Multicore Programming

Locks

8 Nov 2010 (Part 2)

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Test-and-set (TAS) locks

TATAS locks & backoff

Queue-based locks

Hierarchical locks

Parallel performance

Test and set (pseudo-code)

```
bool testAndSet(bool *b) {
  bool result;
  atomic {
    result = *b;
    *b = TRUE;
  }
}
```

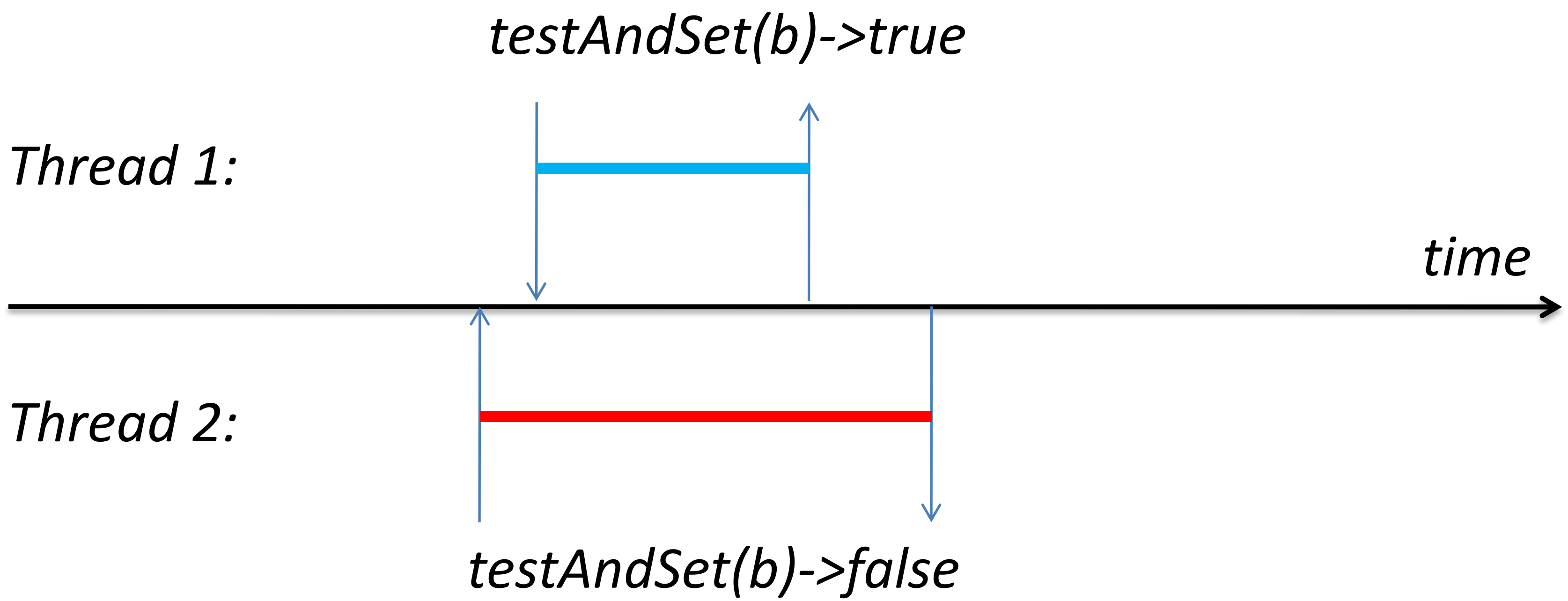
Pointer to a location holding a boolean value (TRUE/FALSE)

Read the current contents of the location b points to…

…set the contents of *b to TRUE

Test and set

- Suppose two threads use it at once



Test and set lock

lock: FALSE

FALSE => lock available
TRUE => lock held

```
void acquireLock(bool *lock) {
  while (testAndSet(lock)) {
    /* Nothing */
  }
}
```

Each call tries to acquire the lock, returning TRUE if it is already held

```
void releaseLock(bool *lock) {
  *lock = FALSE;
}
```

NB: all this is pseudo-code, assuming SC memory

Test and set lock

lock: TRUE

```
void acquireLock(bool *lock) {
   while (testAndSet(lock)) {
      /* Nothing */
   }
}
```

```
void releaseLock(bool *lock) {
   *lock = FALSE;
}
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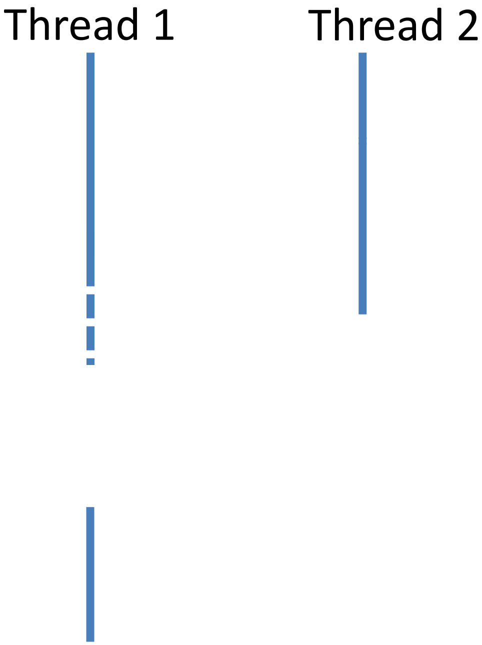


What are the problems here?

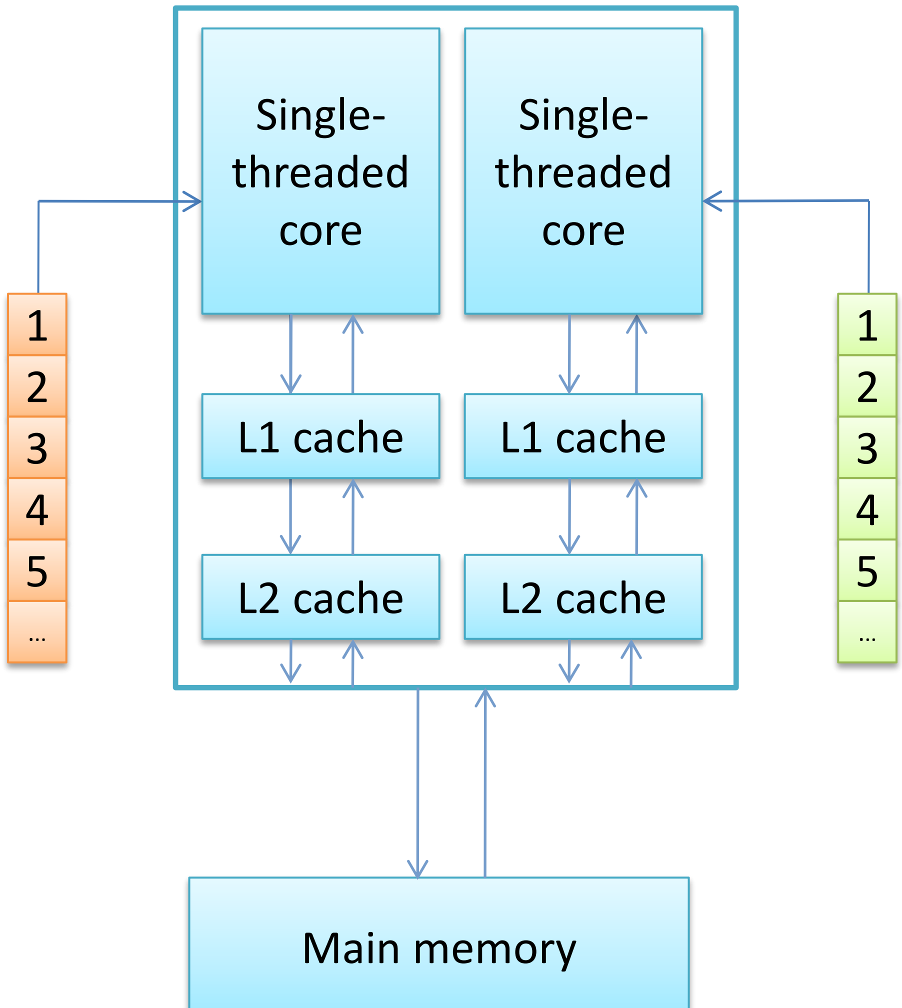
testAndSet implementation causes contention

No control over locking policy

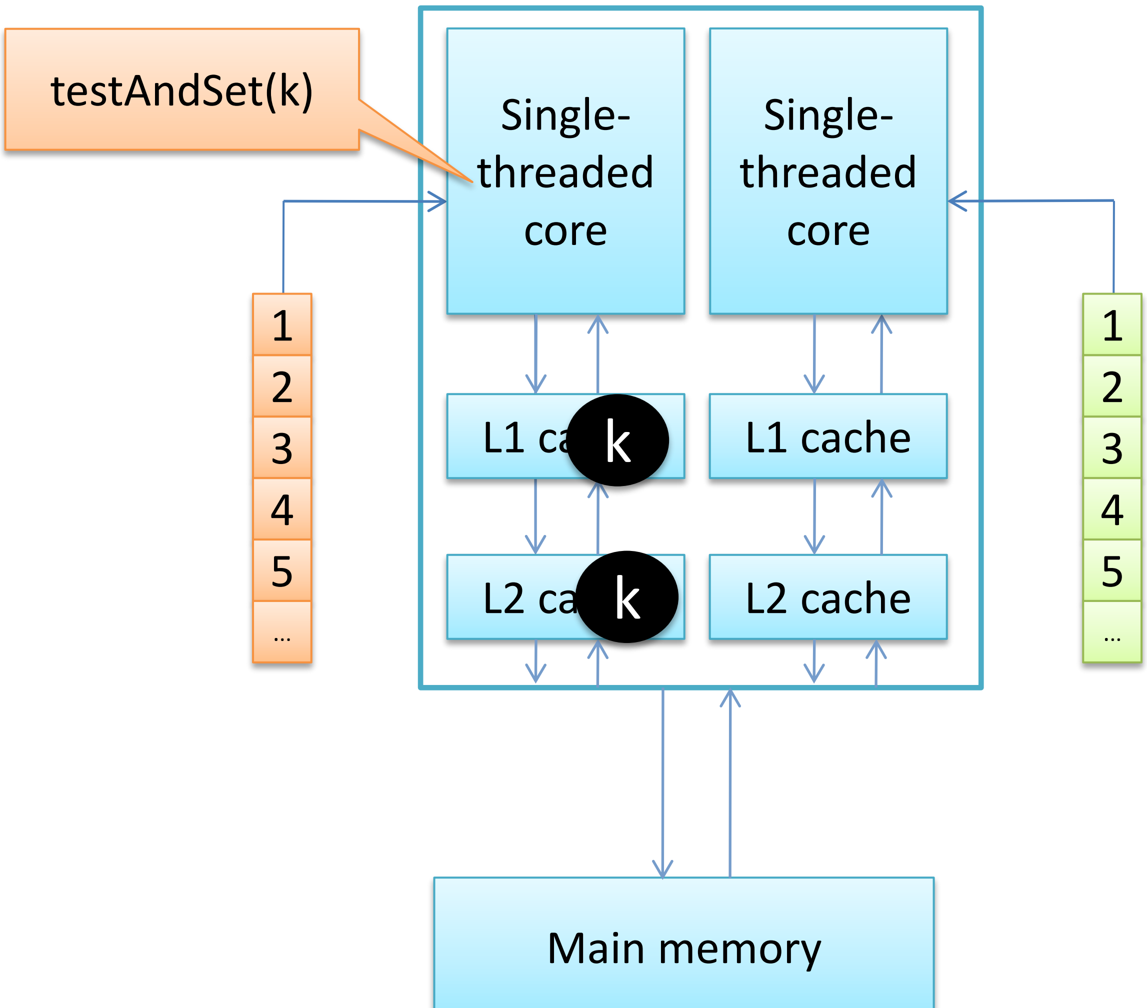
Only supports mutual exclusion: not reader-writer locking

Spinning may waste resources while waiting

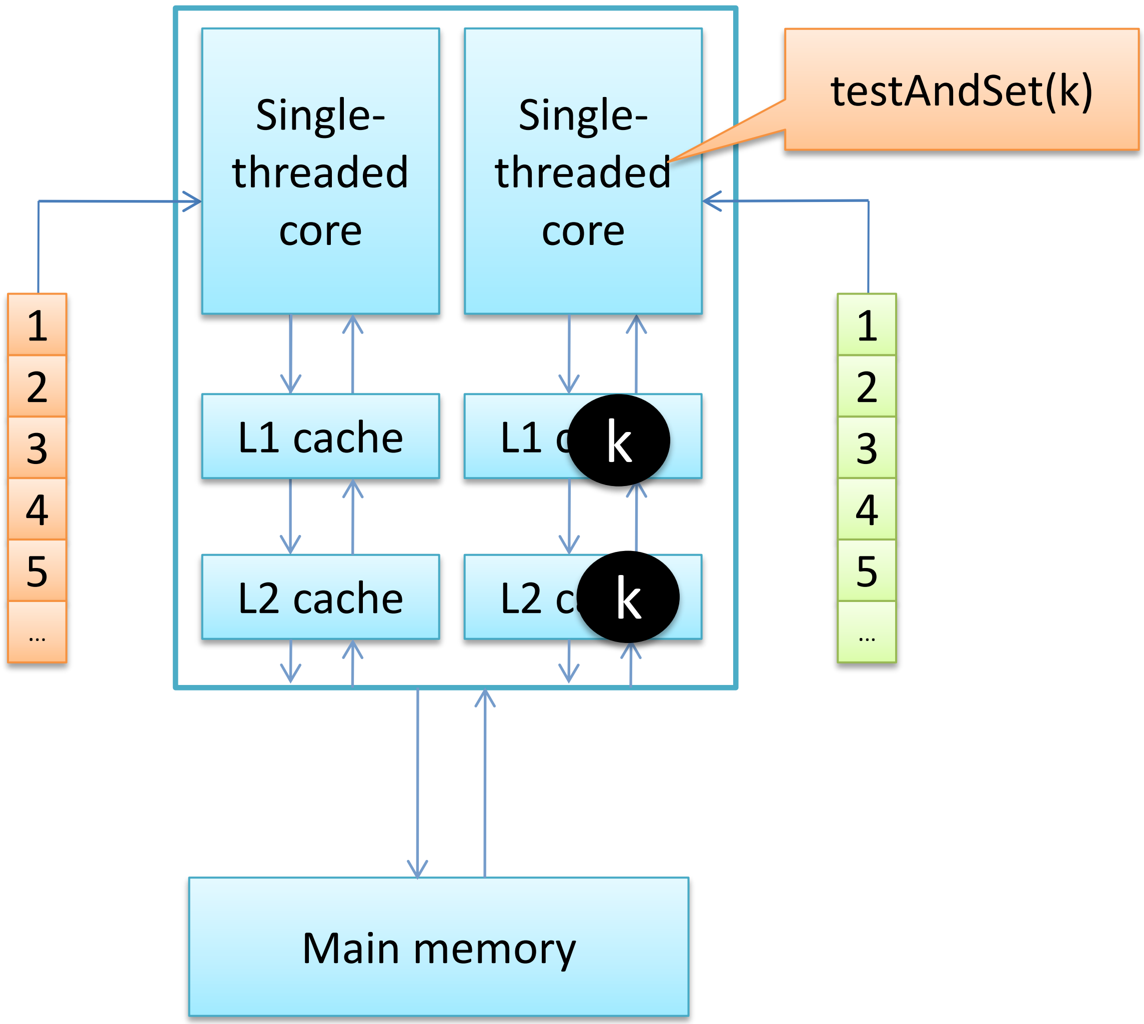
Contention from testAndSet



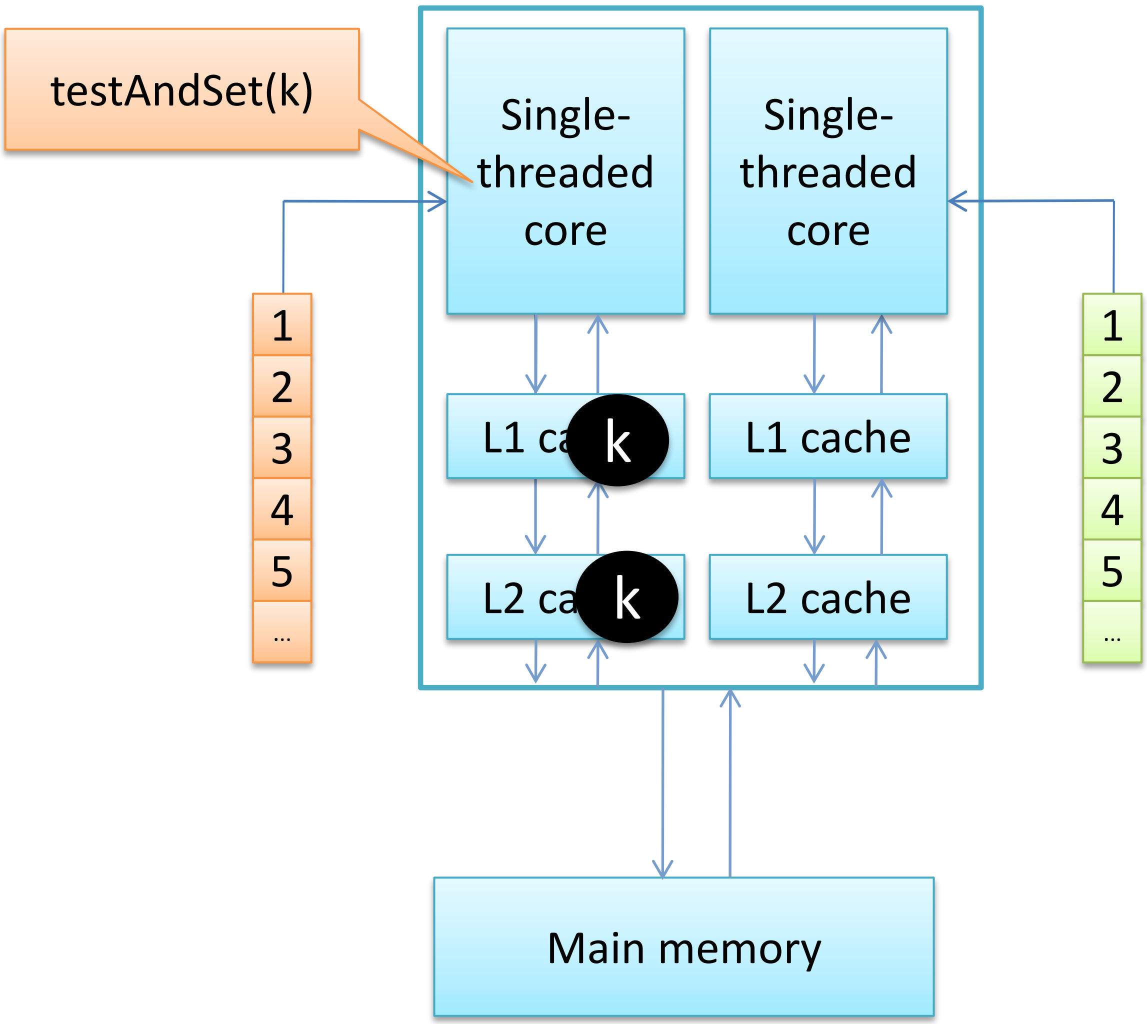
Multi-core h/w – separate L2



Multi-core h/w – separate L2



Multi-core h/w – separate L2



General problem

- No *logical conflict* between two failed lock acquires
- Cache protocol introduces a *physical conflict*
- For a good algorithm: only introduce physical conflicts if a logical conflict occurs

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Test and test and set lock

lock: FALSE

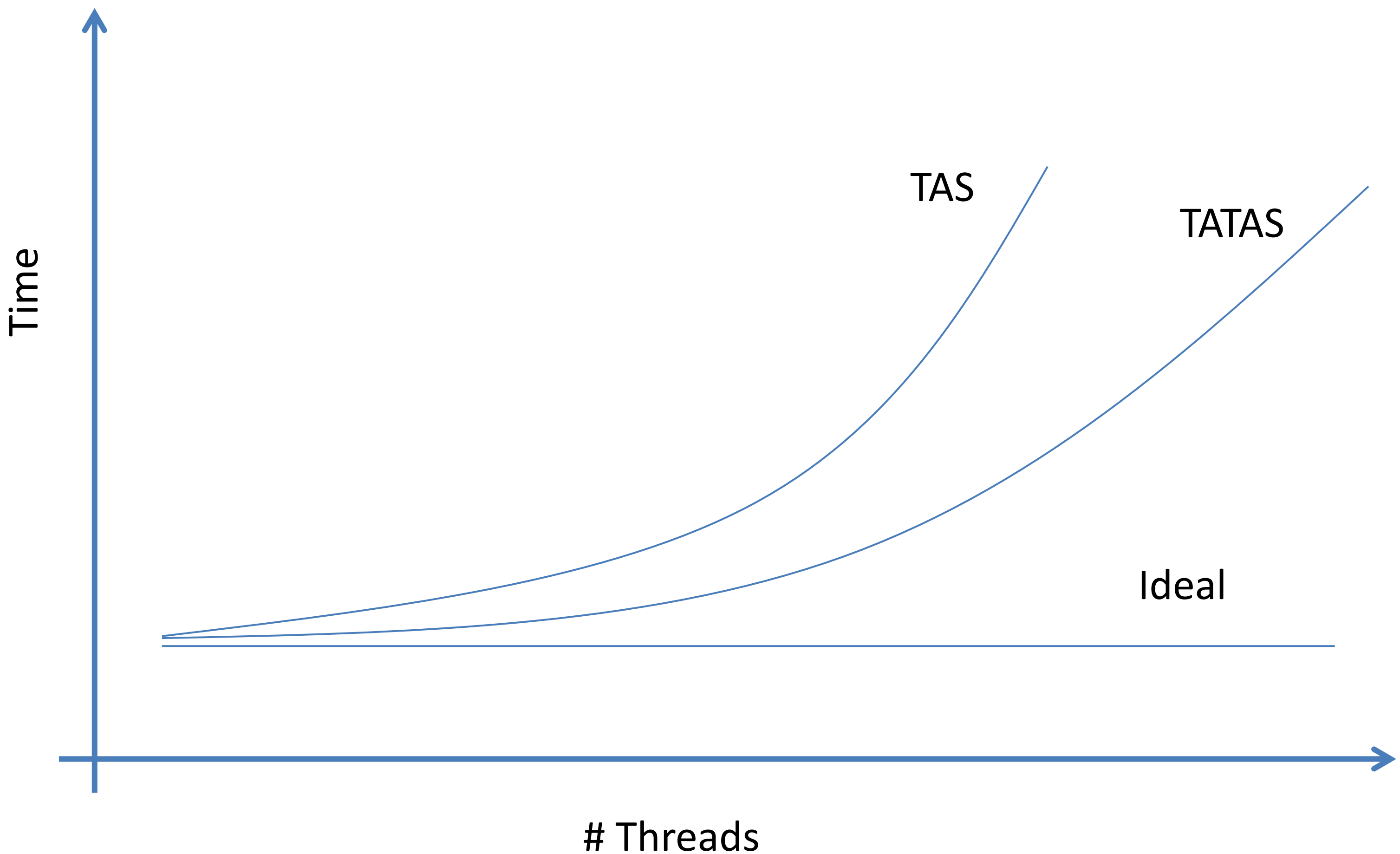
FALSE => lock available
TRUE => lock held

```
void acquireLock(bool *lock) {
  do {
    while (*lock) { }
  } while (testAndSet(lock));
}
```

Spin while the lock is held… only do testAndSet when it is clear

```
void releaseLock(bool *lock) {
  *lock = FALSE;
}
```

Performance

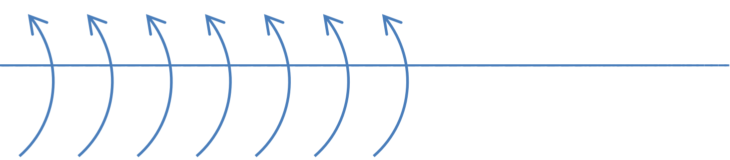


Based on Fig 7.4, Herlihy & Shavit, “The Art of Multiprocessor Programming”

Stampedes

lock: TRUE

```
void acquireLock(bool *lock) {
  do {
    while (*lock) { }
  } while (testAndSet(lock));
}
```



```
void releaseLock(bool *lock) {
   *lock = FALSE;
}
```

Back-off algorithms

1. Start by spinning, watching the lock
2. After an interval *c* spin locally for *s* *(without watching the lock)*

What should "c" be?
What should "s" be?

Time spent waiting "c"

- Lower values:
  - Less time to build up a set of threads that will stampede
- Higher values:
  - Less likelihood of a delay between a lock being released and a waiting thread noticing

Spinning time “s”

- Lower values:
  - More responsive to the lock becoming available
- Higher values:
  - If the lock doesn’t become available then the thread makes fewer accesses to the shared variable

Methodical approach

- For a given workload and performance model:
  - What is the best that an oracle could do (e.g. given perfect knowledge of lock demands)?
  - How does a practical algorithm compare with this?
- Look for an algorithm with a bound between its performance and that of the oracle
- “Competitive spinning”

Rule of thumb

- Spin for a duration that's comparable with the shortest back-off interval
- Exponentially increase the per-thread back-off interval (resetting it when the lock is acquired)
- Use a maximum back-off interval that is large enough that waiting threads don't interfere with the system's performance

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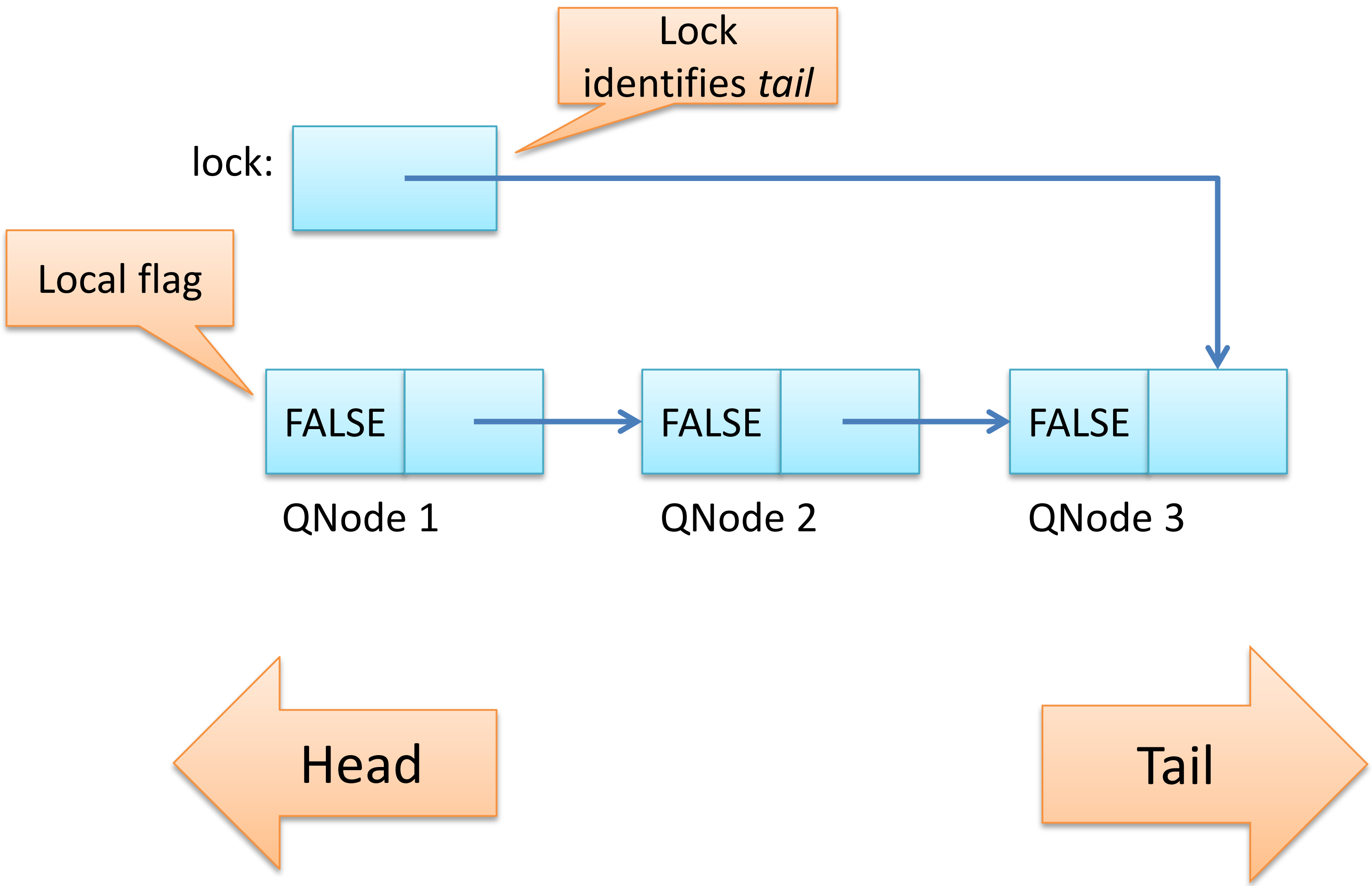
Queue-based locks

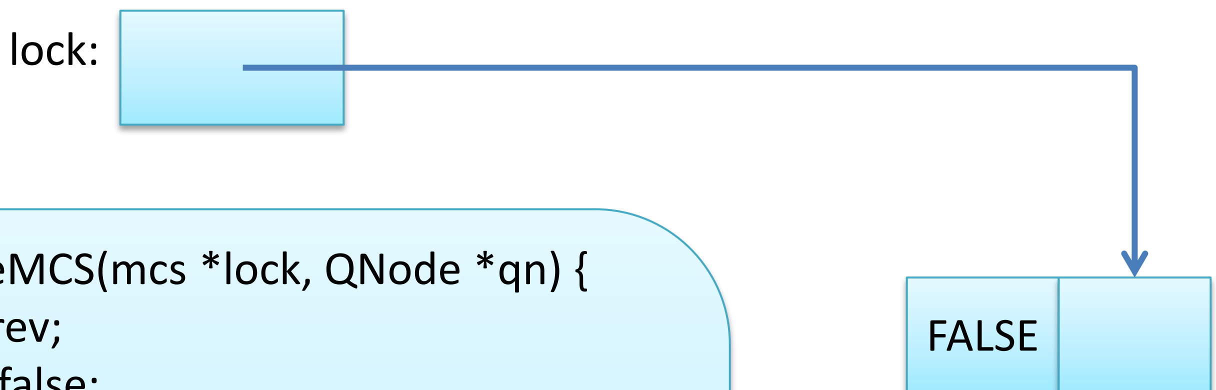
- Lock holders queue up: immediately provides FCFS behavior
- Each spins *locally* on a flag in their queue entry: no remote memory accesses while waiting
- A lock release wakes the next thread directly: no stampede

MCS locks



Lock identifies *tail*
lock:
Local flag
FALSE
FALSE
FALSE
QNode 1
QNode 2
QNode 3
Head
Tail

MCS lock acquire




```
void acquireMCS(mcs *lock, QNode *qn) {
  QNode *prev;
  qn->flag = false;
  qn->next = NULL;
  while (true) {
    prev = lock->tail;
    /*Label 1*/
    if (CAS(&lock->tail, prev, qn)) break;
  }
  if (prev != NULL) {
    prev->next = qn; /*Label 2*/
    while (!qn->flag) { } // Spin
} }
```

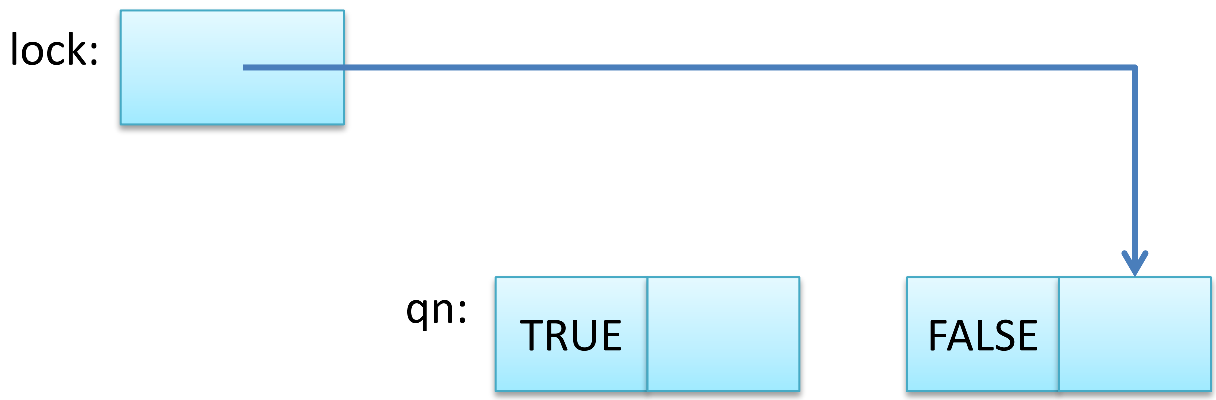
Find previous tail node

Atomically replace “prev” with “qn” in the lock itself

Add link within the queue

NB: the two labels in the source code are referred to in the exercise sheet; they are not necessary for the algorithm

MCS lock release




```
void releaseMCS(mcs *lock, QNode *qn) {
  if (lock->tail = qn) {
    if (CAS(&lock->tail, qn, NULL)) return;
  }
  while (qn->next != NULL) { }
  qn->next->flag = TRUE;
}
```

If we were at the tail then remove us

Wait for next lock holder to announce themselves; signal them

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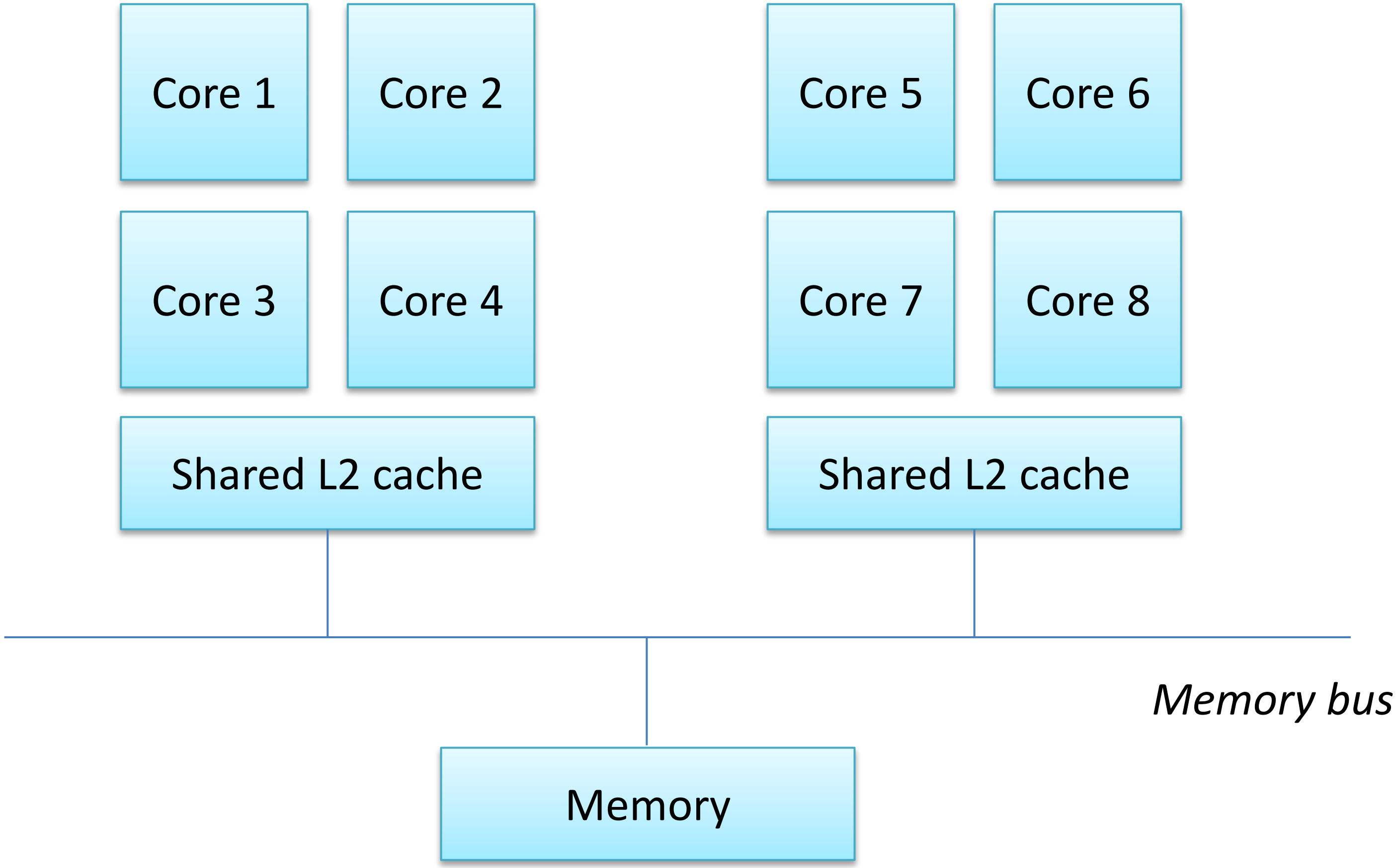
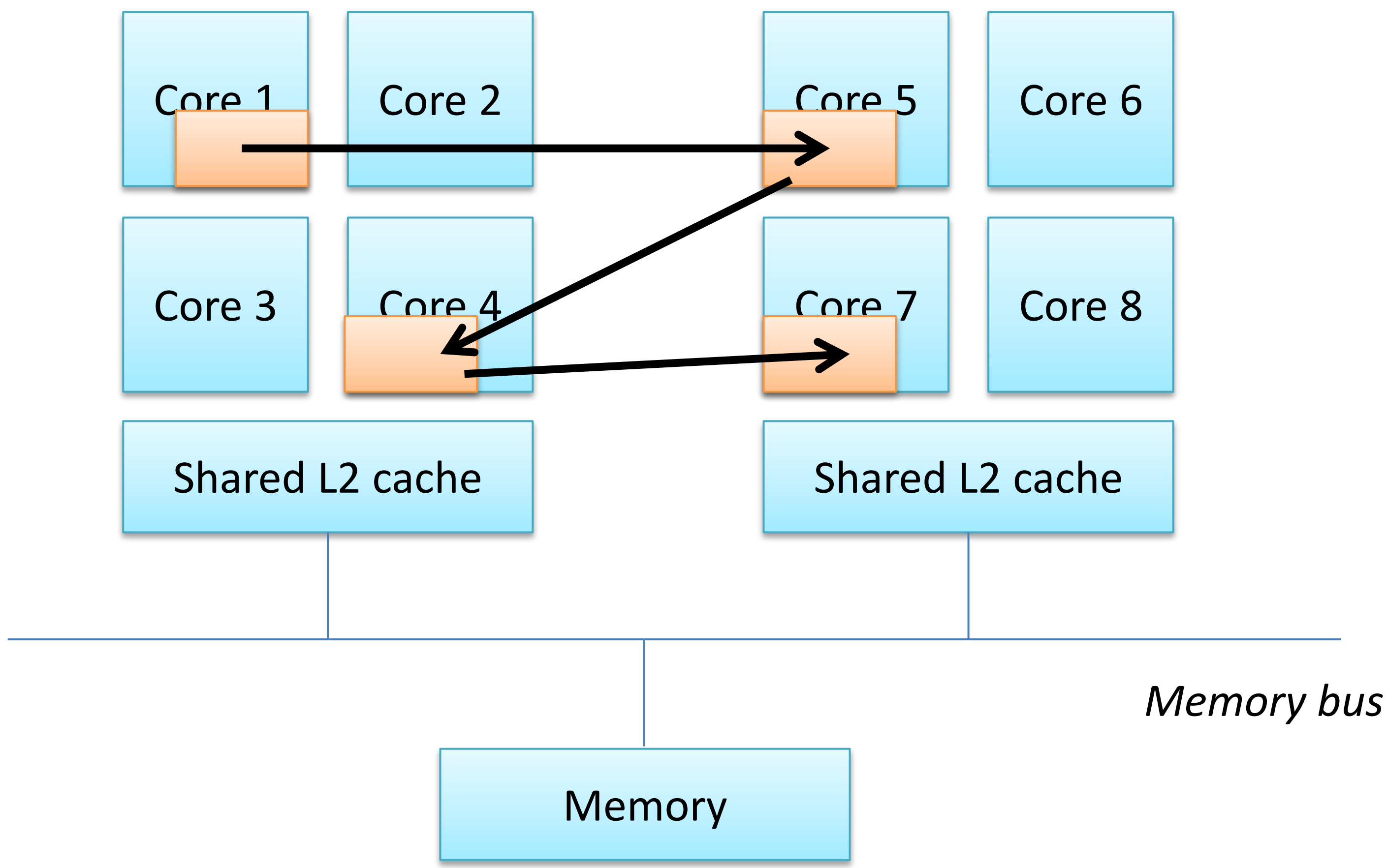
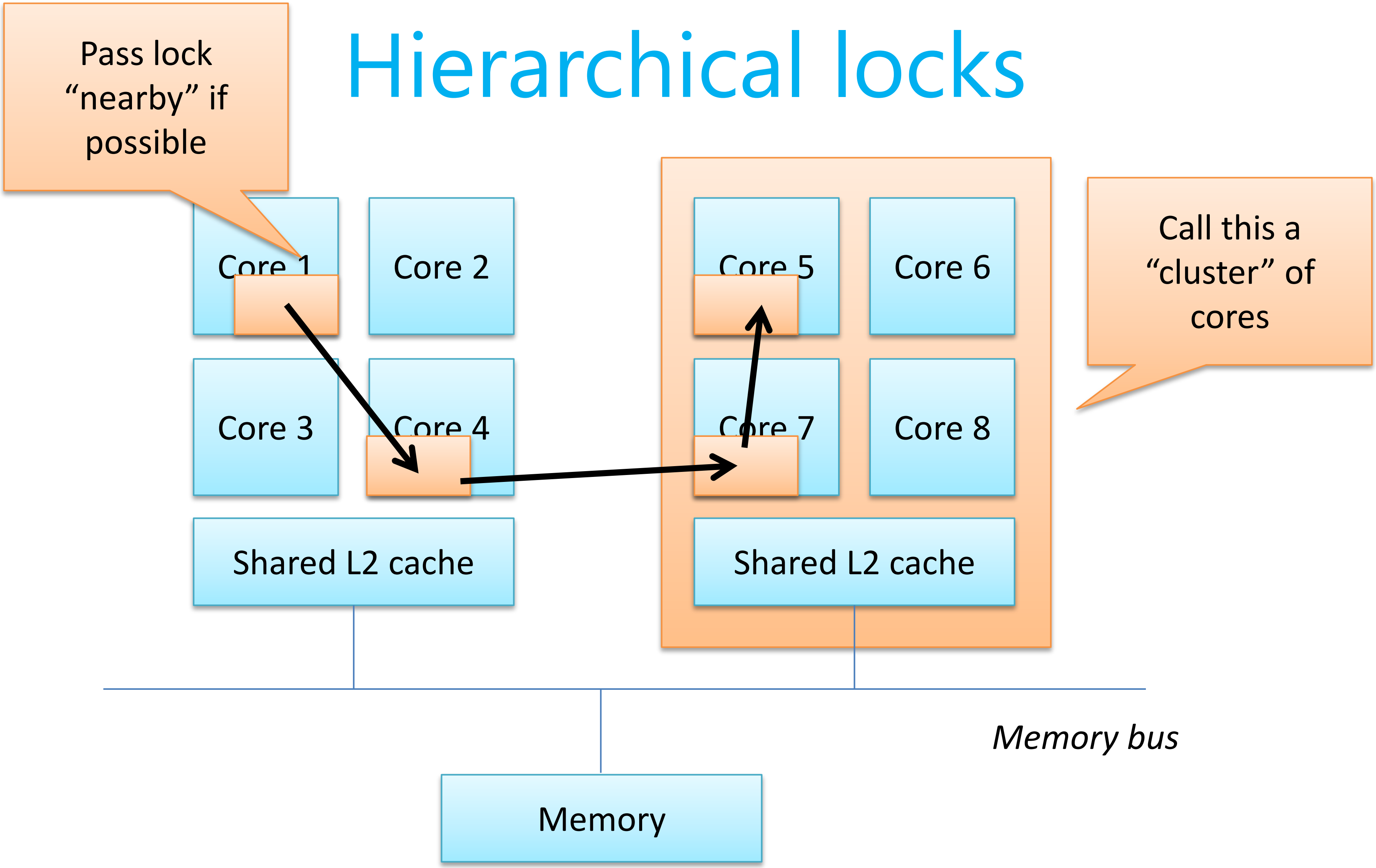


Hierarchical locks



Hierarchical locks



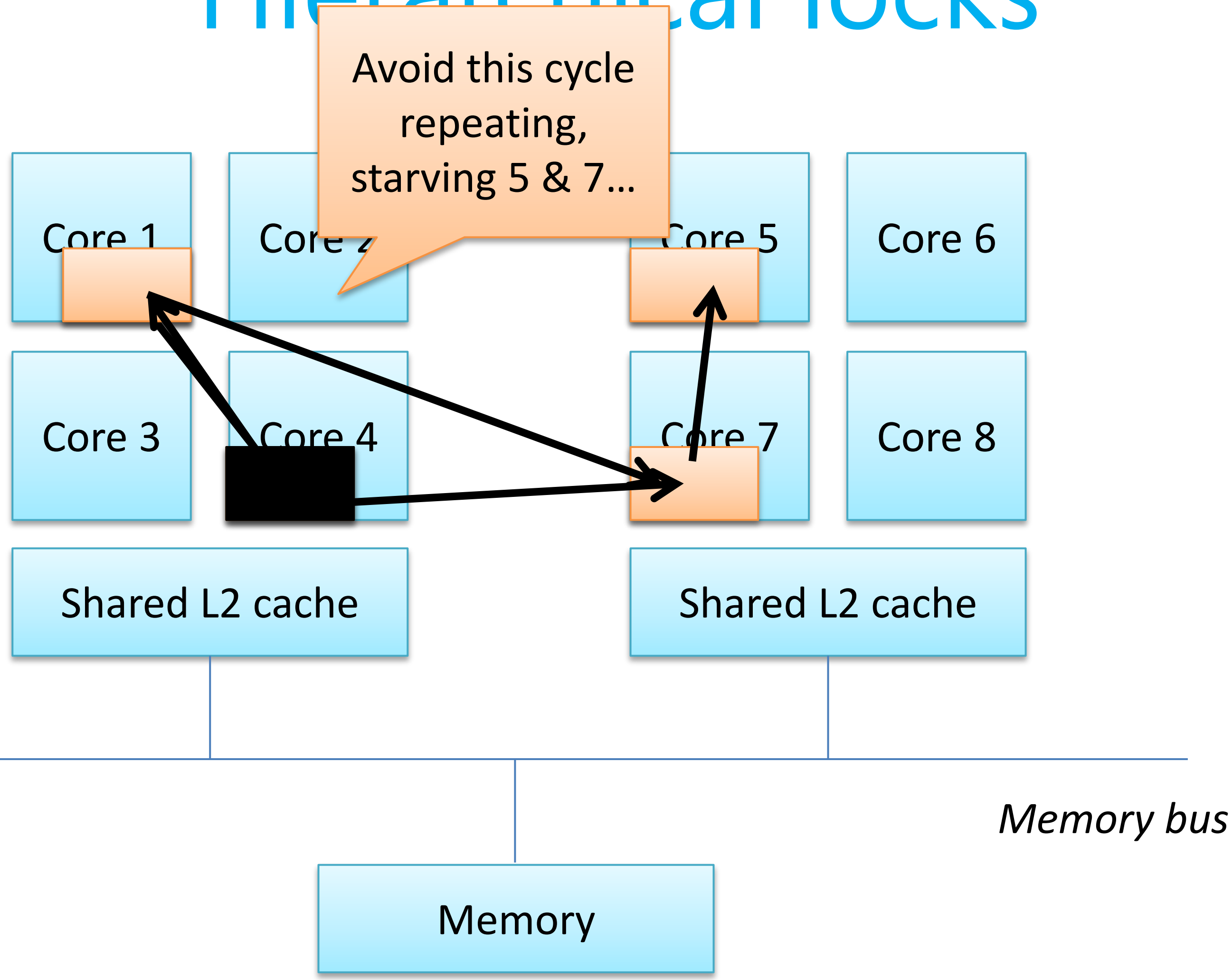
Hierarchical TATAS with backoff

lock: -1

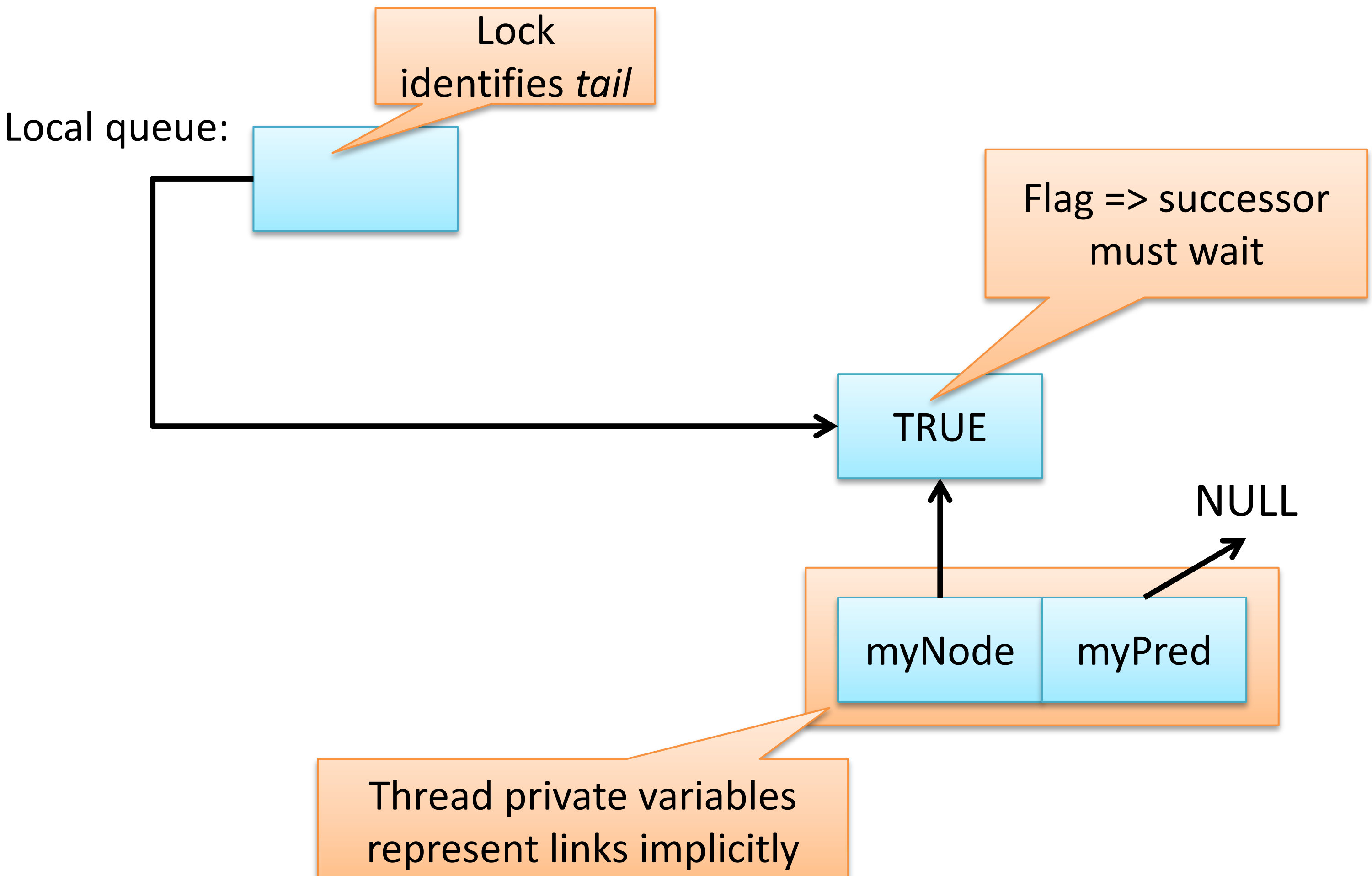
-1 => lock available
n => lock held by cluster n

```
void acquireLock(bool *lock) {
  do {
    holder = *lock;
    if (holder != -1) {
      if (holder == MY_CLUSTER) {
        BackOff(SHORT);
      } else {
        BackOff(LONG);
      }
    }
  } while (!CAS(lock, -1, MY_CLUSTER));
}
```

Hierarchical locks

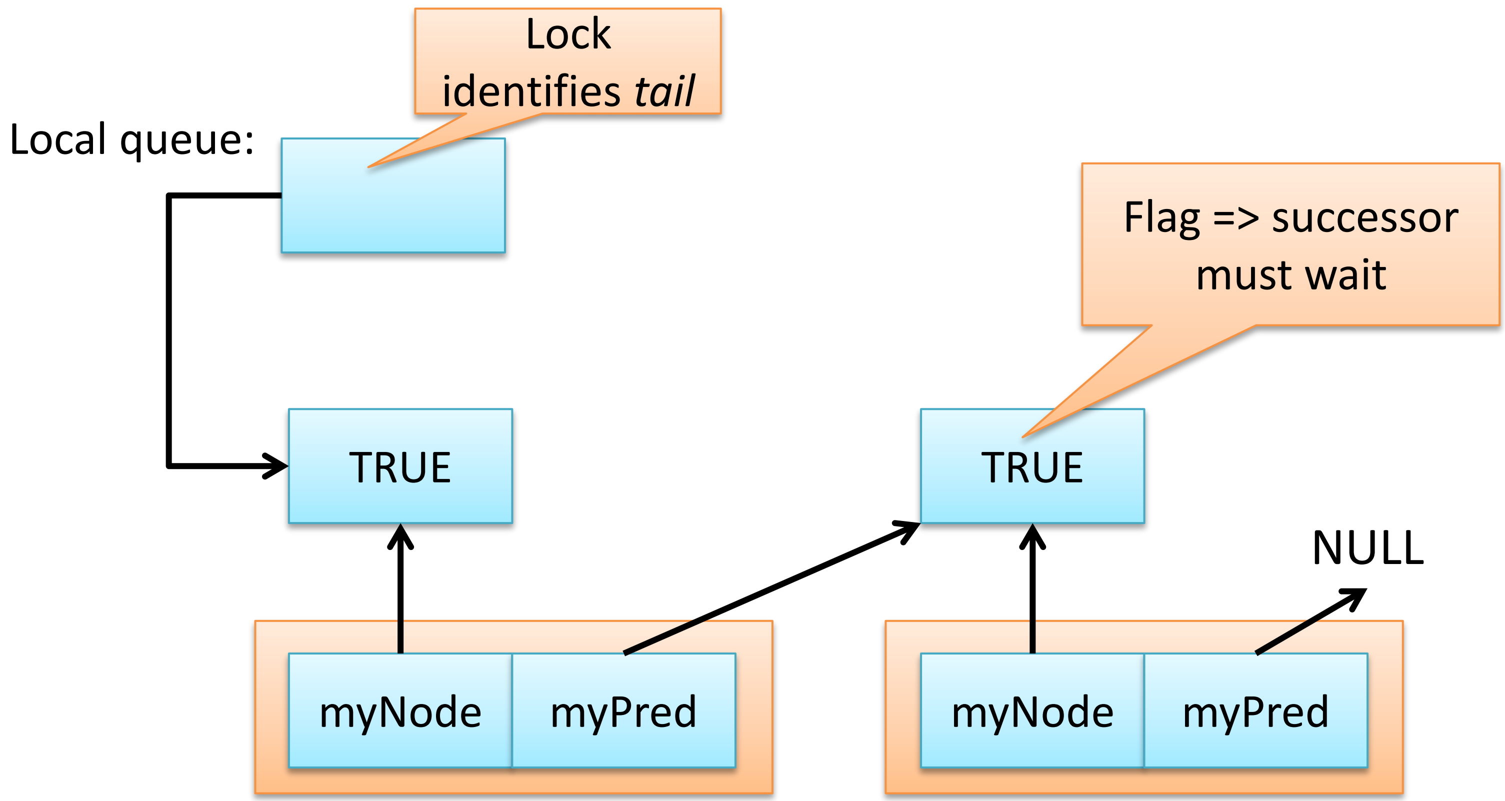


Hierarchical CLH queue lock



Based on hierarchical CLH lock of Luchangco, Nussbaum, Shavit

Hierarchical CLH queue lock



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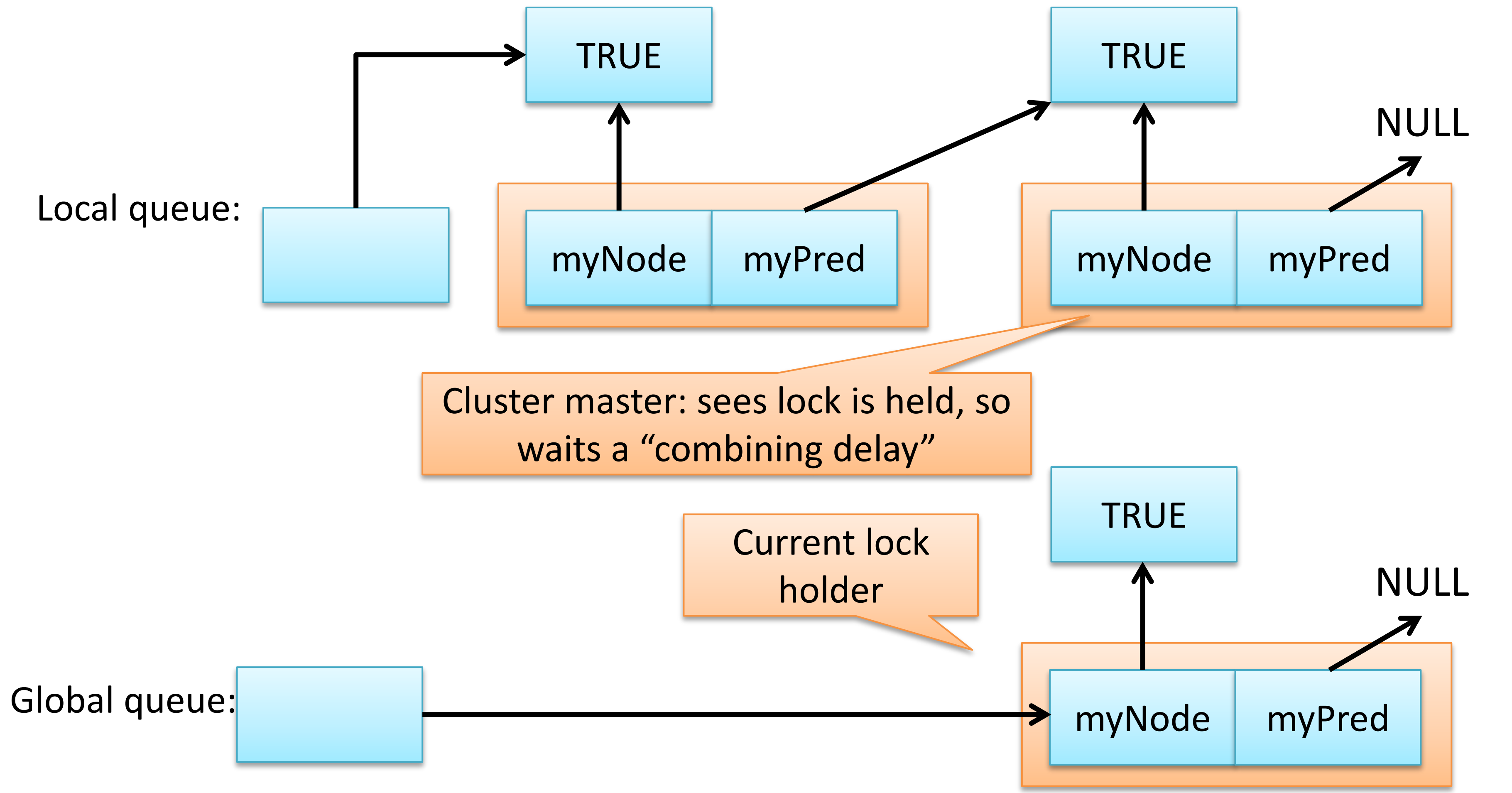
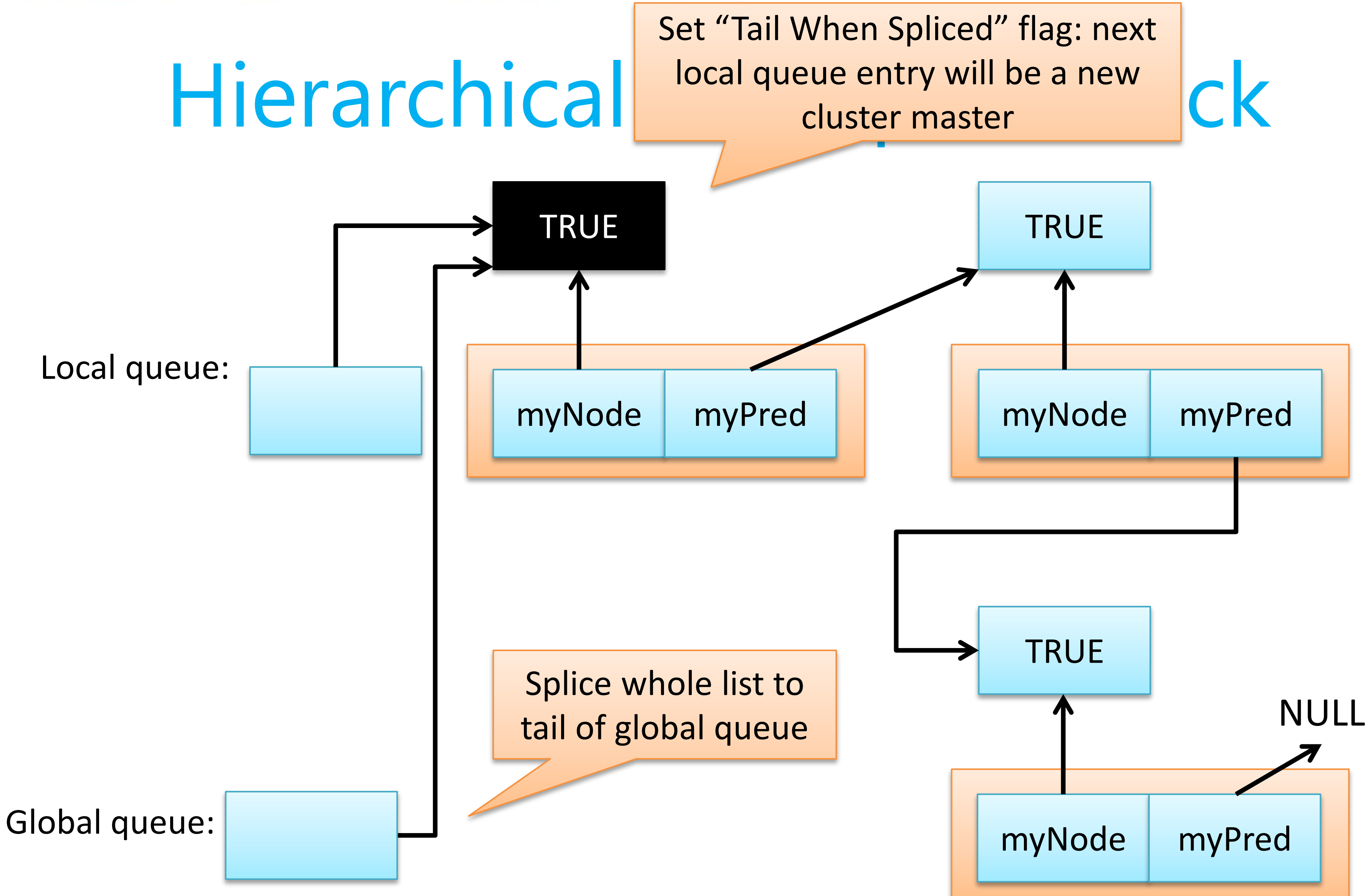
Hierarchical CLH queue lock



Based on hierarchical CLH lock of Luchangco, Nussbaum, Shavit

Hierarchical ck



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An aside: is this a better algorithm?

- How fast does it run without contention?
  - Each thread acquires and releases different locks
  - Threads acquire and release the same lock… but not at the same time
- How fast does it run with contention?
  - *n* threads trying to acquire the same lock at the same time
  - How does performance scale as *n* varies?

An aside: is this a better algorithm?

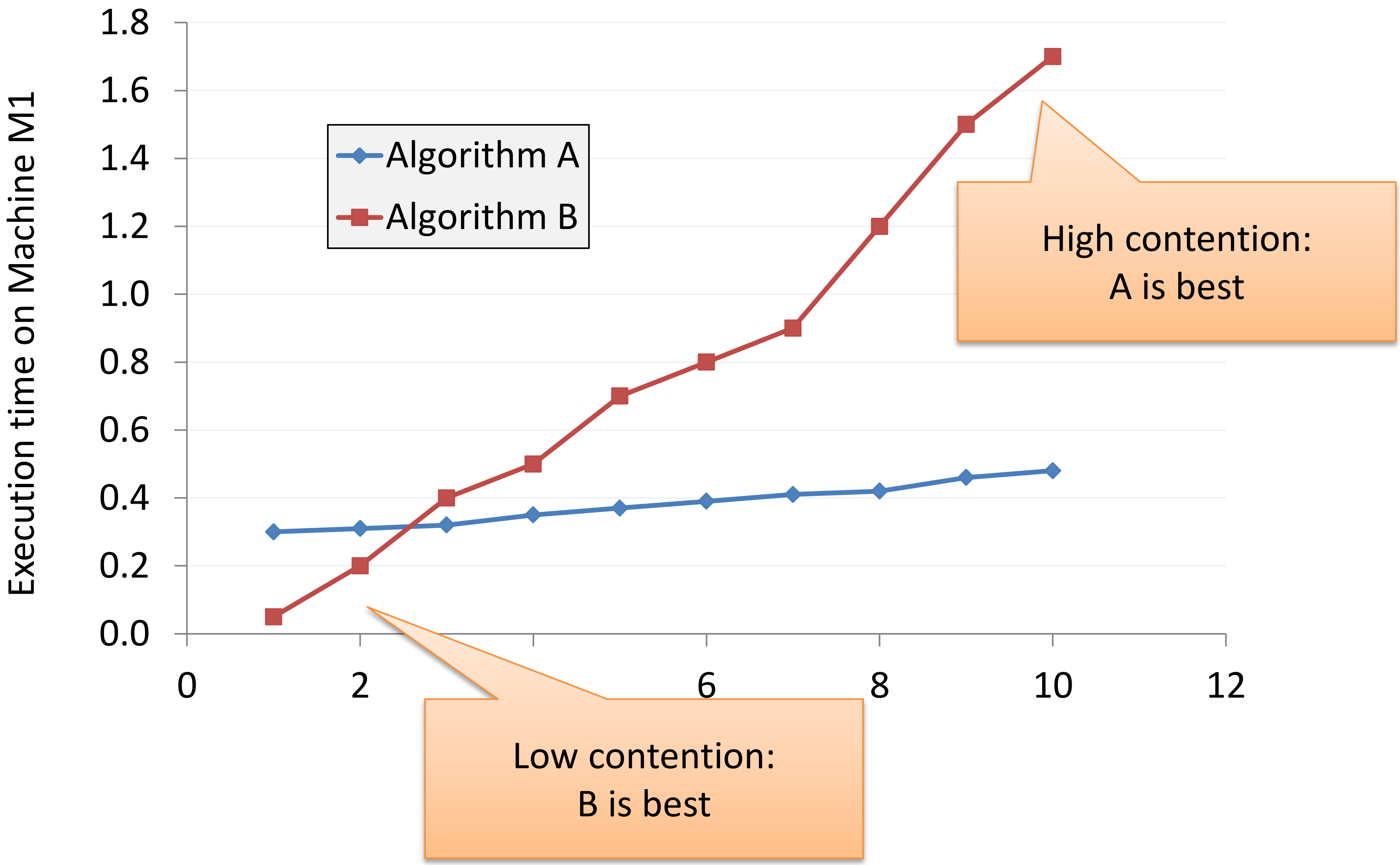
Wall-clock time?

Memory accesses?

Instruction count?

Cache lines read/written?

An aside: is this a better algorithm?



An aside: is this a better algorithm?