Lab Course: distributed data analytics

03. Distributed Environments - Hadoop

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Outline

1. Hadoop Architecture
2. HDFS and YARN
3. MapReduce
4. Hadoop Streaming

Outline

Apache Hadoop

- Apache Hadoop is an open source software framework that can be installed on a cluster of machines such that the machines can communicate and work together to store and process large amounts of data in a highly distributed manner.
- The core of Apache Hadoop consists of a storage part, Hadoop Distributed File System (HDFS), and a processing part, MapReduce programming model.
  - Hadoop Common: contains libraries and utilities needed by other Hadoop modules.
  - From Hadoop 2.x, Hadoop YARN: a resource-management platform responsible for managing computing resources.

Apache Hadoop

- Hadoop consists of two main components:
  - Hadoop Distributed File System (HDFS): responsible for managing data stored on disks across a cluster.
  - Yet Another Resource Negotiator (YARN): responsible for allocating computational assets to applications that wish to perform a distributed computation.
- HDFS and YARN are implemented by several daemon process.
  - Processes that run in the background and do not require user input.
  - Hadoop processes run all the time on a cluster node and accept input and deliver output through the network.

Hadoop Architecture Overview

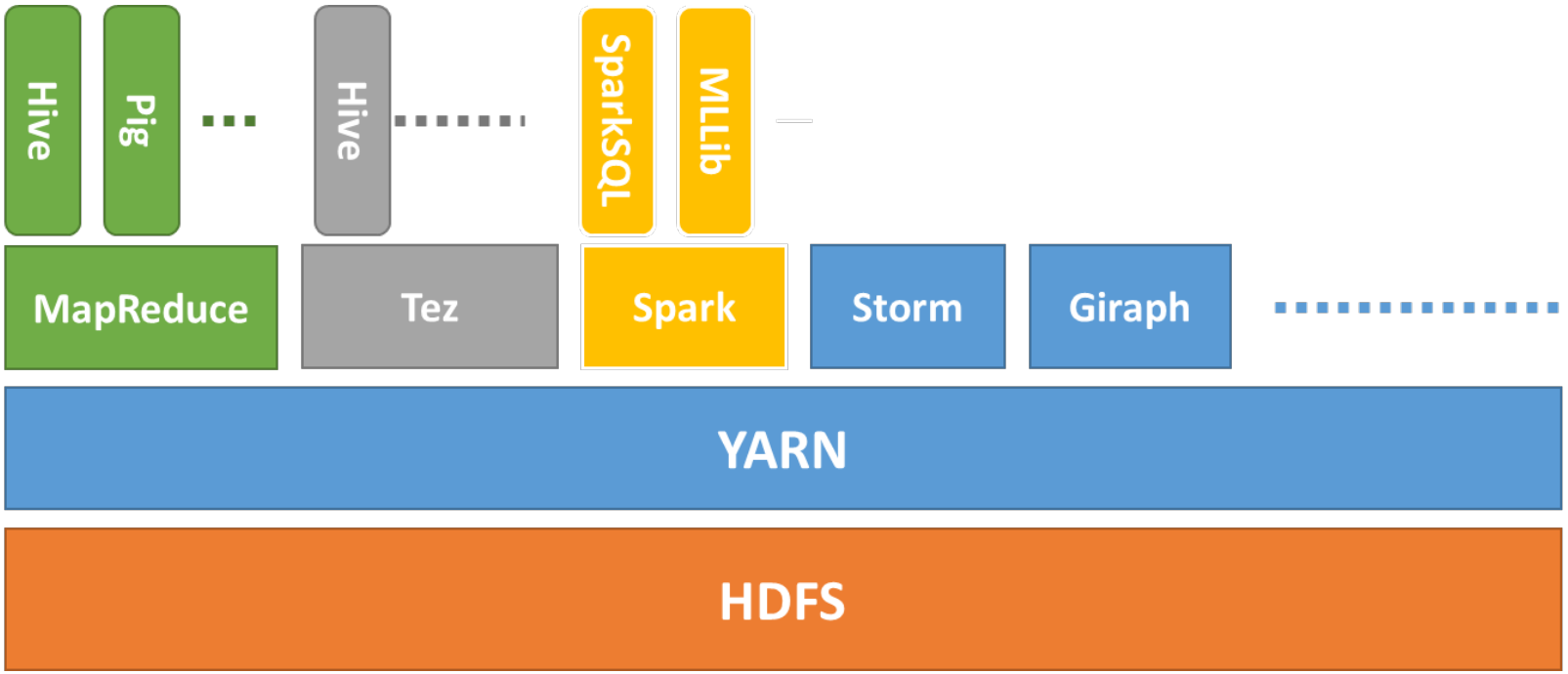


Figure: Hadoop architecture [14]

A Hadoop Cluster

- A Hadoop cluster is a set of machines that runs HDFS and YARN.
- Each individual machine is called a node.
- Nodes may be partitioned in racks. This is the hardware part of the infrastructure.
- A cluster can have a single node, or many thousands of nodes.
- Nodes are scale horizontally.
- Adding more nodes results in the total cluster increase in both capacity and performance in a linear manner.

A Hadoop Cluster

- Each node in the cluster is identified by the type of process or processes that it runs:
  - Master nodes
    - one or a few master nodes in the cluster.
    - run coordinating services for worker nodes.
    - entry points for user access to the cluster.
  - Worker nodes
    - majority of the computers in the cluster.
    - run services that accept tasks from master nodes.
    - a distributed computation is run by parallelizing across worker nodes.

A Hadoop Cluster

- For HDFS, the master and worker nodes are:
  - NameNode (Master)
    - stores the directory tree of the file system, file metadata, and the locations of each file across the cluster.
  - Secondary NameNode (Master)
    - performs housekeeping tasks and checkpoint schedule.
  - DataNode (Worker)
    - stores data in HDFS blocks on the local disk.

A Hadoop Cluster

- For YARN, the master and worker nodes ares:
  - ResourceManager (Master)
    - monitors and allocates available cluster resources to needed applications.
    - schedules jobs on the cluster.
  - ApplicationMaster (Master)
    - tracks the execution of jobs scheduled by the ResourceManager.
  - NodeManager (Worker)
    - runs processing tasks on local node.

Outline

HDFS

- HDFS is a distributed file system designed to run on commodity hardware.
- HDFS is highly fault-tolerant and is designed to be deployed on low-cost hardware.
- HDFS provides high throughput access to application data and is suitable for applications that have large data sets.
- Key HDFS goals:
  - Quick and automatic recovery from hardware failure.
  - Batch processing and streaming data.
  - Support huge data sets from gigabytes to terabytes in size.

HDFS

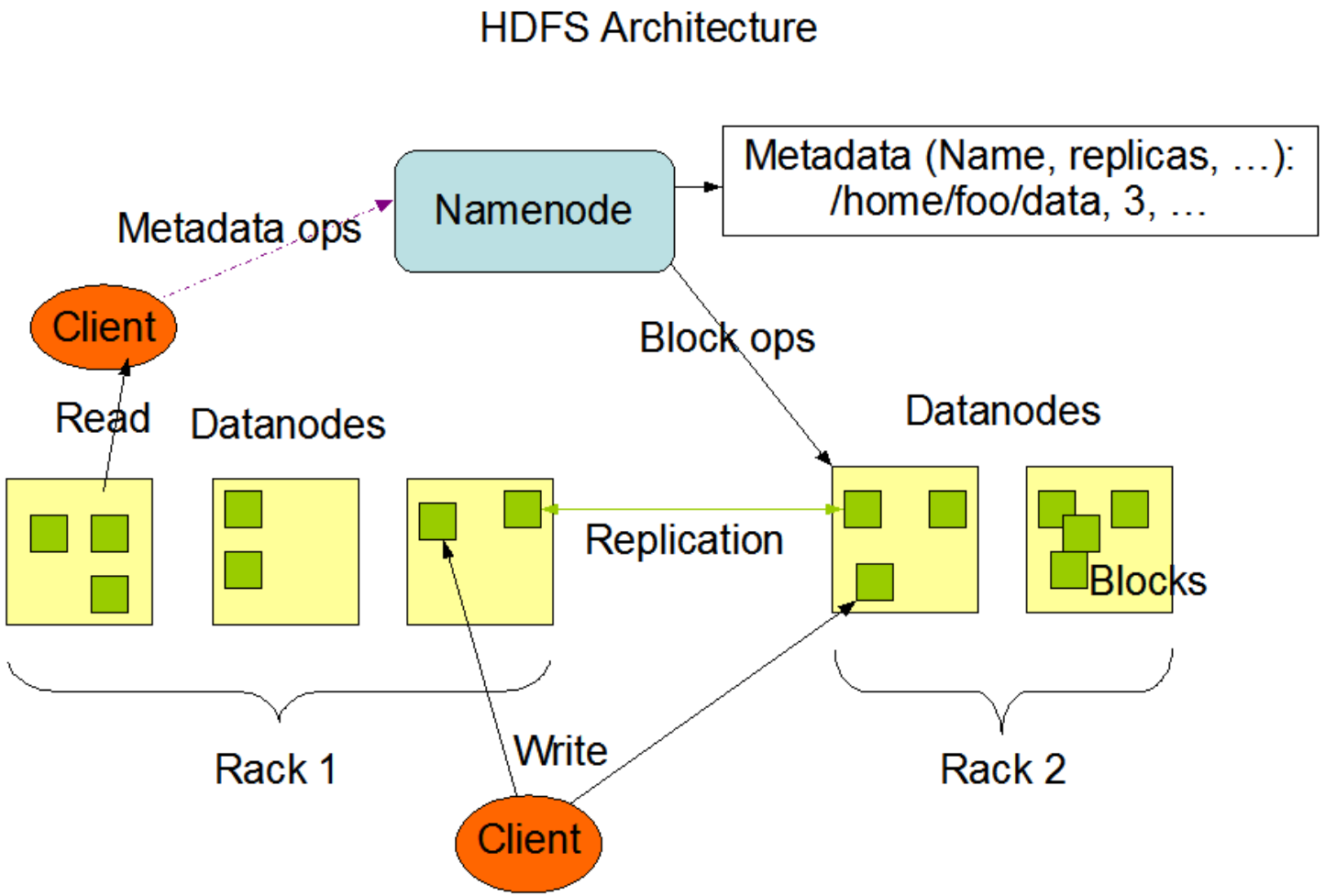


Figure: HDFS architecture [1]

YARN

- YARN is responsible for providing the computational resources (e.g., CPUs, memory, etc.) needed for application executions.
- The application startup process is the following:
  - a client submits an application to the Resource Manager.
  - the Resource Manager allocates a container.
  - the Resource Manager contacts the related Node Manager.
  - the Node Manager launches the container.
  - the Container executes the Application Master.

YARN

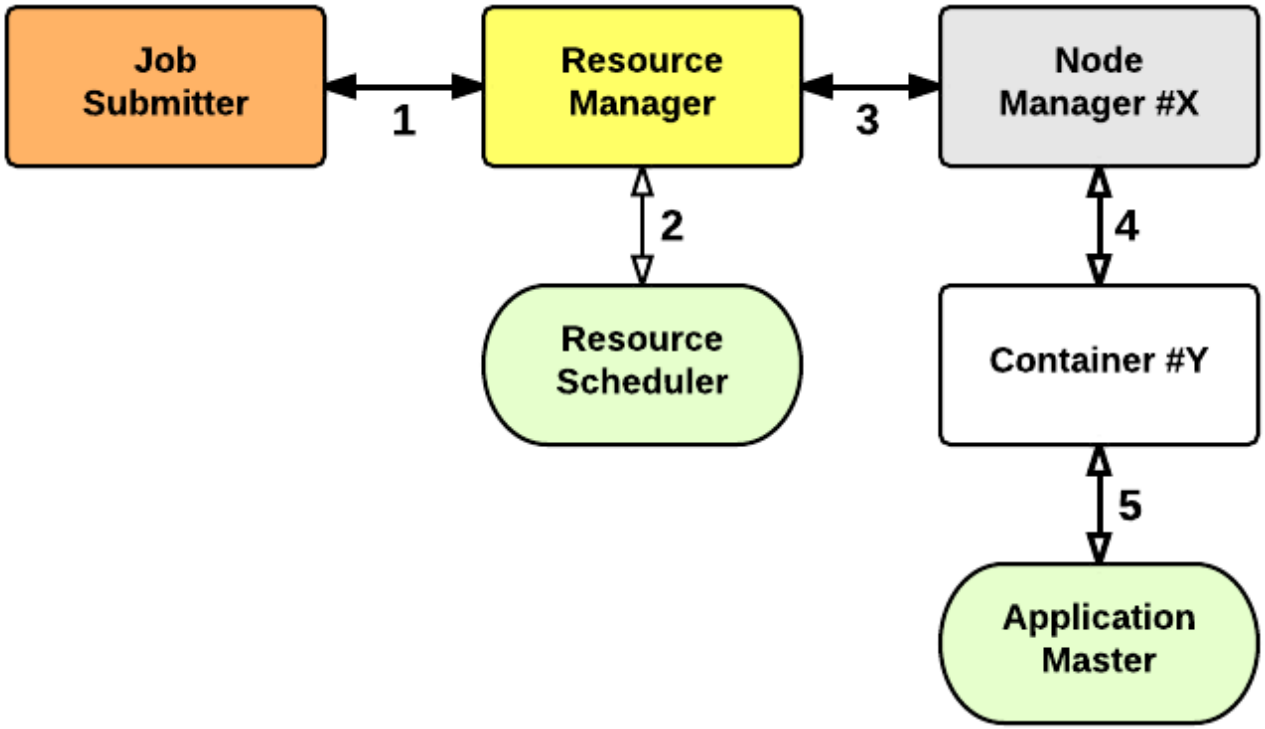


Figure: Application startup process in YARN [1]

Outline

MapReduce

- MapReduce is a functional programming model and an associated implementation for processing and generating big data sets with a parallel, distributed algorithm on a cluster.
  - Stateless; independent functions; depend solely on input.
  - Work on small chunks of datasets.
- The model is a specialization of the split-apply-combine strategy for data analysis.
- MapReduce is specifically designed to enable fault-tolerant distributed computation across a cluster.
- MapReduce provides analytical capabilities for analyzing huge volumes of complex data.

MapReduce

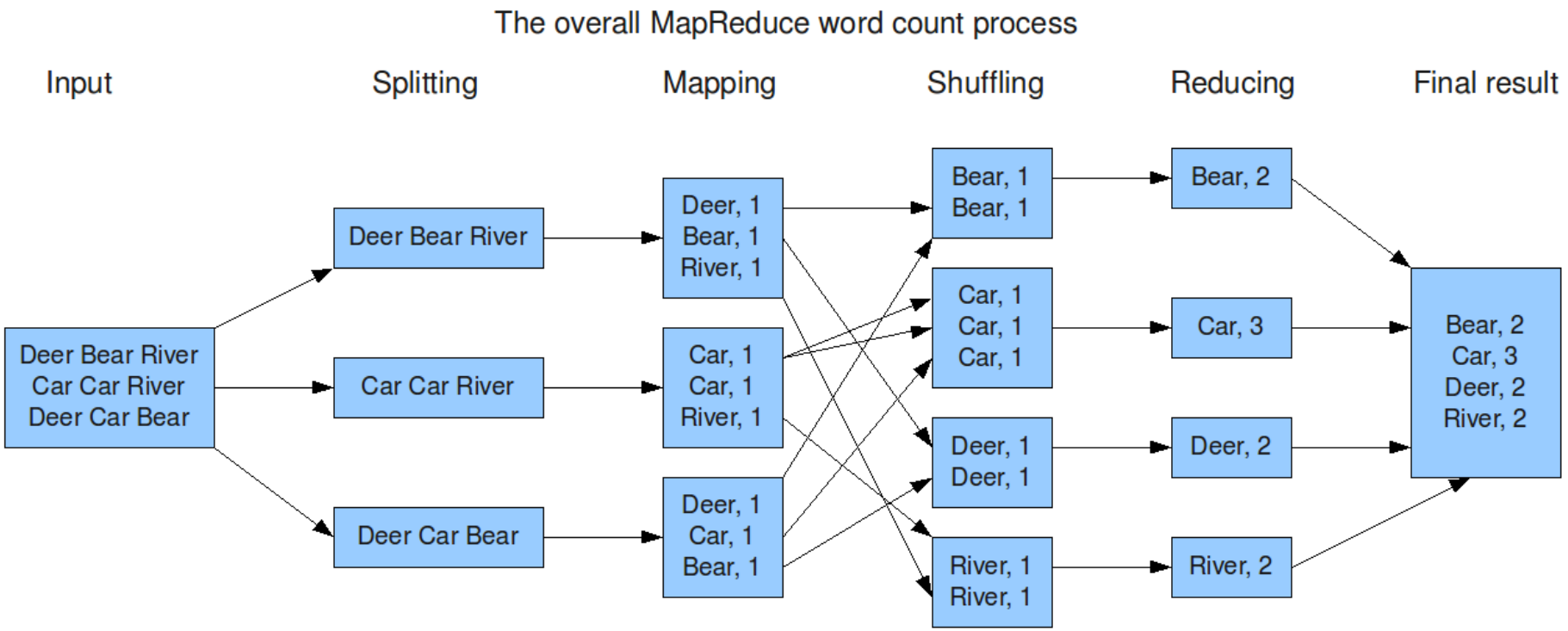
- MapReduce consists of two functions that distribute work and aggregate results: `map` and `reduce`.
- MapReduce utilizes `key-value` pairs to coordinate computation.
- The Pseudo-code for `map` and `reduce` looks as follows:

```
1 def map(key, value):
2   # perform processing
3   return (inter_key, inter_value)
4
5 def reduce(inter_key, inter_value):
6   # perform processing
7   return (key, value)
```

How MapReduce works?

- MapReduce works in two main phases, namely `map` and `reduce`:
  - In the `map` phase, a `map` function takes as input a series of key-value pairs and operates on each individual pair.
  - After the map phase, any `emitted` key-value pairs will then be grouped by key and those key-value groups are applied as input to `reduce` functions on a per-key basis.
  - In the `reduce` phase, a `reduce` function takes the output from `map` as an input and combines key-value pairs into a smaller set of tuples.
  - The `reduce` function is always performed after the `map` function.

How MapReduce works?



How MapReduce works?

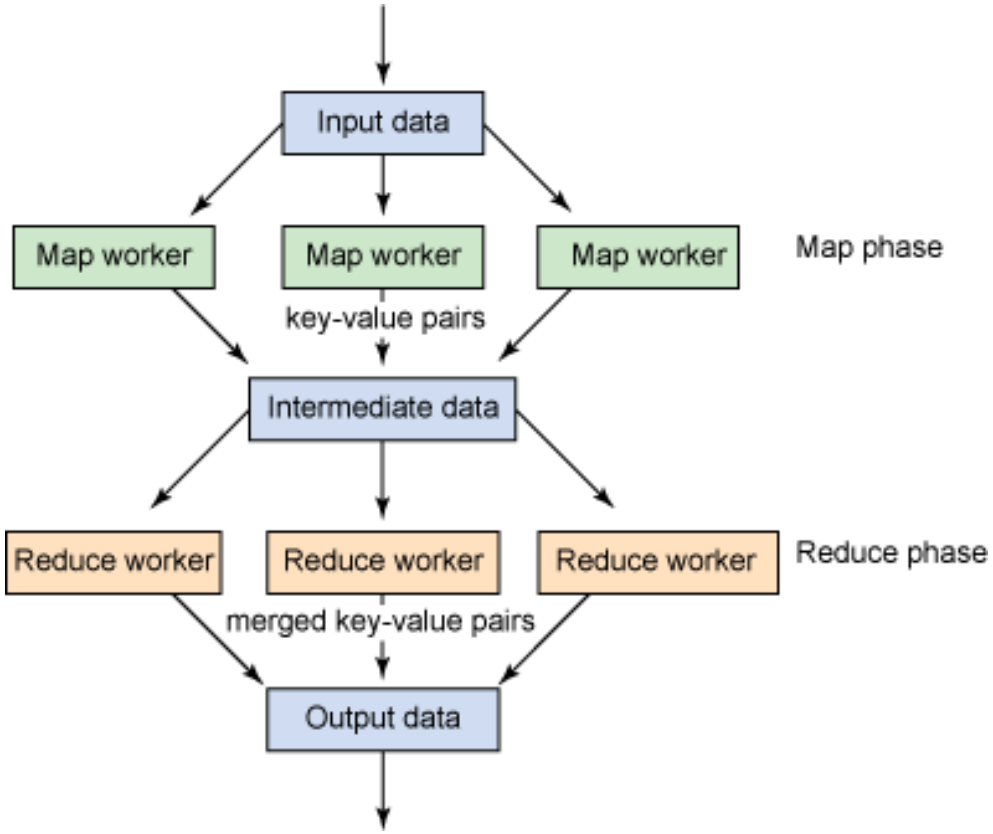


Figure: Simplified view of MapReduce processing [15]

Implementation of MapReduce on a cluster

- Because `mappers` and `reducers` apply the same function to each element independently, they are suitable for distribution across nodes on a cluster.
- There can be any number of `mappers` and `reducers` working on as much data as possible.
- Either network communication between `mappers` or network communication between `reducers` is required.
- Carefully consider how the key-value pairs are defined.

Implementation of MapReduce on a cluster

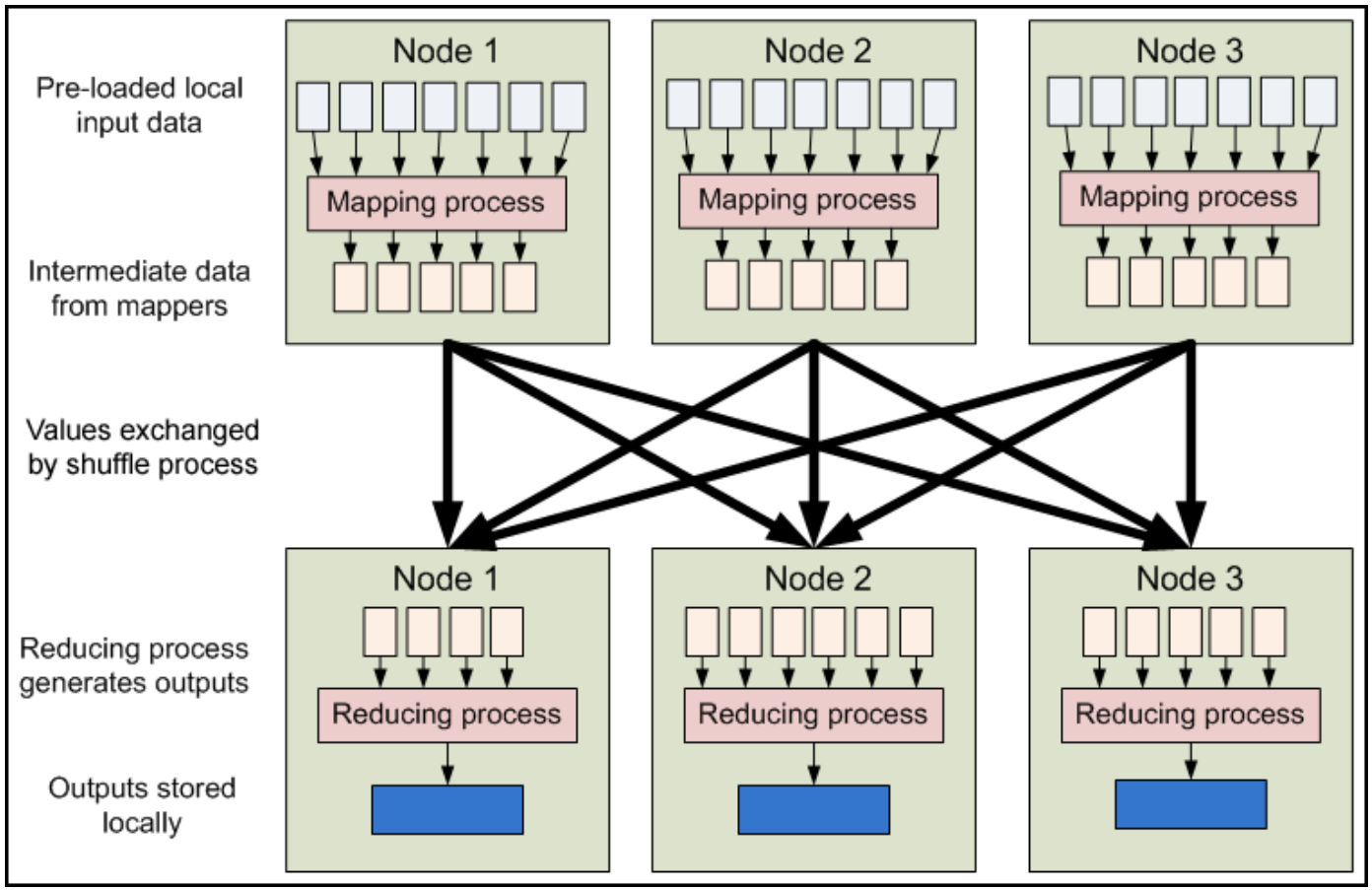


Figure: Data flow of a MapReduce job being executed on a cluster [10]

Implementation of MapReduce on a cluster

- Local storage vs. HDFS storage.
- `mapper.py` and `reducer.py` are stored in local storage.
- Required datasets are copied into HDFS.
- Output of `reduce` jobs are stored on HDFS.
- `-getmerge` or copy the output from HDFS to local storage.

Outline

Hadoop Streaming

- Hadoop Streaming is a utility, packaged as a `JAR` file that comes with the Hadoop distribution.
- Its location in the Hadoop directory is: `%HADOOP_HOME%/share/hadoop/tools/lib/hadoop-streaming-*.ja` e.g. * is 2.7.3.
- Hadoop Streaming utilizes the standard Unix streams for input and output [12].
- Input to both `mapper` and `reducer` is read from `stdin`, which can be accessed via standard `import sys` module in Python.
- Similarly, output from both `mapper` and `reducer` is exported via `stdout`.

Hadoop Streaming

- `$ cat input.txt | ./mapper.py | sort | ./reducer.py > output.txt`

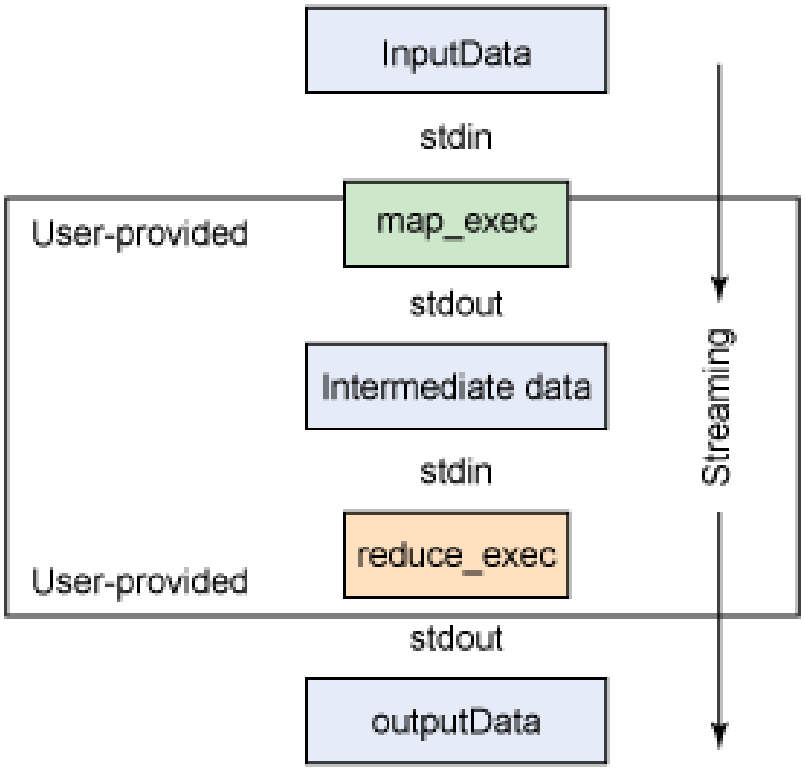


Figure: Graphical streaming example [15]

How Hadoop Streaming works?

- We need to create two Python files, a `mapper.py` and a `reducer.py`, that we need to import the `sys` module to get access to `stdin` and `stdout`.
- The `mapper.py` converts the input data it gets from `stdin`, operates some operations while simultaneously passes results to `stdout`.
- The `mapper` expects output to be in a string key-value format, where key and value are separated by some separator, e.g. tab (\t).
- The key-value strings from the `mapper` are streamed into `reducer` as input via `stdin`.
- The data is then be grouped by key and emitted to `stdout`.

A pipeline for Hadoop Streaming jobs

1. Define what operations one should do in the `map` phase: `mapper.py`

```
import sys
for line in sys.stdin:
  # do somthing to define keys
  for key in keys:
    value = 1
    print('{0}\t{1}'.format(key, value))
```

2. Define what operations one should do in the `reduce` phase: `reducer.py`

```
import sys
for line in sys.stdin:
  # do somthing to calcuate values
  print( "{0}\t{1}".format(key, total_values))
```

3. Copy required datasets from local storage to HDFS, e.g hdfs_path/data_files
4. Set a desired path for output directory on HDFS, e.g. hdfs_path/output_folder. The output directory is automatically generated.

A pipeline for Hadoop Streaming jobs

5. Execute the streaming job (* is the Hadoop version); assume that `mapper.py` and `reducer.py` are at the folder where you execute the `hadoop` command:
   - Ubuntu:
```
hadoop jar
$HADOOP_HOME/share/hadoop/tools/lib/hadoop-streaming-*.jar
-input /hdfs_path/data_files
-output /hdfs_path/output_folder
-mapper mapper.py
-reducer reducer.py
-file ./mapper.py -file ./reducer.py
```
   - Windows:
```
hadoop jar
%HADOOP_HOME%/share/hadoop/tools/lib/hadoop-streaming-*.jar
-input /hdfs_path/data_files
-output /hdfs_path/output_folder
-mapper "python mapper.py"
-reducer "python reducer.py"
-file mapper.py -file reducer.py
```

A pipeline for Hadoop Streaming jobs

6. Check and debug the processes by scanning the output texts in the terminal during the job is executed and/or browsing Hadoop User Interface.

7. The results are now in hdfs_path/output_folder

   - One can choose to download the results using Hadoop User Interface, or
   - run the command line: `hdfs dfs -getmerge /hdfs_path/output_folder output.txt`

Further Reading

1. Apache Hadoop official wiki `https://wiki.apache.org/hadoop`
2. White, T. (2012). Hadoop: The definitive guide. " O'Reilly Media, Inc.".
3. Schutt, R., & O'Neil, C. (2013). Doing data science: Straight talk from the frontline. " O'Reilly Media, Inc.".
4. Vavilapalli, V. K., Murthy, A. C., Douglas, C., Agarwal, S., Konar, M., Evans, R., ... & Saha, B. (2013, October). Apache hadoop yarn: Yet another resource negotiator. In Proceedings of the 4th annual Symposium on Cloud Computing (p. 5). ACM.
5. Dean, J., & Ghemawat, S. (2008). MapReduce: simplified data processing on large clusters. Communications of the ACM, 51(1), 107-113.
6. Dean, J., & Ghemawat, S. (2010). MapReduce: a flexible data processing tool. Communications of the ACM.
7. Intro to Hadoop and MapReduce `https://www.udacity.com/course/intro-to-hadoop-and-mapreduce--ud617`
8. Introduction to YARN `https://www.ibm.com/developerworks/library/bd-yarn-intro/`

Further Reading

9. Hadoop internals `http://ercoppa.github.io/HadoopInternals/`
10. Yahoo! Developer Network: MapReduce
    `https://developer.yahoo.com/hadoop/tutorial/module4.html`
11. Udemy: Programming Hadoop with Python
    `https://www.udemy.com/programming-hadoop-with-python/`
12. Overview of STREAMS
    `http://www.shrubbery.net/solaris9ab/SUNWdev/STREAMS/p4.html`
13. Hadoop streaming `https://hadoop.apache.org/docs/r2.7.3/hadoop-streaming/HadoopStreaming.html`
14. Perera, S. (2013). Hadoop MapReduce Cookbook. Packt Publishing Ltd.
15. Distributed data processing with Hadoop
    `https://www.ibm.com/developerworks/library/l-hadoop-3/`