NETWORK-BASED COMPUTING LABORATORY

Enhancing Startup Performance of Parallel Applications with SLURM

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Overview

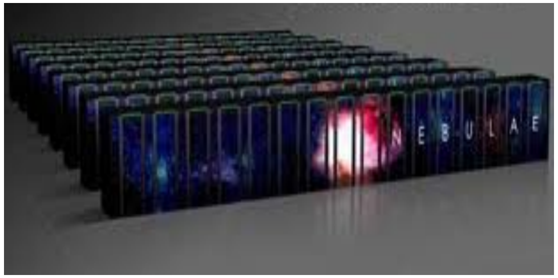
- **Introduction**
- Challenges
- PMI Ring Extension
- Non-blocking PMI Extensions
- Conclusion

Current Trends in HPC

- Supercomputing systems scaling rapidly
  - Multi-core architectures and
  - High-performance interconnects
- InfiniBand is a popular HPC interconnect
  - 259 systems (51.8%) in top 500
- MPI and MPI+X programming models used by vast majority of HPC applications
- Job launchers for high performance middleware like MPI need to become more scalable to handle this growth!

Stampede@TACC

SuperMUC@LRZ



Nebulae@NSCS

Why is Fast Startup Important

Developing and debugging

- Developers spend a lot of time launching the application
- Reducing job launch time saves developer-hours

Regression testing

- Complex software have a lot of features to test
- Large number of short-running tests need to be launched

System testing

- Full-system size jobs to stress-test the network and software

Checkpoint-restart

- An application restart is similar to a launching a new job
- Faster startup means less time recovering from a failure

Requirement for Out-of-band Startup Mechanisms in High-performance MPI Libraries

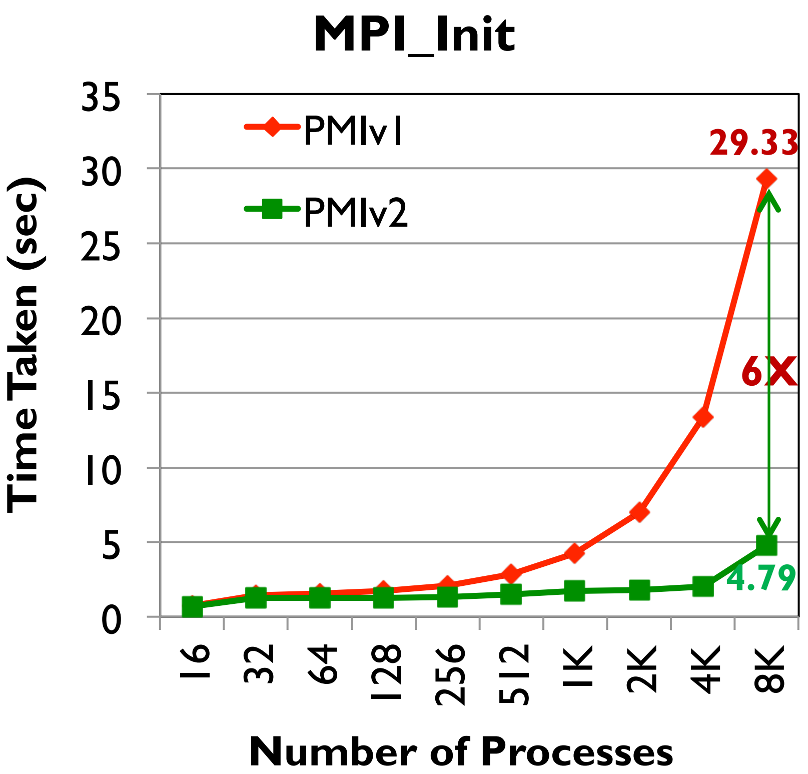
- InfiniBand is a low-latency, high-bandwidth network widely used in HPC clusters
- Lacks efficient hostname based lookup
- Requires some out-of-band communication before connection establishment
- Most MPI libraries use the Process Management Interface (PMI)[1] as the out-of-band communication substrate

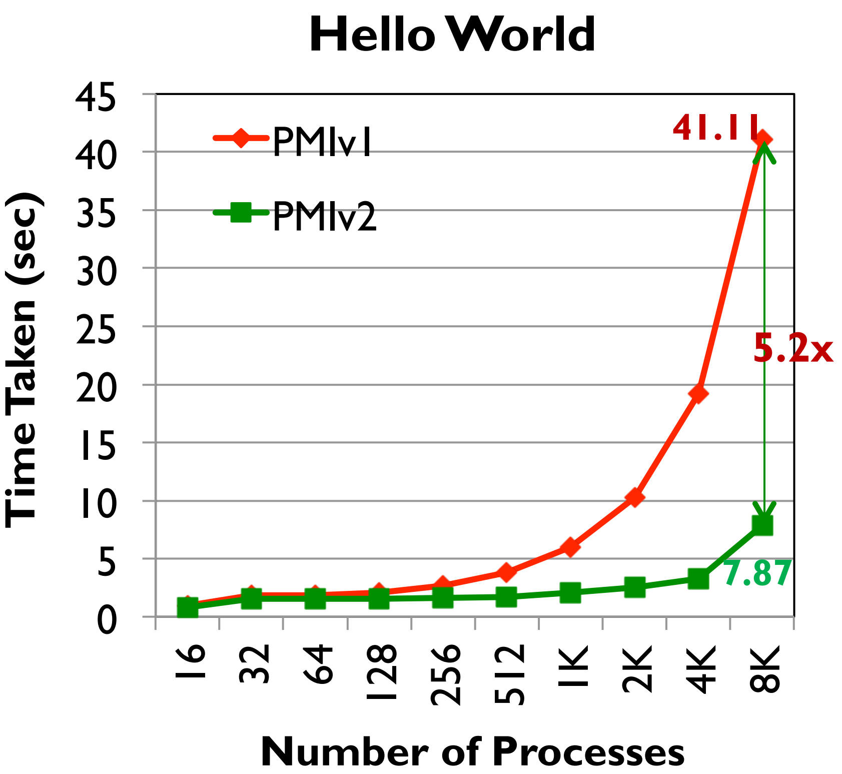
[1] PMI: A Scalable Parallel Process-management Interface for Extreme-scale Systems; Balaji, Pavan and Buntinas, Darius and Goodell, David and Gropp, William and Krishna, Jayesh and Lusk, Ewing and Thakur, Rajeev; EuroMPI'10

Process Management Interface (PMI)

- Portable interface between middleware (e.g. MPI) and resource manager (e.g. SLURM, mpirun_rsh, Hydra)
- External process acts as the client, resource manager works as the server
- PMI provides these broad functionalities:
  - Creating/connecting with existing parallel jobs
  - Accessing information about the parallel job or the node on which a process is running
  - **Exchanging information used to connect processes together**
  - Exchanging information related to the MPI Name publishing interface

USE PMI-2!





Supported by most MPI libraries including MVAPICH2, OpenMPI

MVAPICH2

- **High Performance open-source MPI Library for InfiniBand, 10Gig/iWARP, and RoCE**
  - MVAPICH (MPI-1) , Available since 2002
  - MVAPICH2 (MPI-2.2, MPI-3.0 and MPI-3.1), Available since 2004
  - MVAPICH2-X (Advanced MPI + PGAS), Available since 2012
  - Support for GPGPUs (MVAPICH2-GDR), Available since 2014
  - Support for MIC (MVAPICH2-MIC), Available since 2014
  - Support for Virtualization (MVAPICH2-Virt), Available since 2015
  - Used by more than 2,450 organizations in 76 countries
  - More than 285,000 downloads from the OSU site directly
  - Empowering many TOP500 clusters (Jun'15 ranking)
    - 8^{th} ranked 519,640-core cluster (Stampede) at TACC
    - 11^{th} ranked 185,344-core cluster (Pleiades) at NASA
    - 22^{nd} ranked 76,032-core cluster (Tsubame 2.5) at Tokyo Institute of Technology and many others
  - Available with software stacks of many IB, HSE, and server vendors including RedHat and SuSE
  - http://mvapich.cse.ohio-state.edu
- **Empowering Top500 systems for over a decade**
  - System-X from Virginia Tech (3^{rd} in Nov 2003, 2,200 processors, 12.25 TFlops) ->
  - Stampede at TACC (8^{th} in Jun'15, 462,462 cores, 5.168 PFlops)

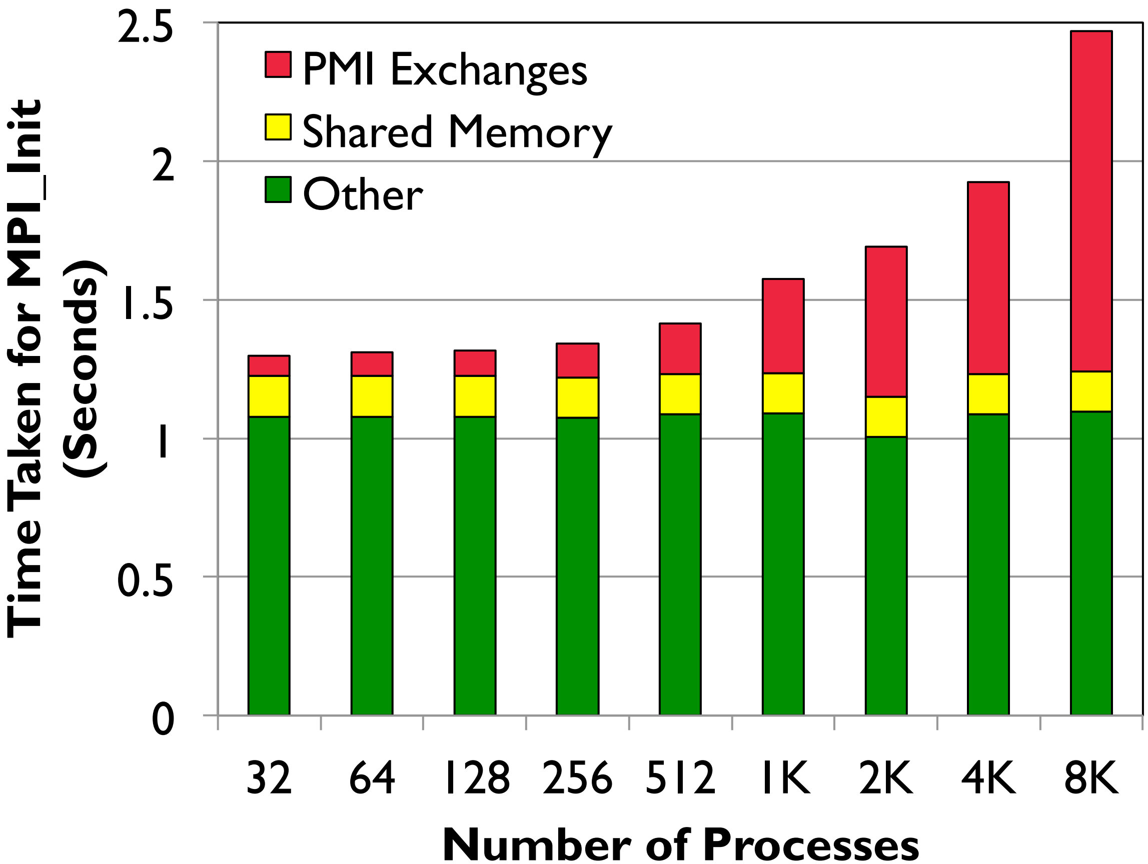
Current PMI2 APIs

- PMI provides a global key-value store where each process can store or retrieve data from
- PMI2_KVS_Put (key, value)
  - Store a new <key,value> pair
- PMI2_KVS_Fence ()
  - Publish/synchronize the KVS across processes
  - Blocking operation, needs to be called by every process
- PMI2_KVS_Get (…, key, …)
  - Lookup a <key,value> pair from the KVS

Use of PMI in High-performance MPI Libraries

- MPI libraries use the Put-Fence-Get operations to exchange their high-performance network endpoint addresses
- Each process Puts its own network endpoint address into the key-value store and calls Fence
- Each process does up to (Number of Processes – 1) Gets to look up the network endpoint address of remote processes

Breakdown of MVAPICH2 Startup



- Key-Value exchange over PMI takes more time as system size increases
- Other costs are relatively constant

- All numbers taken on TACC Stampede with 16 processes/node
- Based on MVAPICH2-2.0b & SLURM-2.6.5

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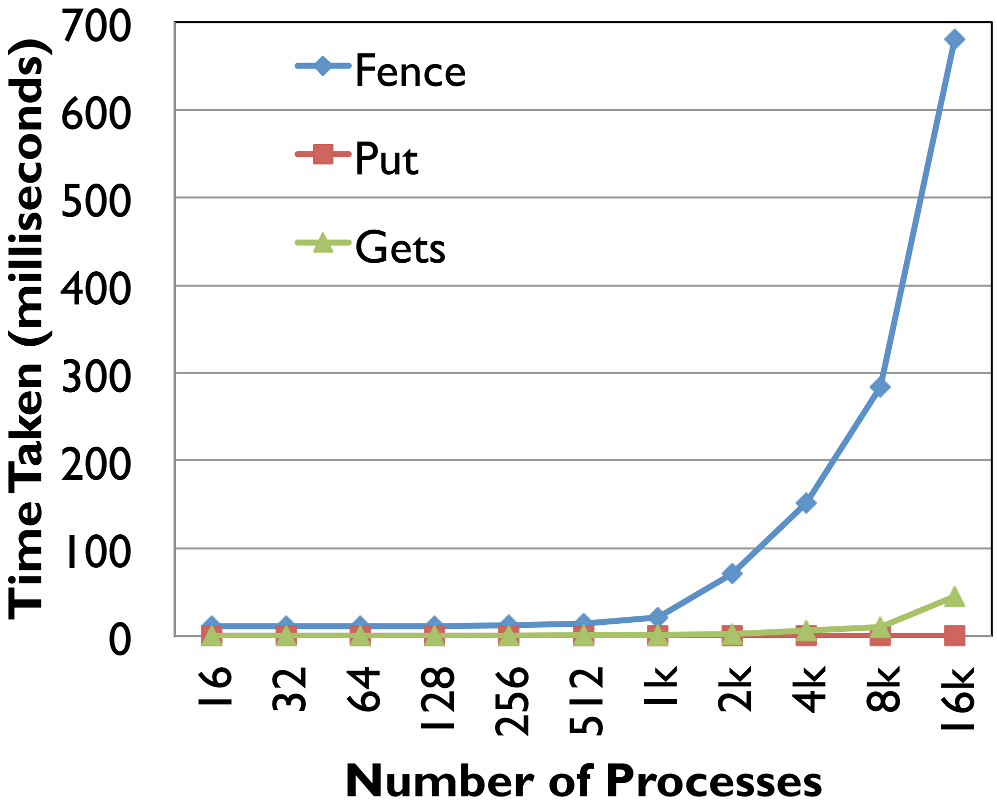
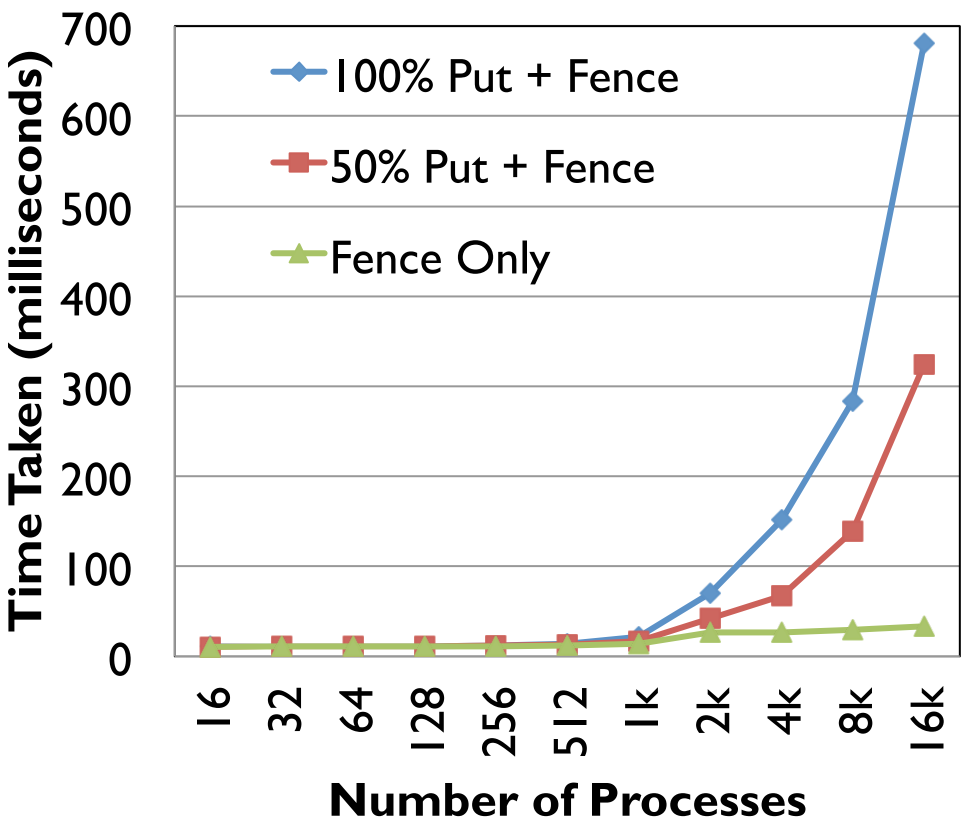
Time Spent in Different PMI Operations



- One Put followed by a Fence and multiple Gets
- Put & Get are local operations and take negligible time
- Time taken by Fence is the bottleneck[2]

[2] PMI Extensions for Scalable MPI Startup S. Chakraborty , H. Subramoni , J. Perkins , A. Moody , M. Arnold , and D. K. Panda EuroMPI/ASIA 2014, Sep 2014

Time Spent in Different PMI Operations



- Time taken by Fence is determined by Data transferred
- Fence with no data movement is much faster
- Can we come up with other primitives to improve the performance?

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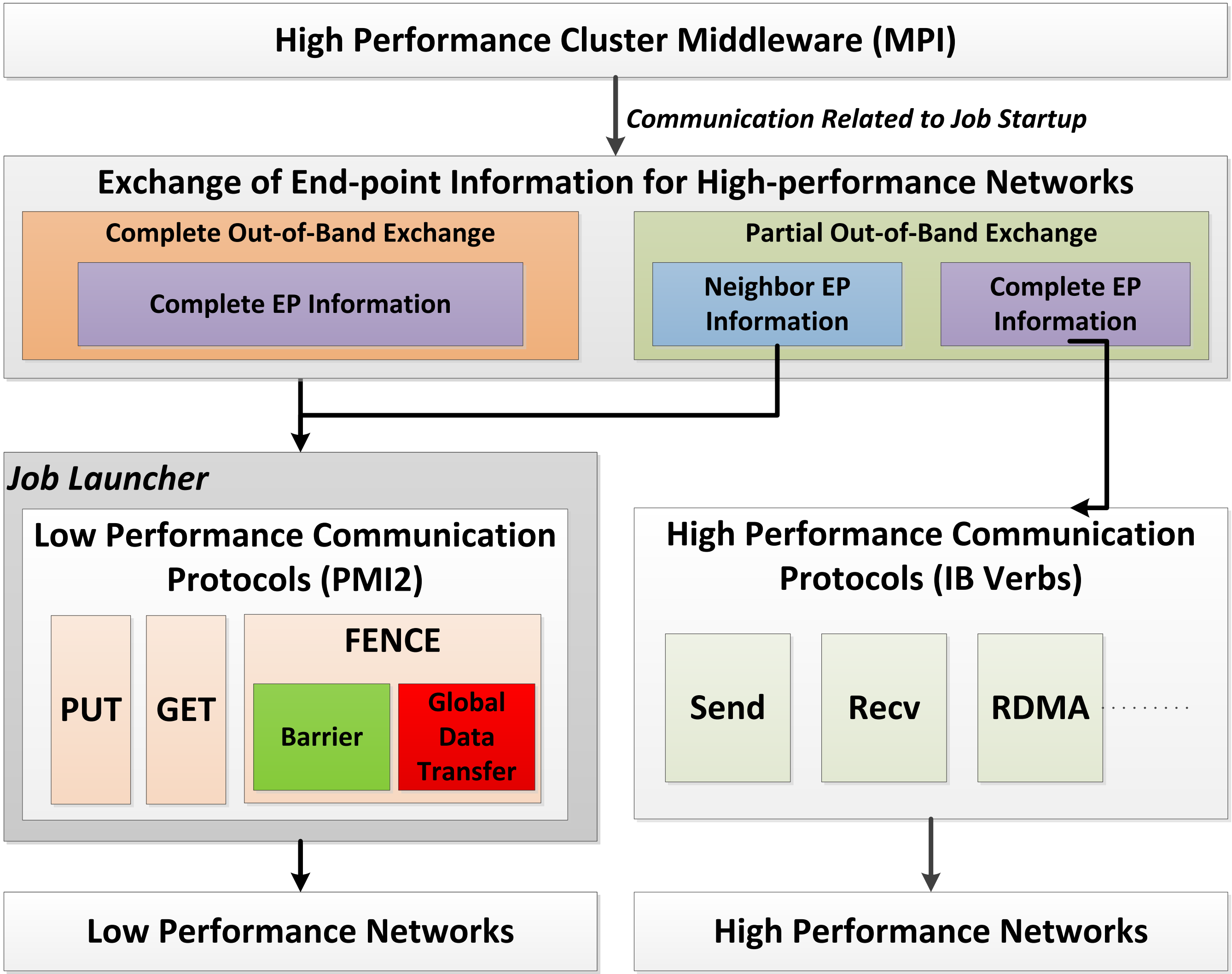
Using High Performance Networks for PMI



The PMI Ring Extension

```
int PMIX_Ring (
  const char value[], // IN – Own value
  int *rank,          // OUT – Rank in ring
  int *size,          // OUT – Size of ring
  char left[],        // OUT – Value from rank-1
  char right[],       // OUT – Value from rank+1
  int maxvalue        // IN – Max length of values
);
```

rank and size can be different from PMI size and rank

Already available in slurm-15.08.0 (thanks to Adam Moody)

Using PMI Ring Extension

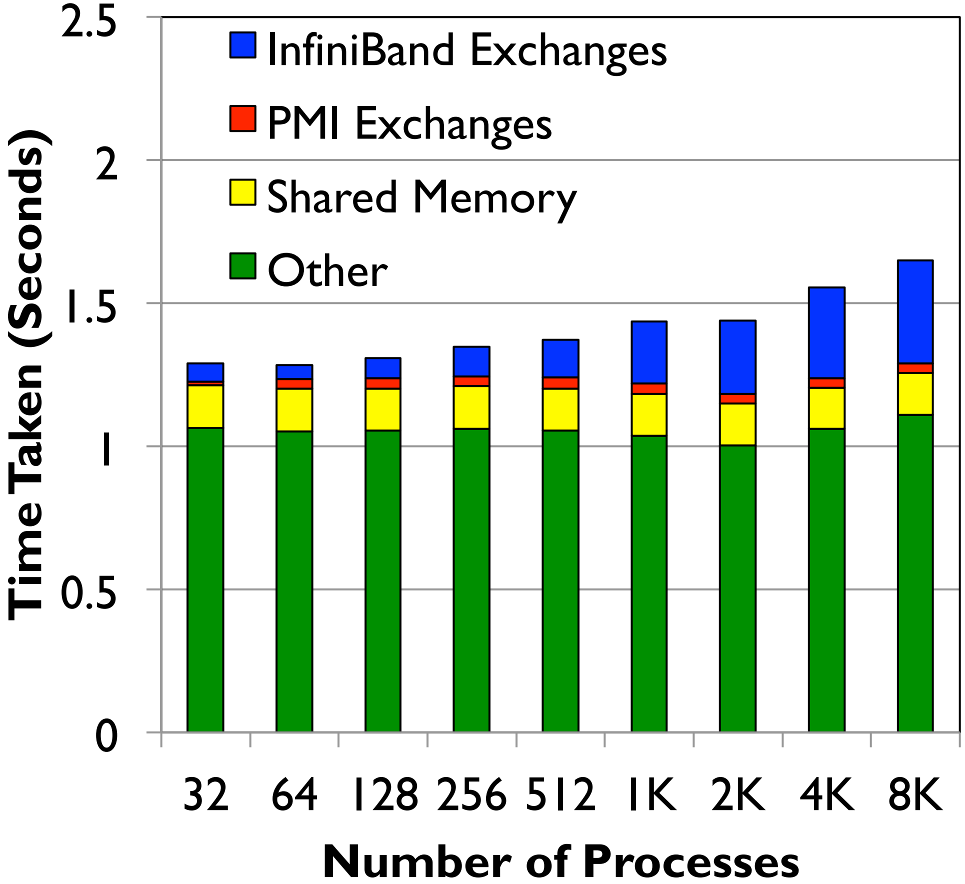
Each process acquires its own InfiniBand address

PMIX_Ring – Exchange address with Left and Right neighbor processes

Form a Ring over InfiniBand using exchanged addresses

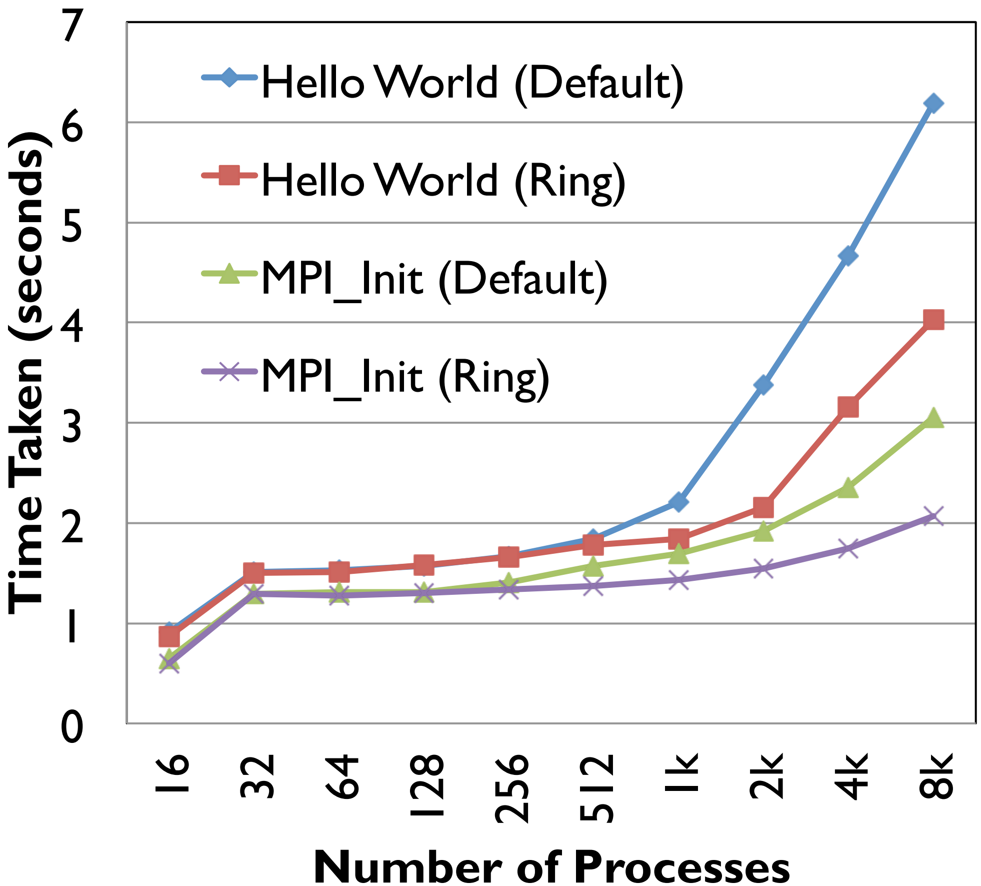
Perform Allgather operation over InfiniBand ring to gather addresses from all other processes

MVAPICH2 Startup with PMIX_Ring



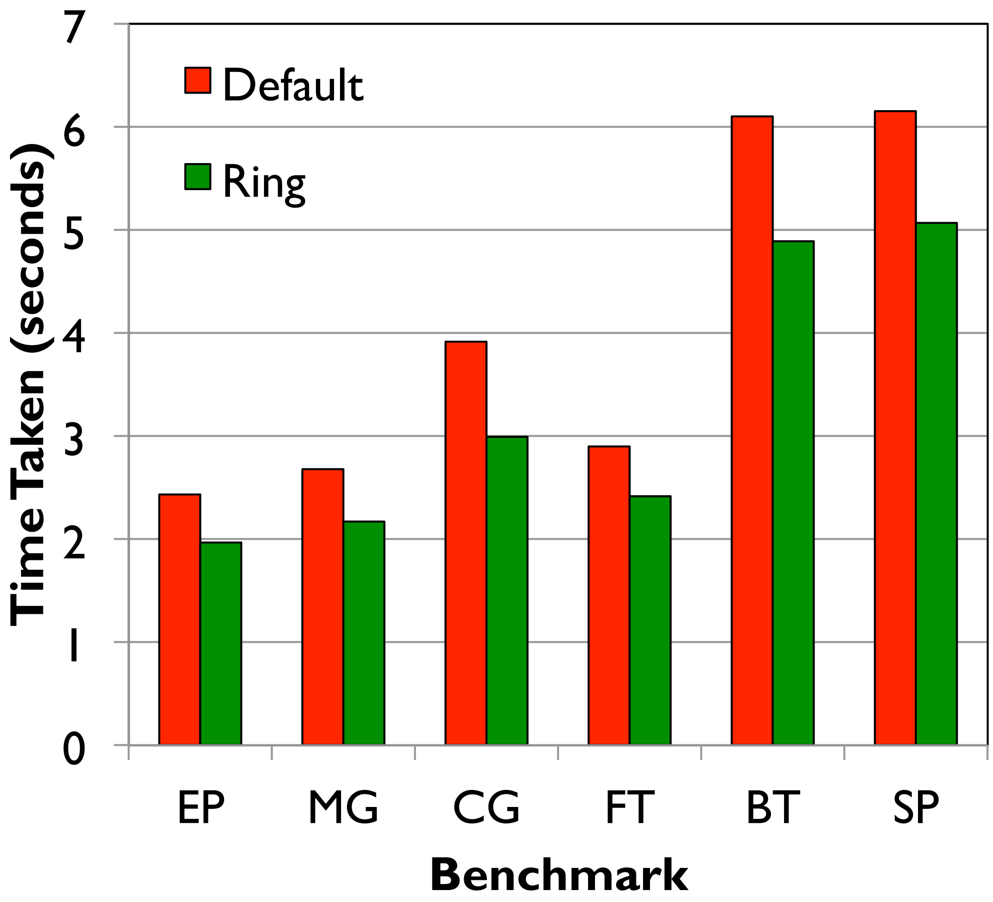
- Amount of data transferred over TCP sockets reduced significantly
- Bulk of the data is exchanged over high-performance network (InfiniBand)

MPI_Init and Hello World with PMIX_Ring



- MPI_Init time reduced by 34%
- Time taken by Hello_World improved by 33% at 8,192 processes

Application Performance with PMIX_Ring



- NAS Parallel Benchmarks at 1,024 processes, class B data
- Up to 20% improvement in total execution time

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Non-blocking PMI Extensions

- Process manager (slurmd) is responsible for progressing the PMI exchanges. Can be overlapped with:
- Different initialization related tasks, e.g.
  - Registering memory with the HCA
  - Setting up shared memory channels
  - Allocating resources
- Any computation between MPI_Init and the first communication, e.g.
  - Reading input files
  - Preprocessing the input
  - Dividing the problem into sub-problems

Proposed Non-blocking PMI Extensions

```
int PMIX_Allgather (
     const char value[],
     void *buffer);
```

- Each process provides an input value and an output buffer
- Values from each process are collected into the output buffer
- Values are ordered by their source rank

PMIX_Request

- Request objects are used to track completions of non-blocking operations
- Each non-blocking operation returns a handle to the request object
- Actual type of the object is determined by the implementation

```
int PMIX_Wait (PMIX_Request request);
```

- Wait until the operation specified by the request object is complete

Proposed Non-blocking PMI Extensions

```
int PMIX_Iallgather (
     const char value[],
     void *buffer,
     PMIX_Request *request_ptr);
```

- Non-blocking version of the PMIX_Allgather
- Return does not indicate completion
- Output buffer will contain valid data only after successfully invoking the corresponding PMIX_Wait

```
int PMIX_KVS_Ifence (PMIX_Request *request_ptr);
```

- Non-blocking version of the PMI2_KVS_Ifence

- All functions return 0 on success and and error code on failure
- PMI2_KVS_* can not be invoked between calling PMIX_KVS_Ifence and calling PMIX_Wait

Using Non-blocking PMI Extensions

Current

```
MPI_Init() {
   PMI2_KVS_Put();
   PMI2_KVS_Fence();
   /* Do other tasks */
}
Connect() {
   PMI2_KVS_Get();
   /* Use values */
}
```

Proposed

```
MPI_Init() {
   PMIX_Iallgather();
   /* Do other tasks */
}

Connect() {
   PMIX_Wait();
   /* Use values */
}
```

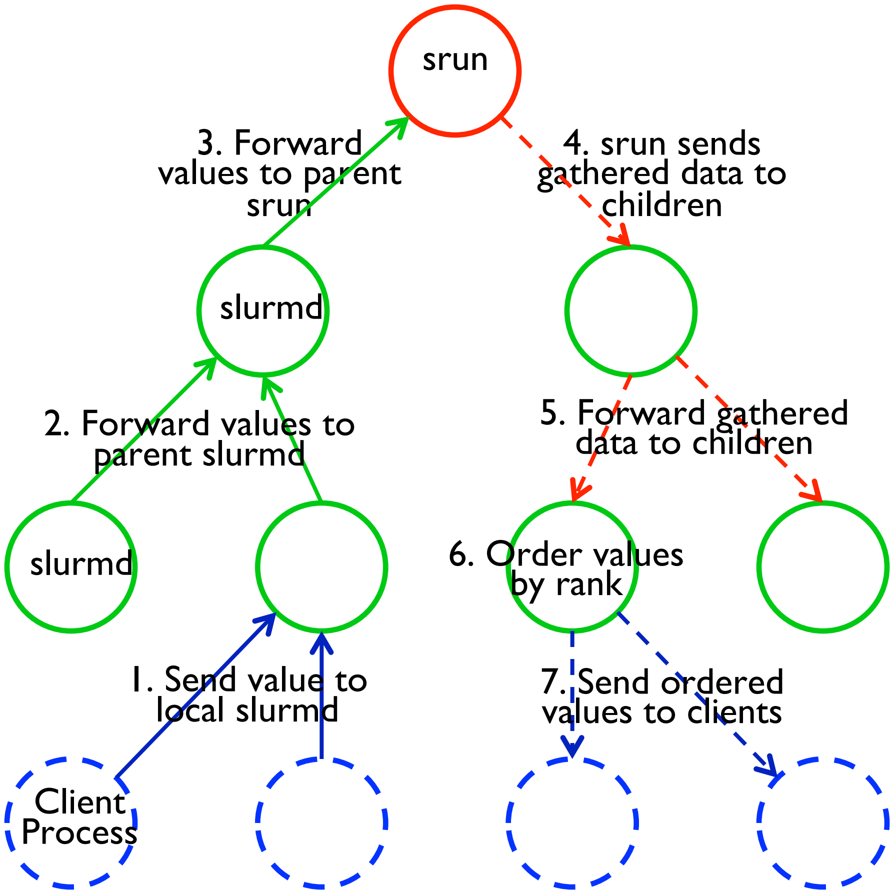
Design of PMIX_Allgather

- Put-Fence-Get combined into a single function
- Collective across all processes
- Optimized for symmetric data movement

```
int PMIX_Allgather (
  const char value[],    //UTF-8, NULL terminated
  void *buffer           //size = NumProcs*MaxLength
);
```

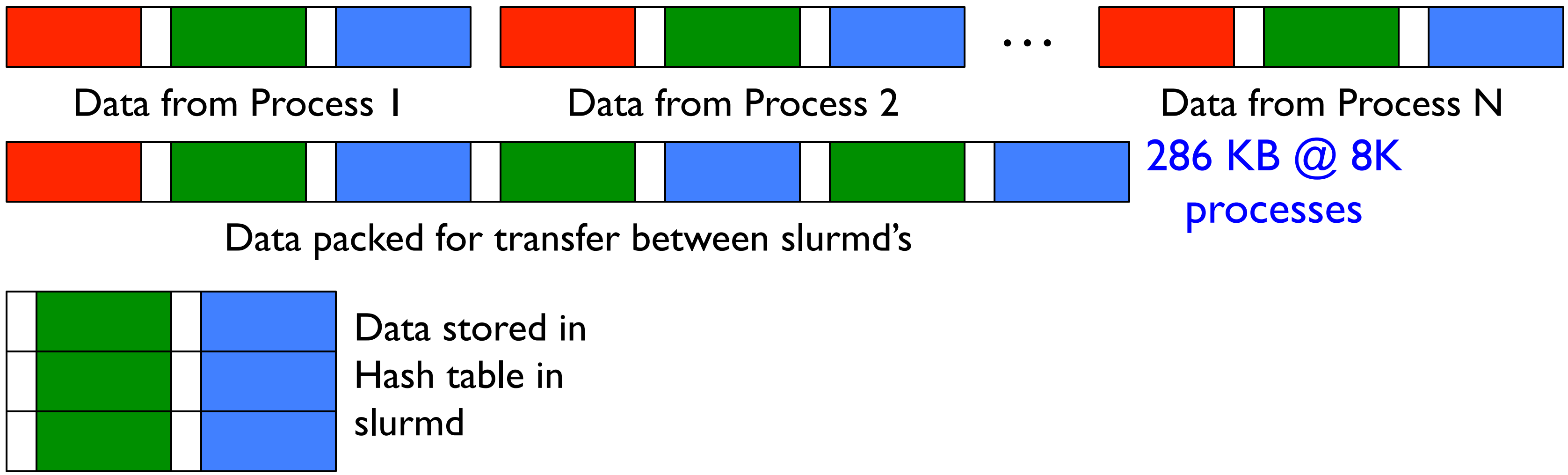
- Equivalent to Fence with rank used as the key
- Values are directly accessed from the result buffer
- Data from rank r is available at buffer[r*MaxLength]
- Further optimization by parameterizing MaxLength

Design of PMIX_Allgather

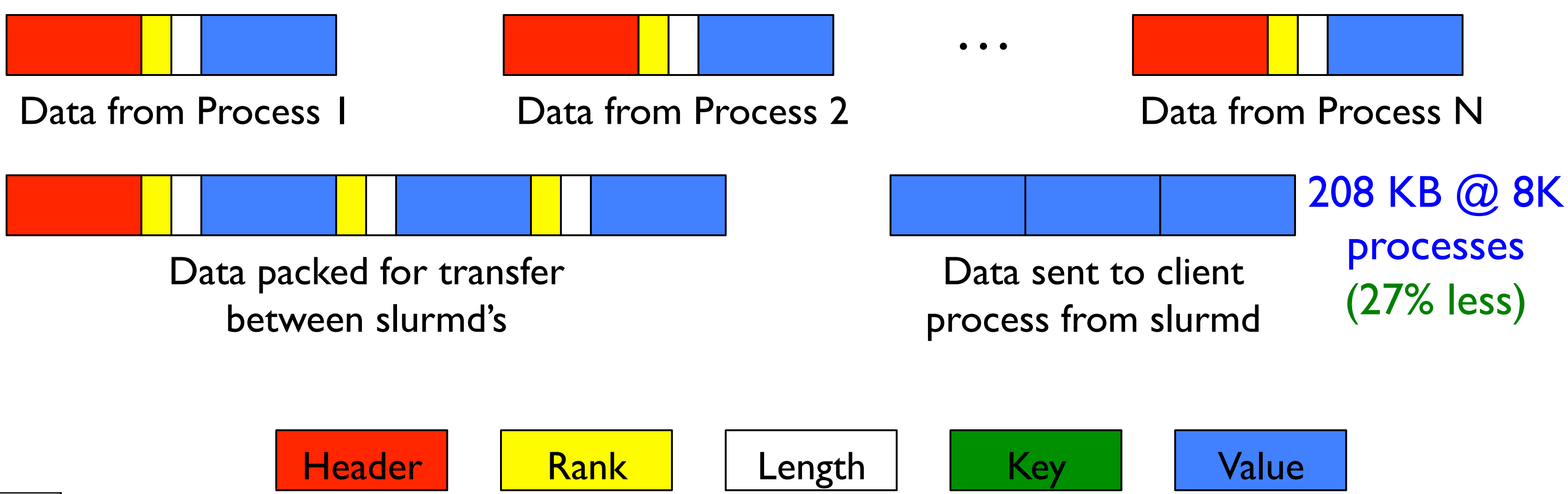


- Processes send the value to parent slurmd
- slurmd's propagate the values (tagged with the source rank) to their parent
- srun sends the aggregated data to children
- slurmd's order the data by rank and sends to client processes
- More efficient packing/less data movement
- Avoids the expensive hash-table creation step

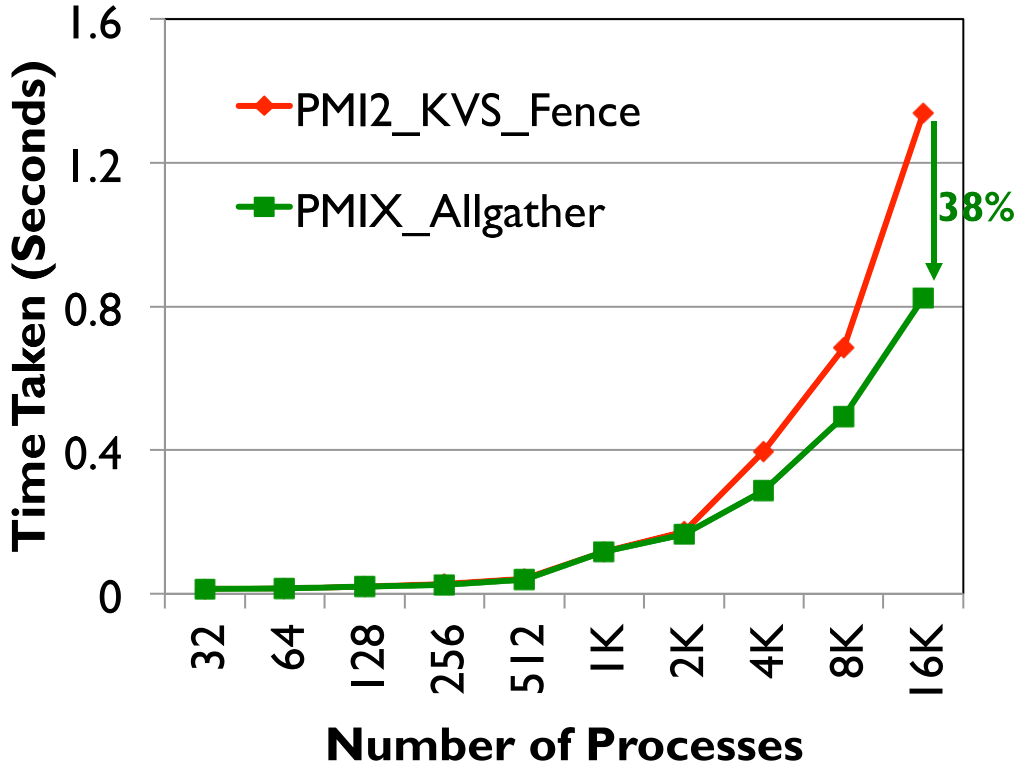
Data Packing and Movement in Fence



Data Packing and Movement in Allgather



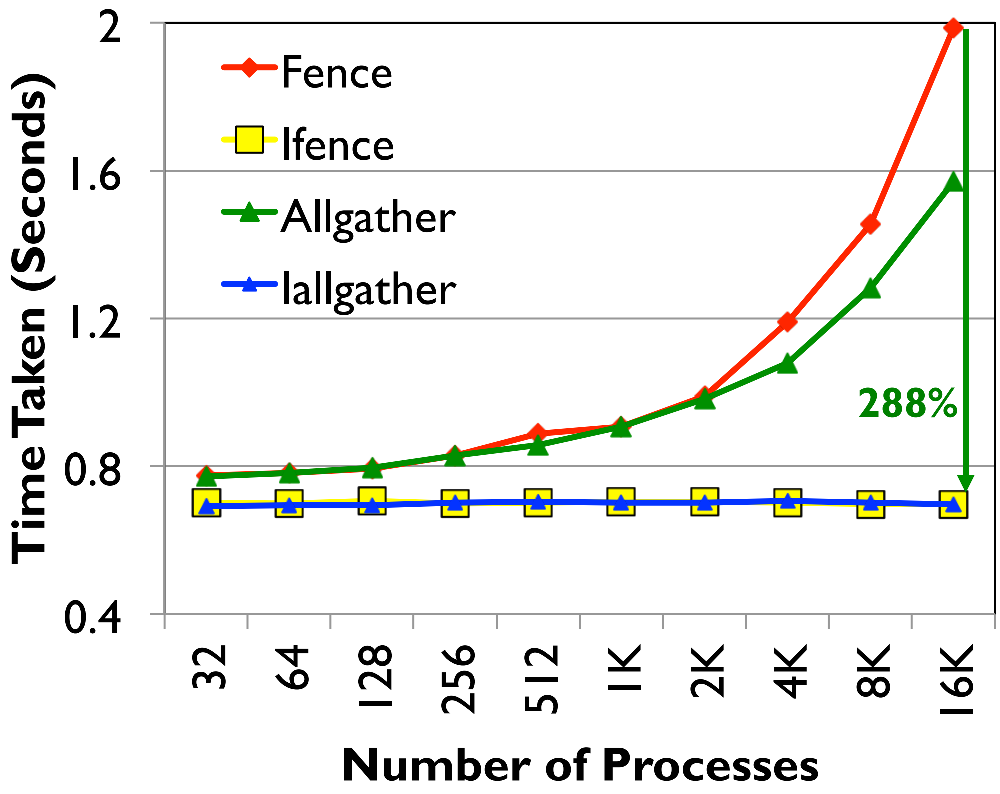
Performance of PMIX_Allgather



- Allgather performs 38% better than Fence at 16K processes
- Reduced data movement and processing overhead

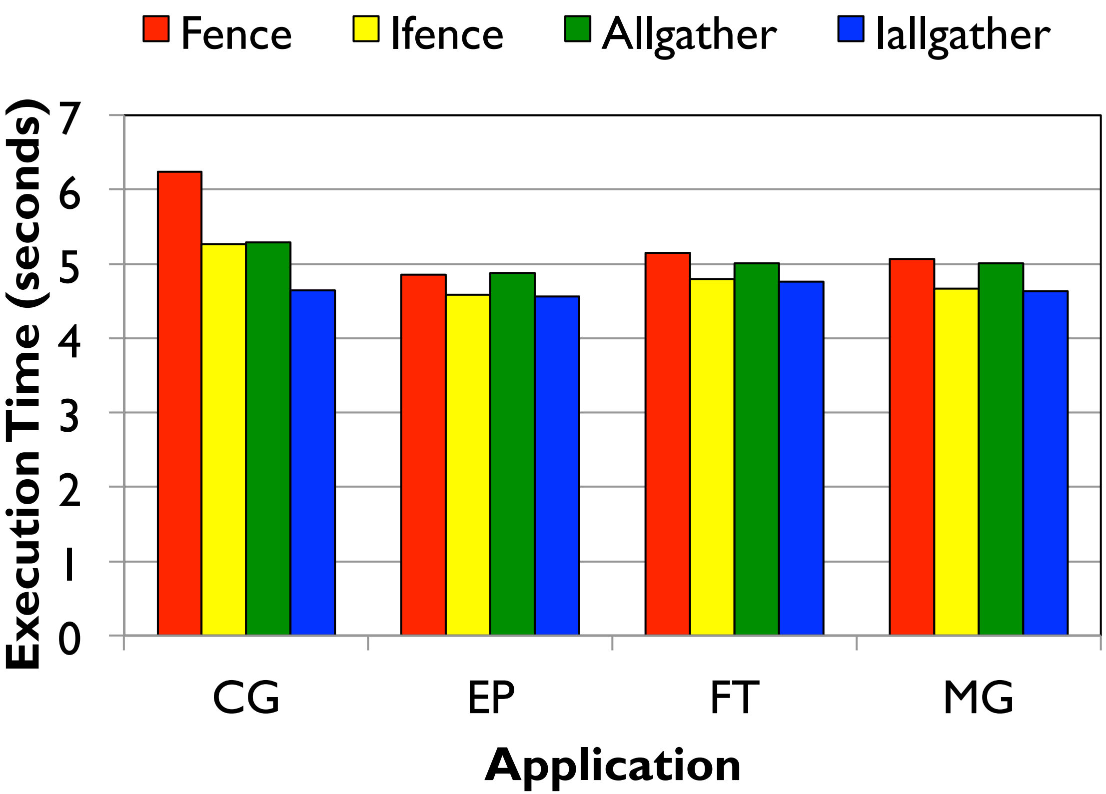
- All numbers taken on TACC Stampede with 16 processes/ node
- Based on MVAPICH2-2.0b & SLURM-2.6.5

Performance of MPI_Init with Non-blocking PMI



- Constant MPI_Init time using non-blocking PMI calls
- MPI_Init using Iallgather is 288% faster than using Fence at 16K processes
- Replacing the blocking Fence with blocking Allgather yields 21% benefit

Application Performance with Non-blocking PMI



- Sources of improvement
  - Overlap inside MPI_Init, depends on library and system size
  - Overlap outside MPI_Init, depends on application
- NAS Parallel Benchmarks
  - 4,096 processes
  - Class B data
- Improvements of up to 10% in total application run-time (as reported by the job launcher)

[3] Non-blocking PMI Extensions for Fast MPI Startup. S. Chakraborty, H. Subramoni, A. Moody, A. Venkatesh, J. Perkins, and D. K. Panda, CCGrid '15

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Conclusion

- PMIX_Ring moves bulk of the PMI exchange over High-performance network like InfiniBand
- MPI_Init and Hello World is 33% faster @ 8K processes

- PMIX_Iallgather and PMIX_KVS_Ifence allows for overlap of PMI exchanges with library initialization and application computation
- MPI_Init can be completed in constant time at any scale using the proposed non-blocking PMI extensions (288% faster @ 16K)
- Total execution time of NAS benchmarks reduced by up to 20%

- Support for PMIX_KVS_Ifence is available since MVAPICH2-2.1
- SLURM support coming soon!

Thank you!

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MVAPICH
MPI, PGAS and Hybrid MPI+PGAS Library