Shuffling: A Lock Contention Aware Thread Scheduling Technique

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Multicores are Ubiquitous

- Deliver computing power via parallelism
- Potential for delivering high performance for multithreaded applications

Oracle SPARC M7-8

Mobile phones

Complexity of Achieving High Performance

Application Characteristics

- Degree of Parallelism
- Lock Contention
- Memory Requirements

Operating System Policies

- Thread Scheduling
- Memory Management

Architecture

- Cache Hierarchy
- Cross-chip Interconnect Protocols

Modern Operating Systems

Improve System Utilization and Provide Fairness

- Thread Scheduling: Time Share → Fairness
- Memory Allocation: Next → Data Locality

Do not consider relationships between threads of a multithreaded application

Application characteristics should be considered

OS Load Balancing vs Lock Contention

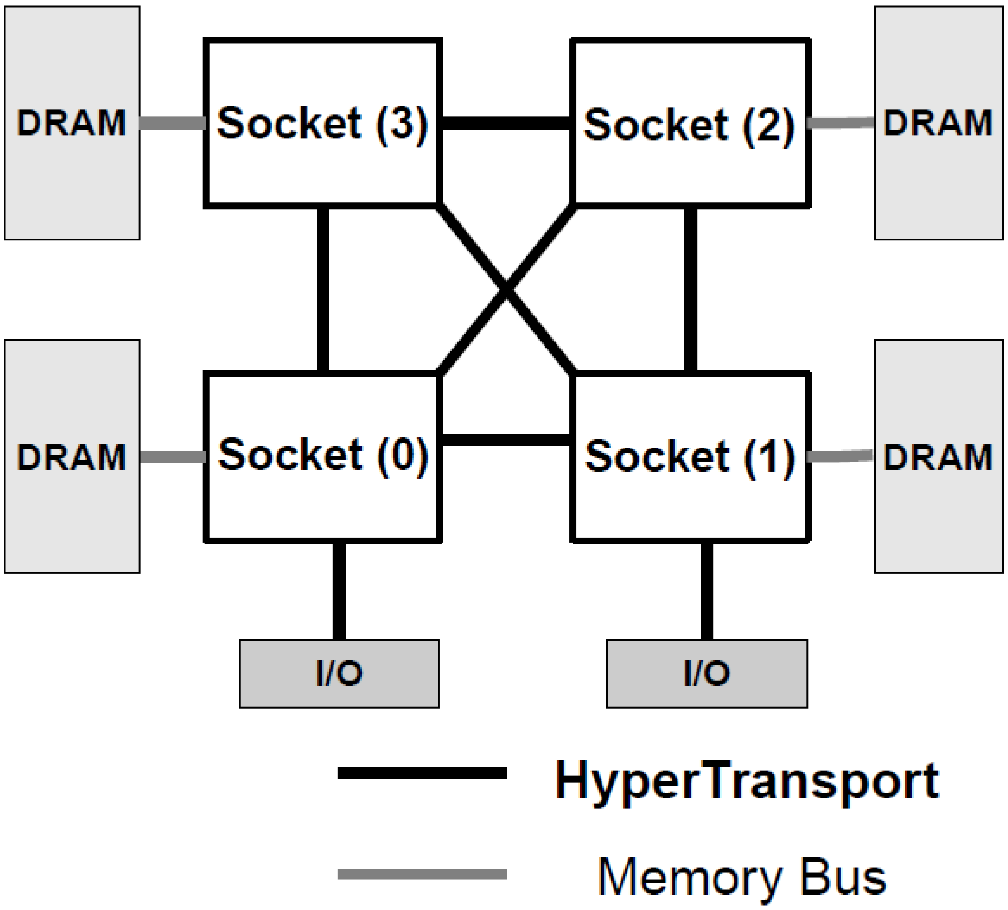
- OS load balancing is oblivious of lock contention
- Performance of multithreaded program with high lock contention is sensitive to the distribution of threads across sockets
- Inappropriate distribution of threads → increases frequency of lock transfers
- Increases lock acquisition latencies
- Increases LLC misses in the critical path

Outline

- Introduction
- Motivation
- Shuffling Framework
- Experimental Results

Lock Contention Study

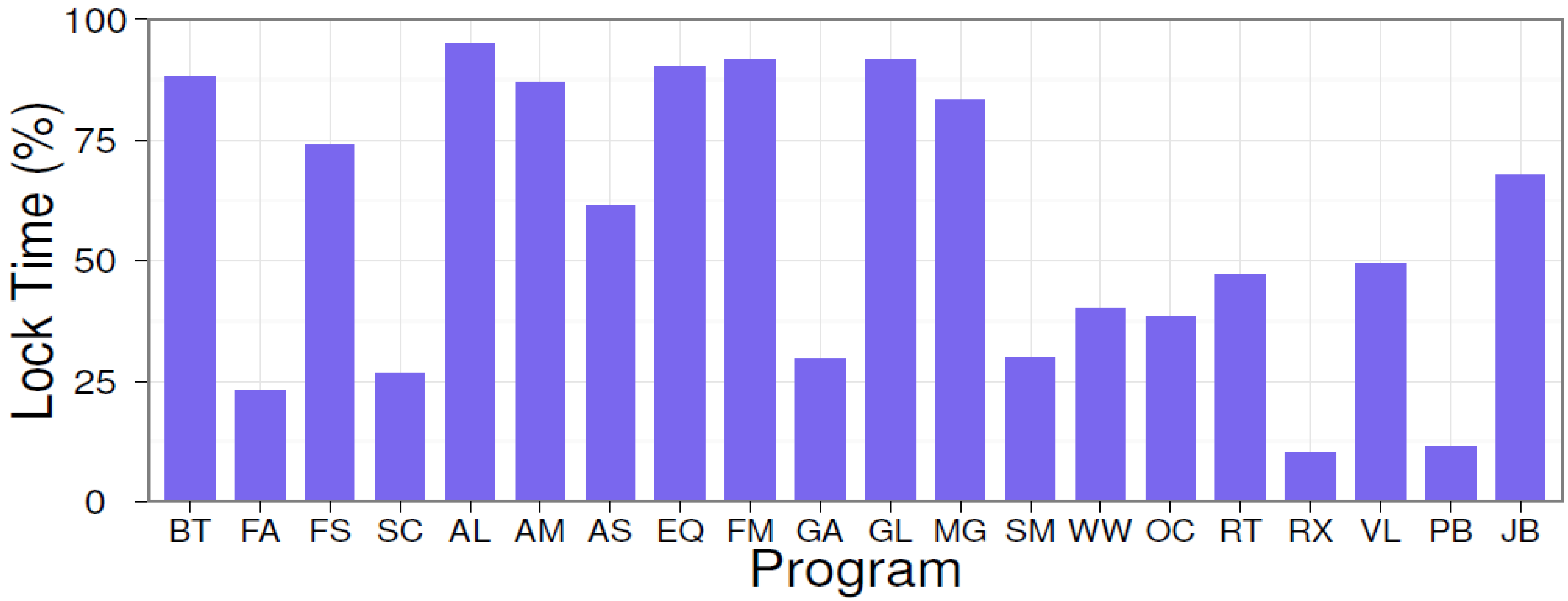
Lock contention is an important performance limiting factor



23 programs (pthreads)
- SPEC JBB2005
- PARSEC
- SPEC OMP2001
- SPLASH 2x

Run with 64 threads
64-core machine
Four 16-core Sockets (AMD Opteron)

Lock Contention on Performance



Lock time: the percentage of elapsed time a process spends on waiting for lock operations in user space

Lock Transfers

Acquire Lock
Execute Critical Section
Release Lock

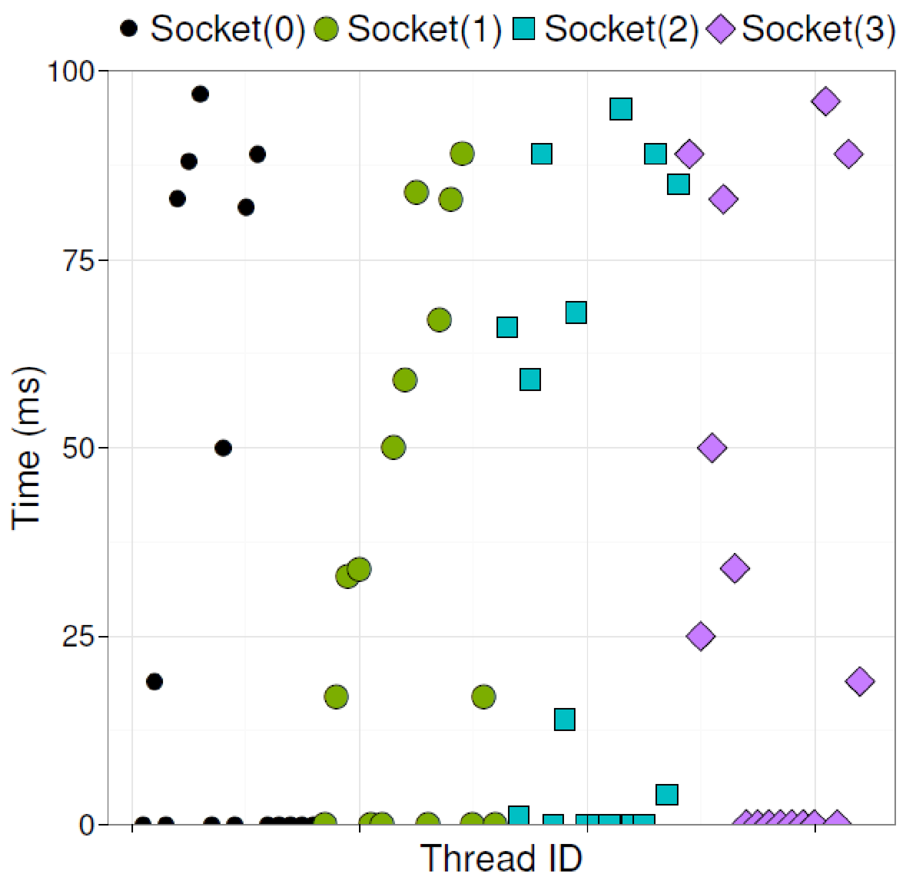
Overhead of Lock Transfer:

- **T_low** → Lock transfers between threads located on the same Socket
- **T_high** → Lock transfers between threads located on different Sockets

e.g.: bodytrack (BT) with 64 threads

Lock Transfer	Solaris
T_low	31%
T_high	69%

High Frequency of LLC misses & Its Cause



BT with 64 threads

- Lock arrival times spread across a wide interval
- The likelihood of lock acquired by a thread on a different socket is very high

Lock arrival times of threads per socket at the entry of a lock within a 100 ms time interval

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Thread Shuffling [PACT 2014]

Minimize variation in lock arrival times of threads

Schedule threads whose lock arrival times are clustered in a small time interval

Once a thread releases the lock it is highly likely that another thread on the same Socket will successfully acquire the lock

Thread Shuffling (algorithm)

Input: N → Number of Threads; S → Number of Sockets

repeat

1. Monitor Threads – sample lock times of N threads

if *lock times exceed threshold* **then**

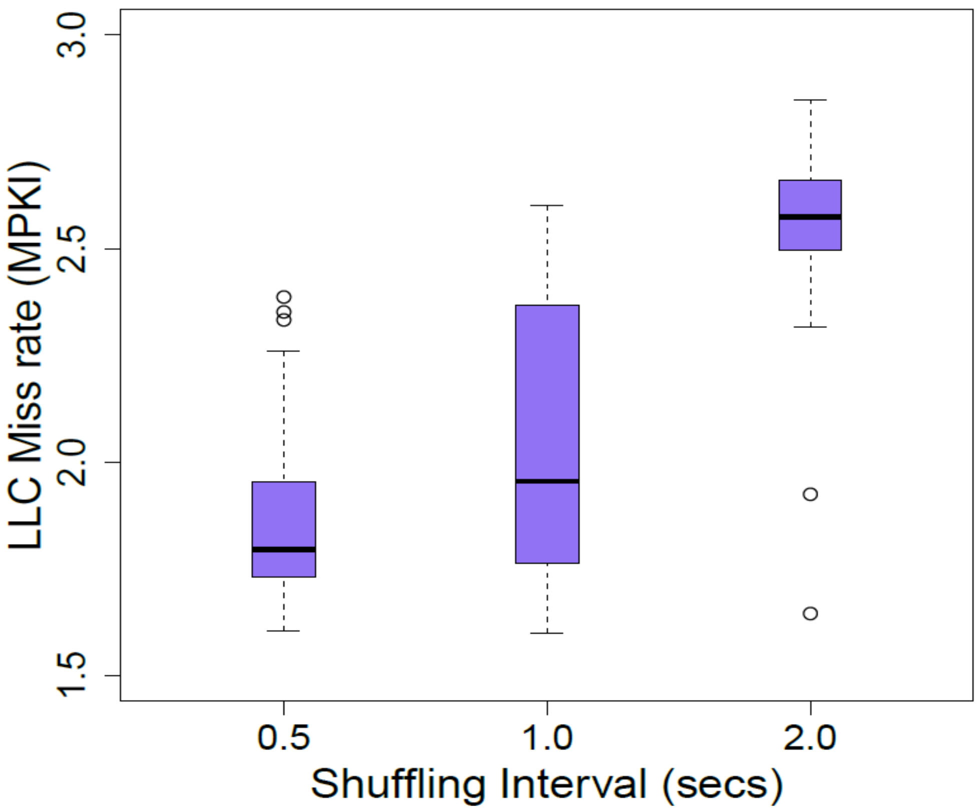
2. Form Thread Groups – sort threads according to lock times and divide them into S groups

3. Perform Shuffling – shuffle threads to establish newly computed groups

until (application terminates)

Shuffling Interval

Impacts Lock transfers between sockets → LLC misses

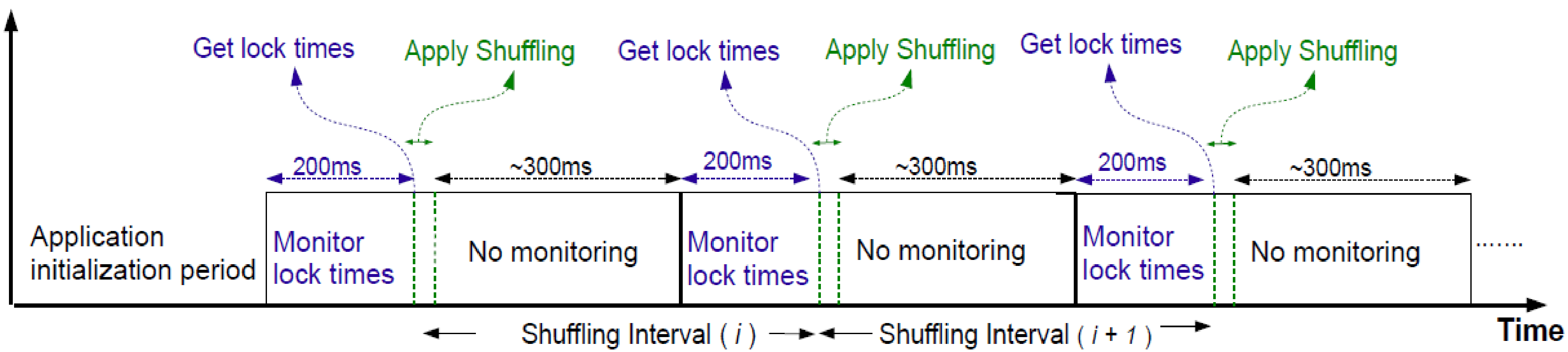


500 ms as a shuffling interval

BT: LLC miss rate vs Shuffling interval

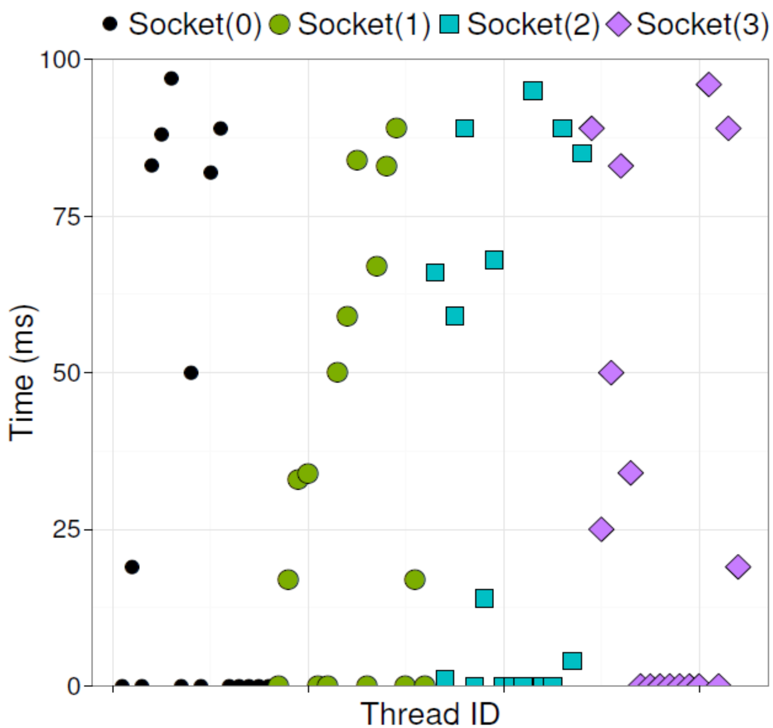
Shuffling Overhead Negligible

Frequency of monitoring and shuffling

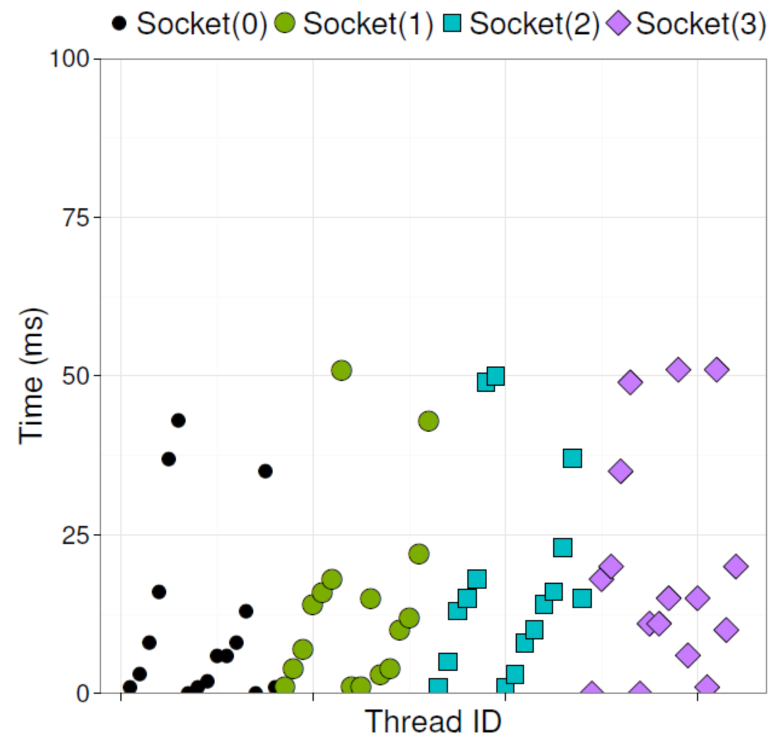


Overhead is negligible (< 1% of system time)

Lock Transfers: Solaris vs Shuffling



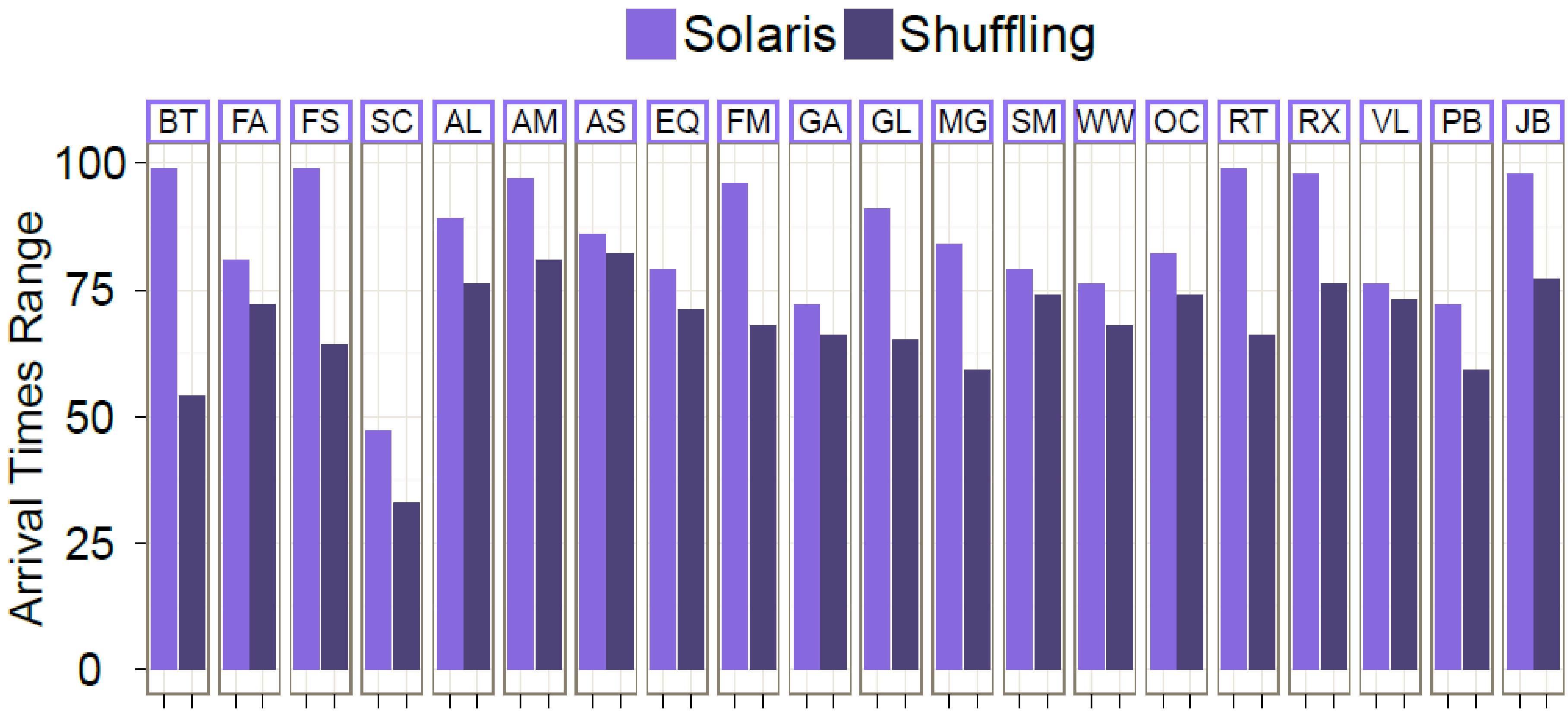
BT



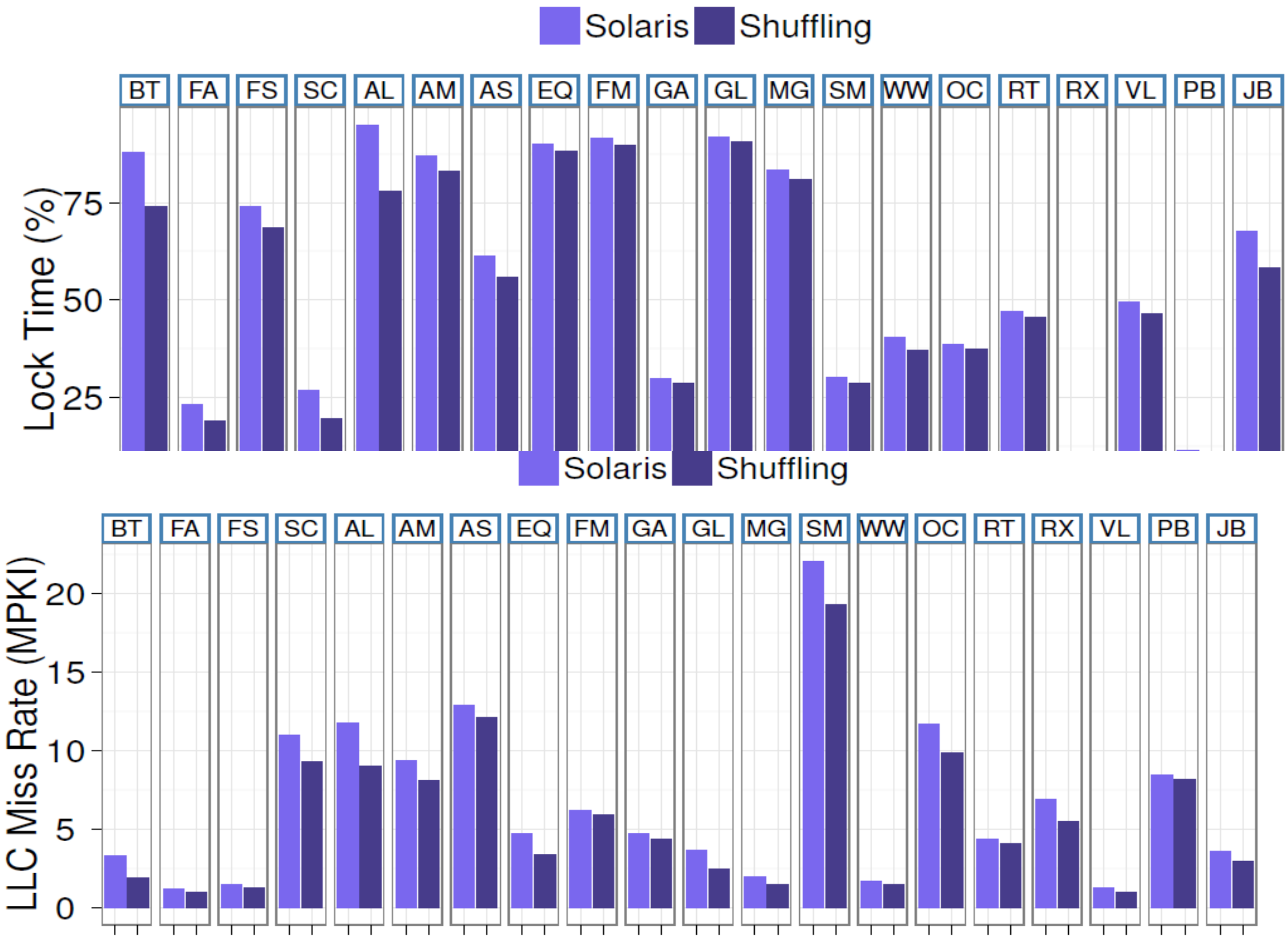
Lock Transfer	Shuffling	Solaris
T_low	46%	31%
T_high	54%	69%

	Shuffling	Solaris
LLC miss rate	1.9	3.3
Lock time	72%	86%

Thread Lock Arrival-time Ranges



Lock contention & LLC miss rate



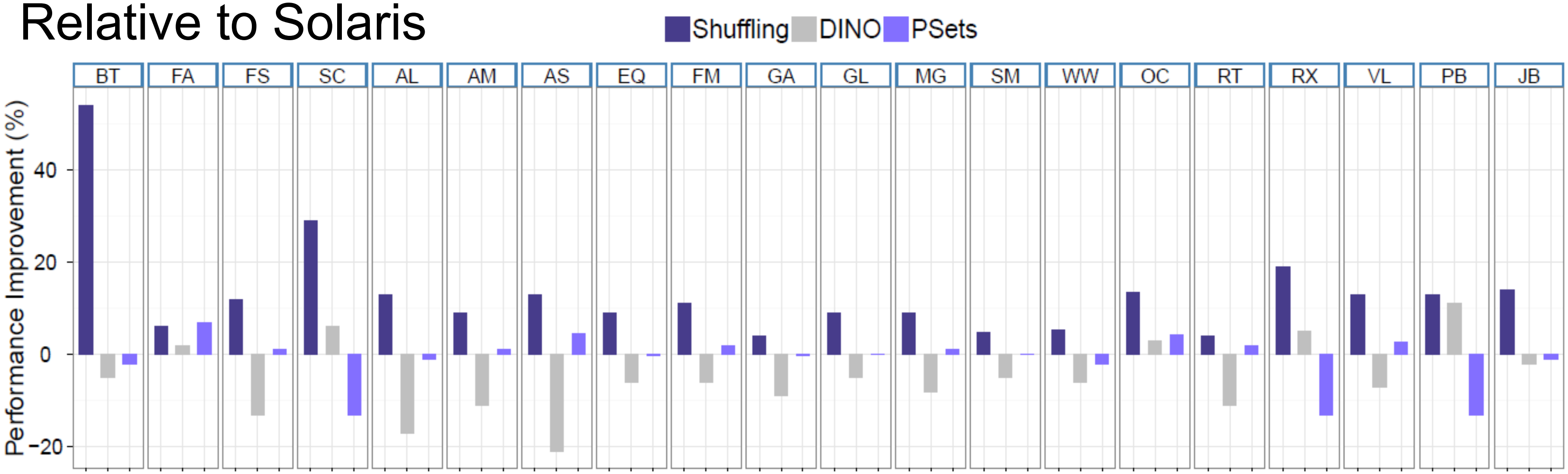
Reduces Lock contention & LLC misses

Evaluating Thread Shuffling (cont.)

Up to 54%
Avg. 13%

Memcached: 17%
TATP: 28%

Relative to Solaris



DINO: only considers LLC misses

PSets: binding a pool of threads to a pool of cores

Conclusions

Problem:

OS thread scheduling is oblivious to lock contention and fails to maximize performance of multithreaded applications on multicore multiprocessor systems

Idea:

Minimize variation in lock arrival times of threads

Advantages:

- Improves performance on average 13% (max of 54%)
- No need to modify application source code