

# HDP Developer: Apache Pig and Hive

## Student Guide

Rev 6.1







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# Understanding Hadoop

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe the Three Vs of Big Data
- ✓ Describe the Six Key Hadoop Data Types
- ✓ Describe Use Cases
- ✓ Describe Hadoop
- ✓ Describe the Hortonworks Data Platform (HDP)
- ✓ Describe the Path to ROI

## Three Vs of Big Data

Big data is a common buzzword in the world of IT nowadays, and it is important to understand what the term means.

Big data describes the realization of greater business intelligence by storing, processing, and analyzing data that was previously ignored or siloed due to the limitations of traditional data-management technologies.

Notice from this definition that there is more to big data than just a lot of data, and there is more to big data than just storing it.

### Processing

If you are just storing a lot of data, then you probably do not have a use case for big data. Big data is data that you want to be able to process and use as part of a business application

### Analyzing

In addition to making the data a part of your applications, big data is also data that you want to analyze (i.e. mine the data) to find information that was otherwise unknown

The characteristics of big data are often defined as the three Vs:

#### Variety

Any type of structured or unstructured data

#### Volume

Terabytes and petabytes (and even exabytes) of data

#### Velocity

Data flows in to your organization at increasing rates

### **Note**

A common aspect of big data is that it is often data that was otherwise ignored in your business because you did not have the capability to store, process, and analyze it.

For example, your customers' personal information stored in an RDBMS and used in online transactions is not big data. However, the three terabytes of web- log files from millions of visits to your website over the last ten years is probably big data.

## **Big Data Types**

Big data includes all types of data:

### **Structured**

The data has a schema, or a schema can be easily assigned to it

### **Semi-structured**

Has some structure, but typically columns are often missing or rows have their own unique columns

### **Unstructured**

Data that has no structure, like JPGs, PDF files, audio and video files, etc.

## **Big Data Characteristics**

Big data also has two inherent characteristics:

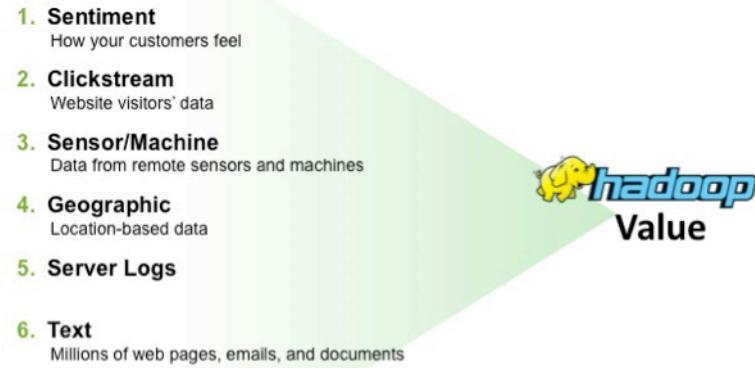
### **Time based**

A piece of data is something known at a certain moment in time, and that time is an important element. For example, you might live in San Francisco and tweet about a restaurant that you enjoy. If you later move to New York, the fact that you once liked a restaurant in San Francisco does not change

### **Immutable**

Because of its connection to a point in time, the truthfulness of the data does not change. We look at changes in big data as new entries, not updates of existing entries

## Hadoop Data Types



6 Key Hadoop Data Types

The type of big data that ends up in Hadoop typically fits into one of the following categories:

### **Sentiment**

Understand how your customers feel about your brand and products right now

### **Clickstream**

Capture and analyze website visitors' data trails and optimize your website

### **Sensor/Machine**

Discover patterns in data streaming automatically from remote sensors and machines

### **Geographic**

Analyze location-based data to manage operations where they occur

### **Server Logs**

Research log files to diagnose and process failures and prevent security breaches

### **Text**

Understand patterns in text across millions of web pages, emails, and documents

## Use Cases

Example use cases include:

- Sentiment
- Geolocation

### Sentiment



- Analyze customer sentiment on the days leading up to and following the release of the movie *Iron Man 3*.
- Questions to answer:
  - How did the public feel about the debut?
  - How might the sentiment data have been used to better promote the launch of the movie?

*Sentiment Use Cases*

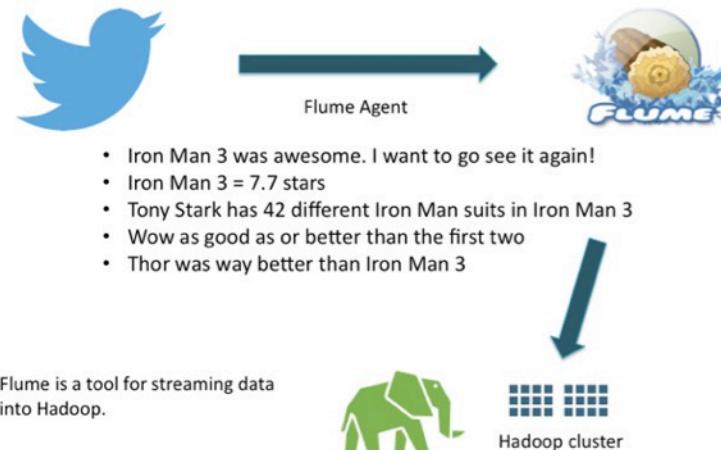
The goal was to determine how the public felt about the debut of the Iron Man 3 movie using Twitter, and how the movie company might better promote the movie based on the initial feedback. Here are the steps that were performed:

- Use Flume to get the Twitter feeds into HDFS.
- Use HCatalog to define a shareable schema for the data.
- Use Hive to determine sentiment.
- Use an Excel bar graph to visualize the volume of tweets.
- Use MS PowerView to view sentiment by country on a map.

### Reference

Visit <http://hortonworks.com/hadoop-tutorial/how-to-refine-and-visualize-sentiment-data/> to watch a video that walks through the steps above.

### Getting Twitter Feeds into Hadoop



*Getting Twitter Feeds into Hadoop*

Flume was used to input the Twitter feeds into Hadoop.

### Using HCatalog to Define a Schema

Once the data was in HDFS, HCatalog was used to define a schema:

```
CREATE EXTERNAL TABLE tweets_raw (
  id BIGINT,
  created_at STRING,
  source STRING,
  favorited BOOLEAN,
  retweet_count INT,
  text STRING
)
```

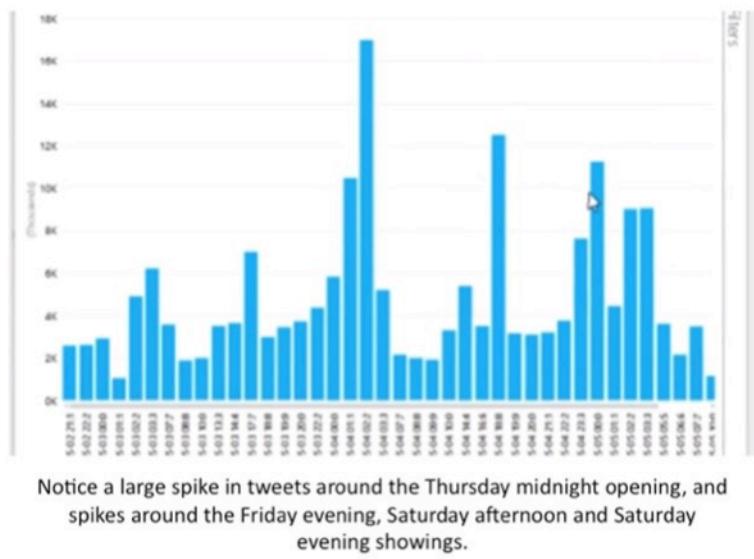
### Using Hive to Determine Sentiment

There were a lot of Hive queries used to create the final result. Hive looks like SQL. For example:

```
CREATE TABLE tweetsbi
STORED AS RCFile
AS
SELECT
  t.*,
  case s.sentiment
    when 'positive' then 2
    when 'neutral' then 1
    when 'negative' then 0
  end as sentiment
FROM tweets_clean t LEFT OUTER JOIN tweets_sentiment s on t.id = s.id;
```

### Using Excel to Show Volume

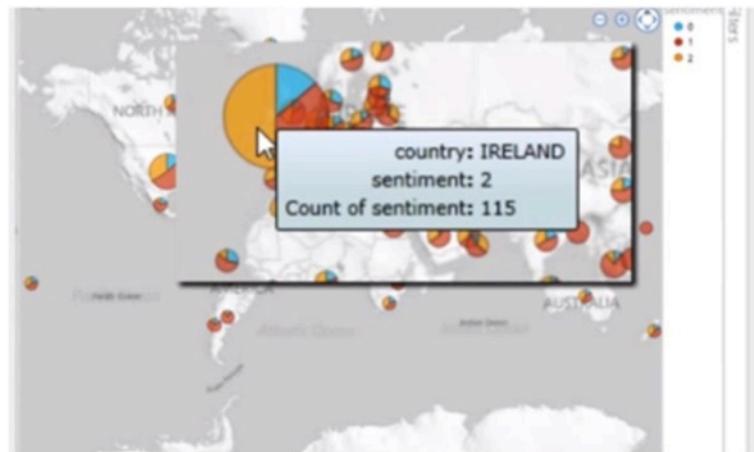
The following graph shows the volume of tweets over the opening weekend of the movie:



[View Spikes in Tweet Volume](#)

### Using Power View to Show Tweets by Country

The sentiment of the tweets was graphed by country:



Viewing the tweets on a map shows the sentiment of the movie by country. For example, Ireland had 50% positive tweets, while 67% of tweets from Mexico were neutral.

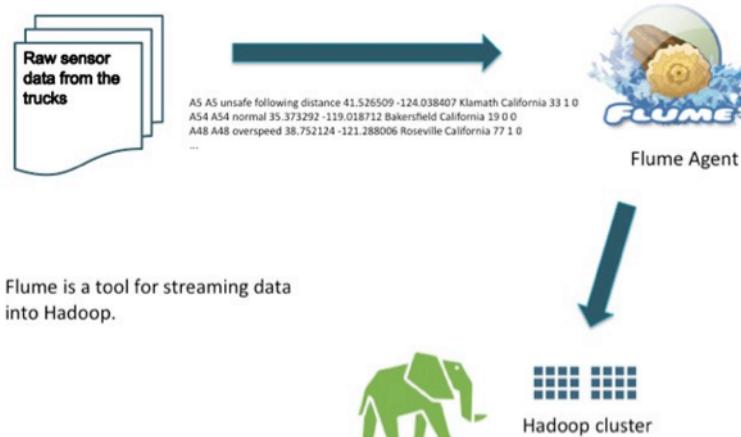
[View Sentiment by Country](#)

## Geolocation

A trucking company collects sensor data from its trucks based on GPS coordinates and logs driving events like speed, acceleration, stopping too quickly, driving too close to other vehicles, and so on. These events get collected and put into Hadoop for analysis. The goal of the trucking company is to reduce fuel costs and improve driver safety by recognizing high-risk drivers.

- Flume is used to get the raw sensor data into Hadoop
- Sqoop is used to get the data about each vehicle from an RDBMS into Hadoop
- HCatalog contains all of the schema definitions
- Hive is used to analyze the gas mileage of trucks
- Pig is used to compute a risk factor for each truck driver based on his/her events
- Excel is used to create bar graphs and maps showing where and how often events are occurring

### Using Flume



*Getting Raw Data into Hadoop*

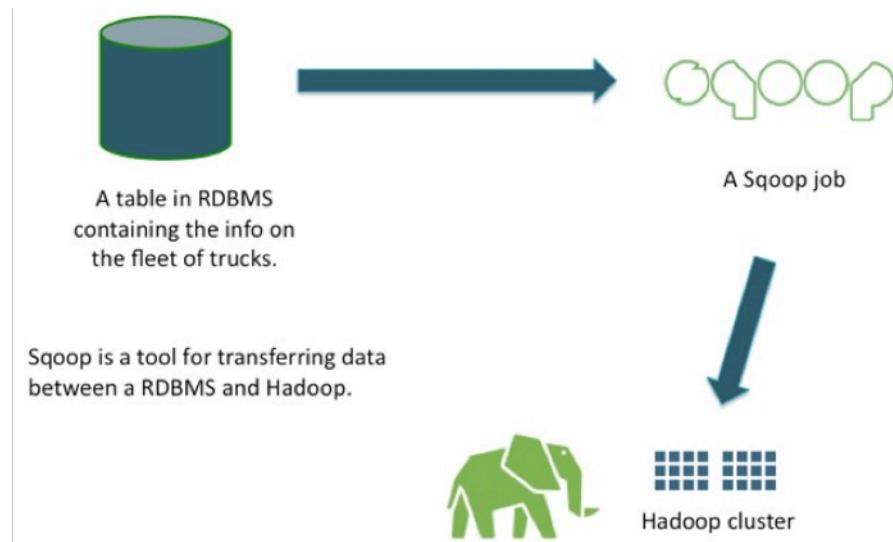
Flume was used to input the data into HDFS. The data collected from the trucks looks like:

```
truckid
driverid
event
latitude
longitude
city
state
velocity
event_indicator (0 or 1)
idling_indicator (0 or 1)
```

For example:

```
A5 A5 unsafe following distance 41.526509 -124.038407 Klamath California 33 1 0
A54 A54 normal 35.373292 -119.018712 Bakersfield California 19 0 0
A48 A48 overspeed 38.752124 -121.288006 Roseville California 77 1 0
```

### Using Sqoop



*Getting Truck Data into Hadoop Using Sqoop*

The details of the trucks and drivers are stored in a relational database. Sqoop was used to import the relational data into HDFS, and HCatalog was used to define schemas for this data:

```
create table trucks (
  driverid string,
  truckid string,
  model string,
  monthyear_miles int,
  monthyear_gas int,
  total_miles int,
  total_gas double,
  mileage double
);
```

### Evaluating the Data with Hive

Lots of Hive queries were used to evaluate the data. Hive looks like SQL:

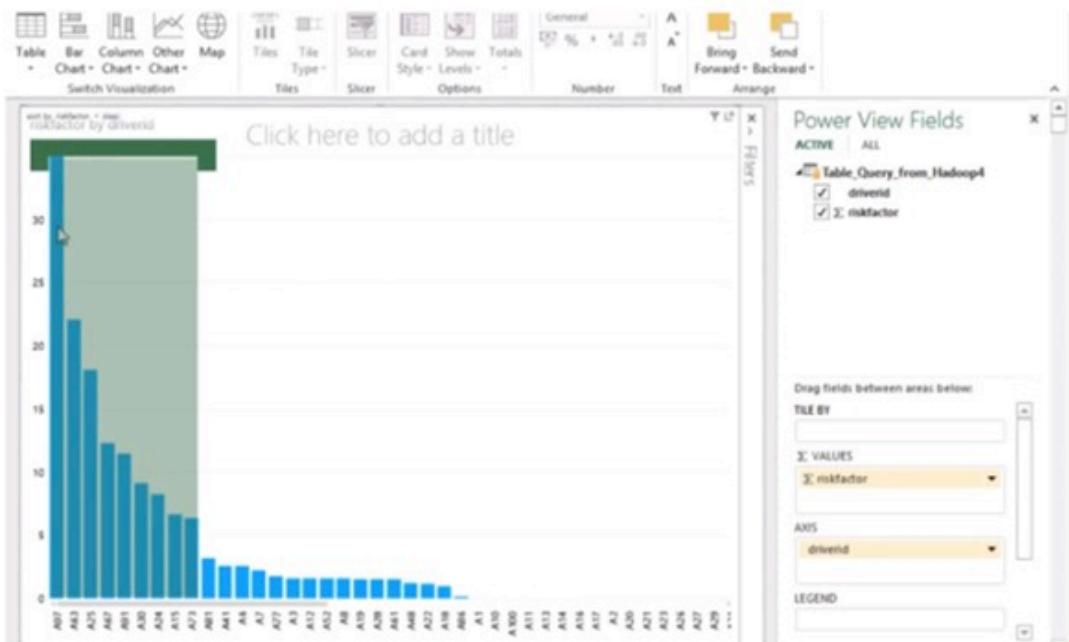
```
CREATE TABLE truck_mileage AS
  SELECT truckid, rdate, miles, gas, miles/gas mpg
  FROM trucks
  LATERAL VIEW stack(54,
'jun13',jun13_miles,jun13_gas,'may13',may13_miles, may13_gas,'apr13',apr13_miles
,apr13_gas,...)
  ) dummyalias AS rdate, miles, gas;
```

## Computing Risk with Pig

Pig is a scripting language that has an SQL-like look to it. Pig was used to compute the risk factor of each driver:

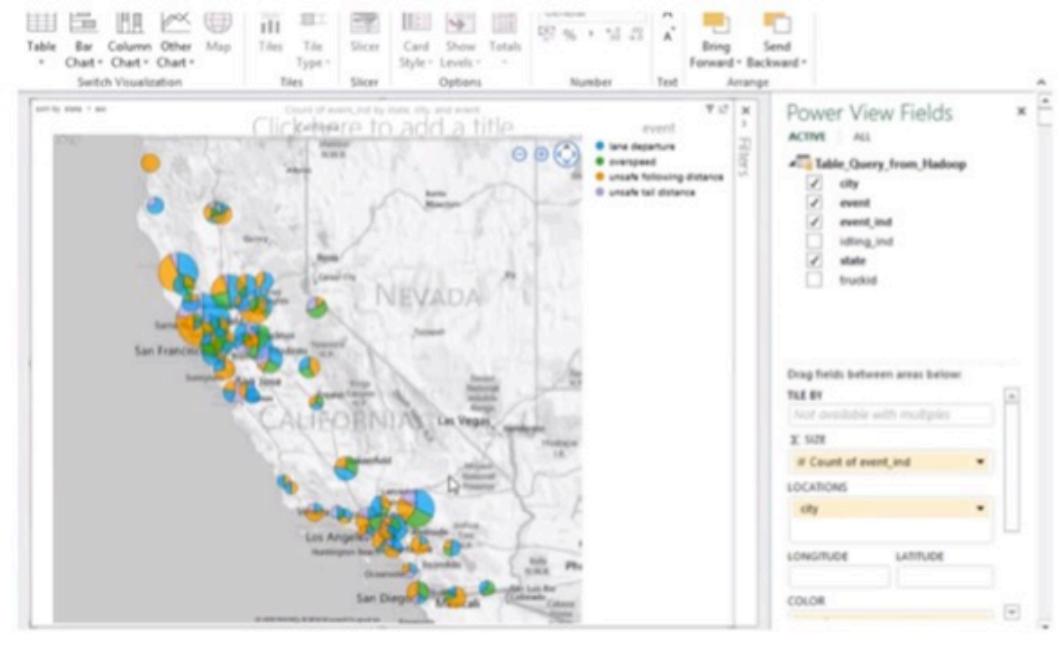
```
a = LOAD 'events'
    using org.apache.hive.hcatalog.pig.HCatLoader();
b = filter a by event != 'Normal';
c = foreach b
generate driverid, event, (int) '1' as occurrence; d = group c by driverid;
e = foreach d generate group as driverid,
SUM(c.occurrence) as t_occ;
f = LOAD 'trucks'
    using org.apache.hive.hcatalog.pig.HCatLoader();
g = foreach f generate driverid,
((int) apr09_miles + (int) apr10_miles) as t_miles; join_d = join e by
(driverid), g by (driverid); final_data = foreach join_d generate
$0 as driverid, (float) $1/$3*1000 as riskfactor; store final_data into
'riskfactor'
using org.apache.hive.hcatalog.pig.HCatStorer();
```

## Using Power View



Displaying Risk in Power View

The risk factors were also plotted on a map:



Risk Factors Viewed on a Map

## Reference

Visit <http://hortonworks.com/hadoop-tutorial/how-to-refine-and-visualize-sentiment-data/>

## About Hadoop

Apache Hadoop, <http://hadoop.apache.org/>, is one such system. Hadoop ties together a cluster of commodity machines with local storage using free and open-source software to store and process vast amounts of data at a fraction of the cost of any other system.

### Framework for solving data-intensive processes

Meaning the bottleneck was waiting to read data from the disk. The potential bottlenecks in a computing system are CPU, RAM, network, and disk IO. Hadoop was designed to solve the problem of disk IO

### Designed to scale massively

To scale massively, it is important things are as simple as possible, provide redundancy, and avoid the need for any sharing of a single system, such as locking files for operations. To meet these goals, the Hadoop file system is “write once” and files are immutable

### Hadoop is very fast for big jobs

Hadoop does scale. A 20-node cluster with 10 disks per machine running a large MapReduce job will have close to 200 disks reading and processing data all at once. The relative speed of work done in parallel when compared to a non-parallel system will be significant

## Variety of processing engines

Big data on Hadoop can be processed using multiple different processing engines, including Tez, Spark and Storm.

## Designed for hardware and software failures

Which is accomplished by “sharing nothing.” Core Hadoop systems are designed to share as little information about state as possible. DataNodes do not know what file a block belongs to. A map task writes to a temporary directory, and that data is thrown away at failure. A task is either running to success or it fails completely, and subsequent attempts do not acquire state from the failed task

All of these features put together create a powerful data processing framework that not only stores large amounts of data but also processes large amounts of data in a relatively short amount of time.

## Relational Databases vs. Hadoop

Relational		Hadoop
Required on write	schema	Required on read
Reads are fast	speed	Writes are fast
Standards and structured	governance	Loosely structured
Limited, no data processing	processing	Processing coupled with data
Structured	data types	Multi and unstructured
Interactive OLAP Analytics Complex ACID Transactions Operational Data Store	best fit use	Data Discovery Processing unstructured data Massive Storage/Processing

*Relational Database vs. Hadoop*

Understanding how schemas work in Hadoop might help you better understand how Hadoop is different from relational databases:

- With a relational database, a schema must exist before the data is written to the database, which forces the data to fit into a particular model
- With Hadoop, data is input into HDFS in its raw format without any schema. When data is retrieved from HDFS, a schema can be applied then to fit the specific use case and needs of your application

## Important

Hadoop is not meant to replace your relational database. Hadoop is for storing big data, which is often the type of data that you would otherwise not store in a database due to size or cost constraints. You will still have your database for relational, transactional data.

## About Hadoop 2.x

Hadoop 2.x refers to the next generation of Hadoop. As expected, the Hadoop framework has grown to meet the demands of its own popularity and usage, and 2.x reflects the natural maturing of the open-source project.

The Apache Hadoop 2.x project (the open-source version number) consists of the following modules:

### Hadoop Common

The utilities that provide support for the other Hadoop modules

### HDFS

The Hadoop Distributed File System

### YARN

A framework for job scheduling and cluster resource management

### MapReduce

For processing large data sets in a scalable and parallel fashion

## New in Hadoop 2.x



*What's New in Hadoop 2.x*

There are two exciting and significant additions to the Hadoop framework:

### HDFS HA and Federation

Provides a name service that is scalable and reliable

## YARN

Stands for *Yet Another Resource Negotiator*. It divides the two major functions of the JobTracker (resource management and job lifecycle management) into separate components

### Key Issues for Hadoop 1.x

A key issue with Hadoop 1.x was providing a NameNode that was highly available. Hadoop 2.x provides an HA NameNode.

Federation provides the ability to configure multiple NameNodes, and therefore multiple namespaces, to provide a distribution of workloads since the NameNodes can now scale horizontally.

YARN provides a logical separation of duties for negotiating and executing jobs across a Hadoop cluster. The end result of YARN is a new, more generic resource-management framework that works with more than just MapReduce jobs.

## The Hadoop Ecosystem



Hadoop is more than HDFS and MapReduce. There is a large group of technologies and frameworks that are associated with Hadoop, including:

### Pig

A scripting language that simplifies the creation of MapReduce jobs, and excels at exploring and transforming data

### Hive

Provides SQL-like access to your big data

### HBase

A Hadoop database

**Accumulo**

A robust, scalable, high-performance data-storage and retrieval system, built on Hadoop and Zookeeper

**Ambari**

Provisioning, managing, and monitoring Apache Hadoop clusters Sqoop Efficiently transfers bulk data between Hadoop and RDBMS

**Falcon**

A data processing and management solution, designed for pipeline coordination, lifecycle management, and data discovery

**Oozie**

A workflow scheduler system to manage Apache Hadoop jobs

**Solr**

A standalone enterprise search server with a REST-like API

**Flume**

Efficiently collects, aggregates, and moves log data

**ZooKeeper**

An open-source server that enables highly reliable distributed coordination

**Mahout**

An Apache project whose goal is to build scalable-machine learning libraries

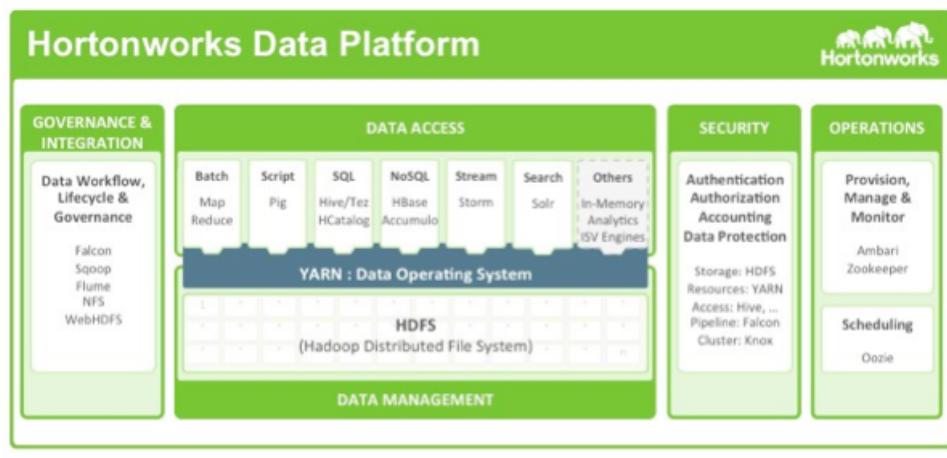
**Storm**

Framework that provides real-time processing of streams of data

**Spark**

A fast and general engine for large-scale data processing

## Hortonworks Data Platform



*Hortonworks Data Platform*

The Hortonworks Data Platform, or HDP for short, is the only 100% open-source data- management platform for Apache Hadoop and is the most stable and reliable Apache Hadoop distributor. It delivers the cost effectiveness of Hadoop and the advanced services required for enterprise deployments.

The key features of HDP include:

### High Availability

HA is now achievable in HDP 2.x without the use of an outside technology

### Open-Source Cluster Management

HDP includes Apache Ambari, the only open-source operations tool that allows you to provision, manage, and monitor a Hadoop cluster of any size

### Metadata Services & HCatalog

HCatalog provides metadata services and a REST interface that provides an additional SQL-like interface to Hadoop

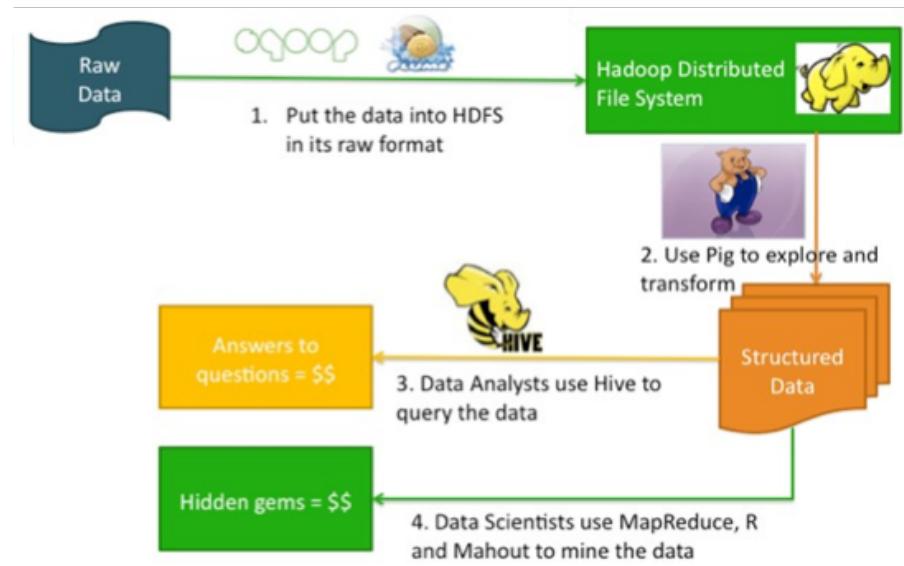
### Data Integration Services

Including Sqoop, Flume, and WebHDFS

### ODBC Done Right

Hive has a free high-performance ODBC driver that includes an SQL engine so you can interact with nearly every BI tool, including all SQL-92 interfaces

## Path to ROI



Along with the tools and frameworks in the Hadoop ecosystem, there are also the individuals who must push the data through Hadoop, answer questions, and find hidden gems within the big data. The path to ROI in Hadoop involves several steps and roles, including:

### Put the data into HDFS

Because you do not need to apply a schema to the data, it is best to keep it in its raw format and to try not to force a structure on the data that may only fit a few use cases. By keeping all of the original raw data, you leave the door open for answers to future questions that you may not have thought to ask yet.

### Explore and Transform

Often the raw data needs to be transformed. Pig is an excellent tool for exploring the raw data and transforming it into a structure more suitable for your specific use case.

### Answer questions

Hive is a great tool for performing queries on structured data. The Hive query language is essentially SQL, so it is familiar and comfortable to use for data analysts.

### Find hidden gems

The real ROI comes from mining the data, a task that fits under the moniker of data science. The data scientist uses a variety of tools and frameworks, including Java, MapReduce, R, Mahout, Python, and other tools and scripting languages.

### Note

The diagram above is meant only to show a typical use case of how data might flow through Hadoop and how the various elements of the Hadoop ecosystem are typically used. There are certainly many other scenarios and use cases, along with many other tools available for answering questions and mining big data.

## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) What are 1,024 petabytes known as?
- 2 ) What are 1,024 exabytes known as?
- 3 ) List the three Vs of big data:
- 4 ) What technology might you use to stream Twitter feeds into Hadoop?
- 5 ) Sentiment is one of the six key types of big data. List the other five:
- 6 ) What technology might you use to define, store, and share the schemas of your big data stored in Hadoop?
- 7 ) What are the two main new components in Hadoop 2.x?

## Answers

1 ) What are 1,024 petabytes known as?

**Answer:** 1,024 petabytes = 1 Exabyte

2 ) What are 1,024 exabytes known as?

**Answer:** 1,024 Exabytes = 1 Zettabyte And for what it's worth:

1,024 Zettabytes = 1 Yottabyte

1,024 Yottabytes = 1 Brontobyte

1,024 Brontobytes = 1 Geopbyte

3 ) List the three Vs of big data:

**Answer:** Variety, Volume, and Velocity

4 ) Sentiment is one of the six key types of big data. List the other five:

**Answer:** Clickstream

Sensor and machine data

Location-based (geographic) data

Server logs

Text (web pages, emails, documents, etc.)

5 ) What technology might you use to stream Twitter feeds into Hadoop?

**Answer:** Flume is commonly used for importing Twitter feeds into a Hadoop cluster

6 ) What technology might you use to define, store, and share the schemas of your big data stored in Hadoop?

**Answer:** HCatalog is designed to easily store and share schemas for your big data.

7 ) What are the two main new components in Hadoop 2.x?

**Answer:** HDFS Federation and YARN.

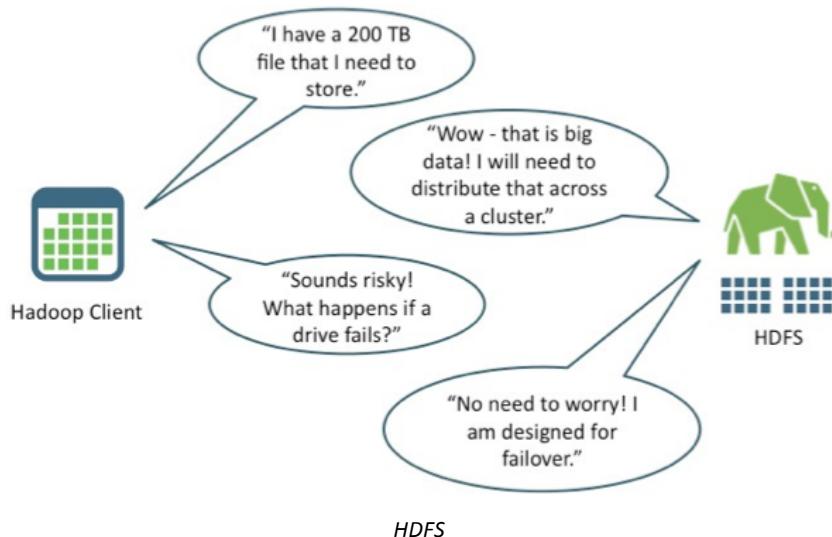
# Hadoop Distributed File System (HDFS)

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe HDFS
- ✓ Describe How to Understand Block Storage
- ✓ Describe the NameNode
- ✓ Describe the DataNodes
- ✓ Describe HDFS Commands

## About HDFS



Data in Hadoop is stored on a filesystem referred to as HDFS or the Hadoop Distributed File System. With HDFS, data is broken down into chunks and distributed across a cluster of machines.

HDFS has the following characteristics:

- Primary storage system for Hadoop: it stores large files as small blocks
- Designed to be deployed on low-cost hardware
- Designed to scale easily and effectively (adding more nodes increases both storage space and computing throughput)
- Reliability: data is replicated so that disk failover is not only acceptable but expected and handled seamlessly

### Note

HDFS is the data-storage mechanism for Hadoop. In Hadoop 2.x, YARN is referred to as the data operating system.

## Hadoop vs. RDBMS

Hadoop	RDBMS
<ul style="list-style-type: none"> <li>Assumes a task will require reading a significant amount of data off of a disk</li> <li>It does not maintain any data structure</li> <li>Simply reads the entire file</li> <li>Scales well (increase the cluster size to decrease the read time of each task)</li> </ul>	<ul style="list-style-type: none"> <li>Uses indexes to avoid reading an entire file (very fast lookups)</li> <li>Maintains a data structure in order to provide a fast execution layer</li> <li>Works well as long as the index fits in RAM</li> </ul>
<ul style="list-style-type: none"> <li>- 2,000 blocks of size 256MB</li> <li>- 1.9 seconds of disk read for each block</li> <li>- On a 40 node cluster with 8 disks on each node, it would take about 14 seconds to read the entire 500 GB</li> </ul>	 <p>61 minutes to read this data off of a disk (assuming a transfer rate of 1,030 Mbps)</p>

*Hadoop vs. RDBMS*

To help better understand how Hadoop works, let's compare it to something you may be very familiar with: a relational database. From a very high level, the difference between Hadoop and RDBMS is:

- A relational database uses complex in-memory data structures to avoid the expense of disk access
- Hadoop uses a collection of disks to parallelize the expense of disk access

Using indexes optimizes a relational database's performance by avoiding disk access. In order to store a lot of data and access it efficiently, RDBMS uses a smaller, organized representation of the data (an index) that can be loaded into memory and can allow a lightning-fast lookup as to whether or not a disk seek and read is needed. This works very well up to the point that your index no longer fits in RAM or up to the point that your final result set, or the operations performed while generating this result set, require a lot of disk access.

Hadoop looks at this problem in another way. Hadoop assumes that the operation will require reading a significant amount of data off of disk. To avoid seeks, Hadoop simply reads the entire file.

### *Example – Disk Read Performance*

Suppose a RDBMS had to process a 500G data file. The time it takes to read this data off of disk would be 61 minutes. This assumes a transfer rate of 1030Mbps. (Source: [http://www.calctool.org/CALC/prof/computing/transfer\\_time](http://www.calctool.org/CALC/prof/computing/transfer_time)). Typically you would look at your queries, add some indexes, and try to optimize the access to avoid this disk seek.

In Hadoop, this file could be stored as 2,000 256Mb chunks. If we processed it in Hadoop doing a single search for records matching a pattern, then Hadoop would perform 2,000 individual file reads. Each of these 2,000 tasks will require 1.9 seconds of disk read. A cluster of 40 DataNodes with eight disks each (so a total of 320 disks) will get an average six or seven of these file chunk reads, for a total transfer time of 14 seconds. The bottleneck of processing this 500G file has been taken from 60 minutes to seven times 1.9 seconds, or roughly 14 seconds.

## Note

This does not mean the overall MapReduce job would take 14 seconds. This example is ignoring the overhead of both MapReduce and RDBMS and is only comparing the amount of time spent reading from disk. Regardless of the overhead, this demonstrates how Hadoop reads large amounts of data in an extremely efficient manner.

## HDFS Components

A Hadoop instance consists of a cluster of HDFS machines often referred to as the Hadoop cluster or the HDFS cluster. There are two main components of an HDFS cluster:

### NameNode

The “master” node of HDFS that manages the data (without actually storing it) by determining and maintaining how the chunks of data are distributed across the DataNodes.

### DataNode

Stores the chunks of data and is responsible for replicating the chunks across other DataNodes.

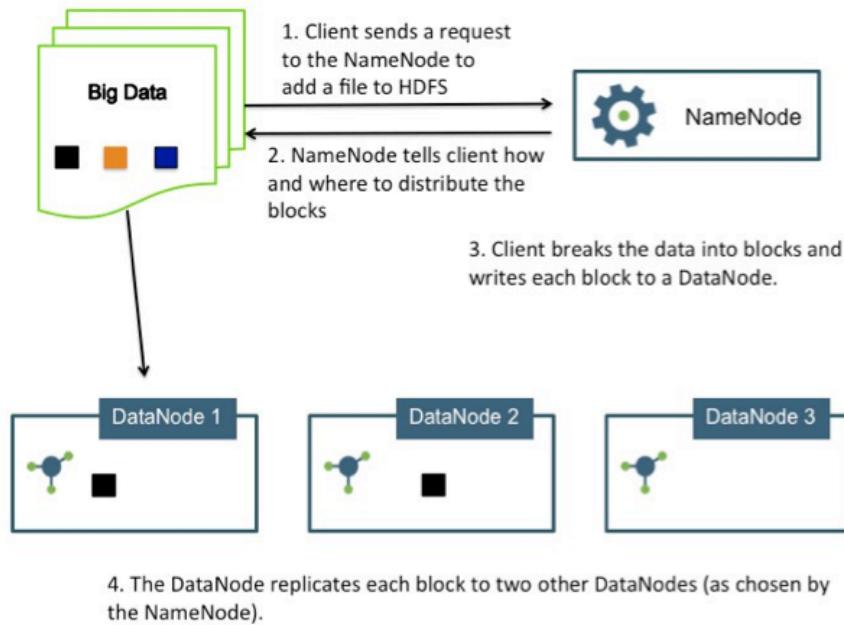
The NameNode and DataNode are daemon processes running in the cluster. Some important concepts involving the NameNode and DataNodes:

- A NameNode represents a single namespace. A cluster can have multiple NameNodes if multiple namespaces are desired
- Data never resides on or passes through the NameNode. Your big data only resides on DataNodes
- DataNodes are referred to as “slave” daemons to the NameNode and are constantly communicating their state with the NameNode
- The NameNode keeps track of how the data is broken down into chunks on the DataNodes
- The default chunk size is 128MB (but is configurable)
- The default replication factor is three (and is also configurable), which means each chunk of data is replicated across three DataNodes
- DataNodes communicate with other DataNodes (through commands from the NameNode) to achieve data replication

## Note

HDFS supports a traditional hierarchical file organization. A user or an application can create directories and store files inside these directories.

## Block Storage



### *Understanding Block Storage*

Putting a file into HDFS involves the following steps:

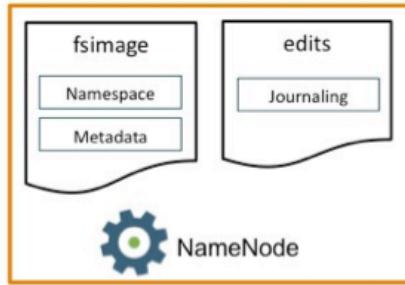
- 1 ) A client application sends a request to the NameNode that specifies where they want to put the file in the filesystem.
- 2 ) The NameNode determines how the data is broken down into blocks and which DataNodes will be used to store those blocks. That information is given to the client application.
- 3 ) The client application communicates directly with each DataNode, writing the blocks onto the DataNodes.
- 4 ) The DataNodes replicate the newly created blocks based on instructions from the NameNode.

You can specify the block size for each file using the `dfs.blocksize` property. If you do not specify a block size at the file level, the global value of `dfs.blocksize` defined in `hdfs-site.xml` is used.

### **Important**

Notice that the data never actually passes through the NameNode. The client program that is uploading the data into HDFS performs I/O directly with the DataNodes. The NameNode only stores the metadata of the filesystem, but is not responsible for storing or transferring the data.

## NameNodes

1. When the NameNode starts, it reads the **fsimage\_N** and **edits\_N** files.
  2. The transactions in **edits\_N** are merged with **fsimage\_N**.
  3. A newly-created **fsimage\_N+1** is written to disk, and a new, empty **edits\_N+1** is created.
- The NameNode will be in *safemode*, a read-only mode.
4. Now a client application can create a new file in HDFS.
  5. The NameNode journals that create transaction in the **edits\_N+1** file.
- 
- NameNode*

HDFS has a master/slave architecture. An HDFS cluster consists of a single NameNode, which is a master server that manages the filesystem namespace and regulates access to files by clients.

The NameNode has the following characteristics:

- Acts as the master of the DataNodes
- Executes filesystem namespace operations, like opening, closing, and renaming files and directories
- Determines the mapping of blocks to DataNodes
- Maintains the filesystem namespace

The NameNode performs these tasks by maintaining two files:

**fsimage\_N**

Contains the entire filesystem namespace, including the mapping of blocks to files and filesystem properties

**edits\_N**

A transaction log that persistently records every change that occurs to filesystem metadata

When the NameNode starts up, it enters safemode (a read-only mode). It loads the **fsimage\_N** and **edits\_N** from disk, applies all the transactions from the **edits\_N** to the in-memory representation of the **fsimage\_N**, and flushes out this new version into a new **fsimage\_N+1** on disk.

## Hadoop Distributed File System (HDFS)

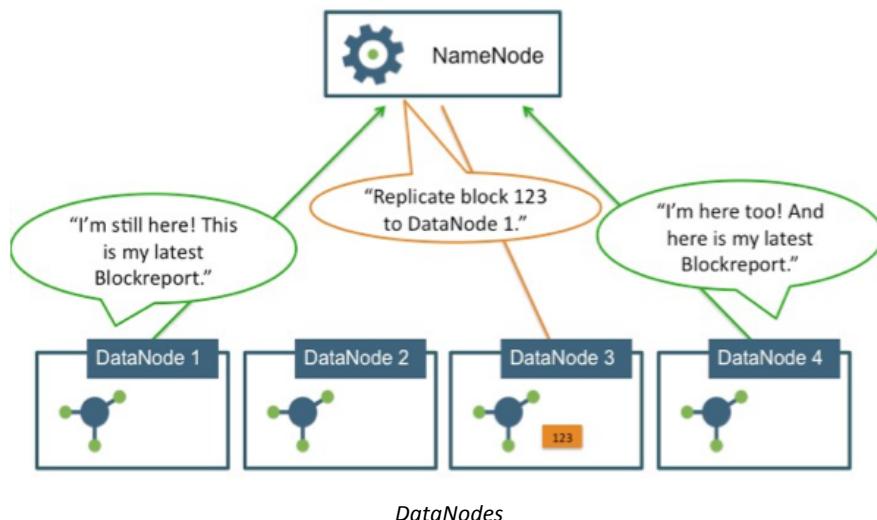
For example, initially you will have an `fsimage_0` file and an `edits_inprogress_1` file. When the merging occurs, the transactions in `edits_1` are merged with `fsimage_0` and a new `fsimage_1` file is created. In addition, a new empty `edits_2` file is created for all future transactions that occur after the creation of `fsimage_1`. This process is called a checkpoint. Once the NameNode has successfully checkpointed, it will leave safemode, thus enabling writes.

### Note

On your classroom VM, you can view the `fsimage` and `edit` files in the **Error! Hyperlink reference not valid.** folder on the namenode machine:

```
# ssh namenode  
  
[namenode ~]# ls -la /hadoop/hdfs/namenode/current/ total 1048  
  
-rw-r--r-- 1 hdfs hdfs1048576 edits_inprogress_000000000000000000000000  
-rw-r--r-- 1 hdfs hdfs336 fsimage_000000000000000000000000  
-rw-r--r-- 1 hdfs hdfs62 fsimage_000000000000000000000000.md5  
-rw-r--r-- 1 hdfs hdfs2 seen_txid  
-rw-r--r-- 1 hdfs hdfs202 VERSION
```

## DataNodes



HDFS exposes a filesystem namespace and allows user data to be stored in files. Internally, a file is split into one or more blocks and these blocks are stored in a set of DataNodes.

The NameNode determines the mapping of blocks to DataNodes. The DataNodes are responsible for:

- Handling read and write requests from application clients
- Performing block creation, deletion, and replication upon instruction from the NameNode
- (The NameNode makes all decisions regarding replication of blocks)
- Sending heartbeats to the NameNode
- Sending a Blockreport to the NameNode

The NameNode periodically receives a Heartbeat and a Blockreport from each of the DataNodes in the cluster. Receipt of a Heartbeat implies that the DataNode is functioning properly. A Blockreport contains a list of all blocks on a DataNode.

DataNodes have the following characteristics:

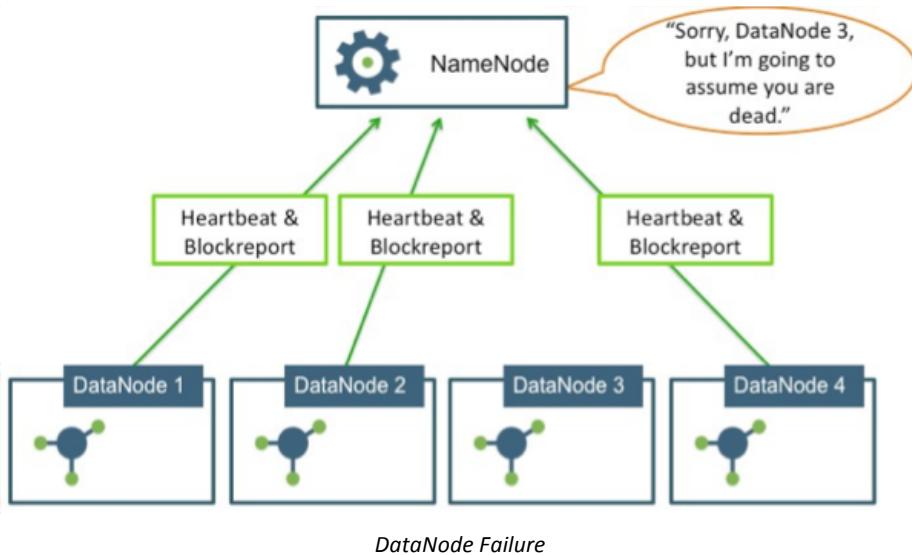
- The DataNode has no knowledge about HDFS files
- It stores each block of HDFS data in a separate file on its local filesystem
- The DataNode does not create all files in the same local directory. Instead, it uses a discovery technique to determine the optimal number of files per directory and creates subdirectories appropriately

When a DataNode starts up, it scans through its local file system, generates a list of all HDFS data blocks that correspond to each of these local files, and then sends this information to the NameNode (as a Blockreport)

### Reference

For tips on configuring a network for a Hadoop cluster, visit <http://hortonworks.com/kb/best-practices-for-cluster-network-configuration/>.

## DataNode Failure



The primary objective of HDFS is to store data reliably even in the presence of failures. Hadoop is designed to recover gracefully from a disk failure or the network failure of a DataNode:

- If a DataNode fails to send a Heartbeat to the NameNode, that DataNode is labeled as dead
- Any data that was registered to a dead DataNode is not available to HDFS anymore
- The NameNode does not send new I/O requests to a dead DataNode, and its blocks are replicated to live DataNodes

DataNode death typically causes the replication factor of some blocks to fall below their specified value. The NameNode constantly tracks which blocks need to be replicated and initiates replication whenever necessary.

**Note**

It is possible that a block of data fetched from a DataNode arrives corrupted, either from a disk failure or network error. HDFS implements checksum checking on the contents of HDFS files. When a client creates an HDFS file, it computes a checksum of each block of the file and stores these checksums in a separate hidden file in the same HDFS namespace. When a client retrieves file contents, it verifies that the data it received from each DataNode matches the checksum stored in the associated checksum file. If not, then the client can opt to retrieve that block from another DataNode that has a replica of that block.

## HDFS Commands

The `hdfs` application is a Hadoop client application that allows you to issue commands to HDFS from a command line. The `hdfs` application has the following syntax:

```
hdfs dfs -command <args>
```

A command is one of the following:

```
# hdfs dfs
Usage: hadoop fs [generic options]
[-appendToFile <localsrc> ... <dst>] [-cat [-ignoreCrc] <src> ...]
[-checksum <src> ...]
[-chgrp [-R] GROUP PATH...]
[-chmod [-R] <MODE[,MODE]... | OCTALMODE> PATH...]
[-chown [-R] [OWNER] [:GROUP]] PATH...
[-copyFromLocal [-f] [-p] <localsrc> ... <dst>]
[-copyToLocal [-p] [-ignoreCrc] [-crc] <src>...<localdst>] [-count [-q] <path>
...]
[-cp [-f] [-p] <src> ... <dst>]
[-createSnapshot <snapshotDir> [<snapshotName>]] [-deleteSnapshot <snapshotDir>
<snapshotName>]
[-df [-h] [<path> ...]]
[-du [-s] [-h] <path> ...] [-expunge]
[-get [-p] [-ignoreCrc] [-crc] <src> ... <localdst>] [-getfacl [-R] <path>]
[-getmerge [-nl] <src> <localdst>] [-help [cmd ...]]
[-ls [-d] [-h] [-R] [<path> ...]]
[-mkdir [-p] <path> ...]
[-moveFromLocal <localsrc> ... <dst>] [-moveToLocal <src> <localdst>]
[-mv <src> ... <dst>]
[-put [-f] [-p] <localsrc> ... <dst>]
[-renameSnapshot <snapshotDir> <oldName> <newName>] [-rm [-f] [-r|-R] [-
skipTrash] <src> ...]
[-rmdir [--ignore-fail-on-non-empty] <dir> ...]
[-setfacl [-R] [{-{b|-k} {-m|-x <acl_spec>} <path>}|[--set <acl_spec> <path>]]
[-setrep [-R] [-w] <rep> <path> ...]
[-stat [format] <path> ...]
[-tail [-f] <file>]
[-test -[defsz] <path>]
[-text [-ignoreCrc] <src> ...] [-touchz <path> ...]
[-usage [cmd ...]]
```

## Hadoop Distributed File System (HDFS)

Use the help option for a description of a command. For example:

```
# hdfs dfs -help put

-put [-f] [-p] <localsrc> ... <dst>
Copy files from the local file system into fs. Copying fails if the file
already exists, unless the -f flag is given. Passing

-p preserves access and modification times, ownership and the mode. Passing -f
overwrites the destination if it already exists.
```

## HDFS Command Examples

The following mkdir command makes a new directory named mydata:

```
hdfs dfs -mkdir mydata
```

This put command copies a local file named numbers.txt into mydata in HDFS:

```
hdfs dfs -put numbers.txt mydata/
```

Use the ls command to view the contents of the mydata folder:

```
# hdfs dfs -ls mydata
Found 1 items
-rw-r--r-- 3 root root 2549 2013-08-29 mydata/numbers.txt
```

### Note

The logs for HDFS are, by default, in the /var/log/hadoop/hdfs folder. Hadoop uses log4j via the Apache Commons Logging framework for logging.

The hdfs dfs command is the same command as hadoop fs, and you may see the two used interchangeably.

## HDFS File Permissions

- File and directories have owners and groups
- r = read
- w = write
- x = permission to access the contents of a directory

```
drwxr-xr-x  - hue      hue          0 2013-08-27 23:00 /user/hue/oozie/worksites/unmanaged/shell
-rw-r--r--  3 hue      hue          77 2013-08-27 23:00 /user/hue/oozie/worksites/unmanaged/shell/hello.py
drwxr-xr-x  - hue      hue          0 2013-08-27 23:00 /user/hue/oozie/worksites/unmanaged/sleep
-rw-r--r--  3 hue      hue          0 2013-08-27 23:00 /user/hue/oozie/worksites/unmanaged/sleep/empty
drwxr-xr-x  - hue      hue          0 2013-08-27 23:00 /user/hue/oozie/worksites/unmanaged/sqoop
-rw-r--r--  3 hue      hue         7175 2013-08-27 23:00 /user/hue/oozie/worksites/unmanaged/sqoop/TT.java
drwxr-xr-x  3 hue      hue          428 2013-08-27 23:00 /user/hue/oozie/worksites/unmanaged/sqoop/db.hsqldb.properties
-rw-r--r--  3 hue      hue          276 2013-08-27 23:00 /user/hue/oozie/worksites/unmanaged/sqoop/db.hsqldb.script
drwxr-xr-x  - hue      hue          0 2013-08-27 23:00 /user/hue/oozie/worksites/unmanaged/ssh
-rw-r--r--  3 hue      hue          0 2013-08-27 23:00 /user/hue/oozie/worksites/unmanaged/ssh/empty
drwxr-xr-x  - root     root         0 2013-08-29 03:22 /user/root
drwxr-xr-x  - root     root         0 2013-08-29 03:23 /user/root/mydata
-rw-r--r--  3 root     root        2549 2013-08-29 03:23 /user/root/mydata/numbers.txt
-rw-r--r--  3 root     root       3613198 2013-08-28 21:55 /user/root/stocks.csv
[root@sandbox demos]#
```

### HDFS File Permissions

HDFS implements a permissions model for files and directories that shares much of the POSIX model:

- Each file and directory is associated with an owner and a group
- The file or directory has separate permissions for the user that is the owner, for other users that are members of the group, and for all other users
- For files, the r permission is required to read the file and the w permission is required to write or append to the file
- For directories, the r permission is required to list the contents of the directory, the w permission is required to create or delete files or directories, and the x permission is required to access a child of the directory

The output of the ls and ls -R commands shows the file permissions:

```
drwxr-xr-x- root root          0 2013-08-29 03:23 /user/root/mydata
-rw-r--r--3 root root      2549 2013-08-29 03:23 /user/root/mydata/numbers.txt
-rw-r--r--3 root root  3613198 2013-08-28 21:55 /user/root/stocks.csv
```

**Note**

HDFS also supports ACLs, which provide even finer-grained authorization capabilities.

## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) Which component of HDFS is responsible for maintaining the namespace of the distributed filesystem?
- 2 ) What is the default file-replication factor in HDFS?
- 3 ) True or False: To input a file into HDFS, the client application passes the data to the NameNode, which then divides the data into blocks and passes the blocks to the DataNodes.
- 4 ) Which property is used to specify the block size of a file stored in HDFS?
- 5 ) The NameNode maintains the namespace of the filesystem using which two sets of files?

- 6 ) What does the following command do?

```
hdfs dfs -ls -R /user/thomas/
```

- 7 ) What does the following command do?

```
hdfs dfs -ls /user/thomas/
```

## Answers

- 1 ) Which component of HDFS is responsible for maintaining the namespace of the distributed filesystem?

**Answer:** NameNode

- 2 ) What is the default file-replication factor in HDFS?

**Answer:** 3

- 3 ) True or False: To input a file into HDFS, the client application passes the data to the NameNode, which then divides the data into blocks and passes the blocks to the DataNodes.

**Answer:** False. A file's data in HDFS never passes through the NameNode. Client applications read and write directly from the DataNodes.

- 4 ) Which property is used to specify the block size of a file stored in HDFS?

**Answer:** dfs.blocksize

- 5 ) The NameNode maintains the namespace of the filesystem using which two sets of files?

**Answer:** The fsimage\_N and edits\_N files

- 6 ) What does the following command do?

**hdfs dfs -ls -R /user/thomas/**

**Answer:** Recursively lists the contents of /user/thomas in HDFS and all of its subfolders

- 7 ) What does the following command do?

**hdfs dfs -ls /user/thomas/**

**Answer:** Lists the file and folders in /user/thomas, but not recursively. (The files in the subfolders of /user/thomas are not listed.)

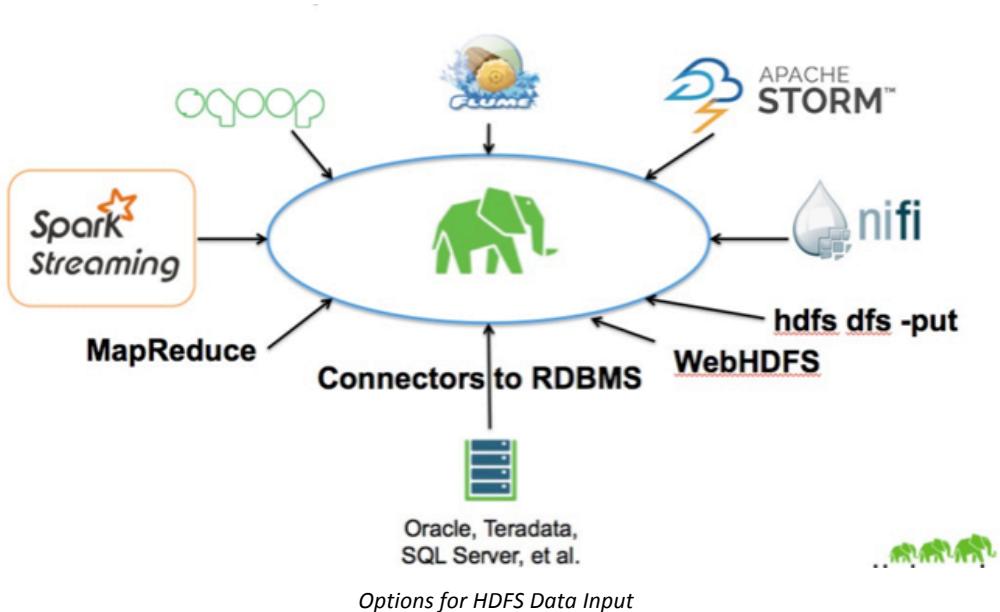
# Putting Data into HDFS

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe the Options for Data Input
- ✓ Describe Flume
- ✓ Describe Sqoop
- ✓ Use Sqoop to transfer data between HDFS and a relational database

## Data Input Options



Typically the first task in using a Hadoop cluster is getting your big data into HDFS. You have several options to choose from, and typically you may need to use more than one tool depending on the sources of your big data.

### Best Practice

When putting data into Hadoop, do not forget one of the essentials of Hadoop: no schema is applied when the data goes in. In other words, keep your big data in its raw format and worry about applying structure and schema to it later when you transform and analyze the data.

### The Hadoop Client

The hadoop client works well for inputting files from a local file system into HDFS:

```
Usage: hdfs dfs -put <localsrc> ... <dst>
```

Obviously you do not have a 2 Petabyte file sitting around on your local hard drive that you want to store into HDFS, but the put command is still an extremely useful tool that you will use on a regular basis when doing development.

#### Note

The `put` command also reads input from `stdin` and writes to a specified file in HDFS. Just use a dash “`-`” for the `localsrc`:

```
# hdfs dfs -put - myinput.txt
```

## WebHDFS

WebHDFS is a REST API for accessing all of the HDFS file system interfaces. WebHDFS supports all HDFS user operations, including reading files, writing to files, making directories, changing permissions, and renaming. With WebHDFS, you can use common tools, like `curl`, `wget`, or any web services client, to access the files in a Hadoop cluster.

Some of the features of WebHDFS include:

#### Secure Authentication

Uses Kerberos (SPNEGO) and Hadoop delegation tokens for authentication

#### Data Locality

Redirects the file read and file write calls to the corresponding Datanodes. It uses the full bandwidth of the Hadoop cluster for streaming data

#### Built into Hadoop

Runs inside NameNode and DataNodes, so there are no additional servers to install

The syntax for an HTTP request looks like:

```
http://host:port/webhdfs/v1/<PATH>?op=...
```

For example, the following GET request reads a file named `/test/mydata.txt`:

```
http://host:port/webhdfs/v1/test/mydata.txt?op=OPEN
```

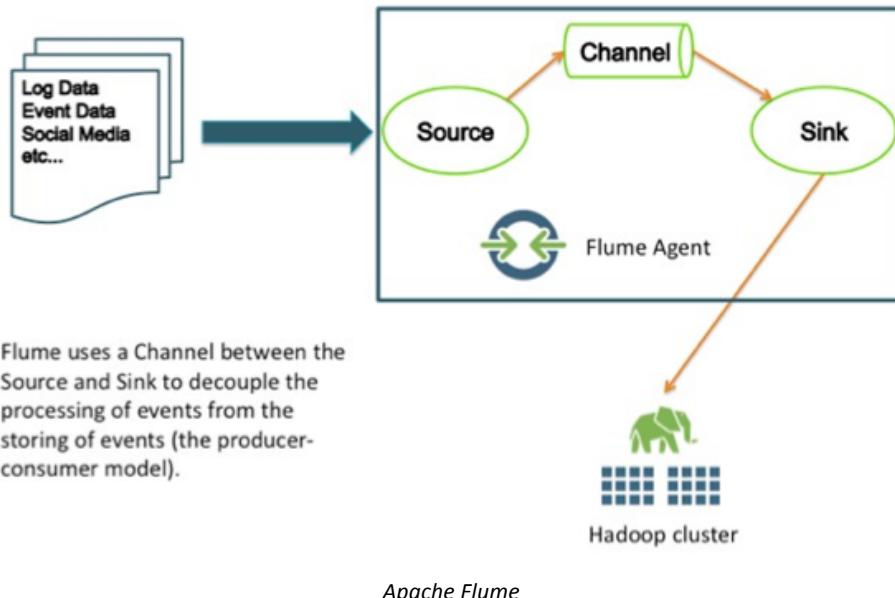
The following PUT request makes a new directory in HDFS named `/user/root/data`:

```
http://host:port/webhdfs/v1/user/root/data?op=MKDIRS
```

The following is a POST request that appends the posted data to the file named `/test/mydata.txt`:

```
http://host:port/webhdfs/v1/test/mydata.txt?op=APPEND
```

## About Flume



Flume is an open-source Apache project that is a system for efficiently collecting, aggregating, and moving large amounts of log data from many different sources into HDFS. You can also customize Flume to work with network traffic data, social-media-generated data, email messages, and pretty much any data source possible.

Flume uses a producer-consumer model for handling events where the Source is the producer and the Sink is the consumer of the events. Examples of a Source include:

- System log files
- Network traffic log files
- Website traffic logs
- Twitter feeds and other social media sources

The events travel through an asynchronous Channel to a Sink. Examples of a Sink include:

- HDFS
- HBase

A Channel drains into a Sink, but because it is asynchronous the Channel is not required to send events to the Sink at the same rate that it receives them from the Source. This allows for a Source to not have to wait for Flume to store the event in its final destination, which can improve performance by decoupling the Sink from the Source.

### Note

A Flume process can consist of more than one Agent with a single Source and Sink. You can have multiple Agents that aggregate data from multiple Sources, and you can configure multiple Sinks that output events to different destinations.

## Flume Example

To use Flume, you start an Agent. An Agent has a configuration file associated with it that defines its Sources and Sinks. The command to start an Agent looks like:

```
flume-ng agent -n my_agent -c conf -f myagent.conf
```

The code myagent.conf is the configuration file.

The following Agent config file demonstrates streaming a web server's log file into HDFS as a sequence file:

```
my_agent.sources = webserver my_agent.channels = memoryChannel my_agent.sinks = mycluster

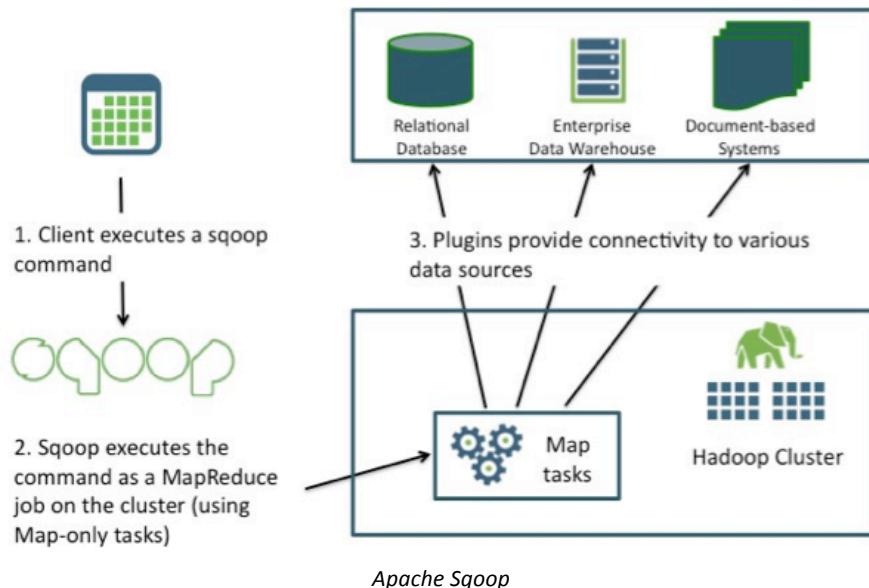
my_agent.sources.webserver.type = exec my_agent.sources.webserver.command =
tail -F /var/log/hadoop/hdfs/hdfs-audit.log
my_agent.sources.webserver.batchSize = 1 my_agent.sources.webserver.channels =
memoryChannel

my_agent.channels.memoryChannel.type = memory
my_agent.channels.memoryChannel.capacity = 10000

my_agent.sinks.mycluster.type = hdfs my_agent.sinks.mycluster.channel =
memoryChannel my_agent.sinks.mycluster.hdfs.path =
hdfs://127.0.0.1:8020/hdfsaudit/
```

- The name of the Agent is my\_agent
- The names of the Sink, Source, and Channel are arbitrary
- This Flume Agent has one Source named webserver
- The webserver Source is of type exec, which means it executes a given Unix command. In this example, it executes the tail command on the httpd access log file
- The Agent has one Sink named mycluster, which sends the events to a sequence file in a specified folder in HDFS
- The Agent has one Channel named memoryChannel
- The memoryChannel is configured with a memory type, which means it stores the events in memory. Notice that it is configured with a capacity of 10,000. No more than 10,000 events can fit in this Channel
- Other options for a Channel include a database, a file, or you can define your own custom channel
- Other options for a Sink include a system log (as INFO events), an IRC destination, local files, HBase, and Elastic Search

## About Sqoop



Sqoop is a tool designed to transfer data between Hadoop and external structured datastores like RDBMS and data warehouses. Using Sqoop, you can provision the data from an external system into HDFS. Sqoop uses a connector-based architecture that supports plugins that provide connectivity to additional external systems.

As you can see in the diagram, Sqoop uses MapReduce to distribute its work across the Hadoop cluster:

- The `sqoop` command line executes a Sqoop job
- Map tasks (4 by default) execute the command in Sqoop
- Plugins are used to communicate with the outside data source. The data source provides the schema, and Sqoop generates and executes SQL statements using JDBC or other connectors

### Note

Using MapReduce to perform Sqoop commands provides parallel operation as well as fault tolerance.

HDP provides the following connectors for Sqoop:

- Teradata
- MySQL
- Oracle JDBC connector
- Netezza

A Sqoop connector for the SQL Server is also available from Microsoft: SQL Server R2 connector

## Transferring Data Between HDFS and RDBMS

With Sqoop, you can import data from a relational database system into HDFS:

- The input to the import process is a database table

- Sqoop will read the table row by row into HDFS. The output of this import process is a set of files containing a copy of the imported table
- The import process is performed in parallel. For this reason, the output will be in multiple files
- These files may be delimited text files (for example, with commas or tabs separating each field) or binary Avro or SequenceFiles containing serialized record data

## Sqoop Input Tool

The import command looks like:

```
sqoop import (generic-args) (import-args)
```

The import command has the following requirements:

- Must specify a connect string using the `--connect` argument
- Can include credentials in the connect string, using the `--username` and `--password` arguments
- Must specify either a table to import using `--table` or the result of an SQL query using `--query`

### *Importing a Table*

The following Sqoop command imports a database table named StockPrices into a folder in HDFS named /data/stockprices:

```
sqoop import  
--connect jdbc:mysql://host/nyse  
--table StockPrices  
--target-dir /data/stockprice/  
--as-textfile
```

Based on the import command above:

- The connect string in this example is for MySQL. The database name is nyse
- The `--table` argument is the name of the table in the NYSE database
- The `--target-dir` is where the data will be imported into HDFS
- The default number of map tasks for Sqoop is four, so the result of this import will be in four files
- The `--as-textfile` argument imports the data as plain text

### Note

You can use `--as-avrodatafile` to import the data to Avro files and use `--as-sequencefile` to import the data to sequence files.

Other useful import arguments include:

--columns

A comma-separated list of the columns in the table to import (as opposed to importing all columns, which is the default behavior)

--fields-terminated-by

Specify the delimiter. Sqoop uses a comma by default

--append

The data is appended to an existing dataset in HDFS

--split-by

The column used to determine how the data is split between mappers. If you do not specify a split-by column, then the primary key column is used

-m

The number of map tasks to use

--query

Use instead of --table. The imported data are the resulting records from the given SQL query

--compress

Enables compression

--direct

Sqoop will attempt the direct import channel, which may be higher performance than using JDBC

## Note

The import command shown here looks like it was entered over multiple lines, but you have to enter this entire Sqoop command on a single command line.

## Reference

Visit <http://sqoop.apache.org/docs/1.4.6/SqoopUserGuide.html> for a list of all arguments available for the import command.

### **Import Specific Columns**

Use the `--columns` argument to specify which columns from the table to import.

For example:

```
sqoop import
--connect jdbc:mysql://host/nyse
--query "SELECT * FROM StockPrices s
WHERE s.Volume >= 1000000
AND \$CONDITIONS"
--target-dir /data/highvolume/
--as-textfile
--split-by StockSymbol
```

### **Importing from a Query**

Use the `--query` argument to specify which rows to select from a table. For example:

```
sqoop import
--connect jdbc:mysql://host/nyse
--query "SELECT * FROM StockPrices s
WHERE s.Volume >= 1000000
AND \$CONDITIONS"
--target-dir /data/highvolume/
--as-textfile
--split-by StockSymbol
```

Based on the command above:

- Only rows whose Volume column is greater than 1,000,000 will be imported
- The \$CONDITIONS token must appear somewhere in the WHERE clause of your SQL query so that the data can be split between mappers
- If you use `--query`, then you must also specify a `--split-by` column or the Sqoop command will fail to execute

#### **Note**

Using `--query` is limited to simple queries where there are no ambiguous projections and no OR conditions in the WHERE clause. Use of complex queries (such as queries that have sub-queries or joins leading to ambiguous projections) can lead to unexpected results.

#### **Warning**

You can use either `--query` or `--table`, but attempting to define both results in an error.

## **Sqoop Export Tool**

Sqoop's export process will read a set of delimited text files from HDFS in parallel, parse them into records, and insert them as new rows in a target database table. The syntax for the export command is:

```
sqoop export (generic-args) (export-args)
```

The Sqoop export tool runs in three modes:

### **Insert Mode**

The records being exported are inserted into the table using an `SQL INSERT statement`

### **Update Mode**

An `UPDATE SQL statement` is executed for existing rows, and an `INSERT` can be used for new rows

### **Call Mode**

A stored procedure is invoked for each record

#### *Call Mode*

The mode used is determined by the arguments specified:

`--table`

The table to populate in the database. This table must already exist in the database. If no `--update-key` is defined, the command is executed in Insert Mode

`--update-key`

The primary key column for supporting updates. If you define this argument, the Update Mode is used and existing rows are updated with the exported data

`--call`

Invokes a stored procedure for every record, thereby using Call Mode. If you define `--call`, do not define the `--table` argument or an error will occur

#### *Sqoop Expert Arguments*

The following are sqoop export arguments:

`--export-dir`

The directory in HDFS that contains the data to export

`--input-fields-terminated-by`

The input field delimiter. A comma is the default

`--update-mode`

Specifies how updates are performed when new rows are found with non-matching keys in the database. Values are `updateonly` (the default) and `allowinsert`

*Exporting to a Table*

The following Sqoop command exports the data in the /data/logfiles/ folder in HDFS to a table named LogData:

```
sqoop export  
--connect jdbc:mysql://host/mylogs  
--table LogData  
--export-dir /data/logfiles/  
--input-fields-separated-by "\t"
```

Based on the command above:

- The table LogData needs to already exist in the mylogs database
- The column values are determined by the delimiter, which is a tab in this example
- All files in the /data/logfiles/ directory will be exported

Sqoop will perform this job using four mappers, but you can specify the number to use with the -m argument

## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) What tool would work best for importing data from a relational database into HDFS?
- 2 ) What tool would work best for putting a file on your local filesystem into HDFS?
- 3 ) List the three main components of a typical Flume agent:
- 4 ) What is the default number of map tasks for a Sqoop job?
- 5 ) How do you specify a different number of mappers in a Sqoop job?
- 6 ) What is the purpose of the `$CONDITIONS` value in the `WHERE` clause of a Sqoop query?

## Answers

1 ) What tool would work best for importing data from a relational database into HDFS?

**Answer:** Sqoop

2 ) What tool would work best for putting a file on your local filesystem into HDFS?

**Answer:** The Hadoop client (hdfs dfs -put command)

3 ) List the three main components of a typical Flume agent:

**Answer:** A Flume agent consists of a source, channel, and sink

4 ) What is the default number of map tasks for a Sqoop job?

**Answer:** Four map tasks by default

5 ) How do you specify a different number of mappers in a Sqoop job?

**Answer:** The -m option is for specifying the number of mappers

6 ) What is the purpose of the \$CONDITIONS value in the WHERE clause of a Sqoop query?

**Answer:** The \$CONDITIONS value is used internally by Sqoop to specify LIMIT and OFFSET clauses so the data can be split up amongst the map tasks

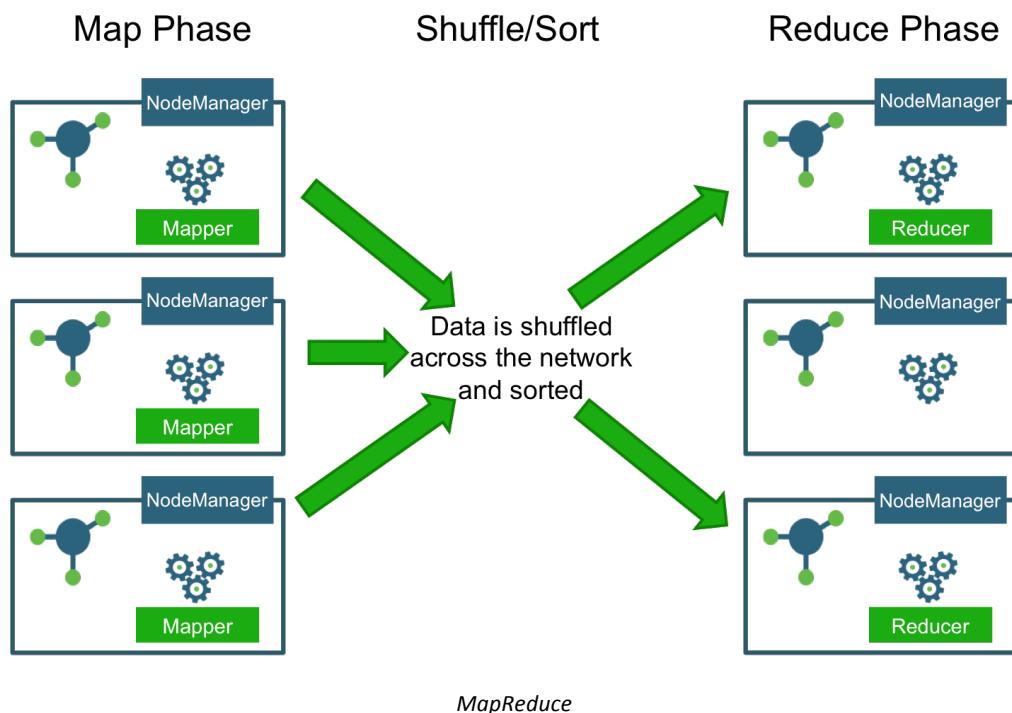
# MapReduce Framework

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe MapReduce
- ✓ Describe the Map Phase
- ✓ Describe the Reduce Phase

## MapReduce



MapReduce is a software framework for developing applications that process large amounts of data in parallel across a distributed environment. As its name implies, a MapReduce program consists of two main phases: a map phase and a reduce phase:

### Map phase

Data is input into the mapper, where it is transformed and prepared for the reducer

### Reduce phase

Retrieves the data from the mapper and performs the desired computations or analyses

To write a MapReduce program, you define a mapper class to handle the map phase and a reducer class to handle the reduce phase.

**Note**

The shuffle/sort phase of MapReduce is a part of the framework, so it does not require any programming on your part.

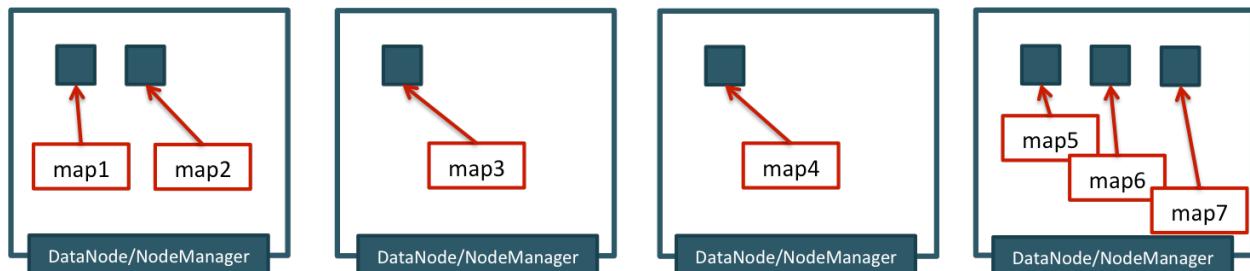
## MapReduce Concepts

Some important concepts to understand about MapReduce:

- The map and reduce tasks run in their own JVM on the DataNodes
- The mapper inputs key/value pairs from HDFS files and outputs intermediate key/value pairs. The data types of the input and output pairs can be different
- After all of the mappers finish executing, the intermediate key/value pairs go through a shuffle-and-sort phase where all of the values that share a key are combined and sent to the same reducer
- The reducer inputs the intermediate <key, value> pairs and outputs its own <key, value> pairs, which are typically written to HDFS
- The number of mappers is determined by the input format
- The number of reducers is determined by the MapReduce job configuration
- A Partitioner is used to determine which <key, value> pairs are sent to which reducer
- A Combiner can be optionally configured to combine the output of the mapper, which can increase performance by decreasing the network traffic of the shuffle and sort phase

## The MapReduce Process

- 1) Suppose a file is the input to a MapReduce job. That file is broken down into blocks stored on DataNodes across the Hadoop cluster.



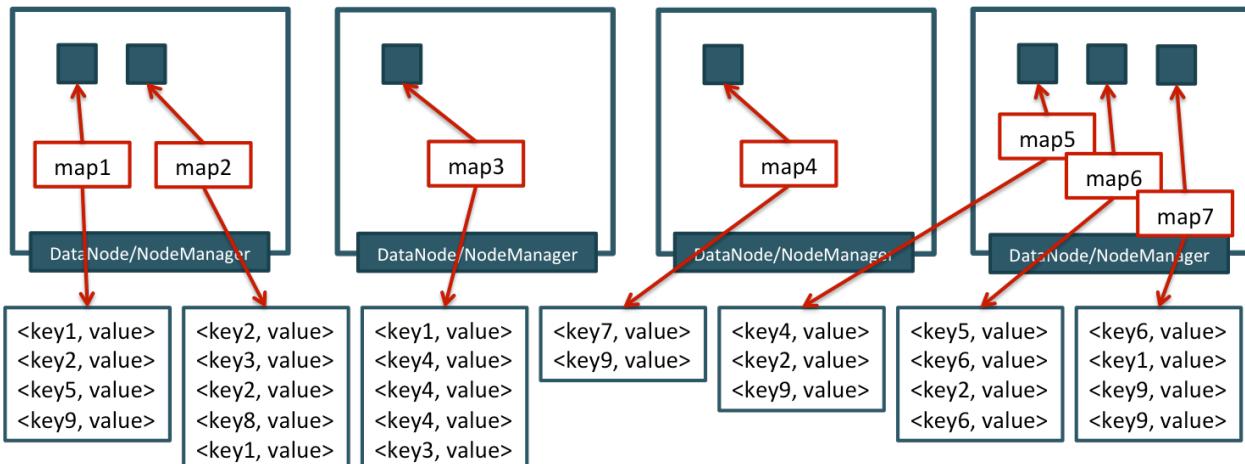
- 2) During the Map phase, map tasks process the input of the MapReduce job, with a map task assigned to each Input Split. The map tasks are Java processes that ideally run on the DataNodes where the blocks are stored.

The map phase involves running map tasks on NodeManagers. The main purpose of the map phase is to read all of the input data. The goal (in order to gain the best performance) is to achieve data locality, where a map task runs on a DataNode where its Input Split (or at least most of the split) is stored.

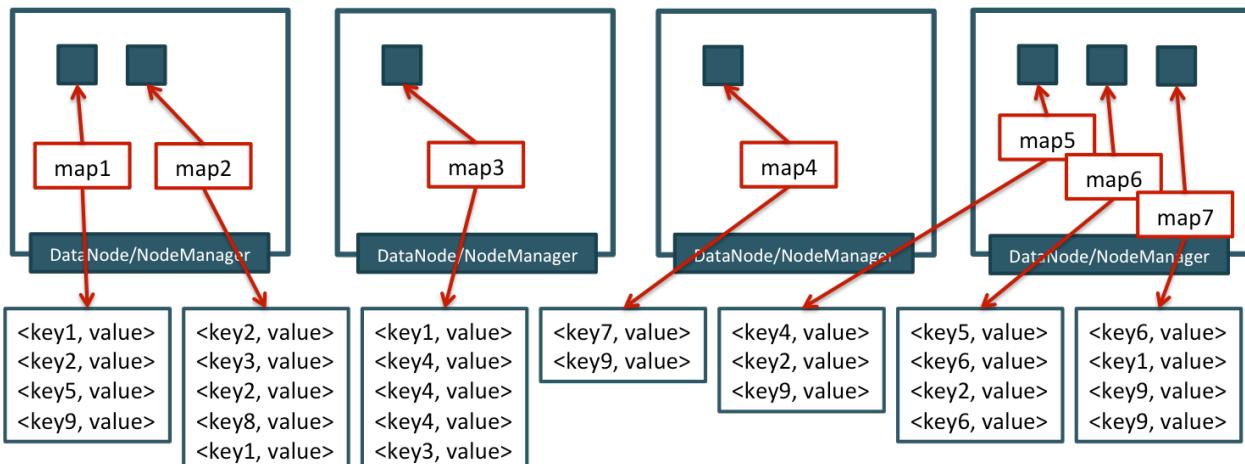
- 3 ) A block of data rarely maps exactly to an Input Split, but it is often close, especially when processing text data. Records that spill over to a subsequent block have to be pulled over the network so the map task can process the entire record, but this is normally an acceptable overhead

The number of map tasks in a MapReduce job is based on the number of Input Splits

If no NodeManager is available where a specific block resides, then you lose data locality and the block has to be pulled across the network



- 4 ) Each map task processes its Input Split and outputs records of <key, value> pairs.



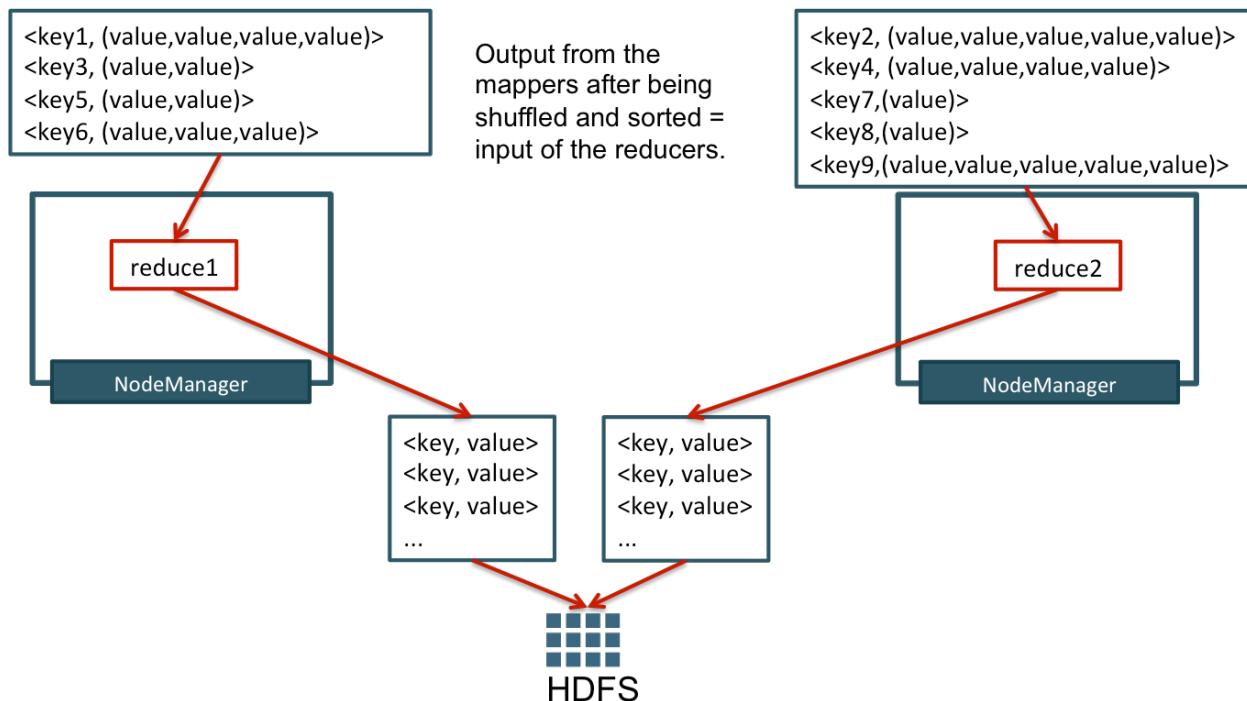
- 5 ) The <key,value> pairs go through a shuffle/sort phase, where records with the same key end up at the same reducer. The specific pairs sent to a reducer are sorted by key, and the values are aggregated into a collection.

Map tasks output `<key, value>` pairs, which are written to a temporary file on the local filesystem

When a map task finishes, its output becomes immediately available to the reduce tasks. Each reducer asks each mapper for the `<key, value>` pairs designated for that reducer. This designating of records is called partitioning.

As a reducer reads-in its `<key, value>` pairs, the values are aggregated into a collection and the entire input to the reducer is sorted by keys. This is referred to as the shuffle/sort phase

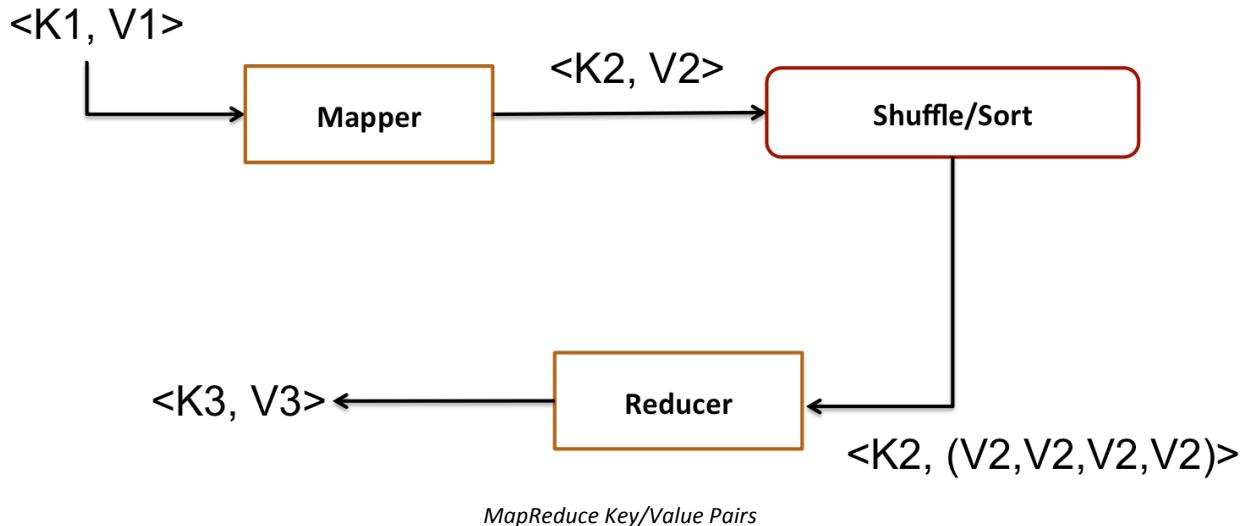
- 6 ) Reduce tasks run on a NodeManager as a Java process. Each Reducer processes its input and outputs `<key,value>` pairs that are typically written to a file in HDFS.



The main purpose of the reduce phase is typically business logic: going through the data output by the mappers and answering a question or solving a problem. The `<key, value>` pairs coming into the reducer are combined by key, meaning each key is presented once to the reducer along with all of the values that belong to that key.

- Reducers also output `<key, value>` pairs
- The output of a reducer is typically a file in HDFS. For example, if you have five reducers, the output will be five different files
- The number of reduce tasks in a MapReduce job is a setting that you get to choose

## Key/Value Pairs



The data types of the  $\langle \text{key}, \text{value} \rangle$  pairs in a MapReduce job look like:

$\langle K1, V1 \rangle$

**Input to the mapper**

$\langle K2, V2 \rangle$

**Output from the mapper**

$\langle K2, \text{Iterable}\langle V2 \rangle \rangle$

**Input to the reducer**

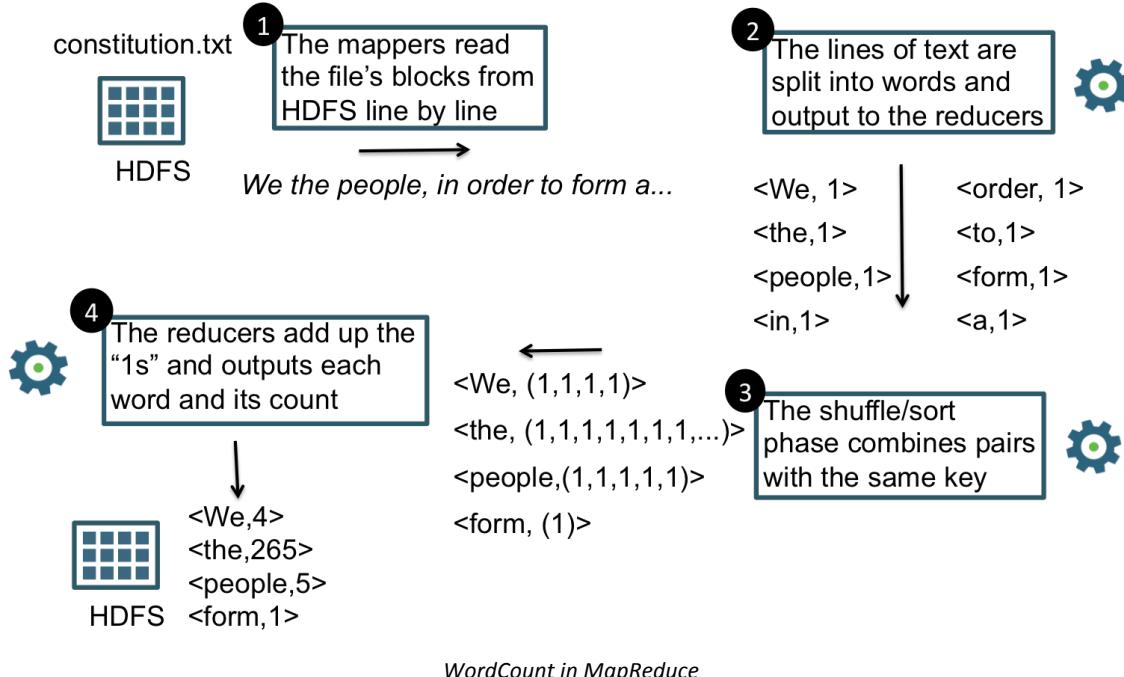
$\langle K3, V3 \rangle$

**Output from the reducer**

### Note

Keys are constantly being compared and sorted in MapReduce, and both keys and values get serialized and deserialized between the map and reduce phases.

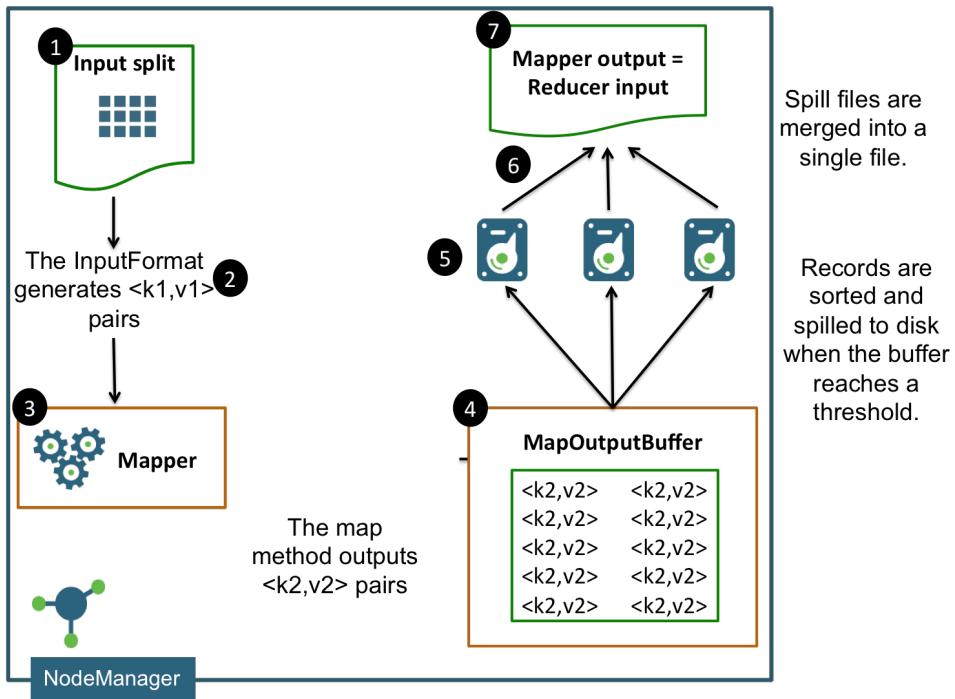
## WordCount in MapReduce



The “Hello, World” of Hadoop programming is the word-count application, which reads in a text file and counts the number of occurrences of each distinct word.

The diagram above shows how the `<key,value>` pairs of the word-count application are passed through the MapReduce job.

## The Map Phase



*The Map Phase*

Data is passed into the mapper as a  $\langle \text{key}, \text{value} \rangle$  pair generated by an InputFormat instance. The key and value are determined by the specific InputFormat that you configure.

### Map Phase Flow

Data flows through the map phase as follows:

- 1) The InputFormat determines where the input data needs to be split between the mappers, and then it generates an InputSplit instance for each split
- 2) MapReduce spawns a map task for each InputSplit generated by the InputFormat
- 3) Each  $\langle \text{key}, \text{value} \rangle$  pair generated by the InputFormat is passed to the map method of the mapper class  
The map method outputs a  $\langle \text{key}, \text{value} \rangle$  pair that is serialized into an unsorted buffer in memory
- 4) When the buffer fills up, or when the map task is complete, the  $\langle \text{key}, \text{value} \rangle$  pairs in the buffer are sorted then spilled to the disk
- 5) If more than one spill file was created, these files are merged into a single file of sorted  $\langle \text{key}, \text{value} \rangle$  pairs
- 6) The sorted records in the spill file wait to be retrieved by a reducer

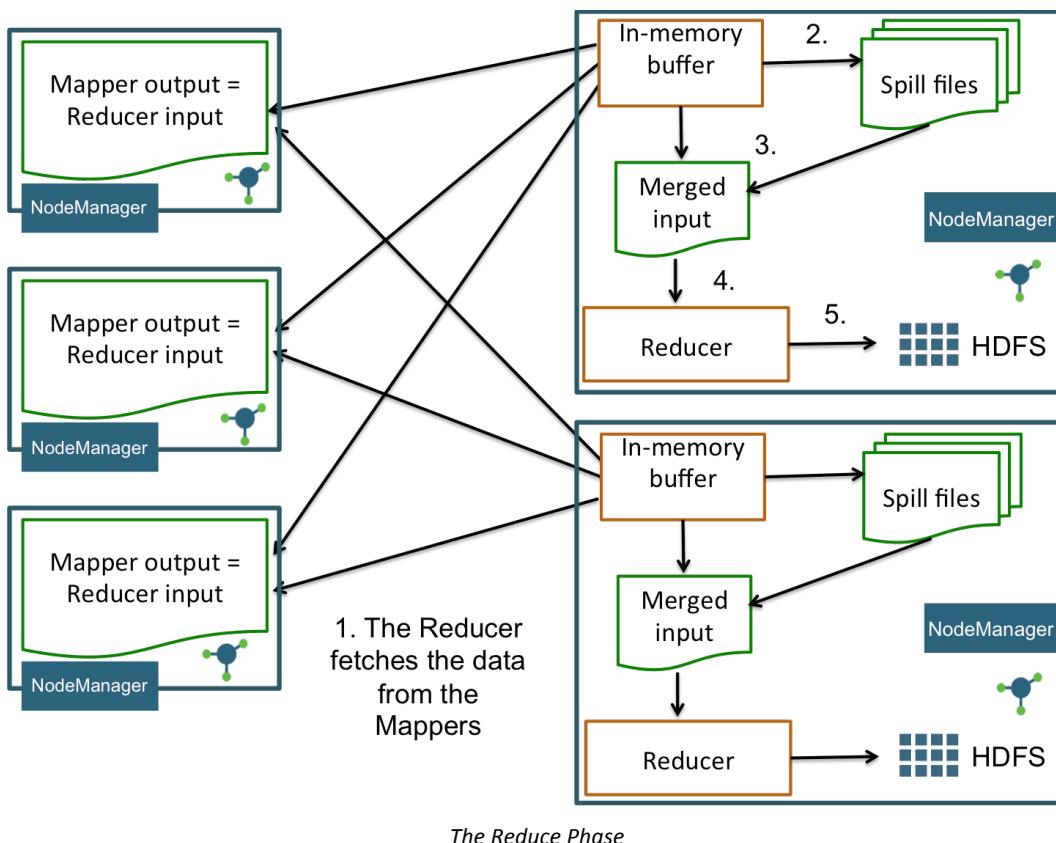
**Note**

The size of the mapper's output memory buffer is configurable with the `mapreduce.task.io.sort.mb` property. A spill occurs when the buffer reaches a certain capacity configured by the `mapreduce.map.sort.spill.percent` property.

**Important**

Spilling to disk cannot be entirely avoided because there is always one spill to disk when the mapper is complete. However, the ideal scenario is to avoid any intermediate spills. If an intermediate spill occurs, those `<key, value>` pairs need to be written to disk, then read and rewritten one more time, which results in three times the disk I/O for those spilled records

## The Reduce Phase



The reducer fetches the records from the mapper and uses them to generate and output another set of `<key, value>` pairs that are output to HDFS (or some other configurable location).

The reduce phase can actually be broken down in three phases:

### **Shuffle**

Also referred to as the fetch phase, this is when reducers retrieve the output of the mappers. All records with the same key are combined and sent to the same reducer

### **Sort**

This phase happens simultaneously with the shuffle phase. As the records are fetched and merged, they are sorted by key

### **Reduce**

The reduce method is invoked for each key, with the records combined into an iterable collection

### **Notes on Reduce Phase**

- All records that share the same key are sent to the same reducer
- During shuffling, the records are sorted by key and the values are combined into a collection
- The values in the collection are not sorted by default
- The number of reducers is determined by the mapreduce.job.reduces property
- A MapReduce job does not require a reducer. Setting the number of reducers to zero results in the mapper sending its output directly to HDFS
- A reducer can actually start fetching the output of mappers after the first mappers finish (but others are still working). This is done using threads, and the number of threads is configurable with the mapreduce.reduce.shuffle.parallelcopies property

### **Reduce Phase Flow**

Data flows through the reduce phase as follows:

- 1 ) As mappers finish their tasks, the reducers start fetching the records and storing them into a buffer in their JVM's memory
- 2 ) If the buffer fills, it is spilled to disk
- 3 ) Once all mappers complete and the reducer has fetched all its relevant input, all spill
- 4 ) records are merged and sorted (along with any records still in the buffer)
- 5 ) The reduce method is invoked on the reducer for each key
- 6 ) The output of the reducer is written to HDFS (or wherever the output was configured to be sent)

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## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) What are the three main phases of a MapReduce job?
- 2 ) Suppose the mappers of a MapReduce job output <key,value> pairs that are of type <integer,string>. What will the pairs look like that are processed by the corresponding reducers?
- 3 ) What happens if all the <key,value> pairs output by a mapper do not fit into the memory of the mapper?
- 4 ) What determines the number of mappers of a MapReduce job?
- 5 ) What determines the number of reducers of a MapReduce job?
- 6 ) True or False: The shuffle/sort phase sorts the keys and values as they are passed to the reducer.

## Answers

- 1 ) What are the three main phases of a MapReduce job?

**Answer:** Map phase, shuffle/sort phase, and reduce phase

- 2 ) Suppose the mappers of a MapReduce job output <key,value> pairs that are of type <integer,string>. What will the pairs look like that are processed by the corresponding reducers?

**Answer:** The pairs coming into the reducer will look like <integer, (string,string,string,...)>

- 3 ) What happens if all the <key,value> pairs output by a mapper do not fit into the memory of the mapper?

**Answer:** When the map output buffer reaches a threshold, the <key,value> pairs are spilled to disk, meaning they are written to a temporary file on the local filesystem.

- 4 ) What determines the number of mappers of a MapReduce job?

**Answer:** The number of mappers is determined by the input splits.

- 5 ) What determines the number of reducers of a MapReduce job?

**Answer:** You get to choose the number of reducers.

- 6 ) True or False: The shuffle/sort phase sorts the keys and values as they are passed to the reducer.

**Answer:** False. The keys are sorted, but the values are not.

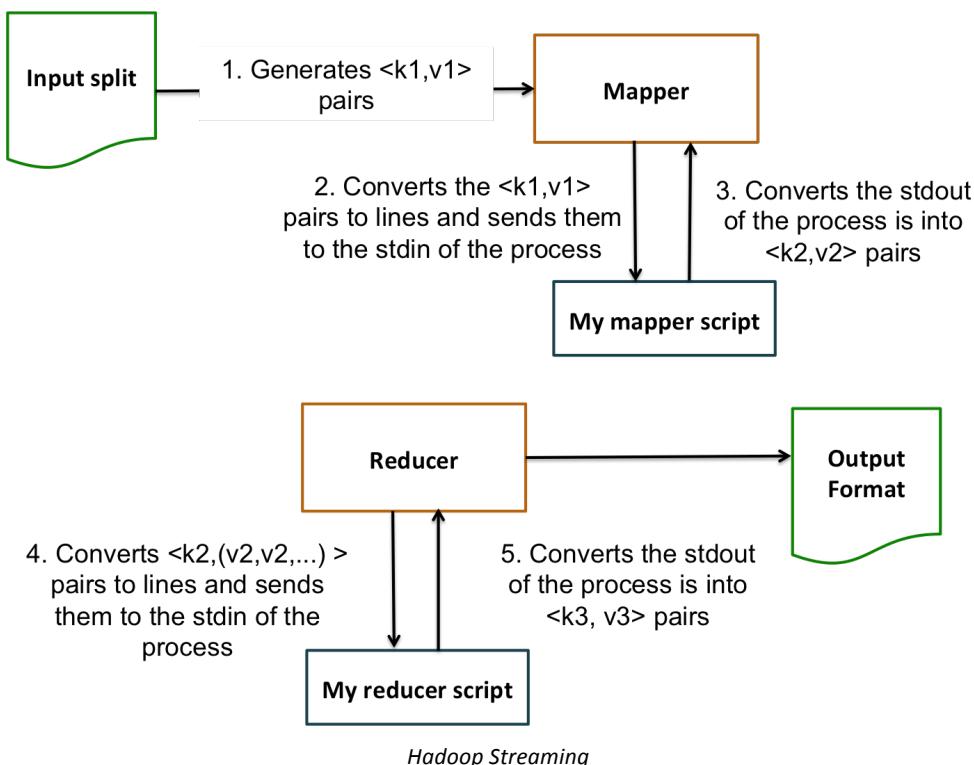
# Hadoop Streaming

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe Hadoop Streaming
- ✓ Run a Hadoop Streaming Job

## Hadoop Streaming



Hadoop Streaming is a part of HDP, and it allows you to create and run MapReduce jobs with any executable or script as the mapper and/or the reducer. Streaming allows you to take advantage of the benefits of MapReduce while using any scripting language you like.

## Hadoop Streaming Process

- 1 ) The MapReduce job starts as any other job, with the input splits sending key/value pairs to a map task
- 2 ) The Streaming mapper converts the key/value pairs into lines of text and sends each line of text to the stdin of the mapper process
- 3 ) The Streaming mapper reads each line of text from the stdout of the process and converts the line to a key/value pair using a tab as the delimiter between the key and the value

- 4 ) Similarly, the Streaming reducer converts the input key/values pairs into lines of text and sends them to the stdin of the reducer process
- 5 ) The output from stdout of the process is converted to key/value pairs (using a tab as the delimiter) and output by the Streaming reducer

## Running a Hadoop Streaming Job

The command to run a Hadoop Streaming job looks like the following (entered on a single command line):

```
> hadoopjarhadoop-streaming.jar  
-input input_directories  
-output output_directories  
-mapper mapper_script  
-reducer reducer_script
```

For example, the following command executes a Streaming job that uses cat as the mapper and grep as its reducer:

```
> hadoopjarhadoop-streaming.jar  
-input test/data.txt  
-output streamtest  
-mapper /bin/cat  
-reducer 'grep -i hadoop'
```

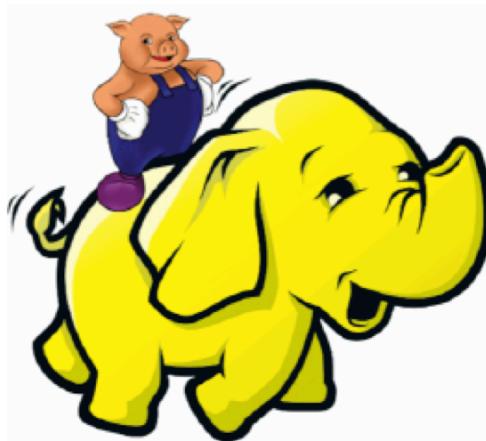
# Introduction to Pig

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe Pig
- ✓ Describe Pig Latin
- ✓ Define a Schema
- ✓ Describe common Pig Operators:
  - GROUP
  - FOREACH GENERATE
  - FILTER
  - LIMIT

## Apache Pig



*Apache Pig*

Apache Pig, <http://pig.apache.org/>, is a Hadoop platform for creating MapReduce jobs. Pig was created at Yahoo! to make it easier to analyze the data in your HDFS without the complexities of writing a traditional MapReduce program. Pig uses a high-level SQL-like programming language named Pig Latin. The benefits of Pig include the ability to:

- Run a MapReduce job with a few simple lines of code
- Process structured data with a schema, or Pig can process unstructured data without a schema (Pigs eat anything)
- Use a familiar SQL-like syntax in Pig Latin
- Read and write data from HDFS with Pig scripts
- Create code with a data flow language, a logical solution for many MapReduce algorithms

The developers of Pig published their philosophy to summarize the goals of Pig using comparisons to actual pigs:

**Pigs eat anything**

Pig can process any data, structured or unstructured

**Pigs live anywhere**

Pig can run on any parallel data processing framework, so Pig scripts do not have to run just on Hadoop

**Pigs are domestic animals**

Pig is designed to be easily controlled and modified by its users

**Pigs fly**

Pig is designed to process data quickly

## Pig Latin

Pig Latin is a high-level data flow scripting language. Pig Latin scripts can be executed in one of three ways:

**Pig script**

Write a Pig Latin program in a text file and execute it using the pig executable

**Grunt shell**

Enter Pig statements manually one at a time from a CLI tool known as the Grunt interactive shell

**Embedded in Java**

Use the PigServer class to execute a Pig query from within Java code

Pig executes in a unique fashion: some commands build on previous commands, while certain commands trigger a MapReduce job.

- During execution, each statement is processed by the Pig interpreter
- If a statement is valid, it gets added to a logical plan built by the interpreter
- The steps in the logical plan do not actually execute until a DUMP or STORE command is used

## The Grunt Shell



Grunt shell

```
rich — root@sandbox:~ — ssh — 59x5
grunt> employees = LOAD 'pigdemo.txt' AS (state, name);
grunt> describe employees;
employees: {state: bytearray, name: bytearray}
grunt> employees_grp = group employees by state;
grunt> dump employees;
```

*The Grunt Shell*

Grunt is an interactive shell that enables users to enter Pig Latin statements and also interact with HDFS. To enter the Grunt shell, run the pig executable in the `PIG_HOME\bin` folder:

```
# pig
grunt>
```

The Grunt shell provides tab completion for commands (unfortunately there is no tab completion for files or folders), as well as command-line history and editing.

You can run HDFS commands directly from the Grunt shell, which also has the concept of a “present working directory” with the ability to change directories using the `cd` command.

## Relation Names

Each processing step of a Pig Latin script results in a new data set, referred to as a relation. You assign names to relations, and the name of a relation is referred to as its alias. For example, consider the following Pig Latin statement:

```
stocks = LOAD 'mydata.txt' using TextLoader();
```

The alias `stocks` is assigned to the relation created by the `LOAD` statement, which in this statement is a line of text from the `mydata.txt` file. The `stocks` alias now represents the collection of records in `mydata.txt`.

Relation names (aliases) are not variables, even though they look like variables. You can reassign an alias to a different relation, but that is not recommended.

### Note

`TextLoader` is a simple way of loading each line of text in a file into a record, no matter what the format of the data is.

## Field Names

You can also define field names when using the `LOAD` command to define a relation. Use the `AS` keyword to define field names:

```
salaries = LOAD 'salary.data' USING PigStorage(',') AS (gender, age, income, zip);
```

The alias for this relation is `salaries`, and `salaries` has four field names: `gender`, `age`, `income` and `zip`.

Field names can be used in subsequent processing commands. For example, when filtering a relation, you can refer to its fields in the `BY` clause, as shown in the following statement:

```
highsalaries = FILTER salaries BY income > 1000000;
```

Field names contain the values of the current record as the data passes through the pipeline of the Pig application. The `highsalaries` relation will contain all records whose `income` field is greater than 1,000,000.

Both field names and relation names must satisfy the following naming criteria:

- Must start with an alphabetic character
- Can contain alphabetic and numeric characters, as well as the underscore (`_`) character
- Can only contain ASCII characters

### Important

Field names and relation names are case sensitive in your Pig Latin scripts. User Defined Functions (UDFs) are also case sensitive. However, Pig Latin keywords (like `LOAD` and `AS`) are not case sensitive.

## Data Types

### Scalar Data Types

Pig has six built-in **scalar data types**:

`int`  
A 32-bit signed integer

`long`  
A 64-bit signed integer

`float`  
A 32-bit floating-point number

`double`  
A 64-bit floating-point number

`chararray`  
Strings of Unicode characters (represented as `java.lang.String` objects)

bytearray

A blob or array of bytes

boolean

Can be either true or false (case-sensitive)

datetime

A date and time stored in the format 1970-01-01T00:00:00.000+00:00

bigdecimal and BigInteger

For performing precision arithmetic

## Complex Data Types

Pig has three complex data types:

Tuple

Ordered set of fields. A tuple is analogous to a row in an SQL table, with the fields being SQL columns

Tuples are indicated by parentheses. For example, the following tuple has four fields:

```
(OH,Mark,Twain,31225)
```

Bag

Unordered collection of tuples

Bags are constructed using curly braces, and commas separate the tuples within the bag. The following bag has three tuples in it:

```
{(OH,Mark,Twain,31225),(UK,Charles,Dickens,42207),  
(ME,Robert,Frost,11496)}
```

Map

Collection of key value pairs

Maps are key/value pairs where the key must be a unique chararray type and the value can be any data. Maps are formed using square brackets, with a hashtag between the key and value. The following map has three key#value pairs:

```
[state#OH,name#Mark Twain,zip#31225]
```

Complex types can be nested. For example, a bag can be an element of a tuple, which is the result of the GROUP BY operator:

```
(CA,{(CA,Ulf),(CA,manish),(CA,Brian
```

## Defining a Schema

Pig will eat any kind of data, but if your data has a known structure to it, then you can define a schema for it. The schema is typically defined when you load the data using the AS keyword.

For example:

```
customers = LOAD 'customer_data' AS (firstname:  
chararray, lastname:chararray, house_number:int,  
street:chararray, phone:long, payment:double);
```

The customers relation has six fields, and each field is a specific data type.

If you load a customer record that has more than six fields, the extra fields will be truncated. If you load a customer record that has fewer than six fields, it will pad the end of the record with nulls.

The schema can also specify complex types. For example, suppose we have the following dataset in a file named ‘bag\_demo.txt’:

```
F,66,{(41000,95103),(33000,57701)}  
M,40,{(76000,95102)}  
F,58,{(95000,95103),(60000,95105)} M,85,{(14000,95102),(0,95105),(2000,94040)}
```

The corresponding relation might look like:

```
salaries = LOAD 'bag_demo.txt' AS (gender:chararray, age:int,  
details:bag{(salary:double,zip:long)});
```

The salaries relation is a tuple of three fields: the first field is a chararray named gender, the second field is an int named age, and the third field is a bag named details.

Pig is very lenient when it comes to schemas:

- If you define a schema, then Pig will perform error-checking with it
- If you do not define a schema, Pig will make its best guess as to how the data should be treated

## Pig Operators

Common Pig operators include:

- GROUP
- FOREACH
- FILTER
- LIMIT

## GROUP

salaries					salariesbyage	
gender	age	salary	zip		group	salaries
F	17	41000.00	95103		17	{(F,17,41000.0,95103), (M,17,35000.0,95103)}
M	19	76000.00	95102		19	{(M,19,76000.0,95102), (F,19,60000.0,95105), (M,19,14000.0,95102)}
F	22	95000.00	95103			
F	19	60000.00	95105		22	{(F,22,95000.0,95103)}
M	19	14000.00	95102			
M	17	35000.00	95103			

salariesbyage = **GROUP** salaries **BY** age;

```
grunt> DESCRIBE salariesbyage;
salariesbyage: {group:int,
                salaries:{(gender: chararray, age: int,salary: double,zip: int)}}
```

*Result of a GROUP Operation*

One of the most common operators in Pig is GROUP, which collects all records with the same value for a provided key and puts them together into a bag. The result of a GROUP operation is a relation that includes one tuple per group. This tuple contains two fields:

- The first field is named "group" and is the same type as the group key
- The second field takes the name of the original relation and is type bag

Suppose we have the following data set:

```
F,66,41000,95103
M,40,76000,95102
F,58,95000,95103
F,68,60000,95105
M,85,14000,95102
...
```

Let's group the records together by age:

```
salaries = LOAD 'salaries.txt' USING PigStorage(',') AS (gender:chararray,
age:int,salary:double,zip:int);
salariesbyage = GROUP salaries BY age;
```

The salariesbyage relation has two fields. The first is group, which will be an int because age is an int, followed by the salaries field as a tuple:

```
> DESCRIBE salariesbyage;
salariesbyage: {group:int, salaries:{(gender: chararray, age: int,salary: double,zip: int)}}}
```

## Introduction to Pig

The records will look like:

```
> DUMP salariesbyage; (17, { (F,17,0.0,95050), (M,17,0.0,95103), (M,17,0.0,95102) })  
(19, { (M,19,0.0,95050) })  
(22, { (F,22,90000.0,95102) }) (23, { (M,23,89000.0,95105), (M,23,64000.0,94041) })
```

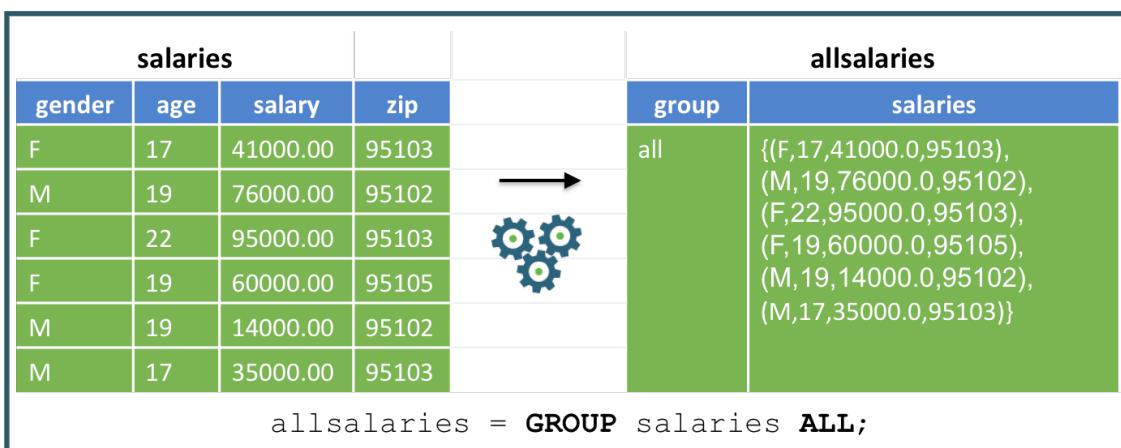
You can also group a relation by multiple keys. The keys must be listed in parentheses. For example:

```
> mygroup = GROUP salaries BY (gender, age);  
> describe mygroup;  
mygroup: {group: (gender: chararray, age: int), salaries: {(gender: chararray, age: int, salary: double, zip: int)}}
```

Notice the group field is a tuple containing both gender and age. The resulting records in the mygroup relation look like:

```
((M,17), { (M,17,0.0,95103), (M,17,0.0,95102) })  
((M,19), { (M,19,0.0,95050) })  
((M,23), { (M,23,64000.0,94041), (M,23,89000.0,95105) })
```

### The ALL Option



```
grunt> DESCRIBE allsalaries;  
allsalaries: {  
    group: chararray,  
    salaries: {(gender: chararray, age: int, salary: double, zip: int)}}}
```

### GROUP ALL Option

You can group all of the records of a relation into a single tuple using the ALL option. For example:

```
> allsalaries = GROUP salaries ALL;  
> describe allsalaries;  
allsalaries: {group: chararray, salaries: {(gender: chararray, age: int, salary: double, zip: int)}}
```

In this case, the value of group will be the chararray “all” followed by a bag of all records:

```
(all, {(F,66,41000.0,95103), (M,40,76000.0,95102), (F,58,95000.0,95103), (F,68,6000
0.0,95105), (M,85,14000.0,95102), (M,14,0.0,95105), (M,52,2000.0,94040), (M,67,9900
0.0,94040), (F,43,11000.0,94041), (F,37,65000.0,94040), (M,72,83000.0,94041), (M,68,
15000.0,95103), (F,74,37000.0,95105), (F,15,0.0,95050), (F,83,0.0,94040), (F,30,10
000.0,95101), (M,19,0.0,95050), (M,23,89000.0,95105), (M,1,0.0,95050), (F,4,0.0,951
03) })
```

### *Relations Without a Schema*

salaries				salariesgroup	
\$0	\$1	\$2	\$3	group	salaries
F	17	41000.00	95103	95103	{(F,17,41000.0,95103), (F,22,95000.0,95103) (M,17,35000.0,95103)}
M	19	76000.00	95102	95102	{(M,19,76000.0,95102), (M,19,14000.0,95102)}
F	22	95000.00	95103		
F	19	60000.00	95105		
M	19	14000.00	95102		
M	17	35000.00	95103	95105	{(F,19,60000.0,95105)}

salariesgroup = GROUP salaries BY \$3;

```
grunt> DESCRIBE salariesgroup;
salariesgroup: {group:bytearray,
                salaries:{()}}
```

### *Relations without a Schema*

If you do not define a schema, then the fields of a relation are specified using an index that starts at \$0. This works well for datasets that have a lot of columns or for data that is not structured.

The following relation has four columns but does not define a schema:

```
salaries = LOAD 'salaries.txt' USING PigStorage(' ',');
```

Notice what the output is when you try to describe this relation:

```
> DESCRIBE salaries;
Schema for salaries unknown.
```

The following relation groups salaries by its fourth field:

```
salariesgroup = GROUP salaries BY $3;
```

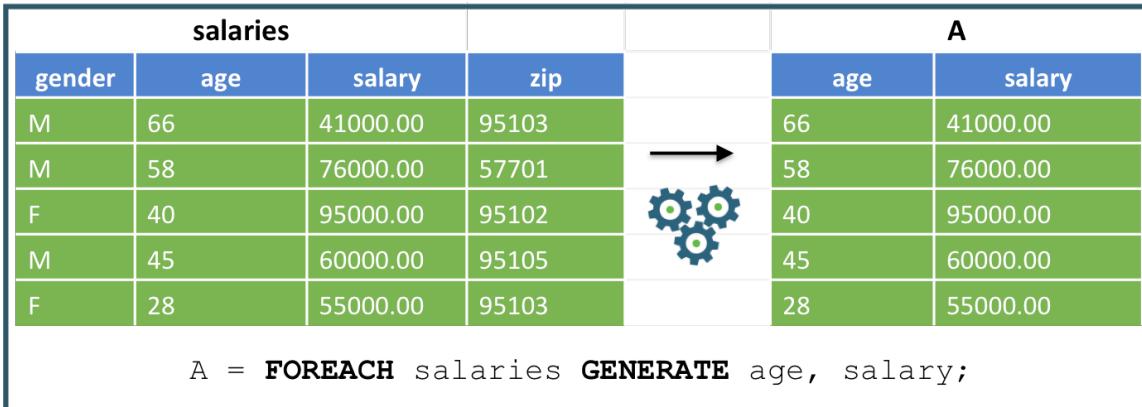
Notice the salariesgroup relation does not have a schema for its salaries field:

```
> describe salariesgroup
salariesgroup: {group: bytearray,salaries: {()}}
```

Why is the datatype of group bytearray?

**Answer:** Because the salaries relation does not have a schema, the data type of the field used for grouping is the default bytearray type.

## FOREACH GENERATE



```
grunt> DESCRIBE A;
A: {age: int, salary: double}
```

### *The FOREACH GENERATE Operator*

The FOREACH...GENERATE operator transforms records based on a set of expressions that you define. The operator works on each record in the data set (as in, “for each record”). The result of a FOREACH is a new tuple, typically with a different schema.

The FOREACH operator is a great tool for transforming your data into different data sets. The expression in a FOREACH can contain fields, constants, mathematical expressions, the result of invoking a Pig function, and many other variations and nestings.

Let’s look at an example. The following command takes in the salaries relation and generates a new relation that only contains two of the columns in salaries:

```
> A = FOREACH salaries GENERATE age, salary;
> DESCRIBE A;
A: {age: int, salary: double}
```

The records in the A relation look like:

```
(66,84000.0)
(39,3000.0)
(84,14000.0)
```

You can perform mathematical computations in the GENERATE clause:

```
B = FOREACH salaries GENERATE salary, salary * 0.07;
```

The resulting relation contains each salary along with the salary multiplied by 7%:

```
(69000.0,4830.000000000001)  
(91000.0,6370.000000000001)  
(0.0,0.0)  
(48000.0,3360.000000000005)  
(3000.0,210.000000000003)
```

### **Specifying Ranges**

In the GENERATE clause, you can specify a range of values, which is useful when working with datasets that have a large number of fields. For example:

```
salaries = LOAD 'salaries.txt' USING PigStorage(',') AS (gender:chararray,  
age:int,salary:double,zip:int);  
C = FOREACH salaries GENERATE age..zip;
```

The C relation will contain three fields: age, salary, and zip:

```
> describe C;  
C: {age: int,salary: double,zip: int}
```

You can also specify an open-ended range:

```
D = FOREACH salaries GENERATE age..;  
E = FOREACH salaries GENERATE ..salary;
```

D will contain age, salary, and zip. E will contain gender, age, and salary. This syntax also works well with large relations that do not have a schema:

```
customer = LOAD 'data/customers';  
F = FOREACH customer GENERATE $12..$23;
```

### **Field Names**

A relation created from a FOREACH statement is a new tuple. Pig infers the data types of the fields in the new tuple, but sometimes the names of the fields are not inferred. In the following simple projection, Pig will use the same field name as the original relation:

```
> salaries = LOAD 'salaries.txt' USING PigStorage(',') AS (gender:chararray,  
age:int,salary:double,zip:int);  
> C = FOREACH salaries GENERATE zip, salary;  
> DESCRIBE C;  
C: {zip: int,salary: double}
```

in the following projection, Pig cannot determine a field name for the second value in the new tuple:

```
> D = FOREACH salaries GENERATE zip, salary * 0.10;  
> DESCRIBE D;  
D: {zip: int,double}
```

Notice the second field in D only has a datatype, but no name. You would have to use the \$1 to refer to this field in D.

You can use the AS keyword to assign a name to the fields in the new tuple. For example:

## Introduction to Pig

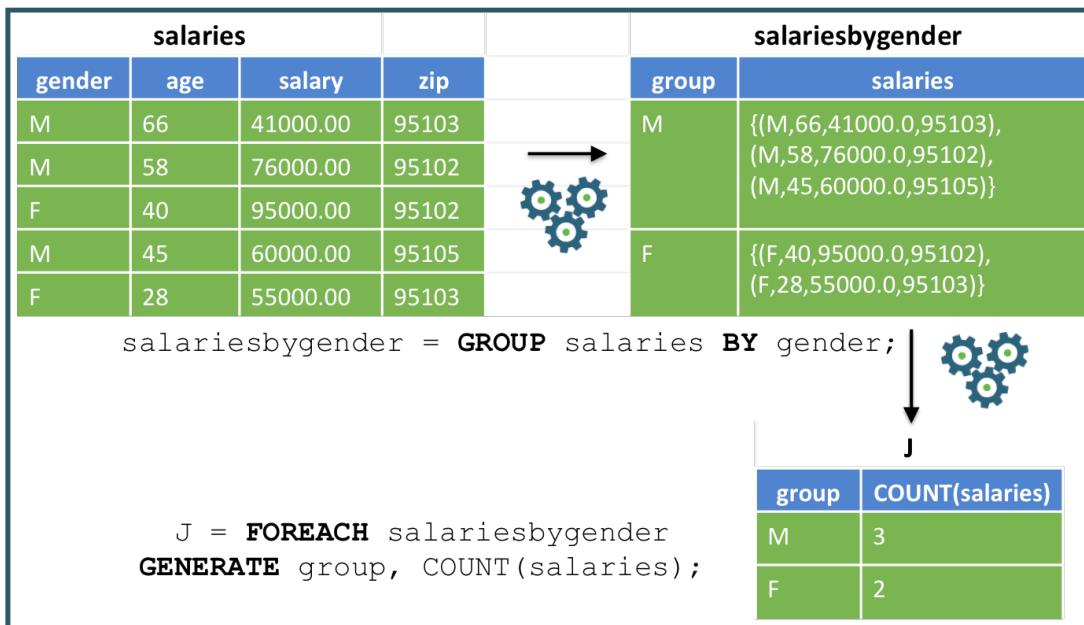
```
> E = FOREACH salaries GENERATE zip, salary * 0.10 AS bonus;  
> DESCRIBE E;  
E: {zip: int, bonus: double}
```

Notice the second field in E has the name bonus.

### Note

You can use the AS keyword for any of the fields in the GENERATE clause, even if Pig can infer the field name.

### FOREACH with Groups



### FOREACH with Groups

Let's look at an example of a Pig script that performs a FOREACH operation on a group:

```
salaries = LOAD 'salaries.txt' USING PigStorage(',') AS (gender:chararray,  
age:int,salary:double,zip:int);  
salariesbygender = GROUP salaries BY gender;
```

The salariesbygender relation has two fields: group and a bag named salaries:

```
salariesbygender: {group: chararray,salaries: { (gender: chararray,age:  
int,salary: double,zip: int) }}
```

Since there are only two possible values of group (M or F), then there will be at most two rows. The following FOREACH counts the number of tuples in each salaries bag:

```
J = FOREACH salariesbygender GENERATE group, COUNT(salaries);
```

The J relation looks like:

```
J: {group: chararray, long}
```

The output of J is:

```
(F, 24)
(M, 26)
```

This means our `salaries.txt` file contains 24 female records and 26 male records.

If you need to specifically refer to a field inside the bag of a group relation, you use the dot operator. For example, suppose we only want to refer to the salary field in the salaries bag of the `salariesbygender` relation:

```
K = FOREACH salariesbygender GENERATE group, MAX(salaries.salary);
```

The K relation will contain the group (so either M or F) and the maximum salary field in that particular salaries bag. The output of running this code is:

```
(F, 95000.0)
(M, 99000.0)
```

## FILTER

salaries					G			
gender	age	salary	zip		gender	age	salary	zip
F	17	41000.00	95103		M	19	76000.0	95102
M	19	76000.00	95102	→	F	22	95000.0	95103
F	22	95000.00	95103		F	19	60000.0	95105
F	19	60000.00	95105					
M	19	14000.00	95102					
M	17	35000.00	95103					

```
G = FILTER salaries BY salary >= 50000.0;
```

*The FILTER Operator*

The FILTER operator selects tuples from a relation based on specified Boolean expressions. Use FILTER to select the rows you want, or filter out the rows you do not. The FILTER operator looks like:

```
FILTER alias BY expression;
```

For example, the following command filters the salaries relation to contain only those tuples whose salary field is greater than 10,000:

```
G = FILTER salaries BY salary >= 10000.0;
```

Conditions can be combined using AND or OR:

```
H = FILTER salaries BY gender == 'F' AND age >= 50;
```

### The NOT Operator

Use the NOT operator to reverse a condition. Suppose we have the following dataset:

```
SD Rich
NV Barry
CO George
CA ULF
IL Danielle
OH Tom
CA Manish
CA Brian
CO Mark
```

The following NOT operator filters out all rows that match a regular expression:

```
> employees = LOAD 'pigdemo.txt' AS (state:chararray, name:chararray);
> no_b = FILTER employees BY NOT name MATCHES '.*b|B.*';
```

The no\_b relation will contain all records that do not contain the letter 'b' or 'B':

```
> employees = LOAD 'pigdemo.txt' AS (state:chararray, name:chararray);
> no_b = FILTER employees BY NOT name MATCHES '.*b|B.*';
```

The no\_b relation will contain all records that do not contain the letter 'b' or 'B':

```
(SD,Rich)
(CO,George)
(CA,Ulf)
(IL,Danielle)
(OH,Tom)
(CA,Manish)
(CO,Mark)
```

### Note

The FILTER command does not change the schema of a relation or the structure. It only narrows down the number of records belonging to that relation.

## LIMIT

The LIMIT command limits the number of output tuples for a relation:

```
employees = LOAD 'pigdemo.txt' AS (state:chararray, name:chararray); emp_group
= GROUP employees BY state;
L = LIMIT emp_group 3;
```

Note that there is no guarantee which three tuples will be returned, and the tuples that are returned can change from one run to the next. Using the data shown earlier, the output of one of the executions was:

```
(CA, { (CA,Ulf), (CA,manish), (CA,Brian) })
(CO, { (CO,George), (CO,Mark) })
(IL, { (IL,Danielle) })
```

**Note**

If you define an ORDER BY (discussed in the next lesson) immediately before the LIMIT, then you will be guaranteed to get the same results each time.

## Introduction to Pig

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## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) List two Pig commands that cause a logical plan to execute:
- 2 ) Which Pig command stores the output of a relation into a folder in HDFS?  
Suppose the prices.csv file looks like:

```
XFR,2004-05-13,22.90,400 XFR,2004-05-12,22.60,400000 XFR,2004-05-11,22.80,2600 XFR,2004-05-10,23.00,3800 XFR,2004-05-07,23.55,2900  
XFR,2004-05-06,24.00,2200
```

And assume we have the following relation defined:

```
prices = load 'prices.csv' using PigStorage(',')  
as (symbol:chararray, date:chararray, price:double, volume:int);
```

Explain what each of the following Pig commands or relations do:

- 3 ) describe prices;
- 4 ) A = group prices by symbol;
- 5 ) B = foreach prices generate symbol as x, volume as y;
- 6 ) C = foreach A generate group, SUM(prices.volume);
- 7 ) D = foreach prices generate symbol..price;
- 8 ) Write a Pig relation that only contains prices with a volume greater than 3,000:

## Answers

- 1 ) List two Pig commands that cause a logical plan to execute:

**Answer:** STORE, DUMP, and ILLUSTRATE all cause a logical plan to execute

- 2 ) Which Pig command stores the output of a relation into a folder in HDFS?

**Answer:** STORE

Suppose the prices.csv file looks like:

```
XFR,2004-05-13,22.90,400 XFR,2004-05-12,22.60,400000 XFR,2004-05-11,22.80,2600 XFR,2004-05-10,23.00,3800 XFR,2004-05-07,23.55,2900 XFR,2004-05-06,24.00,2200
```

And assume we have the following relation defined:

```
prices = load 'prices.csv' using PigStorage(',')  
as (symbol:chararray, date:chararray, price:double, volume:int);
```

Explain what each of the following Pig commands or relations do:

- 3 ) describe prices;

**Answer:** prices: {symbol: chararray,date: chararray,price: double,volume: int}

- 4 ) A = group prices by symbol;

**Answer:** The result is a collection of bags, with a bag for each distinct symbol. The A relation looks like:

```
A: {group: chararray,prices: { (symbol: chararray,date: chararray,price: double,volume: int) }}
```

- 5 ) B = foreach prices generate symbol as x, volume as y;

**Answer:** The B relation is a projection of the symbol and volume fields of prices. The schema was also changed. B looks like:

**B: {x: chararray,y: int}**

- 6 ) C = foreach A generate group, SUM(prices.volume) ;

**Answer:** C is a projection of A. The group field is the symbol field of prices, and the SUM function adds up the volume field of each group of symbols. The C relation looks like:

```
C: {group: chararray,long}
```

The output of C looks like:

```
(XFR, 411900)
```

- 7) D = foreach prices generate symbol..price;

**Answer:** D is a projection of all fields of prices between symbol and price. The D relation looks like:

```
D: {symbol: chararray, date: chararray, price: double}
```

- 8) Write a Pig relation that only contains prices with a volume greater than 3,000:

**Answer:** E = filter prices by volume > 3000;



# Advanced Pig Programming

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe advanced Pig operators

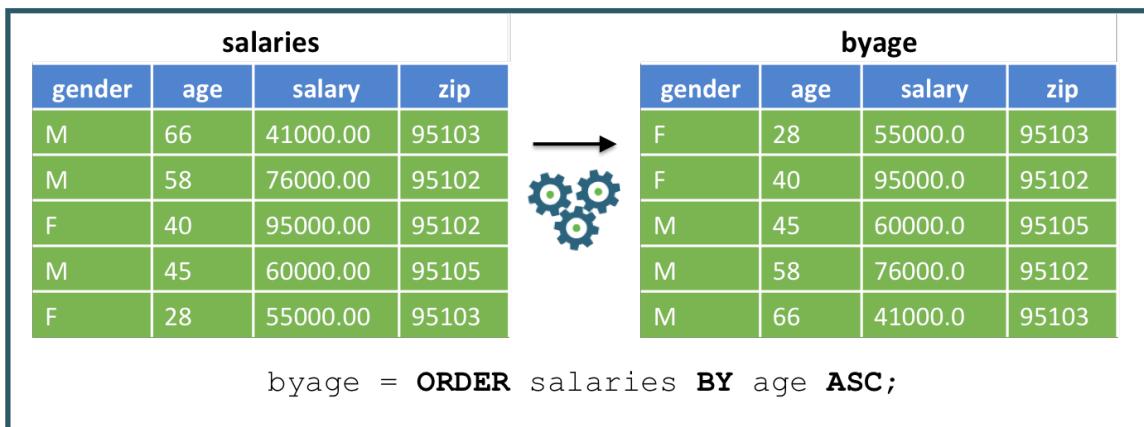
- ORDER BY
- CASE
- DISTINCT
- PARALLEL
- FLATTEN
- Nested FOREACH
- JOIN
- COGROUP

- ✓ Describe User-Defined Functions (UDFs)

## Advanced Pig Operators

More advanced features of Pig include sorting, parallelization, joins, and user-defined functions.

### ORDER BY



*The ORDER Operator*

The ORDER BY command allows you to sort the data in a relation:

```
salaries = LOAD 'salaries.txt' USING PigStorage(',') AS  
(gender:chararray,age:int,salary:double,zip:chararray);  
byage = ORDER salaries BY age ASC;
```

The records in the byage relation will be sorted by age:

```
(M,19,0.0,95050)
(F,22,90000.0,95102)
(M,23,89000.0,95105)
(M,23,64000.0,94041)
(F,30,10000.0,95101)
(M,31,95000.0,94041)
```

You can use DESC or ASC in the BY clause. You can also order by multiple fields:

```
agesalary = ORDER salaries BY age ASC, salary ASC;
```

The output is similar to byage, except the salary field is sorted in ascending order. Compare the two outputs of the records with age = 23:

```
(M,19,0.0,95050)
(F,22,90000.0,95102)
(M,23,64000.0,94041)
(M,23,89000.0,95105)
(F,30,10000.0,95101)
(M,31,95000.0,94041)
```

### Note

The resulting output of an ORDER BY relation is a total ordering, which means the data will be sorted across all output files. In other words, part-r-00000 will contain the first set of ordered tuples then part-r-00001 will continue where the first records left off and so on.

### Important

If you define a relation with an ordering then process that relation in another expression, the ordering is no longer guaranteed. For example:

The records in B are no longer guaranteed to be ordered by lastname in descending order.

## CASE

salaries				bonuses	
gender	age	salary	zip	salary	bonus
M	66	41000.0	95103	41000.0	2050.0
M	58	76000.0	95102	76000.0	7600.0
F	40	95000.0	95102	95000.0	9500.0
M	45	20000.0	95105	20000.0	0.0
F	28	55000.0	95103	55000.00	2750.0

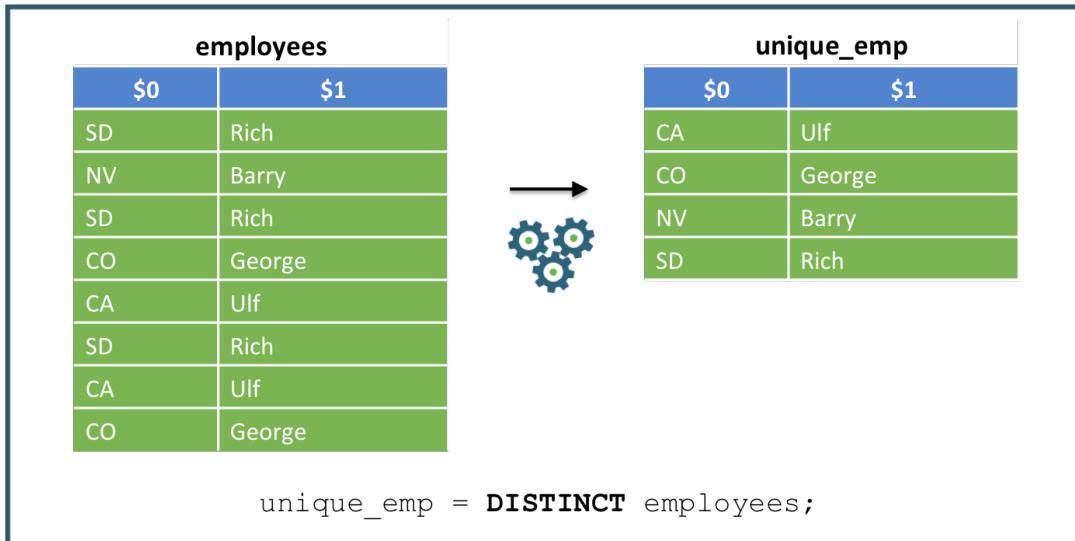
The CASE Operator

Pig has a CASE operator that allows you to make decisions within a FOREACH GENERATE statement. A CASE clause contains an arbitrary number of WHEN...THEN clauses and contains an END statement to denote the end of the CASE.

For example:

```
bonuses = FOREACH salaries GENERATE salary, (
    CASE
        WHEN salary >= 70000.00 THEN salary * 0.10
        WHEN salary < 70000.00 AND salary >= 30000.0
            THEN salary * 0.05
        WHEN salary < 30000.0 THEN 0.0
    END) AS bonus;
```

## DISTINCT



*The DISTINCT Operator*

The **DISTINCT** operator removes duplicate tuples in a relation. The syntax is:

```
DISTINCT alias;
```

Suppose we have the following data:

```
SD  Rich
NV  Barry
SD  Rich
CO  George
CA  Ulf
SD  Rich
CA  Ulf
CO  George
```

Applying **DISTINCT** removes the duplicates:

```
employees = LOAD 'employees.txt';
unique_emp = DISTINCT employees;
```

The tuples in **unique\_emp** are:

```
(CA,Ulf)
(CO,George)
(NV,Barry)
(SD,Rich)
```

## PARALLEL

The PARALLEL operator is a clause used to determine the number of reducers in the subsequent MapReduce job for that particular operation.

The syntax for the PARALLEL clause is:

```
PARALLEL n;
```

In this clause, n is the number of reducers. For example:

```
A = LOAD 'data1';
B = LOAD 'data2';
C = JOIN A by $1, B by $3 PARALLEL 20;
D = ORDER C BY $0 PARALLEL 5;
```

The JOIN operation will use 20 reducers, and the ORDER operation will use five reducers.

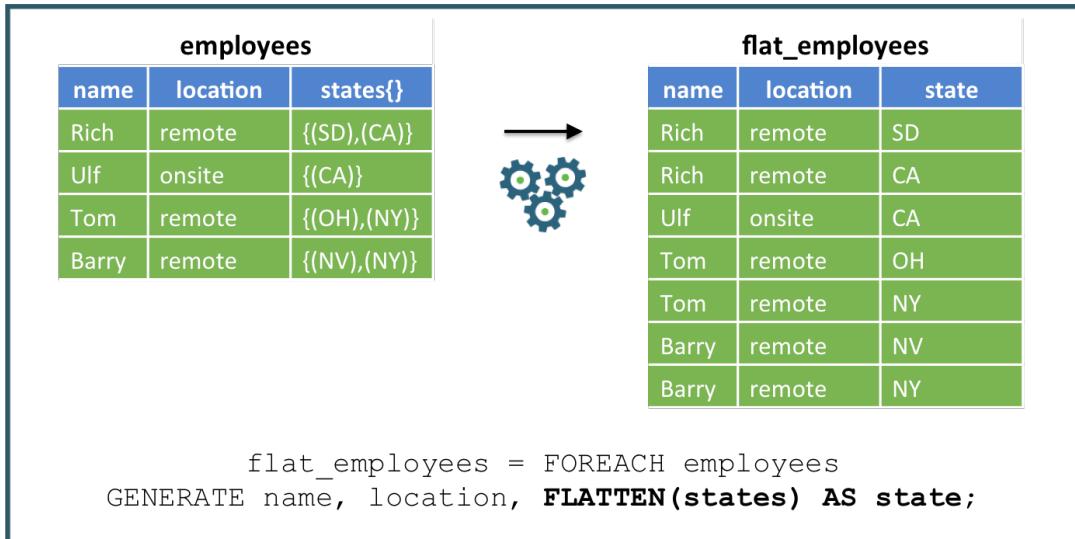
You can use the default\_parallel property to set the number of reducers at the script level. As an example, there will be eight reducers for each reduce task in the following Pig script:

```
SET default_parallel 8;
A = LOAD 'data1';
B = LOAD 'data2';
C = JOIN A by $1, B by $3;
D = ORDER C BY $0;
```

### Note

Some operators have a reduce phase, like GROUP, ORDER BY, DISTINCT, JOIN, LIMIT, and COGROUP. But some Pig operators do not require a reduce phase; these are LOAD, FOREACH, FILTER, and SAMPLE. For those types of operators, it does not make sense to specify a PARALLEL value.

## FLATTEN

*The FLATTEN Operator*

The **FLATTEN** operator removes the nesting of nested tuples and bags. You invoke **FLATTEN** like a function, passing in the tuple or bag that you want to flatten:

```
FLATTEN(relation)
```

The **FLATTEN** operator is best understood by an example. Suppose we have the following data set:

```
Richremote { (SD) , (CA) }
Ulfonsite { (CA) }
Tomremote { (OH) , (NY) }
Barry remote { (NV) , (NY) }
```

The Pig Latin statements below load the data using a schema. Notice the states are in a bag:

```
> employees = LOAD 'locations.txt' AS (
name:chararray,
location:chararray,
states:bag{t:tuple(state:chararray)});
> describe employees;
employees: {name: chararray,location: chararray,states: {t: (state: chararray)}}
```

The output of the employees relation is the following:

```
(Rich,remote,{ (SD) , (CA) })
(Ulf,onsite,{ (CA) })
(Tom,remote,{ (OH) , (NY) })
(Barry,remote,{ (NV) , (NY) })
```

Notice that each record has a bag containing one or more states. If you flatten the states field in the employees relation, each entry in the bag becomes its own full record:

```
flat_employees = FOREACH employees GENERATE name,
    location, FLATTEN(states) AS state;
```

The FLATTEN operator produces a cross-product of every record in the bag, with all of the other expressions in the GENERATE clause. The output of flat\_employees is:

```
(Rich,remote,SD)
(Rich,remote,CA)
(Ulf,onsite,CA)
(Tom,remote,OH)
(Tom,remote,NY)
(Barry,remote,NV)
(Barry,remote,NY)
```

### Note

The example here flattened a bag, but you can also flatten a nested tuple, which simply removes the nesting so that each field in the tuple is at the top level. Suppose a tuple looks like:

```
(1, (2, 3))
```

After this tuple was flattened, it would look like:

```
(1,2,3)
```

## Nested FOREACH

A nested FOREACH (also known as an inner foreach) is a FOREACH statement that contains a nested block of code. The nested block of code has the following criteria:

- Can contain CROSS, DISTINCT, FILTER, FOREACH, LIMIT, and ORDER BY operations
- Must end with a GENERATE statement

The syntax looks like:

```
FOREACH nested_alias {
    alias = nested_operation;
    alias = nested_operation;
    GENERATE expression;
};
```

The following example shows how to count unique entries in a group using a nested FOREACH. The data is daily stock prices from the New York Stock Exchange (NYSE); each row looks like:

```
NYSE,AEA,2010-02-08,4.42,4.42,4.21,4.24,205500,4.24
```

The first field is the exchange name, and the second field is the stock symbol. These are the only two fields we need for our problem:

```
dailyA = LOAD 'NYSE_daily_prices_A.csv' USING
    PigStorage(',') AS (exchange,symbol);
dailyA_grp = GROUP dailyA BY exchange;
unique_symbols = FOREACH dailyA_grp {
    symbols = dailyA.symbol;
    unique_symbol = DISTINCT symbols;
    GENERATE group, COUNT(unique_symbol);
};
```

- The `dailyA_grp` contains all of the stock symbols grouped by exchange
- Within the `FOREACH`, the `symbols` relation takes the bag `dailyA.symbol` and produces a new relation that is a bag with tuples that only have the field `symbol`
- The `unique_symbol` relation is also a list of symbols but with all of the duplicates removed
- The `GENERATE` statement projects the group (which is “NYSE” in this example) and the number of values in `unique_symbol`

The output is:

```
(NYSE, 203)
```

This means there are 203 unique stock symbols in the `NYSE_daily_prices_A.csv` file.

### Note

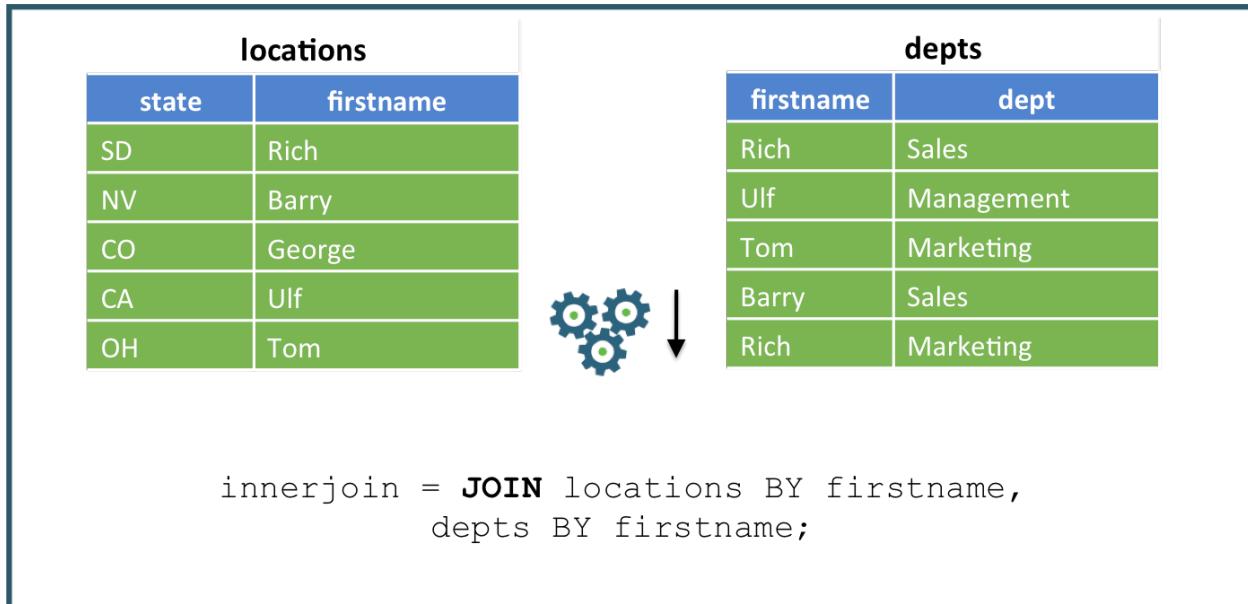
Another common task inside a nested `FOREACH` is `ORDER BY`. For example:

```
dailyA = LOAD 'NYSE_daily_prices_A.csv' USING
    PigStorage(',') AS (exchange,symbol,date);
dailyA_grp = GROUP dailyA BY symbol;
result = FOREACH dailyA_grp {
    sorted = ORDER dailyA BY date ASC;
    first_traded_date = LIMIT sorted 1;
    GENERATE group, first_traded_date;
};
```

## JOIN

Joins are a common occurrence in data processing. The JOIN operation in Pig performs both inner and outer joins of two data sets using keys indicated for each input. If the keys are equal then the two rows are joined.

### *Inner JOIN*



```
grunt> DESCRIBE innerjoin;
innerjoin: {locations::state: chararray, locations::firstname: chararray,
           depts::firstname: chararray, depts::dept: chararray}
```

innerjoin			
locations::state	locations::firstname	depts::firstname	depts::dept
OH	Tom	Tom	Marketing
CA	Ulf	Ulf	Management
SD	Rich	Rich	Sales
SD	Rich	Rich	Marketing
NV	Barry	Barry	Sales

*Performing an Inner Join*

An inner join in Pig looks like the following:

```
alias = JOIN alias1 BY key1, alias2 BY key2;
```

Let's look at an example. Suppose we have the following file containing states and first names:

```
SD  Rich
NV  Barry
CO  George
CA  Ulf
OH  Tom
```

The second data set contains first names and departments:

```
RichSales
UlfManagement
TomMarketing
BarrySales
RichMarketing
```

The following Pig Latin commands perform an inner join on these two data sets using the first name in both data sets as the key:

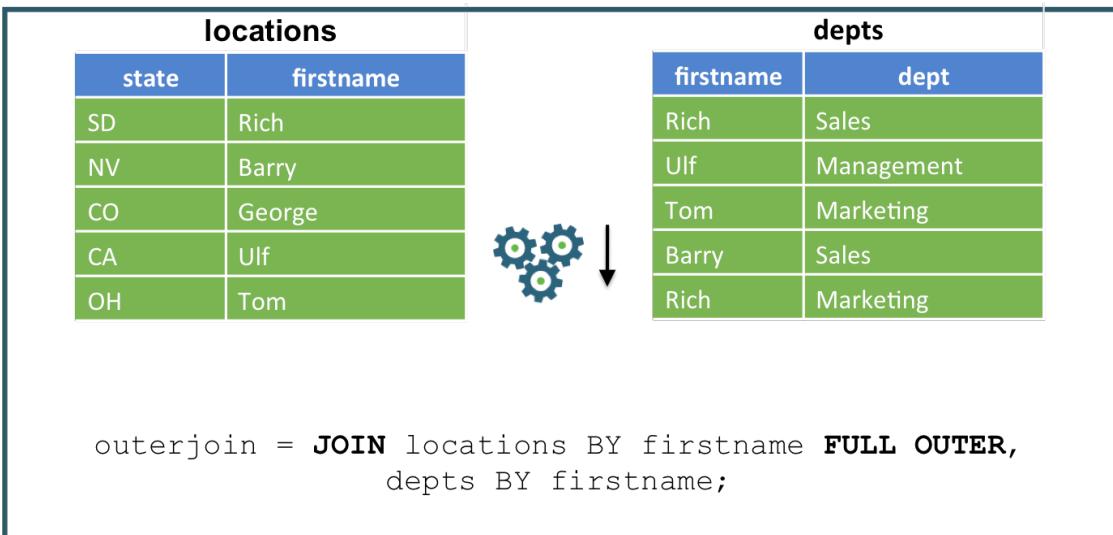
```
locations = LOAD 'pigdemo.txt' AS
    (state:chararray,firstname:chararray);
deps = LOAD 'joindemo.txt' AS
    (firstname:chararray,dept:chararray);
innerjoin = JOIN locations BY firstname, deps BY firstname;

> describe innerjoin;
innerjoin:{ 
    locations::state: chararray,
    locations::firstname: chararray,
    deps::firstname: chararray,
    deps::dept: chararray
}
```

Notice the innerjoin relation contains all fields from both data sets in the join. The :: operator is needed to avoid ambiguity when the two data sets share the same field names (like firstname in this example).

The output of innerjoin is:

```
(OH,Tom,Marketing)
(CA,Ulf,Ulf,Management)
(SD,Rich,Rich,Sales)
(SD,Rich,Rich,Marketing)
(NV,Barry,Barry,Sales)
```

**Outer JOIN**

```
grunt> DESCRIBE outerjoin;
outerjoin: {locations::state: chararray, locations::firstname: chararray,
           depts::firstname: chararray, depts::dept: chararray}
```

outerjoin			
locations::state	locations::firstname	depts::firstname	depts::dept
OH	Tom	Tom	Marketing
CA	Ulf	Ulf	Management
SD	Rich	Rich	Sales
SD	Rich	Rich	Marketing
NV	Barry	Barry	Sales
CO	George		

*Performing an Outer Join*

An outer join in Pig uses the **OUTER** keyword, along with either **LEFT**, **RIGHT**, or **FULL**. The syntax looks like:

```
alias = JOIN alias1 BY key1 [LEFT|RIGHT|FULL] OUTER, alias2 BY key2;
```

The main difference between an inner join and an outer join is that records that do not have a match on the other side are included in the outer join. Pig inserts null values into the missing fields.

Let's look at an example using the same data from the previous example:

```
outerjoin = JOIN locations BY firstname FULL OUTER,
           depts BY firstname;
```

In this case, no records on either side will be omitted. The output looks like:

```
(OH, Tom, Tom, Marketing)
(OH, Tom, Tom, Marketing)
(CA, Ulf, Ulf, Management)
(SD, Rich, Rich, Sales)
(SD, Rich, Rich, Marketing)
(NV, Barry, Barry, Sales)
(CO, George,,)
```

If you perform a LEFT join, you get all records from the left data set, but non-matching records in the right data set are omitted:

```
leftjoin = JOIN locations BY firstname LEFT OUTER,
           dept BY firstname;
```

In our simple example, the result of leftjoin is the same as FULL OUTER because our data on the right does not contain any records that are non-matching:

```
(OH, Tom, Tom, Marketing)
(CA, Ulf, Ulf, Management)
(SD, Rich, Rich, Sales)
(SD, Rich, Rich, Marketing)
(NV, Barry, Barry, Sales)
(CO, George,,)
```

### *Replicated JOIN*

A replicated join is useful when one of the data sets in the join is small enough to fit into memory. This results in a map-side join, saving an enormous amount of network traffic during the shuffle/sort phase of the resulting MapReduce job.

To take advantage of a replicated join, list the smaller data set last in the BY clause and follow it with a USING ‘replicated’ statement. For example:

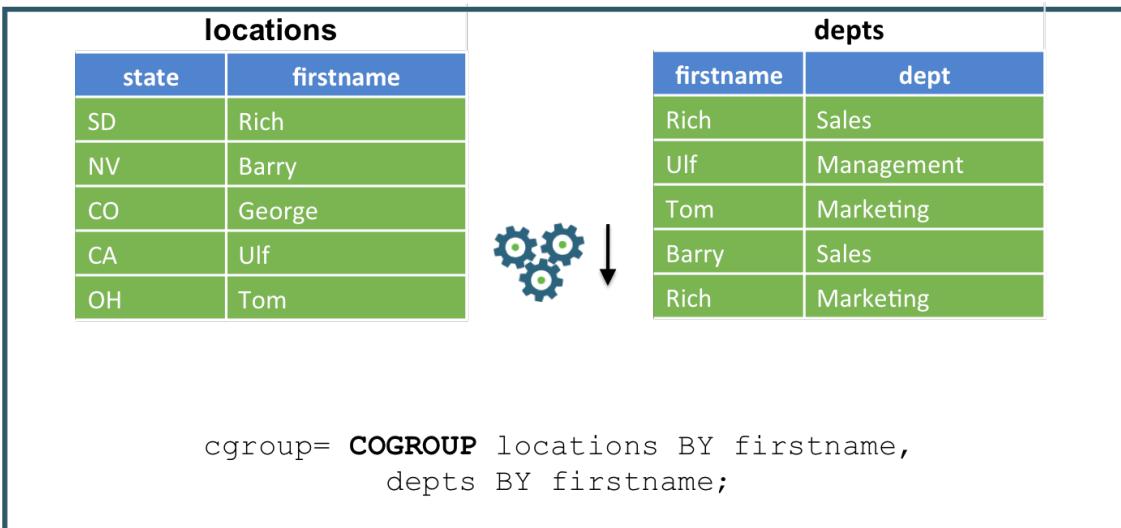
```
replicatedjoin = JOIN locations BY firstname,
                  dept BY firstname USING 'replicated';
```

The departments data set will be distributed across all map tasks (using a feature of MapReduce called a LocalResource), and the join will occur in the map side instead of on the reduce side.

### **Best Practice**

Use replicated joins whenever you can. The increase in performance is noticeable. Just be careful: if the data set does not fit in the memory, the underlying MapReduce will generate an error and fail.

## COGROUP



```
grunt> DESCRIBE cgroup;
cgroup: {group: chararray, locations: {(state: chararray, firstname: chararray)},
         depts: {(firstname: chararray, dept: chararray)}}
```

cgroup		
group	locations	depts
Tom	{{(OH,Tom)}}	{{(Tom,Marketing)}}
Ulf	{{(CA,Ulf)}}	{{(Ulf,Management)}}
Rich	{{(SD,Rich)}}	{{(Rich,Sales),(Rich,Marketing)}}
Barry	{{(NV,Barry)}}	{{(Barry,Sales)}}
George	{{(CO,George)}}	{}

*The COGROUP Operator*

The COGROUP operator is actually identical to the GROUP operator, except we use COGROUP when grouping together more than one relation. For each input, the result of a COGROUP is a record with a key and one bag. You can think of a COGROUP as the first half of a JOIN: the keys are collected, but the cross-product is not performed.

Let's look at an example using the locations and departments data:

```
> cgroup = COGROUPE locations BY firstname,
      departments BY firstname;
> DESCRIBE cgroup;
cgroup: {group: chararray,
locations: {
    (state: chararray,
     firstname: chararray)
},
departments: {
    (firstname: chararray,
     dept: chararray) }
}
```

Notice the schema of the cgroup relation consists of a key followed by a bag for each data set. The output of cgroup is:

```
(Tom, { (OH, Tom) }, { (Tom, Marketing) })
(Ulf, { (CA, Ulf) }, { (Ulf, Management) })
(Rich, { (SD, Rich) }, { (Rich, Sales), (Rich, Marketing) })
(Barry, { (NV, Barry) }, { (Barry, Sales) })
(George, { (CO, George) }, {})
```

You could use the cgroup relation to count the number of records that would occur in the join's result:

```
counters = FOREACH cgroup GENERATE group, COUNT(locations),
           COUNT(departments);
```

The first number is the inner join count, and the second number is the outer join count:

```
(Tom,1,1)
(Ulf,1,1)
(Rich,1,2)
(Barry,1,1)
(George,1,0)
```

### Note

The only difference between GROUP and COGROUP is the readability. If you see GROUP, that implies the grouping of a single relation. If you see COGROUP, that implies the grouping of two or more relations.

## Parameter Substitution

Pig provides a parameter substitution feature that allows your Pig scripts to refer to values that can be defined at runtime, either from the command line or in a properties file. A parameter is a value that starts with a dollar sign (\$).

For example, \$INPUTFILE is a parameter in the following LOAD statement:

```
stocks = load '$INPUTFILE' USING PigStorage(',') ;
```

When you execute the script, specify a value for \$INPUTFILE using the -p switch:

```
> pig -p INPUTFILE=NYSE_daily_prices_A.csv myscript.pig
```

Use the -param\_file switch if your properties are stored in a text file:

```
> pig -param_file stock.params myscript.pig
```

The text file stock.params looks like this:

```
INPUTFILE=NYSE_daily_prices_A.csv
```

## User-Defined Functions

The Pig API has a large collection of built-in functions for performing common tasks and computations. However, some Pig scripts may require User-Defined Functions (UDFs) to complete their tasks. Pig UDFs can be written in six languages:

- Java
- Jython
- Python
- JRuby
- JavaScript
- Groovy

You write a UDF in Java following these steps:

- 1 ) Write a Java class that extends EvalFunc.
- 2 ) Deploy the class in a JAR file.
- 3 ) Register the JAR file in the Pig script using the REGISTER command.
- 4 ) Optionally define an alias for the UDF using the DEFINE command.

### Reference

The Pig API Javadocs are at: <http://pig.apache.org/docs/r0.14.0/api/>

## UDF Example

Let's take a look at an example. The following UDF adds a comma between two input strings:

```
package com.hortonworks.udfs;

public class CONCAT_COMMA extends EvalFunc<String> {

    @Override
    public String exec(Tuple input) throws IOException {
        String first = input.get(0).toString().trim();
        String second = input.get(1).toString().trim();

        return first + ", " + second;
    }
}
```

- The `CONCAT_COMMA` class extends `EvalFunc`
- The generic of `EvalFunc` represents the data type of the return value. Notice the `exec` method returns a `String`
- The `exec` method is called when the UDF is invoked from the Pig script
- The input parameter is a `Tuple` instance, which allows for an arbitrary number of arguments.
- The `get` method of `Tuple` is used to retrieve the arguments passed in

## Invoking a UDF

Before you can invoke a UDF, the function needs to be registered by your Pig script so that the Pig compiler knows where to find the definition of the UDF. Use the `REGISTER` command to register a JAR:

```
register my.jar;
```

You can specify a relative path or a full path to the JAR file. Once the JAR is registered, call the UDF using its fully qualified class name:

```
x = FOREACH logevents
    GENERATE com.hortonworks.udfs.CONCAT_COMMA(level, code);
```

As an option, you can use the `DEFINE` command to define an alias that simplifies the syntax for invoking the UDF:

```
DEFINE CONCAT_COMMA com.hortonworks.udfs.CONCAT_COMMA();
```

Now you can invoke the UDF using the alias:

```
x = FOREACH logevents GENERATE CONCAT_COMMA(level, code);
```

## Optimizing Pig Scripts

Here are a few best practices that can make the difference in the performance of Pig scripts:

### **Filter early and often**

Getting rid of data as quickly as possible will improve the performance by reducing the amount of data that gets shuffled and sorted across the network

### **Project early and often**

Use a FOREACH to remove unwanted or unused fields in your records as soon as possible

### **Drop nulls before a join**

Filter out null records before the JOIN. The gain can be significant, even if you have a small percentage of null values

### **Use replicated joins whenever possible**

A map-side join is always much more efficient than a reduce-side

### **Optimize regular join ordering**

Make sure that the table with the largest number of tuples per key is the last table in your query

### **Use PARALLEL**

Know your cluster. Setting this value too high can actually slow down the job, and setting it too low is not a good use of your cluster's resources

### **Use compression**

Enable the compression of the temporary data files used between map/reduce tasks and jobs by setting mapreduce.map.output.compress to true and specifying a compression codec with mapreduce.map.output.compress.codec. Enable compression of the output files between MapReduce jobs within a Pig processing pipeline by setting the pig.tmpfilecompression and pig.tmpfilecompression.codec properties

### **Choose the correct data types**

If you are treating a field as a specific data type, define the type in the LOAD statement with a schema. This will avoid unnecessary data-type conversions later

### **Tip**

When you start Pig, a special file named .pigbootup is searched for in the user's home folder and executed. The .pigbootup file is a great place to configure properties, register JAR files, define UDFs, and perform any other task that can be applied globally to all of your Pig scripts.

## The DataFu Library

The DataFu library is an open-source library of Pig UDFs for performing data analysis on Hadoop. DataFu contains UDFs for:

- Bag operations, like append and concatenate
- Set operations, like union and intersect
- Running PageRank on a collection of graphs
- Statistical computations, like quantiles and variance
- Sessionization functions for working with page views

To use the functions in the DataFu library, you need to register the DataFu JAR file, just like you would with any other Pig UDF library:

```
register /usr/hdp/current/pig-client/lib/datafu.jar;
```

### *Quantiles*

A quantile is a set of points from the cumulative distribution function of a random variable, taken at regular intervals. The number of points, n, is the name of the quantile. For example: If n = 4, you have a four-quantile (commonly called a quartile). If n = 5, you have a five-quantile, and so on.

The datafu library has a quantile UDF named datafu.pig.stats.Quantile that computes a quantile based on provided intervals and passed in to the UDF's constructor. For example, an evenly distributed five-quantile function would be defined as:

```
define Quintile datafu.pig.stats.Quantile('0.0','0.20',
    '0.40','0.60','0.80','1.0');
```

You can also instantiate a Quantile by passing in the number of evenly-spaced ranges. For example, the above Quintile could also be defined as:

```
define Quintile datafu.pig.stats.Quantile('6');
```

Quintiles are what five-quantiles are called, but we could have used any alias. Invoking this UDF requires passing in a sorted bag. This is typically accomplished using a nested FOREACH.

Here is what the entire Pig script might look like for computing the quintiles of a collection of high temperatures gathered at various weather stations:

```
register /usr/hdp/current/pig-client/lib/datafu.jar;

define Quintile datafu.pig.stats.Quintile('0.0','0.20',
    '0.40','0.60','0.80','1.0');

temperatures = LOAD 'data.txt' AS (
    location:chararray,
    hightemp:double,
    lowtemp:double
);

temps_filter = FILTER temperatures BY hightemp is not null;
temps_group = GROUP temps_filter BY location;

quintiles = FOREACH temps_group {
    sorted = ORDER temps_filter BY hightemp;
    GENERATE group AS location,
        Quintile(sorted.hightemp) AS quant;
}

dump quintiles;
```

The output for each location is going to be six values, which define five equally numerous subsets of the high temperatures:

```
(Toronto, (-7.22, -3.48, 13.6, 16.05, 19.49, 24.5))
(Moscow, (-9.0, -2.04, 5.5, 18.975, 21.205, 24.98))
(NorthPole, (-20.5, -14.6, -8.76, -2.57, 1.475, 2.445, 3.61))
(Houston, (40.9, 51.12, 69.41, 82.75, 94.55, 105.87))
(IntlFalls, (-14.41, -4.25, -1.15, 12.15, 17.6, 21.73))
```

For example, in Toronto you have an equal number of days where the high temperature was between -7.22 and -3.48 degrees Celsius, between -3.48 and 13.6 degrees Celsius, between 13.6 and 16.05 degrees Celsius, and so on.

## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) If a relation is sorted using ORDER BY and the resulting MapReduce job runs with three reducers, how is the output actually sorted?

Suppose the prices.csv file looks like:

And assume we have the following relation defined:

Explain what each of the following Pig commands or relations do:

2 ) F = foreach prices generate  
(CASE  
WHEN volume > 3000 THEN volume  
WHEN volume <= 3000 THEN -1  
END) AS high\_volume;

3 ) G = distinct prices;

4 ) H = GROUP prices BY symbol;  
I = foreach H {  
J = filter prices by volume > 3000;  
GENERATE group, SUM(J.price);  
};

5 ) What is the benefit of the using ‘replicated’ clause in a Pig join?

6 ) Why is filtering and projecting a relation early a performance benefit in Pig?

## Answers

- 1 ) If a relation is sorted using ORDER BY and the resulting MapReduce job runs with three reducers, how is the output actually sorted?

**Answer:** The ORDER BY command generates a total ordering, meaning that the records will be sorted across all three reducers, with the output of reducer 1 containing the first set of sorted records, reducer 2 containing the second set, and so on.

Suppose the prices.csv file looks like, and assume we have the following relation defined. Explain what each of the following Pig commands or relations do:

- 2 ) F = foreach prices generate  
 (CASE  
 WHEN volume > 3000 THEN volume  
 WHEN volume <= 3000 THEN -1  
 END) AS high\_volume;

**Answer:** The output of F looks like:

```
(-1)
(400000)
(-1)
(3800)
(-1)
(-1)
```

- 3 ) G = distinct prices;

**Answer:** The DISTINCT operator removes duplicate records, but the prices relation does not contain any duplicates, so in this example the G relation is identical to the prices relation.

- 4 ) H = GROUP prices BY symbol;  
 I = foreach H {  
 J = filter prices by volume > 3000;  
 GENERATE group, SUM(J.price);  
 };

**Answer:** The output of I is (XFR, 45.6), which is the sum of the prices fields for each record where the volume is greater than 3,000.

- 5 ) What is the benefit of the using ‘replicated’ clause in a Pig join?

**Answer:** The result is a map-side join, which greatly improves the resulting join operation in MapReduce by limiting network traffic in the shuffle/sort phase to only records that will appear in the result

- 6 ) Why is filtering and projecting a relation early a performance benefit in Pig?

**Answer:** Filtering limits the number of records, and projecting limits the size of the records, which greatly improves both network traffic and processing time of the resulting MapReduce job.

# Hive Programming

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe Hive
- ✓ Define Hive Tables
- ✓ Perform Hive Queries
- ✓ Describe Hive Partitions
- ✓ Sort Hive Data
- ✓ Use Hive Join Strategies

## Apache Hive

Apache Hive, <http://hive.apache.org/>, is a data warehouse system for Hadoop. Hive is not a relational database; it only maintains metadata information about your big data stored on HDFS. Hive allows you to treat your big data as tables and perform SQL-like operations on the data using a scripting language called HiveQL.

- Hive is not a database, but it uses a database (called the metastore) to store the tables that you define. Hive uses Derby by default
- A Hive table consists of a schema stored in the metastore and data stored on HDFS
- Hive converts HiveQL commands into MapReduce or Tez jobs (similar to how Pig Latin scripts execute with Pig)
- One of the key benefits of HiveQL is its similarity to SQL. Data analysts familiar with SQL can run MapReduce jobs by writing SQL-like queries, something they are already comfortable doing
- You can easily perform ad hoc custom queries on HDFS using Hive

Pig and Hive have quite a few similarities, so you might be wondering which framework to choose for your particular application. For most use cases:

- Pig is a good choice for ETL jobs, where unstructured data is reformatted so that it is easier to define a structure to it
- Hive is a good choice when you want to query data that has a certain known structure to it

In other words, you will likely benefit from using both Pig and Hive. Pig is great for moving data around and restructuring it, while Hive is great for performing analyses on the data.

### Note

Hive does not make any promises regarding performance. The benefit of Hive is its simplicity in being able to define and run a MapReduce or Tez job, but the queries are not meant to execute in real time. Even the simplest of Hive queries can take several minutes to execute (just like any MapReduce job), and large Hive queries can feasibly take hours to run.

## Hive vs. SQL

SQL Datatypes	SQL Semantics
INT	SELECT, LOAD, INSERT from query
TINYINT/SMALLINT/BIGINT	Expressions in WHERE and HAVING
BOOLEAN	GROUP BY, ORDER BY, SORT BY
FLOAT	CLUSTER BY, DISTRIBUTE BY
DOUBLE	Sub-queries in FROM clause
STRING	GROUP BY, ORDER BY
BINARY	ROLLUP and CUBE
TIMESTAMP	UNION
ARRAY, MAP, STRUCT, UNION	LEFT, RIGHT and FULL INNER/OUTER JOIN
DECIMAL	CROSS JOIN, LEFT SEMI JOIN
CHAR	Windowing functions (OVER, RANK, etc.)
VARCHAR	Sub-queries for IN/NOT IN, HAVING
DATE	EXISTS / NOT EXISTS

*Comparing Hive to SQL*

Hive provides basic SQL functionality using Tez/MapReduce to execute queries. Hive supports standard SQL clauses:

```
INSERT INTO
SELECT
FROM ... JOIN ... ON
WHERE
GROUP BY
HAVING
ORDER BY
LIMIT
```

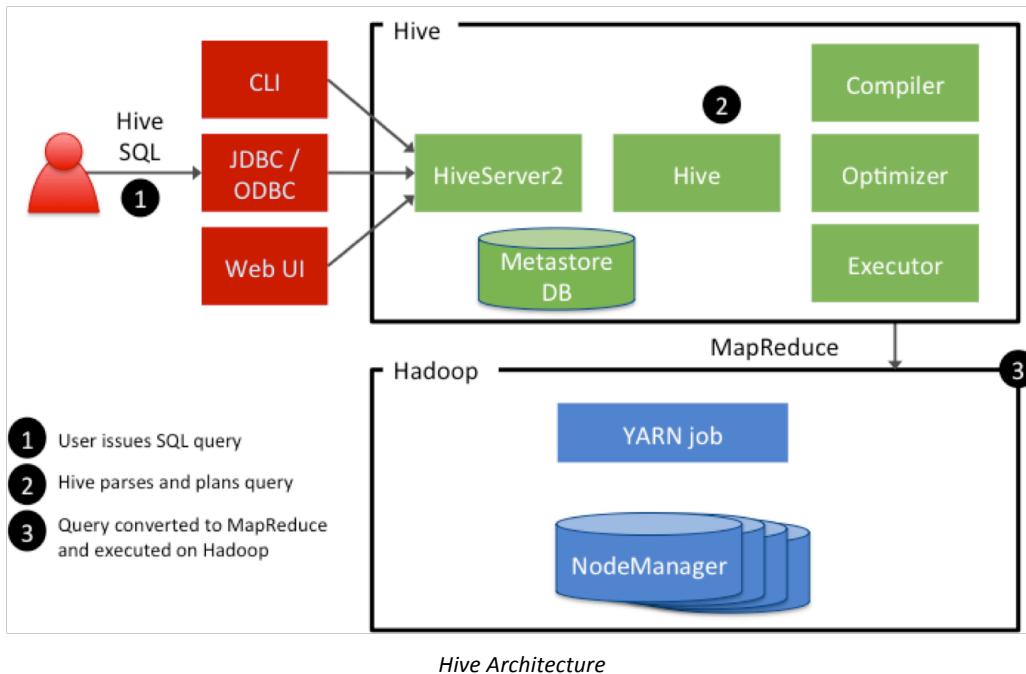
Hive also supports basic DDL commands:

```
CREATE/ALTER/DROP TABLE/DATABASE
```

Some of the limitations of Hive include:

- Index and view support are limited (discussed in detail later)
- The data in Hive is read only (no updates)
- Datatypes do not line up with traditional SQL types
- New partitions can be inserted, but not individual rows

## Hive Architecture



### 1 ) Issuing Commands

Using the Hive CLI, a Web interface, or a Hive JDBC/ODBC client, a Hive query is submitted to the HiveServer

### 2 ) Hive Query Planned

The Hive query is compiled, optimized, and planned as a Tez/MapReduce job

### 3 ) Tez/MapReduce Job Executes

The corresponding Tez or MapReduce job is executed on the Hadoop cluster

## Submitting Hive Queries

Hive queries are written using the HiveQL language, an SQL-like scripting language that simplifies the creation of Tez/MapReduce jobs. With HiveQL, data analysts can focus on answering questions about the data, and let the Hive framework convert the HiveQL into a Tez/MapReduce job.

You have two options for executing HiveQL commands:

### Hive CLI

The Hive command line interface allows you to enter commands directly into the Hive shell or write the commands in a text file and execute the file

### Beeline

A new JDBC client that works with HiveServer2. The Beeline shell works in embedded mode (just like the Hive CLI) and also remote mode, where you connect to a HiveServer2 process using Thrift

The Hive CLI shell is started using the `hive` executable:

```
$ hive
hive>
```

Use the `-f` flag to specify a file that contains a Hive script:

```
$ hive -f myquery.hive
```

Beeline is started using the beeline executable:

```
$ beeline -u url -n username -p password beeline>
```

## Defining Hive Tables

A Hive table allows you to add structure to your otherwise unstructured data in HDFS. Use the `CREATE TABLE` command to define a Hive table, similar to creating a table in SQL.

For example, the following HiveQL creates a new Hive-managed table named `customer`:

```
CREATE TABLE customer (
    customerID INT,
    firstName STRING,
    lastName STRING,
    birthday TIMESTAMP,
) ROW FORMAT DELIMITED FIELDS TERMINATED BY ',';
```

- The `customer` table has four columns
- `ROW FORMAT` is either `DELIMITED` or `SERDE`
- **Hive supports the following data types:** `TINYINT`, `SMALLINT`, `INT`, `BIGINT`, `BOOLEAN`, `FLOAT`, `DOUBLE`, `DECIMAL`, `STRING`, `VARCHAR`, `CHAR`, `BINARY`, `DATE` and `TIMESTAMP`
- **Hive also has four complex data types:** `ARRAY`, `MAP`, `STRUCT`, and `UNIONTYPE`

## Defining an External Table

The following `CREATE` statement creates an external table named `salaries`:

```
CREATE EXTERNAL TABLE salaries (
    gender string,
    age int,
    salary double,
    zip int
)
ROW FORMAT DELIMITED
FIELDS TERMINATED BY ',';
```

An external table is just like a Hive-managed table, except that when the table is dropped, Hive will not delete the underlying `/apps/hive/warehouse/salaries` folder.

## Defining Table LOCATION

Hive does not have to store the underlying data in /apps/hive/warehouse. Instead, the files for a Hive table can be stored in a folder anywhere in HDFS by defining the LOCATION clause. For example:

```
CREATE EXTERNAL TABLE salaries (
    gender string,
    age int,
    salary double,
    zip int
)
ROW FORMAT DELIMITED
FIELDS TERMINATED BY ','
LOCATION '/user/train/salaries/';
```

In the table above, the table data for salaries will be whatever is in the /user/train/salaries directory.

### Important

The sole difference in behavior between external tables and Hive-managed tables is when they are dropped. If you drop a Hive-managed table, then its underlying data is deleted from HDFS. If you drop an external table, then its underlying data remains in HDFS (even if the LOCATION was in /apps/hive/warehouse/).

## Loading Data into a Hive Table

The data for a Hive table resides in HDFS. To associate data with a table, use the LOAD DATA command. The data does not actually get “loaded” into anything, but the data does get moved:

- For Hive-managed tables, the data is moved into a special Hive subfolders of /apps/hive/warehouse
- For external tables, the data is moved to the folder specified by the LOCATION clause in the table’s definition

The LOAD DATA command can load files from the local file system (using the LOCAL qualifier) or files already in HDFS. For example, the following command loads a local file into a table named customers:

```
LOAD DATA LOCAL INPATH '/tmp/customers.csv' OVERWRITE INTO TABLE customers;
```

The OVERWRITE option deletes any existing data in the table and replaces it with the new data. If you want to append data to the table’s existing contents, simply leave off the OVERWRITE keyword.

If the data is already in HDFS, then leave off the LOCAL keyword:

```
LOAD DATA INPATH '/user/train/customers.csv' OVERWRITE INTO TABLE customers;
```

In either case above, the file customers.csv is moved either into HDFS in a subfolder of /apps/hive/warehouse or to the table’s LOCATION folder, and the contents of customers.csv are now associated with the customers table.

You can also insert data into a Hive table that is the result of a query, which is a common technique in Hive. The syntax looks like:

```
INSERT INTO TABLE birthdays
    SELECT firstName, lastName, birthday
    FROM customers
    WHERE birthday IS NOT NULL;
```

The birthdays table will contain all customers whose birthday column is not null.

## Performing Queries

Let's take a look at some sample queries to demonstrate what HiveQL looks like. The following SELECT statement selects all records from the customers table:

```
SELECT * FROM customers;
```

You can use the familiar WHERE clause to specify which rows to select from a table:

```
SELECT customers.*, orders.*
    FROM customers
    JOIN orders ON (
        customers.customerID = orders.customerID
    );
```

To perform an outer join, use the OUTER keyword:

```
SELECT customers.*, orders.*
    FROM customers
    LEFT OUTER JOIN orders
    ON (customers.customerID = orders.customerID);
```

In the SELECT above, a row will be returned for every customer, even those without any orders.

## Hive Partitions

Hive manages the data in its tables using files in HDFS. You can define a table to have a partition, which results in the underlying data being stored in files partitioned by a specified column (or columns) in the table. Partitioning the data can greatly improve the performance of queries because the data is already separated into files based on the column value, which can decrease the number of mappers and greatly decrease the amount of shuffling and sorting of data in the resulting Tez/MapReduce job.

Use the partitioned by clause to define a partition when creating a table:

```
create table employees (id int, name string, salary double)
    partitioned by (dept string);
```

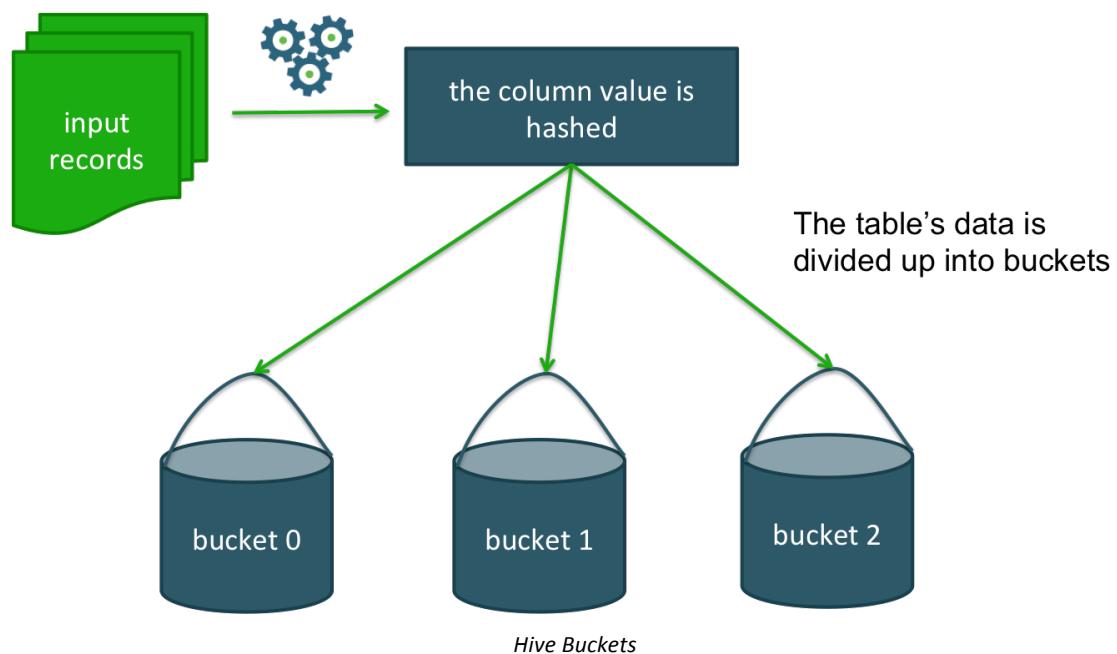
This will result in each department having its own subfolder in the underlying warehouse folder for the table:

```
/apps/hive/warehouse/employees
  /dept=hr/
  /dept=support/
  /dept=engineering/
  /dept=training/
```

### Note

You can partition by multiple columns, which results in subfolders within the subfolders of the table's warehouse directory.

## Hive Buckets



Hive tables can be organized into buckets, which imposes extra structure on the table and the way the underlying files are stored. Bucketing has two key benefits:

### More efficient queries

Especially when performing joins on the same bucketed columns

### More efficient sampling

Because the data is already split up into smaller pieces

Buckets are created using the `clustered by` clause. For example, the following table has 16 buckets that are clustered by the `id` column:

```
create table employees (id int, name string, salary double)
clustered by (id) into 16 buckets;
```

How does Hive determine which bucket to put a record into? If you have n buckets, the buckets are numbered 0 to n-1 and Hive hashes the column value and then uses the modulo operator on the hash value.

## Skewed Tables

In Hive, skew refers to one or more columns in a table that have values that appear very often. If you know a column is going to have heavy skew, you can specify this in the table's schema:

```
CREATE TABLE Customers (
    id int,
    username string,
    zip int
)
SKEWED BY (zip) ON (57701, 57702)
STORED as DIRECTORIES;
```

By specifying the values with heavy skew, Hive will split those out into separate files automatically and take this fact into account during queries so that it can skip whole files if possible.

In the Customers table above, records with a zip of 57701 or 57702 will be stored in separate files because the assumption is that there will be a large number of customers in those two ZIP codes.

## Sorting Data

HiveQL has two sorting clauses:

ORDER BY

**A complete ordering of the data, which is accomplished by using a single reducer**

SORT BY

**Data output is sorted per reducer**

The syntax for the two clauses looks like:

```
select * from table_name [order | sort] by column_name;
```

The syntax for both is identical; only the behavior is different. If there is more than one reducer, sort by provides a partial sorting of the data by reducer but not a total ordering.

Order by implements a total ordering across all reducers. To obtain a parallel total ordering across multiple reducers in Hive, you have to set the following property:

```
hive.optimize.sampling.orderby=true
```

If you do not set the property above then the total ordering is achieved by using one reducer. In that situation, you must add a LIMIT clause to the Hive query to limit the size of the output so that it can be managed by a single reducer.

## Using distribute by

Hive uses the columns in distribute by to distribute the rows among reducers. In other words, all rows with the same distribute by columns will go to the same reducer. For example, suppose you have the following table named salaries with the schema (gender, age, salary, zip):

```
F    66
M    40
F    58
F    68
M    85
...
```

Note that distribute by is typically used in conjunction with an insert statement (or also when using Hadoop streaming with custom mappers and/or reducers). The following command demonstrates distribute by on the age column:

```
set mapreduce.job.reduces=2;
insert overwrite table mytable
  select gender, age, salary from salaries
  distribute by age;
```

Records with the same age will go to the same reducer.

The distribute by does not guarantee any type of clustering of the records. For example, a reducer might get:

```
M, 66, 84000.0
F, 58, 95000.0
M, 40, 76000.0
F, 66, 41000.0
```

The two records with age = 66 are sent to the same reducer, but they are not adjacent. You can use sort by to cluster records with the same distribute by column together:

```
insert overwrite table mytable
  select gender, age, salary from salaries
  distribute by age
  sort by age;
```

The records with the same age will now appear together in the reducer's output:

```
F, 58, 95000.0
M, 66, 84000.0
F, 66, 41000.0
M, 68, 15000.0
F, 68, 60000.0
M, 72, 83000.0
```

### Note

If you use distribute by followed with a sort by on the same column, you can use cluster by and get the same result. For example, the following statement has the same result as the previous Hive statement above:

## Storing Results to a File

The following command outputs the results of a query to a file in HDFS. For example:

```
INSERT OVERWRITE DIRECTORY '/user/train/ca_or_sd/' select name, state from names where state = 'CA' or state = 'SD';
```

You can also output the results of a query to a file on the local file system by adding the LOCAL keyword:

```
INSERT OVERWRITE LOCAL DIRECTORY '/tmp/myresults/' SELECT * FROM bucketnames ORDER BY age;
```

## Specifying MapReduce Properties

Keep in mind that a Hive query is actually a MapReduce job behind the scenes. You can specify some of the properties of that underlying MapReduce job in Hive using the SET command.

You can either set the property in the Hive script:

```
SET mapreduce.job.reduces = 12
```

Or you can set properties at the command line using the `hiveconf` flag:

```
hive -f myscript.hive -hiveconf mapreduce.job.reduces=12
```

You can use `hivevar` for parameter substitution. For example:

```
SELECT * FROM names WHERE age = ${age}
```

Specify `age` using either `SET` or the `hivevar` flag:

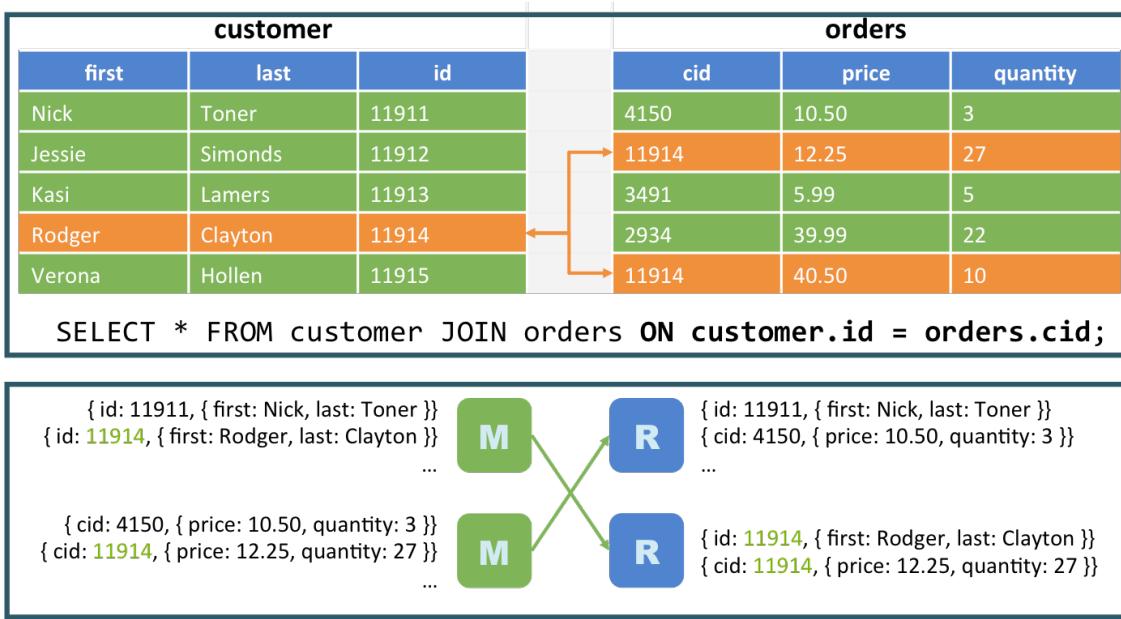
```
hive -f myscript.hive -hivevar age=33
```

## Hive Join Strategies

Some important concepts to understand when performing joins and laying out your Hive data:

- Shuffle joins always work in the sense that if you cannot perform a more efficient type of join, two tables can always be joined using a shuffle join
- A map join is very efficient and ideal if one side of the join is a small enough dataset to fit into memory
- If a map join is not an option, then the next best option is a sort-merge-bucket join, which we will discuss in more detail

## Shuffle Joins



Shuffle Joins

A shuffle join is the default join technique for Hive, and it works with any data sets (no matter how large). Identical keys are shuffled to the same reducer, and the join is performed on the reduce side. This is the most expensive join from a network utilization standpoint because all records from both sides of the join need to be processed by a mapper and then shuffled and sorted, even the records that are not a part of the result set.

## Broadcast Joins

customer			orders		
first	last	id	cid	price	quantity
Nick	Toner	11911	4150	10.50	3
Jessie	Simonds	11912	11914	12.25	27
Kasi	Lamers	11913	3491	5.99	5
Rodger	Clayton	11914	2934	39.99	22
Verona	Hollen	11915	11914	40.50	10

```
SELECT * FROM customer JOIN orders ON customer.id = orders.cid;
```

{ id: 11914, { first: Rodger, last: Clayton } }  
{ cid: 11914, { price: 12.25, quantity: 27 },  
cid: 11914, { price: 12.25, quantity: 27 } }

M

Records are joined during  
the map phase.

## Map (Broadcast) Joins

If one of the datasets is small enough to fit into memory, then it can be distributed (broadcast) to each mapper and perform the join in the map phase. This greatly reduces the number of records being shuffled and sorted because only records that appear in the result set will be passed on to a reducer.

A map join has a special C-style comment syntax for providing a hint to the Hive engine:

```
select /*+ MAPJOIN(states) */ customers.* , states.*  
from customers  
join states on (customers.state = states.state);
```

### Important

In HDP 2.x, Hive joins are automatically optimized without the need for providing hints.

## SMB Joins

customer			orders		
first	last	id	cid	price	quantity
Nick	Toner	11911	4150	10.50	3
Jessie	Simonds	11912	11914	12.25	27
Kasi	Lamers	11913	11914	40.50	10
Rodger	Clayton	11914	12337	39.99	22
Verona	Hollen	11915	15912	40.50	10

```
SELECT * FROM customer join orders ON customer.id = orders.cid;
```

Distribute and sort by the most common join key.

```
CREATE TABLE orders (cid int, price float, quantity int)
CLUSTERED BY(cid) SORTED BY(cid) INTO 32 BUCKETS;
```

```
CREATE TABLE customer (id int, first string, last string)
CLUSTERED BY(id) SORTED BY(cid) INTO 32 BUCKETS;
```

### Sort-Merge-Bucket (SMB) Joins

If you have two datasets that are too large for a map-side join, an efficient technique for joining them is to sort the two datasets into buckets. The trick is to cluster and sort by the same join key.

This provides two major optimization benefits:

- Sorting by the join key makes joins easy. All possible matches reside in the same area on disk
- Hash bucketing a join key ensures all matching values reside on the same node. Equi-joins can then run with no shuffle

For this to work properly, the number of bucket columns has to equal the number of join columns. This means that, in general, you will need to specifically define your Hive tables to fit the requirements of a sort-merge-bucket join, which implies you are aware at design time of the columns that will be most commonly used in join statements.

### SMB Join to SMB Map Join

An SMB join can be converted to an SMB map join. This requires the following configuration settings enabled. (Note that these settings are already set to true in HDP 2.x):

```
hive.auto.convert.sortmerge.join=true;
hive.optimize.bucketmapjoin = true;
hive.optimize.bucketmapjoin.sortedmerge = true;
hive.auto.convert.sortmerge.join.noconditionaltask = true;
```

## Invoking a Hive UDF

Similar to Pig, Hive has the ability to use User-Defined Functions written in Java to perform computations that would otherwise be difficult (or impossible) to perform using the built-in Hive functions and SQL commands.

To invoke a UDF from within a Hive script, you need to:

- 1 ) Register the JAR file that contains the UDF class and
- 2 ) Define an alias for the function using the CREATE TEMPORARY FUNCTION command.

For example, the following Hive commands demonstrate how to invoke the ComputeShipping UDF defined above:

```
ADD JAR /myapp/lib/myhiveudfs.jar;
CREATE TEMPORARY FUNCTION ComputeShipping
    AS 'hiveudfs.ComputeShipping';
FROM orders SELECT address, description, ComputeShipping(zip, weight);
```

## Computing ngrams in Hive

An ngram is a subsequence of text within a large document. The “n” represents the length of the subsequence. The result of an ngram is a frequency distribution

For example, when n is 2 it's called a bigram, and it represents the occurrence of two adjacent terms. A trigram is when n is 3 and represents three adjacent terms, and so on.

Hive contains an ngram function for computing the frequency distribution. For example:

```
select ngrams(sentences(val),2,100) from mytable;
```

The above command computes a bigram of the data in the val column of mytable, returning a frequency distribution of the top 100 results.

Hive also contains a context\_ngram function, which computes ngrams based on a context string that appears around the subsequence of text. For example:

```
select context_ngrams(sentences(val),
    array("error","code",null), 100)
from mytable;
```

The above command generates a frequency distribution of the top 100 words that follow the expression “error code.”

## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) A Hive table consists of a schema stored in the Hive and data stored in (?)and data stored in (?).
- 2 ) True or False: The Hive metastore requires an underlying SQL database.
- 3 ) What happens to the underlying data of a Hive-managed table when the table is dropped?
- 4 ) True or False: A Hive external table must define a LOCATION.
- 5 ) List three different ways data can be loaded into a Hive table:
- 6 ) When would you use a skewed table?

- 7 ) Suppose you have the following table definition:

```
create table movies (title string, rating string,  
length double) partitioned by (genre string);
```

What will the folder structure in HDFS look like for the movies table?

- 8 ) Explain the output of the following query:

```
select * from movies order by title;
```

- 9 ) What does the following Hive query compute?

```
from mytable  
select explode(ngrams(sentences(val),3,100)) as myresult;
```

- 10 )What does the following Hive query compute?

```
from mytable  
select explode(context_ngrams(sentences(val),  
array("I","liked",null),10)) as myresult;
```

## Answers

- 1 ) A Hive table consists of a schema stored in the Hive and data stored in (?)and data stored in (?).

**Answer:** metastore and HDFS

- 2 ) True or False: The Hive metastore requires an underlying SQL database.

**Answer:** True. Hive uses an in-memory database called Derby by default, but you can configure Hive to use any SQL database.

- 3 ) What happens to the underlying data of a Hive-managed table when the table is dropped?

**Answer:** The data and folders are deleted from HDFS.

- 4 ) True or False: A Hive external table must define a LOCATION.

**Answer:** False. An external table can use an external location, but it can also use the Hive warehouse folder.

- 5 ) List three different ways data can be loaded into a Hive table:

**Answer:** There are several ways to load data into a Hive table, including manually copying files into the table's folder in HDFS; using the LOAD DATA command; and inserting data as the result of a query.

- 6 ) When would you use a skewed table?

**Answer:** Skewed tables make sense when your data is naturally skewed, where a small number of columns contain a disproportionate amount of records.

- 7 ) Suppose you have the following table definition:

```
create table movies (title string, rating string,  
length double) partitioned by (genre string);
```

What will the folder structure in HDFS look like for the movies table?

**Answer:** Within /apps/hive/warehouse/movies will be subfolders named /genre=value. For example, /genre=scifi, /genre=comedy, /genre=drama, etc.

- 8 ) Explain the output of the following query:

```
select * from movies order by title;
```

**Answer:** The order by clause causes the output to be totally ordered by title across all output files.

9 ) What does the following Hive query compute?

```
from mytable  
select explode(ngrams(sentences(val),3,100)) as myresult;
```

**Answer:** The ngram output from this query is called a trigram, because the result will be sets of three words. The 100 argument specifies you want the top 100 trigrams from this dataset.

10 )What does the following Hive query compute?

```
from mytable  
select explode(context_ngrams(sentences(val),  
array("I","liked",null),10)) as myresult;
```

**Answer:** The output of this query is the top 10 words in the dataset that follow the phrase “I liked.”



# Using HCatalog

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe HCatalog
- ✓ Describe HCatalog's place in the Hadoop ecosystem
- ✓ Define a schema

## HCatalog

This is programmer Bob.  
He uses Pig to crunch data.



Photo Credit: totalAldo via Flickr

This is analyst Joe. He uses Hive to build reports and answer ad-hoc queries.



Hmm, is it done yet? Where is it? What format did you use to store it in today? Is it compressed? And can you help me load it into Hive?

Dude, we need  
HCatalog

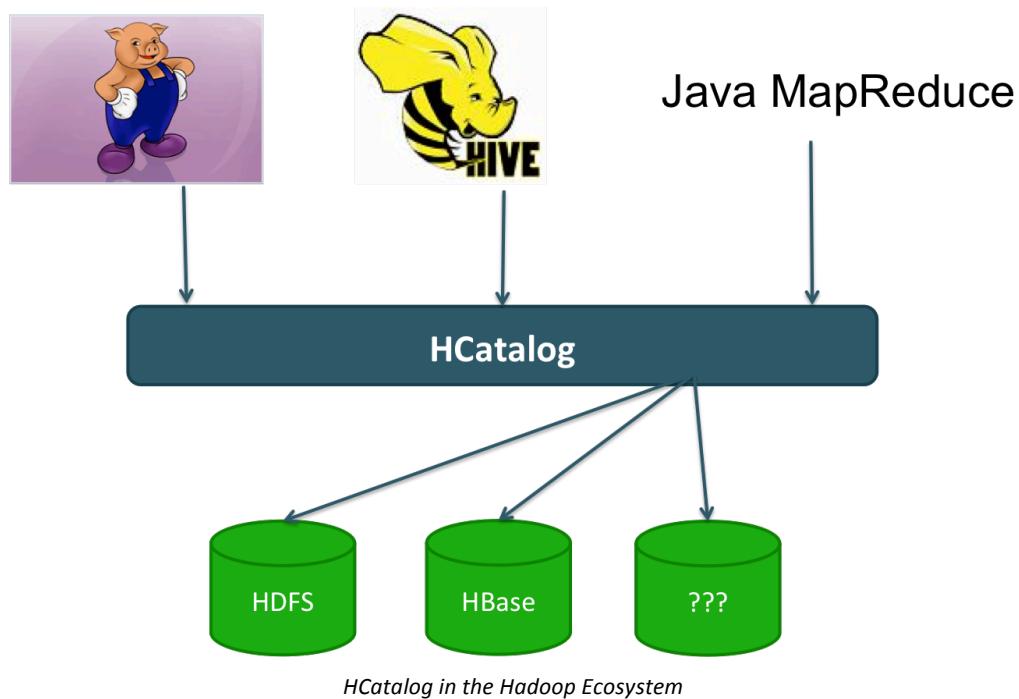
*HCatalog*

One of the most attractive qualities of Hadoop is its flexibility to require schema on read, not on write. HCatalog helps Hadoop deliver on this promise. It is a metadata- and table- management system for Hadoop.

HCatalog has the following features:

- Makes the Hive metastore available to users of other tools on Hadoop
- Provides connectors for MapReduce and Pig so that users of those tools can read data from and write data to Hive's warehouse
- Allows users to share data and metadata across Hive, Pig, and MapReduce
- Provides a relational view through an SQL-like language (HiveQL) to data within Hadoop
- Allows users to write their applications without being concerned about how or where the data is stored
- Insulates users from schema- and storage-format changes

## HCatalog in the Ecosystem



HCatalog provides a consistent data model for the various tools that use Hadoop. It also provides table abstraction, which abstracts some of the details about your data like:

- How the data is stored
- Where the data resides on the filesystem
- What format that data is in
- What the schema is of the data

Having this information available to Hadoop tools in a consistent fashion can simplify the software development process and also bring consistency of algorithms and results across all of the tools and frameworks used in your Hadoop environment.

## Defining a New Schema

HCatalog is an extension of Hive that exposes the Hive metadata to other tools and frameworks. To define a new HCatalog schema, you simply define a table in Hive.

This means you already have HCatalog schemas defined. The benefit of HCatalog is not in the defining of schemas but in its ability to expose the schemas and make them available to frameworks outside of Hive.

## Using HCatLoader with Pig

HCatalog provides two interfaces for use by Pig scripts to read and write data in HCatalog-managed tables:

**HCatLoader**

To read data from HCatalog-managed tables

**HCatStorer**

To write data to HCatalog-managed tables

For example, the following Pig Latin command loads a table named employees managed by HCatalog:

```
emp_relation = LOAD 'employees' USING
org.apache.hive.hcatalog.pig.HCatLoader();
```

Notice that you do not provide a schema when loading a relation with HCatalog. The schema of the relation emp\_relation is whatever the schema is of the employees table.

## Using HCatStorer with Pig

Similarly, if you have a relation that you want to store into an HCatalog-managed table, you use the STORE command along with the USING clause with HCatStorer:

```
STORE customer_projection INTO 'customers' USING
org.apache.hive.hcatalog.pig.HCatStorer();
```

### Important

For the above command to execute successfully, the field names of the customer\_projection relation must match the column names of the customers table.

## The Pig SQL Command

Pig has an SQL command that you can use to run Hive DDL commands. For example, you could create a table from within a Pig script (or the Grunt shell) using the following command:

```
grunt> sql create table movies (
    title string,
    rating string,
    length double)
partitioned by (genre string)
stored as ORC;
```

## Using HCatalog

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## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) Where does HCatalog store its schema information?
- 2 ) List three programming frameworks that can readily access an HCatalog schema:
- 3 ) What Java class does Pig use to load data from an HCatalog table?
- 4 ) True or False: HCatalog is now merged with Hive.

## Answers

- 1 ) Where does HCatalog store its schema information?

**Answer:** In the Hive metastore.

- 2 ) List three programming frameworks that can readily access an HCatalog schema:

**Answer:** Pig, Hive, and Java MapReduce programs can all easily use the schemas shared by HCatalog.

- 3 ) What Java class does Pig use to load data from an HCatalog table?

**Answer:** The HCatLoader class; more specifically, org.apache.hive.hcatalog.pig.HCatLoader.

- 4 ) True or False: HCatalog is now merged with Hive.

**Answer:** True. HCatalog is now a part of Hive.

# Advanced Hive Programming

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ List Hive file formats
- ✓ Describe Views
- ✓ Compute table statistics
- ✓ Describe methods of optimizing Hive performance

## Hive File Formats

Hive does not store data. The data for a table is stored in HDFS in one of the following formats:

Text file

Comma, tab, or other delimited file types

SequenceFile

Serialized key/value pairs that can quickly be deserialized in Hadoop

RCFile

A record columnar file that organizes data by columns (as opposed to the traditional database row format)

ORC File

The optimized row columnar format that improves the efficiency of Hive by a considerable amount (discussed in more detail in the next section)

Use the `STORED AS` clause to specify a file format when you create the table:

```
CREATE TABLE tablename (
...
) STORED AS fileformat;
```

For example, the following table is for data using the `RCFile` format:

```
CREATE TABLE names
  (fname string, lname string)
STORED AS RCFile;
```

## Hive SerDe

A **SerDe** is a combination of a **Serializer** and a **Deserializer** (SerDe).

### Deserializer

Used when querying - takes a string or binary record, and translates it into a Java object that Hive can manipulate.

### Serializer

Used when writing data - takes a Java object that Hive has been working with and transforms it into something that Hive can write to HDFS.

Records can be stored in any custom format you want by writing Java classes, or you can use one of the several built-in SerDes. These include:

AvroSerDe

**For reading and writing files using an Avro schema**

RegexSerDe

**For using a regular expression to deserialize data**

ColumnarSerDe

**For columnar-based storage supported by RCFiles**

OrcSerDe

**For reading and writing to ORC files**

### Note

There are many built-in and third-party SerDes available. Do a search online before attempting to develop a custom SerDe that might already be available.

### ROW FORMAT SERDE Clause

Using a **SerDe** requires the **ROW FORMAT SERDE** clause. For example, the following table is for data stored in the **Avro** format:

```
CREATE TABLE emails (
  from_field string,
  sender string,
  email_body string)
ROW FORMAT SERDE
  'org.apache.hadoop.hive.serde2.avro.AvroSerDe'
STORED AS
  INPUTFORMAT
  'org.apache.hadoop.hive.ql.io.avro.AvroContainerInputFormat' OUTPUTFORMAT
  'org.apache.hadoop.hive.ql.io.avro.AvroContainerOutputFormat' TBLPROPERTIES (
    'avro.schema.url'='hdfs://nn:8020/emailschema.avsc');
```

## Hive ORC Files

The Optimized Row Columnar (ORC) file format, <http://orc.apache.org>, provides a highly efficient way to store Hive data. It was designed to overcome limitations of the other Hive file formats. Using ORC files improves performance when Hive is reading, writing, and processing data.

File formats in Hive are specified at the table level. Use the AS keyword and specify the ORC file format:

```
CREATE TABLE tablename (
...
) AS ORC;
```

You can also modify the file format of an existing table:

```
ALTER TABLE tablename SET FILEFORMAT ORC;
```

And you can specify ORC as the default file format of new tables:

```
SET hive.default.fileformat=Orc
```

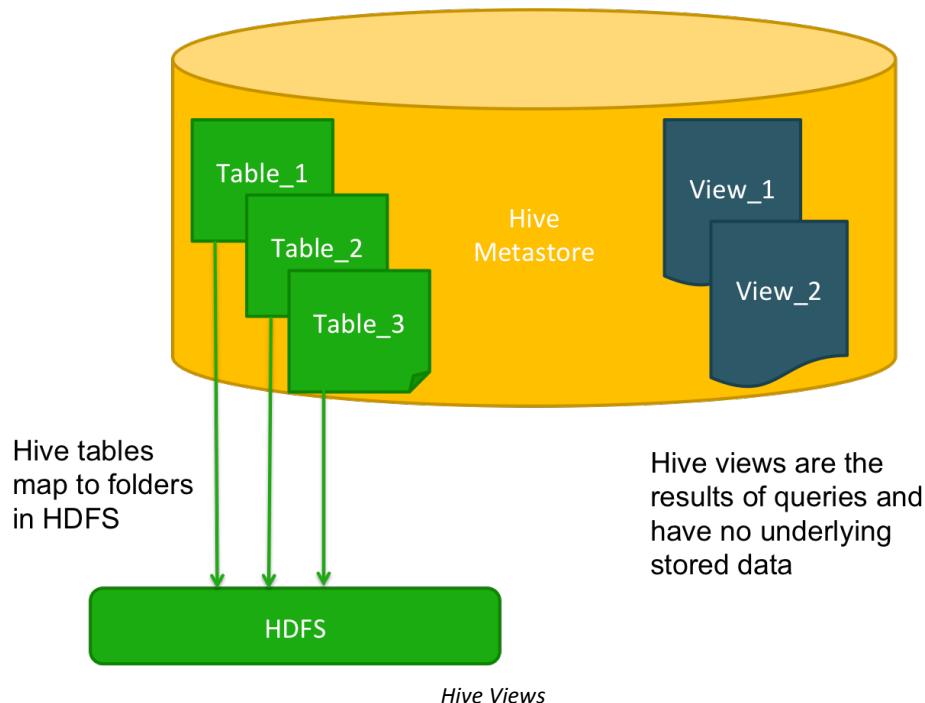
ORC files have three main components:

- Stripe
- Footer
- Postscript

Here are the features of these components:

- An ORC file is broken down into sets of rows called stripes
- The default stripe size is 64 MB in Hive 0.14. Large stripe sizes enable efficient reads of columns
- An ORC file contains a footer that contains the list of stripe locations
- The footer also contains column data like the count, min, max, and sum
- At the end of the file, the postscript holds compression parameters and the size of the compressed footer

## Hive Views



A view in Hive is defined by a **SELECT** statement and allows you to treat the result of the query like a table. The table does not actually exist, and the query does not execute until the statement that refers to the view is executed.

Use cases for using views include:

- Reducing the complexity of a query. For example, a nested **SELECT** statement can be defined separately as a view
- Restricting a user's access to the subset of an actual Hive table by defining a view that contains only the columns and rows that the user needs

### Execution

Depending on the query, a view gets combined (optimized) into the query that is using the view or the view may have to be executed in its own MapReduce job. For example, if the view query contains an **ORDER BY** then it will execute in its own MapReduce job.

Views in Hive are non-materialized, so you can use them without concern of creating more work for the resulting MapReduce job.

## Defining Views

A view is defined using the CREATE VIEW statement. For example, the following Hive statement defines a view named 2010\_visitors:

```
CREATE VIEW 2010_visitors AS
  SELECT fname, lname, time_of_arrival, info_comment
  FROM wh_visits
  WHERE
    cast(substring(time_of_arrival,6,4) AS int) >= 2010
  AND
    cast(substring(time_of_arrival,6,4) AS int) < 2011;
```

2010\_visitors is a view that represents people that visited the White House in the year 2010.

A view is not a table in Hive with actual data, but can be treated like a table. For example, you can run the DESCRIBE command on a view to see its schema:

```
hive> describe 2010_visitors; OK
fname          string  None
lname          string  None
time_of_arrival string  None
info_comment   string  None
```

A view will also show up in your list of tables. Notice the output of the SHOW TABLES command:

```
hive> show tables;
OK
2010_visitors
wh_visits
```

Similar to a table, you can delete a view using the DROP VIEW command:

```
DROP VIEW 2010_visitors;
```

### Note

Views can contain partitions, just like tables. This allows you to define views that behave exactly like your underlying tables, even tables that are partitioned.

## Using Views

You can use a view in a query just like you would use a table. For example, the following query uses the 2010\_visitors view to find visitors to the President:

```
from 2010_visitors
select *
where info_comment like "%CONGRESS%"
order by lname;
```

Notice that you could have performed the above query without using a view. Instead, you could have defined a longer WHERE clause or a nested SELECT statement. However, using a view keeps the SQL easier to read. This is obviously a simple example, but it demonstrates the power and usefulness of views. Hive will determine the best way to convert the above command into one or more MapReduce jobs at runtime .

***TRANSFORM Clause***

You can write your own custom mappers or reducers and use them in Hive using the **TRANSFORM** clause. For example, the following example shows data being processed by a Python script named `splitwords.py` in a **SELECT** clause and then that result being processed by `countwords.py`.

```
add file splitwords.py;
add file countwords.py;

FROM (
  FROM mytable
  SELECT TRANSFORM(keywords) USING 'python splitwords.py'
  AS word, count
  CLUSTER BY word
) wc
INSERT OVERWRITE TABLE word_count
SELECT TRANSFORM (wc.word, wc.count)
USING 'python countwords.py'
AS word, count;
```

By default, columns will be transformed to **STRING** and delimited by a tab before being fed to the user script. The output of the script will be treated as tab-separated **STRING** columns.

You can achieve a similar result using the **MAP** and **REDUCE** clauses:

```
add file splitwords.py;
add file countwords.py;

FROM (
  FROM mytable
  MAP keywords USING 'python splitwords.py'
  AS word, count
  CLUSTER BY word
) wc
INSERT OVERWRITE TABLE word_count
REDUCE wc.word, wc.count USING 'python countwords.py'
AS word, count;
```

**Note**

Using **MAP** and **REDUCE** as an alias to **SELECT TRANSFORM** may not have the exact affect that you desire, since there is no guarantee that your specified script will be executed during a map or reduce phase. The end result of your query will likely be the same, but **MAP** does not force a map phase, and **REDUCE** does not force a reduce phase.

**OVER Clause**

orders			result set	
cid	price	quantity	cid	max(price)
4150	10.50	3	2934	39.99
11914	12.25	27	4150	10.50
4150	5.99	5	11914	40.50
2934	39.99	22		
11914	40.50	10		

SELECT cid, max(price) FROM orders GROUP BY cid;

orders			result set	
cid	price	quantity	cid	max(price)
4150	10.50	3	2934	39.99
11914	12.25	27	4150	10.50
4150	5.99	5	4150	10.50
2934	39.99	22	11914	40.50
11914	40.50	10	11914	40.50

SELECT cid, max(price) OVER (PARTITION BY cid) FROM orders;

*The OVER Clause*

Hive 0.11 introduced windowing capabilities to the Hive QL. Similar to an aggregate function (like `GROUP BY`), a window function performs a calculation across a set of table rows that are somehow related, except that a window function does not cause rows to become grouped into a single output row; the rows retain their separate identities.

This is best demonstrated by the `OVER` clause, as you can see in the result above. The `GROUP BY` statement finds the maximum price of each order, and the results are aggregated into a single row for each unique `cid`.

The `OVER` clause does not aggregate the result but instead maintains each row of data and outputs the maximum price of the each `cid` group.

## Using Windows

orders			result set	
cid	price	quantity	cid	sum(price)
4150	10.50	3	4150	5.99
11914	12.25	27		16.49
4150	5.99	5		36.49
4150	39.99	22		70.49
11914	40.50	10		12.25
4150	20.00	2		52.75

→

```
SELECT cid, sum(price) OVER (PARTITION BY cid ORDER BY price
ROWS BETWEEN 2 PRECEDING AND CURRENT ROW) FROM orders;
```

### *Using Windows*

The OVER clause allows you to define a window over which to perform a specific calculation. For example, the following Hive statement computes the sum of each order, but the sum is not computed over all prices in an order. Instead, the sum is computed over a window that includes the current row and the two preceding rows, as ordered by the price column.

```
SELECT cid, sum(price) OVER (PARTITION BY cid ORDER BY price ROWS BETWEEN 2
PRECEDING AND CURRENT ROW) FROM orders;
```

Study the output carefully and see if you can verify that the result is what you expected based on the query.

The FOLLOWING statement is used to specify rows after the current row:

```
SELECT cid, sum(price) OVER (PARTITION BY cid ORDER BY price ROWS BETWEEN 2
PRECEDING AND 3 FOLLOWING) FROM orders;
```

Use the UNBOUNDED statement to specify all prior or following rows:

```
SELECT cid, sum(price) OVER (PARTITION BY cid ORDER BY price ROWS BETWEEN
UNBOUNDED PRECEDING AND CURRENT ROW) FROM orders;
```

Hive window functions also include the LEAD and LAG functions for specifying the number of rows to lead ahead or lag behind in the window. Their usage is identical to the SQL standard.

## Analytics Functions

orders			result set		
cid	price	quantity	cid	quantity	rank
4150	10.50	3	4150	2	1
11914	12.25	27	4150	3	2
4150	5.99	5	4150	5	3
4150	39.99	22	4150	22	4
11914	40.50	10	11914	10	1
4150	20.00	2	11914	27	2

→

```
SELECT cid, quantity, rank() OVER (PARTITION BY cid
ORDER BY quantity) FROM orders;
```

*Hive Analytic Functions*

Hive 0.11 also added the following SQL standard analytics functions:

### RANK

Returns the rank of each row within the partition of a result set

### DENSE\_RANK

Returns the rank of rows within the partition of a result set without any gaps in the ranking

### PERCENT\_RANK

Calculates the relative rank of a row within a group of rows

### ROW\_NUMBER

Returns the sequential number of a row within a partition of a result set

### CUME\_DIST

Calculates the number of rows with values lower than or equal to the value of r, divided by the number of rows evaluated in the partition for a row r

### NTILE

Distributes the rows in an ordered partition into a specified number of groups. For each row, NTILE returns the number of the group to which the row belongs

## Computing Table Statistics

Hive can store table and partition statistics in its metastore. There are two types of table statistics currently supported by Hive:

### Table and partition statistics

Number of rows, number of files, raw data size, and number of partitions

### Column level Top K statistics

Computed using the Top K algorithm: number of null values, number of true/false values, maximum and minimum values, estimate of number of distinct values, average column length, maximum column length, and height balanced histograms

The **ANALYZE TABLE** command gathers statistics for a table, a partition, and columns and writes them to the Hive metastore. To compute table statistics, the syntax looks like:

```
ANALYZE TABLE tablename COMPUTE STATISTICS;
```

For computing column statistics, use the following syntax:

```
ANALYZE TABLE tablename COMPUTE STATISTICS FOR COLUMNS column_name_1,  
column_name_2,  
...
```

For computing stats on partitions, use the **PARTITION** command:

```
ANALYZE TABLE tablename PARTITION(part1, part2,...) COMPUTE STATISTICS
```

The **ANALYZE** command runs a MapReduce job that processes the entire table. The table and partition stats are outputed to the command window:

```
Table default.customers stats: [num_partitions: 0, num_files: 11, num_rows:  
891048, total_size: 4605775, raw_data_size: 0]
```

You can also view these stats for a table by running the **DESCRIBE** command:

```
DESCRIBE FORMATTED tablename  
DESCRIBE EXTENDED tablename
```

You can also specify one or more partitions to view details for at the partition level:

```
DESCRIBE EXTENDED tablename PARTITION(part1=value1, part2=value2)
```

## Hive Optimization

Helpful design tips:

- Divide data amongst different files that can be pruned out by using partitions, buckets, and skews
- Use the ORC file format
- Sort and Bucket on common join keys
- Use map (broadcast) joins whenever possible
- Increase the replication factor for hot data (which reduces latency)
- Take advantage of:
  - HiveServer2
  - Hive on Tez
  - Cost-based optimization with Calcite
  - Vectorization
- Use multi-table inserts

## Hive Query Tunings

Hive has a lot of parameters that can be set globally in `hive-site.xml` or at the script level using the `set` command. Here are some of the more important parameters to improve the performance of your Hive queries:

`mapreduce.input.fileinputformat.split.maxsize`  
if the max is too small, you will have too many mappers

`mapreduce.input.fileinputformat.split.minsize`  
If the min is too large, you will have too few mappers

`mapreduce.tasks.io.sort.mb`  
Increase this value to avoid disk spills

Always set the following properties:

```
hive.optimize.mapjoin.mapreduce=true; hive.optimize.bucketmapjoin=true;
hive.optimize.bucketmapjoin.sortedmerge=true; hive.auto.convert.join=true;
hive.auto.convert.sortmerge.join=true;
hive.auto.convert.sortmerge.join.noconditionaltask=true;
```

When bucketing data, set the following properties:

```
hive.enforce.bucketing=true;
hive.enforce.sorting=true;
```

## Important

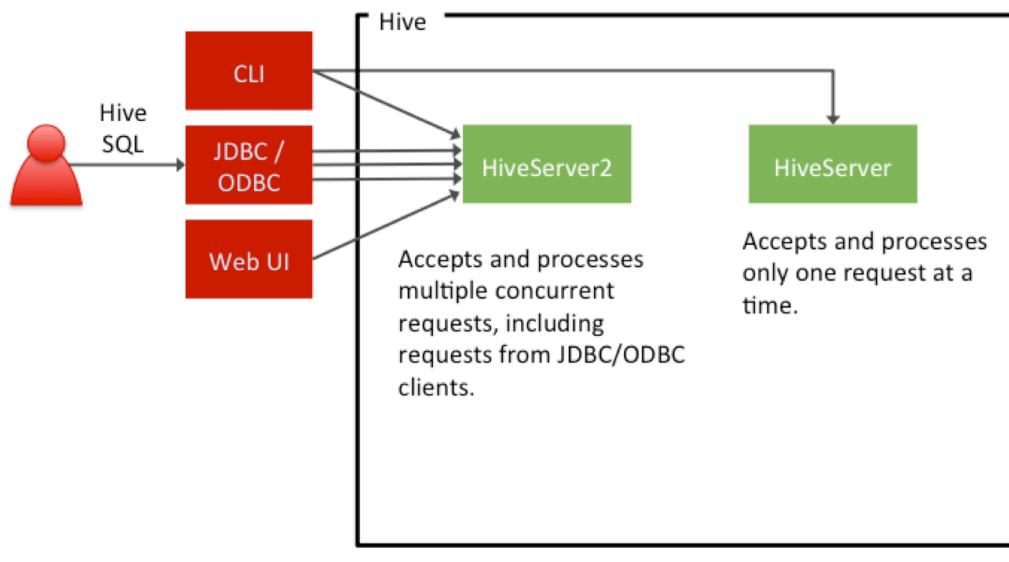
In HDP, these values are set to true by default. You can verify by viewing the properties in `hive-site.xml`. If a property is not set, just use the `set` command in your Hive script. For example:

```
set hive.optimize.mapjoin.mapreduce=true;
```

## The .hiverc File

Hive has a special file called the `.hiverc` file that gets executed each time you launch a Hive shell. This makes the `.hiverc` file a great place for adding custom configuration settings that you use all the time or for loading JAR files that contain frequently used UDFs. The file is saved in the `Hive conf` directory, which is `/etc/hive/conf` for an HDP installation.

## HiveServer2



Hive queries are submitted to a HiveServer process. Older versions of Hive used the `hiveserver` process, which can only process one request at a time. HDP 2.x ships with HiveServer2, a Thrift-based implementation that allows multiple concurrent connections and also supports Kerberos authentication.

- A new HiveServer2 instance is started with the `hiveserver2` binary, or it can be run as a service
- Settings are defined in `hive-site.xml`, except for the bind host and port, which can be defined using the `HIVE_SERVER2_THRIFT_BIND_HOST` and `HIVE_SERVER2_THRIFT_PORT` environment variables. This allows you to run multiple HiveServer2 instances on the same machine

For example:

```
set HIVE_SERVER2_THRIFT_PORT=12345
hive --service hiveserver2
```

The above command runs a `hiveserver2` instance on port 12345.

## Multi-Table/File Insert

```
insert overwrite directory '2014_visitors' select * from wh_visits
where visit_year='2014'
insert overwrite directory 'ca_congress' select * from congress
where state='CA';
```

No semicolon

```
from visitors
INSERT OVERWRITE TABLE gender_sum
SELECT visitors.gender, count_distinct(visitors.userid)
GROUP BY visitors.gender
INSERT OVERWRITE DIRECTORY '/user/tmp/age_sum'
SELECT visitors.age, count_distinct(visitors.userid)
GROUP BY visitors.age;
```

### *Performing a Multi-Table/File Insert*

Hive queries are converted into one or more MapReduce jobs and executed on a Hadoop cluster. Your Hive query might result in a map-only job, in a single mapper and a single reducer, or in multiple mappers and multiple reducers. Each MapReduce job requires a lot of work on the cluster, and some Hive queries can take a very long time (hours) to execute.

One clever trick you can use when querying Big Data using Hive is to perform a multi-table or multi-file insert, where you essentially run multiple queries within a single MapReduce job. The queries do not even need to process the same tables.

Consider the following simple Hive query that selects all White House visitors for the year 2013.

```
insert overwrite directory '2013_visitors' select * from wh_visits where
visit_year='2013' ;
```

Now suppose we have the following query on a different table named congress:

```
insert overwrite directory 'ca_congress' select * from congress where
state='CA' ;
```

As expected, each query above requires a MapReduce job.

Notice in the following Hive query that we perform both selects in the same query:

```
insert overwrite directory '2013_visitors' select * from wh_visits where
visit_year='2013'
insert overwrite directory 'ca_congress' select * from congress where
state='CA' ;
```

Notice the only difference is that the semicolon was removed after the first query, which means the Hive code above is a single statement. The important result is that the above Hive command runs as a single MapReduce job. Two output folders are created (`2013_visitors` and `ca_congress`) and the data from two separate Hive tables are processed, but all in a single MapReduce job.

The following example demonstrates querying from the same table, with one result being output to another table and the other result getting written to HDFS:

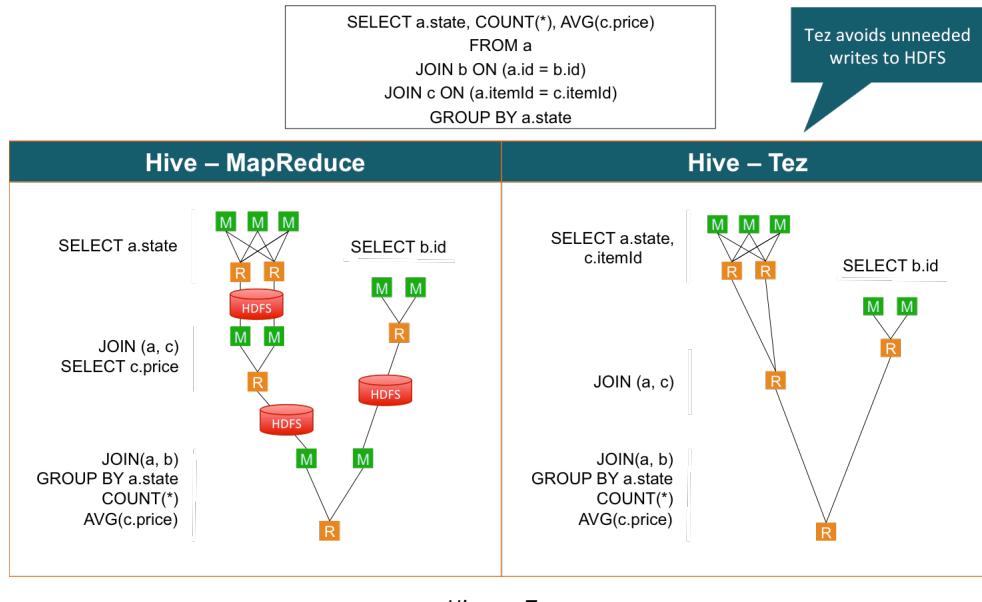
```
from visitors
INSERT OVERWRITE TABLE gender_sum
SELECT visitors.gender, count_distinct(visitors.userid)
GROUP BY visitors.gender

INSERT OVERWRITE DIRECTORY '/user/tmp/age_sum'
SELECT visitors.age, count_distinct(visitors.userid)
GROUP BY visitors.age;
```

### Note

It is important to understand how Hive queries relate to underlying MapReduce jobs. In general, you can gain a lot of performance by running two tasks at the same time instead of running two separate MapReduce jobs.

## Hive on Tez



Tez, <http://tez.apache.org>, provides a general-purpose, highly customizable framework that simplifies data-processing tasks across both small-scale (low-latency) and large-scale (high-throughput) workloads in Hadoop. It generalizes the MapReduce paradigm to a more powerful framework by providing the ability to execute a complex DAG of tasks for a single job.

As you can see in the diagram above, a Hive query without Tez can consist of multiple MapReduce jobs. Tez performs a Hive query in a single job, avoiding the intermediate writes to disk that were a result of the multiple MapReduce jobs.

## Using Tez for Hive Queries

To use Tez for a Hive query, you need to define the following property in your Hive script or in `hive-site.xml`:

```
set hive.execution.engine=tez;
```

Note that this property is set to `mr` by default.

## Cost-based Optimization with Calcite

In the first phase of Calcite and CBO in Hive, Calcite is used to reorder joins and to pick the right join algorithm to reduce query latency. Table cardinality and boundary statistics are used for this cost-based optimization.

Suppose you want to use CBO on a table named `tweets` that has columns named `sender` and `topic` that are commonly used in your Hive JOIN queries.

1 ) First you need to analyze the table:

```
analyze table tweets compute statistics;
```

2 ) Second, compute the column statistics for `sender` and `topic`:

```
analyze table tweets compute statistics
  for columns sender, topic;
```

3 ) Third, set the following properties to enable CBO:

```
set hive.compute.query.using.stats=true;
set hive.cbo.enable=true;
set hive.stats.fetch.column.stats=true;
```

## Vectorization



*Vectorization + ORC files = Hive Query Performance*

Vectorization is a joint effort between Hortonworks and Microsoft. The improvements from vectorization, in addition to the new ORC file format, have helped increase the speed of Hive queries by a magnitude.

Vectorization allows Hive to process a batch of up to 1,024 rows together instead of processing one row at a time. Each batch consists of a column vector, which is usually an array of primitive types. Operations are performed on the entire column vector, improving the instruction pipelines and cache usage.

To take advantage of vectorization, your table needs to be in the ORC format and you need to enable vectorization with the following property:

```
hive.vectorized.execution.enabled=true
```

When vectorization is enabled, Hive examines the query and the data to determine whether vectorization can be supported. If it cannot be supported, Hive will execute the query with vectorization turned off.

## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) What is the benefit of performing two insert queries in the same Hive command?
- 2 ) True or False: Hive views are materialized when they are defined.
- 3 ) Suppose an employees table has 200 rows and its department column has 15 distinct values. How many rows would be in the result set of the following query?
- 4 ) Explain what the following query is computing:
- 5 ) Which Hive file format provides the best performance?
- 6 ) What does DAG stand for?

## Answers

- 1 ) What is the benefit of performing two insert queries in the same Hive command?

**Answer:** Two queries that would normally require two MapReduce jobs can be combined and accomplished in a single MapReduce job.

- 2 ) True or False: Hive views are materialized when they are defined.

**Answer:** False. Hive views are not materialized until they are used in another query.

- 3 ) Suppose an employees table has 200 rows and its department column has 15 distinct values. How many rows would be in the result set of the following query?

**Answer:** 200. The OVER clause causes the group aggregation to not occur, so each employees row will be output. There will only be 15 salary values, the maximum salary in each department.

- 4 ) Explain what the following query is computing:

**Answer:** The result will contain the fname, lname, and the average salary of this employee and the five preceding employees whose salaries are less than or equal to the current employee.

- 5 ) Which Hive file format provides the best performance?

**Answer:** ORC files are a part of the Stinger Initiative and provide the best performance for Hive queries.

- 6 ) What does DAG stand for?

**Answer:** DAG = Directed Acyclic Graph. Hive queries are processed into a series of jobs that look like a DAG.

# Hadoop 2 and YARN

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Define HDFS Federation
- ✓ Explain how NameNode HA is implemented
- ✓ Define YARN

## HDFS Federation

Hadoop 2.x introduced a scaling mechanism for the NameNode referred to as HDFS Federation. As opposed to a single NameNode (which was used in Hadoop 1.x), the new Hadoop infrastructure provides for multiple NameNodes that run independently of each other providing:

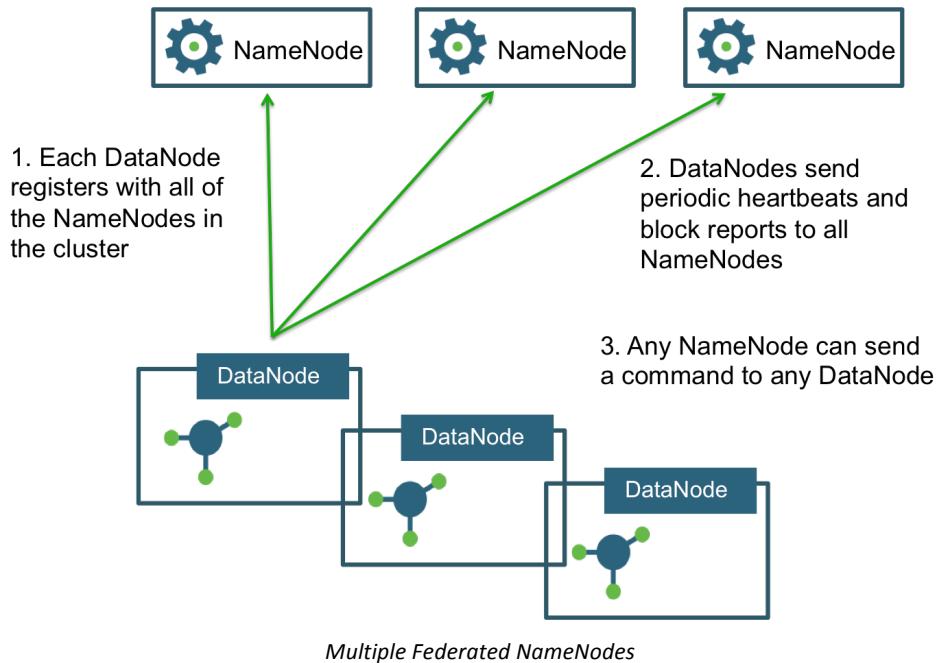
### Scalability

NameNodes can now scale horizontally, allowing you to improve the performance of NameNode tasks by distributing reads and writes across a cluster of NameNodes

### Namespaces

The ability to define multiple Namespaces allows for the organizing and separating of your big data

## Multiple Federated NameNodes



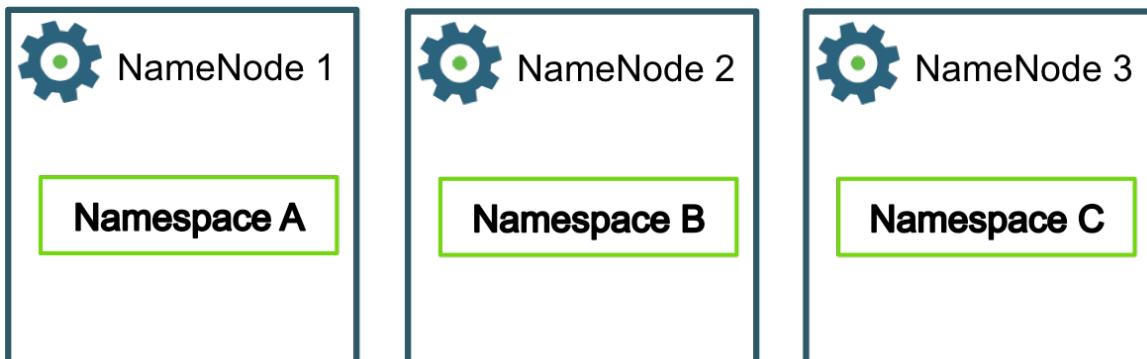
The NameNodes are federated: that is, the NameNodes are independent and don't require coordination with each other.

The DataNodes are used as common storage for blocks by all of the NameNodes.

NameNodes and DataNodes communicate as follows:

- Each DataNode registers with all of the NameNodes in the cluster
- DataNodes send periodic heartbeats and block reports to the NameNodes
- NameNodes send commands to the DataNodes

## Multiple Namespaces



*Multiple Namespaces*

Benefits of multiple Namespaces include:

### Scalability

Having multiple independent Namespaces is what makes scaling possible in Hadoop 2.x

### File Management

You can now associate your big data with a Namespace, making it easier to manage and maintain files

### Note

A NameNode can only define one namespace.

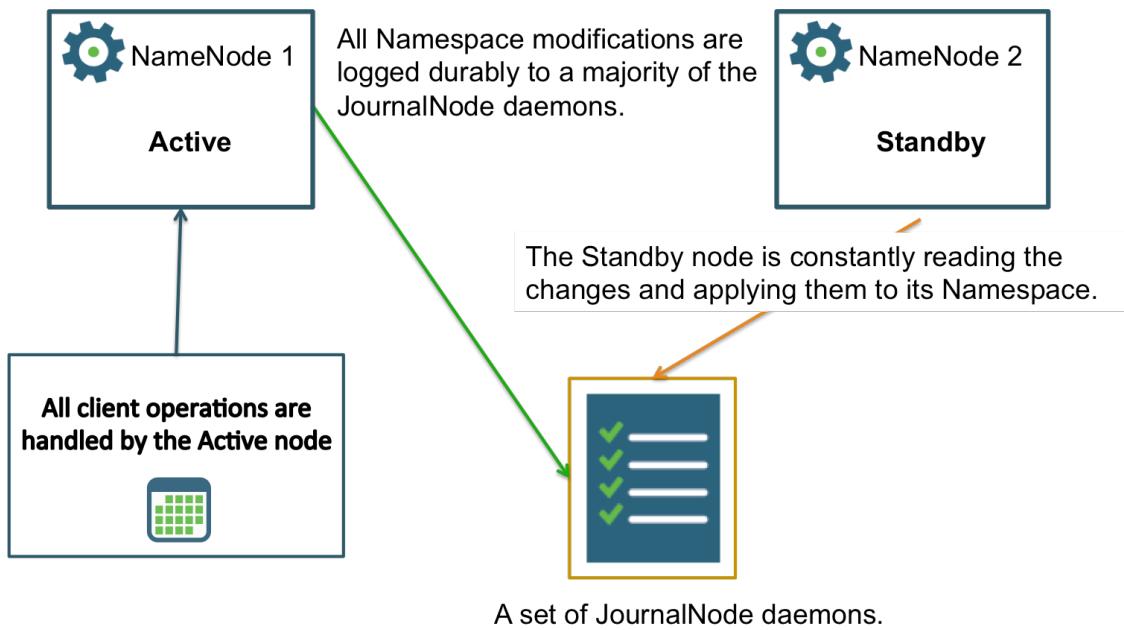
## Implementing NameNode HA

Prior to Hadoop 2.0, the NameNode was a single point of failure in an HDFS cluster. Each cluster had a single NameNode, and if that machine or process became unavailable, the cluster as a whole would be unavailable until the NameNode was either restarted or brought up on a separate machine.

The HDFS High Availability (HA) feature addresses this issue by providing the option of running two redundant NameNodes in the same cluster in an Active/Passive configuration with a hot standby. This allows a fast failover to a new NameNode in the case that a machine crashes or a graceful administrator-initiated failover occurs for the purpose of planned maintenance.

You can now achieve NameNode HA by configuring your cluster to use the Quorum Journal Manager (QJM), which we will discuss next.

## Quorum Journal Manager



*Quorum Journal Manager*

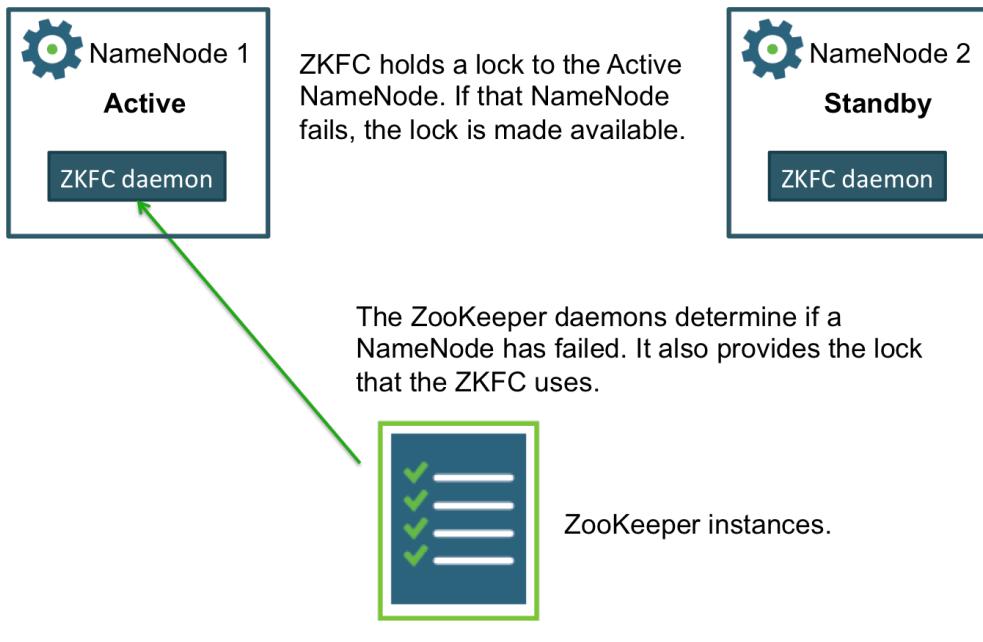
Two separate machines are configured as NameNodes. At any point in time, exactly one of the NameNodes is in an Active state and the other is in a Standby state. The Active NameNode is responsible for all client operations in the cluster, while the Standby is simply acting as a slave, maintaining enough state to provide a fast failover if necessary.

- Both nodes communicate with a group of separate daemons called JournalNodes
- All Namespace modifications are logged durably to a majority of the JournalNode daemons (hence the name Quorum)
- As the Standby Node sees the edits in the JournalNodes, it applies them to its own namespace

## Failover

In the event of a failover, the Standby must read all of the edits from the JournalNodes before promoting itself to the Active state. This ensures that the namespace state is fully synchronized before a failover occurs.

### Automatic Failover



*Configuring Automatic Failover*

Up to this point, you have a Quorum Journal Manager, but note that it requires manual failover. If you want your HA NameNodes to failover automatically, you need to configure ZooKeeper.

More specifically, you need the following within your cluster:

ZooKeeper

An odd number of ZooKeeper daemons that monitor when a NameNode fails

ZKFailoverController (ZKFC)

A new component that is a ZooKeeper client that monitors and manages the state of a NameNode

## YARN

YARN takes Hadoop beyond just MapReduce for data processing. You will still be able to execute MapReduce jobs across your Hadoop cluster, but YARN provides a generic framework that allows for any type of application to execute on the big data across your clusters.

### Open-source YARN Use Cases

#### Tez

Improves the execution of MapReduce jobs

#### Slider

Deploys existing frameworks on YARN

#### Storm

Used for real-time computing

**Spark**

A MapReduce-like cluster computing framework designed for low-latency iterative jobs and interactive use from an interpreter

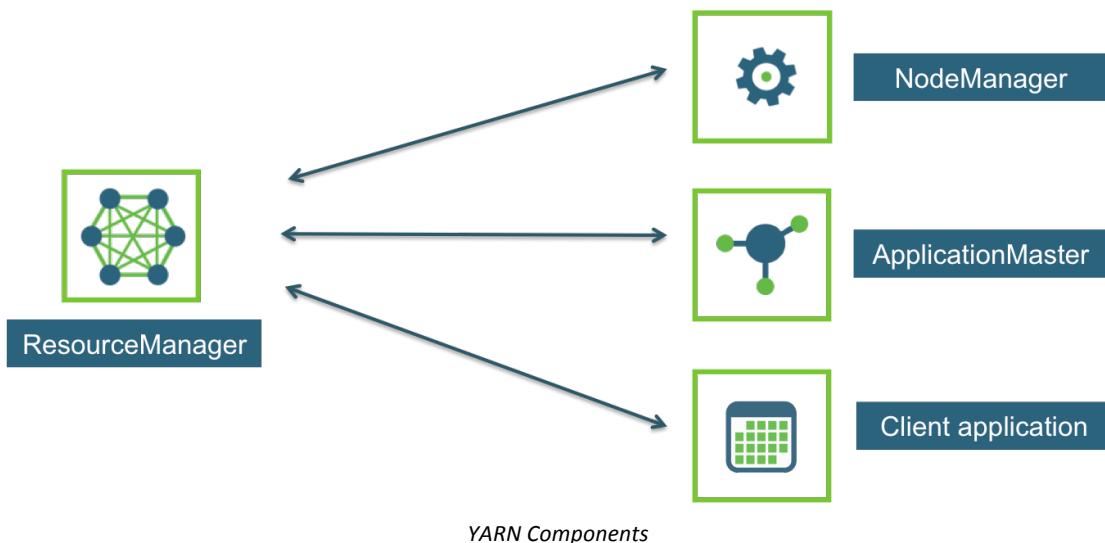
**Apache Giraph**

A graph-processing platform

Now that Hadoop can run applications beyond MapReduce, there are countless possibilities for the type of processing that can be done on data stored in HDFS. Above are some open-source projects that are currently being ported onto YARN for use in Hadoop 2.x.

You can expect other computing frameworks to be developed once YARN becomes prevalent.

## YARN Components



YARN consists of the following main components:

- ResourceManager
- NodeManager
- ApplicationsMaster

### ResourceManager

The ResourceManager typically runs on its own machine and is responsible for scheduling and allocating resources. The two main components of the ResourceManager are:

- Scheduler
- Applications Manager (AsM)

The ResourceManager is the central controlling authority for resource management and makes allocation decisions. It:

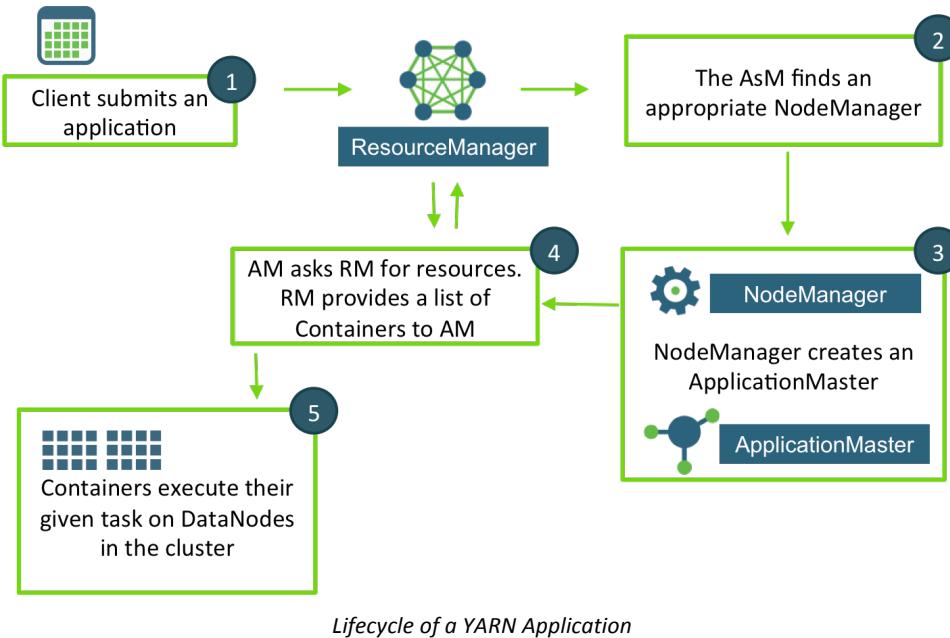
- Has a pluggable scheduler that allows for different algorithms (such as capacity and fair scheduling)
- Tries to optimize the cluster (use all resources all the time) based on the constraints

### Hadoop 1.x JobTracker

If you are familiar with Hadoop 1.x, note that YARN splits up the functionality of the JobTracker into two separate processes:

- **ResourceManager**  
A daemon process that allocates cluster resources to applications
- **ApplicationMaster**  
A per-application process that provides the runtime for executing applications

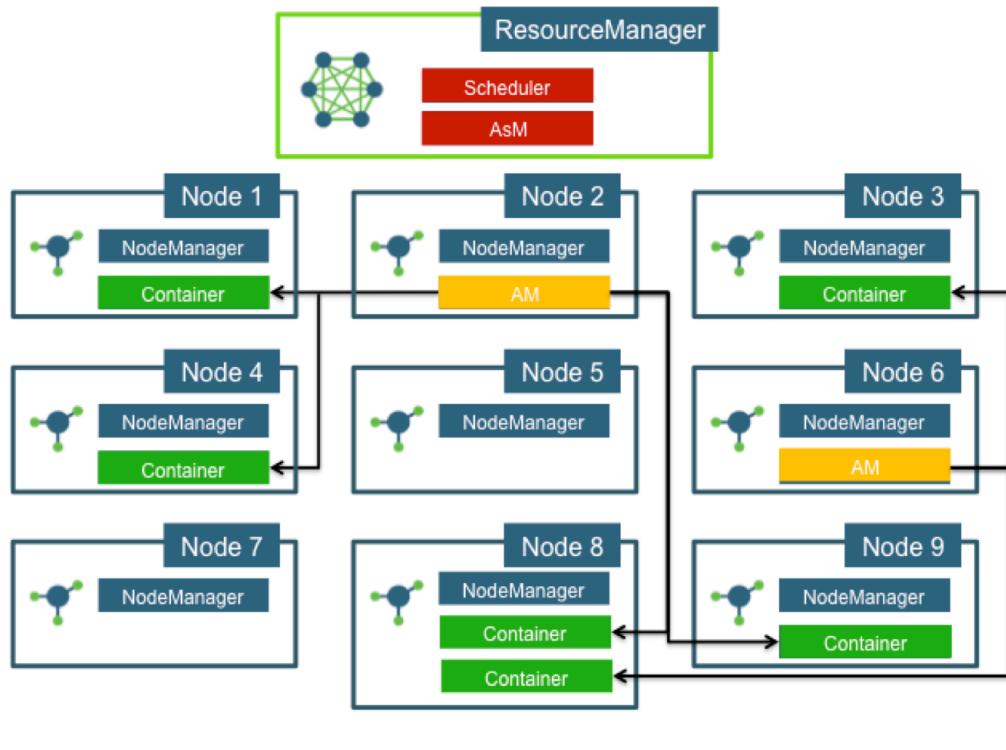
## YARN Application Lifecycle



- 1 ) It all starts with a client submitting a new Application Request to the Resource Manager (RM)
- 2 ) The ApplicationsManager (AsM) finds an available DataNode on the cluster that is not too busy
- 3 ) That node's NodeManager (NM) creates an instance of the ApplicationMaster (AM)
- 4 ) The AM then sends a request to the RM, asking for specific resources, like memory and CPU requirements. The RM replies with a list of Containers, which includes the specific DataNodes to start the Containers
- 5 ) The AM starts a Container on each DataNode as instructed by the RM. The Container performs a task, as directed by the AM

As the tasks are being performed by the Containers, the client application can request status updates directly from the ApplicationMaster.

## Cluster View



*Cluster View Example*

Use the illustration above to answer the following questions:

- 1 ) How many applications are running on the cluster?

**Answer:** 2

- 2 ) How many containers are being used by the application controlled by AM on Node 2?

**Answer:** 4

- 3 ) Node 8 appears to have two Containers running on it. Is this allowed in YARN?

**Answer:** Yes

- 4 ) Is it possible that a Container could be executed on the same node as its corresponding AM?

**Answer:** Yes – It depends on the availability of resources on a node

## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) True or False: A NameNode can contain multiple namespaces.
- 2 ) What is the key benefit of the new YARN framework?
- 3 ) What are the three main components of YARN?
- 4 ) What happens if a Container fails to complete its task in a YARN application?

## Answers

- 1 ) True or False: A NameNode can contain multiple namespaces.

**Answer:** False. A NameNode can represent only a single namespace.

- 2 ) What is the key benefit of the new YARN framework?

**Answer:** Hadoop jobs are no longer restricted to MapReduce. With YARN, any type of computing paradigm can be implemented to run on Hadoop.

- 3 ) What are the three main components of YARN?

**Answer:** ResourceManager, NodeManager, and ApplicationMaster

- 4 ) What happens if a Container fails to complete its task in a YARN application?

**Answer:** It is up to the ApplicationMaster to request a new Container from the ResourceManager and attempt the task again.

# Introducing Apache Spark

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe the origin of Apache Spark
- ✓ Understand the rapid growth of the Spark ecosystem
- ✓ Recognize some of the use cases for Spark
- ✓ Describe some major differences between Spark and MapReduce

## Apache Spark



*What is Apache Spark?*

Apache Spark started as a research paper in 2009 by a graduate student at Berkley. The framework surfaced as part of the evolving Berkeley Data Analytics Stack (BDAS). Spark was created to be a general-purpose data processing engine, focused on in-memory distributed computing use-cases. Spark took many concepts from MapReduce and implemented them in a new ways.

The Berkley research paper and BDAS started because of the struggles current users were having with certain use cases in the MapReduce framework.

The following is a timeline of some of the major moments in Spark's creation:

- 2009: BDAS research project
- June 2013: Accepted as an Apache Incubator project
- February 2014: Became a top-level Apache project
- December 2014: Spark became part of the HDP stack with version 2.2

### Note

Spark API's are available in Scala, Python, Java and recently were added for R.

## The Spark Ecosystem



### *The Spark Ecosystem*

Spark consists of a core library. Spark SQL, Streaming, ML-Lib (for machine learning applications) and GraphX were built upon it. Spark SQL and its Dataframe concept have exploded in popularity recently as there have been many performance improvements. GraphX is very new and currently not supported by anyone.

## Why Spark?

Spark was built with the developer in mind. Spark has very elegant high-level APIs, which seek to minimize the “plumbing” that developers traditionally have to worry about. Spark provides APIs that allow developers to focus on the business logic; not the framework internals.

Spark has brought forward in-memory computation for Hadoop which has been very effective for iterative computations. This allows large amounts of data to be stored in memory and to be quickly accessed. Some applications have seen as much as a 100x speed increase due to these new abilities.

One of the biggest drivers for adoption from the development community is that Spark provides a single framework for most data processing needs. This allows for a single programmatic approach to be utilized for importing, transforming and exporting data for a wide variety of workloads including the following:

- MLlib for Data Scientists
- Spark SQL for Data Analysts
- Spark Streaming for micro batch use cases
- Spark Core, SQL, Streaming, ML-Lib and GraphX for data-processing applications

The features (all in open source), plus its performance improvements for many scenarios and the full integration with Hadoop are the cornerstones for the rapid adoption of Spark.

## Spark Use Cases

The following real world uses for Spark help to explain its applicability and flexibility:

**NASA JPL** NASA's Jet Propulsion Laboratory receives 10+ TB of data daily from Instrument and Ground Systems for Earth Monitoring and runs multiple kinds of jobs ranging from long running to sub second. JPL created SciSpark library to allow for interactive computation and exploration possible using scientific processing. SciSpark provides support for scientific data formats and created a new type of RDD called a scientific RDD (sRDD).

<b>eBay</b>	eBay uses Spark on clusters close to 2000 nodes, with 100 TB Ram and 20,000 cores. Ebay leverages Spark for interrogation of complex data, data modeling and data scoring among other things. eBay uses ML-Llib to cluster sellers together via Kmeans. By clustering sellers together, they're able to increase the user experience by helping users find products they may like more, and provide alternatives or recommendations. In addition, eBay uses SQL with Spark, to increase the performance of their queries. They report that the queries are running at least 5x faster than their Hive counterparts.
<b>Conviva</b>	Conviva provides monitoring and optimization for online video providers. Customers include ESPN, Yahoo, Microsoft, Comcast amongst many others. They use Spark to process 150gb / week of compressed summary data. They found Spark to be 30x faster than Hive. Processing time went from 24 hours to 45 minutes for their weekly Geo Report. Biggest speed up came from reducing disk reads, and storing only relevant data in memory. 30% of their reports currently use Spark, as of 2012.
<b>Yahoo!</b>	Yahoo has a cluster with over 35k servers, 150PB of data spanning 800m users. Yahoo needs a way to quickly learn about users and provide a personalized homepage to increase the user experience. Yahoo's data scientists leveraged spark to create models to find what news stories would appeal to each users. These models need to run fast, really fast. With Spark they were able to create models in under an hour which greatly enhanced Yahoo's ability to provide personalized news stories to users.

## Spark vs MapReduce

As the following diagram suggests, some use cases that can benefit from Spark's in-memory data storage can achieve up to 100x performance improvements.



Just as important is developer productivity. The following provides the source code of the quintessential Hadoop "Word Count" example as written in the Java MapReduce API.

## Introducing Apache Spark

```
package org.myorg;

import java.io.IOException;
import java.util.*;

import org.apache.hadoop.fs.Path;
import org.apache.hadoop.conf.*;
import org.apache.hadoop.io.*;
import org.apache.hadoop.mapreduce.*;
import org.apache.hadoop.mapreduce.lib.input.FileInputFormat;
import org.apache.hadoop.mapreduce.lib.input.TextInputFormat;
import org.apache.hadoop.mapreduce.lib.output.FileOutputFormat;
import org.apache.hadoop.mapreduce.lib.output.TextOutputFormat;

public class WordCount {

    public static class Map extends Mapper<LongWritable, Text, Text, IntWritable> {
        private final static IntWritable one = new IntWritable(1);
        private Text word = new Text();

        public void map(LongWritable key, Text value, Context context) throws IOException, InterruptedException {
            String line = value.toString();
            StringTokenizer tokenizer = new StringTokenizer(line);
            while (tokenizer.hasMoreTokens()) {
                word.set(tokenizer.nextToken());
                context.write(word, one);
            }
        }
    }

    public static class Reduce extends Reducer<Text, IntWritable, Text, IntWritable> {
        public void reduce(Text key, Iterable<IntWritable> values, Context context)
            throws IOException, InterruptedException {
            int sum = 0;
            for (IntWritable val : values) {
                sum += val.get();
            }
            context.write(key, new IntWritable(sum));
        }
    }

    public static void main(String[] args) throws Exception {
        Configuration conf = new Configuration();
        Job job = new Job(conf, "wordcount");

        job.setOutputKeyClass(Text.class);
        job.setOutputValueClass(IntWritable.class);

        job.setMapperClass(Map.class);
        job.setReducerClass(Reduce.class);

        job.setInputFormatClass(TextInputFormat.class);
        job.setOutputFormatClass(TextOutputFormat.class);

        FileInputFormat.addInputPath(job, new Path(args[0]));
        FileOutputFormat.setOutputPath(job, new Path(args[1]));

        job.waitForCompletion(true);
    }
}
```

Conversely, here is Word Count implemented with Spark.

```
text_file = spark.textFile("hdfs://...")
counts = text_file.flatMap(lambda line: line.split(" "))
    .map(lambda word: (word, 1))
    .reduceByKey(lambda a, b: a + b)
counts.saveAsTextFile("hdfs://...")
```

In fairness, this high-level API should be compared to something like Pig. Here's the analogous version in that language.

```
a = load '/user/hue/word_count_text.txt';
b = foreach a generate flatten(TOKENIZE((chararray)$0)) as word;
c = group b by word;
d = foreach c generate COUNT(b), group;
store d into '/user/hue/pig_wordcount';
```

## Faster

First, and Quite the increase in speed is seen from there.

- The biggest reason is that Spark can cache data into memory. Reading from memory is measured in nanoseconds, reading from disk is measured in milliseconds.
- Scheduling of tasks in Spark has greatly decreased from MapReduce. Spark has dedicated resources, so scheduling of tasks doesn't require a resource request. Because of this, scheduling has gone from 15-20s to 15-20ms.
- There can be multiple reduces and maps in a row. You do not need a map phase for every reduce phase. Skipping this extra map save reading and writing data to disk.

## Massive Growth

Spark is a top level project at Apache as of February 2014. Spark's previous release (as of November 2015) had over 1000 commits with 230 developers contributing. Spark is one of the largest open source projects currently at Apache. Releases of spark are independent of the major Hadoop distributions, with an average .x release of Spark every three months.

Spark is growing massively and many new features, along with bug fixes and internal optimizations, are being released all the time. One of the biggest jumps in Spark usability was the new feature of Spark SQL and Dataframes.

## Spark and HDP

As stated earlier, Spark was introduced into the Hortonworks Data Platform (HDP) in December 2014. The following bullets reference some key version points for both HDP and Spark:

- HDP 2.3.2 – Spark 1.4.1
- HDP 2.2.8 – Spark 1.3.1
- HDP 2.2.4 – Spark 1.2.1

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## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) What are some of the reasons Spark is faster than MapReduce?
- 2 ) What distribution of HDP includes Spark 1.4.1?
- 3 ) What are the four libraries that build upon Spark Core?
- 4 ) Name another benefit to using Spark vs. MapReduce?

## Answers

1 ) What are some of the reasons Spark is faster than MapReduce?

**Answer:** Task scheduling, in-memory data caching, can link multiple maps and reduces together, less reading & writing to HDFS

2 ) What distribution of HDP includes Spark 1.4.1?

**Answer:** HDP 2.3.2

3 ) What are the four libraries that build upon Spark Core?

**Answer:** GraphX, Spark SQL, ML-Lib and Spark Streaming

4 ) Name another benefit to using Spark vs MapReduce?

**Answer:** High-level API, many committers and/or rapid improvements & bug fixes

# Programming with Apache Spark

## Lesson Objectives

- ✓ Start the Spark shell
  - ✓ Understand what an RDD is
  - ✓ Use common Spark Actions
  - ✓ Explain lazy evaluation
  - ✓ Describe (Key Value) Pair RDDs
  - ✓ Create a Word Count Application

## Starting the Spark Shell

The fastest way to get started with Apache Spark is using a command-line based Spark shell application. In addition to learning Spark, the shells are great for debugging, exploring data, and when building applications. Spark has two shells available, one for Python and one for Scala.

In order to start the scala shell, the user needs to enter “spark-shell” on the command line.

In order to start the python shell, the user needs to enter “`pyspark`” on the command line.

*The pyspark RPEL*

Generally speaking, a shell is often referred to as a REPL, which stands for Read – Evaluate – Print – Loop. This lesson will refer to the two shells as the REPL to avoid confusion.

## Reference

Spark's Programming Guide, <http://spark.apache.org/docs/1.4.1/programming-guide.html>, is an invaluable resource.

## Spark Context

For any application to become a Spark application, an instance of the `SparkContext` class must be instantiated. In `pyspark`, the following code has already been executed for you at start up.

```
conf = SparkConf().setAppName(appName).setMaster(master)
sc = SparkContext(conf=conf)
```

This allows subsequent use of the needed `SparkContext` object through the `sc` variable created for you. This class has many APIs that can be used for accessing configurations:

- `sc.appName()` sets the application name
- `sc.master()` determines what kind of Spark Master (local or YARN enabled) is in use
- `sc.version()` displays to the user which version of Spark they are utilizing

The context object also has APIs that perform operations such as the following which will be discussed further:

- `sc.parallelize()` creates an RDD from local data
- `sc.textFile()` creates an RDD from a text file residing on HDFS
- `sc.stop()` stops the `SparkContext` object

## Reference

More details on the `SparkContext` class used in `pyspark` are available at <http://spark.apache.org/docs/1.4.1/api/python/pyspark.html#pyspark.SparkContext>.

## Working with RDDs

The Resilient Distributed Dataset (RDD) is an *immutable* collection of objects (or records) that can be operated on in parallel. RDD's adhere to these key attributes that make up their namesake:

<b>Resilient</b>	Can be recreated from parent RDDs – and RDD keeps its lineage information.
<b>Distributed</b>	Partitions of data are distributed across nodes in the cluster.
<b>Dataset</b>	A set of data than can be accessed.

Each RDD is composed of one, or more, partitions. The user can control the number of partitions, by increasing partitions, the user increase the parallelism.

RDD's are not a physical entity. They are a set of instructions on how to transform data. The only time an RDD every physically exists is when the data is cached into memory.

For HDFS files, the RDD partitions will be aligned with the file's blocks thus leveraging the same kind of parallelism that Hadoop is famous for.

## Creating an RDD

A common way to create an RDD is to simple read a text file. This file can exist in a variety of place such as HDFS, S3 or the local filesystem and can be loaded from a single line:

```
rdd1 = sc.textFile("file:/path/to/file.txt")
rdd2 = sc.textFile("hdfs://namenode:8020/mydata/data.txt")
```

The method can also accept a comma separated list of files, or a wildcard list of files:

```
rdd3 = sc.textFile("mydata/*.txt")
rdd4 = sc.textFile("data1.txt,data2.txt")
```

## Working with RDDs and Lazy Evaluation

RDDs have the following two types of operations:

**Transformations** The RDD is transformed into a new RDD.

**Actions** An action is performed on the RDD and the result is returned to the application or saved somewhere.

Transformations are lazy: they do not compute until an action is performed. This is an important concept of Spark. Spark likes to do the least amount of work possible and will only process data when it is forced too.

### *Transformation Example*

Using Word Count as an example, the following lines of Spark code illustrates multiple transformation that work toward building possible directed acyclic graphs (DAG), the mechanism to describe the job flow steps, for eventual execution.

```
file = sc.textFile("hdfs://some-text-file")
counts = file.flatMap(lambda line: line.split(" "))
    .map(lambda word: (word, 1))
    .reduceByKey(lambda a, b: a + b)
```

### *Action Example*

The save operation below writes the newly created text file back to HDFS which constitutions an action that triggers execution of the whole DAG.

```
counts.saveAsTextFile("hdfs://wordcount-out")
```

Restating this, lazy evaluation means that transformations will be only executed when actions are called. While build a pipeline, spark creates a DAG of the transformations. When an action is called on an RDD, it triggers the execution of the entire finalized DAG.

## Reference

The keyword `lambda` is Python's approach for small anonymous functions that can be used wherever function objects are required.

See <https://docs.python.org/2/tutorial/controlflow.html#lambda-expressions> for more on this approach.

## Functional Programming

Spark uses functional programming which this allows the user to process data in parallel. Functional programming is a paradigm shift from object-oriented programming and the following are some of its architectural tenants:

- Programs are built on functions instead of objects
- Mutation is forbidden – all variables are final
- Functional purity – if you pass A into a function, you're always getting back B
- Functions have input and output only – no state or side effects
- Passing functions as input to other functions
- Anonymous functions – undefined functions passed inline

## Reference

Visit [https://en.wikipedia.org/wiki/Functional\\_programming](https://en.wikipedia.org/wiki/Functional_programming) for a more thorough explanation of the functional programming paradigm.

## Common Spark Actions

Spark action operations trigger execution.

### **count() Action**

The `count()` action returns the number of elements in an RDD.

```
data = [5, 12, -4, 7, 20]
rdd= sc.parallelize(data)
rdd.count()

5
```

### **reduce() Action**

The `reduce()` action's aggregation of elements of an RDD using a defined function has many use cases in Spark applications. The reducing logically happens over and over with only two of the RDD elements at a time. Once those two have been reduced, then the outcome will be part of another logical reduce step until all elements have been accounted for.

This concept of having multiple passes on the reduce phase is similar to the Java MapReduce API's Combiner. Because of this, *the function used by the reduce must be both commutative and associative*. For example,  $a+b = b+a$ . A richer example shows that  $a+(b+c) = (a+b)+c$ .

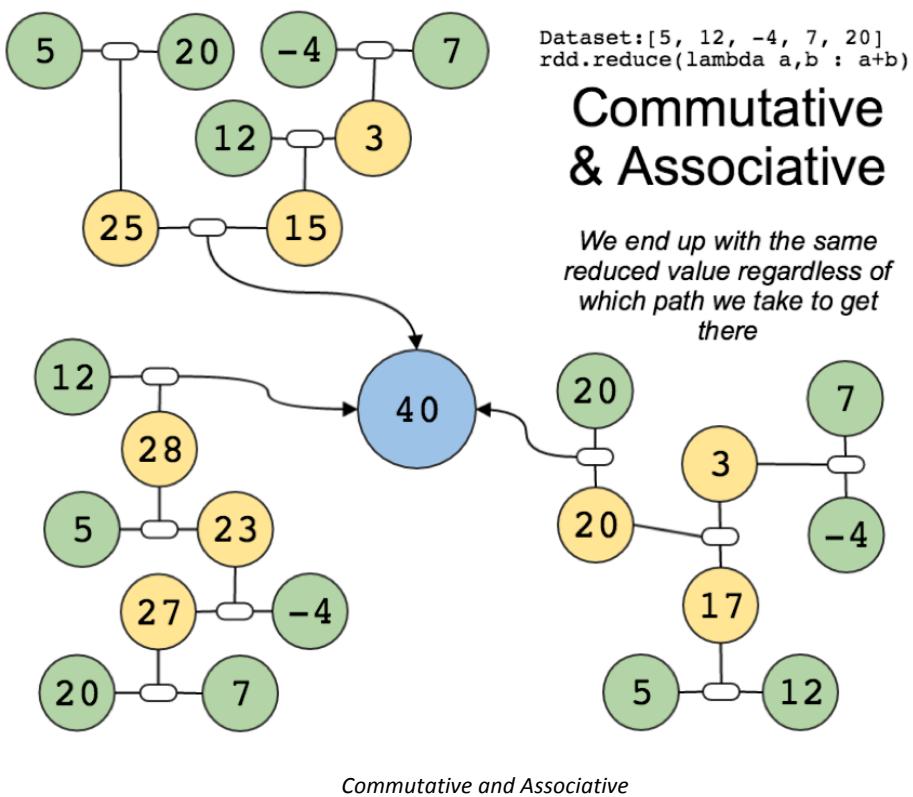
The following show examples of the reduce() action.

```
Dataset:[5, 12, -4 , 7, 20]
rdd.reduce(lambda a, b : a+b)
40

rdd.reduce(lambda a, b: a if (a>b) else b)
20
```

The reason for the requirement to be commutative and associative is that Spark does not guarantee the order in which the data will be processed.

### Commutative and Associative



**Commutative** = (of a binary operation) having the property that one term operating on a second is equal to the second operating on the first, as  $a \times b = b \times a$

**Associative** = (of an operation on a set of elements) giving an equivalent expression when elements are grouped without change of order, as  $(a + b) + c = a + (b + c)$

## Other Useful Spark Actions

The following are additional Spark actions that are leveraged heavily.

- `first()` returns the first element in the RDD
- `take()` returns the first n elements of the RDD
- `collect()` returns all the elements in the RDD to the driver
- `saveAsTextFile()` writes the RDD to a file

```
Dataset:[5, 12, -4 , 7, 20]
rdd.first()
5
rdd.take(3)
[5, 12, -4]
rdd.saveAsTextFile("myfile")
```

### Important

Make sure you only call `collect()` on small datasets or risk crashing your shell/application.

## Lazy Evaluation

Spark transformation operations create new RDDs from existing ones. Transformations are lazy and processing does not occur until an action is called on the RDD, or a subsequent RDD. Transformation create a recipe, or lineage, that Spark uses to process the data. Spark will pipeline data through these transformations.

### map() Transformation

The `map()` transformation applies a function to each element of an RDD. It takes a *one input to one output* approach.

```
rdd = sc.parallelize([1, 2, 3, 4, 5])
rdd.map(lambda x: x*2+1).collect()
[3, 5, 7, 9, 11]
```

### flatMap() Transformation

`flatMap()` applies a function to each element of the RDD and returns a collection. The main difference between `map()` and `flatMap()` are the outputs. This transformation takes a *one input to many output* approach.

```
rdd = sc.parallelize([1, 2, 3, 4, 5])

rdd.map(lambda x: [x, x*2]).collect()
[(1,2), (2, 4), (3,6), (4,8), (5,10)]

rdd.flatMap(lambda x: [x, x*2]).collect()
[1, 2, 2, 4, 3, 6, 4, 8, 5, 10]
```

The reason for the requirement to be commutative and associative is that Spark does not guarantee the order in which the data will be processed.

## filter() Transformation

The `filter()` transformation keeps elements based on a predicate. It will include the current element of the RDD being evaluated in the new RDD when the function being used evaluates to true.

```
rdd = sc.parallelize([1, 2, 3, 4, 5])
rdd.map(lambda x: x*2+1).collect()
[3, 5, 7, 9, 11]
```

## KVP RDDs

Pair RDDs are a different type of RDD than previously discussed. A Pair RDD, or Key Value Pair (KVP) RDD, is an RDD whose elements comprise a pair of values – key and value. Pair RDDs are very useful for many applications. We can create KVPs then allow group operations to occur based on the key. Examples of these operations include `join()`, `groupByKey()` and `reduceByKey()`.

## Creating Pair RDDs

Pair RDDs are often created from regular RDDs by using the `map()` or `flatMap()` transformation operations as shown in the following example:

```
wordlist = 'this is my list and it is a nice list'
rdd1 = sc.parallelize([wordlist])

kv_rdd = rdd1.flatMap(lambda x: x.split(' ')).map(lambda x: (x,1))
kv_rdd.collect()
[(this, 1), (is, 1), (my, 1), (list, 1), (and, 1), ... (list,1)]
```

## Creating a Word Count Application

A common action taken on Pair RDDs is the `reduceByKey()` function. It performs reduce actions on all values with the same key and collapses them all down to a single KVP with only the value being updated by whatever function is used in the operation. Like with the less complex `reduce()` action, the function still must be commutative and associative. The easily understood Word Count functionality helps in understanding this operation.

```
kv_rdd.reduceByKey(lambda a,b: a+b).collect()
[('this', 1), ('my', 1), ('and', 1), ('list', 2), ('a', 1), ('it', 1),
('is', 2), ('nice', 1)]
```

## Use Case Examples

### Note

These simple examples might lead one to believe that the keys and/or values must be primitive values, but in fact, they can be very complex & nested tuple structures.

**Keys & Values can contain rich tuples.**

The following example implements the familiar use case, but introduces some additional data elements to both sides of the KVP being utilized.

```

suess = ['I do not like green eggs and ham I do not like them Sam I am']
parallelSuess = sc.parallelize(suess)
parallelSuess.take(1)
['I do not like green eggs and ham I do not like them Sam I am']

suessWords = parallelSuess.flatMap(lambda sentence: sentence.split(' '))
suessWords.take(5)
['I', 'do', 'not', 'like', 'green']

notSimplePair = suessWords.map(lambda word: ((word, 'theKey'), ('theVal', 1)))
notSimplePair.sortByKey(ascending=False).take(5)
[('them', 'theKey'), ('theVal', 1), ('not', 'theKey'), ('theVal', 1),
 ('not', 'theKey'), ('theVal', 1), ('like', 'theKey'), ('theVal', 1),
 ('like', 'theKey'), ('theVal', 1)]

notSimplePair.reduceByKey(lambda oneValue,anotherValue: ('n/a', oneValue[1] +
anotherValue[1])).sortByKey(ascending=False).collect()
[('them', 'theKey'), ('theVal', 1), ('not', 'theKey'), ('n/a', 2),
 ('like', 'theKey'), ('n/a', 2), ('ham', 'theKey'), ('theVal', 1),
 ('green', 'theKey'), ('theVal', 1), ('eggs', 'theKey'), ('theVal', 1),
 ('do', 'theKey'), ('n/a', 2), ('and', 'theKey'), ('theVal', 1), ('am',
'theKey'), ('theVal', 1), ('Sam', 'theKey'), ('theVal', 1), ('I',
'theKey'), ('n/a', 3)]

```

## pyspark Tips

The following suggestions may make your experience using pyspark more navigable:

- Take advantage of your command history by utilizing the "up arrow" key similar to the Linux shell
- Instead of initially chaining together a long list of methods, consider creating temporary variable, or at least adding one method at a time and using `take()` to see if it appears each operation is working as expected before adding another method
- Leverage `dir()` to get a list of current variables – like with Pig's `aliases` command, there will be additional system-oriented variable names present
- Consider trimming down the extra "noise" by calling `sc.setLogLevel('WARN')` to eliminate INFO messages

## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) What are the three ways we can create an RDD?
- 2 ) What are the two types of operations we can perform on an RDD? Give example of each.
- 3 ) What is functional programming?
- 4 ) What is Lazy Execution?
- 5 ) What does the R stand for in RDD? What does that mean?

## Answers

1 ) What are the three ways we can create an RDD?

**Answer:** From a filesystem/db, parallelizing a collection, from another RDD

2 ) What are the two types of operations we can perform on an RDD? Give example of each.

**Answer:** Action (count, collect, take) and Transformation (map, flatMap, filter)

3 ) What is functional programming?

**Answer:** Functional programming allows us to build applications on functions and not objects, passing functions as inputs to other functions, functions have inputs and outputs – no side effects, no “state”

4 ) What is Lazy Execution?

**Answer:** Lazy execution means Spark doesn't process data until it has to when an action is performed

5 ) What does the R stand for in RDD? What does that mean?

**Answer:** R stands for Resilient. We're able to recompute the data using lineage in case we were to lose part of it

# Spark SQL and DataFrames

## Lesson Objectives

This lesson explores the additional Spark ecosystem framework called Spark SQL and its tightly coupled DataFrame API. Upon completion of this lesson, students should be able to:

- ✓ Describe Spark SQL
- ✓ Describe data manipulation and access options
- ✓ Use DataFrames

## Spark SQL Overview

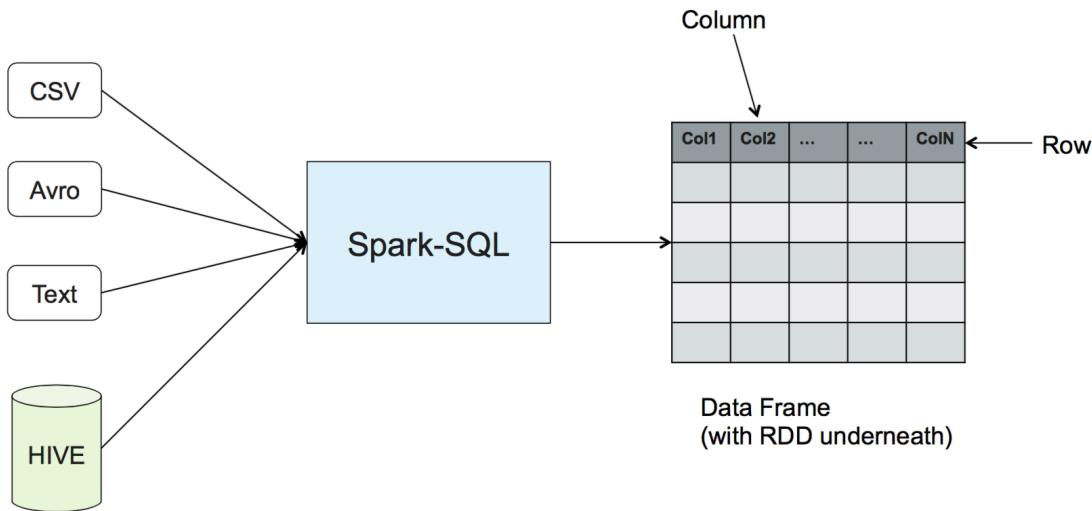


*What is Apache Spark?*

Spark SQL is Spark's integrated module for working with structured data. In addition to the following bullets, Spark SQL features a uniform data access approach and Hive compatibility.

- It is a module built on top of Spark Core
- Provides a programming abstraction for distributed processing of large-scale structured data in Spark
- Data is described as a DataFrame with row, columns and a schema
- Data manipulation and access is available with two mechanisms
  - SQL Queries
  - DataFrames API

## The DataFrame Abstraction



- A DataFrame is inspired by the dataframe concept in R (dplr, Dataframe) and Python (pandas), but stored using RDDs underneath in a distributed manner
- A DataFrame is organized into named columns – an RDD of "Row" objects
- The DataFrame API is available in Scala, Java, Python and R

## DataFrame Primary Sources

- DataFrames from Hive data
  - Reading from Hive tables
  - Writing to Hive tables
- DataFrames from file
  - Built-in: JSON, JDBC, Parquet, HDFS
  - External plug-in: CSV, HBase, Avro, memsql, elasticsearch

## SQLContext and HiveContext

To use Spark SQL from your Spark application, an instance of the `SQLContext` class must be instantiated. In `pyspark`, the following code has already been executed for you at start up.

```
from pyspark.sql import SQLContext
sqlContext = SQLContext(sc)
```

This allows subsequent use of the needed `SQLContext` object through the `sqlContext` variable created for you. Alternatively, you can create a `HiveContext` instance to connect with Hive.

```
from pyspark.sql import HiveContext
hc = HiveContext(sc)
```

**Note**

Since HiveContext is a specialized subclass of SQLContext you can use it in place of the already instantiated sqlContext reference for consistency.

## Data Manipulation and Access Options

Accessing and manipulating data is available via two options:

- [DataFrames API](#)
- [SQL Syntax](#)

### DataFrames API

The following illustrates an example of using the DataFrame API:

```
from pyspark.sql import HiveContext
hc = HiveContext(sc)

hc.sql("use demo")
df1 = hc.table("crimes")
.select("year", "month", "day", "category")
.filter("year > 2014").head(5)
```

### SQL Syntax

The following illustrates an example of using the SQL syntax:

```
from pyspark.sql import HiveContext
hc = HiveContext(sc)

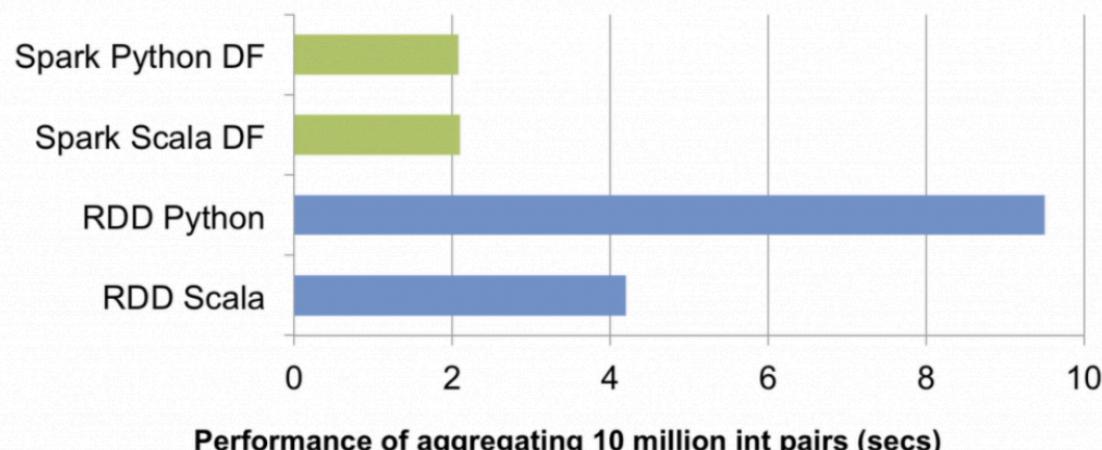
hc.sql("use demo")
df1 = hc.sql("""
SELECT year, month, day, category
FROM crimes
WHERE year > 2014""").head(5)
```

**Note**

When the SQL statement spans more than one line, wrap it with three sets of double-quotes. Otherwise, a single set of double-quotes is sufficient.

## DataFrames

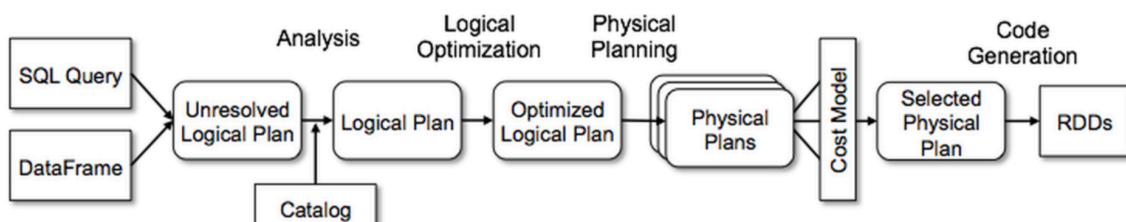
Spark SQL uses an extensible cost-based optimizer (CBO) called Catalyst. This CBO engine understands the structure of data & semantics of operations and performs optimizations accordingly with results like those shown below compared with Spark Core's RDD processing.



*DataFrame Performance Comparison*

Much of the performance gains are due to the Catalyst optimizer that features the following functionality and highlights:

- Query or DataFrame operations are modeled as a tree
- Logical plan is created and optimized
- Various physical plans are created then the best one is chosen based on overall cost
- Code generation and execution



## Creating DataFrames

There are multiple ways to create DataFrames (DF) as the following subsections identify.

- From Hive
- From a file
- From an RDD
- From a text file

## **From Hive**

An entire Hive table could be loaded to create a DataFrame:

```
df = hc.table("patients")
```

Alternatively, a DataFrame could be created from the results of a SQL query such as these examples show:

```
df1 = hc.sql("SELECT * FROM patients WHERE age > 50")

df2 = hc.sql("""
SELECT col1 AS timestamp, SUBSTR(date,1,4) AS year, event
  FROM events
 WHERE year > 2014""")
```

## **From a File**

With the built-in adapters and an extensible framework, virtually any file format could be read to create a DataFrame.

Here are two approaches for reading from a JSON file:

```
df = hc.read.json("somefile.json")

df = hc.read.format("json").load("somefile.json")
```

### **Note**

There are two syntax options for reading files types. The following model can be used for well-known and tested file formats:

```
hc.read.TECH-NAME("FILE-NAME")
```

The more extensible syntax follows:

```
hc.read.format("TECH-NAME").load("FILE-NAME")
```

Examples reading from Parquet and CSV files using the built-in and external plug-in models, respectively:

```
dfParquet = hc.read.parquet("somefile.parquet")

dfCSV = hc.read.format("com.databricks.spark.csv")
.options(header='true').load("somefile.csv")
```

## **From an RDD**

You can create an RDD of Row objects and then use its `toDF()` function:

```
from pyspark.sql import Row

rdd = sc.parallelize([Row(name='Alice', age=12, height=80),
    Row(name='Bob',    age=15, height=120)])
df = rdd.toDF()
```

Another approach would be to let Spark SQL infer the schema using the `createDataFrame()` function:

```
rdd = sc.parallelize([('Alice',12,80), ('Bob',15,120)])
df = hc.createDataFrame(rdd, ['name', 'age', 'height'])
```

### **From a Text File**

When you have a file with some known structure and format you can read the file into an RDD and then leverage the same available options to convert it to a DataFrame.

```
from pyspark.sql import Row

lines = sc.textFile("examples/src/main/resources/people.txt")
parts = lines.map(lambda l: l.split(","))
people = parts.map(lambda p: Row(name=p[0], age=int(p[1])))

# Infer the schema, and register the DataFrame as a table.
schemaPeople = sqlContext.inferSchema(people)
schemaPeople.registerTempTable("people")

# SQL can be run over DataFrames that have been registered as a table.
teenagers = sqlContext.sql("SELECT name FROM people WHERE age >= 13 AND age <= 19")
```

The following Scala example is presented to show the benefit of defining a full class on the fly (or defining it elsewhere) to provide "column" names & data types and then constructing a new one for each row during the second map transformation below:

```
val sqlContext = new org.apache.spark.sql.SQLContext(sc)
// this is used to implicitly convert an RDD to a DataFrame.
import sqlContext.implicits._

case class Person(name: String, age: Int)

val people = sc.textFile("examples/src/main/resources/people.txt")
.map(_.split(","))
.map(p => Person(p(0), p(1).trim.toInt)).toDF()
```

## DataFrame Operations

---

```
df1 = sc.parallelize(
    [Row(cid='101', name='Alice', age=25, state='ca'), \
     Row(cid='102', name='Bob', age=15, state='ny'), \
     Row(cid='103', name='Bob', age=23, state='nc'), \
     Row(cid='104', name='Ram', age=45, state='fl')]).toDF()
```

	age	cid	name	state
0	25	101	Alice	ca
1	15	102	Bob	ny
2	23	103	Bob	nc
3	45	104	Ram	fl

```
df2 = sc.parallelize(
    [Row(cid='101', date='2015-03-12', product='toaster', price=200), \
     Row(cid='104', date='2015-04-12', product='iron', price=120), \
     Row(cid='102', date='2014-12-31', product='fridge', price=850), \
     Row(cid='102', date='2015-02-03', product='cup', price=5)]).toDF()
```

	cid	date	price	product
0	101	2015-03-12	200	toaster
1	104	2015-04-12	120	iron
2	102	2014-12-31	850	fridge
3	102	2015-02-03	5	cup

Sample DataFrames

### Inspecting Content

As DataFrames are backed by RDDs, you still have access to `first()` and `take()` as before:

```
df1.first()
Row(age=23, cid=u'104', name=u'Bob', state=u'nc')

df1.take(2)
[Row(age=45, cid=u'104', name=u'Ram', state=u'fl')
Row(age=15, cid=u'102', name=u'Bob', state=u'ny')]
```

You also can now leverage some new, DataFrame API specific, method calls.

- `limit()` reduces the DataFrame to a specified number of rows
  - Result is still a DataFrame, not a Python result list
- `show()` prints the first n rows to the console in a formatted manner

```
df1.show(3)
+---+---+---+---+
| age | cid | name | state |
+---+---+---+---+
| 25 | 101 | Alice | ca |
| 15 | 102 | Bob | ny |
| 23 | 103 | Bob | nc |
+---+---+---+---+
```

Sample show() Output

## *Inspecting Schema*

Expected operations to understand the metadata for the DataFrame are also available:

```
# Display column names
df1.columns
[u'age', u'cid', u'name', u'state']

# Display column names and types
df1.dtypes
[('age', 'bigint'), ('cid', 'string'), ('name', 'string'), ('state',
'string')]

# Display detailed schema
df1.schema
StructType(List(StructField(age,LongType,true),
StructField(cid,StringType,true),
StructField(name,StringType,true),
StructField(state,StringType,true)))
```

## *Counting Rows*

You can count all the rows in a DataFrame, too:

```
df1.count()
4
```

## **Important**

`count()` returns the number of non-duplicate rows. Use `df1.rdd.count()` to return the number of actual rows.

## *Removing Duplicates*

The DataFrame API offers a couple of ways to remove duplicates:

```
# Remove duplicate rows
df1.distinct().show()

# Remove duplicate rows by key
df1.drop_duplicates(["name"]).show()
```

## **Note**

Using `show()` without a parameter results in the top 20 rows being returned.

## Saving DataFrames

There are multiple ways to save DataFrames such as those presented below.

```
# Write full file
df.write.format("parquet").save("output.parquet") *
df.write.format("com.databricks.spark.avro").save("output.avro")

# Write only some columns
df.select("name","age").write.format("json").save("namesAndAges.json")

# To partition, just specific the column(s) to partition by
df.write.partitionBy("name","age").parquet("partitionNameAndAge.parquet")
df.write.partitionBy("name","age").format("avro").save("partitionNameAndAge.parquet")
```



# Defining Workflow with Oozie

## Lesson Objectives

After completing this lesson, students should be able to:

- ✓ Describe Oozie
- ✓ Describe an Oozie Coordinator Job

## Oozie

Oozie is an open-source Apache project that provides a framework for coordinating and scheduling Hadoop jobs. Oozie is not restricted to just MapReduce jobs; you can use Oozie to schedule Pig, Hive, Sqoop, Streaming jobs, and even Java programs.

Oozie has two main capabilities:

### Oozie Workflow

A collection of actions (defined in a workflow.xml file)

### Oozie Coordinator

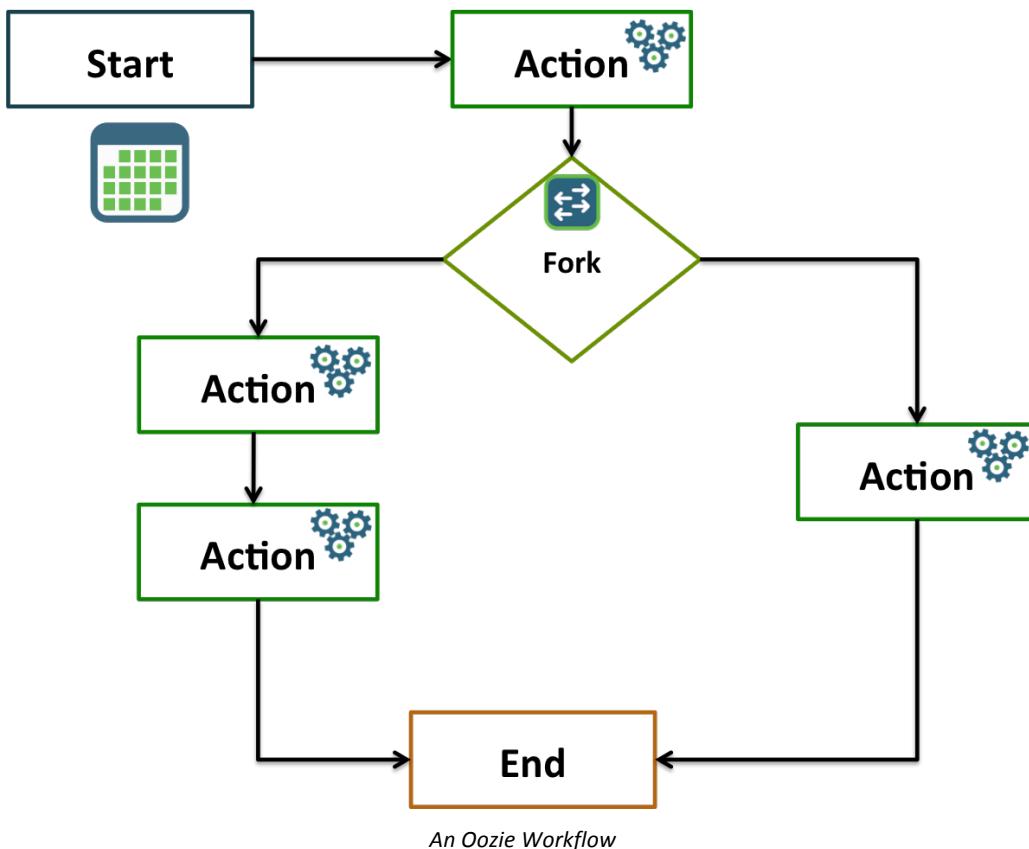
A recurring workflow (defined in a coordinator.xml file)

Behind the scenes, Oozie is a Java web application that runs in a Tomcat instance. You run Oozie as a service then start workflows using the oozie command.

## Reference

For more information on the Apache Oozie project, visit their website at <http://oozie.apache.org/>.

## Defining an Oozie Workflow



An Oozie workflow consists of a workflow.xml file and the necessary files required by the workflow. The workflow is put into HDFS with the following directory structure:

```
/appdir/workflow.xml
/appdir/config-default.xml
```

- The config-default.xml file is optional and contains properties shared by all workflows
- Each workflow can also have a job.properties file (not put into HDFS) for job-specific properties

As you will soon discover, most of your time spent defining an Oozie workflow is in writing workflow.xml. A workflow definition consists of two main entries:

### Control flow nodes

For determining the execution path.

A **fork node** splits one path into multiple paths.

A **join node** waits until every path of a previous fork node arrives to it

### Action nodes

For executing a job or task

## Pig Actions

The pig action starts a Pig job. The workflow job will wait until the Pig job completes before continuing to the next action. Here is an example of a simple workflow that only contains a single Pig script as one of its actions:

```
<workflow-app xmlns="uri:oozie:workflow:0.2"
    name="whitehouse-workflow">

    <start to="transform_whitehouse_visitors"/>

    <action name="transform_whitehouse_visitors">
        <pig>
            <job-tracker>${resourceManager}</job-tracker>
            <name-node>${nameNode}</name-node>
            <prepare>
                <delete path="wh_visits"/>
            </prepare>
            <script>whitehouse.pig</script>
        </pig>
        <ok to="end"/>
        <error to="fail"/>
    </action>
    <kill name="fail">
        <message>Job failed, error
            message[${wf:errorMessage(wf:lastErrorNode())}]
        </message>
    </kill>
    <end name="end"/>
</workflow-app>
```

## Notes

- Every workflow must define a `<start>` and `<end>`
- This workflow has one action named `transform_whitehouse_visitors`
- A workflow looks almost identical to the run method of a MapReduce job, except the job properties are specified in XML
- The `<delete>` function is a convenient way to delete an existing output folder
- The `<ok>` tag determines where the flow should go if the job completes successfully. The `<error>` tag defines where to go if the job fails
- Parameters use the `${}` syntax and represent values defined outside of `workflow.xml`. For example, `${resourceManager}` is the server name and port number where the ResourceManager is running. Instead of hard-coding this value, you define it in an external properties file (`job.properties`)
- The Oozie framework provides functions also, like `wf:user()`, which returns the name of the user running the job, and `wf:lastErrorNode()`, which returns the DataNode where the most recent error occurred. View the Oozie Documentation for a complete list of functions

## Hive Actions

The **hive action** runs a Hive job. It looks similar to a pig action:

```
<action name="find_congress_visits">
  <hive xmlns="uri:oozie:hive-action:0.5">
    <job-tracker>${resourceManager}</job-tracker>
    <name-node>${nameNode}</name-node>
    <prepare>
      <delete path="congress_visits"/>
    </prepare>
    <job-xml>hive-site.xml</job-xml>
    <configuration>
      <property>
        <name>mapreduce.map.output.compress</name>
        <value>true</value>
      </property>
    </configuration>
    <script>congress.hive</script>
  </hive>
  <ok to="end"/>
  <error to="fail"/>
</action>
```

### Notes

- The `congress.hive` script will execute when this action is executed
- The `hive-site.xml` file needs to be packaged in the workflow and needs to contain the various properties for connecting to Hive
- This action compresses the output of the map tasks

## MapReduce Actions

```
<action name="payroll-job">
  <map-reduce>
    <job-tracker>${resourceManager}</job-tracker>
    <name-node>${nameNode}</name-node>
    <prepare>
      <delete path="${nameNode}/user/${wf:user()}/payroll/result"/>
    </prepare>
    <configuration>
      <property>
        <name>mapreduce.job.queuename</name>
        <value>${queueName}</value>
      </property>
      <property>
        <name>mapred.mapper.new-api</name>
        <value>true</value>
      </property>
      <property>
        <name>mapred.reducer.new-api</name>
        <value>true</value>
      </property>
    </configuration>
  </map-reduce>
</action>
```

```

<property>
    <name>mapreduce.job.map.class</name>
    <value>payroll.PayrollMapper</value>
</property>
<property>
    <name>mapreduce.job.reduce.class</name>
    <value>payroll.PayrollReducer</value>
</property>
<property>
    <name>mapreduce.job.inputformat.class</name>
    <value> org.apache.hadoop.mapreduce.lib.input.TextInputFormat
          </value>
</property>
<property>
    <name>mapreduce.job.outputformat.class</name>
    <value> org.apache.hadoop.mapreduce.lib.output.NullOutputFormat
          </value>
</property>
<property>
    <name>mapreduce.job.output.key.class</name>
    <value>payroll.EmployeeKey</value>
</property>
<property>
    <name>mapreduce.job.output.value.class</name>
    <value>payroll.Employee</value>
</property>
<property>
    <name>mapreduce.job.reduces</name>
    <value>20</value>
</property>
<property>
    <name> mapreduce.input.fileinputformat.inputdir</name>
    <value>${nameNode}/user/${wf:user()}/payroll/input</value>
</property>
<property>
    <name> mapreduce.output.fileoutputformat.outputdir</name>
    <value>${nameNode}/user/${wf:user()}/payroll/result</value>
</property>
<property>
    <name>taxCode</name>
    <value>${taxCode}</value>
</property>
</configuration>
</map-reduce>
<ok to="compute-tax"/>
<error to="fail"/>
</action>

```

Notice a <map-reduce> job consists of properties you would expect, like the map class, reduce class, input and output formats, number of reduce tasks, etc.

## Submitting a Workflow Job

Oozie has a command-line tool named `oozie` for submitting and executing workflows. The command looks like:

```
# oozie job -config job.properties -run
```

The code `job.properties` contains the properties passed in to the workflow. Note that the workflow is typically deployed in HDFS and `job.properties` is typically kept on the local filesystem.

Notice the command above does not specify which Oozie workflow to execute. This is specified by the `oozie.wf.application.path` property:

```
oozie.wf.application.path=hdfs://node:8020/path/to/app
```

Here is an example of a `job.properties` file:

```
oozie.wf.application.path=hdfs://node:8020/path/to/app

#Hadoop ResourceManager resourceManager=node:8050

#Hadoop fs.default.name nameNode=hdfs://node:8020/

#Hadoop mapred.queue.name queueName=default
```

The `resourceManager` property was used in `workflow.xml` for the `<job-tracker>` value. Similarly, the `nameNode` property became the `<name-node>` value and the `queueName` property ended up as the value of `mapreduce.job.queuename` in `workflow.xml`. You define your application-specific properties in `job.properties`.

## Fork and Join Nodes

Oozie has fork and join nodes for controlling workflow. For example:

```
<fork name="forking">
    <path start="firstparalleljob"/>
    <path start="secondparalleljob"/>
</fork>
<action name="firstparalleljob">
    <map-reduce>
        ...
    </map-reduce>
    <ok to="joining"/>
    <error to="kill"/>
</action>
<action name="secondparalleljob">
    <map-reduce>
        ...
    </map-reduce>
    <ok to="joining"/>
    <error to="kill"/>
</action>
<join name="joining" to="nextaction"/>
```

## Defining an Oozie Coordinator Job

Oozie Coordinator is a component of Oozie that allows you to define jobs that are recurring Oozie workflows. These recurring jobs can be triggered by two types of events:

### time

Similar to a cron job

### data availability

The job triggers when a specified directory is created

An Oozie Coordinator job consists of two files:

`coordinator.xml`

The definition of the Coordinator application

`coordinator.properties`

For defining the job's properties

## Scheduling Based on Time

Let's take a look at an example of a `coordinator.xml` file. The following Coordinator is triggered based on time:

```
<coordinator-app name="tf-idf"
  frequency="1440"
  start="2013-01-01T00:00Z"
  end="2013-12-31T00:00Z"

  timezone="UTC"
  xmlns="uri:oozie:coordinator:0.1">

  <action>
    <workflow>
      <app-path> hdfs://node:8020/home/train/tfidf/workflow</app-path>
```

- The frequency is in minutes, so this job runs once a day
- Note the Oozie Coordinator has utility functions (similar to the Oozie workflow) like
- `${coord:days(1)}` for specifying the frequency in days
- The job starts at midnight on Jan 1, 2013, and runs every day for a year
- The `<app-path>` specifies the job to run, which is an Oozie workflow job

You submit an Oozie Coordinator job similar to submitting a workflow job:

```
# oozie job -config coordinator.properties -run
```

The `coordinator.properties` file contains the path to the coordinator app:  
`oozie.coord.application.path=hdfs://node:8020/path/to/app`

**Note**

Oozie also supports the scheduling of jobs similar to how cron jobs are scheduled.

## Scheduling Based on Data Availability

The following Coordinator application triggers a workflow job when a directory named `hdfs://node:8020/job/result/` gets created:

```
<coordinator-app name="file_check"
  frequency="1440" start="2012-01-01T00:00Z"
  end="2015-12-31T00:00Z" timezone="UTC"

  xmlns="uri:oozie:coordinator:0.1">
  <datasets>
    <dataset name="input1">
      <uri-template> hdfs://node:8020/job/result/
      </uri-template>
    </dataset>
  </datasets>
  <action>
    <workflow>
      <app-path>hdfs://node:8020/myapp/</app-path>
    </workflow>
  </action>
</coordinator-app>
```

This Coordinator app is scheduled to run once a day. If the folder `hdfs://node:8020/job/result/` exists, the `<action>` executes, which in this example is an Oozie workflow deployed in the `hdfs://node:8020/myapp` folder.

The assumption here is that some MapReduce job executes once a day at an unspecified time. When that job runs, it deletes the `hdfs://node:8020/job/result` directory and then creates a new one, which triggers the Coordinator to run. This Coordinator runs once a day, and if `/job/result` exists, the `/myapp` workflow will execute.

## Knowledge Check

Use the following questions and answers to assess your understanding of the concepts presented in this lesson.

### Questions

- 1 ) What are the two main capabilities of Oozie?
- 2 ) What file is required to be a part of an Oozie workflow?
- 3 ) List three common Oozie workflow actions:
- 4 ) What two types of events can be used to trigger an Oozie coordinator job?

## Answers

- 1 ) What are the two main capabilities of Oozie?

**Answer:** Oozie Workflow, for defining Hadoop job workflows; and the Oozie coordinator, for scheduling recurring workflows.

- 2 ) What file is required to be a part of an Oozie workflow?

**Answer:** Each Oozie workflow must contain a workflow.xml configuration file.

- 3 ) List three common Oozie workflow actions:

**Answer:** <pig>, <hive>, and <map-reduce>

- 4 ) What two types of events can be used to trigger an Oozie coordinator job?

**Answer:** Time based, where a job executes at a specific time; or data based, where a job executes if data is available in a specific location.

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