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The Case for Semi-Permanent Cache Occupancy

PRESENTED BY

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Introduction

- Many communication libraries were designed and optimized for single threaded environments
  - The Message Passing Interface or MPI
  - Protocol processing
- These environments continue to see a radical shift
  - Multi Core
  - Many Core
  - Hardware Threads
- Usage of communication libraries is adapting
- The performance issues we have observed are bound by memory latency
- Thesis – By manipulating cache behavior, we can reduce these latencies increasing performance

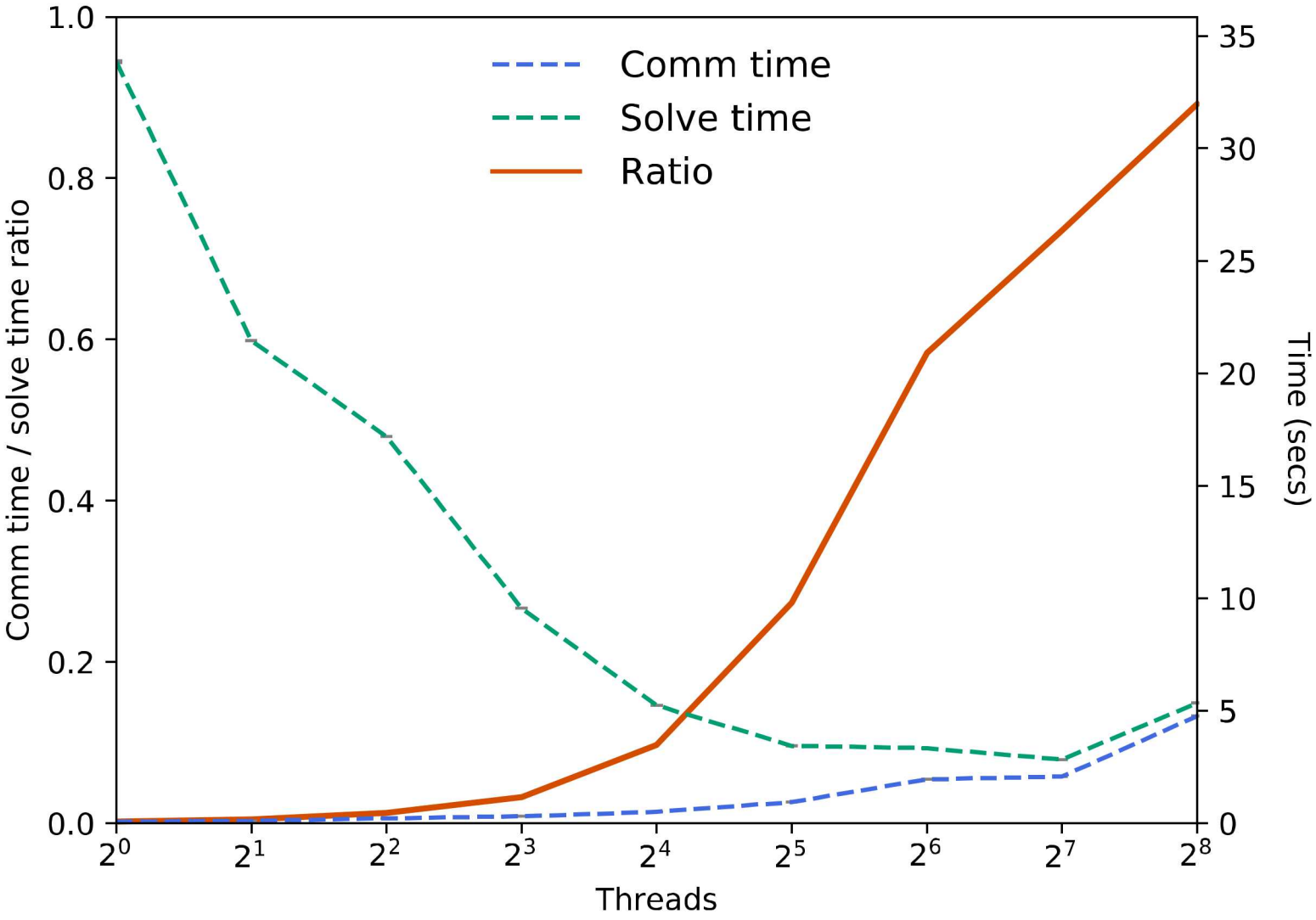
Background - MPI

- MPI is the dominant HPC communication model
- Point-to-point operations
  - Send/Recv
  - Wild-cards
  - Ordering
- Four Thread Models
  - MPI_THREAD_SINGLE
  - MPI_THREAD_FUNNLED
  - MPI_THREAD_SERIALIZED
  - MPI_THREAD_MULTIPLE
- Exascale application developers want to use MPI in a multithreaded manner
  - D. E. Bernholdt, S. Boehm, G. Bosilca, M. Venkata, R. E. Grant, T. Naughton, H. Pritchard, and G. Vallee. A survey of MPI usage in the U.S. exascale computing project. Concurrency and Computation: Practice and Experience, 2017. in press.

The New Computing Environment

- Core counts continue to increase
  - Cori/Trinity – 68 cores or 272 threads
  - Astra – 56 cores or 224 threads
- Applications leverage multithreaded runtimes to use these resources
  - Mahesh Rajan, Douglas W. Doerfler, and Simon D. Hammond. 2015. Trinity Benchmarks on Intel Xeon Phi. Technical Report. Sandia National Laboratories.
- Multithreaded system software access
  - Mechanics – Synchronization, locks, etc.
  - Behaviors – Non-determinism, ordering, etc.
- The mechanics are well studied, but behaviors are not
- What happens when we use multithread communication in a highly optimized application?

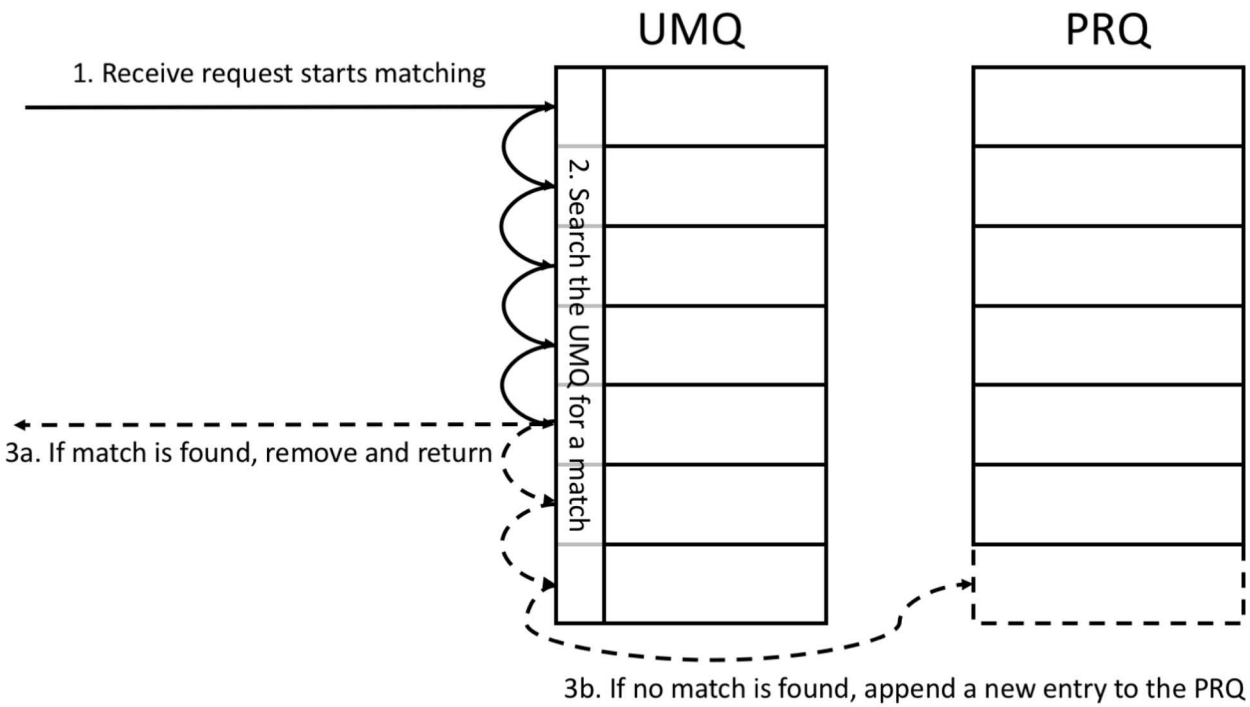
The Effect of Multithreaded Communication on MiniFE



Potential Effects on MPI message processing

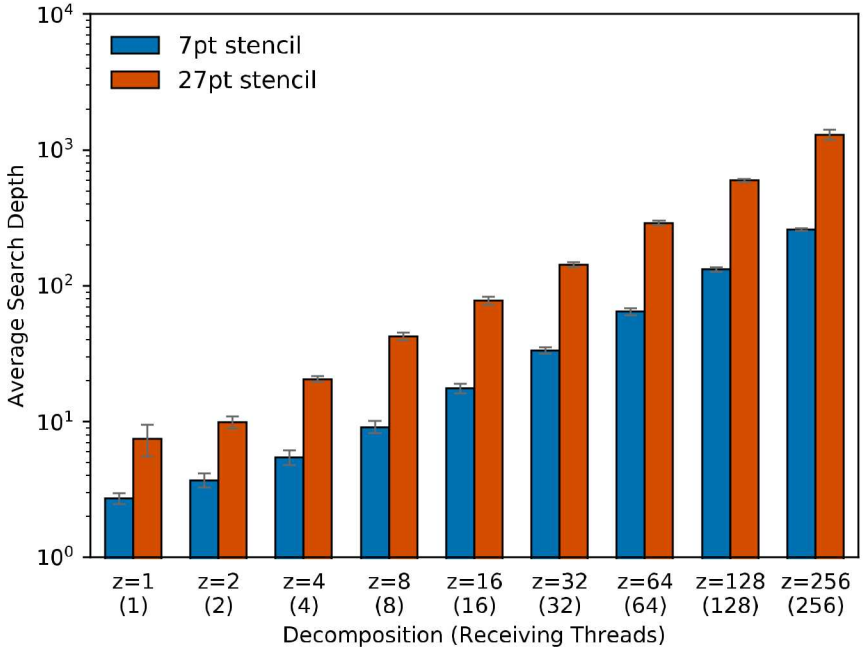
- Message Matching is a processing step for MPI Communication
- It ensures MPI's Send-Receive ordering requirements
- Matches incoming data to a buffer based on three identifiers
  - ContextID – Identifies the communicator
  - Rank – Address of the sending process
  - Tag – A user specified identifier
- Increasing threads
  - More messages to process
  - Increased ordering variance

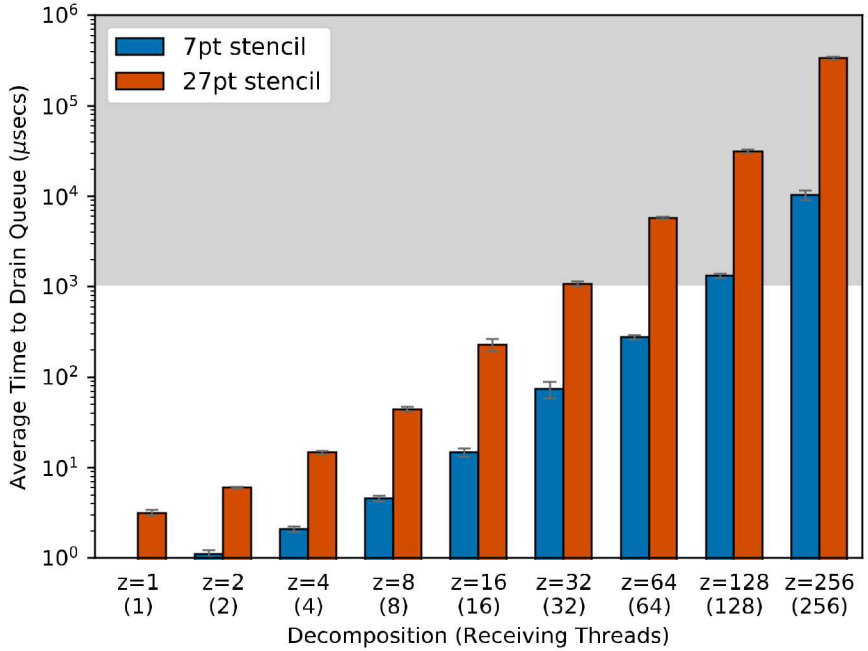
Message Matching Traditional Model



The Impact of Multithreaded Non-determinism

- Modeling multithreaded BPS applications
- Average Search depths exceed 1000 elements
- Matching drain times can exceed iteration targets (grey region)
  - Molecular Dynamics Codes such as LAMMPS and GROMACS





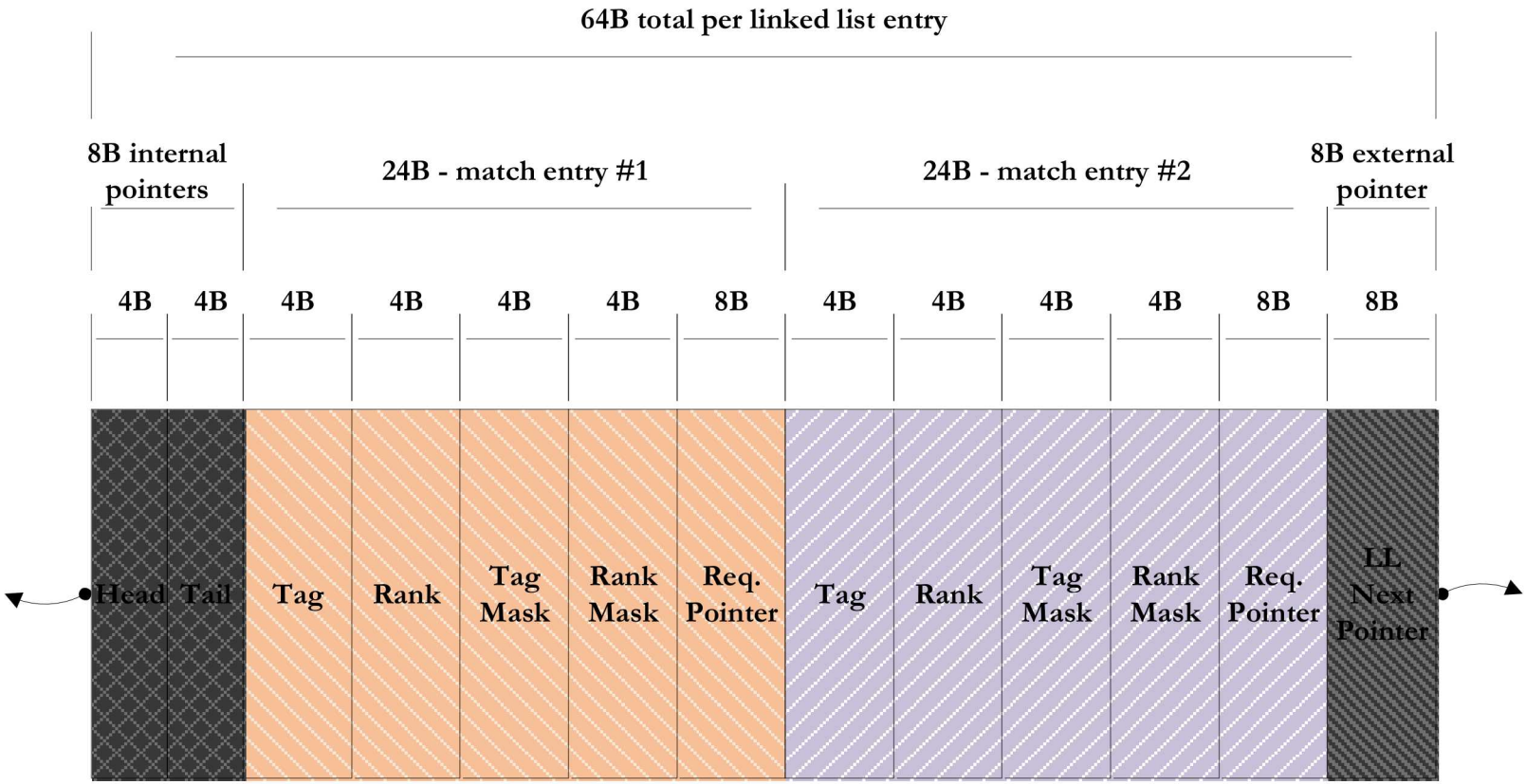
W. Schonbein, M. G. F. Dosanjh, et al. Measuring multithreaded message matching misery. In *Proceedings of the International European Conference on Parallel and Distributed Computing*. 2018.

Data Locality

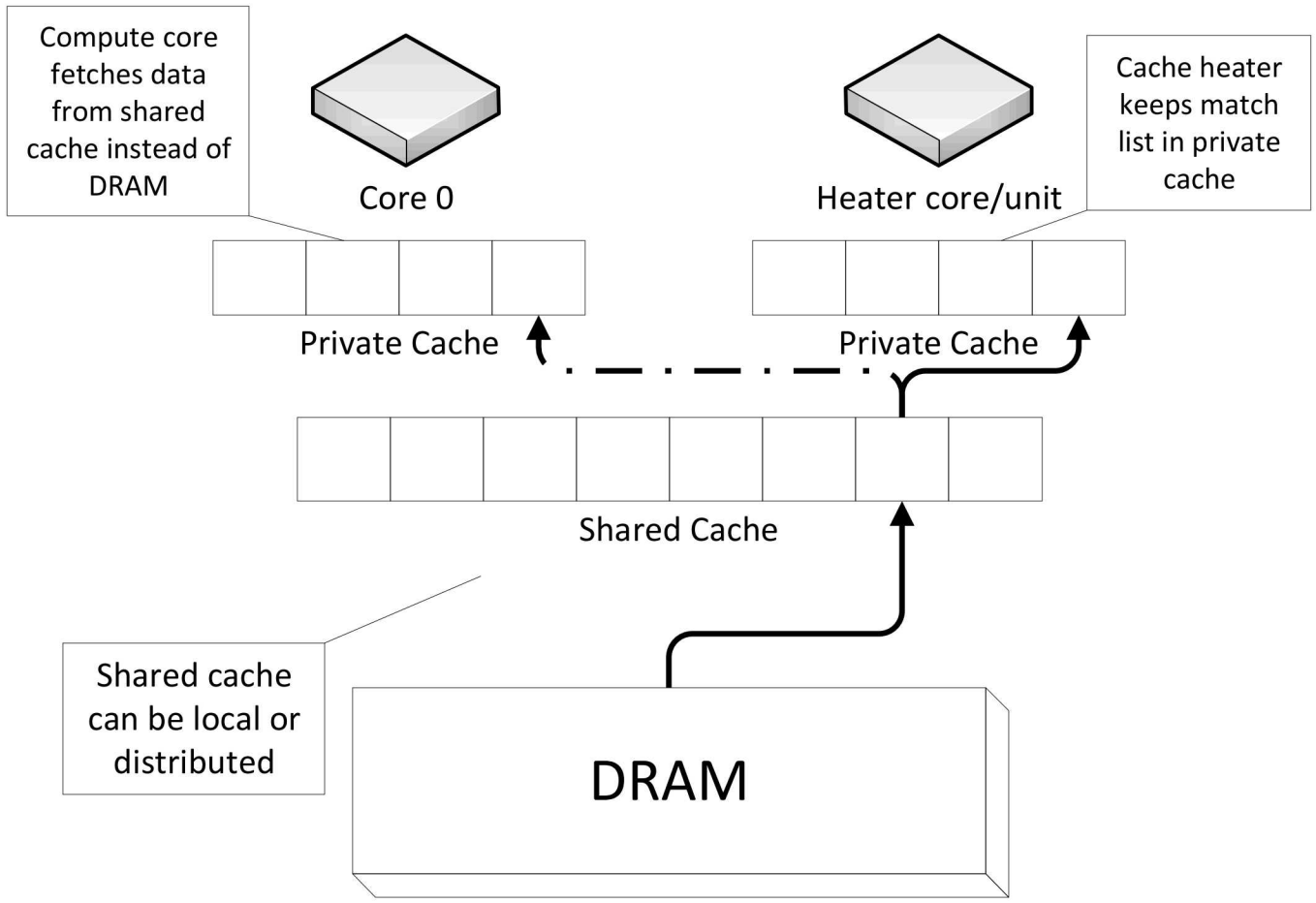
- MPI Message Matching performance is limited by the performance of data access
  - Linked lists elements are non contiguous in memory and span a number of cache lines
  - Linked list searching is difficult for the prefetcher
- How much of this can we improve by eliminating cache misses?
- Most architectures don't provide a cache control interface
- Increasing data locality will reduce the cost of data access
  - Spatial – combining multiple element into contiguous memory
  - Temporal – accessing the list periodically to ensure that the list isn't evicted from cache
- Tools to control locality
  - Spatial Locality - Linked List of Arrays
  - Temporal Locality -Hot Caching

Linked List of Arrays

- A new matching data structure
- Increases spatial locality by leveraging contiguous memory
- Fits multiple elements per cache line



Hot Caching


Compute core fetches data from shared cache instead of DRAM
Core 0
Heater core/unit
Cache heater keeps match list in private cache
Private Cache
Private Cache
Shared Cache
Shared cache can be local or distributed
DRAM

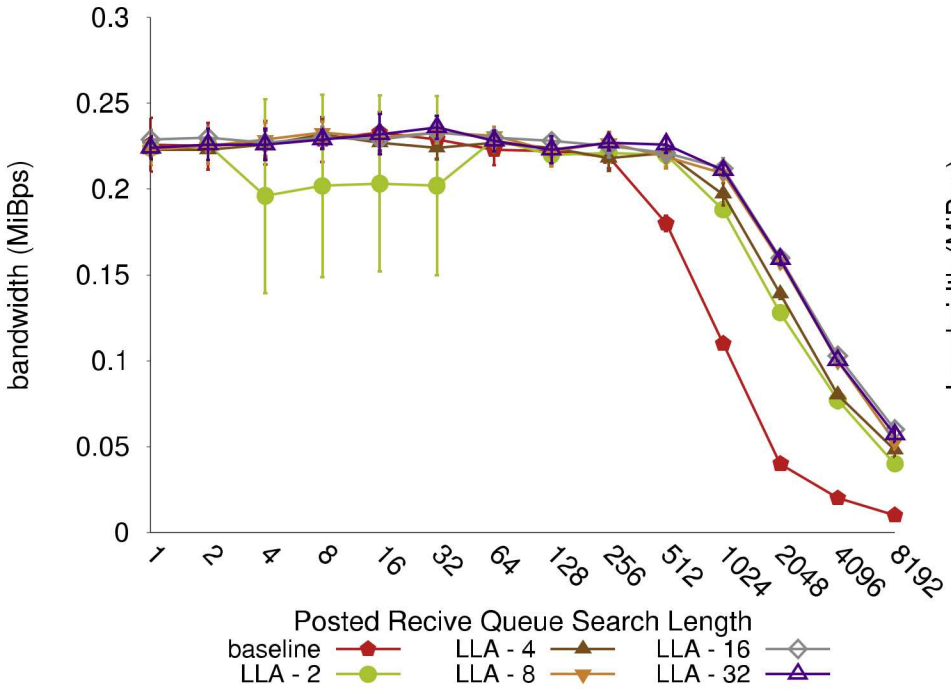
Implementation Notes

- Linked list of arrays has modifiable length of entries per array
- Hot caching and linked list of arrays can be combined
  - Increases both spatial and temporal locality
  - Better control of memory allows from linked list of arrays implementation allows for reduced registration overheads in hot caching

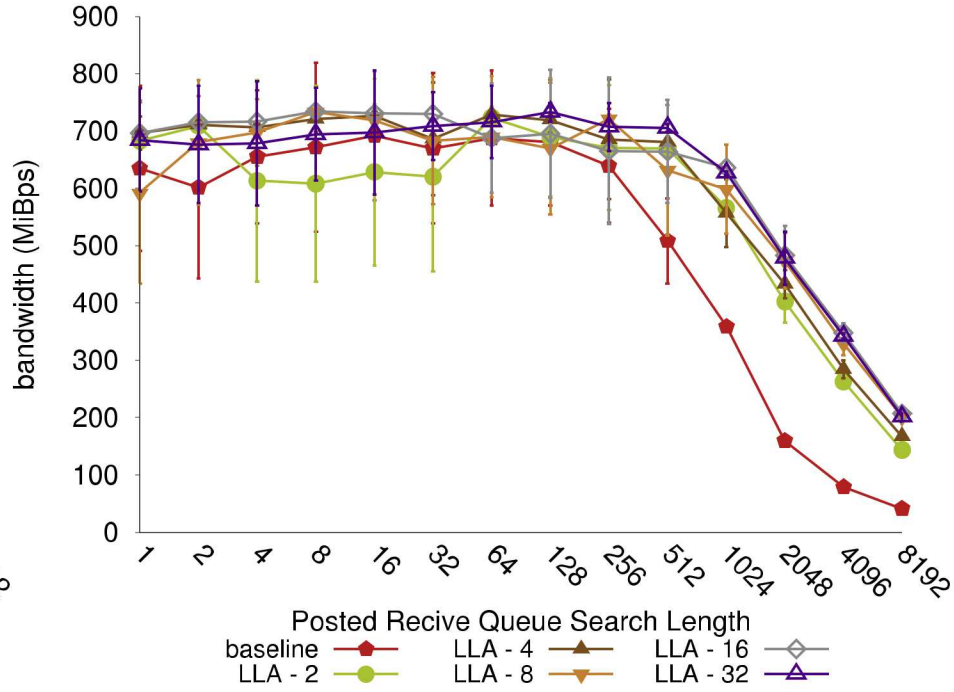
Experimental Setup

- Modified MVAPICH with new matching engines
  - Linked List of Arrays
  - Hot Caching
  - Combination
- Modified OSU Bandwidth Microbenchmark
  - Cache clearing
  - Pre-posting recvs
  - Control of search depths
- Two systems
  - Sandy Bridge
  - Broadwell

Spatial Locality – Sandy Bridge

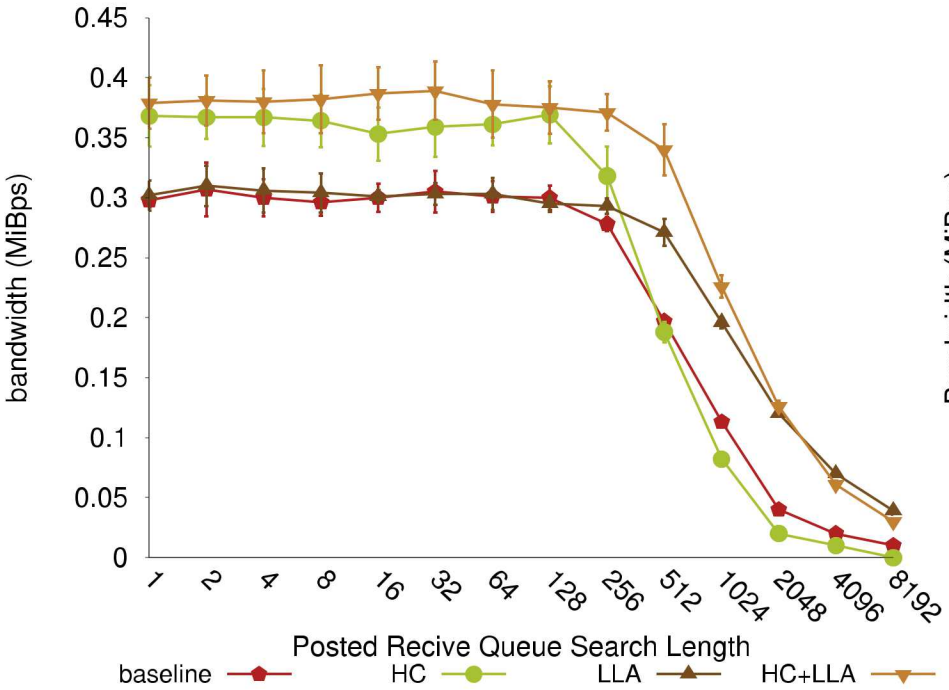


Small Messages (1B)



Medium Messages (4KiB)

Temporal Locality – Sandy Bridge



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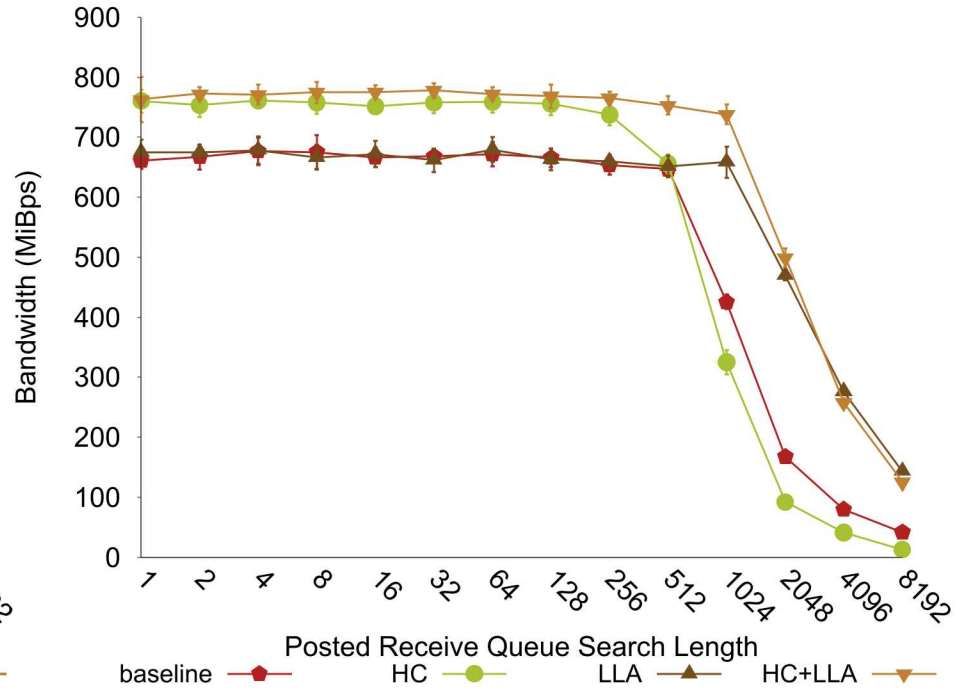

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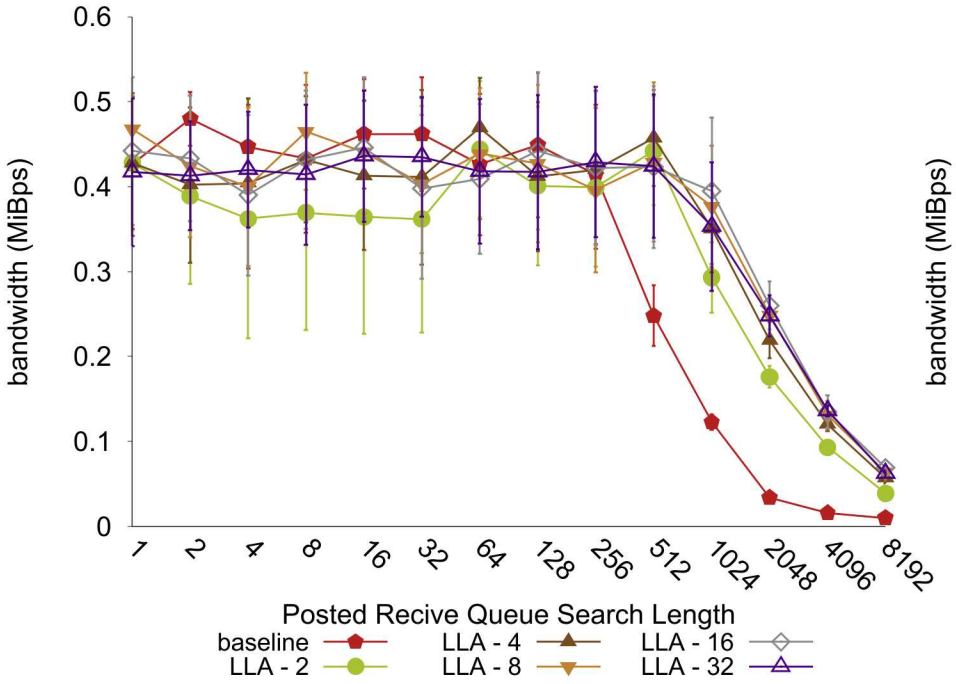
Spatial Locality – Broadwell



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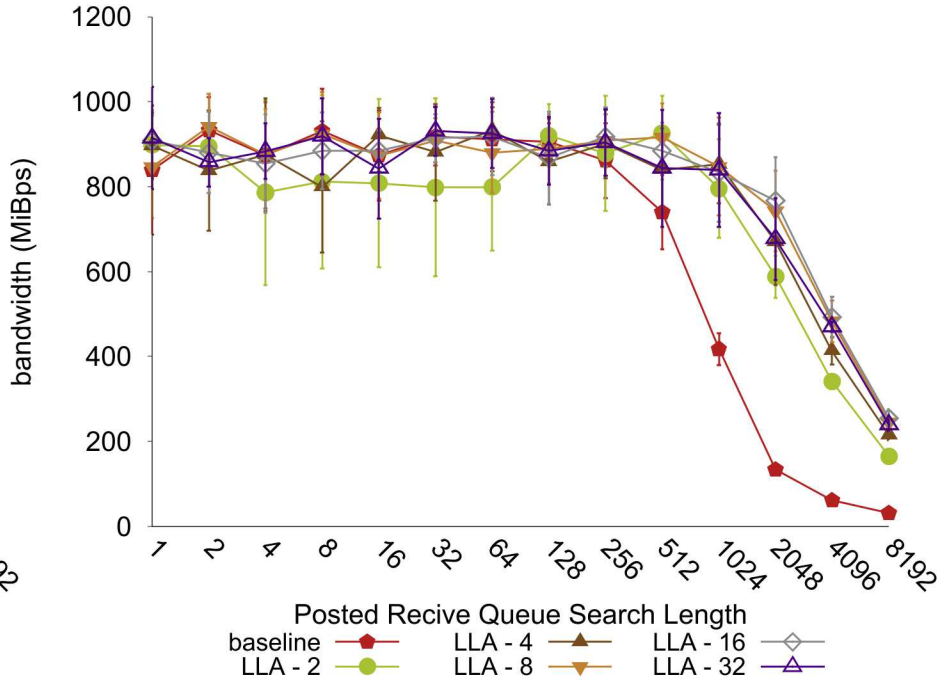

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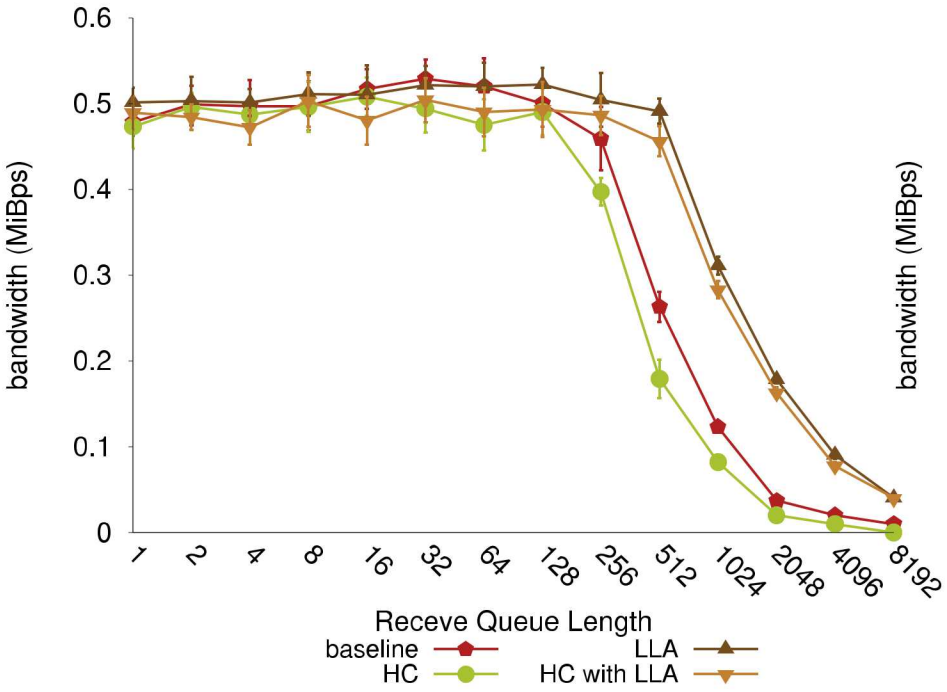
Temporal Locality – Broadwell



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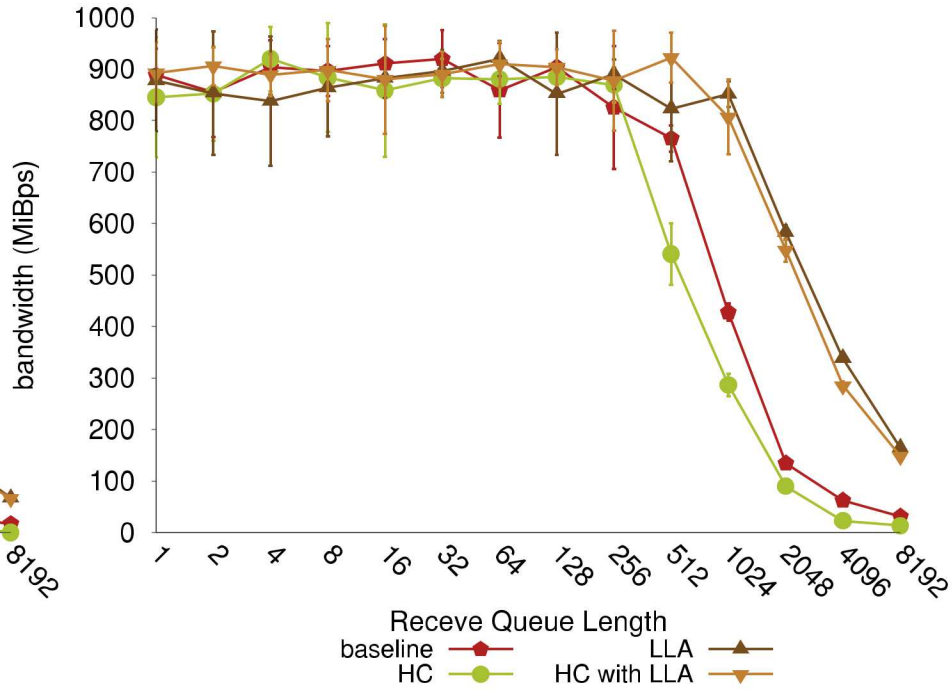


Medium Messages (4KiB)

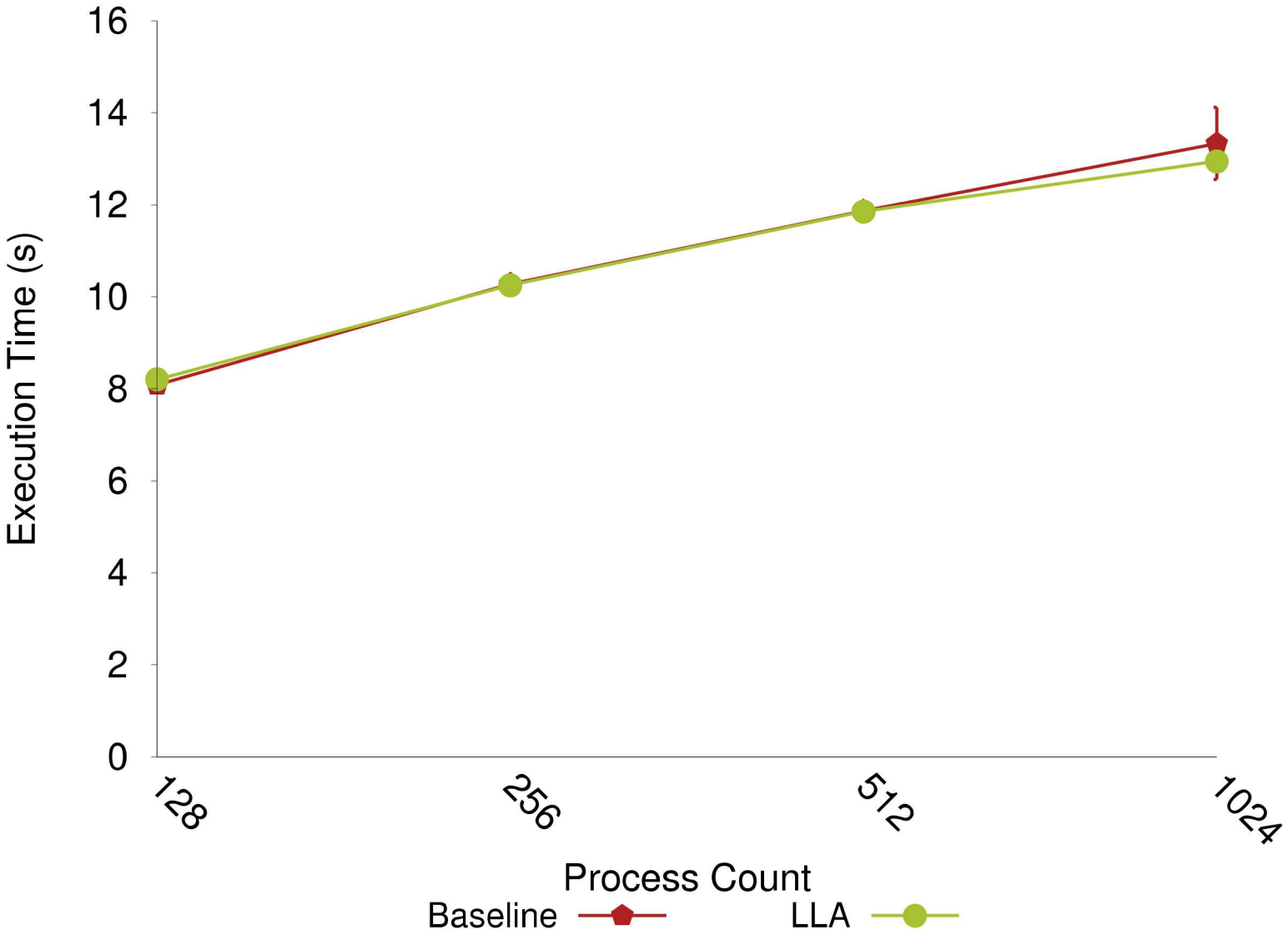
Microbenchmarks Conclusions

- Both architectures show an increase from increased spatial locality
  - Both show a significant impact at 2 elements per cache line
  - We observe diminishing returns from spatial locality between multiple cache-lines
- Sandy Bridge shows a significant speedup from temporal locality
- Broadwell does not, which could be due to a number of reasons
  - Hot-caching proof-of-concept shows an impact
  - Possible causes
    - Tuning mismatch
    - Network speed bottleneck
    - Architectural changes

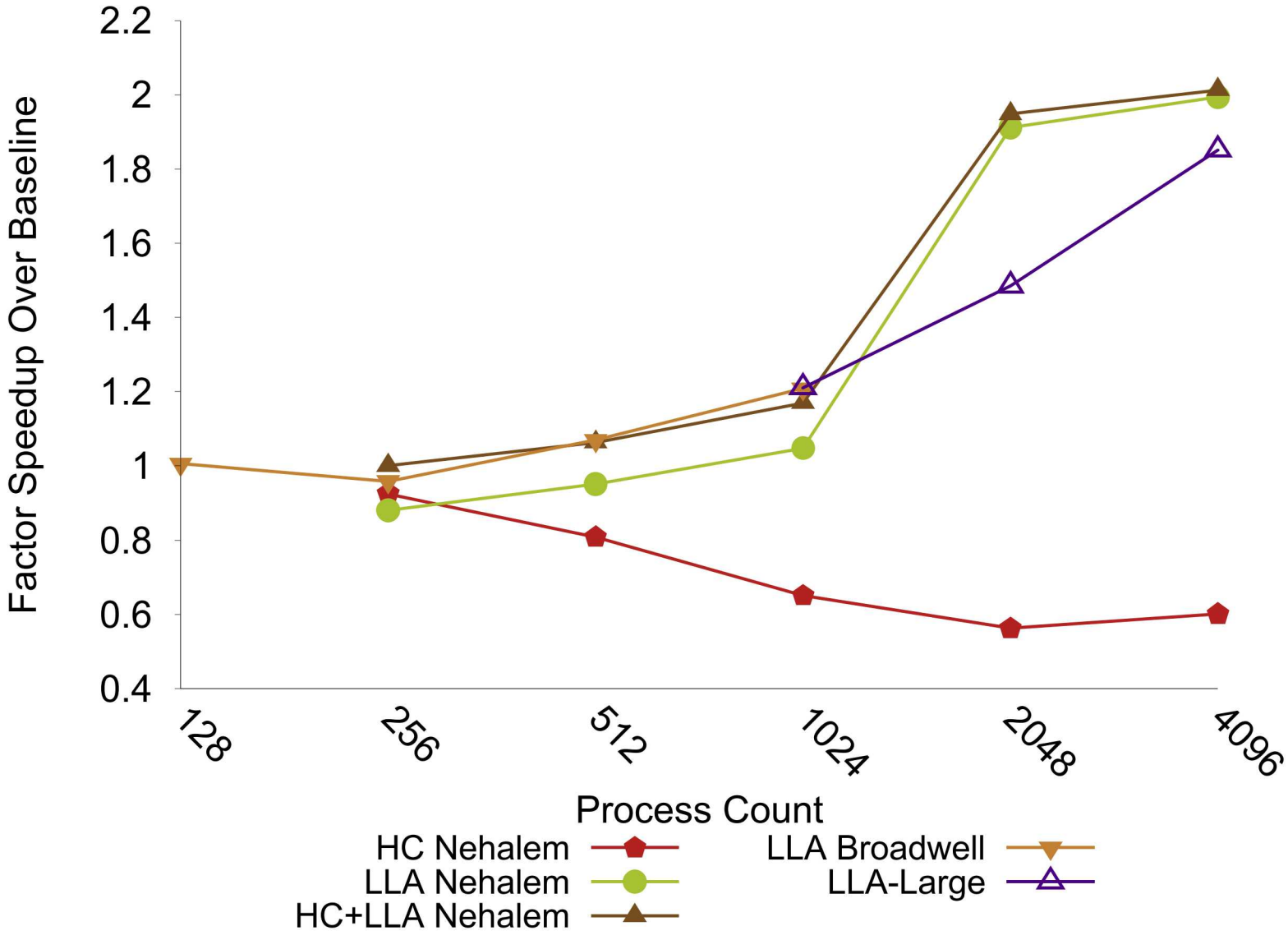
Application Experiments

- To evaluate the application impact of locality we ran multiple proxy and real applications
- AMG2013 is representative on many current applications
  - Adaptive multi grid proxy application
  - Leverages communication determinism to reduce search depths
- Fire Dynamics Simulator (FDS)
  - Full application
  - Currently the defacto message matching benchmark
  - Several communication inefficiencies but closest representation to multithreaded communication behavior from a matching standpoint
- Given the determinism, we expect minimal impact on current applications and significant impact on FDS

Application Impact – AMG



Application Impact – FDS



Pseudo-Permanent Cache Occupancy

- Locality significantly impacts matching performance
- There are a number of ways this can be accomplished
  - Hot caching
  - Network cache
  - Pining memory to cache

Future Work

- Expanding the study to include other parts of message processing
- Leveraging these techniques in other scalable system software
- Exploring the potential for cache pinning within an application
- Simulation of the impact of an on-chip network cache

Questions?