MVAPICH
MPI, PGAS and Hybrid MPI+PGAS Library

Performance of PGAS Models on KNL: A Comprehensive Study with MVAPICH2-X

IXPUG ’17 Presentation

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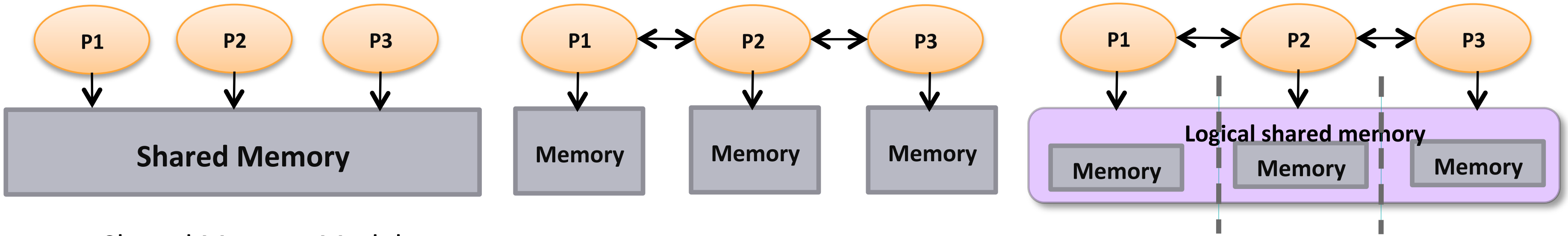
Parallel Programming Models Overview



Shared Memory Model

SHMEM, DSM

Distributed Memory Model

MPI (Message Passing Interface)

Partitioned Global Address Space (PGAS)

Global Arrays, UPC, Chapel, X10, CAF, …

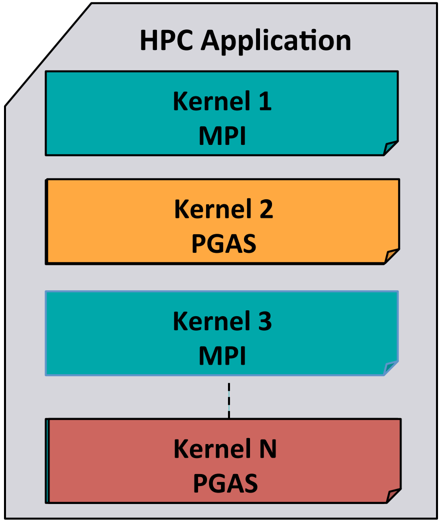
- Programming models provide abstract machine models
- Models can be mapped on different types of systems
  - e.g. Distributed Shared Memory (DSM), MPI within a node, etc.
- PGAS models and Hybrid MPI+PGAS models are gradually receiving importance

Partitioned Global Address Space (PGAS) Models

- Key features
  - Simple shared memory abstractions
  - Light weight one-sided communication
  - Easier to express irregular communication
- Different approaches to PGAS
  - Languages
    - Unified Parallel C (UPC)
    - Co-Array Fortran (CAF)
    - X10
    - Chapel
  - Libraries
    - OpenSHMEM
    - UPC++
    - Global Arrays

Hybrid (MPI+PGAS) Programming

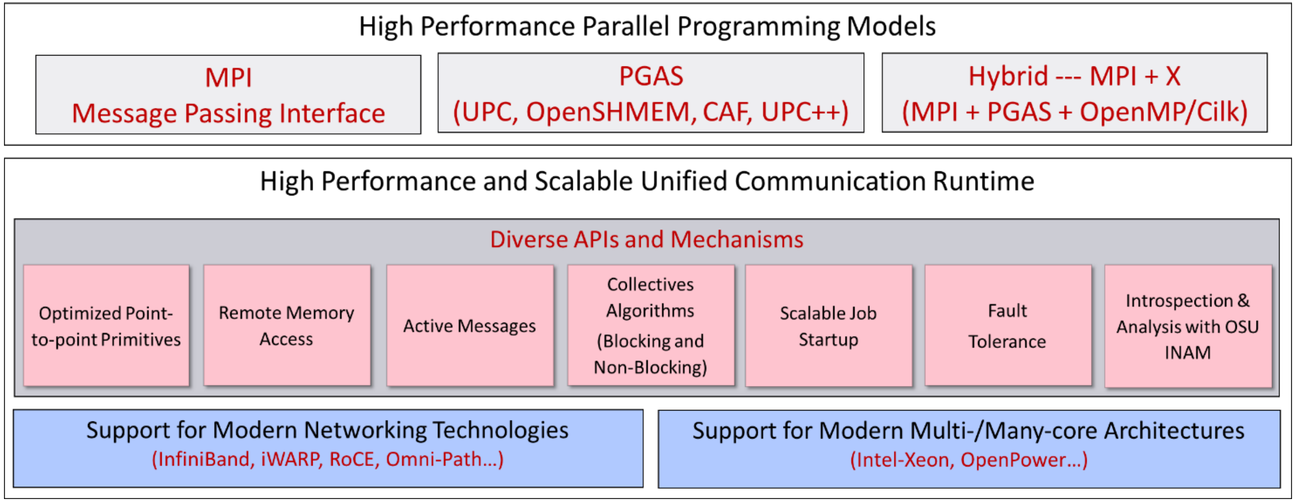
- Application sub-kernels can be re-written in MPI/PGAS based on communication characteristics
- Benefits:
  - Best of Distributed Computing Model
  - Best of Shared Memory Computing Model
- Cons
  - Two different runtimes
  - Need great care while programming
  - Prone to deadlock if not careful



MVAPICH2 Software Family

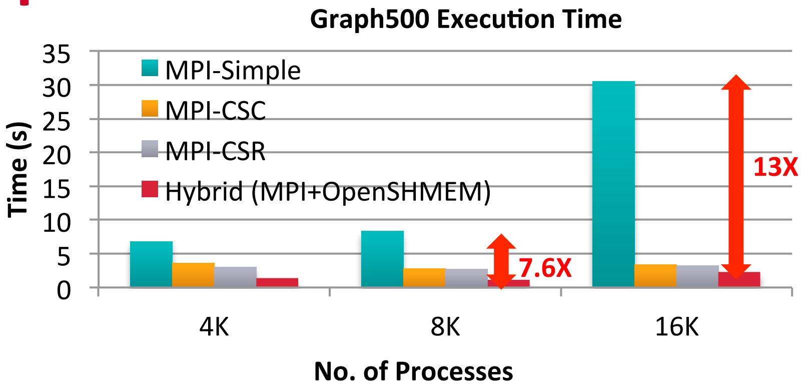
High-Performance Parallel Programming Libraries	
MVAPICH2	Support for InfiniBand, Omni-Path, Ethernet/iWARP, and RoCE
MVAPICH2-X	Advanced MPI features, OSU INAM, PGAS (OpenSHMEM, UPC, UPC++, and CAF), and MPI +PGAS programming models with unified communication runtime
MVAPICH2-GDR	Optimized MPI for clusters with NVIDIA GPUs
MVAPICH2-Virt	High-performance and scalable MPI for hypervisor and container based HPC cloud
MVAPICH2-EA	Energy aware and High-performance MPI
MVAPICH2-MIC	Optimized MPI for clusters with Intel KNC
Microbenchmarks	
OMB	Microbenchmarks suite to evaluate MPI and PGAS (OpenSHMEM, UPC, and UPC++) libraries for CPUs and GPUs
Tools	
OSU INAM	Network monitoring, profiling, and analysis for clusters with MPI and scheduler integration
OEMT	Utility to measure the energy consumption of MPI applications

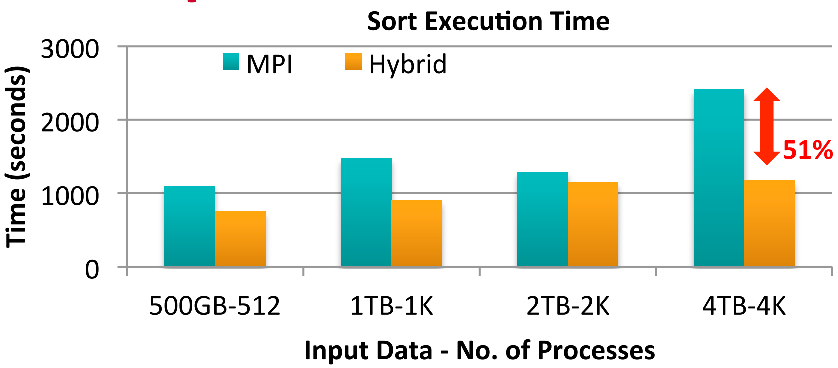
MVAPICH2-X for Hybrid MPI + PGAS Applications



- Current Model – Separate Runtimes for OpenSHMEM/UPC/UPC++/CAF and MPI
  - Possible deadlock if both runtimes are not progressed
  - Consumes more network resource
- Unified communication runtime for MPI, UPC, UPC++, OpenSHMEM, CAF
  - Available with since 2012 (starting with MVAPICH2-X 1.9)
  - http://mvapich.cse.ohio-state.edu

Application Level Performance with Graph500 and Sort





- Performance of Hybrid (MPI+ OpenSHMEM) Graph500 Design
  - 8,192 processes
    - **2.4X** improvement over MPI-CSR
    - **7.6X** improvement over MPI-Simple
  - 16,384 processes
    - **1.5X** improvement over MPI-CSR
    - **13X** improvement over MPI-Simple

- Performance of Hybrid (MPI+OpenSHMEM) Sort Application
  - 4,096 processes, 4 TB Input Size
    - MPI – 2408 sec; 0.16 TB/min
    - Hybrid – 1172 sec; 0.36 TB/min
    - **51%** improvement over MPI-design

J. Jose, K. Kandalla, S. Potluri, J. Zhang and D. K. Panda, Optimizing Collective Communication in OpenSHMEM, Int'l Conference on Partitioned Global Address Space Programming Models (PGAS '13), October 2013.

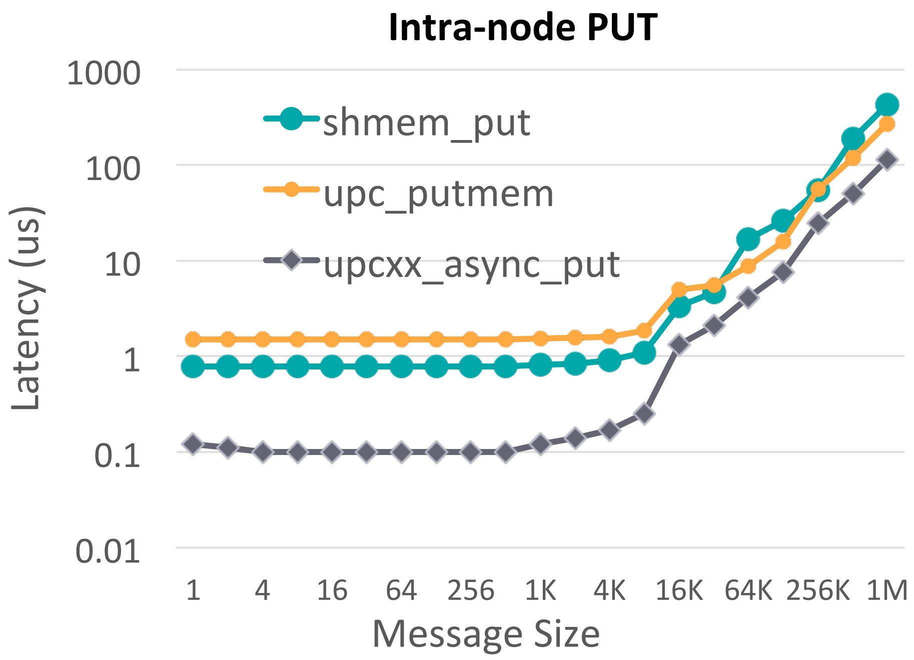
J. Jose, S. Potluri, K. Tomko and D. K. Panda, Designing Scalable Graph500 Benchmark with Hybrid MPI+OpenSHMEM Programming Models, International Supercomputing Conference (ISC'13), June 2013

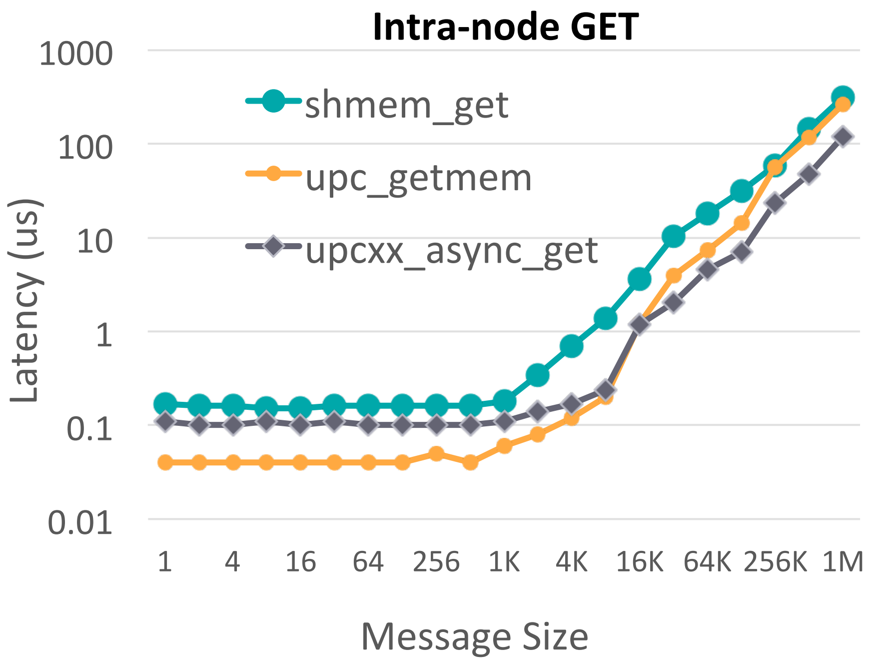
J. Jose, K. Kandalla, M. Luo and D. K. Panda, Supporting Hybrid MPI and OpenSHMEM over InfiniBand: Design and Performance Evaluation, Int'l Conference on Parallel Processing (ICPP '12), September 2012

Performance of PGAS Models on KNL

- Performance of Put and Get with OpenSHMEM, UPC, and UPC++
- Comparison on KNL and Broadwell for OpenSHMEM point-to-point, collectives, and atomics Operations
- Impact of AVX-512 Vectorization and MCDRAM on OpenSHMEM Application Kernels
- Performance of UPC++ Application kernels on MVAPICH2-X communication runtime

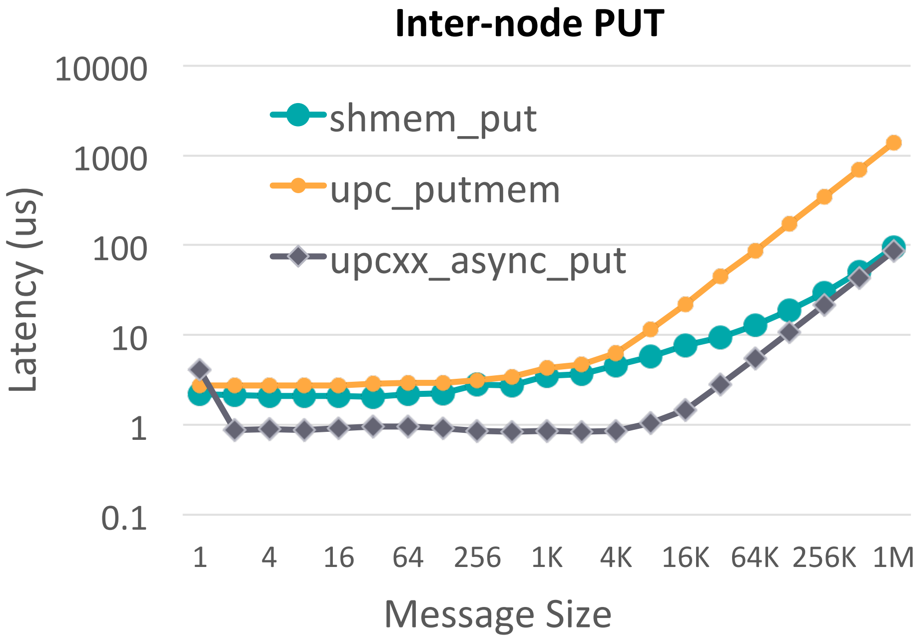
Performance of PGAS Models on KNL using MVAPICH2-X

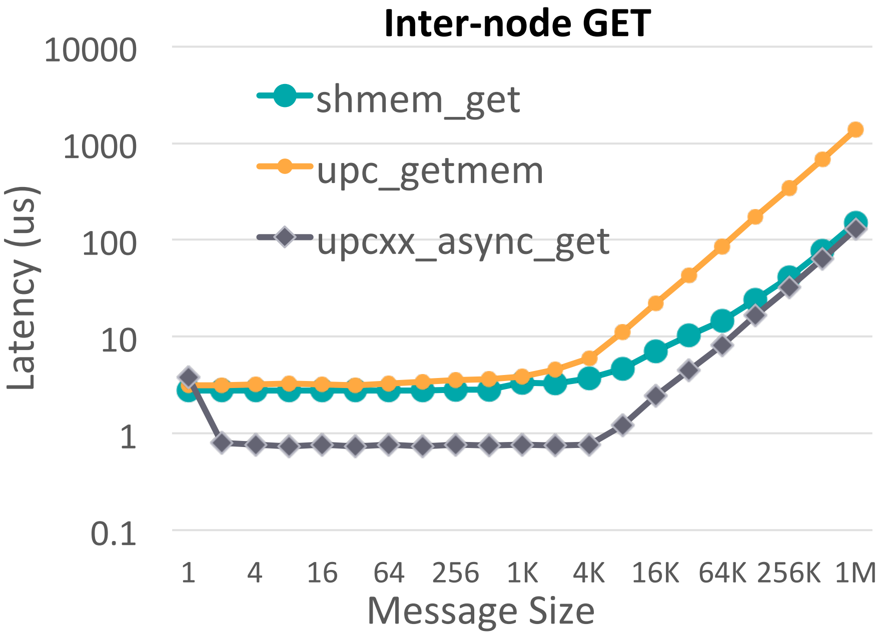




- Intra-node performance of one-sided Put/Get operations of PGAS libraries/languages using MVAPICH2-X communication conduit
- Near-native communication performance is observed on KNL

Performance of PGAS Models on KNL using MVAPICH2-X





- Inter-node performance of one-sided Put/Get operations using MVAPICH2-X communication conduit with InfiniBand HCA (MT4115)
- Native IB performance for all three PGAS models is observed

Performance of PGAS Models on KNL

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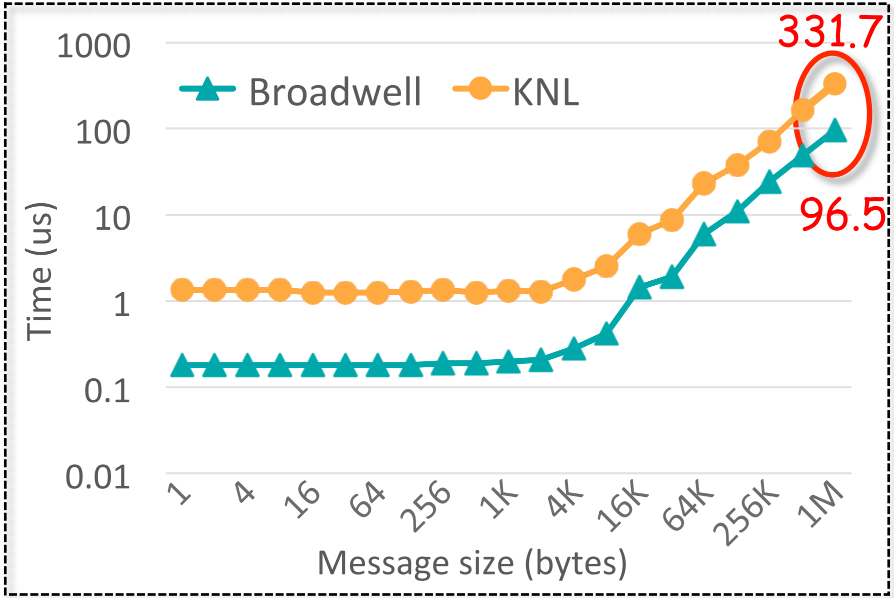
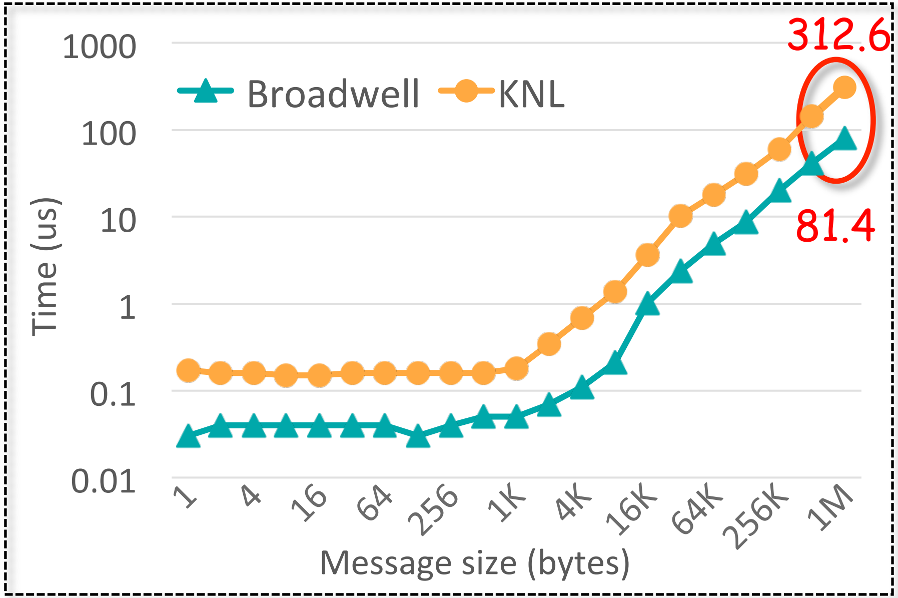
Microbenchmark Evaluations (Intra-node Put/Get)



Shmem_putmem

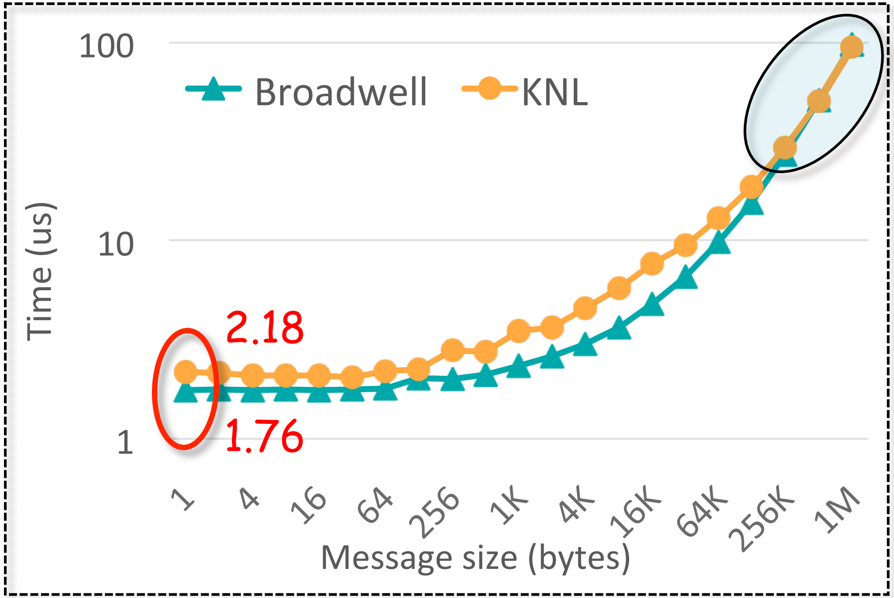


Shmem_getmem

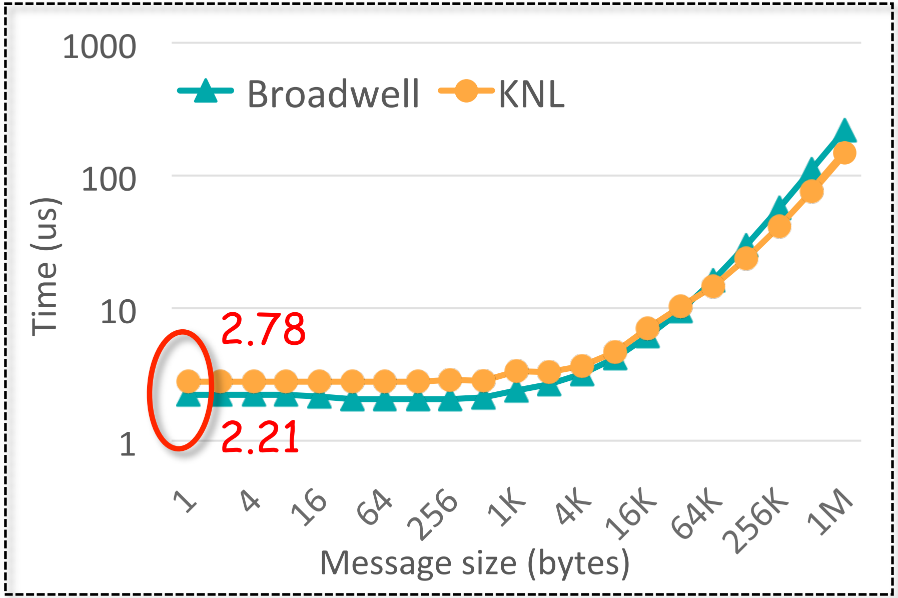
- Broadwell shows about 3X better performance than KNL on large message
- Muti-threaded memcpy routines on KNL could offset the degradation caused by the slower core on basic Put/Get operations

J. Hashmi, M. Li, H. Subramoni, D. Panda, Exploiting and Evaluating OpenSHMEM on KNL Architecture, Fourth Workshop on OpenSHMEM, Aug 2017

Microbenchmark Evaluations (Inter-node Put/Get)



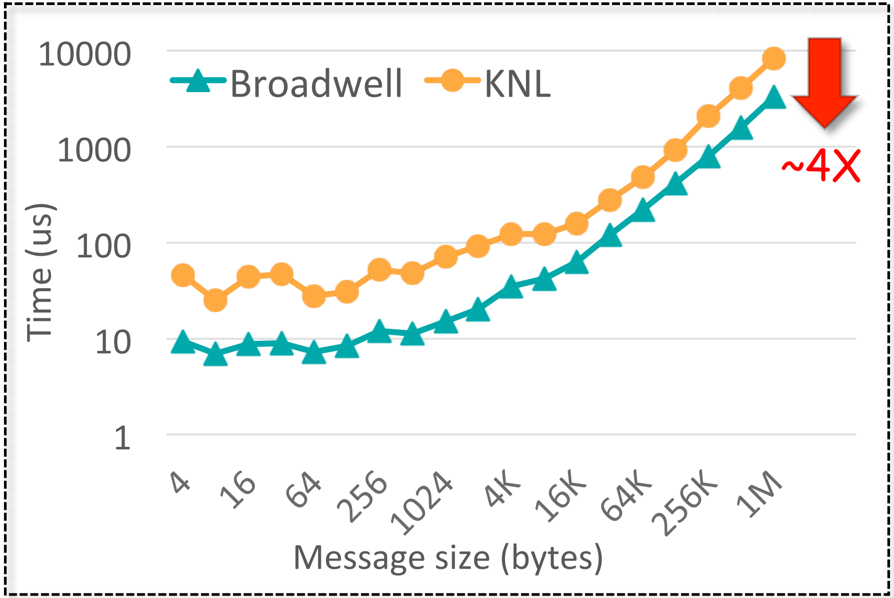
Shmem_putmem



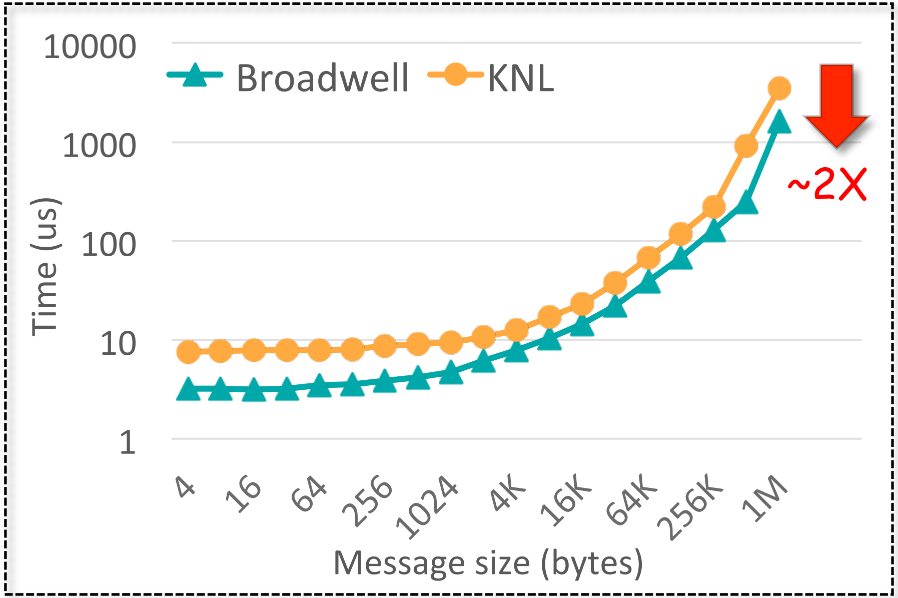
Shmem_getmem

- Inter-node small message latency is only 2X worse on KNL. While large message performance is almost similar on both KNL and Broadwell.

Microbenchmark Evaluations (Collectives)



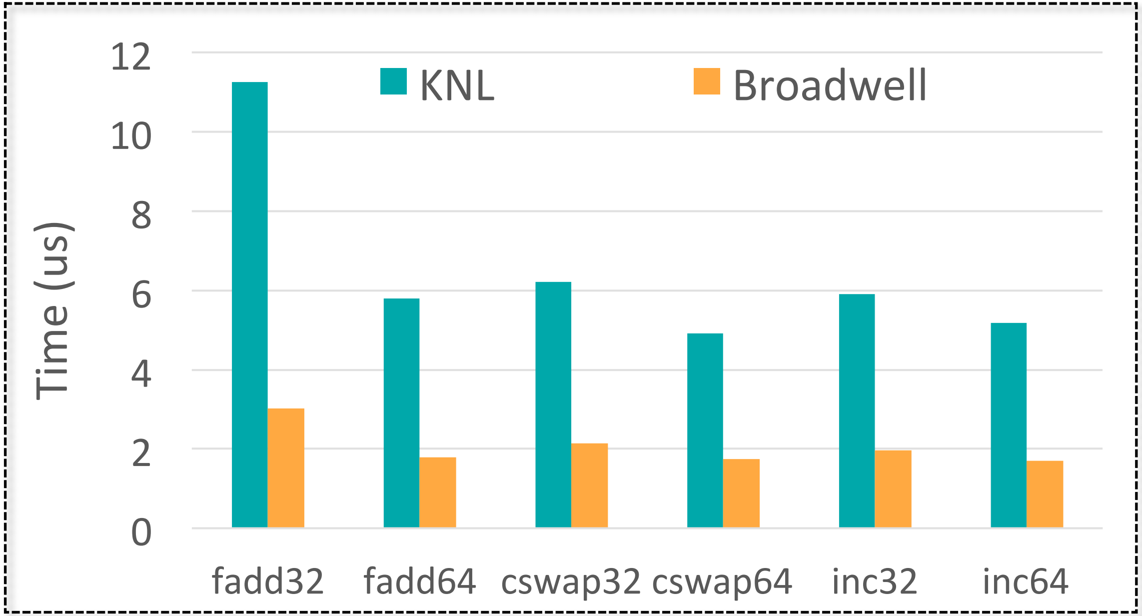
Shmem_reduce on 128 processes



Shmem_broadcast on 128 processes

- 2 KNL nodes (64 ppn) and 8 Broadwell nodes (16 ppn)
- 4X degradation is observed on KNL using collective benchmarks
- Basic point-to-point performance difference is reflected in collectives as well

Microbenchmark Evaluations (Atomics)



OpenSHMEM atomics on 128 processes

- Using multiple nodes of KNL, atomic operations showed about 2.5X degradation on compare-swap, and Inc atomics
- Fetch-and-add (32-bit) showed up to 4X degradation on KNL

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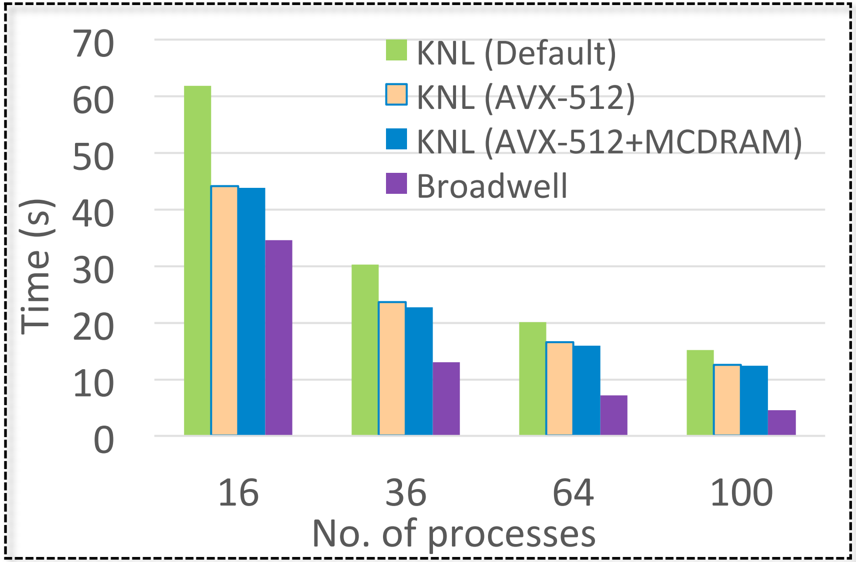
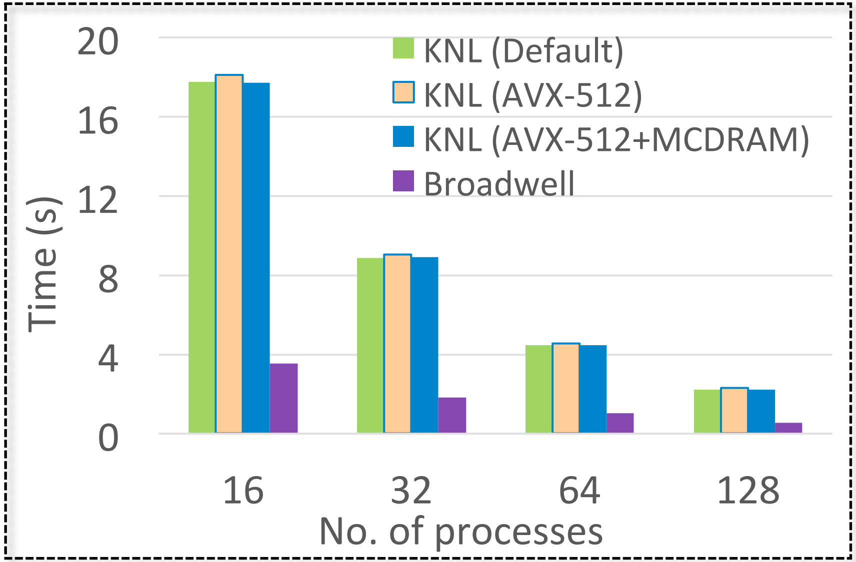
NAS Parallel Benchmark Evaluation

NAS-BT (PDE solver), CLASS=B



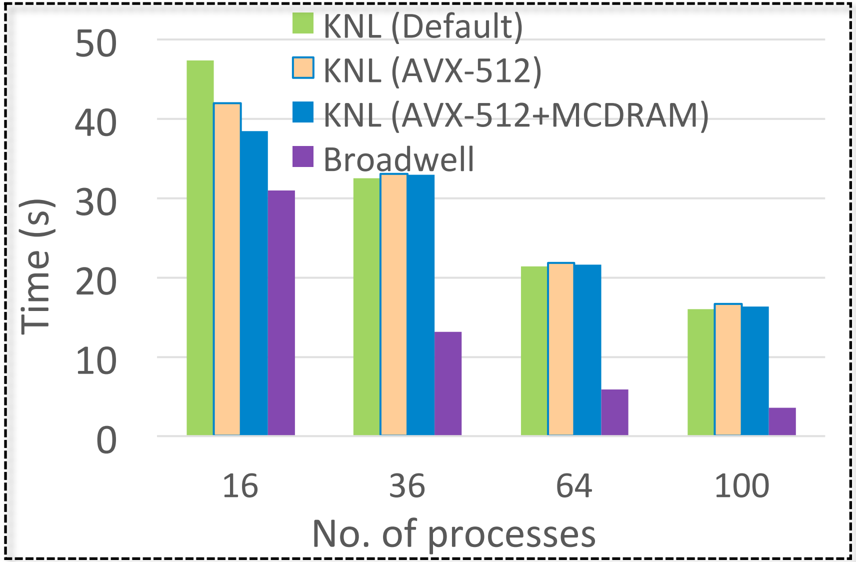
NAS-EP (RNG), CLASS=B



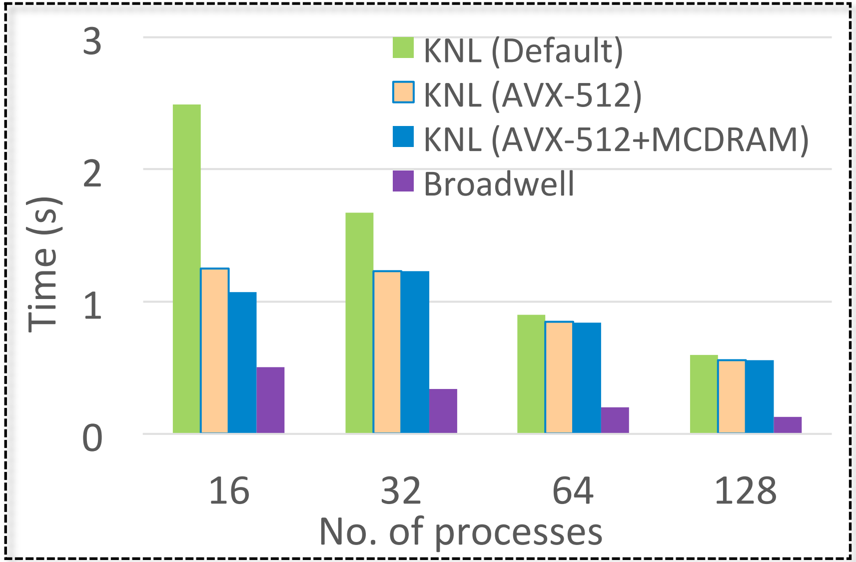
- AVX-512 vectorized execution of BT kernel on KNL showed 30% improvement over default execution while EP kernel didn't show any improvement
- Broadwell showed 20% improvement over optimized KNL on BT and 4X improvement over all KNL executions on EP kernel (random number generation)

NAS Parallel Benchmark Evaluation (Cont'd)

NAS-SP (non-linear PDE), CLASS=B

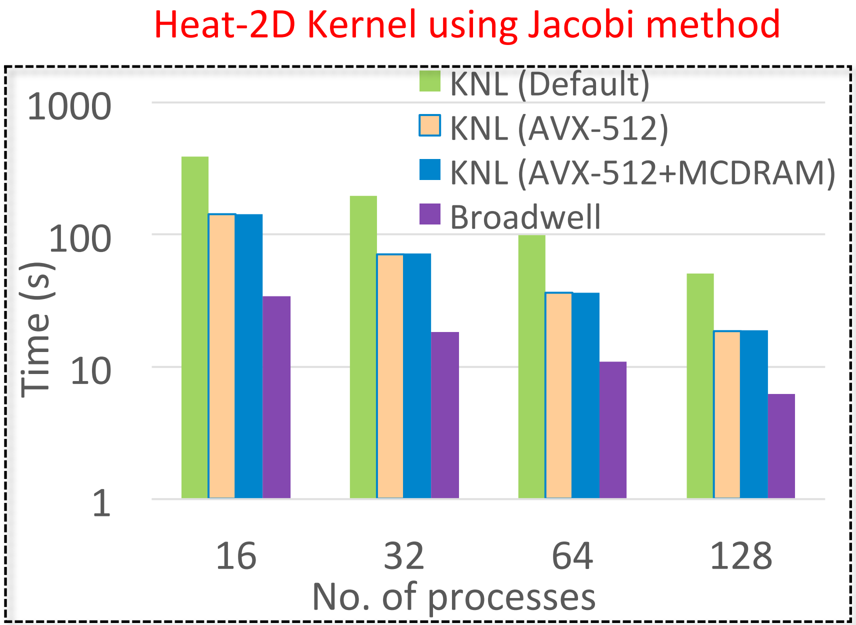


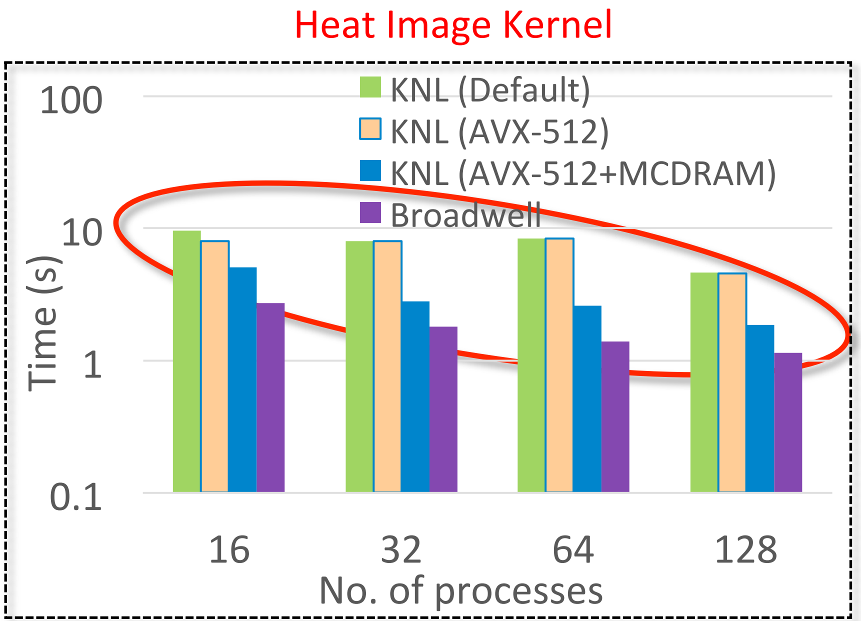
NAS-MG (MultiGrid solver), CLASS=B



- Similar performance trends are observed on BT and MG kernels as well
- On SP kernel, MCDRAM based execution showed up to 20% improvement over default at 16 processes

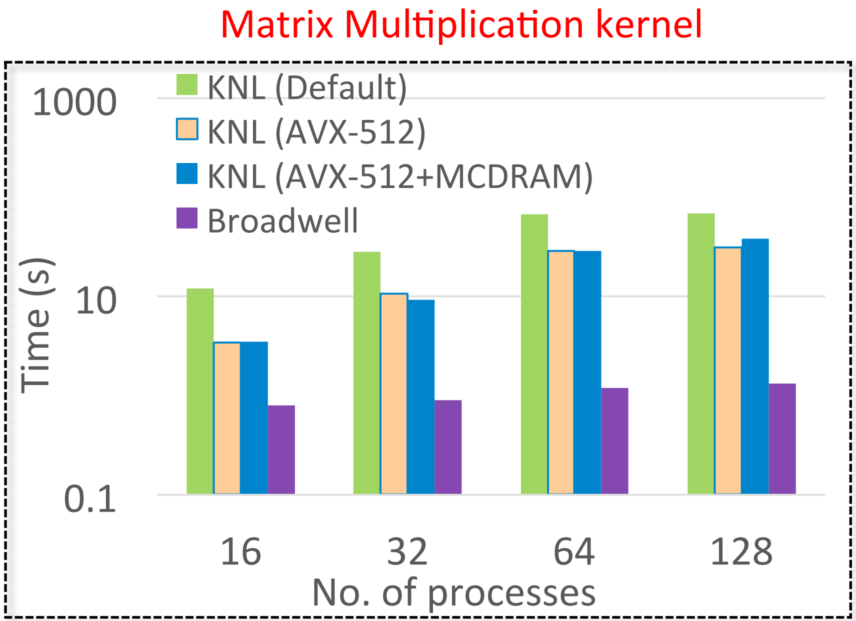
Application Kernels Evaluation

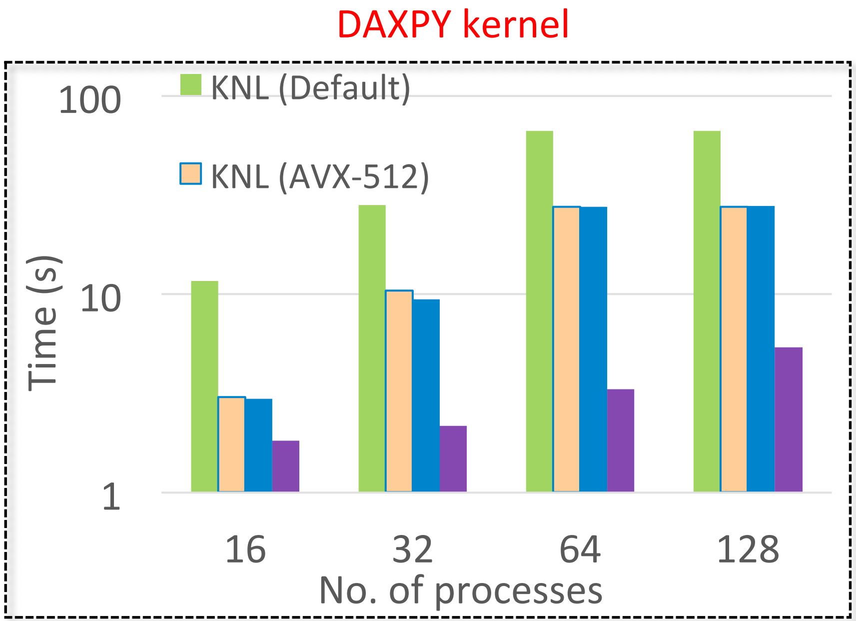




- On heat diffusion based kernels AVX-512 vectorization showed better performance
- MCDRAM showed significant benefits on Heat-Image kernel for all process counts. Combined with AVX-512 vectorization, it showed up to 4X improved performance

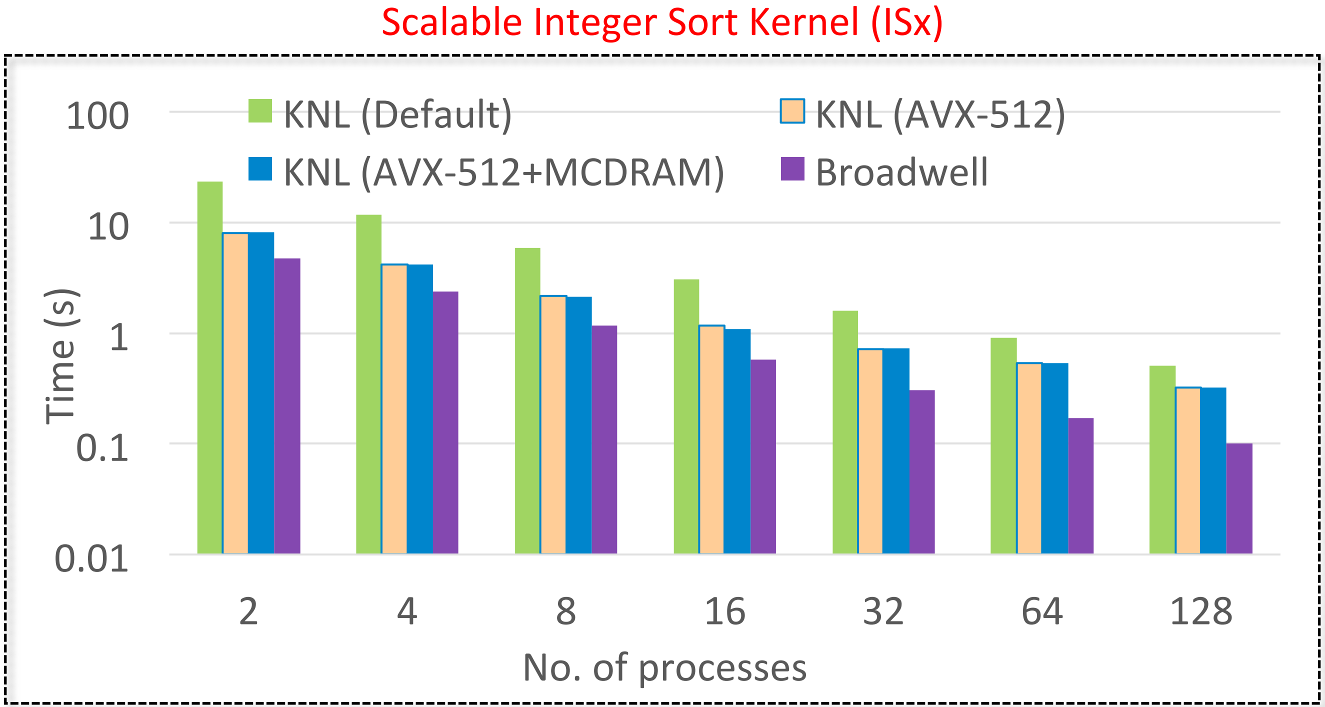
Application Kernels Evaluation (Cont’d)





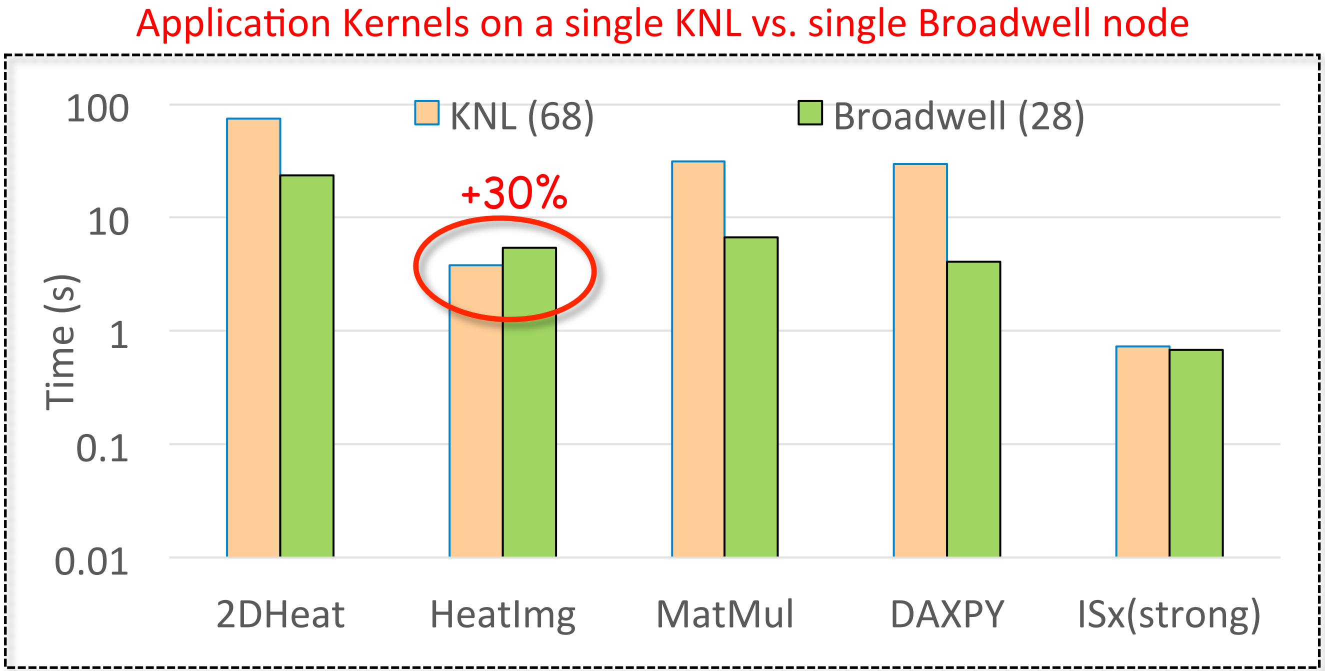
- Vectorization helps in matrix multiplication and vector operations
- Due to heavily compute bound nature of these kernels, MCDRAM didn’t show any significant performance improvement

Application Kernels Evaluation (Cont'd)



- Up to 3X improvement on un-optimized execution is observed on KNL
- Broadwell showed up to 2X better performance for core-by-core comparison

Node-by-node Evaluation using Application Kernels



- A single node of KNL is evaluated against a single node of Broadwell using all the available physical cores
- HeatImage showed better performance than Intel Xeon

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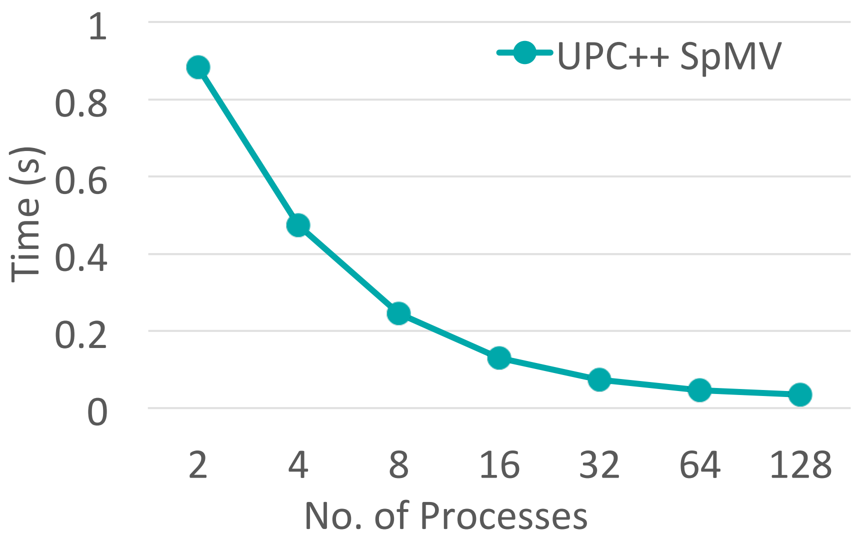
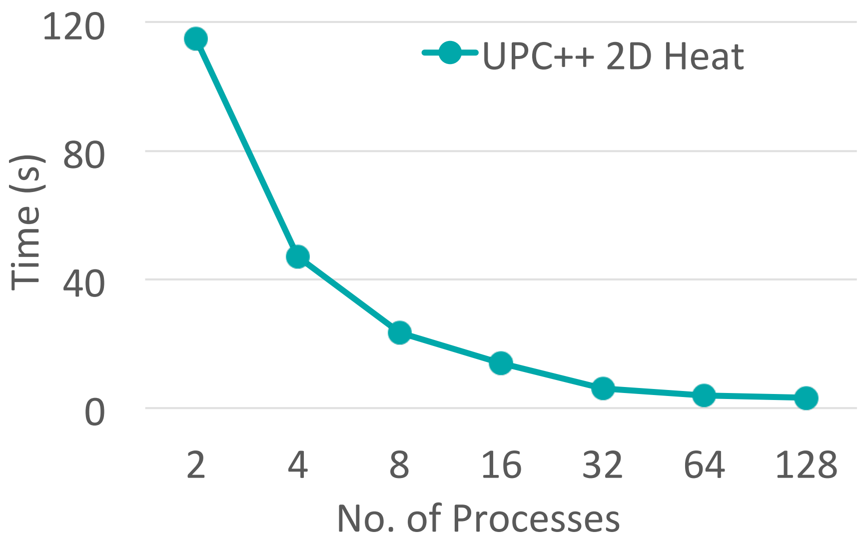
UPC++ Application Kernels Performance on KNL

- Developed and Used two application kernels to evaluate UPC++ model using MVAPICH2-X as communication runtime
- Sparse Matrix Vector Multiplication (SpMV)
- Adaptive Mesh Refinement (AMR) kernel
  - 2D-Heat conduction using Jacobi iterative

Application Kernels Performance of UPC++ on MVAPICH2-X



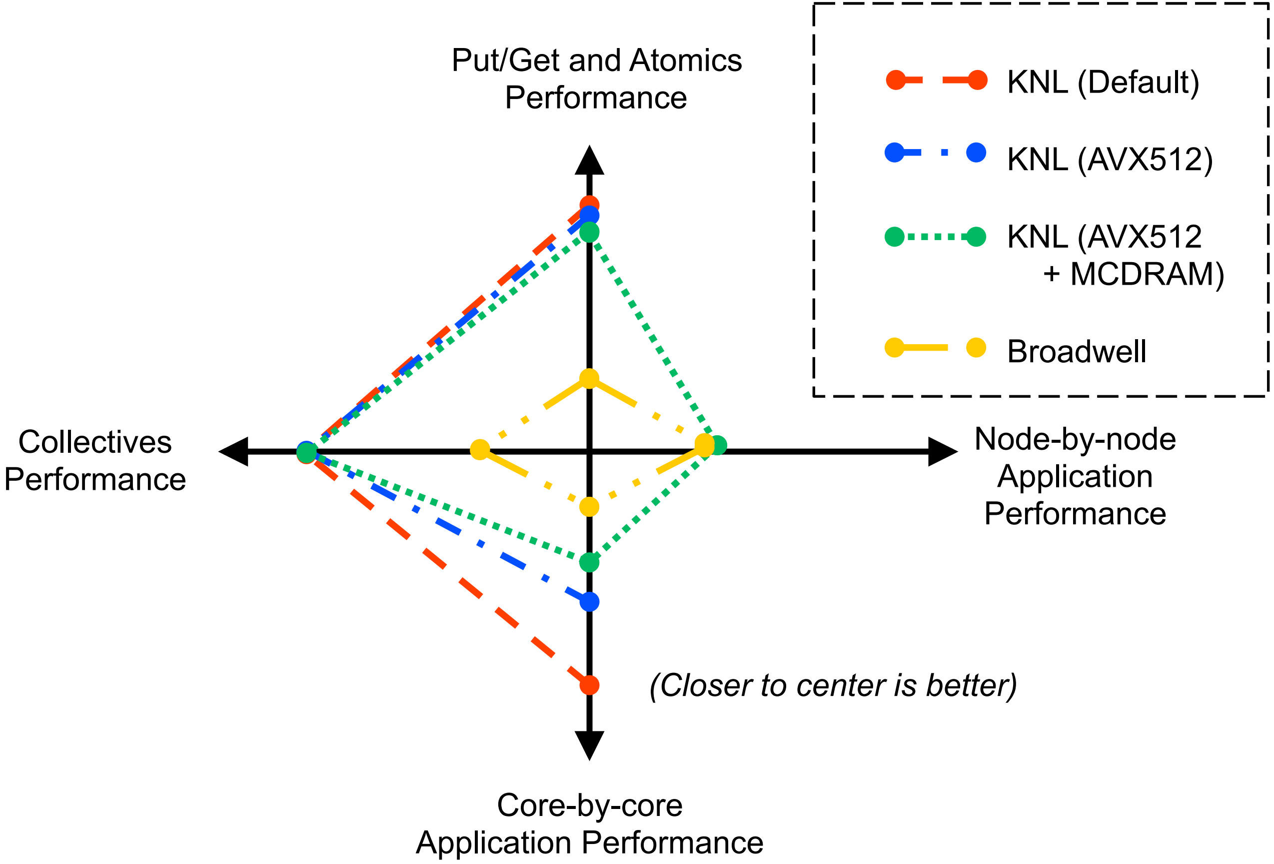
Strong-scaling Performance of SpMV kernel (2Kx2K)



Strong-scaling Performance of 2D-Heat kernel (512x512)

- SpMV and 2D Heat kernels using MVAPICH2-X shows good scalability on increasing number of processes of KNL

Performance Results Summary



Conclusion

- Comprehensive performance evaluation of MVAPICH2-X based OpenSHMEM, UPC, and UPC++ models over the KNL architecture
- Observed significant performance gains on application kernels when using AVX-512 vectorization
  - 2.5x performance benefits in terms of execution time
- MCDRAM benefits are not prominent on most of the application kernels
  - Lack of memory bound operations
- KNL showed up to 3X worse performance than Broadwell for core-by-core evaluation
- KNL showed better or on-par performance than Broadwell on Heat-Image and ISx kernels for Node-by-Node evaluation
- The runtime implementations need to take advantage of the concurrency of KNL cores

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