High-Performance and Scalable Support for Big Data Stacks with MPI

Talk at the 2023 Annual MVAPICH User Group (MUG) Conference

by

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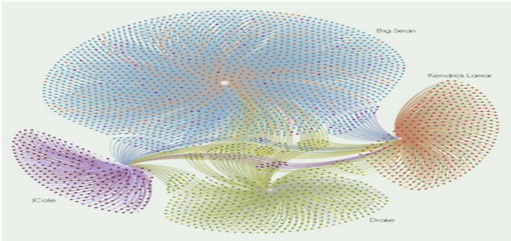
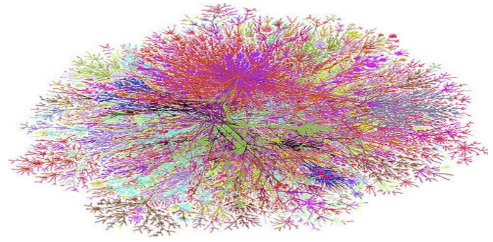
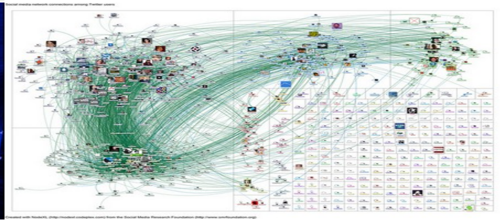
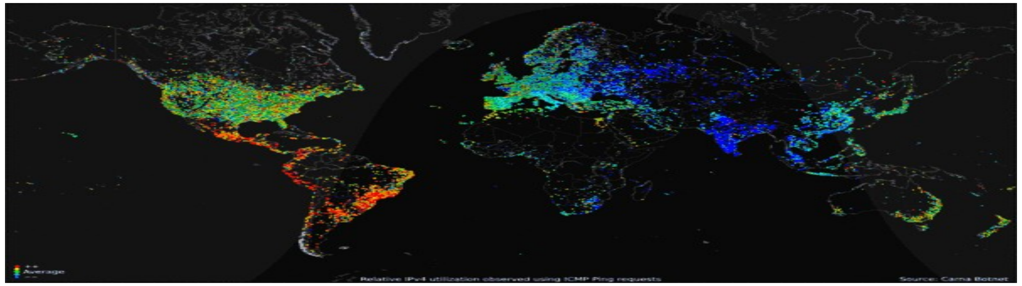
Presentation Outline

- **Introduction to Big Data Analytics**
- Overview, Design and Implementation
  - MPI4Spark
  - MPI4Dask
- Performance Evaluation
  - MPI4Spark
  - MPI4Dask
- Related Publications and Summary

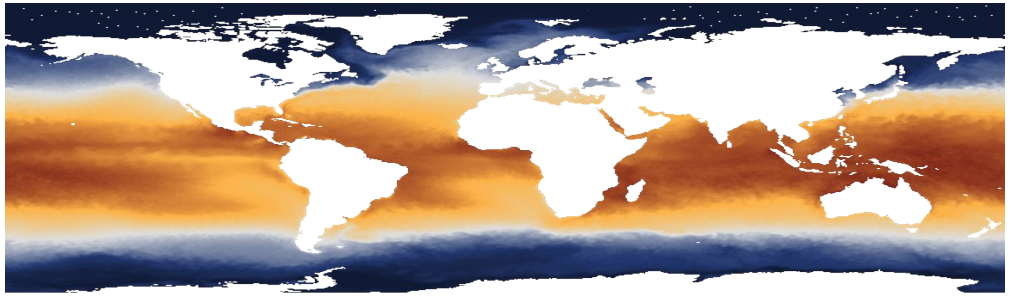
Introduction to Big Data Analytics

- Big Data has changed the way people understand and harness the power of data, both in the business and research domains
- Big Data has become one of the most important elements in business analytics
- Big Data and High Performance Computing (HPC) are converging to meet large scale data processing challenges
- Dask and Spark are two popular Big Data processing frameworks
- Sometimes also called Data Science

http://www.coolinfographics.com/blog/tag/data?currentPage=3



http://www.climatecentral.org/news/white-house-brings-together-big-data-and-climate-change-17194

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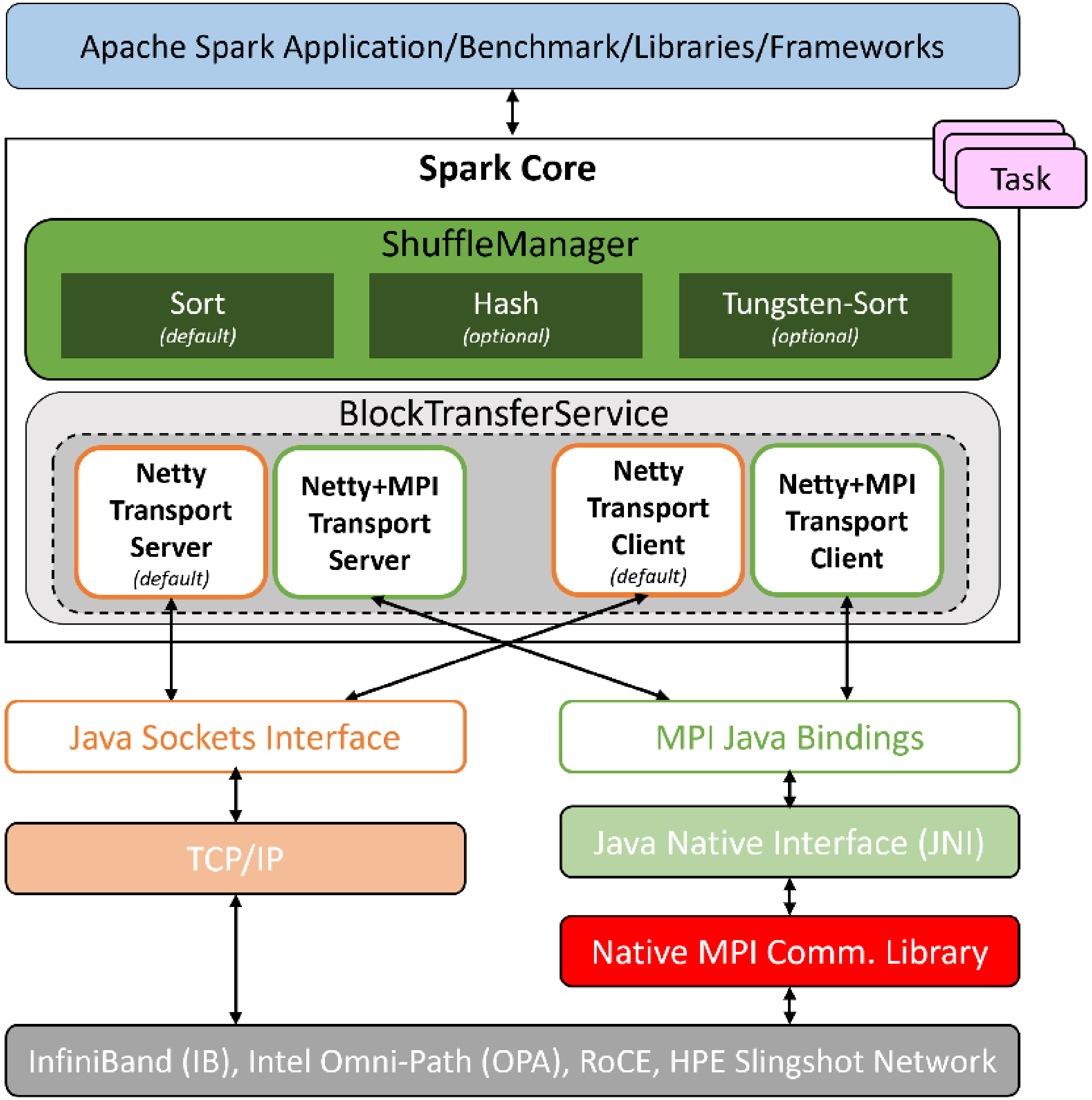
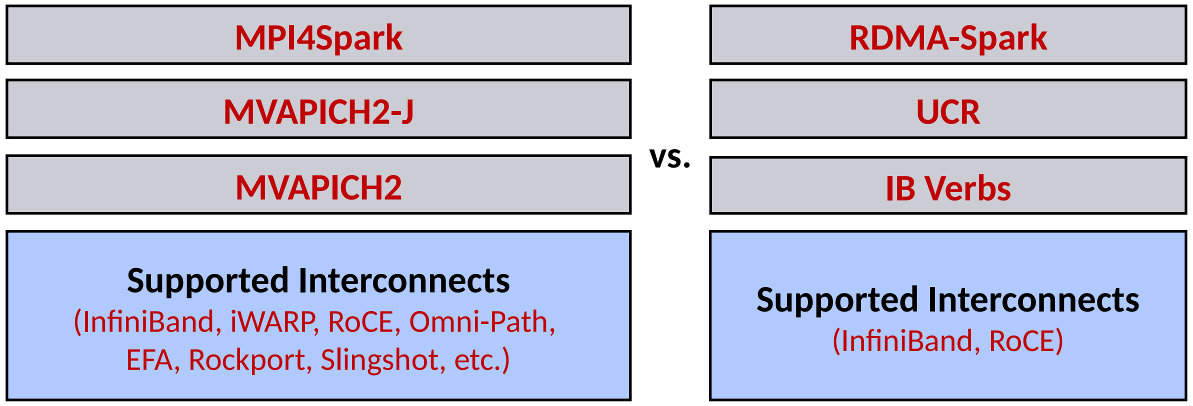
MPI4Spark: Using MVAPICH2 to Optimize Apache Spark

- The main motivation of this work is to utilize the communication functionality provided by MVAPICH2 in the Apache Spark framework
  - MPI4Spark relies on Java bindings of the MVAPICH2 library
- Spark's default Shuffle Manager relies on Netty for communication:
  - Netty is a Java New I/O (NIO) client/server framework for event-based networking applications

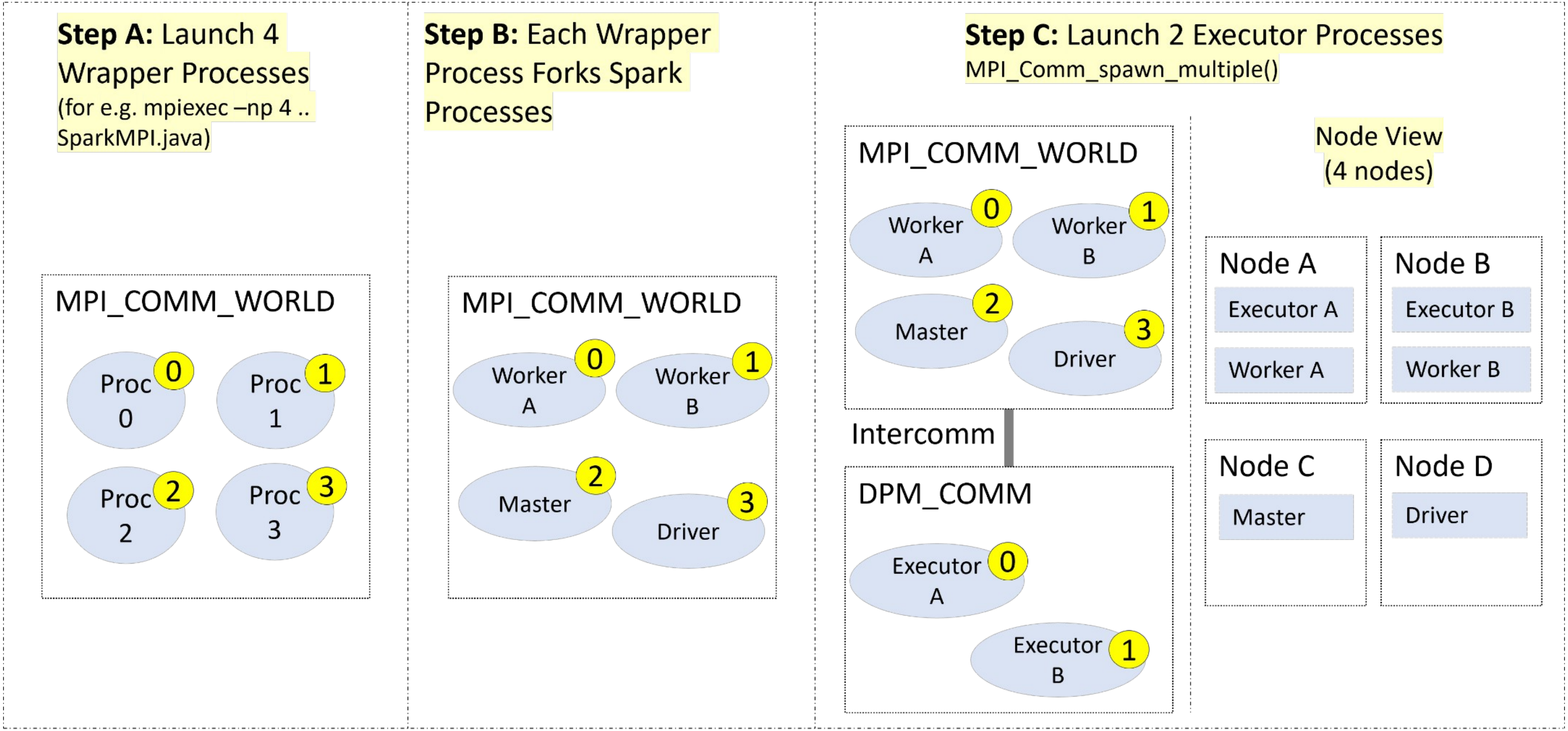


MPI4Spark Interconnect Support

- The current approach is different from its predecessor design, RDMA-Spark (http://hibd.cse.ohio-state.edu)
  - RDMA-Spark supports only InfiniBand and RoCE
  - Requires new designs for new interconnect
- MPI4Spark supports multiple interconnects/systems through a common MPI library
  - Such as InfiniBand (IB), Intel Omni-Path (OPA), HPE Slingshot, RoCE, and others
  - No need to re-design the stack for a new interconnect as long as the MPI library supports it



Launching Spark using MPI with Dynamic Process Management



Next MPI4Spark Release (v0.2)

- MPI4Spark 0.2 release adds support for the YARN cluster manager:
  - Will be available from: http://hibd.cse.ohio-state.edu
- Features:
  - Based on Apache Spark 3.3.0
  - (NEW) Support for YARN cluster manager
  - Compliant with user-level Apache Spark APIs and packages
  - High performance design that utilizes MPI-based communication
    - Utilizes MPI point-to-point operations
    - Relies on MPI Dynamic Process Management (DPM) features for launching executor processes for the standalone cluster manager
    - (NEW) Relies on Multiple-Program-Multiple-Data (MPMD) launcher mode for the YARN cluster manager
  - Built on top of the MVAPICH2-J Java bindings for MVAPICH2 family of MPI libraries
  - Tested with
    - (NEW) OSU HiBD-Benchmarks, GroupBy and SortBy
    - (NEW) Intel HiBench Suite, Micro Benchmarks, Machine Learning and Graph Workloads
    - Mellanox InfiniBand adapters (EDR and HDR 100G and 200G)
    - HPC systems with Intel OPA interconnects
    - Various multi-core platforms

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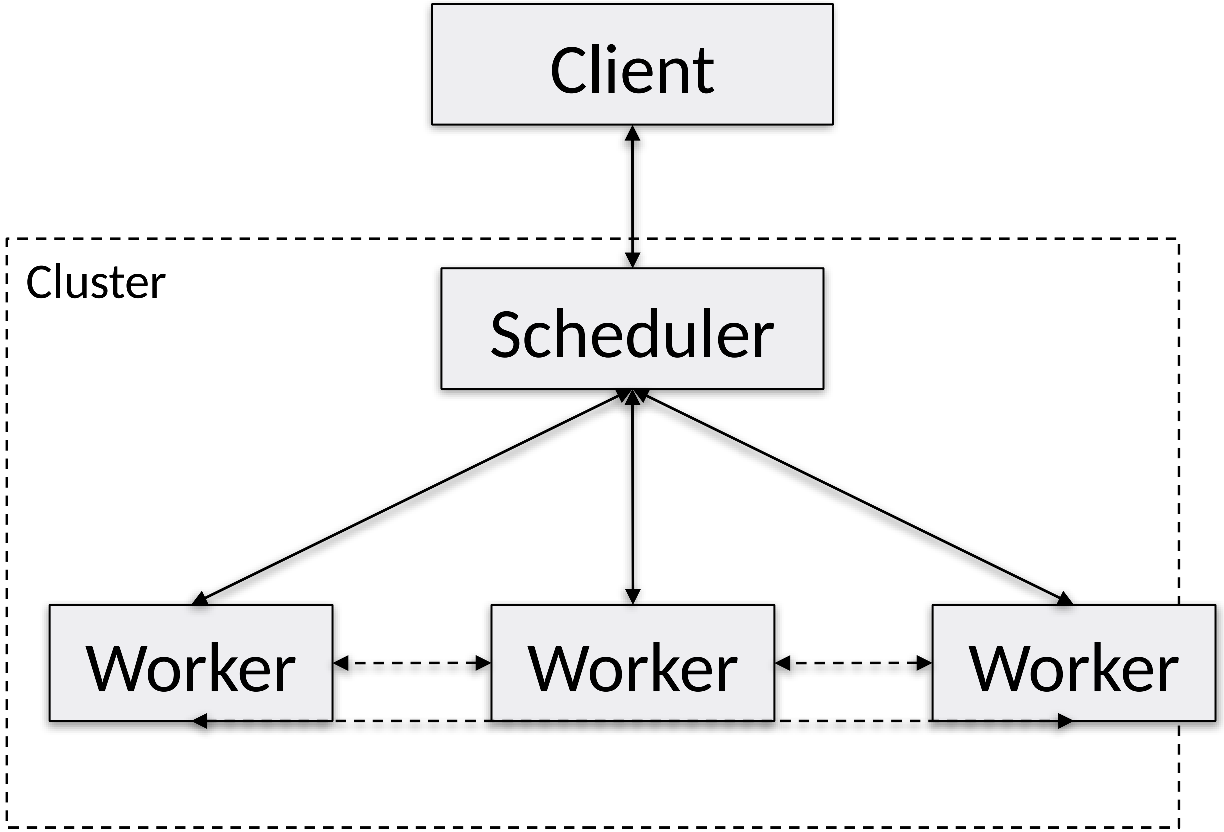
MPI4Dask: MPI backend for Dask

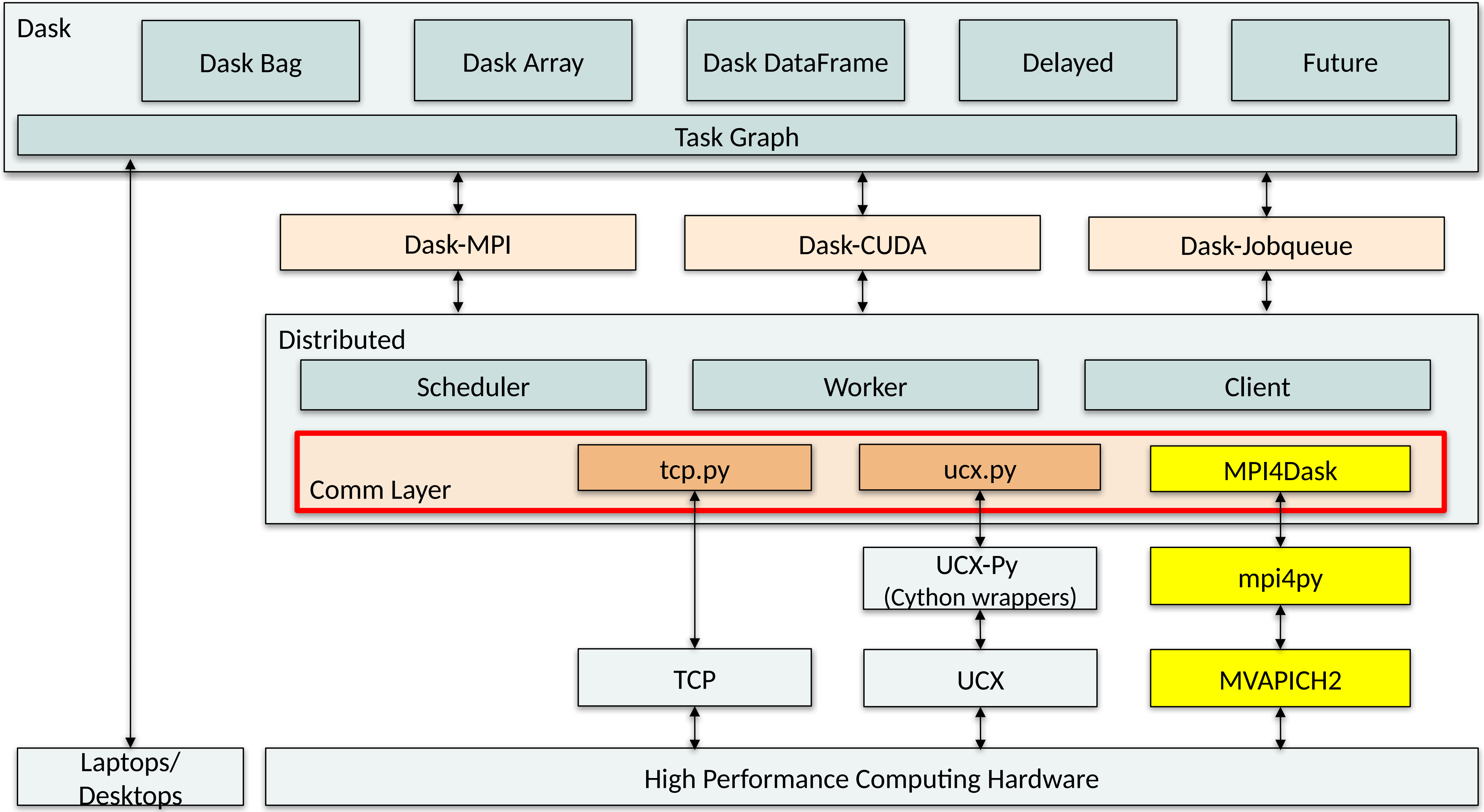
- Dask is a popular task-based distributed computing framework:
  - Scales Python applications from laptops to high-end systems
  - Builds a task-graph that is executed lazily on parallel hardware
- Dask Distributed library historically had two communication backends:
  - TCP: Tornado-based
  - UCX: Built using a GPU-aware Cython wrapper called UCX-Py
- Designed and implemented MPI4Dask communication device:
  - MPI-based backend for Dask
  - Implemented using mpi4py (Cython wrappers) and MVAPICH2
  - Uses Dask-MPI to bootstrap execution of Dask programs

Dask Distributed Execution Model

- Key characteristics:
  1. Scalability
  2. Elasticity
  3. Support for coroutines
  4. Serialization/De-serialization to data to/from GPU memory



MPI4Dask in the Dask Architecture



MPI4Dask: Bootstrapping and Dynamic Connectivity

- Several ways to start Dask programs:
  - Manual
  - Utility classes:
    - LocalCUDACluster, SLURMCluster, SGECluster, PBCCluster, and others
- MPI4Dask uses the Dask-MPI to bootstrap execution of Dask programs
- Dynamic connectivity is established using the asyncio package in MPI4Dask:
  - Scheduler and workers listen for incoming connections by calling asyncio.start_server()
  - Workers and client connect using asyncio.open_connection()

MPI4Dask Release

- MPI4Dask 0.3 was released in Feb ‘23 adding support for high-performance MPI communication to Dask:
  - Can be downloaded from: http://hibd.cse.ohio-state.edu
- Features:
  - (NEW) Based on Dask Distributed 2022.8.1
  - Compliant with user-level Dask APIs and packages
  - Support for MPI-based communication in Dask for cluster of GPUs
    - Implements point-to-point communication co-routines
    - Efficient chunking mechanism implemented for large messages
  - Built on top of mpi4py over the MVAPICH2-GDR library
  - Supports starting execution of Dask programs using Dask-MPI
  - Tested with
    - Mellanox InfiniBand adapters (FDR, EDR, and HDR)
    - (NEW) Various benchmarks used by the community (MatMul, Slicing, Sum Transpose, cuDF Merge, etc.)
    - (NEW) Various multi-core platforms
    - (NEW) NVIDIA V100 and A100 GPUs

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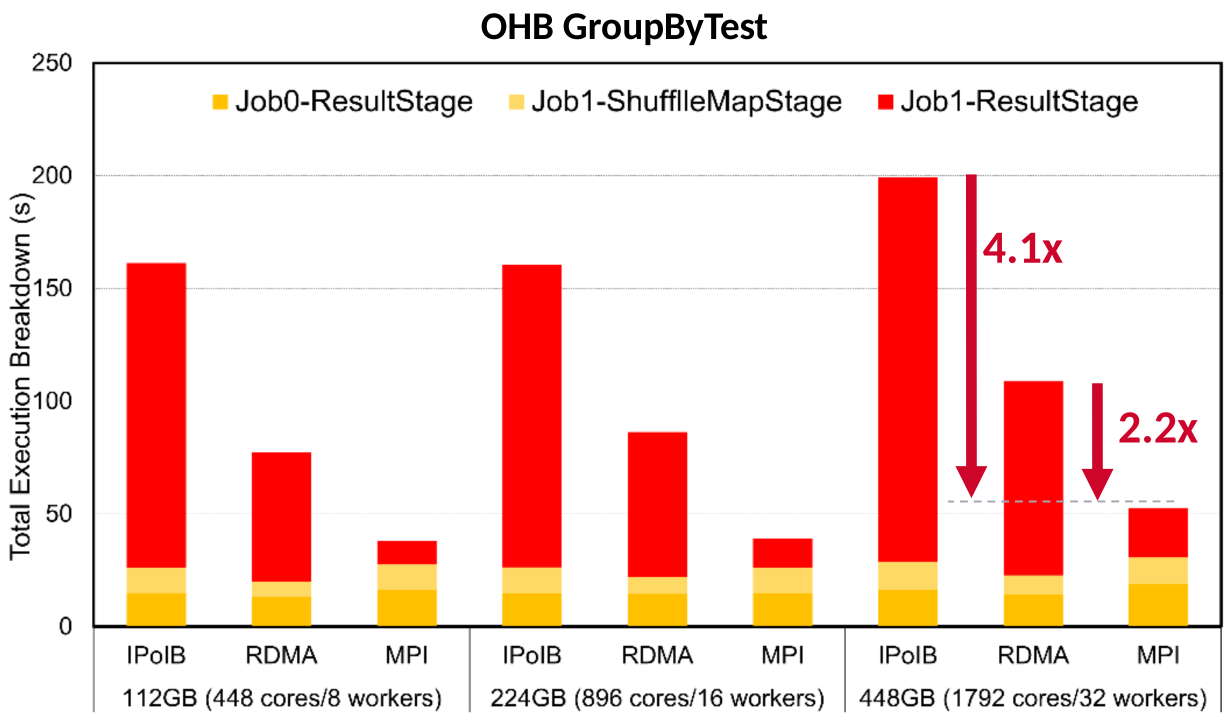
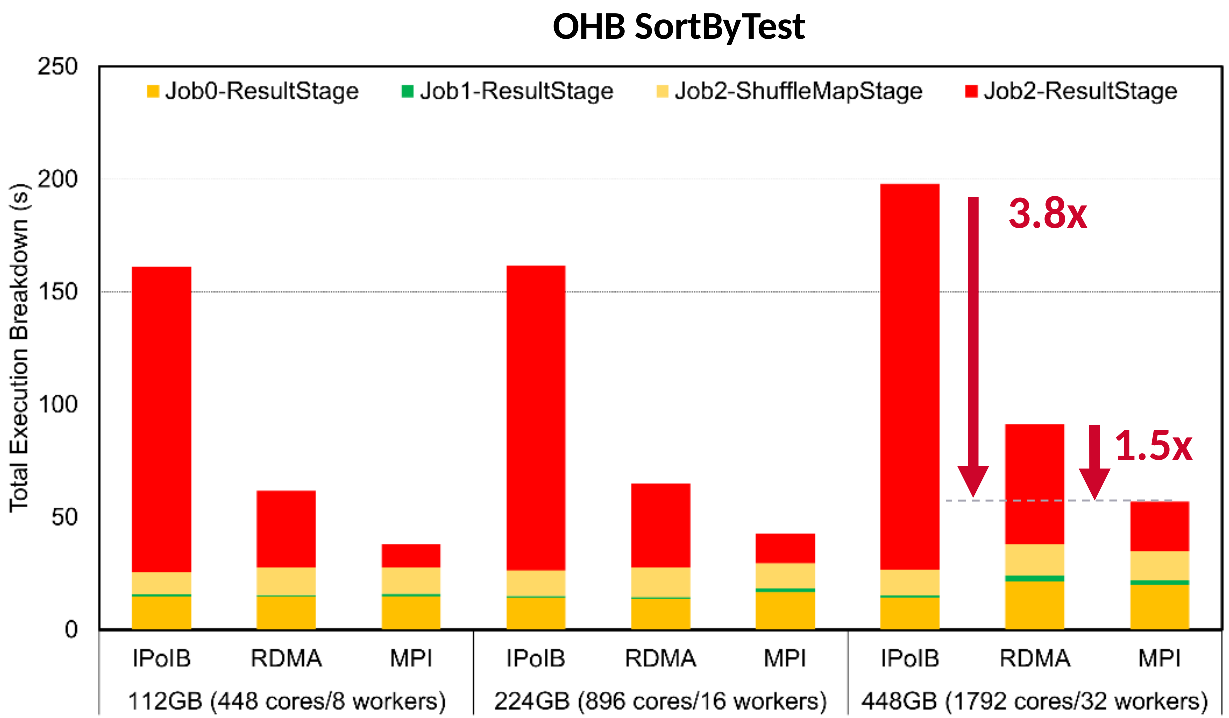
Weak Scaling Evaluation with OSU HiBD Benchmarks (OHB)

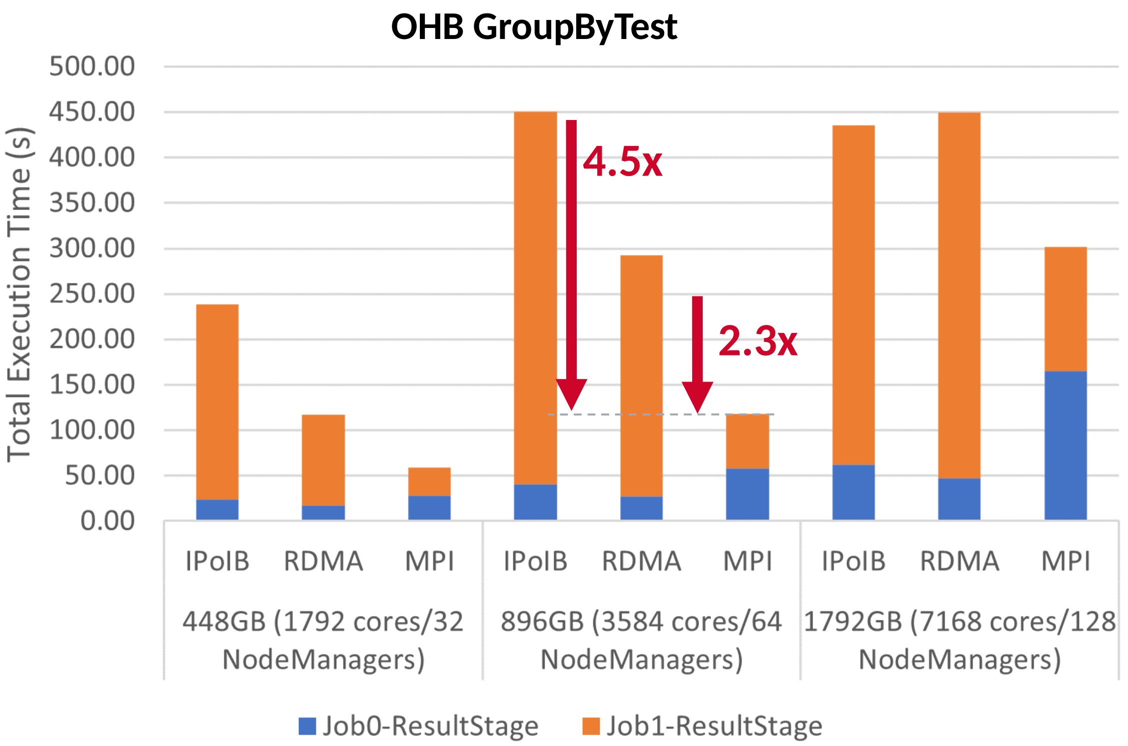


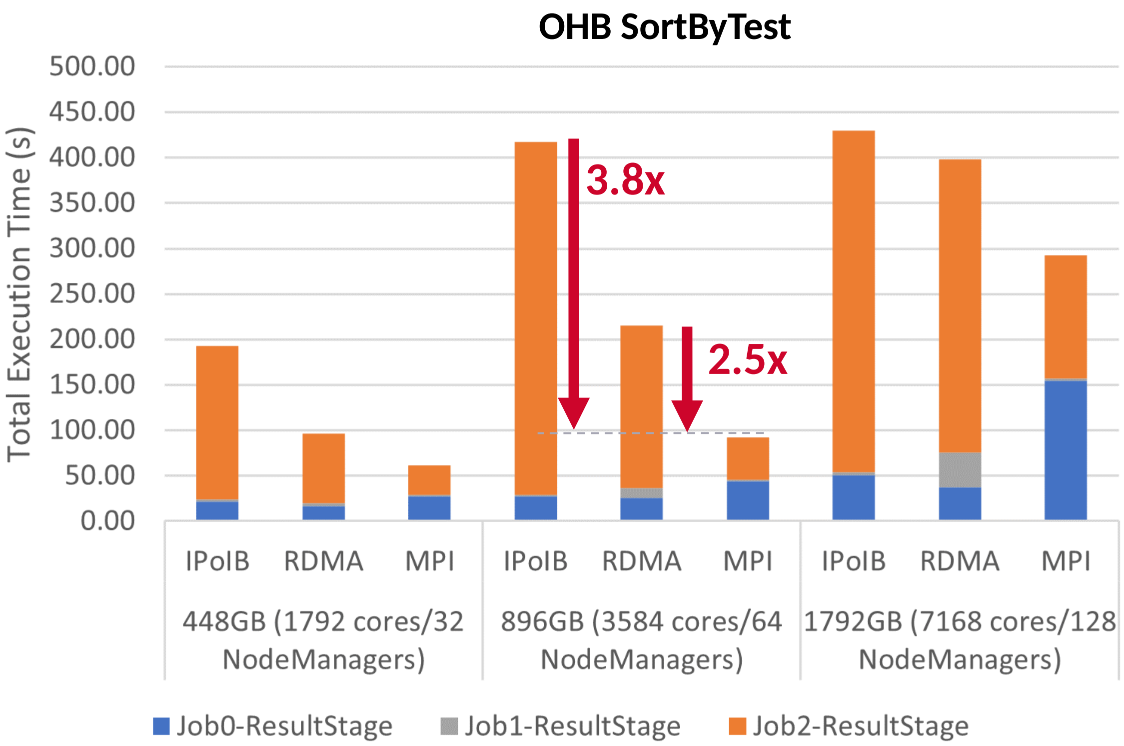


- The above are **weak-scaling** performance numbers of OHB benchmarks (GroupByTest and SortByTest) executed on the TACC Frontera system using the **Standalone cluster manager** in Spark
- Speed-ups for the overall total execution time for 448GB with GroupByTest is 4.1x and 2.2x compared to IPoIB and RDMA, and for SortByTest the speed-ups are 3.8x and 1.5x, respectively
- Speed-ups for the shuffle read stage for 112GB with GroupByTest are 13x compared with IPoIB and 5.6x compared to RDMA, while for SortByTest the speed-ups are 12.8x and 3.2x, respectively

K. Al Attar, A. Shafi, M. Abduljabbar, H. Subramoni, D. Panda, Spark Meets MPI: Towards High-Performance Communication Framework for Spark using MPI, IEEE Cluster '22, Sep 2022.

Weak Scaling Evaluation with OHB (YARN)

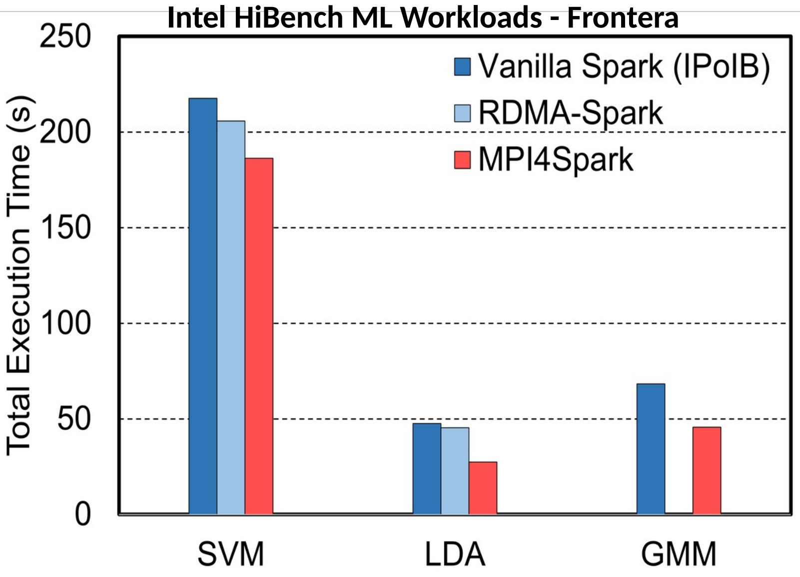




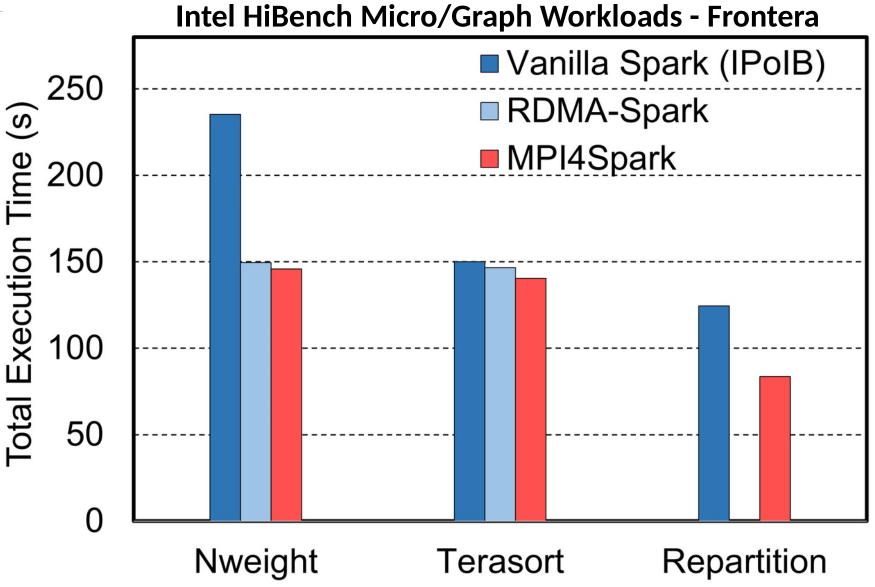
- The above are **weak-scaling** performance numbers of OHB benchmarks (GroupByTest and SortByTest) executed on the TACC Frontera system using the **YARN cluster manager** in Spark
- Speed-ups for the overall total execution time for SortByTest, 64 NodeManagers, are **4.5x** and **2.3x** compared to IPoIB and RDMA, and for GroupByTest, also 64 NodeManagers, the speed-ups are **3.8x** and **2.5x**, respectively
- Speed-ups for the shuffle read stage for 896GB with GroupByTest are **6.8x** compared with IPoIB and **4.4x** compared to RDMA, while for SortByTest the speed-ups are **8.4x** and **3.9x**, respectively

Performance Evaluation with Intel HiBench Workloads

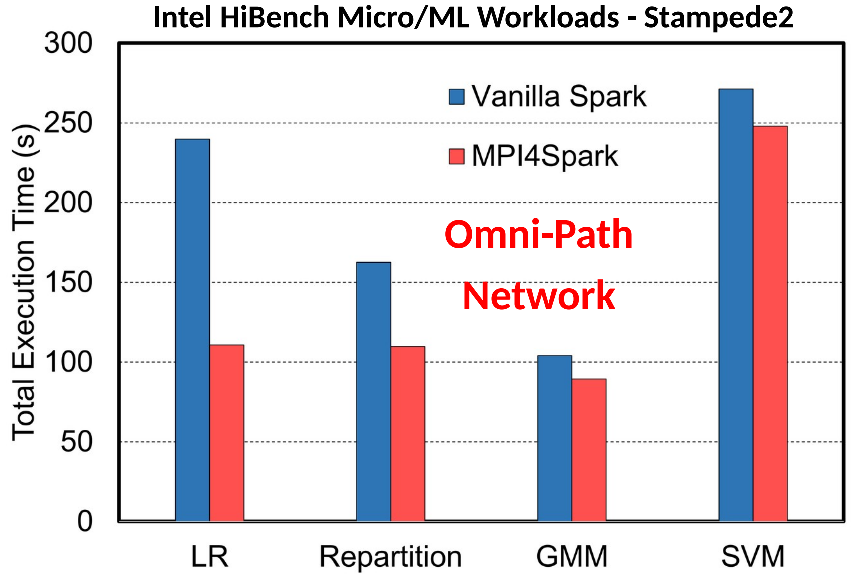
1.4x on average than RDMA-Spark



1.4x on average than Vanilla Spark



1.5x on average than Vanilla Spark



- This evaluation was done on the TACC Frontera (IB) and the TACC Stampede2 (OPA) Systems
- This illustrates the portability of MPI4Spark on different interconnects
- We see a speed-up for the LR machine learning workload on Stampede2 of about **2.2x**
- Speed-ups for the LDA machine learning workload on Frontera are **1.7x** for both IPoIB and RDMA

K. Al Attar, A. Shafi, M. Abduljabbar, H. Subramoni, D. Panda, Spark Meets MPI: Towards High-Performance Communication Framework for Spark using MPI, IEEE Cluster '22, Sep 2022.

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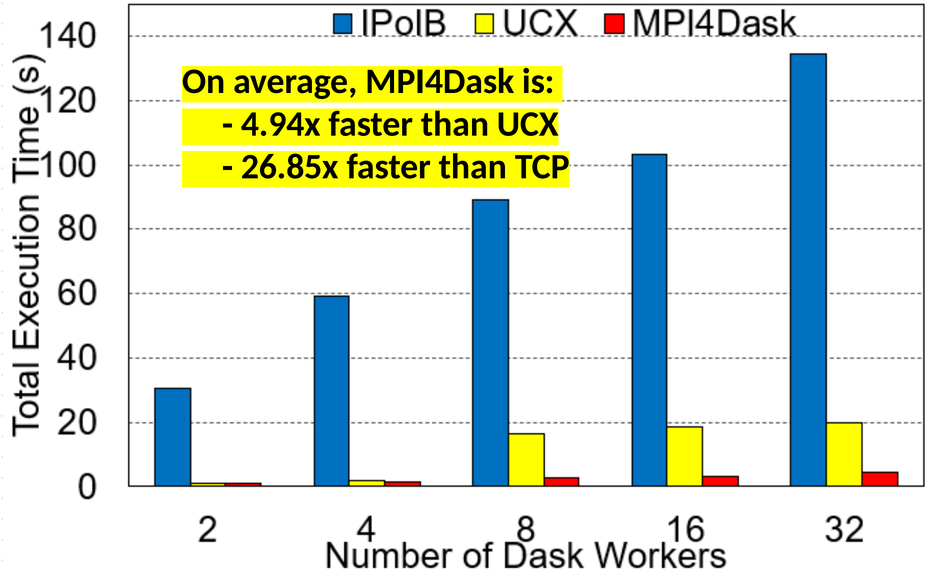
cuDF Merge Benchmark on the Cambridge Wilkes-3 System

- GPU-based Operation: , using persist
  - Merge two GPU data frames, each with length of 32*1e8
  - Compute() will gather the data from all worker nodes to the client node, and make a copy on the host memory.
  - Persist() will leave the data on its current nodes without any gathering

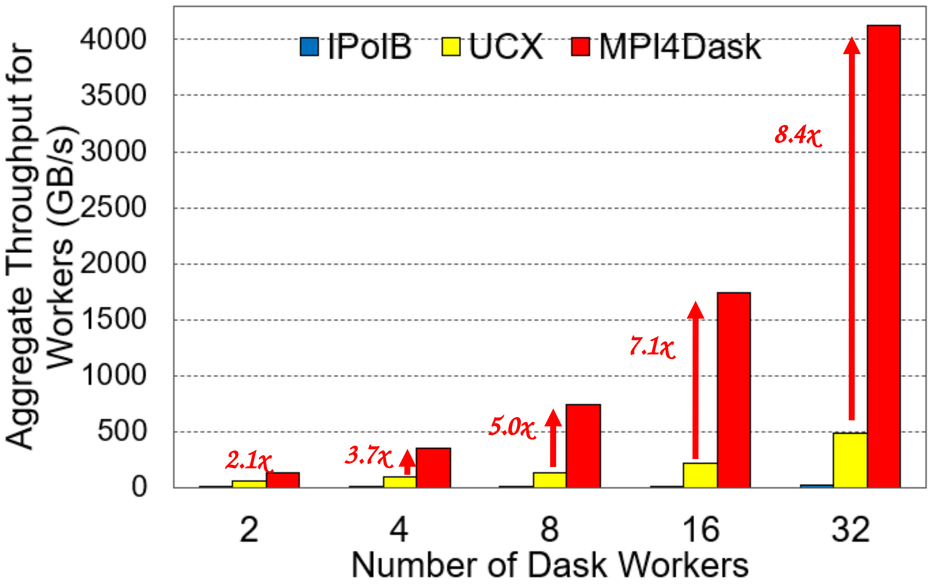
Wilke3 GPU System:

- 80 nodes
- 2x AMD EPYC 7763 64-core Processors
- 1000 GiB RAM
- Dual-rail Mellanox HDR200 IB
- 4x NVIDIA A100 SXM4 80 GB

Execution Time



Aggregated Throughput



MPI4Dask 0.3, Dask 2022.8.1, Distributed, 2022.8.1, MVAPICH2-3.0, UCX v1.13.1, UCX-py 0.27.00

cupy GEMM Benchmark on the Cambridge Wilkes-3 System

- GPU-based Operation: , using persist
  - Arrays are distributed on multiple GPUs
  - Compute() will gather the data from all worker nodes to the client node, and make a copy on the host memory.
  - Persist() will leave the data on its current nodes without any gathering

Wilke3 GPU System:
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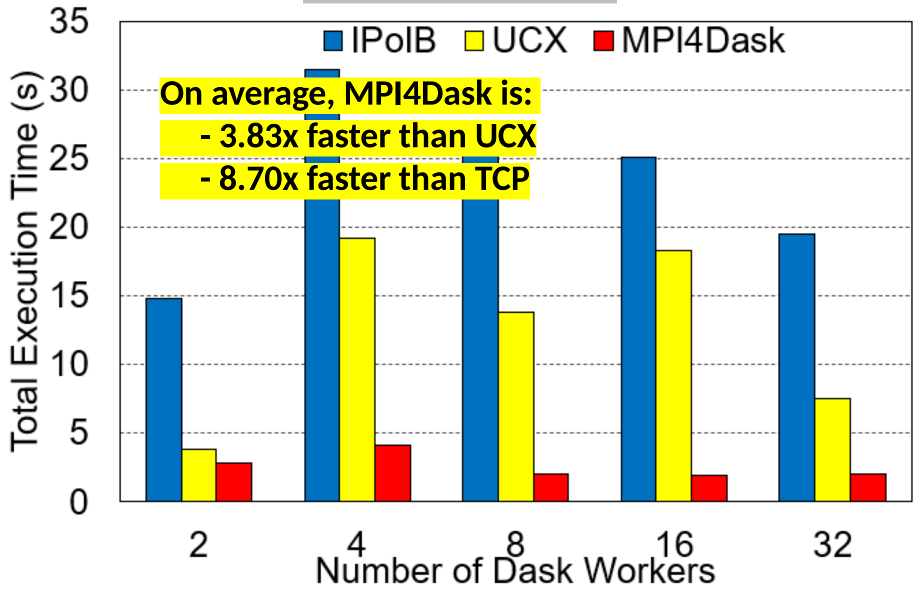

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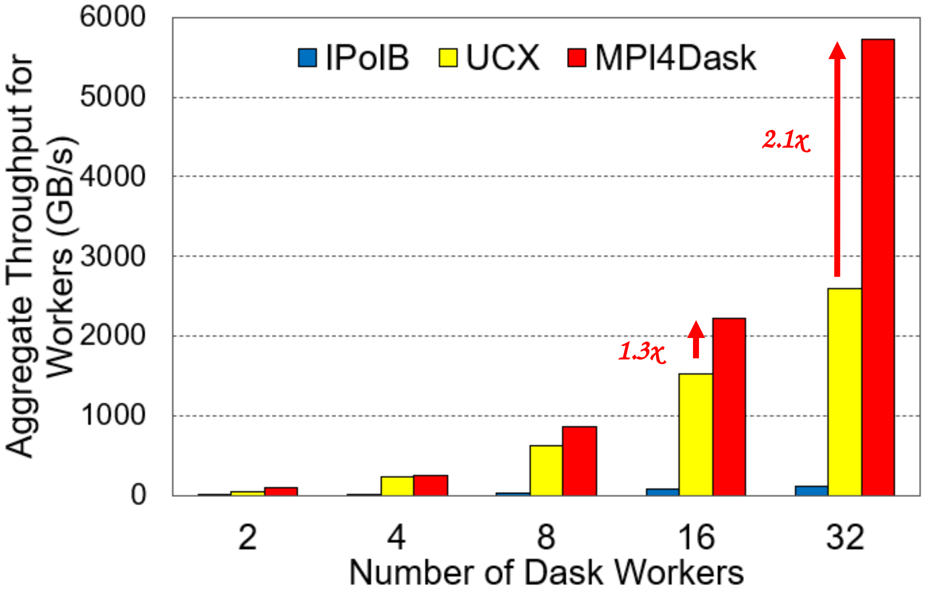
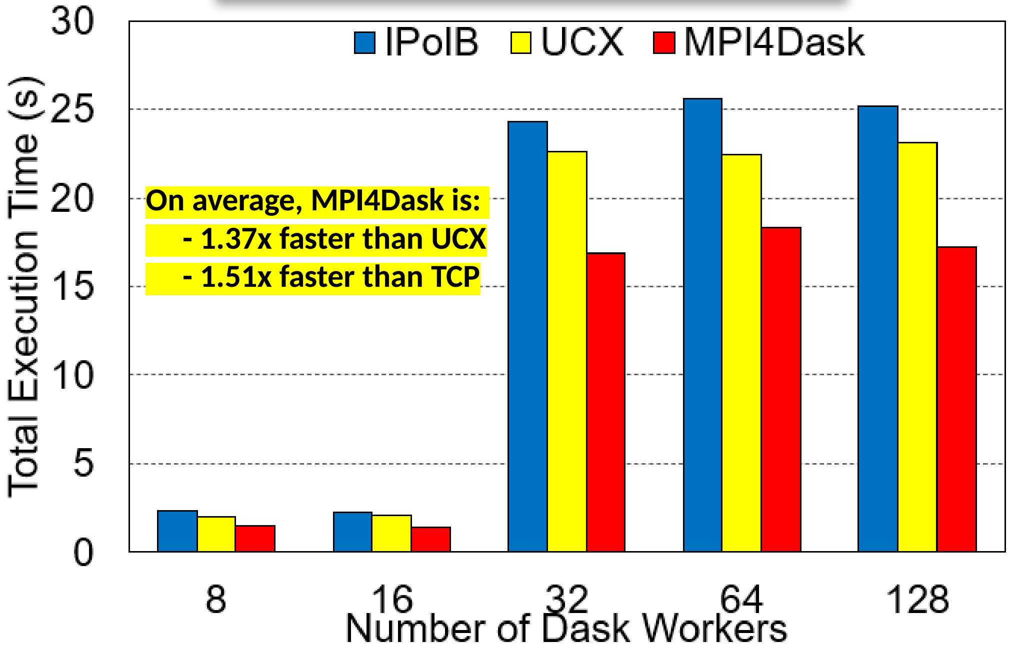


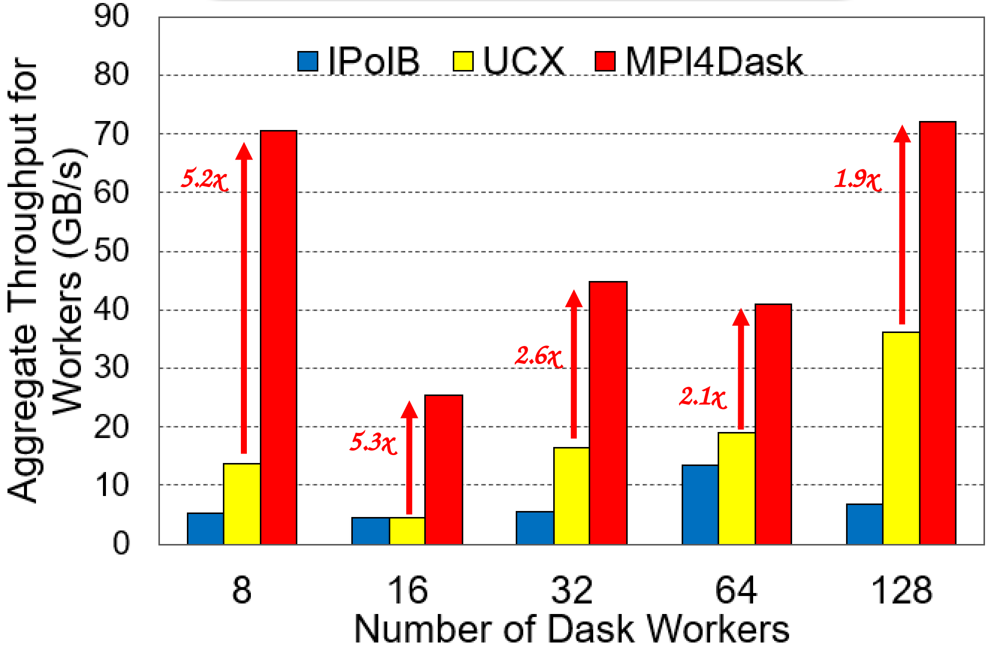
MPI4Dask 0.3, Dask 2022.8.1, Distributed, 2022.8.1, MVAPICH2-3.0, UCX v1.13.1, UCX-py 0.27.00

NumPy Array Slicing Benchmark on TACC Frontera CPU System

1.26x better on average



3.17x better on average



From 32 workers, we increase array size by 16 times

A. Shafi , J. Hashmi , H. Subramoni , and D. K. Panda, Efficient MPI-based Communication for GPU-Accelerated Dask Applications, CCGrid '21
https://arxiv.org/abs/2101.08878

MPI4Dask 0.3 release

(http://hibd.cse.ohio-state.edu)

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- Towards Java-based HPC using the MVAPICH2 Library: Early Experiences K. Al Attar, A. Shafi, H. Subramoni, D. Panda HIPS '22 (IPDPSW), May 2022.

- Efficient MPI-based Communication for GPU-Accelerated Dask Applications A. Shafi, J. Hashmi, H. Subramoni, D. Panda, The 21st IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing, May 2021. https://arxiv.org/abs/2101.08878

- Blink: Towards Efficient RDMA-based Communication Coroutines for Parallel Python Applications A. Shafi, J. Hashmi, H. Subramoni, D. Panda, 27th IEEE International Conference on High Performance Computing, Data, and Analytics, Dec 2020.

Summary

- Apache Spark and Dask are two popular Big Data processing frameworks
- There is existing support for parallel and distributed on HPC systems:
  - One bottleneck is the lack of support for low-latency and high-bandwidth interconnects
- This talk presented latest developments in the MPI4Dask (MPI-based Dask ecosystem) and MPI4Spark (MPI-based Spark ecosystem)
- Provided an overview of issues, challenges, and opportunities for designing efficient communication runtimes
  - Efficient, scalable, and hierarchical designs are crucial for Big Data/Data Science frameworks
  - Co-design of communication runtimes and BigData/Data Science frameworks will be essential

Thank You!

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HiDL
High-Performance Deep Learning

The High-Performance Deep Learning Project
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