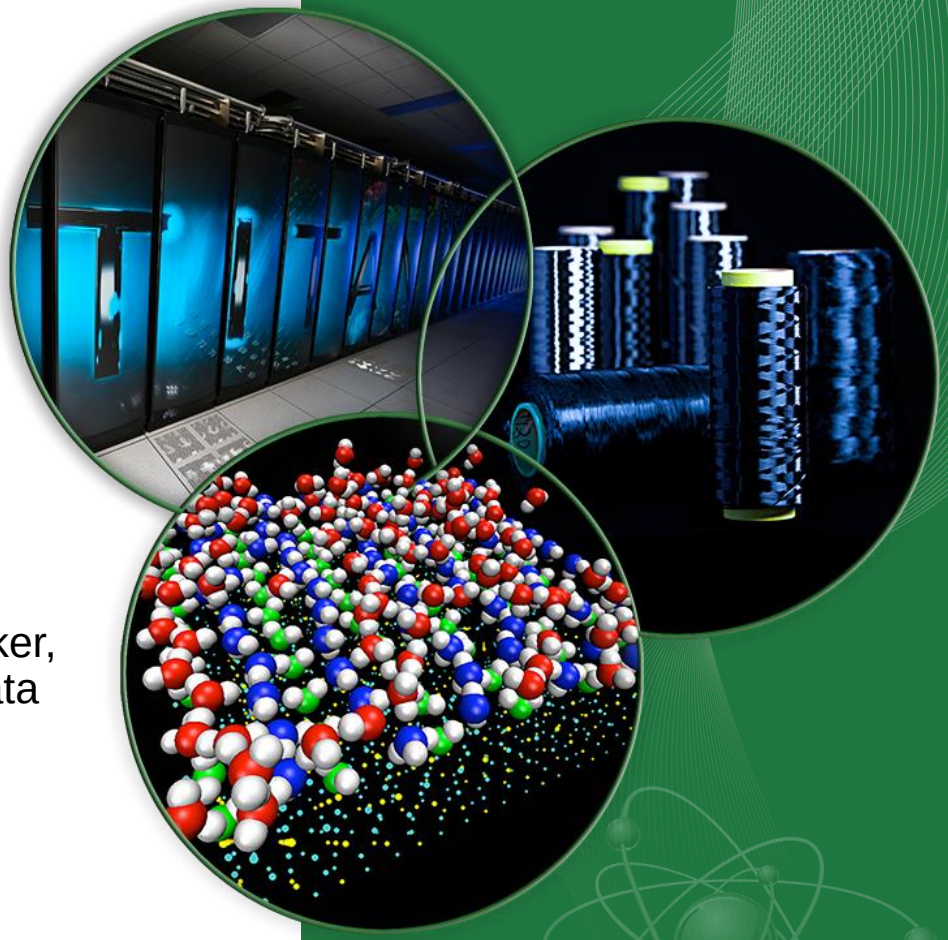
Oak Ridge National Laboratory
Computing and Computational Sciences Directorate

Oak Ridge OpenSHMEM Benchmark Suite



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Talk Summary

- Introduce a set of benchmarks to aid assessment of OpenSHMEM by users & implementors

- Outline
  - Overview of benchmarks in suite
  - Highlight multithreaded enhancements
  - Basic usage and results for illustration

OpenSHMEM Benchmark (OSB) Suite

- Collection of codes ported to use OpenSHMEM
  - Micro-benchmarks
  - Mini-applications / compute kernels
- Target users
  - System implementors
  - Application developers
- Example use cases
  - Assess effects of different implementation strategies
  - Assess performance of different library implementations

OSB Suite

"Mini" Applications

- Graph500 (search/graphs)
- SSCA1 (search/text)
- NPB (compute kernels)

Synthetic Benchmarks

- GUPS (memory)
- SHOMS (oshmem API)

Benchmark	Single Threaded	Multithreaded
Graph500	YES	YES
SSCA1	YES	YES
NPB	YES	NO
GUPS	YES	YES
SHOMS	YES	N/A

Experimental Environments

- **“Turing”**
  - 16-node Linux cluster
  - RHEL 7.4
  - Intel Xeon E5-2660 2.6Ghz
  - 64GB memory / node
  - Mellanox ConnectX-5
- **“EOS”**
  - 736-node Cray XC30
  - CrayOS 5.2.82
  - Intel Xeon E5-2670
  - 64GB memory / node
  - Aries network
- **OpenSHMEMs**
  - Cray-shmem 7.7.0
  - OpenSHMEM-X “devel” (w/ ucx)
  - SOS 1.4.1 (w/ libfabric-cray)

Graph500

- Benchmark to represent data intensive workloads
  - Breadth-First Search (BFS) on large undirected graphs
  - Fine-grained communication
  - Sparse spatial & temporal locality
- Input parameters
  - Problem (graph) size : *scale_factor* & *edge_factor*
    - Number of vertices = 2^{scale_factor}
    - Number of edges = 2 x *edge_factor*
  - Memory required:
    - Example: (2^{24} x (2 x **16**)) x 8 (bytes) = 4MB

scale_factor = 24 *edge_factor* = 16

Graph500

- Roughly three phases
  1. Graph edges generated (Kronecker algorithm)
     - Parameters: *scale_factor* & *edge_factor*
  2. BFS - Randomly designate 64 vertices as “root” vertices, build tree from the “root” vertex, .
  3. BFS is validated for correctness

  – Time measured for all three phases
- Metric
  – TEPS = Number of Traversed Edges Per Second
  – * Also *mean_time* for BFS steps

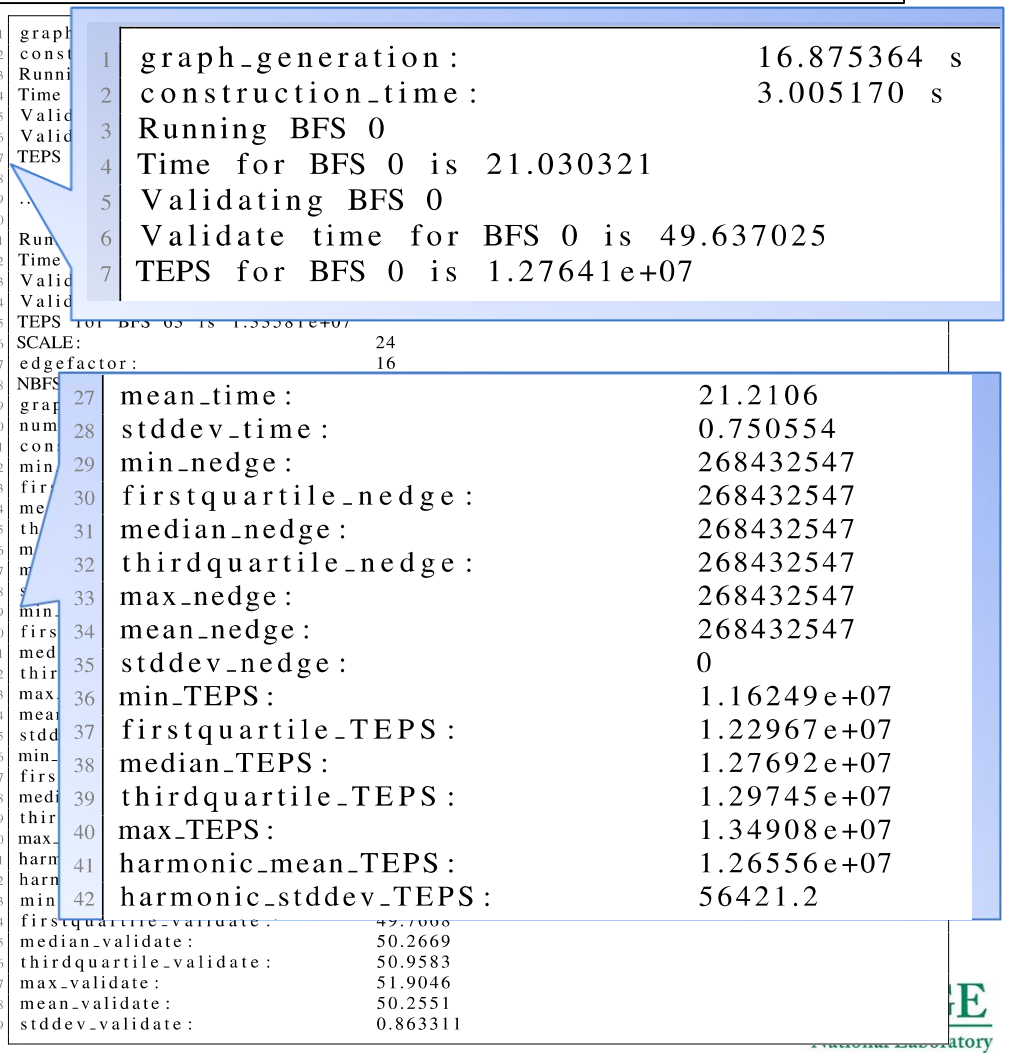
Graph500 OpenSHMEM

- OpenSHMEM version
  - Adapted from MPI version
  - Graph in symmetric heap & partitioned among PEs
  - Vertices & edges accessible to all PEs via OSHMEM
  - During BFS tracks vertex status (visited/discovered/...)
    - Use shmem_put & AMO instead of MPI_Accumulate for updating queues of vertices (e.g., discovered vertices)
- Multithreaded
  - OpenMP threads parallelize workload of BFS
  - Partition discovered vertices among threads
  - Thread executes BFS on vertices in its partition
  - OpenSHMEM context per thread to separate operations

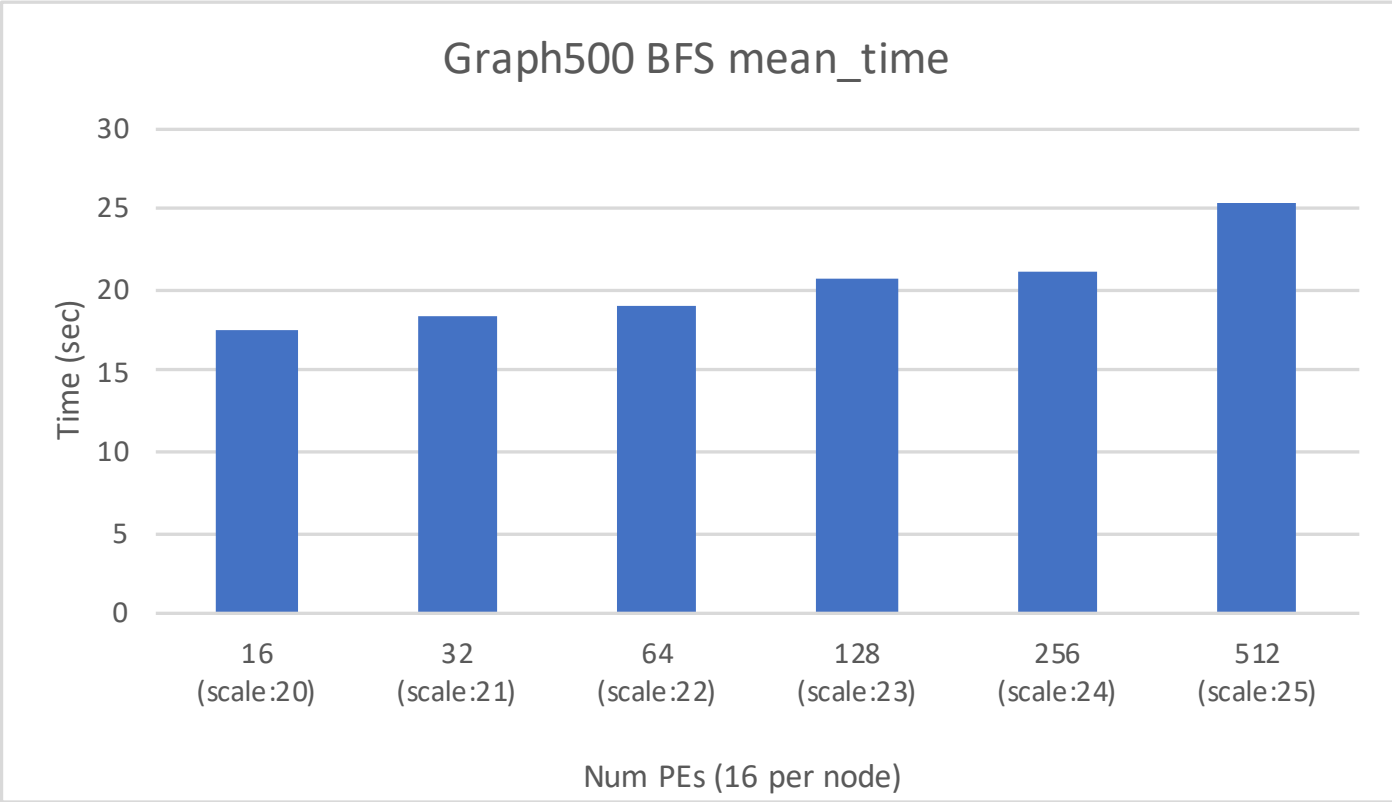
Graph500 Usage & Results

To Execute:
cd mpi/
oshrun –np 32 ./graph500_shmem_one_sided 24 16

- Environment variables
  - SHORT_VALIDATION (8 BFS)
  - SKIP_VALIDATION



Graph500 Usage & Results



- Time for BFS scaling up #PEs (16-512) & scale_factor (20-25)
- Using OpenSHMEM-X on Turing

SSCA1

- SSCA1: Scalable Synthetic Compact Applications 1
  - Sequence alignment algorithm with gap scoring
  - Implemented as dynamic programming algorithm
  - Similarity matrix simulates DNA codon to protein encoding
  - Compare characters in text strings for matches (score)
  - Scoring sequence based on presence of a gap
- Input parameters
  - Problem size: **SCALE** environment variable (integer)
- Metric
  - Time to solution (elapsed time)

SSCA1

- Variants
  - Single threaded: OpenSHMEM or MPI-3 one sided
  - Multithreaded: OpenSHMEM specific
- Application workflow
  - Structure: Outer / Inner loop
  - Many small messages (puts & gets) in inner loop
    - Inner loop: 5 small gets (must finish on each inner loop)
    - Inner loop: 3 small puts (must finish before starting outer loop)
- OpenSHMEM Multithread
  - Outer loop solving a diagonal in matrix (not parallelizable)
  - Inner (parallel) loop solves each entry in the diagonal
  - Inner loop using OpenMP threads

SSCA1 Usage & Results

To Execute:

```
export  SCALE=31
export OMP_NUM_THREADS=4          # If using threaded variant
oshrun –np 256  ./ssca1
```

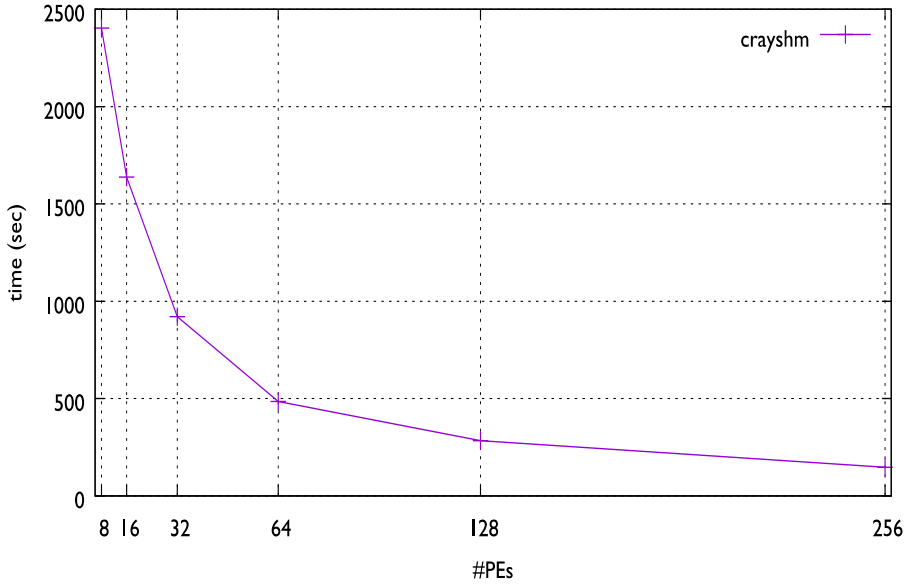
```
Running with OpenMP, thread count: 8
Running with OpenMP, thread count: 8
Running with OpenMP, thread count: 8
Running with OpenMP, thread count: 8
Runni
...<s
Begin

   Ela


Begin

   Ela


Found

Start
posit


veri
   10
  230

verify
  138
     gagaacgactga      13856
  37081  *STARTGAPMIDST—END*  tgaagcacggcgaggacg————
     atgatagacagcacgggggcgccggagaacgactga      37098

...<snip>...
```

```
verifyAlignment 0, succeeded; score 55:
  26590  *IDENTICAL*  tgaatagacgagaacacgatatgcgcgctgt
  29129  *IDENTICAL*  tgaatagacgagaacacgatatgcgcgctgt

verifyAlignment 1, succeeded; score 54:
   1039  *MISQRMATCHES*  tgaatgataagccagaggatggcgacg
  23093  *MISQRMATCHES*  tgaatgataagcaggcagatggcgacg

verifyAlignment 2, succeeded; score 53:
  13839  *STARTGAPMIDST—END*  tgaagcacggcgaggacgggg
     gagaacgactga      13856
  37081  *STARTGAPMIDST—END*  tgaagcacggcgaggacg——
     atgatagacagcacgggggcgccggagaacgactga      37098
```

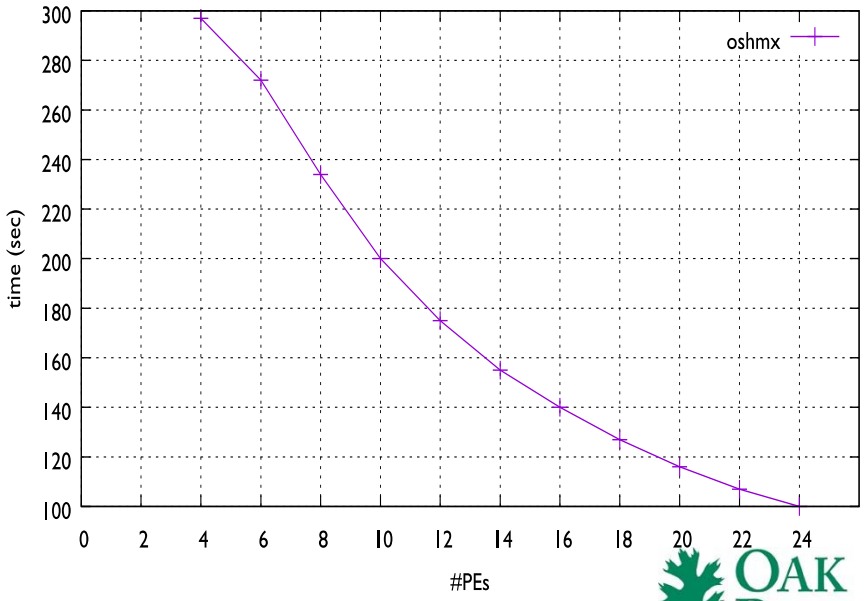
SSCA1 Usage & Results

```
  # OpenSHMEM-X execution line (Turing SSCA1-threaded)
orterun \
        –hostfile hosts \
        –bind-to socket \
        –map-by ppr:2:node \                    # Num PEs per node
        –np 4 \                                 # Num PEs (total)
        –x OMP_NUM_THREADS=8 \                  # Num Threads per PE
        –x SCALE=32 \                           # Problem size
       ./ssca1
```

EOS SSCA1



Turing SSCA1-threaded



NPB

- NPB: NAS Parallel Benchmarks
  - Application kernels for common scientific algorithms
  - OpenSHMEM versions adapted from MPI variants
  - Single threaded OpenSHMEM versions
- Benchmarks / Mini-apps
  - BT: Block Tri-diagonal solver, CFD mini-app (Fortran)
  - SP: Scalar Penta-diagonal solver, CFD mini-app (Fortran)
  - MG: Multi-Grid, long/short distance communication, memory intensive (Fortran)
  - IS: Integer Sort – random memory access (C)
- Metric
  - MOPS – Millions of Operations Per Second

NPB

- OpenSHMEM details
  - Adapted from MPI variants
  - IS: Integer Sort
    - Bucket sort, each process sorts random set of keys in their range
    - Uses put/get to simulate MPI AlltoAll/AlltoAllv to communicate keys
  - MG: Multi-Grid
    - Due to 1-sided communication, only require synchronization (barrier_all) to ensure updates are visible at all PEs & ensures all PEs at same stage
  - BT: Block Tri-diagonal solver
    - Uses gets when solving block tridiagonal equations
  - SP: Scalar Penta-diagonal
    - In OSHMEM case SP has better comp/comm overlap b/c synchronize only when communicated data is used

NPB Usage & Results

To Execute:

```
oshrun –np <nprocs>  ./bin/<benchmark-name>.<class>.<nprocs>
          # where
          #    <benchmark-name>  is  "is", "mg", ”bt” or "sp"
          #    <nprocs>          is  the number of processes
          #    <class>           is  "S", "W", "A", "B", "C", or "D"
```

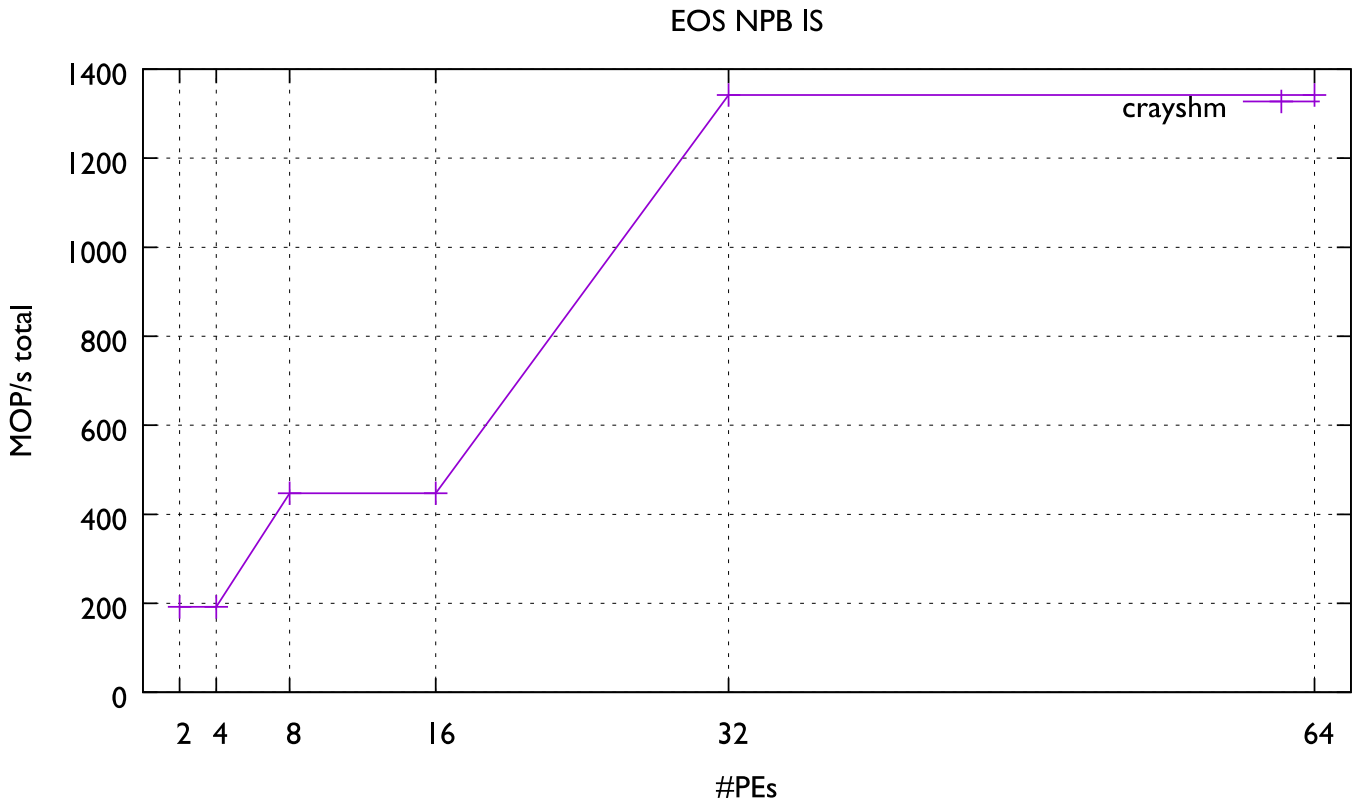
Example:

```
oshrun –np 32 ./bin/is.C.32
```

```
 9  IS Benchmark Completed
10  Class             =                        C
11  Size              =                134217728
12  Iterations        =                       10
13  Time in seconds   =                     1.00
14  Total processes   =                       32
15  Compiled procs    =                       32
16  Mop/s total       =                  1342.18
17  Mop/s/process     =                    41.94
...
CMPI_LIB      = (none)
CMPI_INC      = (none)
CFLAGS        = -O3 -g
CLINKFLAGS    = -O3 -g
...<snip>...
```

NPB Usage & Results

```
# cray-shmem with ALPS launcher

aprun –d 16 –S 1 –n $NPROCS  ./bin/is.C.$NPROCS
```



GUPS

- GUPS: Giga Updates per Second
  - Adapted from Random Access Benchmark
  - Randomly generate address & PE where update occurs
  - Number memory locations randomly updated in 1sec/1 billion
    - “Randomly” - no relationship between locations in address space
    - “Update” – read-modify-write on table (HPCC_Table) of 64bit words
- Input parameters
  - (None)
    - Number of PEs used to automatically calculate table size
- Metric
  - GUPS – Giga Updates Per Second

GUPS

- OpenSHMEM implementation
  - Table (HPCC_Table) shared via symmetric heap
  - Modify uses get/put/quiet to ensure visible on remote PE
  - Based on spec v1.3 – feedback that v1.4 has atomic XOR

- Multithread variant
  - Use OpenMP for the threading
  - Each thread performs random updates of HPCC_Table
  - Use OpenSHMEM contexts to manage thread specific location information

GUPS Usage & Results

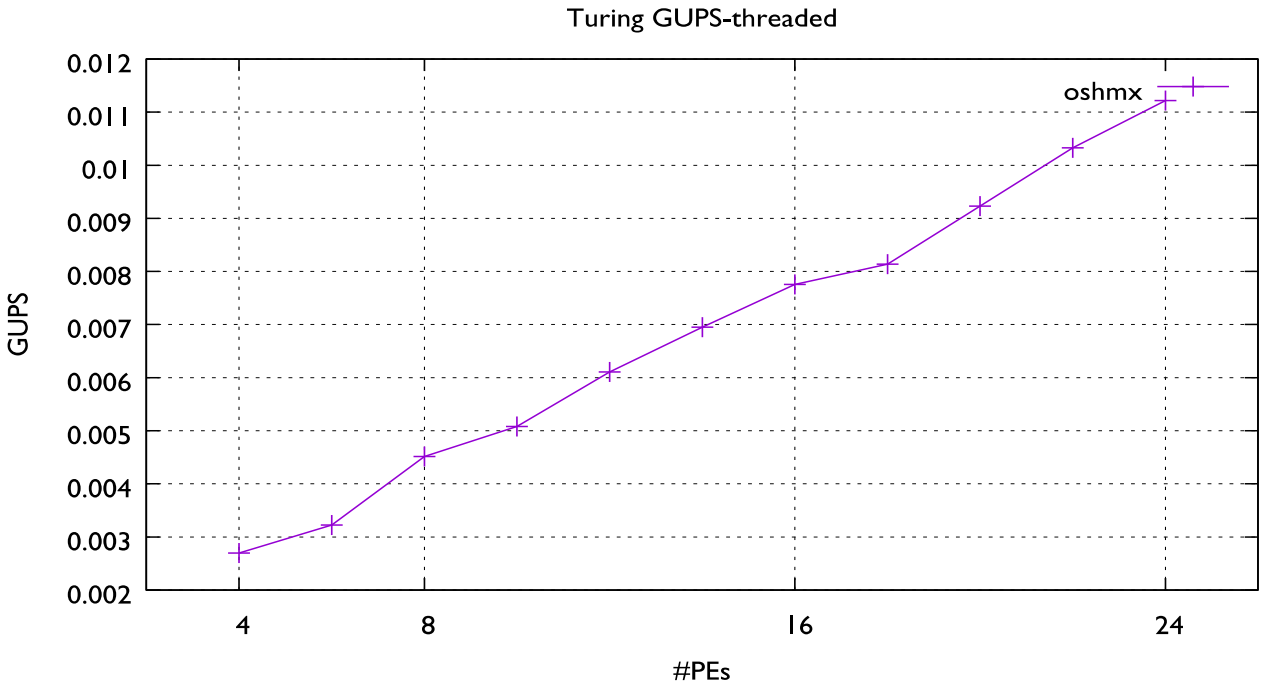
To Execute:
oshrun –np 32 ./gups

```
5 Real time used = 58.660473 seconds
6 0.004576087 Billion(10^9) Updates per second [GUP/s]
7 0.000143003 Billion(10^9) Updates/PE per second [GUP/s]
```

```
1 Runni
2 Total
3 PE Ma
4 Default number of                    = 268435456      and actually done =
      26843545
5 Real time used = 58.660473 seconds
6 0.004576087 Billion(10^9) Updates     per second [GUP/s]
7 0.000143003 Billion(10^9) Updates/PE per second [GUP/s]
```

GUPS Usage & Results

```
  # OpenSHMEM-X execution line (Turing GUPS-threaded)
orterun \
        –hostfile hosts \
        –bind-to socket \
        –map-by ppr:2:node \                    # Num PEs per node
        –np $NPROCS \                           # Num PEs (total)
        –x OMP_NUM_THREADS=10 \                 # Num Threads per PE
       ./gups
```



SHOMS

- SHOMS Micro-benchmark testing suite
  - Based on UOMS benchmark for UPC micro operations
  - Tests OpenSHMEM API
  - Minimal test of each function
- Metric(s)
  - Tests report latencies (min/max/avg)
  - Tests report bandwidth (when function transfers data)
- Highlights
  - Strictly test performance, not test correctness
  - "*Affinity Mode*": subset of tests run on 2 nodes to identify if a core is favored by OpenSHMEM on a particular node

SHOMS Usage & Results

To Execute:
oshrun –np 2 ./shoms [--input test-FEATURE.txt] [FLAGS…]

SHOMS flags

--off_cache: Shifts the data in the symmetric heap in an effort to disable the effects of caches on CPU.

--warmup: Do N/10 untimed iterations before doing N iterations in the main loop. Warms up hardware/caches.

--msglen: Points to a file with a set of message lengths. Put one number per line in the file and it will use N bytes per message for each line in the file.

--minsize: Starts tests a N bytes. Scales up by N*2 bytes on each iteration until it goes above maxsize. Default minsize is 8.

--maxsize: Ends when N*2 is greater than maxsize. Default maxsize is 16777216

--time: Soft limit of N seconds for each iteration. This will not interrupt network operations.

--output: File to write results to. Default stdout. Will truncate existing files.

--input: File that lists tests to perform. By default SHOMS will run all tests available. List one test per line.

--affinity: Run affinity test mode.

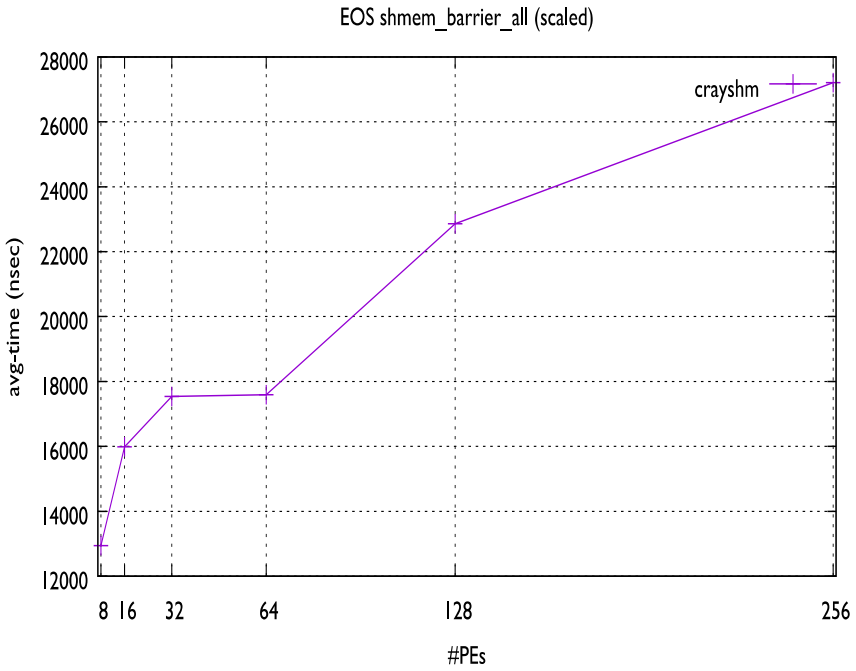
SHOMS Usage & Results

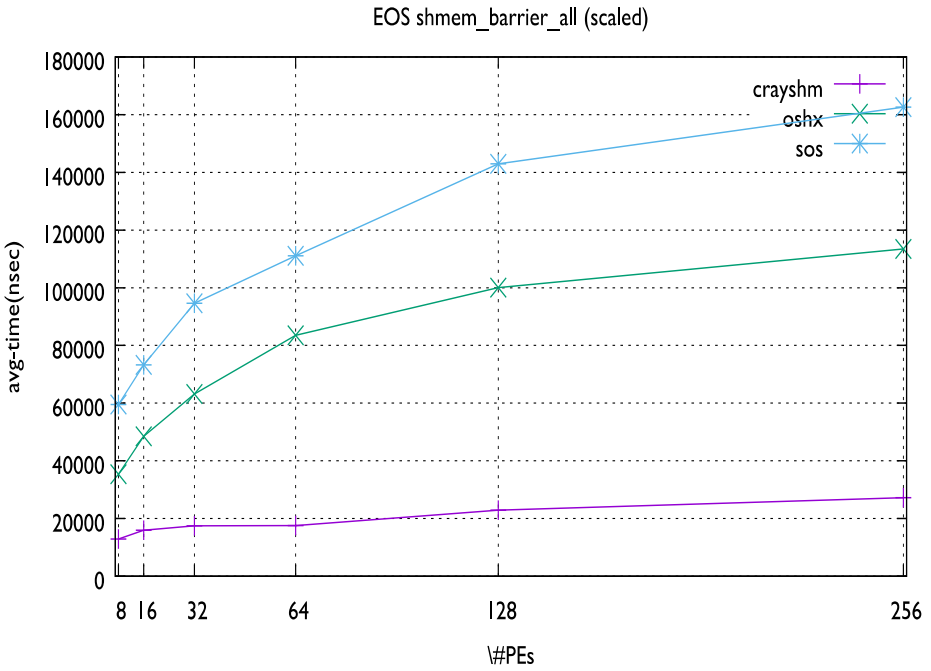
```
Using OpenSHMEM version 1.3
Created all test list.
Will be running with 128 different tests
Will be running with 22 different size configurations
Using OpenSHMEM version 1.3
Running tests

...<snip>...

#-------------------------------------------------
# Benchmarking shmem_barrier_all
# #processes = 8
#-------------------------------------------------
  #bytes  #repetitions  t_min[nsec]  t_max[nsec]  t_avg[nsec]
Bw_aggregated[MB/sec]
       N/A                1000           12345                43411
12937.99                                          N/A
```

...<snip>...

SHOMS Usage & Results

To Execute:
aprun –d 16 –S 1 –n *$NPES* ./shoms --input barrier.txt --maxsize 8





Summary

- Overview of OpenSHMEM Benchmark (OSB) suite
  - Included details on usage & example outputs/metrics
  - Used OSB with different OpenSHMEM implementations
- Highlight enhancements for multithreaded variants
  - Graph500, GUPS & SSCA1
- OSB Suite publicly available
  - Encourage community use & improvements

https://github.com/ornl-languages/osb

Publications where OSB codes appeared

- [2] M. Baker, F. Aderholdt, M. Gorentla Venkata, and P. Shamis. **OpenSHMEM-UCX: Evaluation of UCX for Implementing OpenSHMEM Programming Model**. OpenSHMEM'16.
- [3] M. Baker, A. Welch, and M. Gorentla Venkata. **Parallelizing the Smith-Waterman Algorithm Using OpenSHMEM and MPI-3 One-Sided Interfaces**. OpenSHMEM'15.
- [4] A. Bouteiller, S. Pophale, S. Boehm, M. Baker, and M. Gorentla Venkata. **Evaluating Contexts in OpenSHMEM-X Reference Implementation**. OpenSHMEM'17.
- [6] E. F. D'Azevedo and N. Imam. **Graph500 in OpenSHMEM**. OpenSHMEM'15.
- [11] S. Pophale, R. Nanjegowda, H. Jin, B. Chapman, A. Curtis, S. Poole, and J. A. Kuehn. **OpenSHMEM Performance and Potential: A NPB Experimental Study**. Proc. of PGAS-12, 2012.
- [14] P. Shamis, M. Gorentla Venkata, S. Poole, A. Welch, and T. Curtis. **Designing a High Performance OpenSHMEM Implementation Using Universal Common Communication Substrate as a Communication Middleware**. OpenSHMEM'14.

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Questions?