Multicore Locks: The Case is not Closed Yet

Hugo Guiroux, Renaud Lachaize, Vivien Quéma

June 24, 2016

Université Grenoble Alpes
Grenoble INP

Synchronization on Modern Multicore Machines

Synchronization

- Most multi-threaded applications require synchronization.
- As the number of cores increases, the synchronization primitives become a bottleneck.
- The design of efficient multicore locks is still a hot research topic: (e.g., [ASPLOS'10], [ATC'12], [OLS'12], [PPoPPP'12], [SOSP'13], [OOPSLA'14], [PPoPP'15], [PPoPP'16]).

Pthread Mutex Lock

Lock-based synchronization:

```
pthread_mutex_lock(&mutex);
// Critical section:
// at most 1 thread here at
// a time
...
pthread_mutex_unlock(&mutex);
```

Pthread Mutex Lock

Lock-based synchronization:

```
pthread_mutex_lock(&mutex);
// Critical section:
// at most 1 thread here at
// a time
...
pthread_mutex_unlock(&mutex);
```

Plethora of locking algorithms.

Goals:

- **Performance**
    - Throughput: at high contention
    - Latency: at low contention
- Fairness
- Energy efficiency

Problem Statement I

- Applications suffer from lock contention
- Plethora of locks algorithms
- Developers are puzzled:
  - Does it really matters for my application/my setup?
  - How to choose?
  - Will the chosen lock perform reasonably well on most setups?
  - Should we simply discard old/simple locks?

Problem Statement II

- Previous studies:
    - Are mostly based on microbenchmarks ...
    - ...or on workloads for which a new lock was specifically designed
    - Do not consider state-of-the-art algorithms that are known to perform well (e.g., recent hierarchical locks) or important parameters (e.g., the choice of waiting policy)

Contributions

1. Extended study:

Contributions

1. Extended study:

27 locks

Contributions

1. Extended study:

27 locks

39 applications

Contributions

1. Extended study:

27 locks

3 machines

39 applications

Contributions

1. Extended study:

27 locks

39 applications

3 machines

With/without pinning

Contributions

1. Extended study:

27 locks

39 applications

3 machines

With/without pinning

2. Library for transparent replacement of the lock algorithm

Outline

Locks Algorithms

LiTL: Library for Transparent Lock Interposition

Study of lock/application behavior

Conclusion

Flat Algorithms

- e.g., Spinlock, Backoff
- **Principle:**
  - Loop on a single memory address
  - Use atomic instruction
- **Pros:**
  - Very fast under low lock contention
- **Cons:**
  - Collapse under high contention due to cache coherence traffic

Queue-Based Algorithms

- e.g., MCS, CLH
- **Principle**:
  - List of waiting threads
  - Each thread spins on a private variable
- **Pros**:
  - Mitigation of cache invalidations
  - Fairness
- **Cons**:
  - Inefficient lock handover if successor has been descheduled
  - Memory locality issue (lack of NUMA awareness)

Hierarchical Algorithms

- e.g., Cohort locks, AHMCS
- **Principle:**
  - One local lock per NUMA node + one global lock
  - Per-node batching
- **Pros**:
  - Good behavior on NUMA hierarchies under high contention
- **Cons**:
  - Short-time unfairness
  - High costs under low lock contention

Load-control Algorithms

- e.g., MCS-TimePub, Malthusian locks
- **Principle**:
  - Bypass threads in the waiting list
  - Reduce the number of threads trying to acquire the lock
- **Pros**:
  - Better resilience under resource contention
- **Cons**:
  - Fairness

Delegation-Based Algorithms

- e.g., RCL, CC-Synch
- **Principle:**
  - One thread executes the critical section on behalf of the others
  - Not general purpose, designed for highly contended locks
- *Not considered here:*
  - Need to rewrite the code application
  - Does not support thread-local data, nested locking, ...

Waiting Policy

- Another design dimension (for most locks)
- What should a thread do while waiting for a lock?
  - Park: sleep (default Pthread policy)
  - Spin: busy-wait (active)
  - Spin-Then-Park: spin a little, then go to sleep

LiTL: Library for Transparent Lock Interposition

LiTL: Overview

- Motivation
  - Implementing all existing locks into all applications is laborious
  - No existing library to try a lock implementation easily
- LiTL: lock library on top of Pthread Mutex lock API
  - Support unmodified application via library interposition
  - Supports condition variables
  - Supports nested critical sections
  - 27 locks (easy to add new ones)

https://github.com/multicore-locks/litl

LiTL Design Challenges: Lock Context

- Many lock algorithms rely on "contexts"
  - The Pthread Mutex lock API does not consider contexts
- Solution:
  - Each lock instance comes with an array of contexts, with one entry per thread **to support nested critical sections**
  - Pthread Mutex lock $\rightarrow$ custom lock via hash table (CLHT)

LiTL Design Challenges: Supporting Condition Variables

- Approach: reuse Pthread Condition variable
  1. Take an uncontended Pthread lock with the optimized lock
  2. Use the Pthread lock on `cond_wait` (*paper*)

Overhead Evaluation

- Comparison with manual implementation of all locks on 3 lock-intensive applications
- General trends are preserved
- Average performance difference is below 5%

Study of lock/application behavior

Methodology

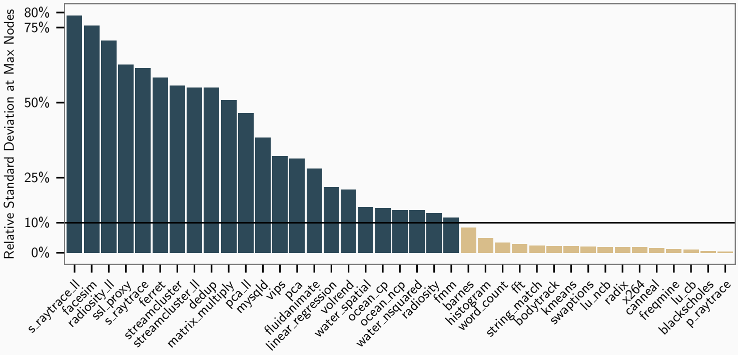
- 5% tolerance margin to take into account deviation
  - Optimal lock: best or at most 5% of performance degradation of the best

Methodology

- 5% tolerance margin to take into account deviation
  - Optimal lock: best or at most 5% of performance degradation of the best
- Linux (3.17.6)
- 3 machines
  - A-64: AMD 64 cores, 8 nodes
  - A-48: AMD 48 cores, 8 nodes
  - I-48: Intel 48 cores, 4 nodes (no hyperthreading)
- *Most results presented here are from the A-64 machine*
- We vary the number of threads used to launch the applications.

Lock-Sensitive Applications

- 60% of the studied applications are lock sensitive



Locks impact application performance

Impact of the Number of Nodes

We consider 2 configurations per application:

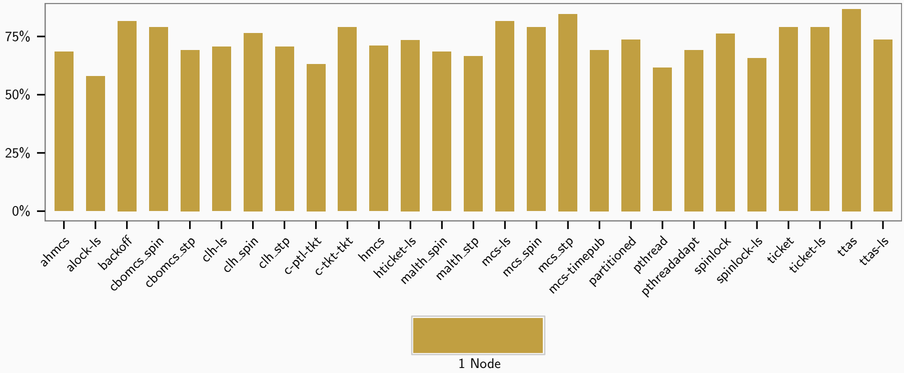
- Maximum number of nodes: use all cores of the machine
- Optimized number of nodes: take the number of nodes for a given lock/application maximizing performance
    - not all locks have the same optimized number of nodes
    - **avoid performance collapse**
    - **take the best of each lock**

Number of nodes impacts lock performance

How Much do Locks Impact Applications?

- At 1 node, **reduced impact**
  - From 2% to 683%:
    - avg. 4%, med. 7%
- At max nodes, **huge impact**
  - From 42% to 3343%:
    - avg. 727%, med. 91%
- At opt nodes, **significant impact**
  - From 6% to 683%:
    - avg. 105%, med. 17%

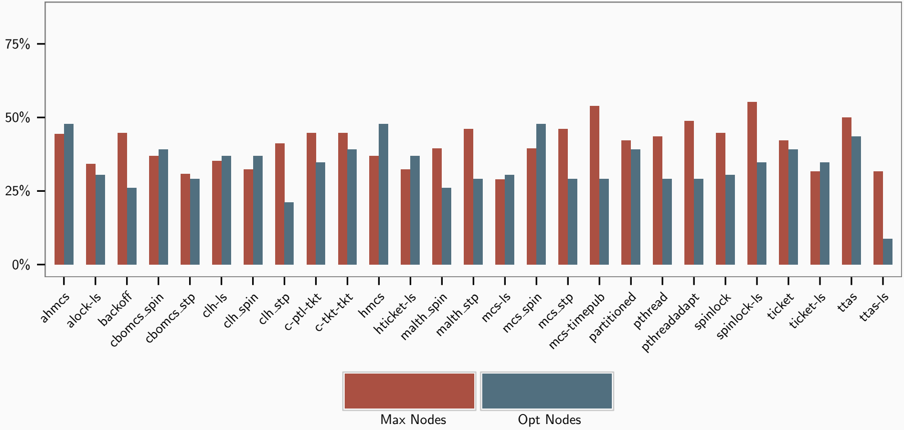
Are Some Locks Always Among the Best? I



Fraction of lock-sensitive applications for which a given lock is optimal

At 1 node, no always-winning lock
80% coverage

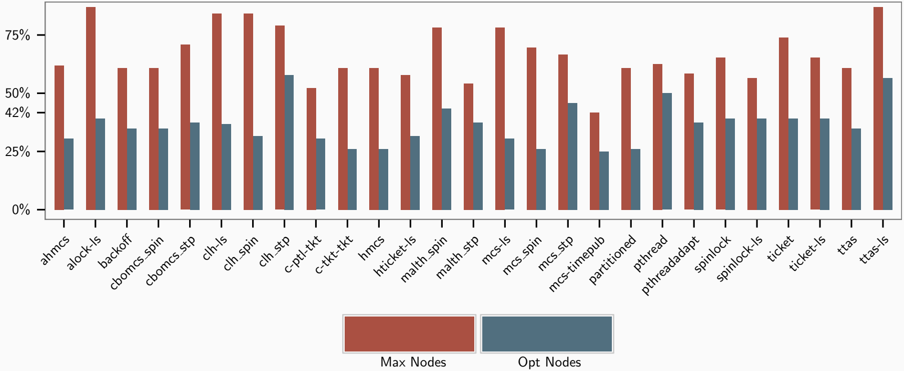
Are Some Locks Always Among the Best? II



Fraction of lock-sensitive applications for which a given lock is optimal

At max and opt nodes, even worse
52% coverage

Are All Locks Potentially Harmful?



Fraction of lock-sensitive applications for which a given lock degrades the performance w.r.t. the best lock (by at least 15%)

Always several applications for which a given lock hurts performance

Is There a Stable Hierarchy Between Locks?

The lock hierarchy **for an application** strongly changes with:

- **The number of nodes**:
  - On average, only 27% of the pairwise comparisons are conserved
- **The machine**:
  - On average, only 30% of the pairwise comparisons are conserved

Additional Remarks

- Using thread pinning **does not change the general observations**
- Pthread Mutex locks **perform relatively well** (i.e., are among the best locks) for a significant share of the studied applications

Conclusion

Summary of Observations

- 60% of the studied applications are lock sensitive
- Lock behavior is strongly impacted by the number of nodes
- Locks impact applications both at max and opt nodes
- No lock is always among the best
- There is no stable hierarchy between locks
    - The number of threads impacts the lock hierarchy
    - The machine impacts the lock hierarchy
- All locks are potentially harmful
- Using thread pinning leads to the same conclusions
- Pthreads locks perform reasonably well

Conclusion

- Lock algorithms should not be hardwired into the code of applications.
- The observed trends call for further research on
  - new lock algorithms
  - runtime support for
    - parallel performance
    - contention management

Extended version of the paper + Data Sets + Source Code
https://github.com/multicore-locks/litl/

Conclusion

- Lock algorithms should not be hardwired into the code of applications.
- The observed trends call for further research on
  - new lock algorithms
  - runtime support for
    - parallel performance
    - contention management

Extended version of the paper + Data Sets + Source Code
https://github.com/multicore-locks/litl/

Thank you for your attention.