OpenSHMEM Sets and Groups: An Approach to Worksharing and Memory Management

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Current Look at Collectives in OpenSHMEM

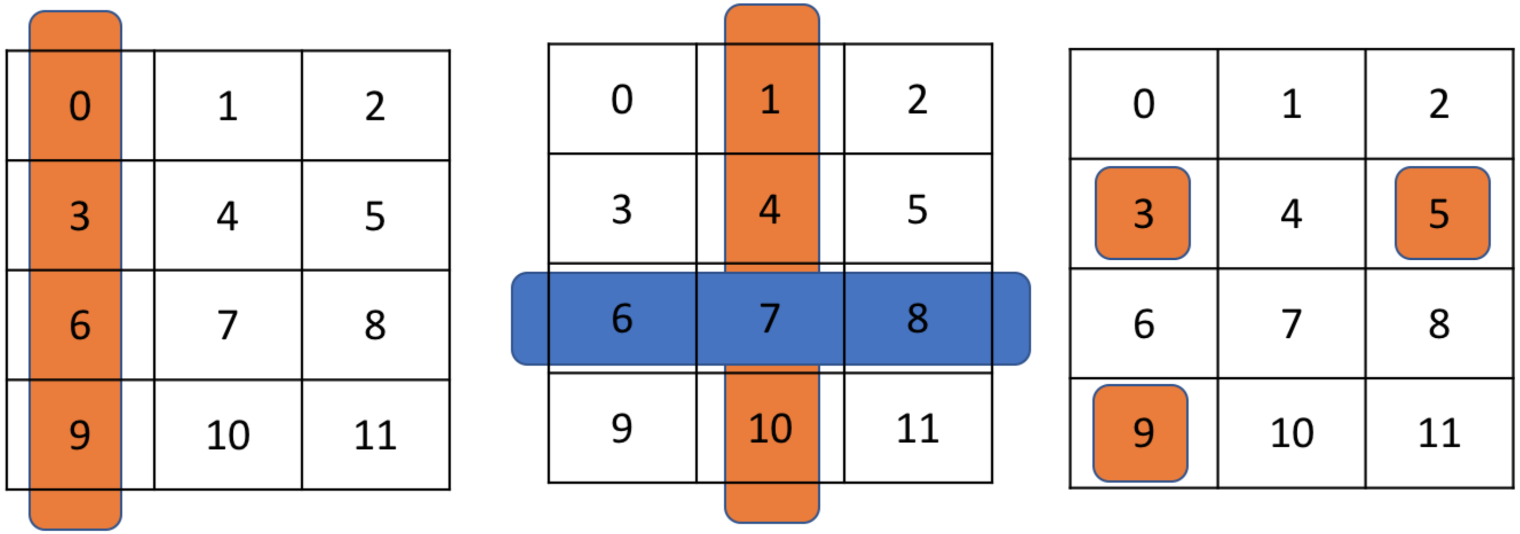
- Collective operations defined over active sets
  - Temporary grouping of PEs
  - Triple of information: starting PE, log base 2 stride, and size
  - Requires Users allocate and initialize their own resources for collectives
    - Synchronization (pSync) and scratchpad (pWrk) buffers
- Need to re-evaluate this concept for future systems
  - **Goal**: flexible, persistent groupings of PEs that have library managed resources

Possible solution?

- Teams
  - Grouping of PEs
  - Created using with strided, 2D, 3D, and color-based split
    - Collective operation over PEs of the parent team
  - Fulfills the persistent grouping of Pes from our goals
  - Did not have library managed resources
    - Users required to allocate and initialize resources
- Our solution: **Sets and Groups**
  - Decoupling of definition (i.e., Sets) and creation (i.e., Groups)
    - Creation collective postponed until needed, and only over Pes in the Group
  - Allocates and initializes resources on Users behalf
  - **Fulfills all of our goals**

Sets

- A group of PEs
  - Indexed based on positive integers monotonically increasing from zero
    - PEs not in the set have a negative index
- Opaque to users
- Created based on:
  - Strides and ranges
  - Modified with unions, intersections, and differences
- Enables:
  - Strided Sets
  - Multiple Strided Sets
  - Disjoint Sets



Sets

- Set creation is a local operation; requires no communication between PEs
  - Local operation: All PEs will calculate the same Set given valid initial Sets
    - Strides and ranges are simple calculations; Unions and Intersections result in the same set
  - Based on a parent Set
- Library provided sets: SHMEM_SET_WORLD, SHMEM_SET_EMPTY
- Set utility interfaces give the user the ability to:
  - Query the size of the set
  - Get the calling PE's index
  - Translate indices between Sets

Sets API (summary)

- Strided creation:
  - int **shmem_create_set_strided**(shmem_set_t * parent_set,

```
int shmem_create_set_strided(shmem_set_t * parent_set,
                             int index_start,
                             int index_stride,
                             int size,
                             shmem_set_t ** new_set);
```

- Range creation:

```
int shmem_create_set_range(shmem_set_t * parent_set,
                           int low_index,
                           int high_index,
                           shmem_set_t ** new_set);
```

Sets API (summary)

- Union/Intersection/Difference
  - ```
    int shmem_set_union(shmem_set_t * set1,
                        shmem_set_t * set2,
                        shmem_set_t ** new_set);
    ```
  - Intersection and Difference interfaces are similar…
    ```

Groups

- A grouping of a valid Set with the resources required for collective operations
  - Resources may include: pSync/pWrk buffers, hardware collective resources, etc.
- Opaque to the user
- Group creation is a collective operation
  - Collective over the Set
  - Ordering provided by the library
  - Blocking operation

Groups API (summary)

- Creation operations
  - Create Group from Set
  - Create Group using a color-based split
  - Duplicate valid Group
- Query operations
  - Determine the size of the group
  - Retrieve the Set the Group is based on

Example of the Difference Between Active Sets and Sets/Groups

```
/*Only odd PEs*/
if (my_pe % 2) {
    /*Some Work*/
    shmem_broadcast64(dest,src,4,0,1,1,(npes/2),pSync3);
    /*Some Work*/
    shmem_barrier(1,1,(npes/2),pSync1);
}
/*All PEs except PE 0*/
if (my_pe > 0) {
    /*Some Work*/
    shmem_broadcast64(dest,src,4,0,1,0,npes-1,pSync4);
    /*Some Work*/
    shmem_barrier(1,0,npes-1,pSync2);
}
shmem_alltoall64(dest,source,4,0,0,npes,pSync5);
```

- Performing 5 collectives over 3 active sets
  - Active Set of odd PEs
  - Active Set of PEs greater than 0
  - Active Set of all the World PEs

Example of the Difference Between Active Sets and Sets/Groups

```
/* Required - Allocating symmetric synchronization arrays */
long * pSync1 = (long *) shmem_malloc(sizeof(long) *
SHMEM_BARRIER_SYNC_SIZE);
long * pSync2 = (long *) shmem_malloc(sizeof(long) *
SHMEM_BARRIER_SYNC_SIZE);
long * pSync3 = (long *) shmem_malloc(sizeof(long) *
SHMEM_BCAST_SYNC_SIZE);
long * pSync4 = (long *) shmem_malloc(sizeof(long) *
SHMEM_BCAST_SYNC_SIZE);
long * pSync5 = (long *) shmem_malloc(sizeof(long) *
SHMEM_ALLTOALL_SYNC_SIZE);
...
/* Required - Initializing symmetric synchronization arrays */
for (int i = 0; i < SHMEM_BARRIER_SYNC_SIZE; i++) {
    pSync1[i] = SHMEM_SYNC_VALUE;
    pSync2[i] = SHMEM_SYNC_VALUE;
}
for (int j = 0; j < SHMEM_BCAST_SYNC_SIZE; j++) {
    pSync3[j] = SHMEM_SYNC_VALUE;
    pSync4[j] = SHMEM_SYNC_VALUE;
}
for (int k = 0; k < SHMEM_ALLTOALL_SYNC_SIZE; k++) {
    pSync5[k] = SHMEM_SYNC_VALUE;
}
```

Allocate pSync arrays

Initialize pSync arrays

Example of the Difference Between Active Sets and Sets/Groups

```
/*Only odd PEs*/
if(my_pe % 2){
    /*Some Work*/
    shmem_group_broadcast64(dest, src, 4, 0, group_odd);
    /*Some Work*/
    shmem_group_barrier(group_odd);
}
/*All PEs except PE 0*/
if(my_pe > 0){
    /*Some Work*/
    shmem_group_broadcast64(dest, src, 4, 0, group_gz);
    /*Some Work*/
    shmem_group_barrier(group_gz);
}
shmem_group_alltoall64(dest, source, 4, group_world);
```

- Becomes 5 collectives with 3 Groups
- Does not really look like much changed…

Example of the Difference Between Active Sets and Sets/Groups

```
shmem_set_t * set_odd, * set_gz;
shmem_group_t * group_odd, * group_gz, * group_world;

shmem_create_set_strided(SHMEM_SET_WORLD, 1, 2, npes / 2, &set_odd);
shmem_create_set_range(SHMEM_SET_WORLD, 1, npes - 1, &set_gz);

shmem_create_group_from_set(set_odd, &group_odd);
shmem_create_group_from_set(set_gz, &group_gz);
shmem_create_group_from_set(SHMEM_SET_WORLD, &group_world);
```

- More has changed here
  - User no longer needs to allocate and initialize the buffers used for the pSync arrays
  - User creates 2 Sets and 3 Groups
    - Allocation and Initialization handled by library

Sets Implementation

- Implementation focuses on minimizing memory usage
  - Stores Set as a stride or list of strides depending on mathematical relationship between Pes
    - E.g., A Set with Pes {0, 1, 2, 3} is stored as a strided Set with a stride of 1; A set with Pes {0, 2, 3, 4} is stored as a list of strides (2)

- Each modification of a set (i.e., Union, Intersection, Difference) will attempt to collapse the Set to a simpler representation
  - The union of sets {0, 2, 3, 4} and {0, 1, 2, 3, 4} results in a single, strided set {0, 1, 2, 3, 4}

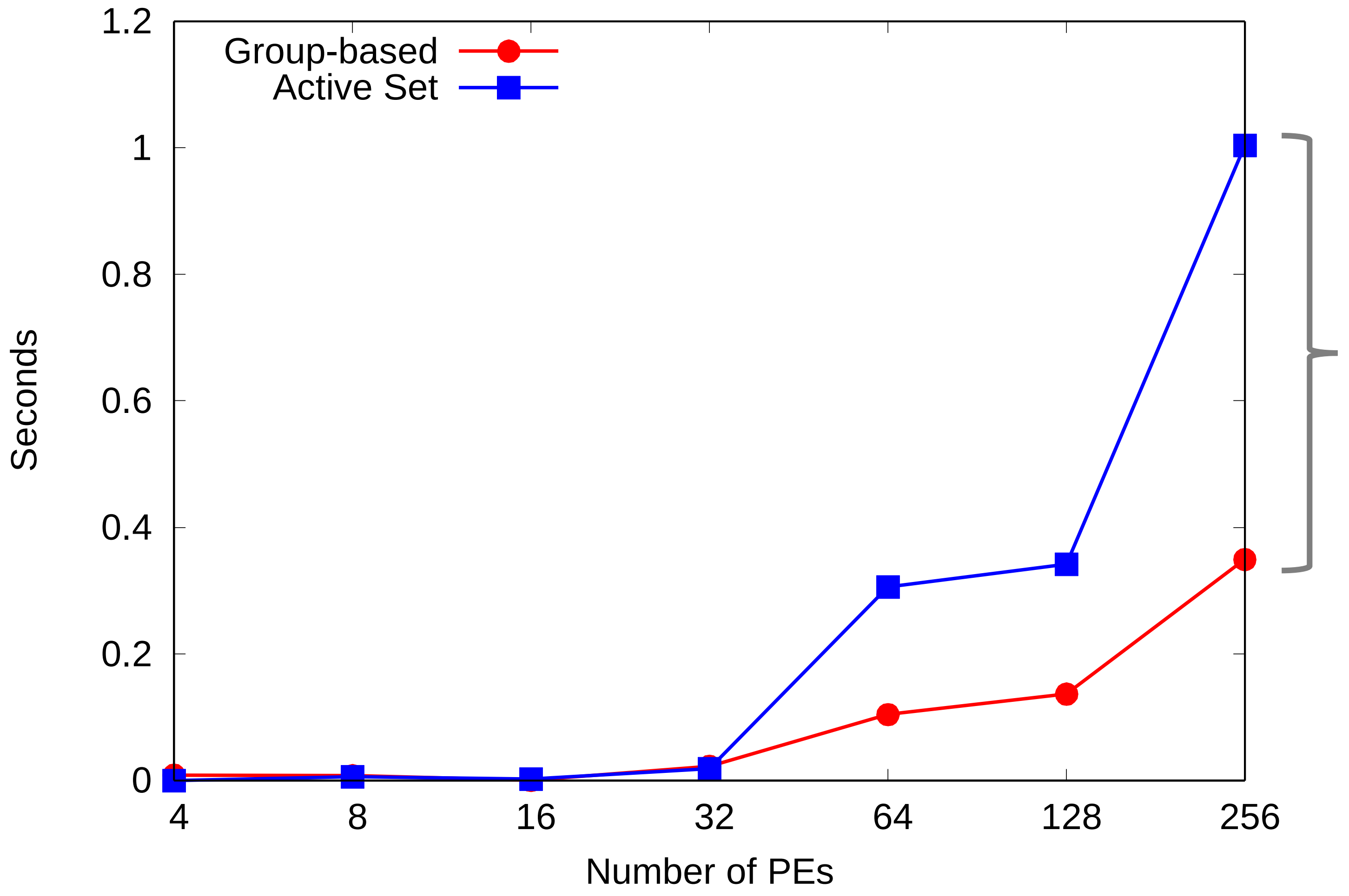
Groups Implementation

- Extended collectives interfaces to support Groups
  - Barrier, Reductions, Collect, etc.
    - As a proof of concept and for the sake of comparison, implemented algorithms are identical
- Implementation of Groups as proof of concept
  - Creation operations linear in nature
    - Can be improved with respect to performance

Evaluation of the Example

- Testbed: 16 node Turing cluster at ORNL
  - Each node: two Intel Xeon processors with 20 logical cores, 128 GB of RAM and a ConnectX-4 InfiniBand interconnect
- Evaluation: Measure the overall execution time
  - Gives us an initial understanding of the performance implications of Sets and Groups

Evaluation of the Example

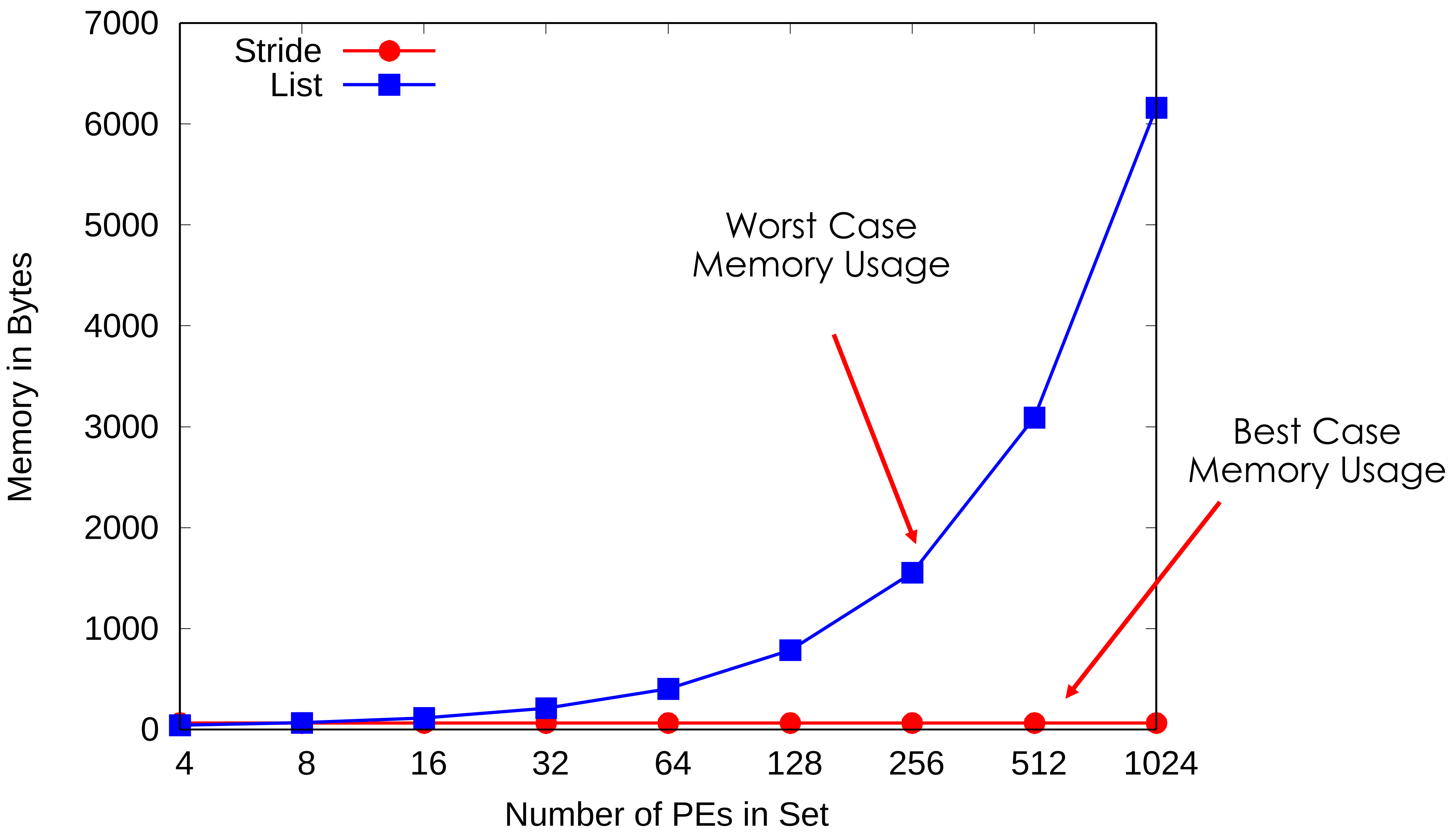


1/3 of the execution time

Experimental Evaluation

- Goals of evaluation
  1. Evaluate Sets memory usage requirements
  2. Overhead of collectives using Groups
  3. Demonstration of Sets/Groups with All-Pairs Shortest Path with a synthetic dataset
- Testbeds at OLCF:
  - Eos (1 & 2)
    - Each node: two 8-core Intel Xeon processors, 64 GB of memory, and Aries interconnect
  - Titan (3)
    - Each node: one 16-core AMD Opteron processors, 32 GB of memory, and the Gemini interconnect

Evaluation: Sets Memory Usage based on representation



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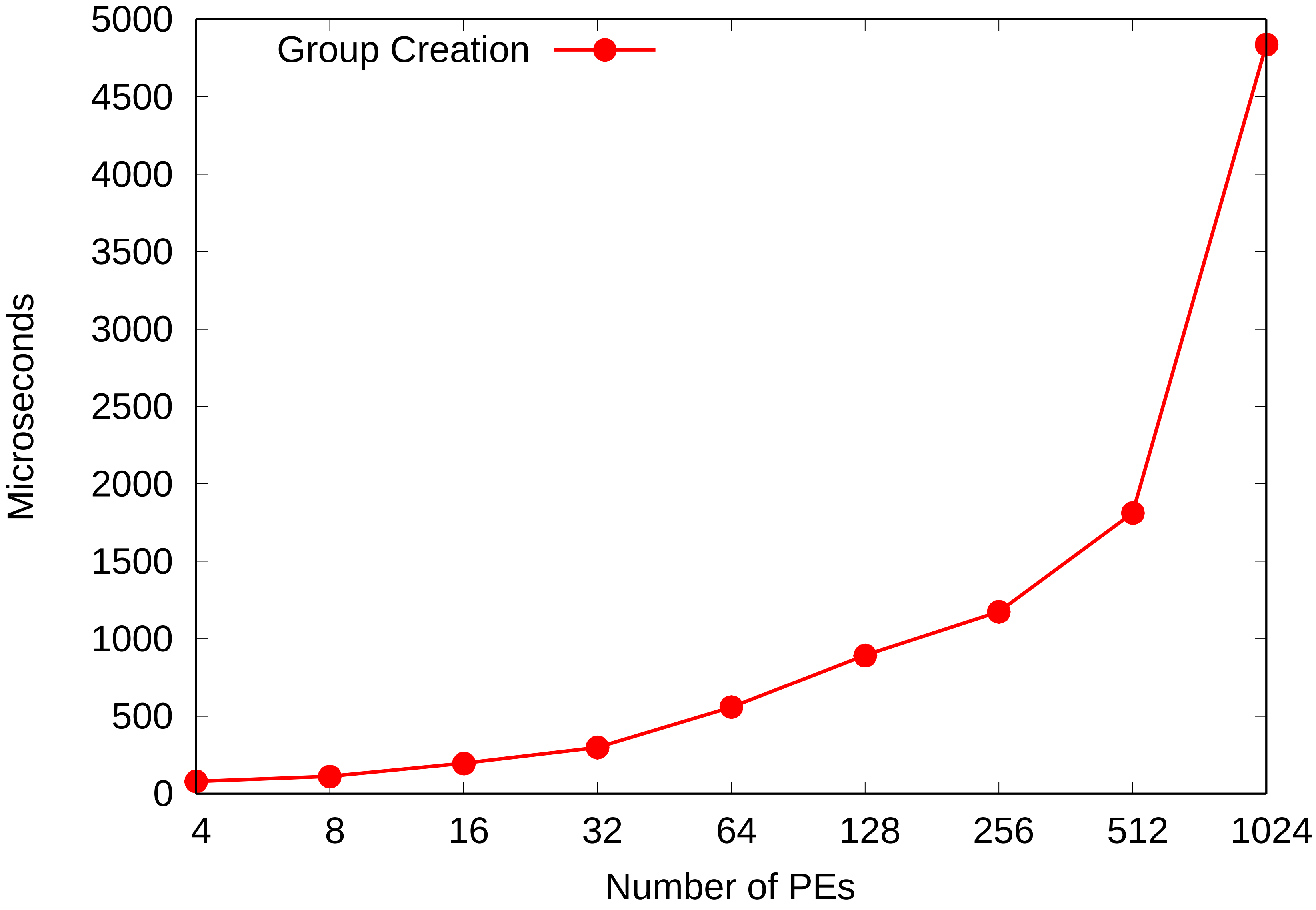
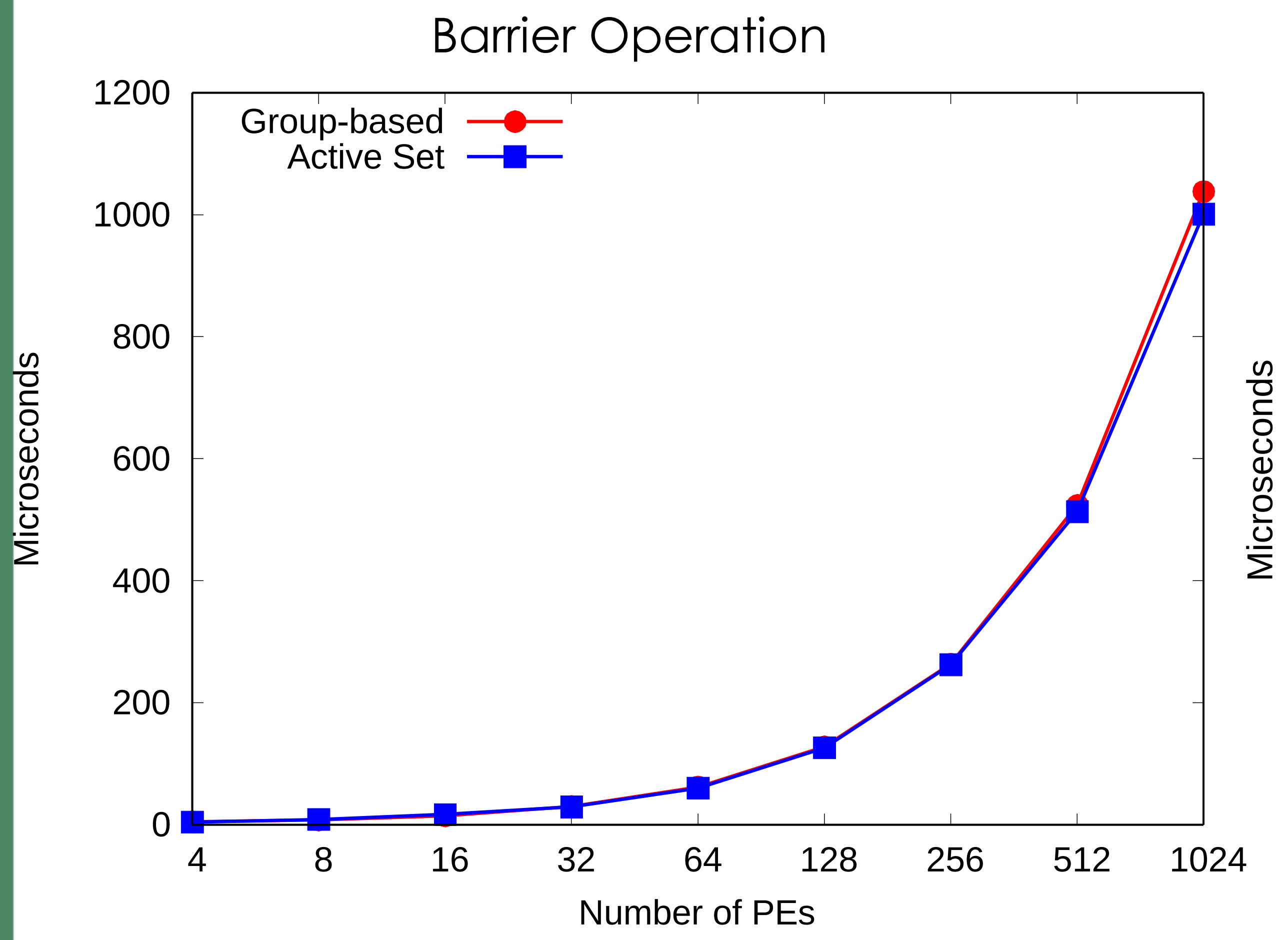
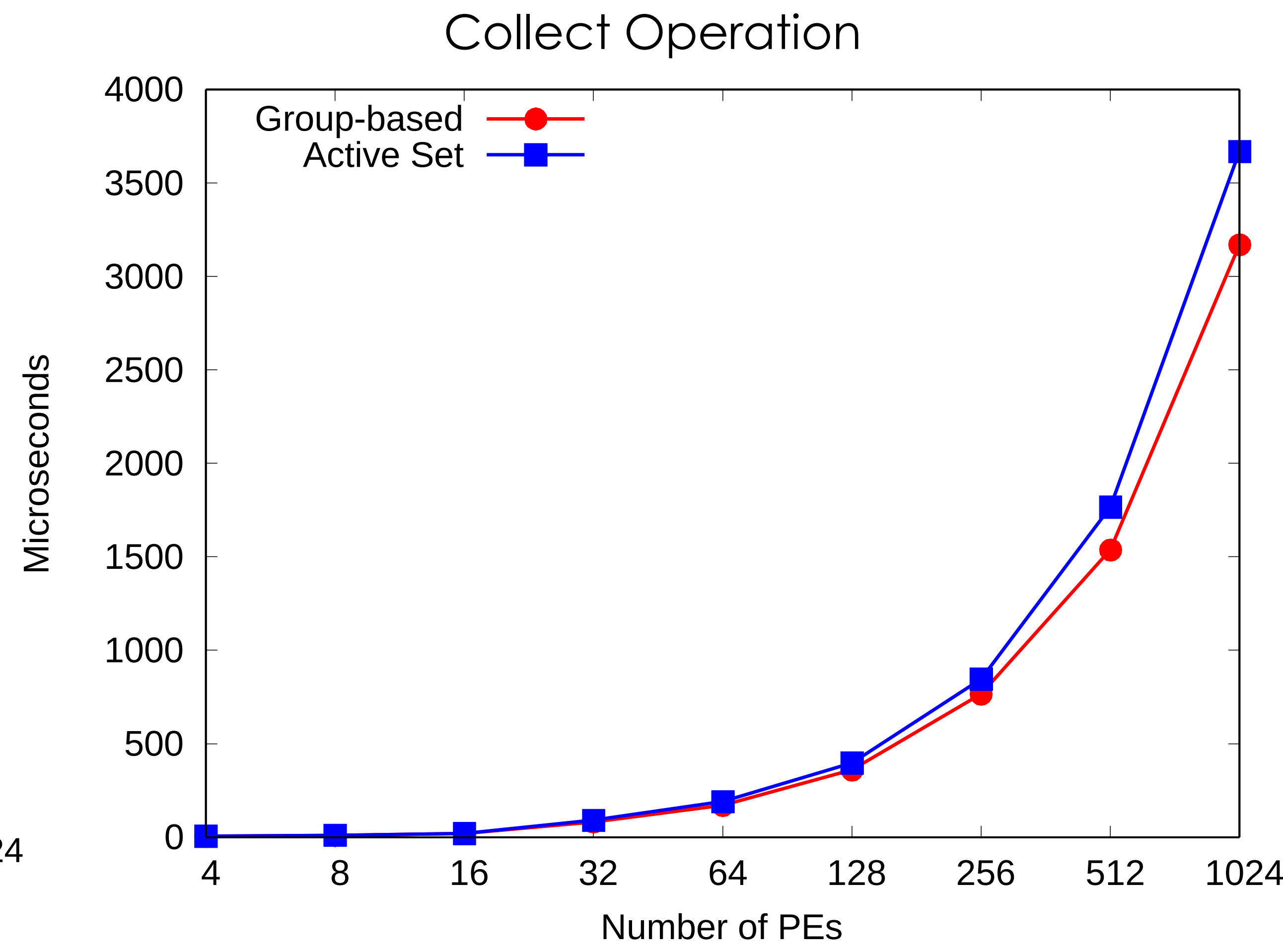
Evaluation: Group Creation Overhead



Evaluation: Micro-benchmarks of Collective Operations





Use Case: All-Pairs Shortest Path

- Briefly Review All-Pairs Shortest Path (APSP)
  - Fundamental Graph Problem
  - Goal: Find the shortest path between each pair of vertices in a graph
  - Results can be used to find the Betweeness Centrality in a graph
  - Multiple methods of solving this problem:
    1. Iterate over sources using SSSP while filling in a graph
    2. Use dynamic programming (i.e., Floyd-Warshall)

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  - Multiple methods of solving this problem:
    1. **Iterate over sources using SSSP while filling in a graph**
       - **SSSP easily parallelizable (e.g., Bellman-Ford)**
       - **Can further parallelize APSP**
    2. Use dynamic programming (i.e., Floyd-Warshall)

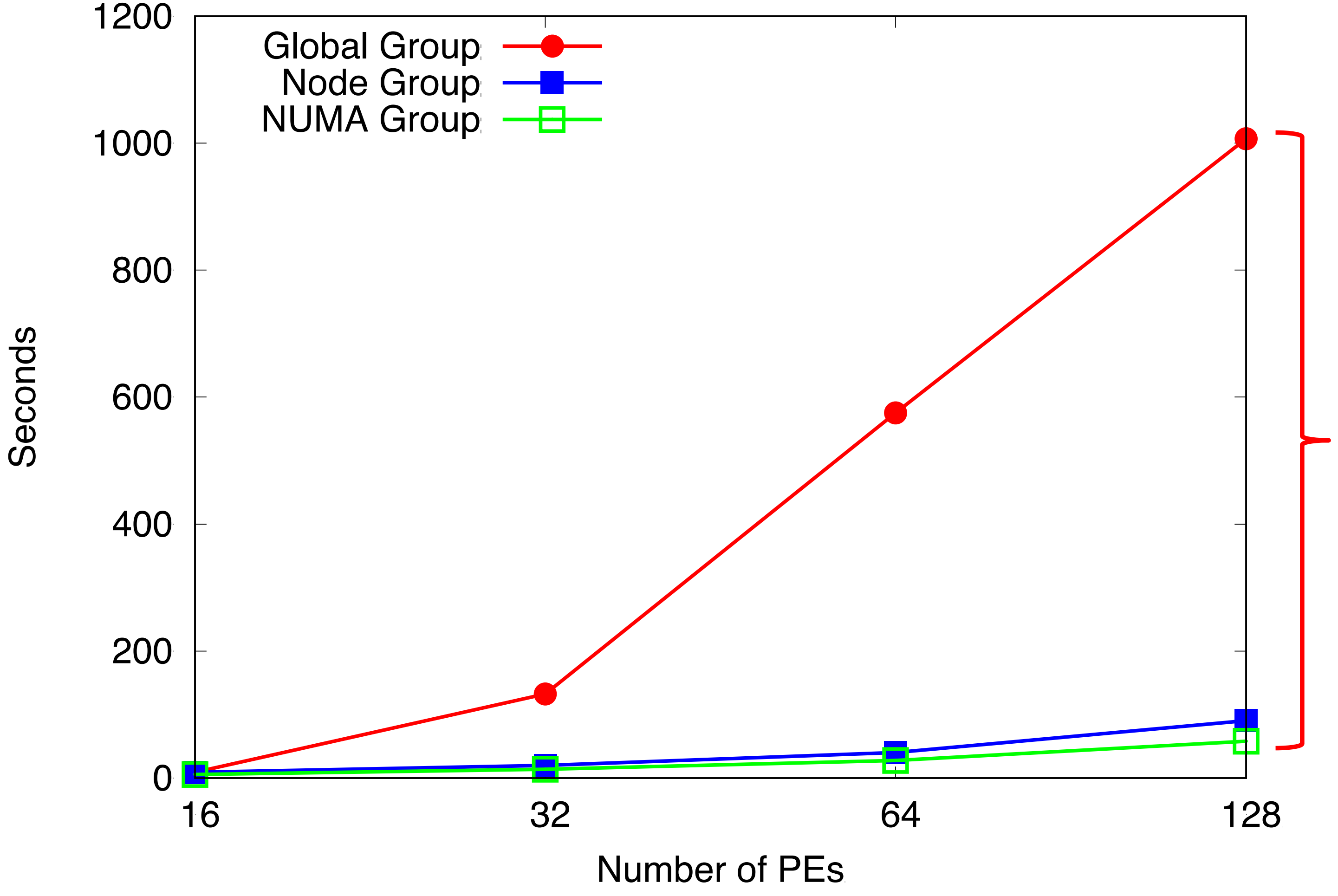
Parallelizing APSP with OpenSHMEM

- We parallelized SSSP (i.e., Bellman-Ford/Dijkstra’s) with OpenSHMEM
- For APSP, we simply:
  - Partition the Pes into Sets/Groups where each Set will have a roughly uniform amount of source vertices
  - Each Group has its own copy of the Graph
  - Each Group can then:
    - Iterates over their sources of the graphs performing the parallel SSSP with OpenSHMEM on the source
    - The resulting distance/predecessor array is stored on stable storage to build the distance matrix
- Work distribution can be simplified:
  - Work queue with Groups taking a source to work on when completing their own

Experimental Evaluation

- Dataset
  - Recursive-Matrix (R-MAT) Graphs
    - Synthetic, scale-free Graphs
    - Parameters for generation
      - A = 0.57, b = 0.19, c = 0.19, and d = 0.05
      - Average vertex degree of 16
    - Using similar scale to Graph500 graphs
      - i.e., scale=10 means 2^{10} vertices
    - Similar to a social network graph
- Evaluation
  - Weak scaling with an initial scale of 10

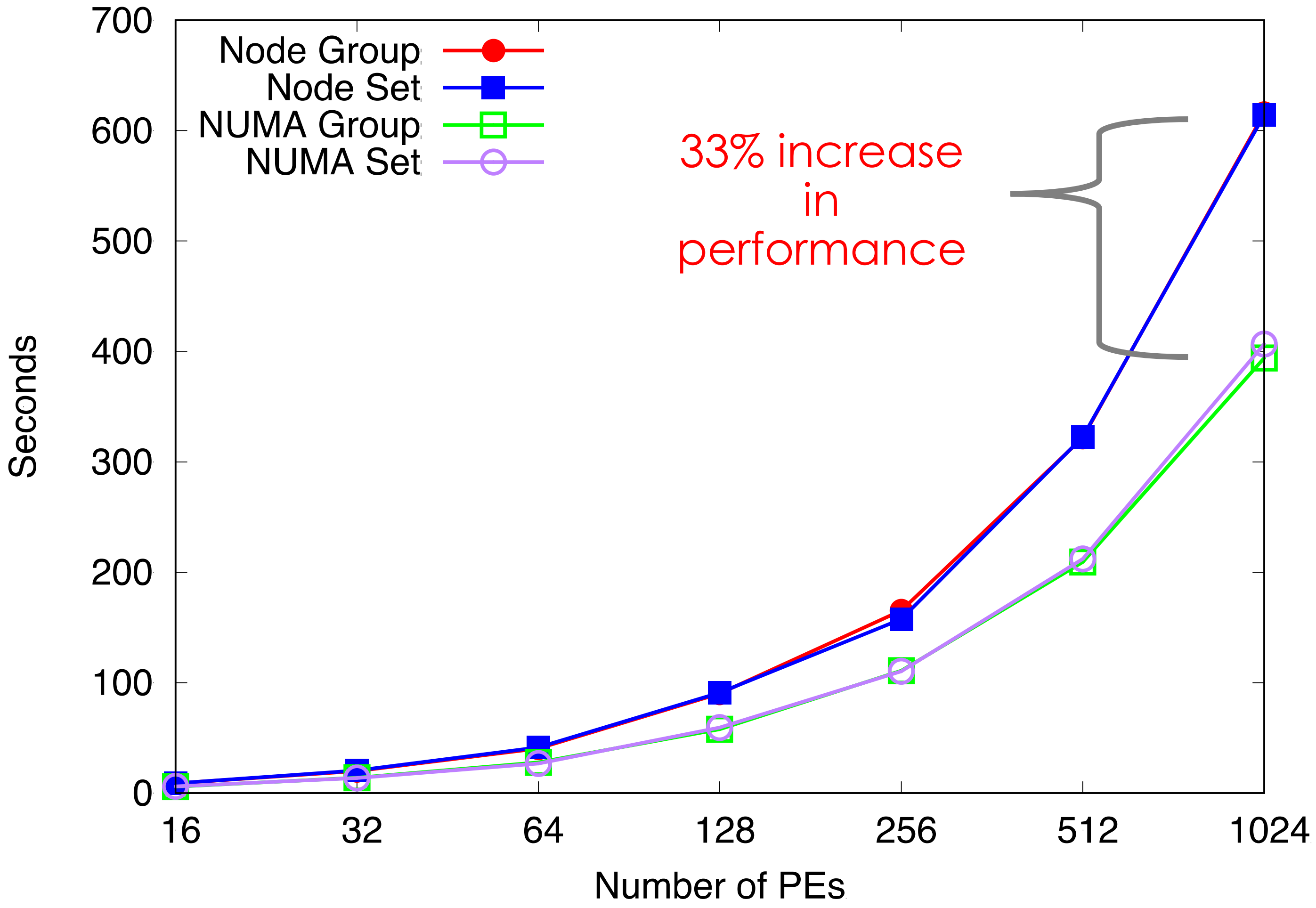
Weak Scaling Performance of Sets/Groups on R-MAT Graphs (initial scale=10)



Global Group is the same as World

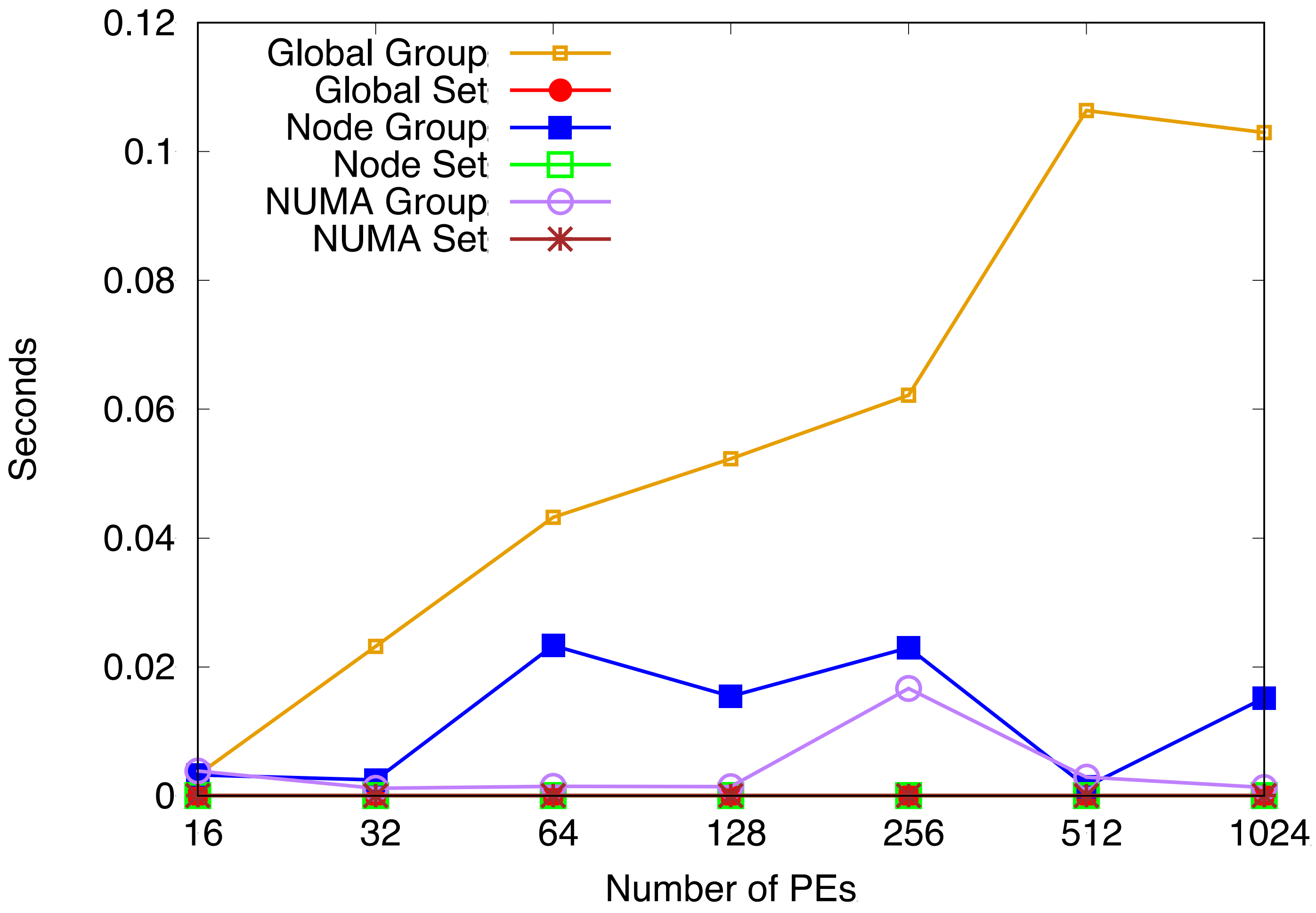
94% difference in performance

Weak Scaling Performance of Sets/Groups on R-MAT Graphs (cont.)



- Sets are using pSync/pWrk arrays allocated using shmem_malloc()
- Groups/Sets have similar performance
- Obvious observation:
  - Grouping of PEs on a single NUMA is best performing, but not always possible

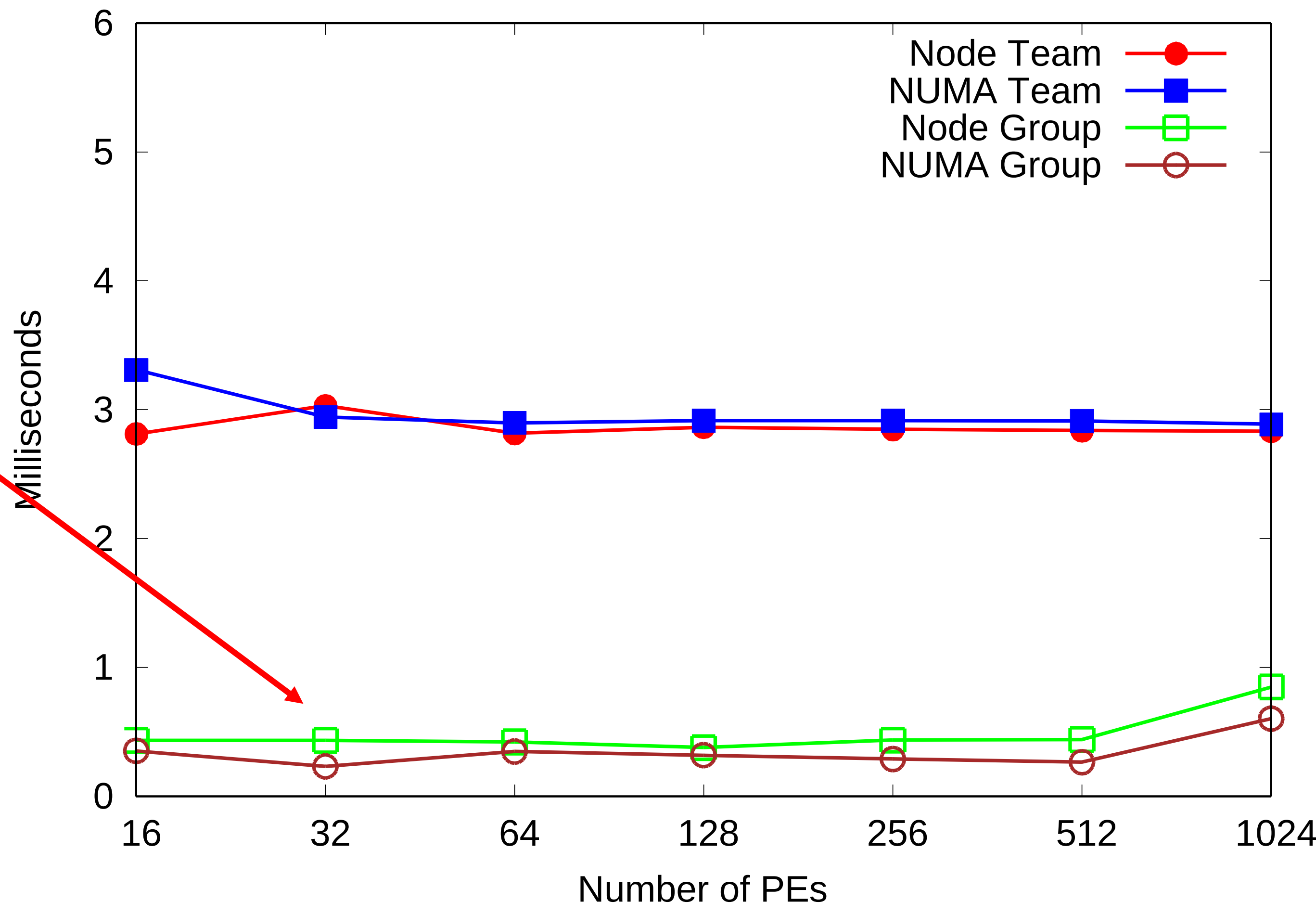
Set/Group Creation Overhead



- Important note: Group creation is expensive
  - It may be more performant to leverage Sets if you know you are going to have global allocations regardless of logical PE groupings
  - Also, if we were to performance asynchronous SSSP as demonstrated in previous paper, no need for Groups
    - All operations are Puts/Gets without collectives

Comparison of Sets/Groups with Cray SHMEM

- Set + Group creation compared with Cray SHMEM Team creation
  - 92% decrease in latency
  - Increased performance due to Group creation being local to its Set
    - Node and NUMA group creation takes advantage of shared memory



Conclusion

- Active Sets provide a useful, but temporary and limiting abstraction for collective operations
- Discussed the Sets/Groups abstractions as a possible replacement for Active Sets with library managed resources
- Demonstrated
  - Flexibility and utility of Sets and Groups
  - Negligible performance overhead related to Groups implementations
  - Multiple-levels of parallelism with All-Pairs Shortest Path and Sets/Groups

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  - Multiple-levels of parallelism with All-Pairs Shortest Path and Sets/Groups
- Hopefully jump started the conversation regarding Teams after lunch!

Acknowledgements

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Questions?