An Apache Spark ⇔ MPI Interface

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In collaboration with UC Berkeley
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Why should MPI codes interface with Spark?

Google trends popularity: MPI vs Hadoop vs Spark
Q: What about less embarrassingly parallel computations?
A: Use Spark and MPI
Example: linear algebra in Spark

Pros for Spark:

- Faster development, easier reuse
- One abstract uniform interface (RDD)
- An entire ecosystem that can be used before and after the NLA computations
- Spark can take advantage of available local linear algebra codes
- Automatic fault-tolerance, out-of-core support

Pros for MPI: Classical MPI-based linear algebra implementations will be faster and more efficient
Motivation

- **NERSC**: Spark for data-centric workloads and scientific analytics
- **RISELab**: characterization of linear algebra in Spark (MLlib, MLMatrix)
- **Cray**: users asking for Spark; understand performance concerns
Case Study: Spark vs. MPI

- Numerical linear algebra (NLA) using Spark vs. MPI
- Computations performed on NERSC supercomputer Cori Phase 1, a Cray XC40
  - 2,388 compute nodes
  - 128 GB RAM/node, 32 2.3GHz Haswell cores/node
  - Lustre storage system, Cray Aries interconnect

Case Study: Spark vs. MPI

- **Numerical linear algebra (NLA)** using Spark vs. MPI
- Matrix factorizations considered include *truncated Singular Value Decomposition* (SVD)
- Data sets include:
  - Ocean temperature data - 2.2 TB
  - Atmospheric data - 16 TB

Case Study: Spark vs. MPI

Rank 20 SVD of 2.2TB ocean temperature data
Case Study: Spark vs. MPI

Rank 20 SVD of 16TB atmospheric data using 48K+ cores
Case Study: Spark vs. MPI

Lessons learned:

• With favorable data (tall and skinny) and well-adapted algorithms, linear algebra in Spark is 2x-26x slower than MPI when I/O is included

• Spark’s overheads:
  • Can be order of magnitude higher than the actual computation times
  • Anti-scale

• The gaps in performance suggest it may be better to interface with MPI-based codes from Spark
• **Alchemist** interfaces between Apache Spark and existing or custom MPI-based libraries for large-scale linear algebra, machine learning, etc.

• **Idea:**
  - Use Spark for regular data analysis workflow
  - When computationally intensive calculations are required, call relevant MPI-based codes from Spark using Alchemist, send results to Spark

• **Combine high productivity of Spark with high performance of MPI**
Target users:

- **Scientific community:** Use Spark for analysis of large scientific datasets by calling existing MPI-based libraries where appropriate

- **Machine learning practitioners** and **data analysts:**
  - Better performance of a wide range of large-scale, computationally intensive ML and data analysis algorithms
  - For instance, SVD for principal component analysis, recommender systems, leverage scores, etc.
Basic Framework

- **Alchemist**: Acts as bridge between Spark and MPI-based libraries
- **Alchemist-Client Interface**: API for user, communicates with Alchemist via TCP/IP sockets
- **Alchemist-Library Interface**: Shared object, imports MPI library, provides generic interface for Alchemist to communicate with library
Basic workflow:

- Spark application:
  - Sends distributed dataset from RDD (IndexedRowMatrix) to Alchemist
  - Tells Alchemist what MPI-based code should be called
- Alchemist loads relevant MPI-based library, calls function, sends results to Spark
• Alchemist can also load data from file
• Alchemist needs to store distributed data in appropriate format that can be used by MPI-based libraries:
  • Candidates: *ScaLAPACK*, *Elemental*, *PLAPACK*
  • Alchemist currently uses Elemental, support for ScaLAPACK under development
Alchemist Architecture

- **Application 1**
  - Driver
  - Worker
  - Worker
  - Worker

- **Application 2**
  - Driver
  - Worker

- **Alchemist**
  - Driver
  - Worker
  - Worker

- **Inter-Driver Socket Communication**

- **Inter-Worker Socket Communication**

- **Dynamic linking**

- **MPI Communication**
import alchemist.{Alchemist, AlMatrix}
import alchemist.libA.QRDecomposition // libA is sample MPI lib

// other code here ...

// sc is instance of SparkContext
val ac = new Alchemist.AlchemistContext(sc, numWorkers)
ac.registerLibrary("libA", ALIlibALocation)

// maybe other code here ...

val alA = AlMatrix(A) // A is IndexedRowMatrix

// routine returns QR factors of A as AlMatrix objects
val (alQ, alR) = QRDecomposition(alA)

// send data from Alchemist to Spark once ready
val Q = alQ.toIndexedRowMatrix() // convert AlMatrix alQ to RDD
val R = alR.toIndexedRowMatrix() // convert AlMatrix alR to RDD

// maybe other code here ...

ac.stop() // release resources once no longer required
Example: Matrix Multiplication

- Requires expensive shuffles in Spark, which is impractical:
  - Matrices/RDDs are row-partitioned
  - One matrix must be converted to be column-partitioned
  - Requires an all-to-all shuffle that often fails once the matrix is distributed
Example: Truncated SVD

Use Alchemist and MLlib to get rank 20 truncated SVD

Experiment Setup

- Spark: 22 nodes; Alchemist: 8 nodes
- A: m-by-10K, where m = 5M, 2.5M, 1.25M, 625K, 312.5K
- Ran jobs for at most 30 minutes (1800 s)
Example: Truncated SVD

**Experiment Setup**

- 2.2TB (6,177,583-by-46,752) ocean temperature data read in from HDF5 file
- Data replicated column-wise
Upcoming Features

- **PySpark, SparkR ⇔ MPI Interface**
  - Interface for Python => PySpark support
  - Future work: Interface for R

- **Direct Python interface, potential Dask integration**

- **More Functionality**
  - Support for sparse matrices
  - Support for MPI-based libraries built on ScaLAPACK

- **Alchemist and Containers**
  - Alchemist running in Docker and Kubernetes
  - Will enable Alchemist on clusters and the cloud
Limitations and Constraints

- Two copies of data in memory
- **Data transfer overhead** between Spark and Alchemist when data on different nodes
  - Subject to network disruptions and overload
- **MPI is not fault tolerant or elastic**
- **Lack of MPI-based libraries for machine learning**
  - No equivalent to MLlib currently available, closest is MaTEx
- Currently, need to run Alchemist and Spark on separate nodes -> more data transfer over interconnects -> larger overheads
Future Work

- **Apache Spark ⇔ X Interface**
  - Interest in connecting Spark with other libraries for distributed computing (e.g. Chapel)
- **Reduce communication costs**
  - Exploit locality
  - Reduce number of messages
  - Use communication protocols designed for underlying network infrastructure
- **Run as network service**
- **MPI computations with (basic) fault tolerance and elasticity**
github.com/project-alchemist/

References


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