# Optimizing a Parallel Runtime System for Multicore Clusters: A Case Study

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# Motivation

- **Almost all clusters consist of multicore nodes**
  - Node size continues to grow
- **The whole software stack needs to be adapted to the multicore architecture**
  - Application-level
  - Parallel languages (including its runtime system)
  - System-level
- **Potential benefits**
  - Latency is much reduced for intra-node messages
  - Shared-memory data structure

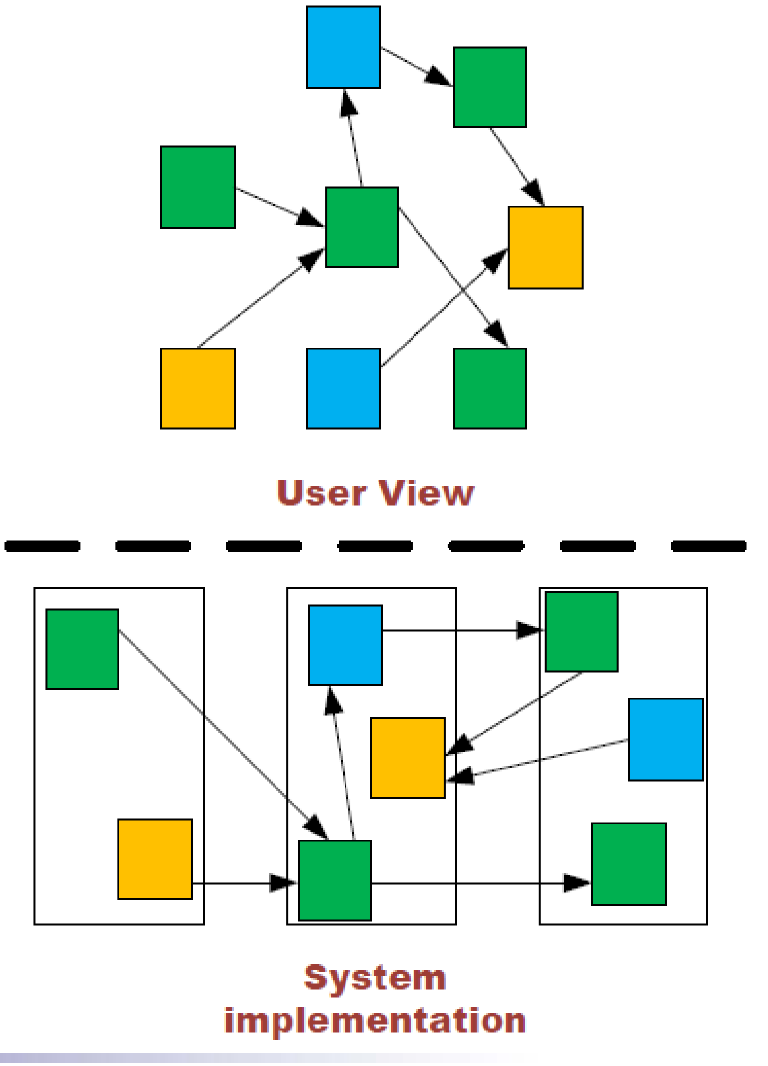
Initial porting of a runtime system doesn't necessarily lead to benefits!

# Outline

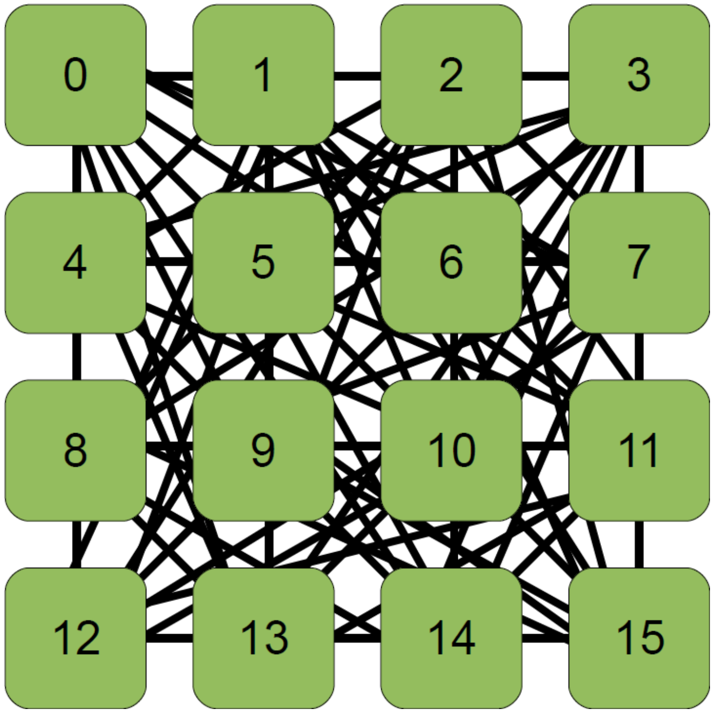
- Introduction to the runtime system
  - Charm++
- Experiment Setup
  - Benchmark
  - 5 multicore machines
- Issues and Optimization Techniques
  - Synchronization overhead
  - Affinity settings
  - …
- Performance for real applications

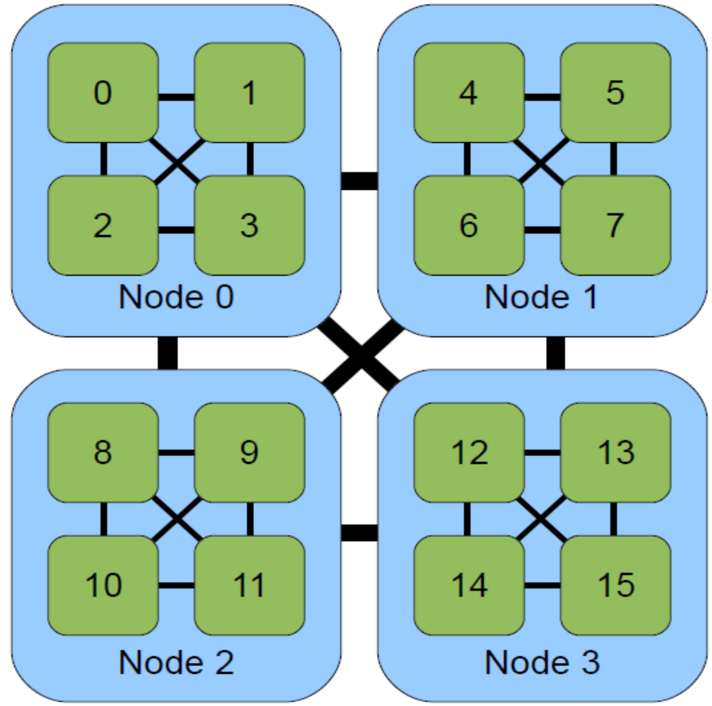
# The Runtime System Case: Charm++

- **Objected oriented C++ based**
- **Message driven execution**
  - Asynchronous non-blocking remote method invocation



# Architectures of Runtime System




- **non-SMP, process**
  - Network stack
  - POSIX shared memory
- **SMP, process + system thread**
  - Shared memory address space

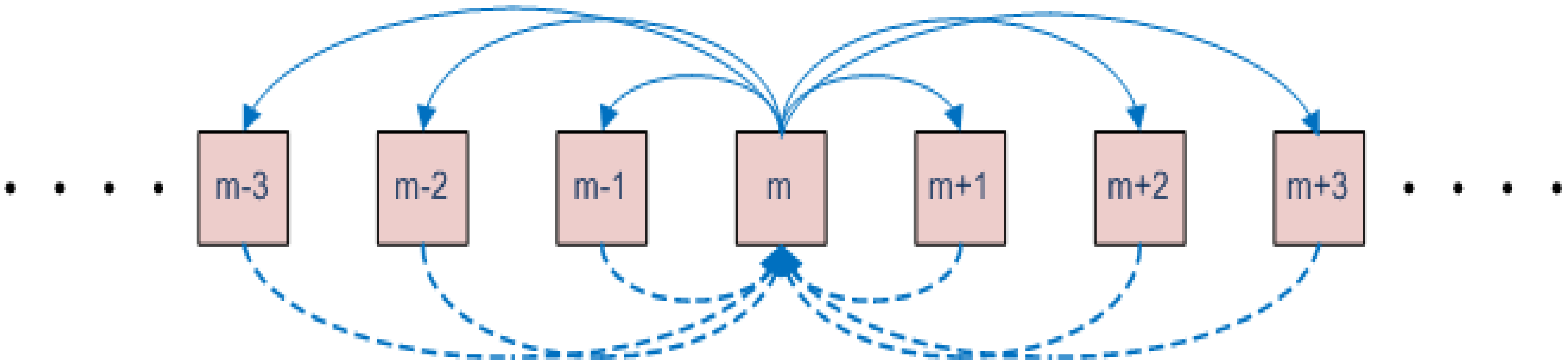
# Initial Experiments Result

- **Applications do not have any performance improvement**
  - NAMD: ~10% degradation ☹
  - ChaNGa: ~2% degradation

- **Attack the problem in two steps**
  - Issues on a single node
  - Issues on multiple nodes

# Experiment Setup: Benchmark

- **kNeighbor (k=3 in our study)**

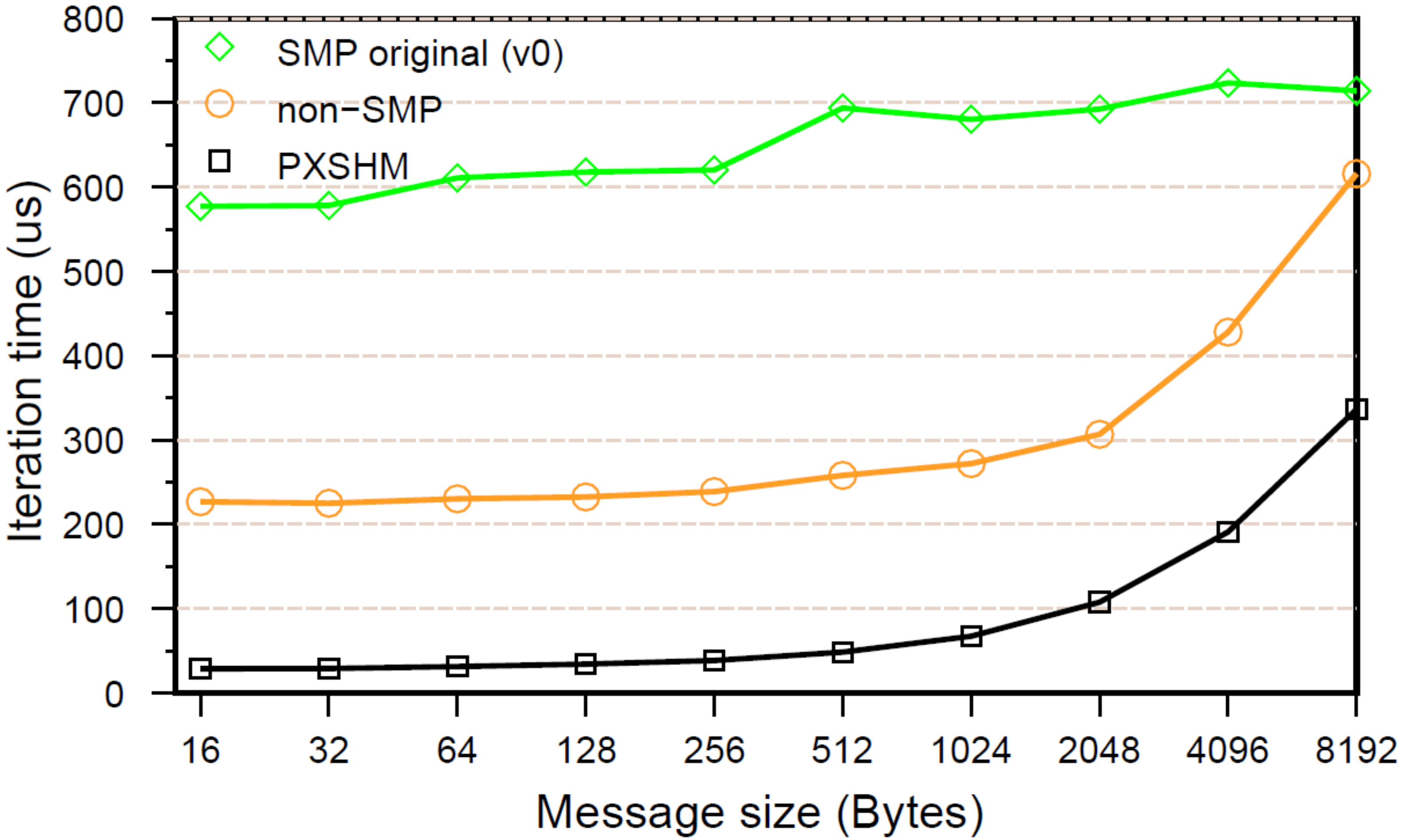



  - Benchmark one iteration time
  - Touch every byte of the message when received
  - Emphasize the performance of message latency in the presence of contention

# Experiment Setup: Multicore Machines

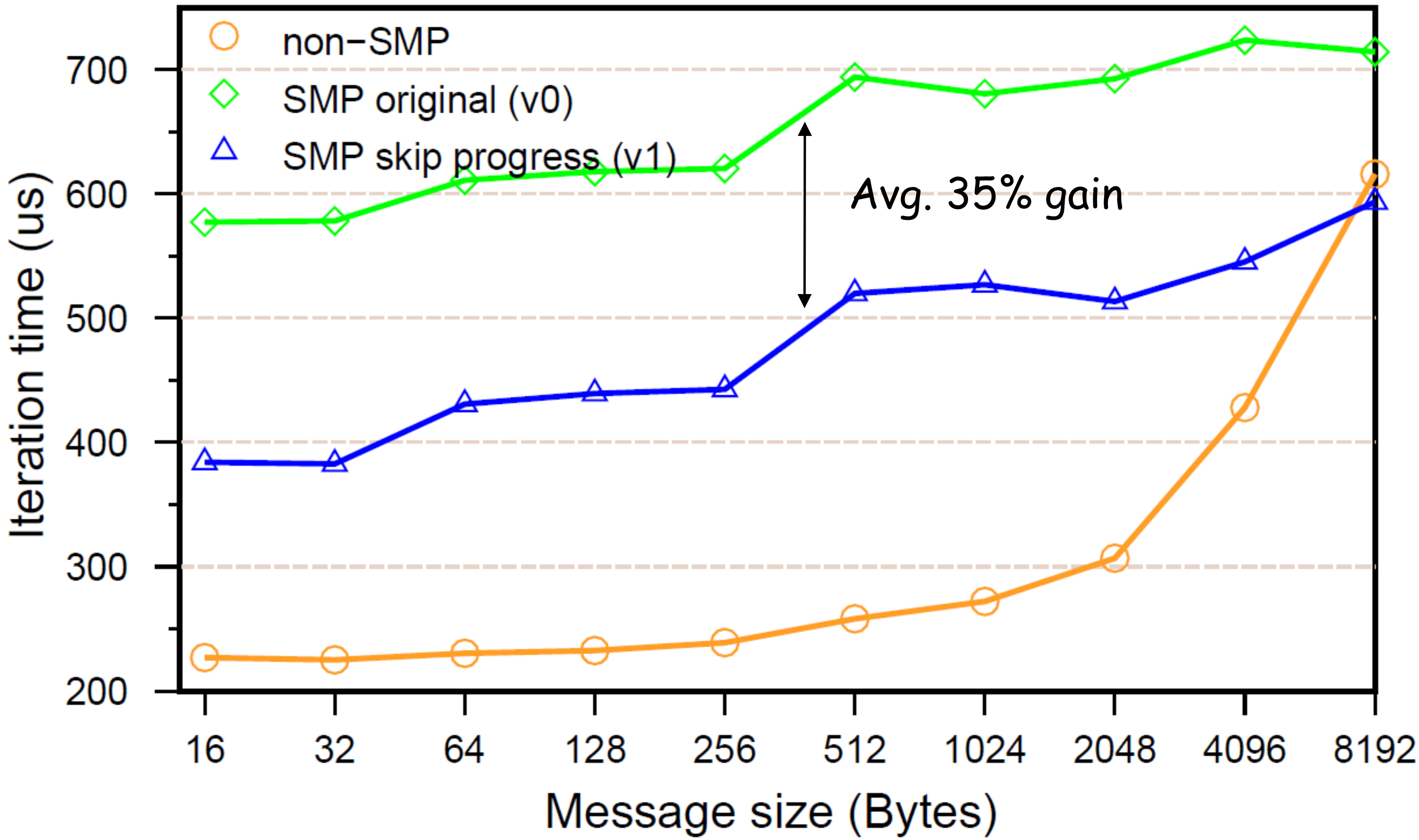
- **Five multicore machines**
  - A: AIX 6.1/IBM Power 5, a 16-core (SMT=2) node
  - B: Ubuntu 8.04/Intel Nehelem Xeon E5520, a 8-core (SMT=2) node
  - C: Ubuntu 8.04/Intel Harpertown Xeon E5405, a 8-core node
  - D: Ubuntun 8.04/AMD Barcelona Opteron 2356, a 8-core node
  - E: CentOS 5.4/Intel Dunnington Xeon E7450, a 24-core node

# Initial Comparison for *k*Neighbor



# Network Progress Engine Issue

- **Network progress engine**
  - Process incoming messages and send outgoing message immediately
  - Expensive
- **Initial Usage**
  - Invoked every time a message is sent
    - contention on the engine
- **Current Usage**
  - Not necessary for intra-node message
  - Only invoke network progress engine if it is an inter-node message



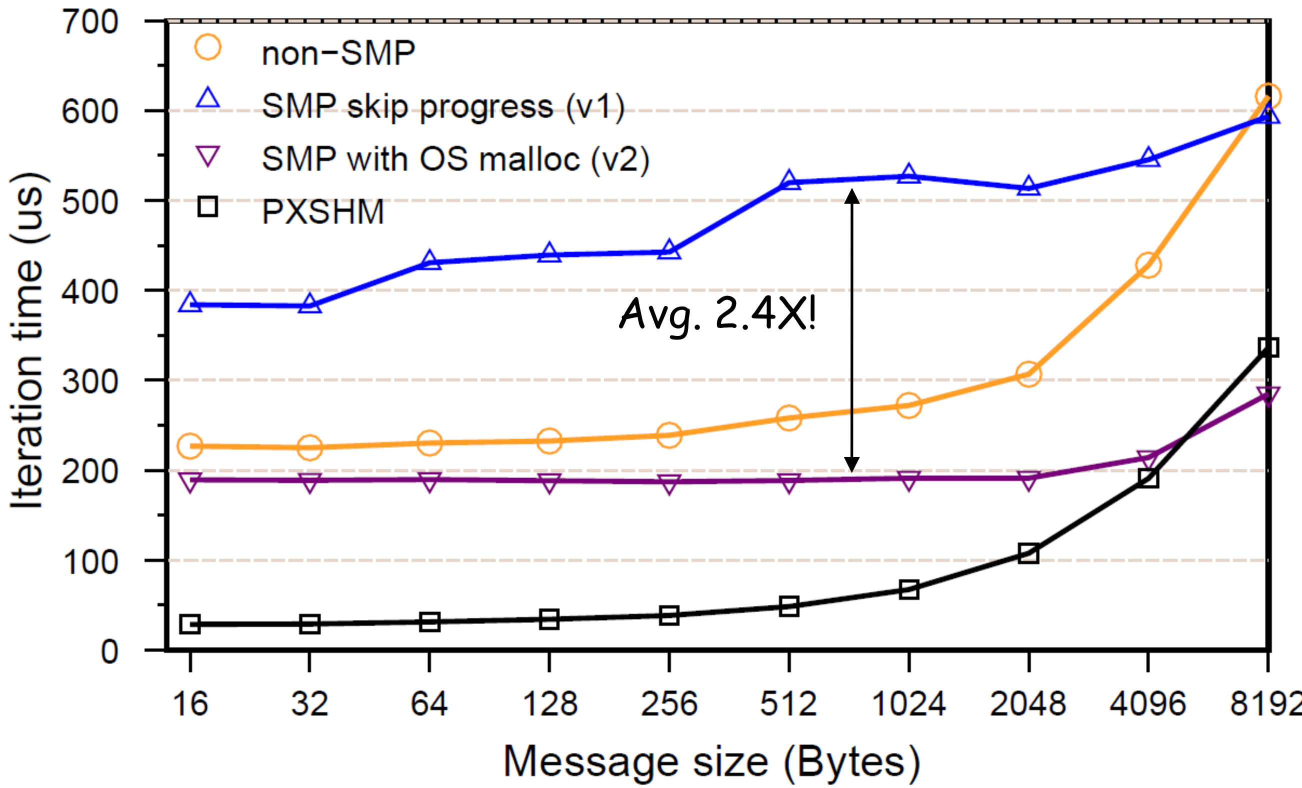

Not simply change processes to threads and make it thread safe, but re-think the overall design of the architecture

# Multi-threaded Performance Issues

- **Efficient locking and synchronization among threads**
  - **key factor for fast fine-grained intra-node communication**
- **Three issues**
  - **Memory management**
  - **Granularity of critical sections**
  - **Message queues**

# Memory Management

- **Charm++ uses its own memory allocator**
  - **Based on a GNU memory allocator developed seven years ago**
  - **Every malloc/free is protected with a lock ☹**
- **Switched to OS provided memory module**



# Performance of OS-provided Memory Module

- **Synthetic benchmark: every thread simultaneously allocates memory of the same size for 100,000 times, then free**

| #thds | A(us) | [redacted] | B(us) | C(us) | D(us) | E(us) |
|---|---|---|---|---|---|---|
| 1 | 1.06 | | 0.78 | 0.80 | 1.13 | 0.68 |
| 2 | 2.23 | | 1.30 | 1.44 | 1.53 | 2.03 |
| 4 | 6.06 | | 3.95 | 2.14 | 2.36 | 2.73 |
| 8 | 15.35 | | 8.71 | 3.69 | 4.72 | 7.06 |
| 16 | 36.89 | | 22.63 | n/a | n/a | 14.58 |
| 24 | n/a | | n/a | n/a | n/a | 21.31 |
| 32 | 210.96 | | n/a | n/a | n/a | n/a |

# Performance of OS-provided Memory Module

- Synthetic benchmark: every thread simultaneously allocates memory of the same size for 100,000 times, then free

| #thds | A(us) | A/M(us) | B(us) | C(us) | D(us) | E(us) |
|---|---|---|---|---|---|---|
| 1 | 1.06 | 1.03 | 0.78 | 0.80 | 1.13 | 0.68 |
| 2 | 2.23 | 1.02 | 1.30 | 1.44 | 1.53 | 2.03 |
| 4 | 6.06 | 1.05 | 3.95 | 2.14 | 2.36 | 2.73 |
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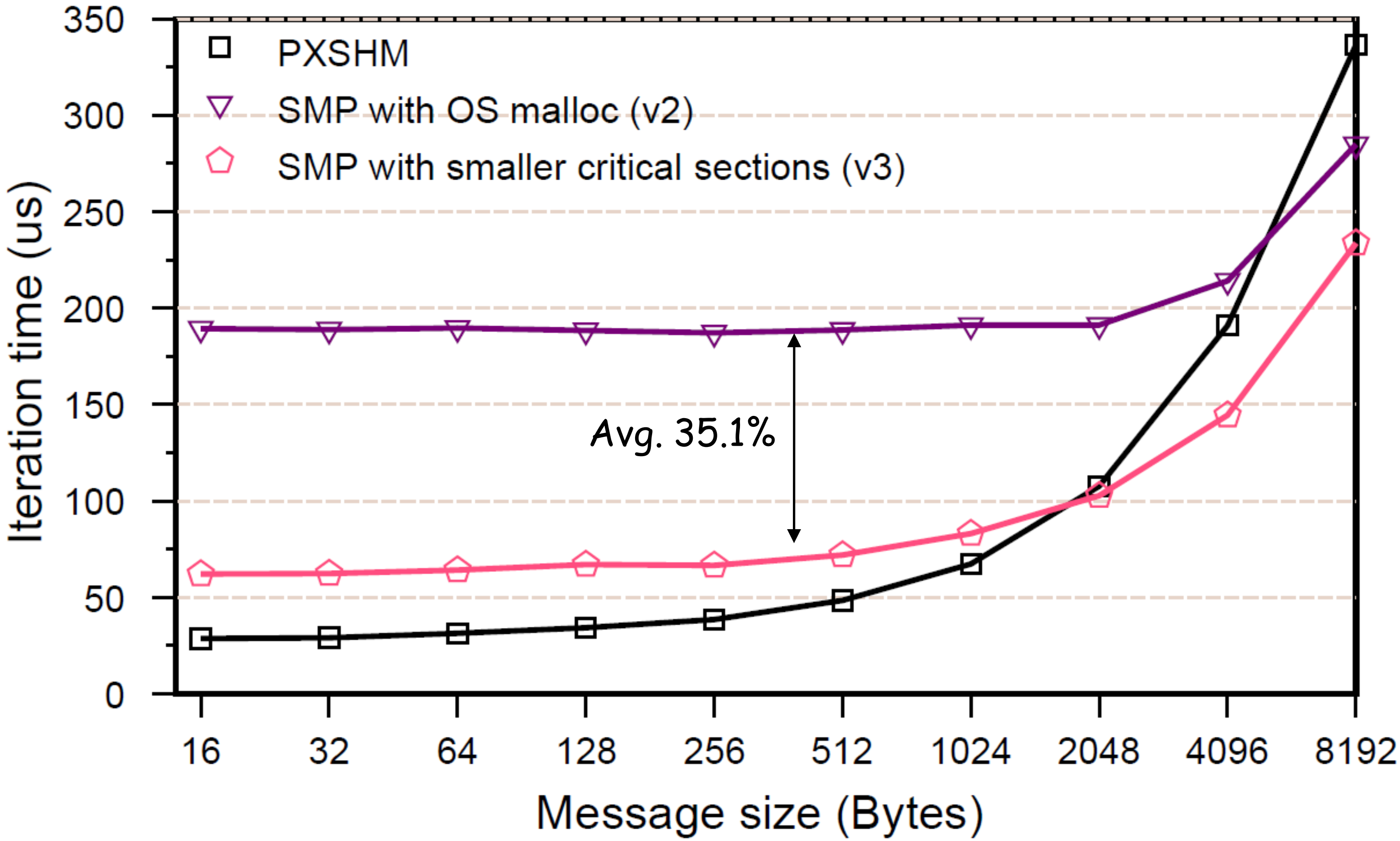
| 24 | n/a | n/a | n/a | n/a | n/a | 21.31 |
| 32 | 210.96 | 1.02 | n/a | n/a | n/a | n/a |

# Granularity of Critical Sections

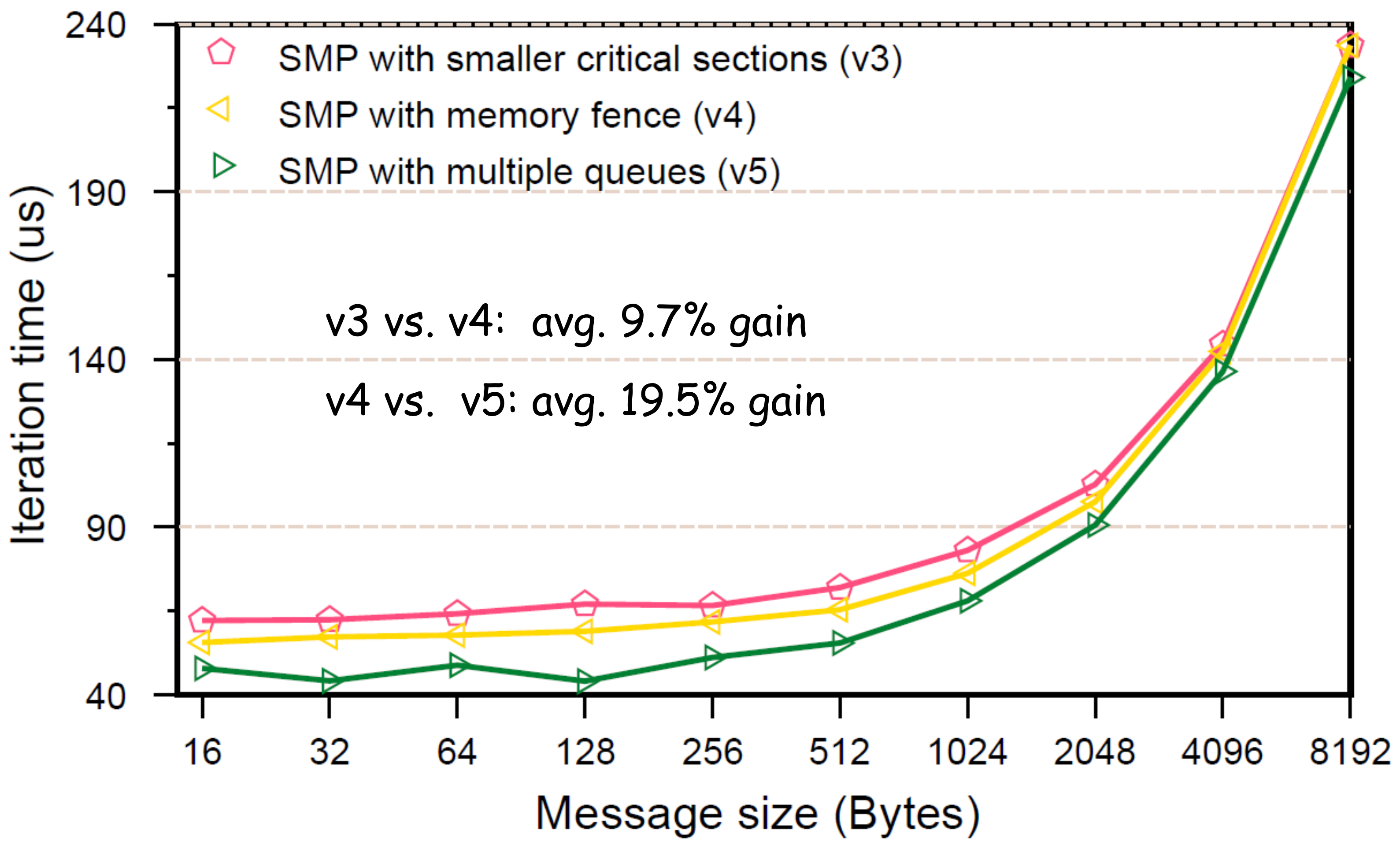
- **Trade-off between productivity and performance**



# Message Queues

- Producer-Consumer Queues (PCQueue)
  - Commonly used data structure for implementing scheduler queues
- Scenario in Charm++
  - Single consumer, multiple producers
- Use memory fence instead of locks
  - A general API across multiple platforms for read/write fence
  - Two steps of optimizations
    - Remove locks for consumer
    - Remove locks for producers by having a queue pair between the single consumer and each producer
      - Polling overhead increased

# Perf. of Optimizing Message Queues

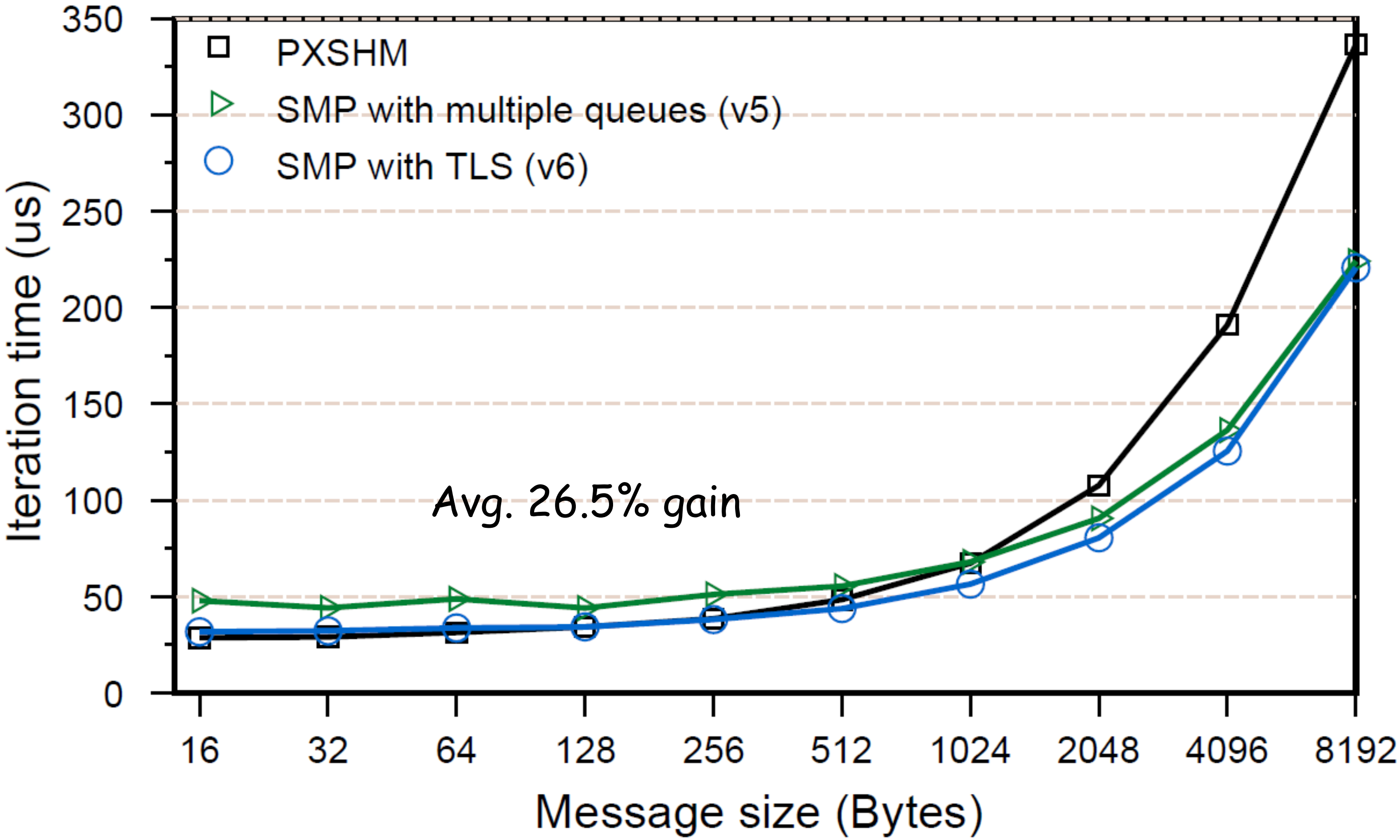


# Handling Processor Private Variables

- **Similar to the thread private variables in OpenMP**
  - "Cpv" macros providing transparent usage in non-SMP/SMP mode, e.g. CpvAccess(var)
- **Initial implementation is array-based:**
  - CpvAccess(var) ➔ var[myrank]
  - false sharing ☹
- **Solution: Thread Local Storage (TLS): explict or implicit**
  - pthread_setspecific/pthread_getspecific on Unix-like
  - TlsSetValue/TlsGetValue on Windows
  - "__thread" if supported by compiler and assembler

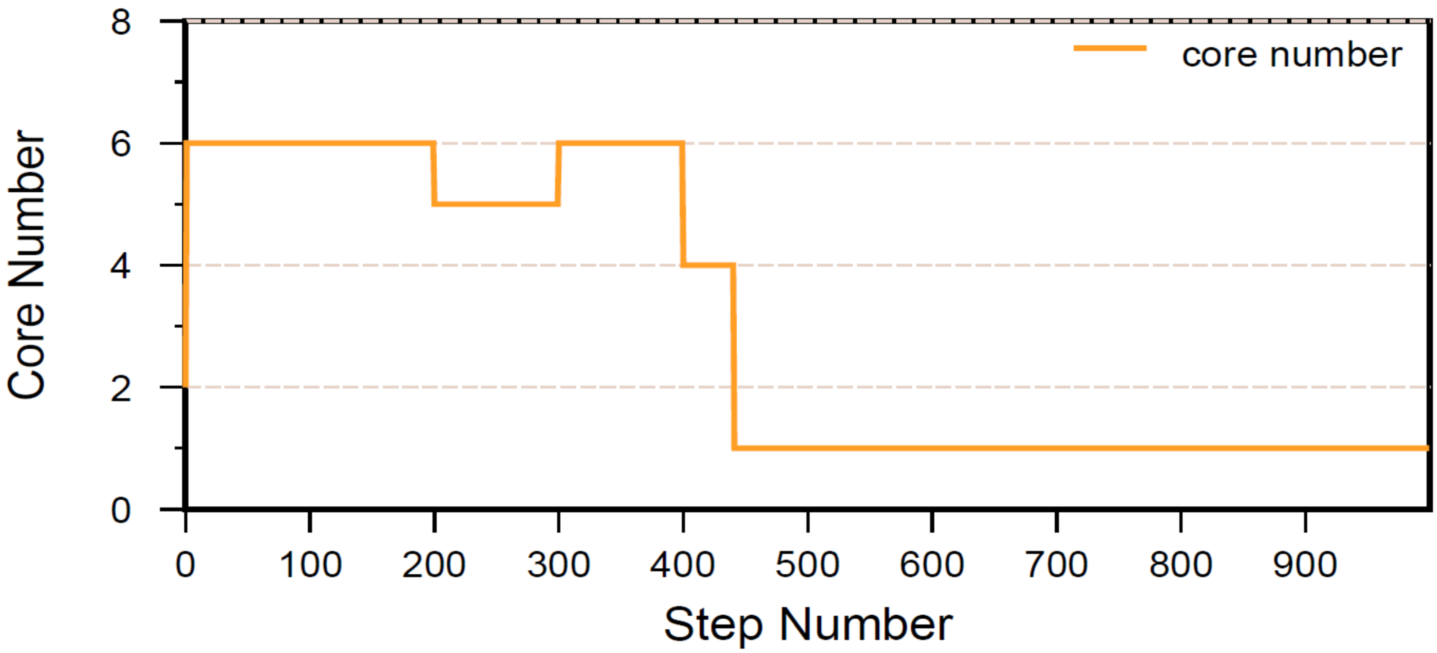
| Platform | A (ns) | B (ns) | C (ns) | D (ns) | E (ns) |
|---|---|---|---|---|---|
| TLS | 0.40 | 1.27 | 1.5 | 1.75 | 1.26 |
| Array-based | 51.58 | 17.52 | 10.03 | 9.61 | 8.50 |

# Perf. Improvement After Using TLS



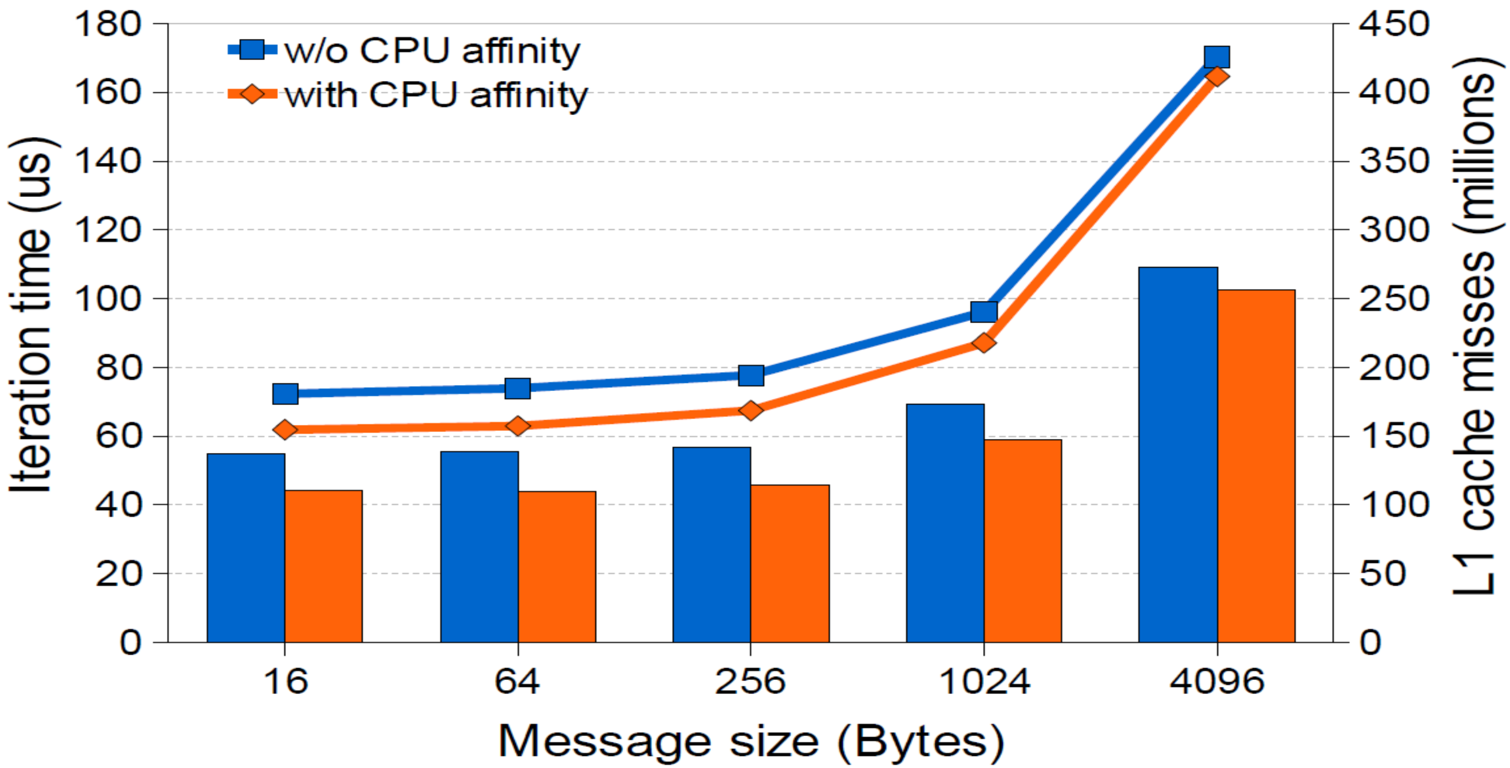
# CPU Affinity (1)

- ***OS adopts natural affinity***
  - ***Keep process/thread on the same CPU as long as possible***



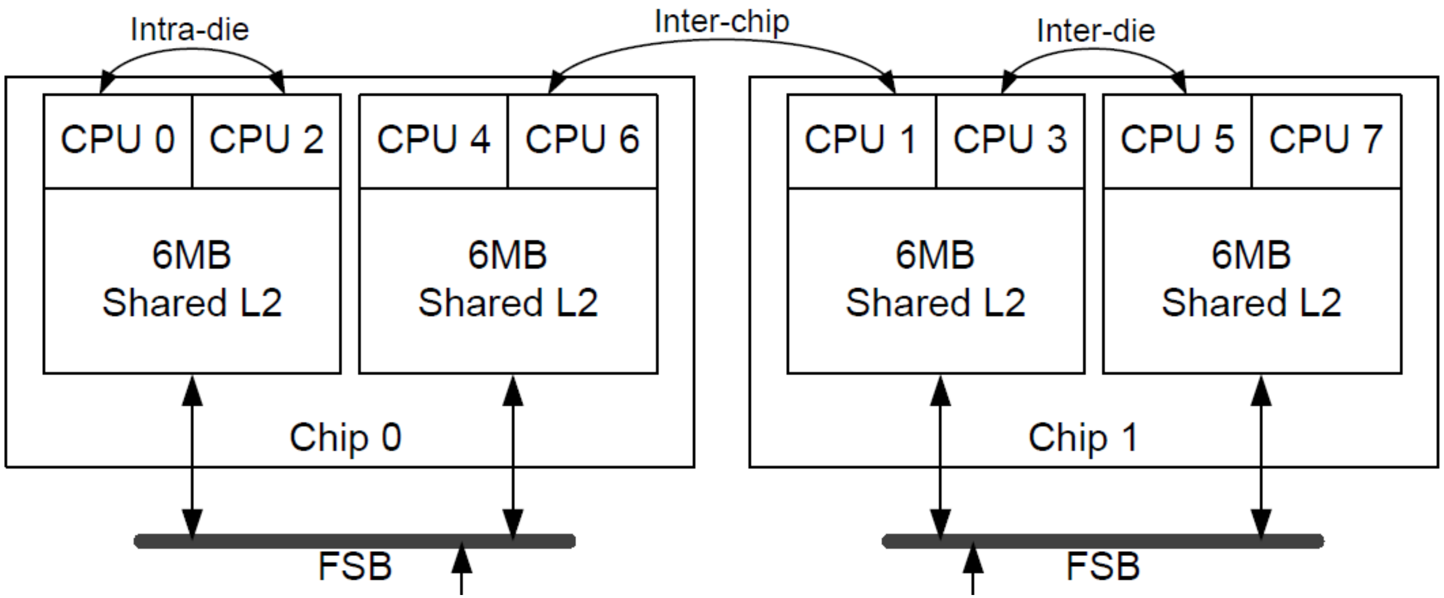
# CPU Affinity (2)

- **Just fixing the affinity shows performance improvement**
  - **Fewer L1 cache misses**
  - **Performance better and more stable**



# CPU Affinity (3)

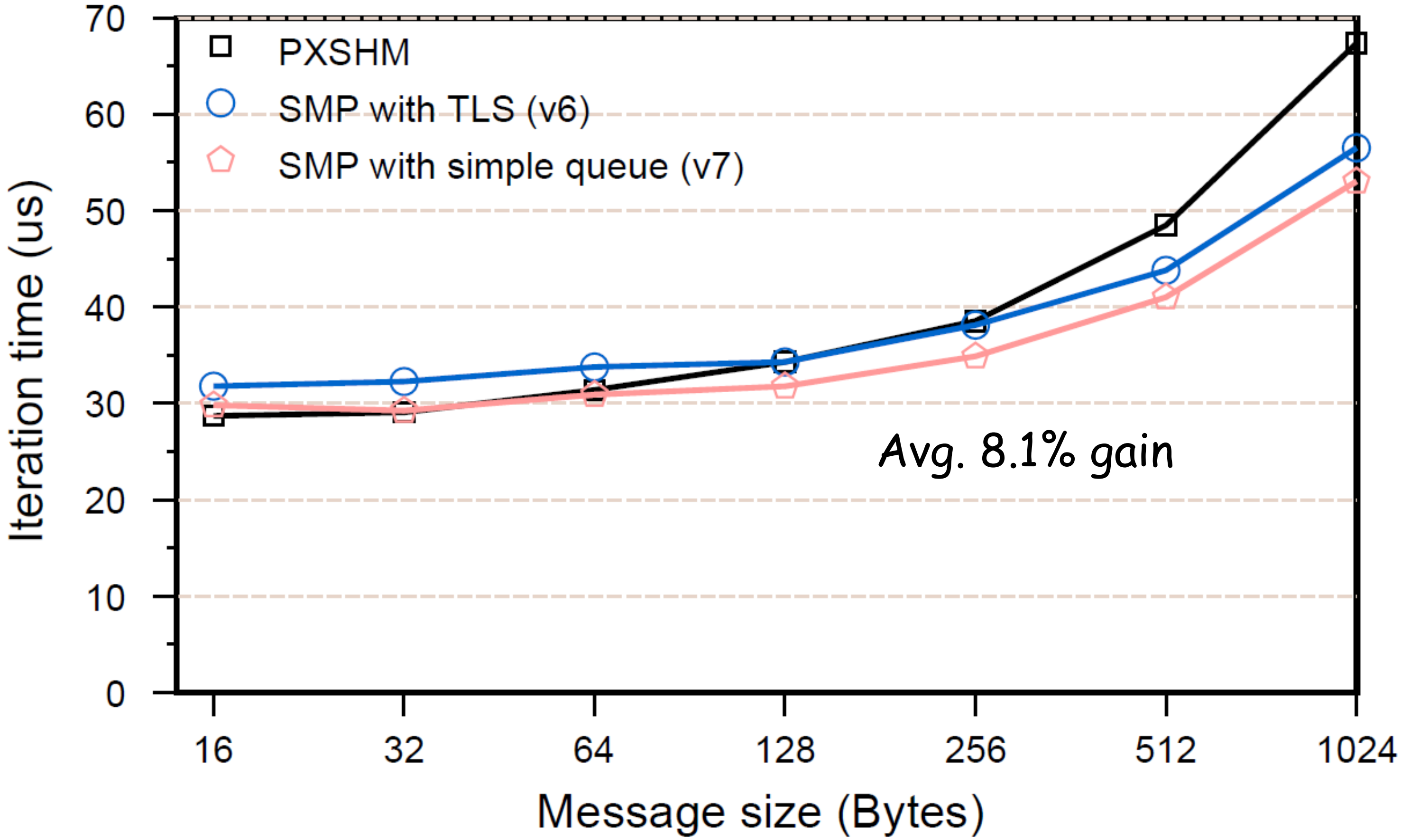
- How to set the CPU affinity generally?
  - A cross-platform function API in Charm++
  - Some TeraGrid sites also provide such functionality when lunching the job
- What's the optimal affinity setting?
  - Depends on the communication pattern of the program
- Example
  - *k*Neighbor in the case of k=1 with 7 elements
  - Message size: 256 bytes
  - Immediate neighbor communication




- Elem(0,1,2,3,4,5,6) → CPU(0,2,4,6,1,3,5): 11.66 us
- Elem(0,1,2,3,4,5,6) → CPU(0,1,2,3,4,5,6): 13.37 us
- Why?
  - Inter-chip: 8 vs. 24
  - Inter-die: 8 vs. 4
  - Intra-die: 12 vs. 0

# Other Issues

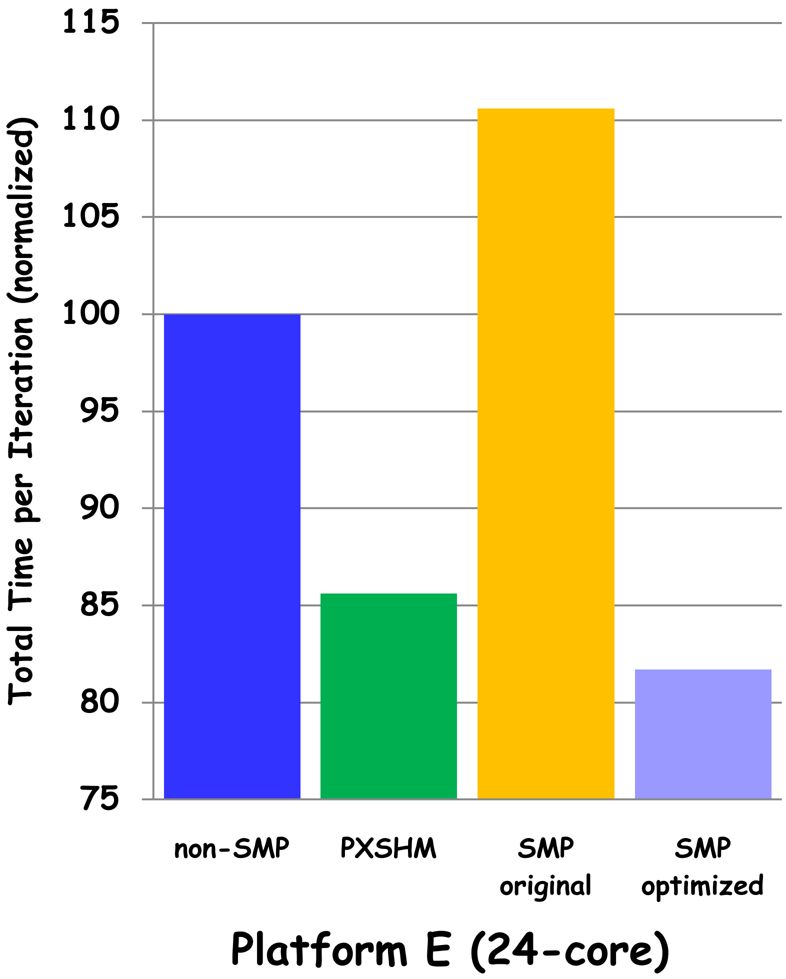
- **Reducing memory accesses in operations of message queues**
  - Very fine-grained performance tuning

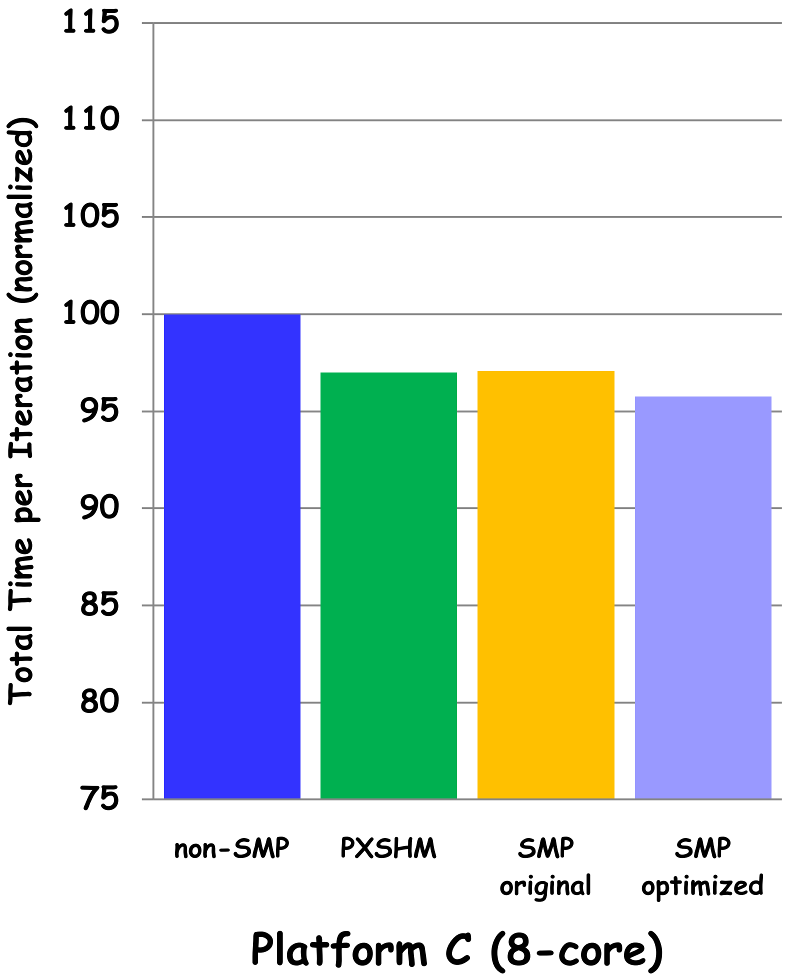


# Overall Improvement for *k*Neighbor

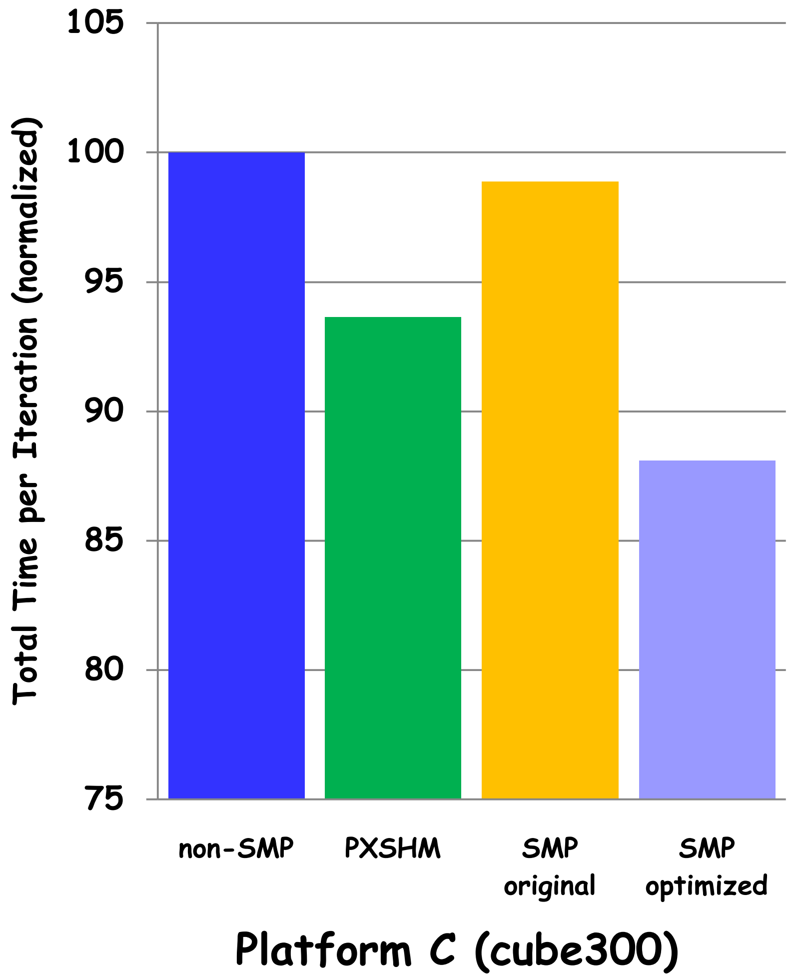
- **14.4X over initial SMP**
- **4.87X over non-SMP**
- **1.21X over non-SMP in PXSHM**

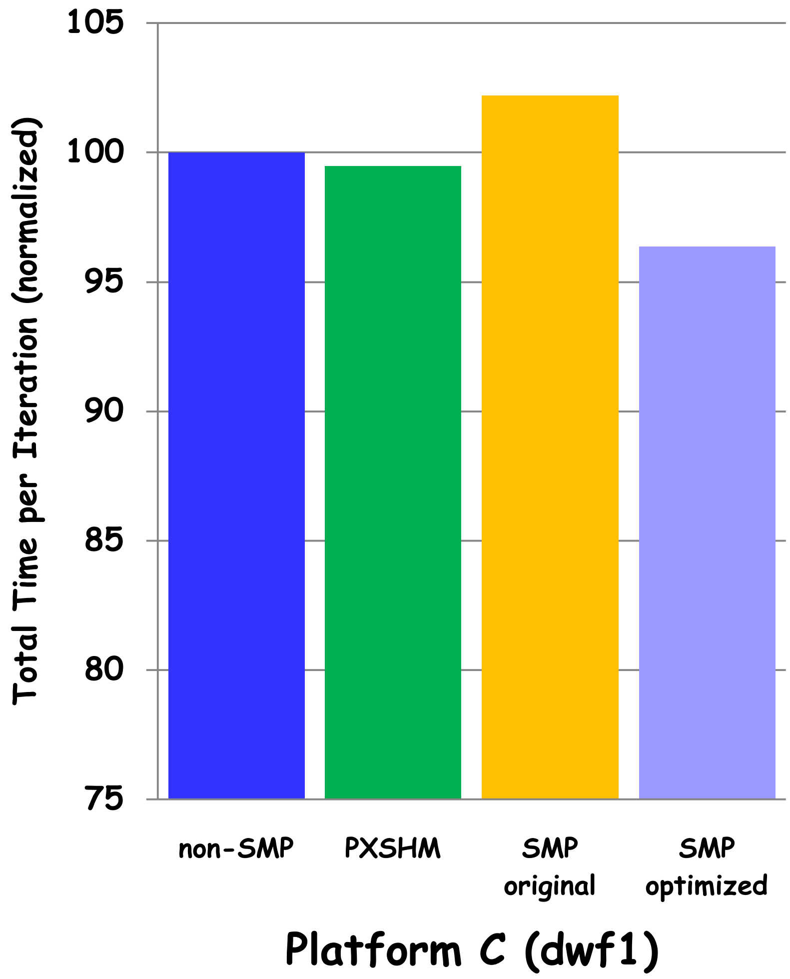
# Application Performance: NAMD



# Application Performance: ChaNGa



# Conclusion

- **Studied the parallelization of a parallel language runtime system for mutlicore platforms via Charm++**
  - Described various issues for the initial implementation
  - Applied optimization techniques correspondingly
    - Lock and synchronization overhead
    - CPU affinity
    - False sharing
- **Should be general enough and useful to other runtime system**

# Thank you !

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http://charm.cs.uiuc.edu