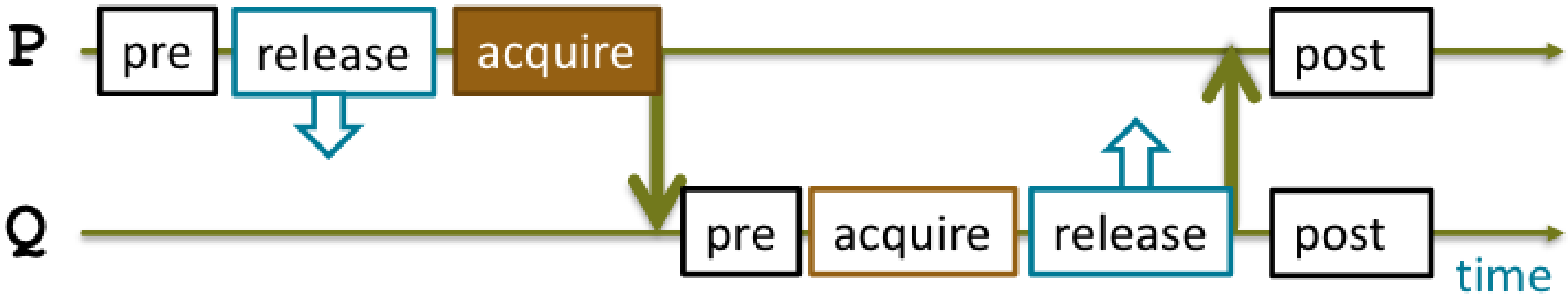
Q first



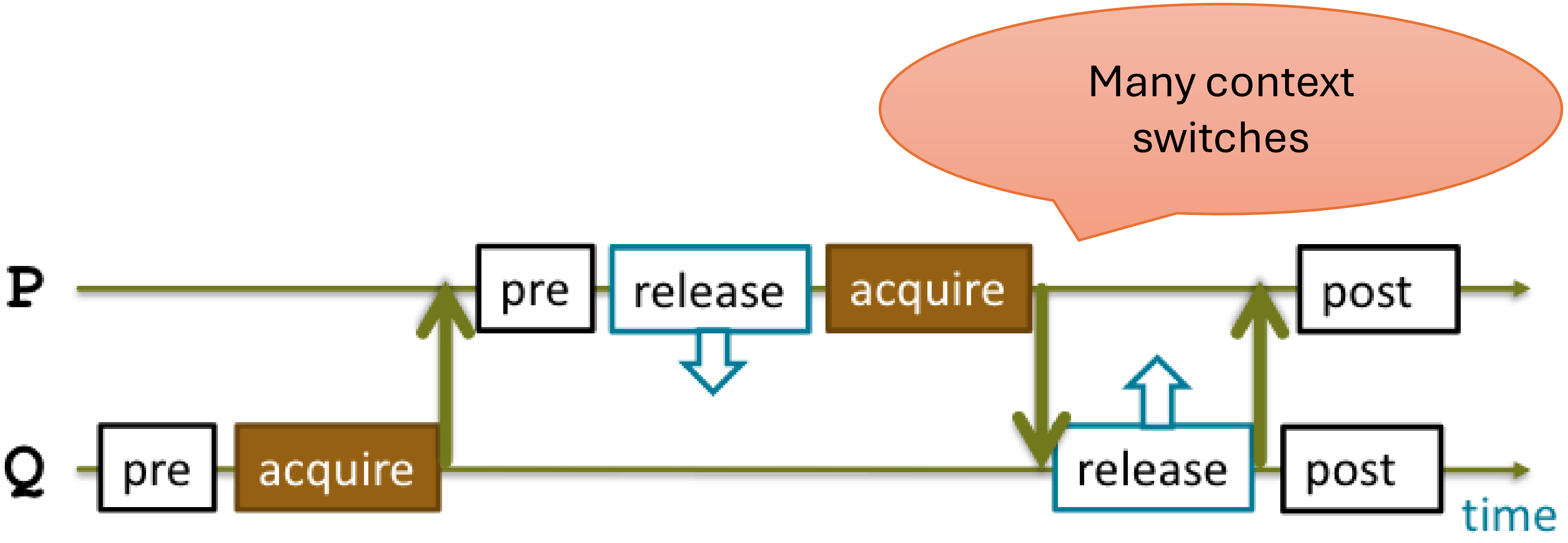
Yes, that works!

	P	Q
init	P_Arrived=0	Q_Arrived=0
pre	...	...
rendezvous	release(P_Arrived) acquire(Q_Arrived)	acquire(P_Arrived) release(Q_Arrived)
post	...	..

P first



Q first



Lets do better!

Synchronize Processes P and Q at one location (Rendezvous)

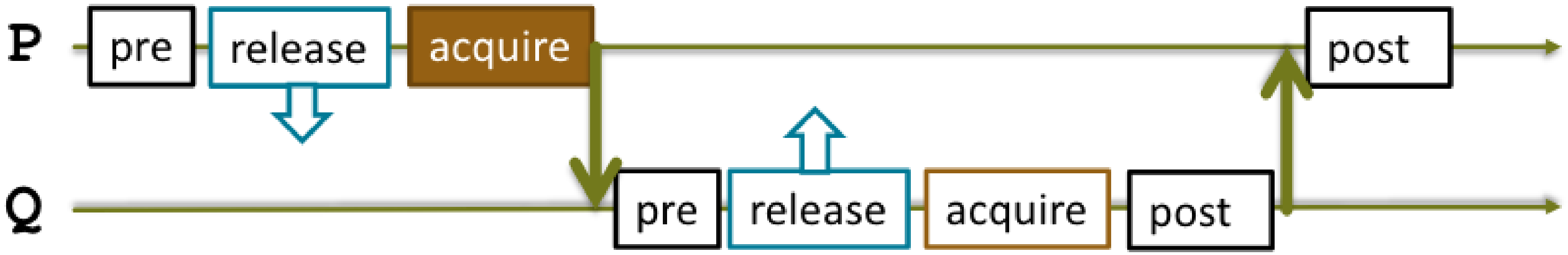
Assume Semaphores P_Arrived and Q_Arrived

	P	Q
init	P_Arrived=0	Q_Arrived=0
pre	...	...
rendezvous	release(P_Arrived) acquire(Q_Arrived)	release(Q_Arrived) acquire(P_Arrived)
post	...	..

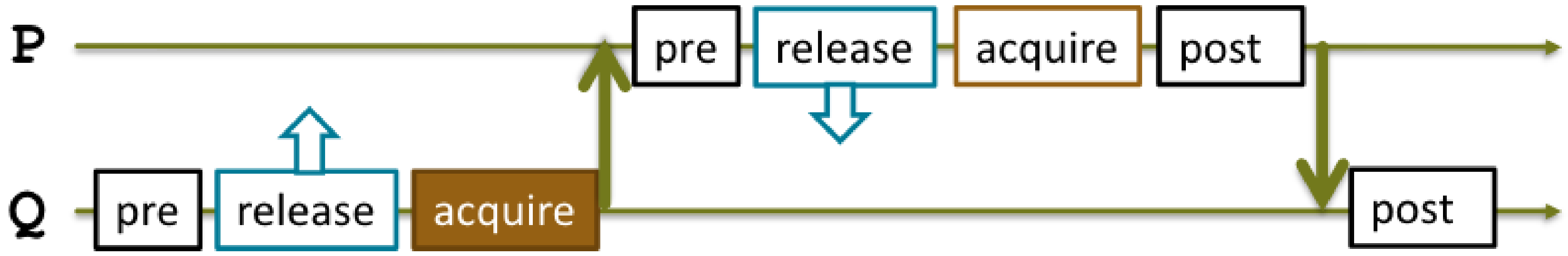
Order does no longer matter

	P	Q
init	P_Arrived=0	Q_Arrived=0
pre	...	...
rendezvous	release(P_Arrived) acquire(Q_Arrived)	release(Q_Arrived) acquire(P_Arrived)
post	...	..

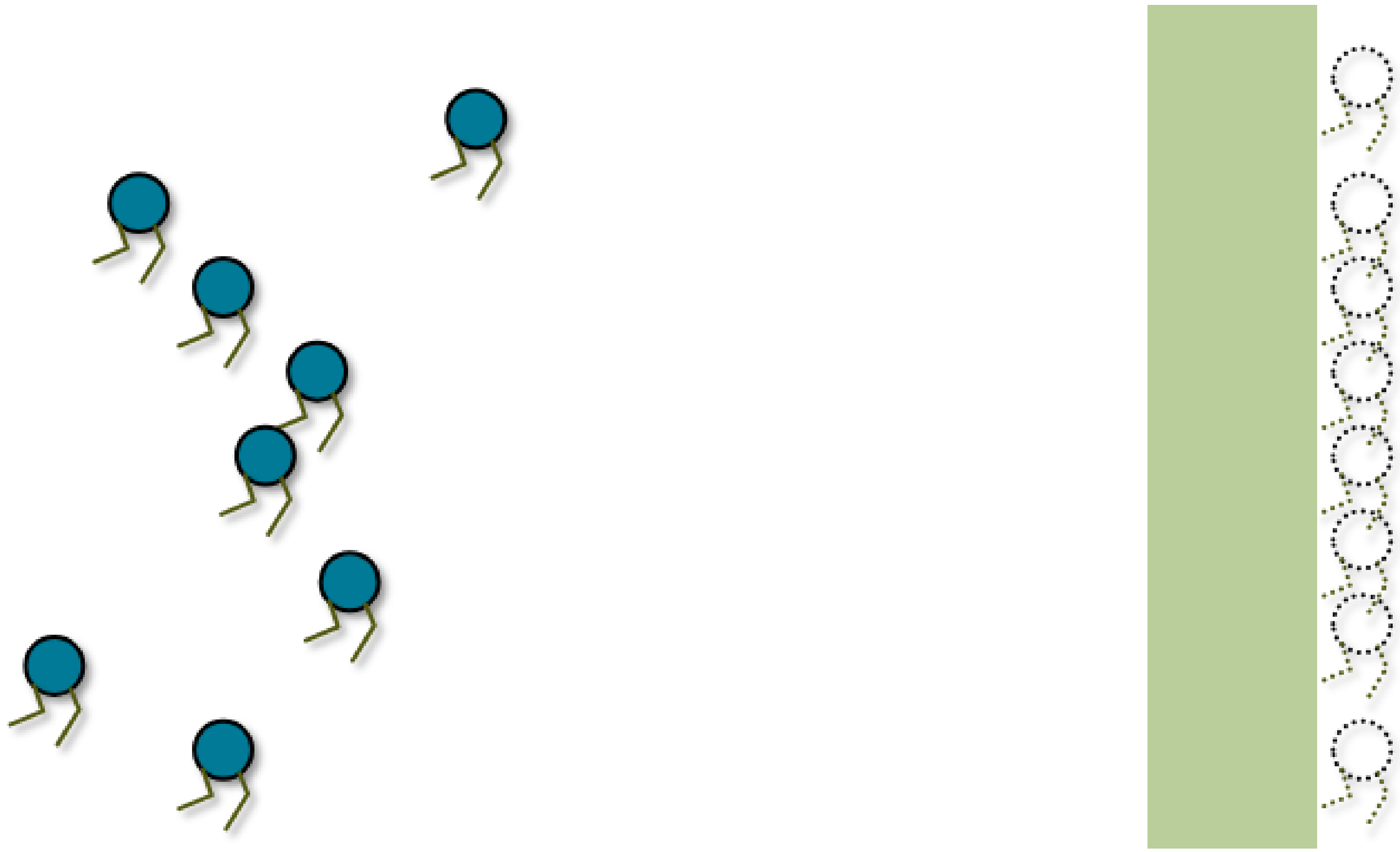
P first



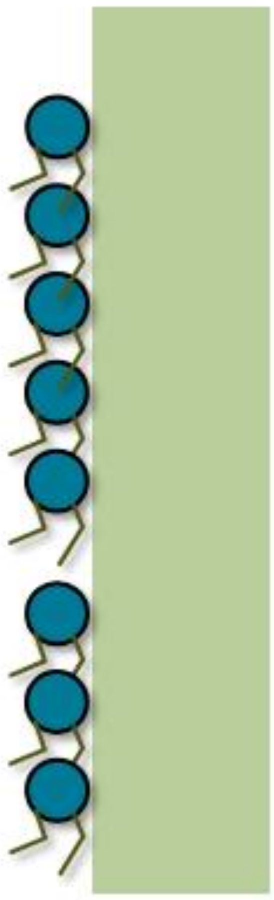
Q first



How about more than two threads? Barriers!



How about more than two threads? Barriers!



First attempt

Synchronize a number (n) of processes.

Semaphore `barrier`. Integer `count`.

	P1	P2	...	Pn
init	barrier = 0; volatile count = 0			
pre	...			
barrier	count++ if (count==n) release(barrier) acquire(barrier)	←	←	←
post	...			

Wrong

Synchronize a number (n) of processes.

Semaphore `barrier`. Integer count.

	P1	P2	...	Pn
init	`barrier = 0; volatile count = 0`			
pre	`...`			

barrier	`count++`
	`if (count==n) release(barrier)`
	`acquire(barrier)`
		←	←	←

post	`...`			

Race Condition !

Some wait forever!

How about this?

Synchronize a number (n) of processes.

Semaphores `barrier`, `mutex`. Integer count.

	P1	P2	. . .	Pn
init	mutex = 1; barrier = 0; count = 0			
pre	...			
barrier	acquire(mutex)			
	count++			
	release(mutex)			
	if (count==n) release(barrier)	←	←	←
	acquire(barrier)			
	release(barrier)			
post	...			

turnstile (acquire(barrier) / release(barrier))

How about this?

Synchronize a number (n) of processes.

Semaphores `barrier`, `mutex`. Integer `count`.

	P1	P2	. . .	Pn
init	mutex = 1; barrier = 0; count = 0			
pre	...			
barrier	acquire(mutex) count++ release(mutex) if (count==n) release(barrier) acquire(barrier) release(barrier) } turnstile	←	←	←
post	...			

Works, but we want it to be reusable!

Reusable Barrier

	P1	. . .	Pn
init	mutex = 1; barrier = 0; count = 0		
pre	…		

barrier	acquire(mutex)
	  count++
	release(mutex)
	if (count==n) release(barrier)
	
	acquire(barrier)
	release(barrier)
	
	acquire(mutex)
	  count--
	release(mutex)
	if (count==0) acquire(barrier)
		←	←

post	...		

Dou you see the problem?

Reusable Barrier

	P1	...	Pn
init	`mutex = 1; barrier = 0; count = 0`		
pre	...		

barrier	`acquire(mutex)`
	`  count++`
	`release(mutex)`
	`if (count==n) release(barrier)`
	
	`acquire(barrier)`
	`release(barrier)`
	
	`acquire(mutex)`
	`  count--`
	`release(mutex)`
	`if (count==0) acquire(barrier)`
		←	←

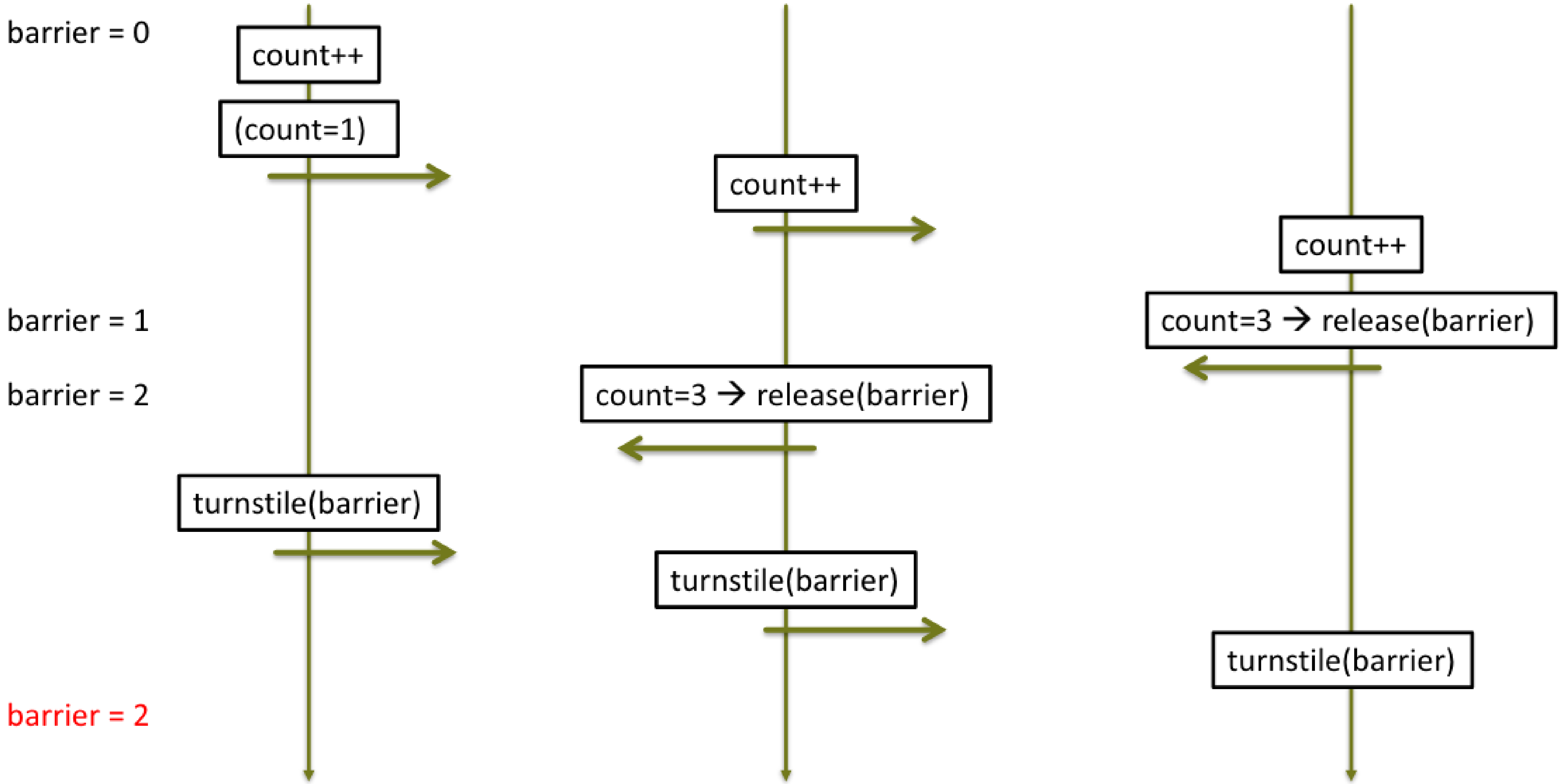
post	...		

Dou you see the problem?

Race Condition !

Race Condition !

Scheduling Scenario



Reusable Barrier 2nd try

	P1	...	Pn
init	mutex = 1; barrier = 0; count = 0		
pre	...		

barrier	acquire(mutex)
	  count++
	  if (count==n) release(barrier)
	release(mutex)		

	acquire(barrier) release(barrier)	←	←

	acquire(mutex)
	  count--
	  if (count==0) acquire(barrier)
	release(mutex)		

post	...		

Dou you see the problem?

Doesn't quite work yet

	P1	. . .	Pn
init	mutex = 1; barrier = 0; count = 0		
pre	...		

barrier	acquire(mutex)
	  count++
	  if (count==n) release(barrier)
	release(mutex)
	
	acquire(barrier)
	release(barrier)
	
	acquire(mutex)
	  count--
	  if (count==0) acquire(barrier)
	release(mutex)
		←	←

post	...		

Dou you see the problem?

Process can pass other processes!

Solution: Two-Phase Barrier

init

```
mutex=1; barrier1=0; barrier2=1; count=0
```

barrier

```
acquire(mutex)
  count++;
  if (count==n)
     acquire(barrier2); release(barrier1)
release(mutex)

acquire(barrier1); release(barrier1);
// barrier1 = 1 for all processes, barrier2 = 0 for all processes
acquire(mutex)
  count--;
  if (count==0)
      acquire(barrier1); release(barrier2)
signal(mutex)

acquire(barrier2); release(barrier2)
// barrier2 = 1 for all processes, barrier1 = 0 for all processes
```

Barriers code examples

- See code

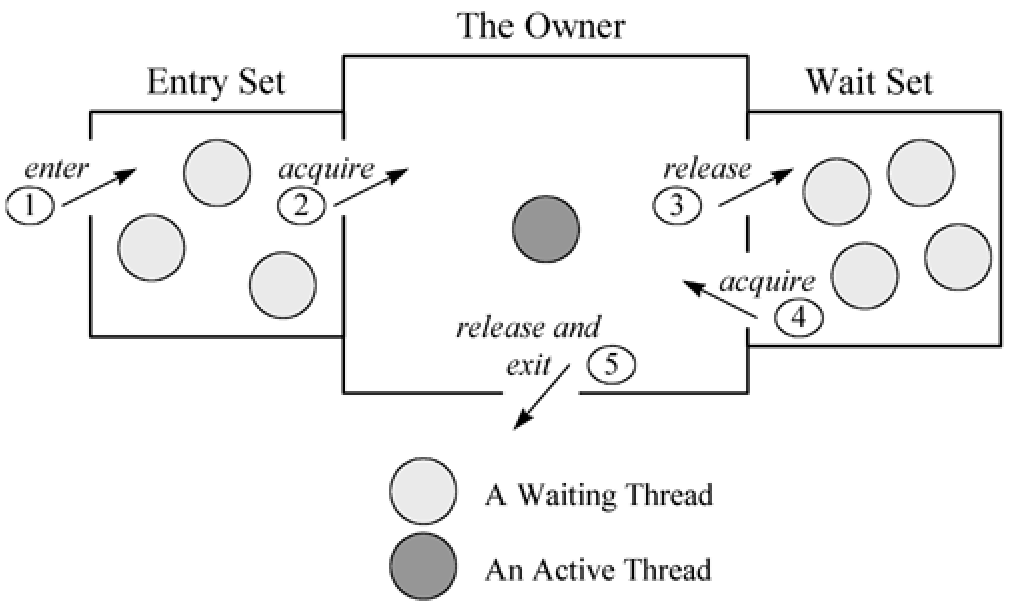
Teaching Awards

- Ich wäre dankbar, wenn ihr für mich abstimmen könntet!

Monitors and Lock Conditions

Lecture Recap: Monitors

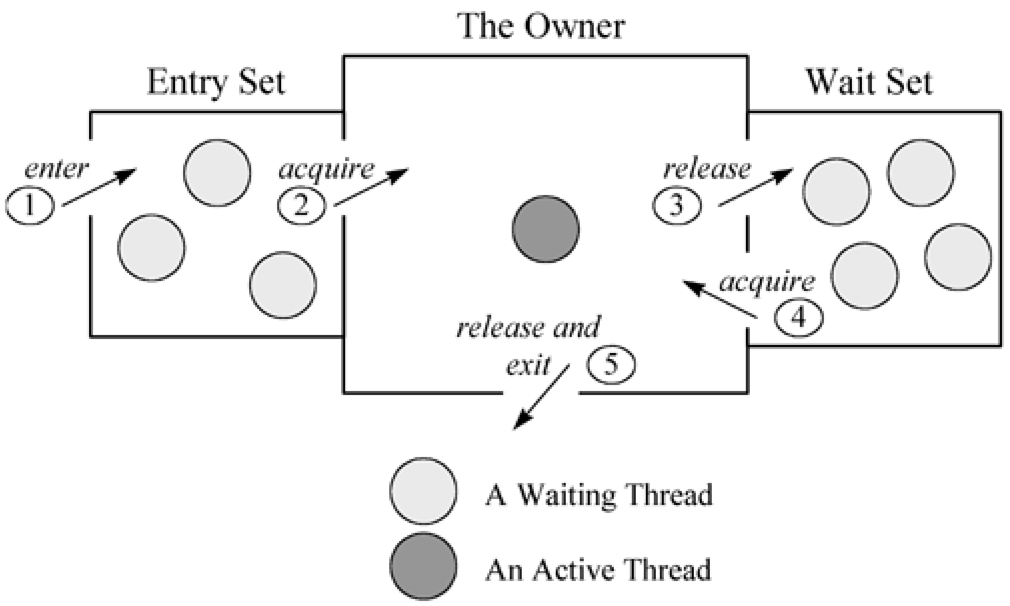
Monitors provide two kinds of thread synchronization: **mutual exclusion** and **cooperation** using a lock



- higher level mechanism than semaphores and more powerful
- instance of a class that can be used safely by several threads
- all methods of a monitor are executed with mutual exclusion

Lecture Recap: Monitors

Monitors provide two kinds of thread synchronization: **mutual exclusion** and **cooperation** using a lock



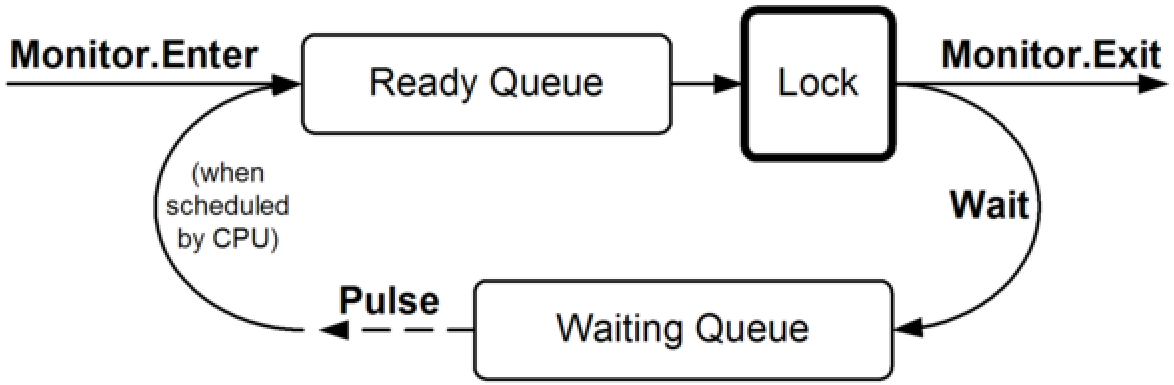
- the possibility to make a thread waiting for a condition
- signal one or more threads that a condition has been met

When thread is sent to wait we release the lock !
Can a monitor induce a deadlock?

Monitors in Java

Uses intrinsic lock (synchronized) of an object

wait() – the current thread waits until it is
notify() – wakes up one waiting thread
notifyAll() – wakes up all waiting threads



Monitors in Java

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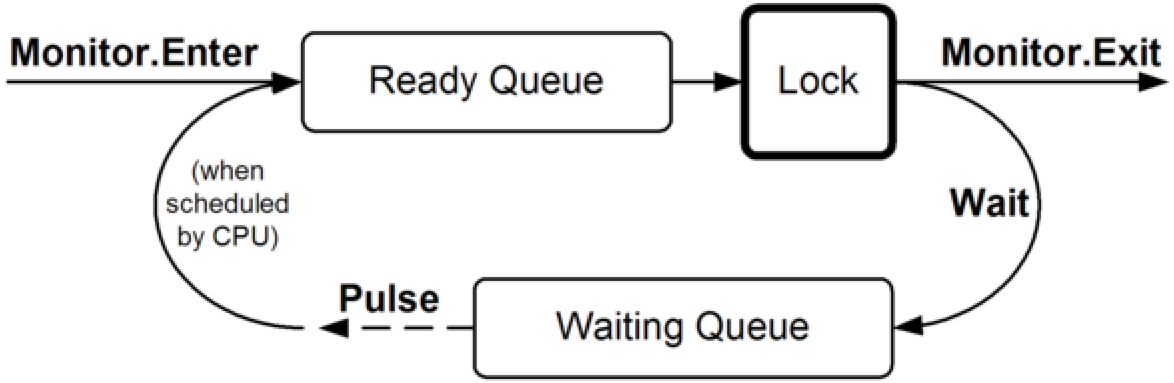


When do you use notify, when notifyAll?

Monitors in Java: Signal & Continue

- signalling process continues running
- signalling process moves signalled process to entry queue

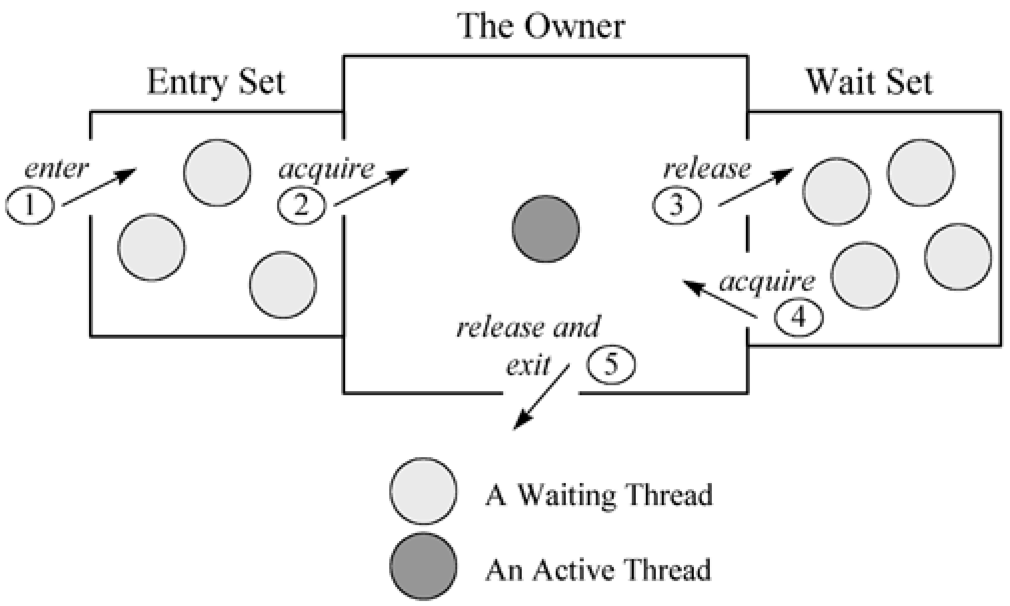


Figure 20-1. A Java monitor.

More theory:

- **Signal & Continue (SC)** : The process who signal keep the mutual exclusion and the signaled will be awaken but need to acquire the mutual exclusion before going. (Java's option)
- **Signal & Wait (SW)** : The signaler is blocked and must wait for mutual exclusion to continue and the signaled thread is directly awaken and can start continue its operations.
- **Signal & Urgent Wait (SU)** : Like SW but the signaler thread has the guarantee than it would go just after the signaled thread
- **Signal & Exit (SX)** : The signaler exits from the method directly after the signal and the signaled thread can start directly.

Monitors in Java: Signal & Continue

- signalling process continues running
- signalling process moves signalled process to entry queue

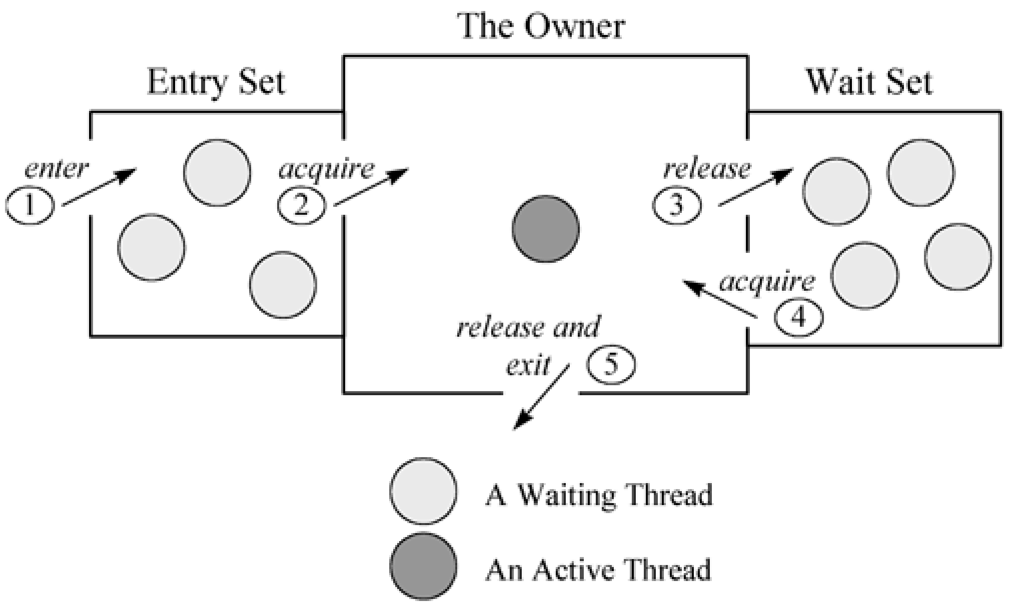
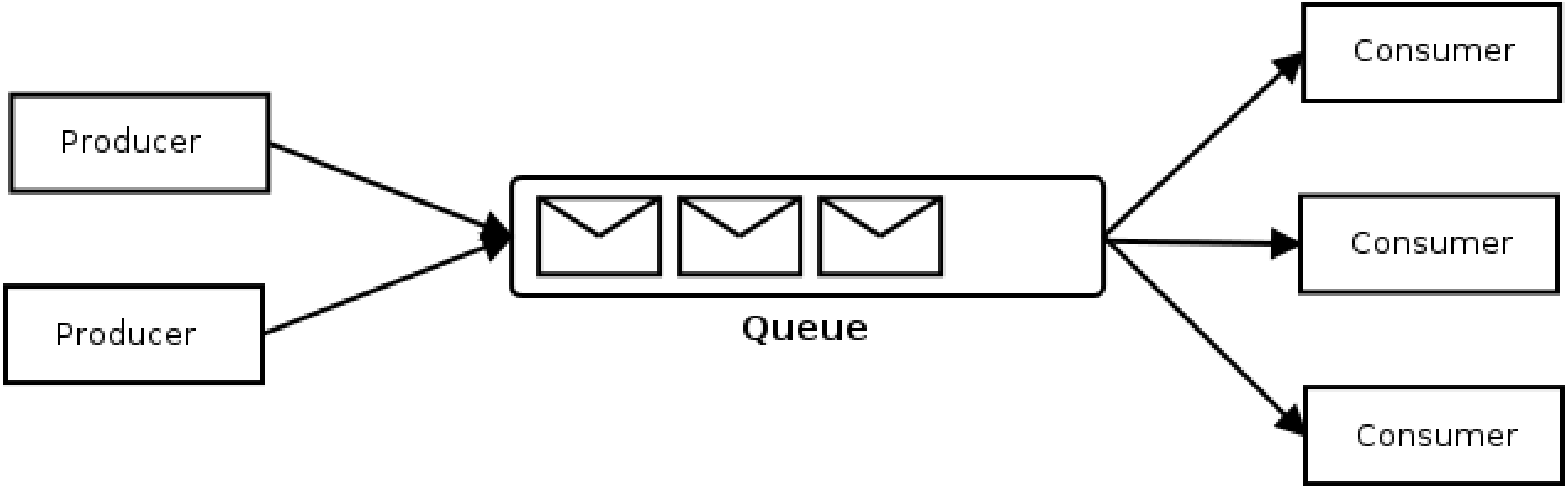


Figure 20-1. A Java monitor.

More abstractly there are 4 options:

- **Signal & Continue (SC)** : The process who signal keep the mutual exclusion and the signaled will be awaken but need to acquire the mutual exclusion before going. (Java's option)
- **Signal & Wait (SW)** : The signaler is blocked and must wait for mutual exclusion to continue and the signaled thread is directly awaken and can start continue its operations.
- **Signal & Urgent Wait (SU)** : Like SW but the signaler thread has the guarantee than it would go just after the signaled thread
- **Signal & Exit (SX)** : The signaler exits from the method directly after the signal and the signaled thread can start directly.

Monitors in Java: Example P/C Queue



A simple implementation, correct?

```java
synchronized void enqueue(long x) {
  if (isFull()){
    try {
      wait();
    } catch (InterruptedException e) {}
  }
  doEnqueue(x);
  notifyAll();
}
```

```java
synchronized long dequeue() {
  long x;
  if (isEmpty()){
    try {
      wait();
    } catch (InterruptedException e) {}
  }
  x = doDequeue();
  notifyAll();
  return x;
}
```

Monitors in Java: Example P/C Queue

```java
synchronized void enqueue(long x) {
  if (isFull()){
    try {
      wait();
    } catch (InterruptedException e) {}
  }
  doEnqueue(x);
  notifyAll();
}
```

1. Queue is full
2. Process Q enters enqueue(), sees `isFull()`, and goes to the waiting list.
3. Process P enters dequeue()
4. In this moment process R wants to enter enqueue() and blocks
5. P signals Q and thus moves it into the ready queue, P then exits dequeue()
6. R enters the monitor before Q and sees `!isFull()`, fills the queue, and exits the monitor
7. Q resumes execution assuming `isFull()` is `false`

=> Inconsistency!

A simple implementation, correct?

```java
synchronized void enqueue(long x) {
  while (isFull()){
    try {
      wait();
    } catch (InterruptedException e) {}
  }
  doEnqueue(x);
  notifyAll();
}
```

```java
synchronized long dequeue() {
  long x;
  while (isEmpty()){
    try {
      wait();
    } catch (InterruptedException e) {}
  }
  x = doDequeue();
  notifyAll();
  return x;
}
```

Whats the problem here?

- Producers and Consumers are in the same “wait” queue
- We must use notifyAll() because we can not target only producer (or consumer)

Lets try Locks

The Lock interface:

- lock(): Acquires the lock, blocks until it is acquired
- tryLock(): Acquire lock only if its lock is free when function is called
- unlock(): Release the lock

How do we wait/notify?

Use Conditions!

Can be used to implement monitors!

Java Locks provide conditions that can be instantiated Condition

```
notFull = lock.newCondition();
```

Java conditions offer

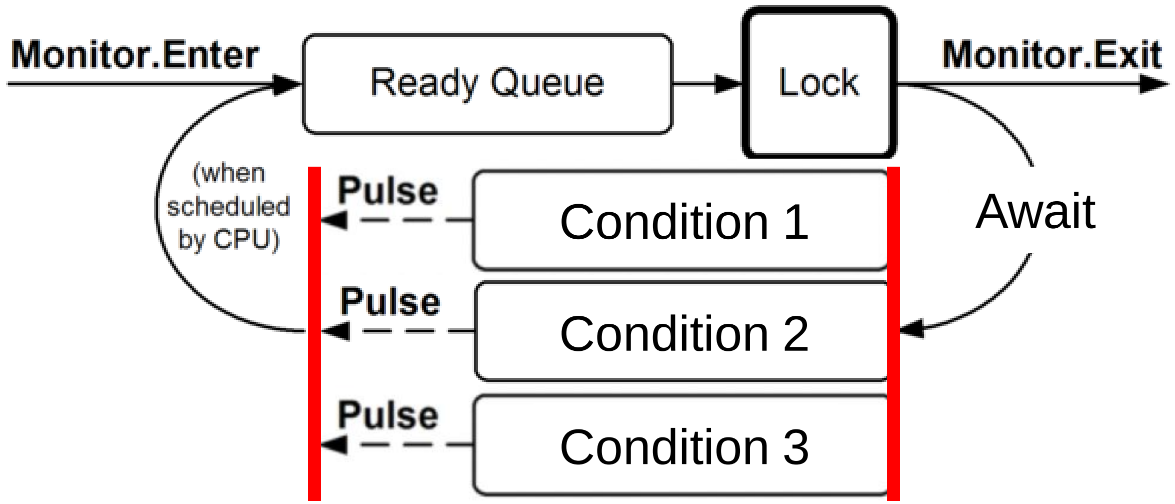
`.await()` – the current thread waits until condition is signaled

`.signal()` – wakes up one thread waiting on this condition

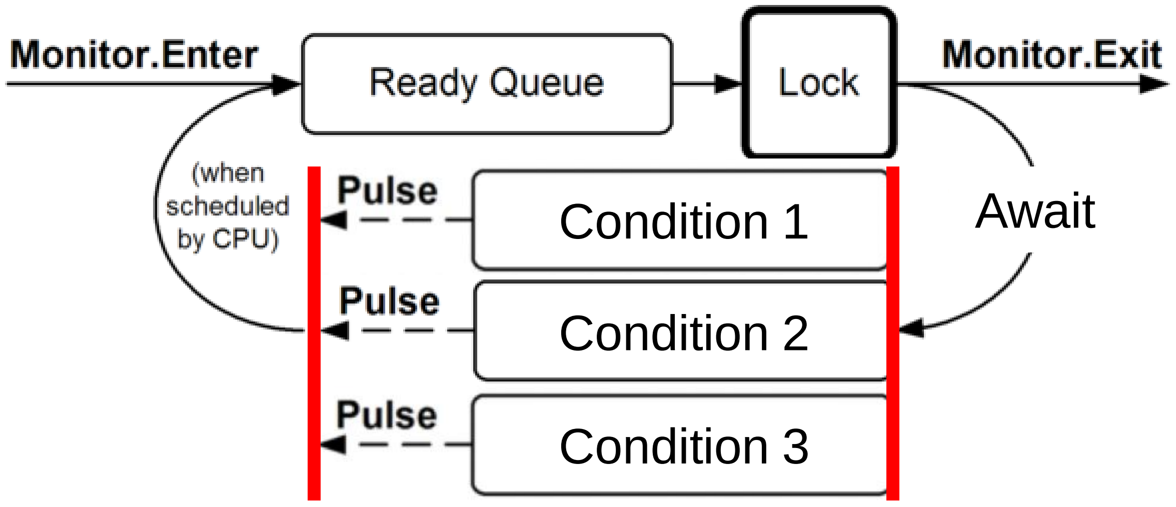
`.signalAll()` – wakes up all threads waiting on this condition

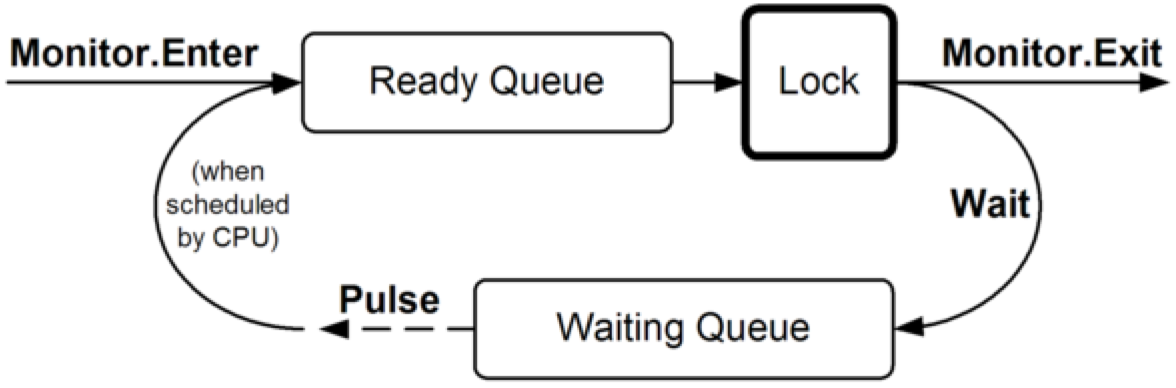
What is the difference to a Monitor?

Lock Conditions



Lock Conditions in Comparison to Monitor





Lock Conditions: Example P/C Queue

```
public class ProducerConsumer {
    private final Queue<Object> items;
    private final int capacity;

    private final Lock lock = new ReentrantLock();

    private final Condition notFull = lock.newCondition();
    private final Condition notEmpty = lock.newCondition();

    public ProducerConsumer(int capacity) {
        items = new ArrayDeque<Object>(capacity);
        this.capacity = capacity;
    }
```

Lock Conditions: Example P/C Queue

```
public void produce(Object data) throws InterruptedException {
    lock.lock();
    try {
        while (items.size()==capacity) {
            notFull.await();
        }
        items.add(data);
        notEmpty.signal();
    } finally {
        lock.unlock();
    }
}
```

```
public Object consume() throws InterruptedException {
    lock.lock();
    try {
        while (items.isEmpty()) {
            notEmpty.await();
        }
        Object result = items.remove();
        notFull.signal();
        return result;
    } finally {
        lock.unlock();
    }
}
```

Why do we need the lock?

```
public void produce(Object data) throws InterruptedException {
    lock.lock();
    try {
        while (items.size()==capacity) {
            notFull.await();
        }
        items.add(data);
        notEmpty.signal();
    } finally {
        lock.unlock();
    }
}
```

```
public Object consume() throws InterruptedException {
    lock.lock();
    try {
        while (items.isEmpty()) {
            notEmpty.await();
        }
        Object result = items.remove();
        notFull.signal();
        return result;
    } finally {
        lock.unlock();
    }
}
```

What is still not perfect?

notFull and notEmpty signal will be sent in any case, even when no threads are waiting.

- This is expensive!

A simple solution: Sleeping Barber

Sleeping barber requires additional counters for checking if processes are waiting:

$m \leq 0 \Leftrightarrow$ buffer full & -m producers (clients) are waiting

$n \leq 0 \Leftrightarrow$ buffer empty & -n consumers (barbers) are waiting

P/C, Sleeping Barber Variant

```
class Queue {
    int in=0, out=0, size;
    long buf[];
    final Lock lock = new ReentrantLock();
    int n = 0; final Condition notFull = lock.newCondition();
    int m; final Condition notEmpty = lock.newCondition();

    Queue(int s) {
        size = s; m = size-1;
        buf = new long[size];
    }
...
}
```

Two variables ☹ sic!
(cf. last lecture)

P/C, Sleeping Barber Variant

```
void enqueue(long x) {

   lock.lock();
   m--; if (m<0)
      while (isFull())
         try { notFull.await(); }
         catch(InterruptedException e){}
   doEnqueue(x);
   n++;
   if (n<=0) notEmpty.signal();
   lock.unlock();

}
```

```
long dequeue() {
   long x;
   lock.lock();
   n--; if (n<0)
      while (isEmpty())
         try { notEmpty.await(); }
         catch(InterruptedException e){}
   x = doDequeue();
   m++;
   if (m<=0) notFull.signal();
   lock.unlock();
   return x;
}
```

Guidelines to using condition waits

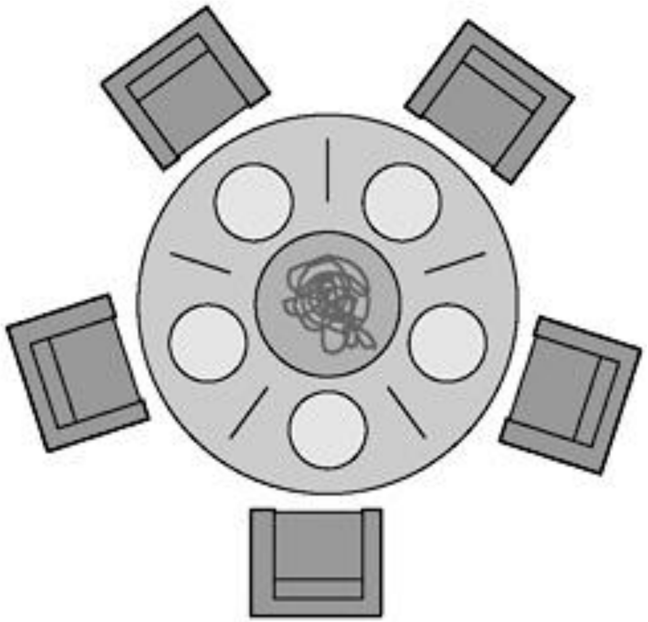
- Always have a condition predicate
- Always test the condition predicate:
  - before calling wait
  - after returning from wait
  - **Always call wait in a loop**
- Ensure state is protected by lock associated with condition
  - What could go wrong if you don’t? (e.g. in sleeping barber variant)

Plan für heute

- Organisation
- Nachbesprechung Assignment 9
- Theory
- **Intro Assignment 10**
- Kahoot
- Exam questions

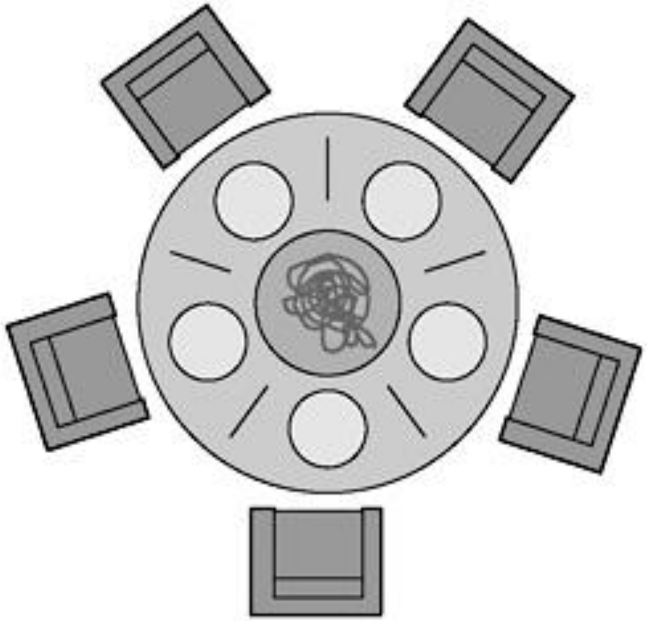
Assignment 10

Task 1 - Dining Philosophers



Originally proposed by E. W. Dijkstra
Imagine five philosophers who spend their lives thinking and eating.
They sit around a circular table with five chairs with a big plate of spaghetti.
However, there are only five chopsticks available.

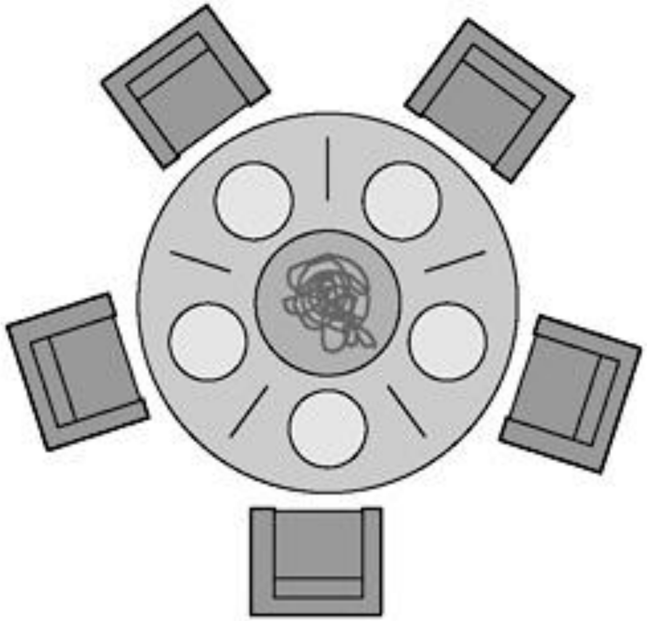
Task 1 - Dining Philosophers



Each philosopher thinks and when he gets hungry picks up the two chopsticks closest to him.

- If a philosopher can pick up BOTH chopsticks, he eats for a while.
- After a philosopher finishes eating, he puts down the chopsticks and starts to think again.

Find a solution that…

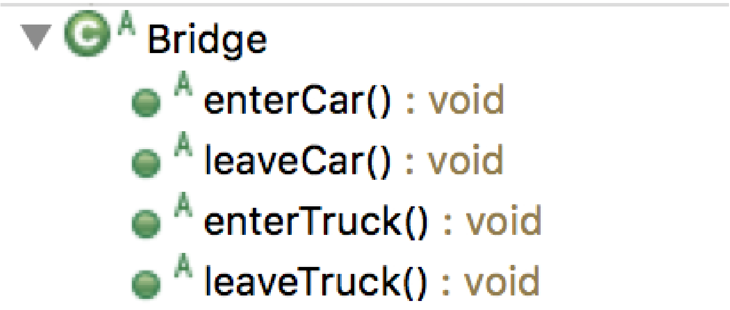


- Makes deadlocks impossible
- Has no starvation
- More than one parallel eating philosopher is possible

Task 2 – Monitors, Conditions and Bridges

Only either 3 cars or one truck may be on the bridge at each moment.

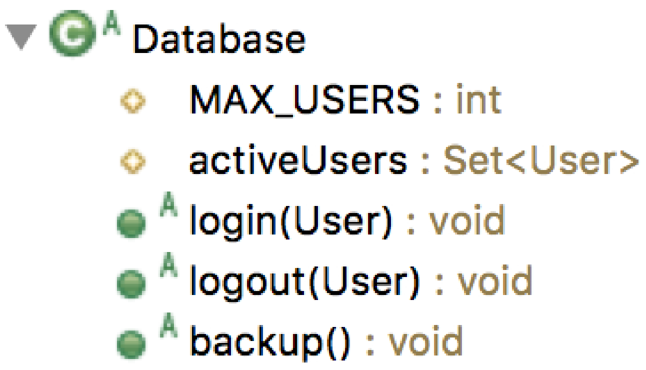
Implement Classes `BridgeMonitor` and `BridgeCondition`



How to Test my Implementation?
Implement method `invariant()` to check if the state is valid: at the end of a method there are never too many cars or trucks on the bridge

Task 3 – Semaphores and Databases

Use semaphores to implement login and logout database functionality that supports up to 10 concurrent users



Use barrier to implement 2-phase backup functionality.

Task 3 – Semaphores and Databases

Implement Classes MySemaphore and MyBarrier

Use monitors for both to avoid busy loop

- Put processes to sleep, when there is no entry into semaphore
- Wake up a waiting process when releasing a semaphore

```
acquire(S) {
       wait until S > 0
       dec(S)
}

release(S) {
       inc(S)
}
```

Try to understand the existing DatabaseJava implementation before implementing your own semaphore and barrier.

Plan für heute

- Organisation
- Nachbesprechung Assignment 9
- Theory
- Intro Assignment 10
- **Kahoot**
- Exam questions

Kahoot!

Plan für heute

- Organisation
- Nachbesprechung Assignment 9
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- **Exam questions**

Barriers and Synchronization (9 points)

11. (a) Wir möchten eine einfache Barriere (muss nicht wiederverwendbar sein) implementieren. Die Barriere soll `N` threads synchronisieren. Markieren Sie welche der folgenden Aussagen auf die jeweiligen implementierungen zutreffen. Sollten Sie den Code für ineffizient halten, nennen sie kurz den Grund.

We want to implement a simple barrier (does not have to be reusable) that allows to synchronize the execution of `N` threads. Mark whether each of the following statements is true for each implementation. If you consider this code to be inefficient, shortly state why. (4)

i.

```
class Barrier {
      AtomicInteger i = new AtomicInteger(0);
      final int threads = N;
      public void await() throws InterruptedException {
              int cur_threads = i.incrementAndGet();
              if(cur_threads < threads) {
                while (i.get() < threads) {}
              }
      }
}
```

◯ Der gezeigte Code hat die gewünschte Semantik. *Code has the desired semantics.*

Barriers and Synchronization (9 points)

11. (a) Wir möchten eine einfache Barriere (muss nicht wiederverwendbar sein) implementieren. Die Barriere soll `N` threads synchronisieren. Markieren Sie welche der folgenden Aussagen auf die jeweiligen implementierungen zutreffen. Sollten Sie den Code für ineffizient halten, nennen sie kurz den Grund.

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        if(cur_threads < threads) {
          while (i.get() < threads) {}
        }
    }
}
```

◯ Der gezeigte Code hat die gewünschte Semantik. *Code has the desired semantics.*

True, there is no data race since `incrementAndGet` increases `i` atomically.

Barriers and Synchronization (9 points)

11. (a) Wir möchten eine einfache Barriere (muss nicht wiederverwendbar sein) implementieren. Die Barriere soll `N` threads synchronisieren. Markieren Sie welche der folgenden Aussagen auf die jeweiligen implementierungen zutreffen. Sollten Sie den Code für ineffizient halten, nennen sie kurz den Grund.

We want to implement a simple barrier (does not have to be reusable) that allows to synchronize the execution of `N` threads. Mark whether each of the following statements is true for each implementation. If you consider this code to be inefficient, shortly state why. (4)

i.

```java
class Barrier {
    AtomicInteger i = new AtomicInteger(0);
    final int threads = N;
    public void await() throws InterruptedException {
        int cur_threads = i.incrementAndGet();
        if(cur_threads < threads) {
          while (i.get() < threads) {}
        }
    }
}
```

◯ Der Code beendet sich immer. *Code will always complete.*

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True, it is a correct barrier implementation.

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Code might not use compute resources efficiently. Why?

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True, the waiting threads are busy waiting.

ii.

```
class Barrier {
        int i = 0;
        final int threads = N;
        public synchronized void await() throws InterruptedException {
                ++i;
                while (i < threads) { wait(); }
                notify();
        }
}
```

○ Der gezeigte Code hat die gewünschte Semantik. *Code has the desired semantics.*

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Code might not use compute resources efficiently. Why?

False, the code makes use of wait/notify and thus does not waste compute resources.

Feedback

- Falls ihr Feedback möchtet sagt mir bitte Bescheid!
- Schreibt mir eine Mail oder auf Discord

Teaching Awards

- Ich wäre dankbar, wenn ihr für mich abstimmen könntet!

Danke

- Bis nächste Woche!