High-Performance Distributed RMA Locks

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NEED FOR EFFICIENT LARGE-SCALE SYNCHRONIZATION
Locks

Inuitive semantics

Various performance penalties

An example structure

Proc p

lock

accesses

unlock

Proc q

lock

accesses

...
LOCKS: CHALLENGES
We need intra- and inter-node topology-awareness

We need to cover arbitrary topologies
LOCKS: CHALLENGES

We need to distinguish between readers and writers

We need flexible performance for both types of processes

What will we use in the design?
WHAT WE WILL USE
MCS Locks

Mellor-Crummey and Scott: Algorithms for Scalable Synchronization on Shared-Memory Multiprocessors, ACM TOCS’91
WHAT WE WILL USE
Reader-Writer Locks
How to manage the design complexity?

How to ensure tunable performance?

What mechanism to use for efficient implementation?
REMOTE MEMORY ACCESS (RMA) PROGRAMMING

Process p
Memory
A
B

Process q
Memory
A
B

A put
get B
flush

Cray BlueWaters

REMOTE MEMORY ACCESS PROGRAMMING

- Implemented in hardware in NICs in the majority of HPC networks (RDMA support).
How to manage the design complexity?

How to ensure tunable performance?

What mechanism to use for efficient implementation?
How to manage the design complexity?

- Each element has its own distributed MCS queue (DQ) of writers
- Readers and writers synchronize with a distributed counter (DC)
- Modular design
- MCS queues form a distributed tree (DT)

P. Schmid, M. Besta, TH: High-Performance Distributed RMA Locks, ACM HPDC’16, best paper
How to ensure tunable performance?

Each DQ: fairness vs throughput of writers

DC: a parameter for the latency of readers vs writers

DT: a parameter for the throughput of readers vs writers

A tradeoff parameter for every structure

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DISTRIBUTED MCS QUEUES (DQs)

Throughput vs Fairness

Each DQ: The maximum number of lock passings within a DQ at level \(i\), before it is passed to another DQ at \(i\).

Larger \( T_{L,i} \): more throughput at level \(i\).
Smaller \( T_{L,i} \): more fairness at level \(i\).

\[ T_{L,1}, T_{L,2}, T_{L,3} \]

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DISTRIBUTED TREE OF QUEUES (DT)
Throughput of readers vs writers

$T_{L,3}$

DT: The maximum number of consecutive lock passings within readers ($T_R$).
**DISTRIBUTED COUNTER (DC)**

Latency of readers vs writers

DC: every $k$th compute node hosts a partial counter, all of which constitute the DC.

$$k = T_{DC}$$

A writer holds the lock

Readers that arrived at the CS

Readers that left the CS

$T_{DC} = 1$

$T_{DC} = 2$

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THE SPACE OF DESIGNS

Higher throughput of writers vs readers

Locality vs fairness (for writers)

Lower latency of writers vs readers

Design A

Design B

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**LOCK ACQUIRE BY READERS**

A lightweight acquire protocol for readers: only one atomic fetch-and-add (FAA) operation.

A writer holds the lock.

Readers that arrived at the CS.

Readers that left the CS.

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**Lock Acquire by Writers**

Acquire the main lock

Acquire the main MCS lock

Acquire the main MCS

Acquire the main MCS

Acquire the main MCS

Acquire the main MCS

Acquire the main MCS

Acquire the main MCS

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EVALUATION

- CSCS Piz Daint (Cray XC30)
- 5272 compute nodes
- 8 cores per node
- 169TB memory
- Microbenchmarks: acquire/release: latency, throughput
- Distributed hashtable
EVALUATION
DISTRIBUTED COUNTER ANALYSIS

Throughput, 2% writers
Single-operation benchmark

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EVALUATION
READER THRESHOLD ANALYSIS

Throughput, 0.2% writers,
Empty-critical-section benchmark

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EVALUATION
COMPARISON TO THE STATE-OF-THE-ART

EVALUATION

COMPARISON TO THE STATE-OF-THE-ART

Throughput, single-operation benchmark

Percentages are values of $F_w$

EVALUATION
DISTRIBUTED HASHTABLE

20% writers

10% writers

EVALUATION
DISTRIBUTED HASHTABLE

2% of writers

0% of writers

Another application area - Databases

- MPI-RMA for distributed databases?

C. Barthels, et al., TH: Distributed Join Algorithms on Thousands of Cores presented in Munich, Germany, VLDB Endowment, Aug. 2017
Another application area - Databases

- MPI-RMA for distributed databases on Piz Daint

![Graph showing throughput vs. number of cores]

- Network dominating
- Compute dominating

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Another application area - Databases

- MPI-RMA for distributed databases on Piz Daint

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OTHER ANALYSES
CONCLUSIONS

Modular distributed RMA lock, correctness with SPIN
Parameter-based design, feasible with various RMA libs/languages

Improves latency and throughput over state-of-the-art

Thank you for your attention

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