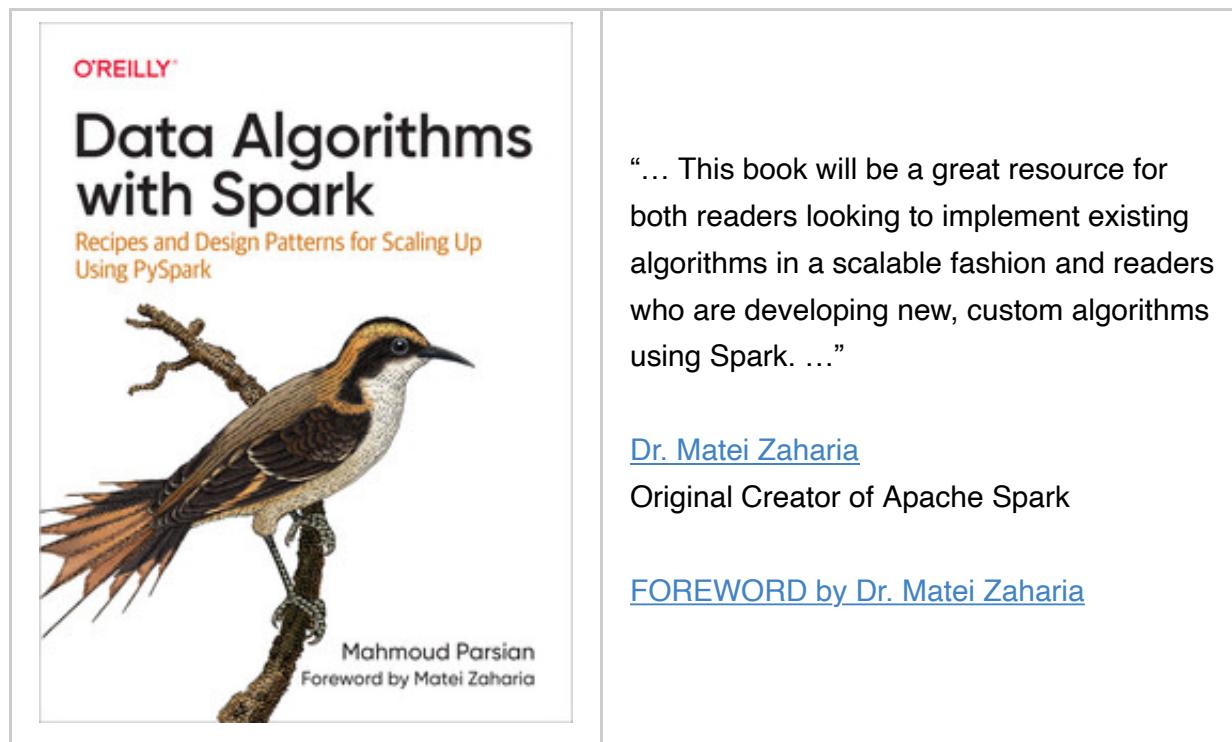


Glossary of Big Data, MapReduce, Spark

- This glossary is written for my students taking [Big Data Modeling & Analytics](#) at [Santa Clara University](#).
- Compiled and edited by: [Mahmoud Parsian](#)
- Last updated date: 2/3/2023



“... This book will be a great resource for both readers looking to implement existing algorithms in a scalable fashion and readers who are developing new, custom algorithms using Spark. ...”

[Dr. Matei Zaharia](#)

Original Creator of Apache Spark

[FOREWORD by Dr. Matei Zaharia](#)



MY GLOSSARY

Glossary

laptop: a small computer you can use on your lap

desktop: a large computer you use on a desk

keyboard: the buttons on a computer with letters and numbers

POWERTOON

Introduction

Big data is a vast and complex field that is constantly evolving, and for that reason, it's important to understand the basic common terms and the more technical vocabulary so that your understanding can evolve with it. The intention is to put these definitions and concepts in one single place for ease of exploring, searching and learning.

Big data environment involves many tools and technologies:

- Data preparation from multiple sources
- Engine for large-scale data analytics (such as Spark)
- ETL processes to analyze prepare data for Query engine
- Relational database systems
- Query engines such as Amazon Athena, Google BigQuery, Snowflake
- much more...

The purpose of this glossary is to shed some light on the fundamental definitions of big data and MapReduce, and Spark. This document is a list of terms, words, concepts, and examples found in or relating to big data, MapReduce, and Spark.

Algorithm

[Mohammed Ibn Musa-al-Khwarizmi](#) was a Persian mathematician and creator of the term: **algorithm**.

- An algorithm is a mathematical formula that can perform certain analyses on data
- An algorithm is a procedure used for solving a problem or performing a computation.
- An algorithm is a set of well-defined steps to solve a problem
- For example, given a set of words, sort them in ascending order
- For example, given a set of text documents, find frequency of every unique word
- For example, given a set of numbers, find (minimum, maximum) of given numbers

Typically an algorithm is implemented using a programming language such as Python, Java, SQL, ...

In big data world, an algorithm can be implemented using a compute engine such as MapReduce and Spark.



In *The Art of Computer Programming*, a famous computer scientist, [Donald E. Knuth](#), defines an algorithm as a set of steps, or rules, with five basic properties:

- 1) **Finiteness**: an algorithm must always terminate after a finite number of steps.
- 2) **Definiteness**: each step of an algorithm must be precisely defined
- 3) **Input**: an algorithm has zero or more inputs
- 4) **Output**: an algorithm has one or more outputs

5) **Effectiveness:** an algorithm is also generally expected to be effective

List of Algorithms

- Simple Algorithms (partial list):
 - Sum of list of numbers
 - Average of list of numbers
 - Median of list of numbers
 - Minimum and Maximum of list of numbers
 - Cartesian product of two sets
 - Given a list of numbers, find (number-of-zeros, number-of-negatives, number-of-positives)
 - Word Count: given a set of text documents, find frequency of every unique word in these documents
 - Given a set of integer numbers, identify prime and non-prime numbers
 - Anagrams Count: given a set of text documents, find frequency of every unique anagram in these documents
- Famous Algorithms (partial list):
 - Tree algorithms
 - Suffix Tree Algorithms
 - Red–Black tree algorithms
 - Dijkstra’s Algorithm.
 - Merge Sort.
 - Quicksort.
 - Depth First Search.
 - Breadth-First Search.
 - Linear Search
 - Binary Search.
 - Minimum Spanning Tree Algorithms.
 - Bloom Filter
 - All-Pairs Shortest Paths – Floyd Warshall Algorithm
 - Kmers for DNA sequences
 - Huffman Coding Compression Algorithm
 - Bioinformatics Algorithms
 - The Knuth-Morris-Pratt algorithm

Example of a Simple Algorithm

US Change Algorithm: Convert some amount of money (in cents/pennies) to fewest number of coins. Here we assume that the **penny**, **nickel**, **dime**, and **quarter** are the circulating coins that we use today.

- one quarter = 25 cents/pennies
- one dime = 10 cents
- one nickle = 5 cents/pennies
- Input: An amount of money, M , in cents/pennies
- Output: The smallest number of quarters q , dimes d , nickles n , and pennies p whose value add to M : the following rules must be satisfied:
 - $25q + 10d + 5n + p = M$ and
 - $q + d + n + p$ is as small as possible.

The following is a basic US Change Algorithm in Python. In this algorithm, we use the `divmod(arg1, arg2)` built-in function which returns a tuple containing the quotient and the remainder when `arg1` (dividend) is divided by `arg2` (divisor).

```

1 # M : number of pennies/cents
2 def change(M):
3     # step-0: make sure that M is an integer
4     if not(isinstance(M, int)):
5         print('M is not an integer')
6         return (0, 0, 0, 0)
7     #end-if
8
9     # here: M is an integer type
10    # step-1: make sure M > 0
11    if (M < 1):
12        return (0, 0, 0, 0)
13    #end-if
14
15    # step-2: find quarters as q
16    q, p = divmod(M, 25)
17    if (p == 0):
18        return (q, 0, 0, 0)
19    #end-if
20
21    # step-3: find dimes
22    d, p = divmod(p, 10)
23    if (p == 0):
24        return (q, d, 0, 0)
25    #end-if
26
27    # step-4: find nickles and pennies/cents
28    n, p = divmod(p, 5)
29
30    # step-5: return the result
31    return (q, d, n, p)
32 #end-def

```

Basic testing of the `change()` function:

```
1 >>> change(None)
2 M is not an integer
3 (0, 0, 0, 0)
4 >>> change([1, 2, 3])
5 M is not an integer
6 (0, 0, 0, 0)
7 >>> change('x')
8 M is not an integer
9 (0, 0, 0, 0)
10 >>> change(2.4)
11 M is not an integer
12 (0, 0, 0, 0)
13 >>> change(0)
14 (0, 0, 0, 0)
15 >>> change(141)
16 (5, 1, 1, 1)
17 >>> change(30)
18 (1, 0, 1, 0)
19 >>> change(130)
20 (5, 0, 1, 0)
21 >>> change(55089)
22 (2203, 1, 0, 4)
23 >>> change(44)
24 (1, 1, 1, 4)
```

Types of Algorithms

- Sorting algorithms: Bubble Sort, insertion sort, and many more. These algorithms are used to sort the data in a particular format.
- Searching algorithms: Linear search, binary search, etc. These algorithms are used in finding a value or record that the user demands.
- Graph Algorithms: It is used to find solutions to problems like finding the shortest path between cities, and real-life problems like traveling salesman problems.
- Dynamic Programming Algorithms

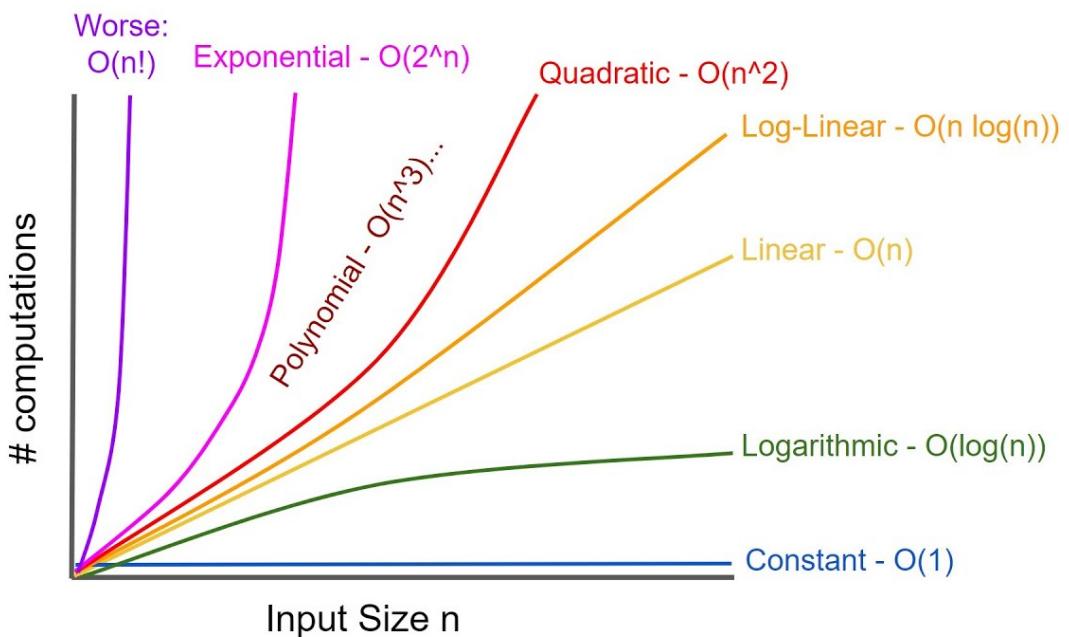
Algorithm Complexity

An algorithm is analyzed using Time Complexity and Space Complexity. Writing an efficient

algorithm help to consume the minimum amount of time for processing the logic. For algorithm A, it is judged on the basis of two parameters for an input of size n :

- **Time Complexity:** Time taken by the algorithm to solve the problem. It is measured by calculating the iteration of loops, number of comparisons etc. In computer science, the time complexity is the computational complexity that describes the amount of computer time it takes to run an algorithm.
- **Space Complexity:** Space taken by the algorithm to solve the problem. It includes space used by necessary input variables and any extra space (excluding the space taken by inputs) that is used by the algorithm. For example, if we use a hash table (a kind of data structure), we need an array to store values so this is an extra space occupied, hence will count towards the space complexity of the algorithm. This extra space is known as Auxiliary Space.

Computational Complexity of Algorithms:



Distributed algorithm

A distributed algorithm is an algorithm designed to run on computer hardware constructed from interconnected processors. Distributed algorithms are used in different application areas of distributed computing, such as DNA analysis, telecommunications, scientific computing, distributed information processing, and real-time process control. Standard problems solved by distributed algorithms include leader election, consensus, distributed search, spanning tree generation, mutual exclusion, finding association of genes in DNA, and resource allocation.

Distributed algorithms run in parallel/concurrent environments.

In implementing distributed algorithms, you have to make sure that your aggregations and reductions are semantically correct (since these are executed partition by partition) regardless of the number of partitions for your data. For example, you need to remember that average of an average is not an average.

Example of systems running distributed algorithms:

- Apache Spark can be used to implement and run distributed algorithms.
- MapReduce/Hadoop can be used to implement and run distributed algorithms.

Partitioner

Partitioner is a program, which distributes the data across the cluster. The types of partitioners are

- Hash Partitioner
- Murmur3 Partitioner
- Random Partitioner
- Order Preserving Partitioner

For example, an Spark RDD of $480,000,000,000$ elements might be partitioned in to $60,000$ chunks (partitions), where each chunk/partition will have a bout $8,000,000$ elements.

$$1 \mid 480,000,000,000 = 60,000 \times 8,000,000$$

One of the main reasons of data partitioning is to process many small partitions in parallel (at the same time) to reduce the overall data processing time.

Aggregation

- A process of searching, gathering and presenting data.
- Data aggregation refers to the process of collecting data and presenting it in a summarised format. The data can be gathered from multiple sources to be combined for a summary.

Data Aggregation

Data aggregation refers to the collection of data from multiple sources to bring all the data together into a common athenaeum for the purpose of reporting and/or analysis.

- Data aggregation is the process of compiling typically some large amounts of information from a given database and organizing it into a more consumable and comprehensive medium.
- For example, find average age of customer by product
- For example, find median rating for movies rated last year

What is Data Aggregation? Data aggregators summarize data from multiple data sources. They provide capabilities for multiple aggregate measurements, such as sum, median, average and counting.

Analytics

- The discovery of insights in data, find interesting patterns in data
- For example, given a graph, find (identify) all of the triangles
- For example, given a DNA data, find genes, which are associated with each other

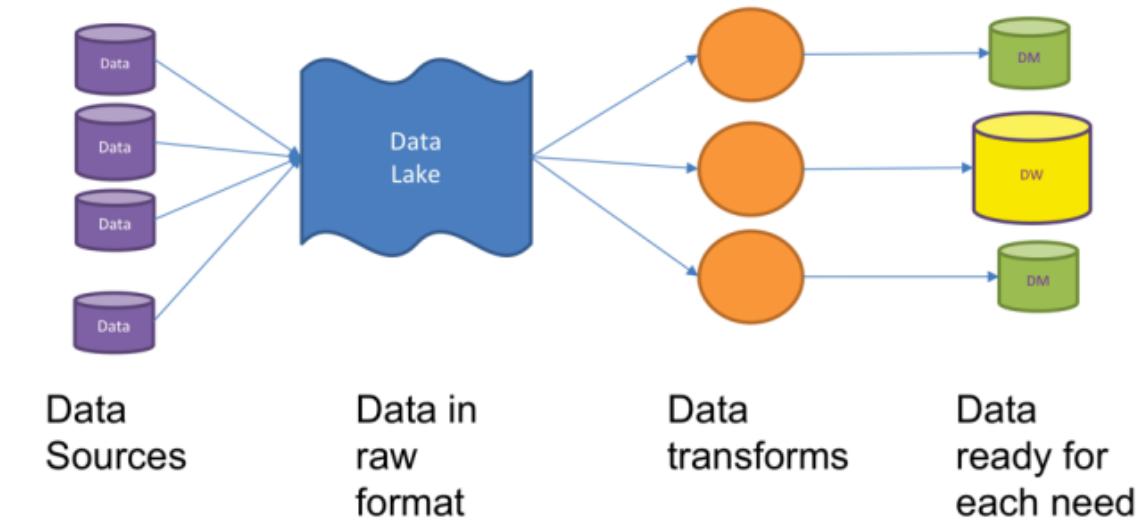
What is Data Analytics? Data analytics helps individuals and organizations make sense of data. Data analysts typically analyze raw data for insights, patterns, and trends.

According to NIST: “analytics is the systematic processing and manipulation of data to uncover patterns, relationships between data, historical trends and attempts at predictions of future behaviors and events.”

Data Lake

A data lake is a centralized repository that allows you to store all your structured and unstructured data at any scale.

The Data Lake Pattern



A storage repository that holds a vast amount of raw data in its native format until it's required. Every data element within a data lake is assigned a unique identifier and set of extended metadata tags. When a business question arises, users can access the data lake to retrieve any relevant, supporting data.

Data Science

Data Science is the field of applying advanced analytics techniques and scientific principles to extract valuable information from data. Data science typically involves the use of statistics, data visualization and mining, computer programming, machine learning and database engineering to solve complex problems.

Data science is the methodology for the synthesis of useful knowledge directly from data through a process of discovery or of hypothesis formulation and hypothesis testing. Data science is tightly linked to the analysis of Big Data, and refers to the management and execution of the end-to-end data processes, including the behaviors of the components of the data system. As such, data science includes all of analytics as a step in the process. Data science contains different approaches to leveraging data to solve mission needs. While the term data science can be understood as the activities in any analytics pipeline that produces knowledge from data, the term is typically used in the context of Big Data.

Data Science Process

According to [NIST](#), Data Science is focused on the end-to-end data processing life cycle of Big Data and related activities. The data science life cycle encompasses the data analytics life cycle (as described below) plus many more activities including policy and regulation, governance, operations, data security, master data management, meta-data management, and retention/destruction. The data analytics life cycle is focused on the processing of Big Data, from data capture to use of the analysis. The data analytics life cycle is the set of processes that is guided by the organizational need to transform raw data into actionable knowledge, which includes data collection, preparation, analytics, visualization, and access.

The end-to-end data science life cycle consists of five fundamental steps:

1. **Capture**: gathering and storing data, typically in its original form (i.e., raw data);
2. **Preparation**: processes that convert raw data into cleaned, organized information;
3. **Analysis**: techniques that produce synthesized knowledge from organized information;
4. **Visualization**: presentation of data or analytic results in a way that communicates to others;
5. **Action**: processes that use the synthesized knowledge to generate value for the enterprise.

Anonymization

- Making data anonymous; removing all data points that could lead to identify a person
- For example, replacing social security numbers with fake 18 digit numbers
- For example, replacing patient name with fake ID.

API

- An Application Programming Interface (API) is a set of function definitions, protocols, and tools for building application software. What Are APIs Used For? APIs are used to abstract the complexity of back-end logic in a variety of software systems.
- For example, MapReduce paradigm provides the following functions
 - mapper: `map()`
 - reducer: `reduce()`

- combiner: `combine()` [optional]
- For example, Apache Spark provides
 - RDDs and DataFrames as Data Abstractions
 - mappers: `map()`, `flatMap()`, `mapPartitions()`
 - filters: `filter()`
 - reducers: `groupByKey()`, `reduceByKey()`, `combineByKey()`
 - SQL access to DataFrames
- For example, Google Maps API: The Google Maps API gives users the privilege of nearly limitless geographic aptitude at their fingertips. Search nearby restaurants, niche shops, and whatever else is in relative distance to your location.
- SQL API:
 - CREATE TABLE
 - DROP TABLE
 - INSERT row(s)
 - DELETE row(s)
 - UPDATE row(s)
 - ...

Application

- An Application is a computer software that enables a computer to perform a certain task
- For example, a payroll application, which issues monthly checks to employees
- For example, a MapReduce application, which identifies and eliminates duplicate records
- For example, an Spark application, which finds close and related communities in a given graph
- For example, an Spark application, which finds rare variants for DNA samples

Data sizes

- Bit: `0` or `1`
- Byte: 8 bits (`00000000 .. 11111111`) : can represent 256 combinations (0 to 255)
- KB = Kilo Byte = 1,024 bytes = 2^{10} bytes ~ 1000 bytes
- MB = Mega Byte = $1,024 \times 1,024$ bytes = 1,048,576 bytes ~ 1000 KB
- GB = Giga Byte = $1,024 \times 1,024 \times 1,024$ bytes = 1,073,741,824 bytes ~ 1000 MB
- TB = Tera Byte = $1,024 \times 1,024 \times 1,024 \times 1024$ bytes = 1,099,511,627,776 bytes ~ 1000 GB

- PB = Peta Byte = $1,024 \times 1,024 \times 1,024 \times 1024 \times 1024$ bytes = 1,125,899,906,842,624 bytes ~ 1000 TB
- EB = Exa Byte = $1,152,921,504,606,846,976 (= 2^{60})$ bytes ~ 1000 PB
- ZB = Zetta Byte = $1,208,925,819,614,629,174,706,176$ bytes ($= 2^{80}$) bytes

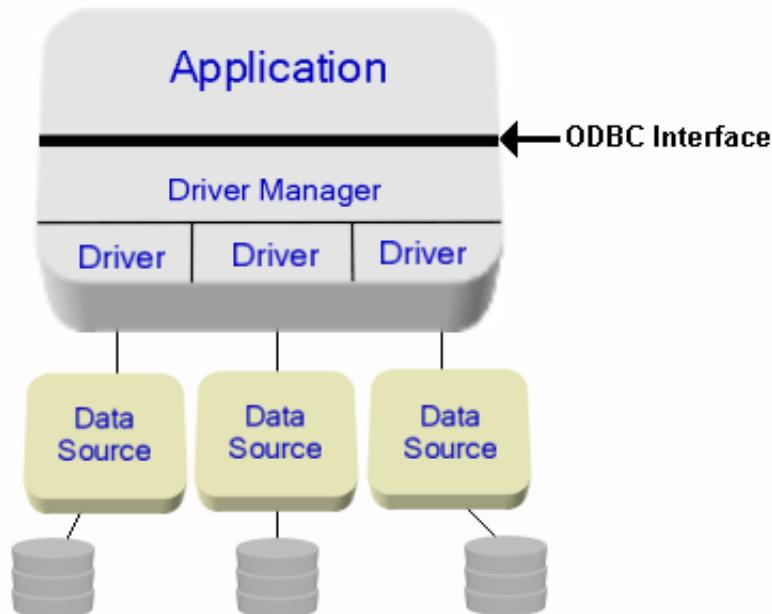
~ denotes “about”

Behavioural Analytics

Behavioural Analytics is a kind of analytics that informs about the how, why and what instead of just the who and when. It looks at humanized patterns in the data.

ODBC

Open Database Connectivity (ODBC) is a standard application programming interface (API) for accessing database management systems (DBMS). The designers of ODBC aimed to make it independent of database systems and operating systems. An application written using ODBC can be ported to other platforms, both on the client and server side, with few changes to the data access code.

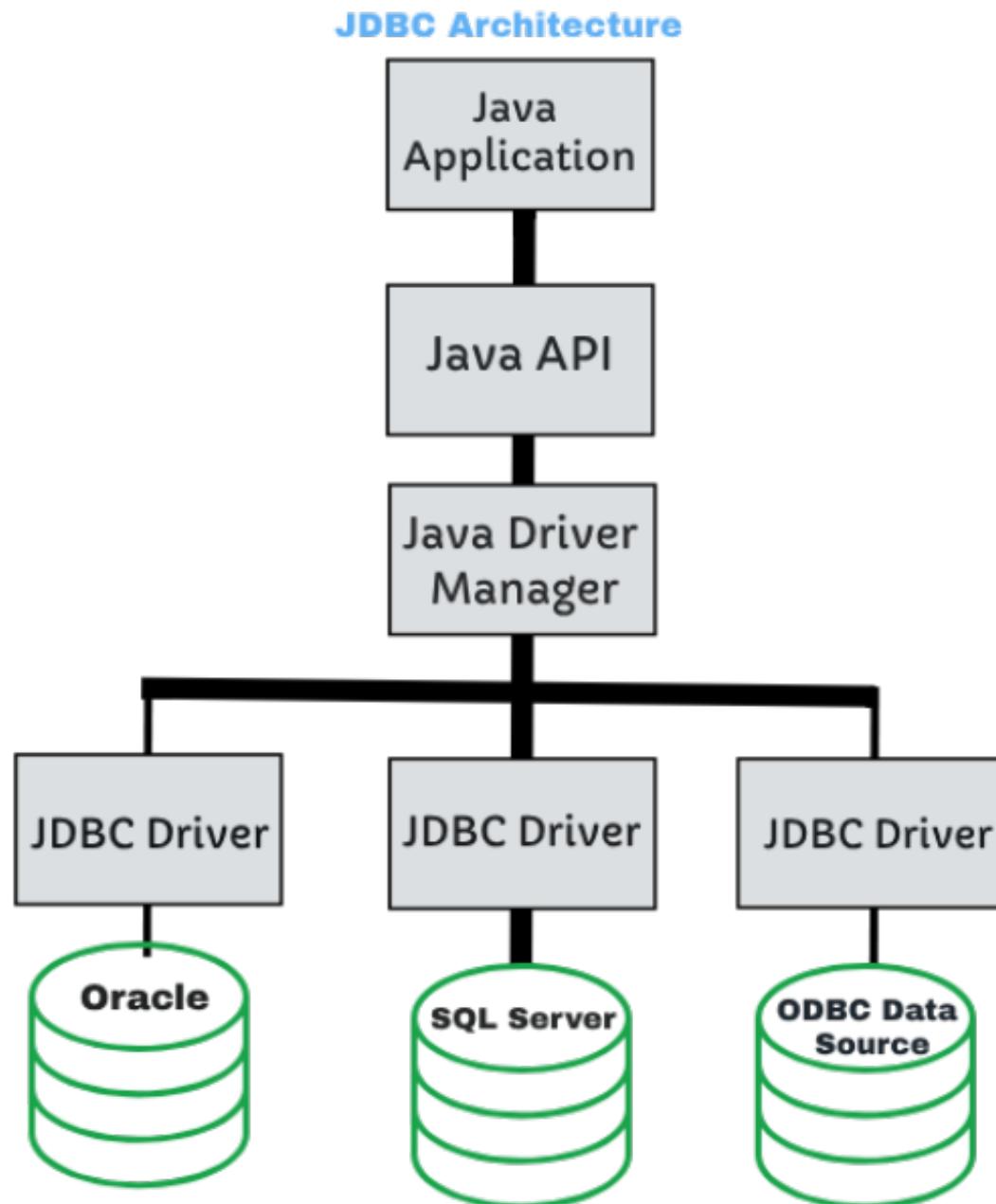


Open Database Connectivity (ODBC) is a protocol that you can use to connect a Microsoft Access database to an external data source such as Microsoft SQL Server.

JDBC

Java database connectivity (JDBC) is the specification of a standard application programming interface (API) that allows Java programs to access database management systems. The JDBC API consists of a set of interfaces and classes written in the Java programming language.

Using these standard interfaces and classes, programmers can write applications that connect to databases, send queries written in structured query language (SQL), and process the results.



Since JDBC is a standard specification, one Java program that uses the JDBC API can connect to any database management system (DBMS), as long as a driver exists for that particular

DBMS.

Big Data

Big Data consists of extensive datasets – primarily in the characteristics of volume, velocity, variety, and/or variability – that require a scalable architecture for efficient storage, manipulation, and analysis.

Big data is an umbrella term for any collection of data sets so large or complex that it becomes difficult to process them using traditional data-processing applications. In a nutshell, big data refers to data that is so large, fast or complex that it's difficult or impossible to process using traditional methods. Also, big data deals with accessing and storing large amounts of information for analytics.

So, what is Big Data? Big Data is a large data set with increasing volume, variety and velocity.

Big data solutions may have many components (to mention some):

- Distributed File System (such as HDFS, Amazon S3)
- Analytics Engine (such as Spark)
- Query Engine (Such as Snowflake, Amazon Athena, Google BigQuery, ...)
- ETL Support
- Relational database systems
- Search engine (sich as Apache Solr, Apache Lucene)
- ...

Big Data Engineering

Big Data engineering is the discipline for engineering scalable systems for data-intensive processing.

Data collected from different sources are in a raw format, i.e., usually in a form that is not fit for Data Analysis. The idea behind what is Big Data Engineering is not only to collect Big Data but also to transform and store it in a dedicated database that can support insights generation or the creation of Machine Learning based solutions.

Data Engineers are the force behind Data Engineering that is focused on gathering information from disparate sources, transforming the data, devising schemas, storing data, and managing its flow.

Big Data Modeling

What is Big Data Modeling? Data modeling is the method of constructing a specification for the storage of data in a database. It is a theoretical representation of data objects and relationships between them. The process of formulating data in a structured format in an information system is known as data modeling.

In a practical sense, Big Data Modeling involves:

- **Queries:** understand queries and algorithms, which needs to be implemented using big data
- **Formalizing Queries:** understanding queries for big data (how big data will be accessed, what are the parameters to these queries): this is a very important step to understand queries before designing proper data model
- **Data Model:** once queries are understood, then design a data model, which optimally satisfies queries
- **Data Analytics Engine:** engine which distributed algorithms and ETL will run; for example: Apache Spark
- **ETL Processes:** design and implement ETL processes to build big data in a suitable format and environment
- **Scalability:** scalability needs to be understood and addressed at every level

Big Data Platforms/Solutions

- Apache Hadoop, which implements a MapReduce paradigm. Hadoop is slow and very complex (does not take advantage of RAM/memory). Hadoop's analytics API is limited to `map-then-reduce` functions.
- Apache Spark, which implements a superset of MapReduce paradigm: it is fast, and has a very simple and powerful API and works about 100 times faster than Hadoop. Spark takes advantage of memory and embraces in-memory computing. Spark can be used for ETL and implementing many types of distributed algorithms.
- Apache Tez
- Amazon Athena (mainly used as a query engine)
- Snowflake (mainly used as a query engine)
- Google BigQuery: is a serverless and multicloud data warehouse designed to help you turn big data into valuable business insights

Biometrics

The use of data and technology to identify people by one or more of their physical traits (for example, face recognition)

Data Modelling

The analysis of data sets using data modelling techniques to create insights from the data:

- data summarization,
- data aggregation,
- joining data

There are 5 different types of data models:

- **Hierarchical Data Model:** A hierarchical data model is a structure for organizing data into a tree-like hierarchy, otherwise known as a parent-child relationship.
- **Relational Data Model:** relational model represents the database as a collection of relations. A relation is nothing but a table of values (or rows and columns).
- **Entity-relationship (ER) Data Model:** an entity relationship diagram (ERD), also known as an entity relationship model, is a graphical representation that depicts relationships among people, objects, places, concepts or events within an information technology (IT) system.
- **Object-oriented Data Model:** the Object-Oriented Model in DBMS or OODM is the data model where data is stored in the form of objects. This model is used to represent real-world entities. The data and data relationship is stored together in a single entity known as an object in the Object Oriented Model.
- **Dimensional Data Model:** Dimensional Modeling (DM) is a data structure technique optimized for data storage in a Data warehouse. The purpose of dimensional modeling is to optimize the database for faster retrieval of data. The concept of Dimensional Modelling was developed by Ralph Kimball and consists of “fact” and “dimension” tables.

Design Patterns

What is a design pattern? In software engineering, a design pattern is a general repeatable solution to a commonly occurring problem in software design. In general, design patterns are categorized mainly into three categories:

- Creational Design Pattern
- Structural Design Pattern

- Behavioral Design Pattern

Gang of Four (Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides) Design Patterns is the collection of 23 design patterns from the book [Design Patterns: Elements of Reusable Object-Oriented Software](#).

What are **data design patterns**? Data Design Pattern is a general repeatable solution to a commonly occurring data problem in big data area.

The following are common **Data Design Patterns**:

- Summarization patterns
- Filtering patterns
- In-Mapper patterns
- Data Organization patterns
- Join patterns
- Meta patterns
- Input/Output patterns

The data design patterns can be implemented by MapReduce and Spark and other big data solutions.

Data Set

A collection of (structured, semi-structured, and unstructured) data.

Example of Data Sets:

- DNA data samples for 10,000 patients can be a data set.
- Daily log files for a search engine
- Weekly credit card transactions
- Monthly flight data for a country
- Twitter daily data
- Facebook daily messages

Data Type

In computer science and computer programming, a **data type** (or simply type) is a set of possible values and a set of allowed operations on it. A data type tells the compiler or interpreter how the programmer intends to use the data.

For example,

- [Java](#) is a strongly typed (strong typing means that the type of a value doesn't change in unexpected ways) language, every variable must be defined by an explicit data type before usage. Java is considered strongly typed because it demands the declaration of every variable with a data type. Users cannot create a variable without the range of values it can hold.
 - Java example

```
1 // bob's data type is int
2 int bob = 1;
3
4 // bob can not change its type: the following line is invalid
5 // String bob = "bob";
6
7 // but, you can use another variable name
8 String bob_name = "bob";
```

- [Python is strongly, dynamically typed:](#)
 - Strong typing means that the type of a value doesn't change in unexpected ways. A string containing only digits doesn't magically become a number, as may happen in Perl. Every change of type requires an explicit conversion.
 - Dynamic typing means that runtime objects (values) have a type, as opposed to static typing where variables have a type.

- Python example

```
1 # bob's data type is int
2 bob = 1
3
4 # bob's data type changes to str
5 bob = "bob"
```

This works because the variable does not have a type; it can name any object. After `bob=1`, you'll find that `type(bob)` returns `int`, but after `bob="bob"`, it returns `str`. (Note that `type` is a regular function, so it evaluates its argument, then returns the type of the value.)

Primitive Data Type

A data type that allows you to represent a single data value in a single column position. In a nutshell, a primitive data type is either a data type that is built into a programming language, or one that could be characterized as a basic structure for building more sophisticated data types.

- Java examples:

```
1 | int a = 10;
2 | boolean b = true;
3 | double d = 2.4;
4 | String s = "fox";
5 | String t = null;
```

- Python examples:

```
1 | a = 10
2 | b = True
3 | d = 2.4
4 | s = "fox"
5 | t = None
```

Composite Data Type

In computer science, a composite data type or compound data type is any data type which can be constructed in a program using the programming language's primitive data types.

- Java examples:

```
1 | import java.util.Arrays;
2 | import java.util.List;
3 | ...
4 | int[] a = {10, 11, 12};
5 | List<String> names = Arrays.asList("n1", "n2", "n3");
```

- Python examples:

```
1 | a = [10, 11, 12];
2 | names = ("n1", "n2", "n3") # immutable
3 | names = ["n1", "n2", "n3"] # mutable
```

In Java and Python, custom composite data types can be created by the concept of “class” and objects are created by instantiation of the class objects.

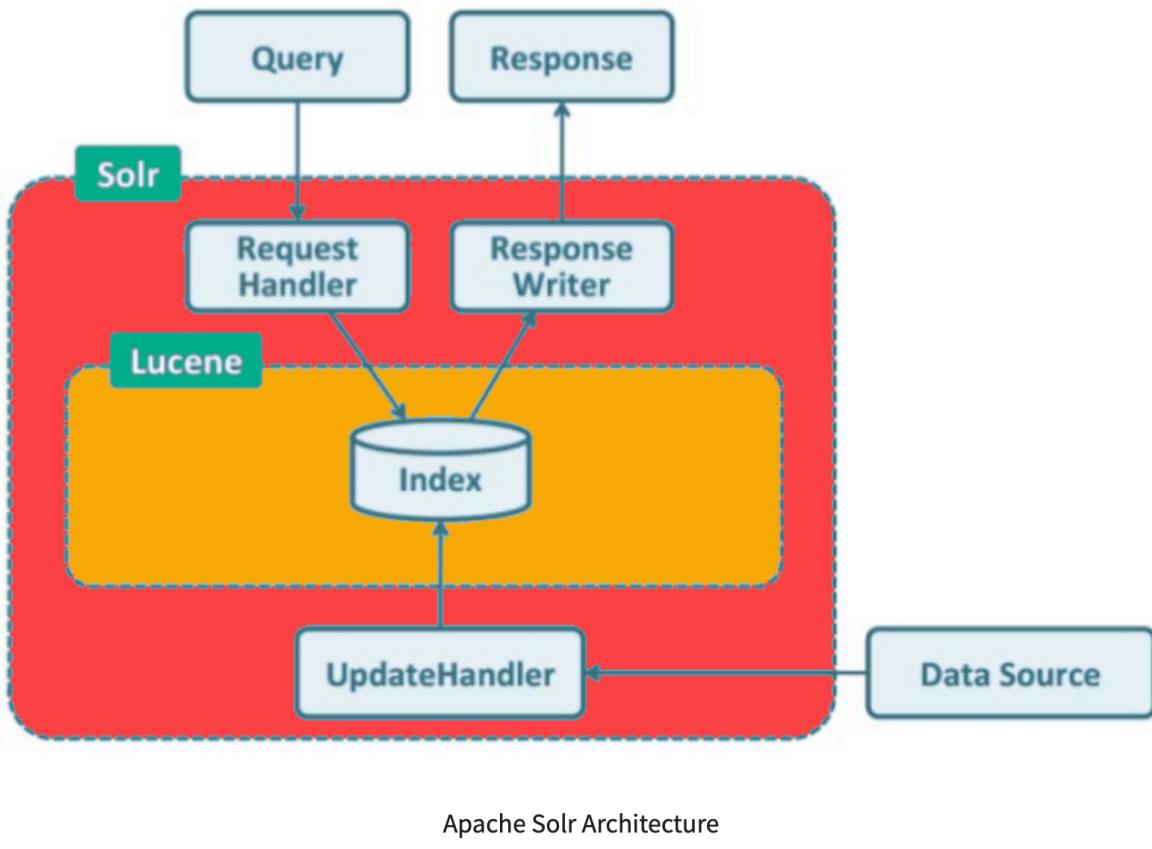
Apache Lucene

[Lucene](#) is an open-source search engine software library written in Java. It provides robust search and indexing features.

Apache Lucene is a high-performance, full-featured search engine library written entirely in Java. It is a technology suitable for nearly any application that requires structured search, full-text search, faceting, nearest-neighbor search across high dimensionality vectors, spell correction or query suggestions.

Apache Solr

[Solr](#) is the popular, blazing-fast, open source enterprise search platform built on Apache Lucene. Solr is highly reliable, scalable and fault tolerant, providing distributed indexing, replication and load-balanced querying, automated failover and recovery, centralized configuration and more. Solr powers the search and navigation features of many of the world’s largest internet sites.

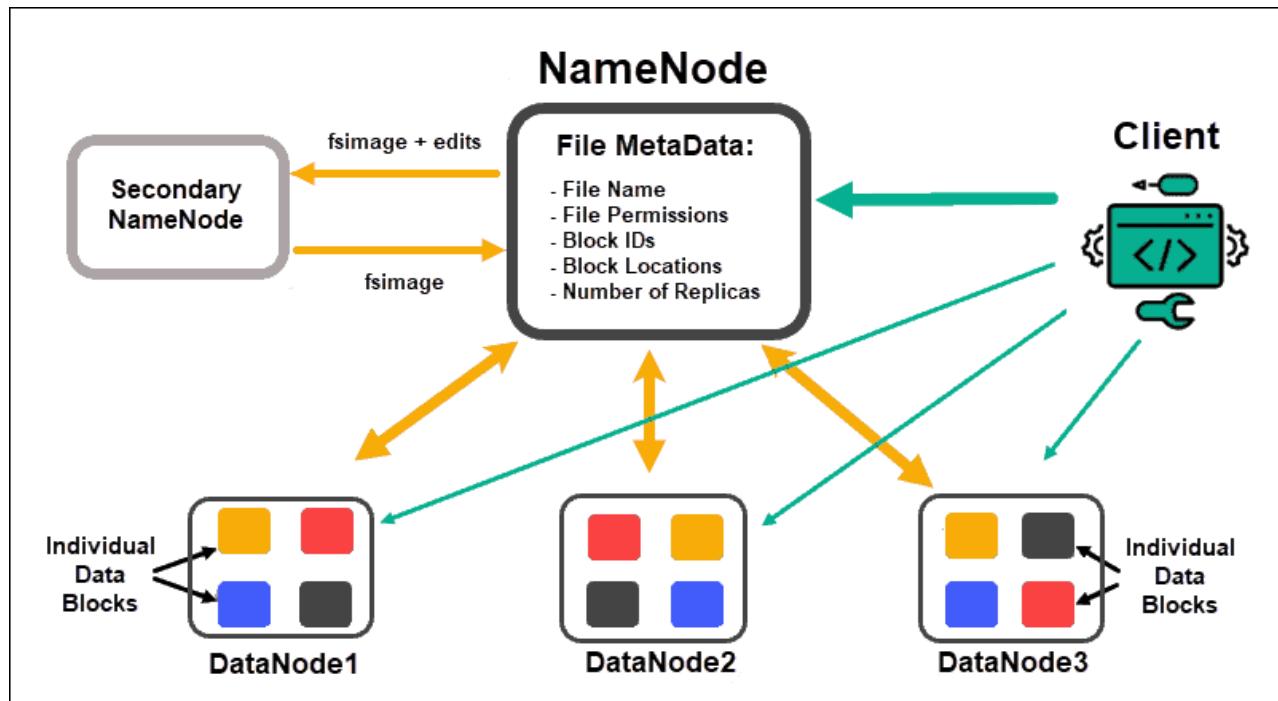


Apache Hadoop

[Hadoop](#) is an open source framework that is built to enable the process and storage of big data across a distributed file system. Hadoop implements MapReduce paradigm, it is slow and complex and uses disk for read/write operations. Hadoop does not take advantage of in-memory computing. Hadoop runs a computing cluster.

Hadoop takes care of running your MapReduce code (by `map()` first, then `reduce()` logic) across a cluster of machines. Its responsibilities include chunking up the input data, sending it to each machine, running your code on each chunk, checking that the code ran, passing any results either on to further processing stages or to the final output location, performing the sort that occurs between the `map` and `reduce` stages and sending each chunk of that sorted data to the right machine, and writing debugging information on each job's progress, among other things.

Hadoop architecture:



NameNode is the master node in the Apache Hadoop HDFS Architecture that maintains and manages the blocks present on the DataNodes (worker nodes). NameNode is a very highly available server that manages the File System Namespace and controls access to files by clients.

Hadoop provides:

- MapReduce: you can run MapReduce jobs by implementing `map()` first, then `reduce()` functions.
- HDFS: Hadoop Distributed File System

What is the difference between Hadoop and RDBMS?

- Hadoop is an implementation of MapReduce paradigm
- RDBMS denotes a relational database system such as Oracle, MySQL, Maria

Criteria	Hadoop	RDBMS
Data Types	Processes semi-structured and unstructured data	Processes structured data
Schema	Schema on Read	Schema on Write
Best Fit for Applications	Data discovery and Massive Storage/Processing of Unstructured data.	Best suited for OLTP and ACID transactions
Speed	Writes are Fast	Reads are Fast
Data Updates	Write once, Read many times	Read/Write many times
Data Access	Batch	Interactive and Batch
Data Size	Tera bytes to Peta bytes	Giga bytes to Tera bytes
Development	Time consuming and complex	Simple
API	Low level (by <code>map()</code> and <code>reduce()</code>) functions	SQL and extensive

Replication Factor (RF)

The total number of replicas across the cluster is referred to as the replication factor (RF). A replication factor of 1 means that there is only one copy of each row in the cluster. If the node containing the row goes down, the row cannot be retrieved. A replication factor of 2 means two copies of each row, where each copy is on a different node. All replicas are equally important; there is no primary or master replica.

Given a cluster of $N+1$ nodes (a master and N worker nodes), if data replication factor is R , then $(R - 1)$ nodes can safely fail without impacting any running job in the cluster.

What makes Hadoop Fault tolerant?

Hadoop is said to be highly fault tolerant. Hadoop achieves this feat through the process of data replication. Data is replicated across multiple nodes in a Hadoop cluster. The data is associated with a replication factor (RF), which indicates the number of copies of the data that are present across the various nodes in a Hadoop cluster. For example, if the replication factor is 4, the data

will be present in four different nodes of the Hadoop cluster, where each node will contain one copy each. In this manner, if there is a failure in any one of the nodes, the data will not be lost, but can be recovered from one of the other nodes which contains copies or replicas of the data.

If replication factor is N , then $N-1$ nodes can safely fail without impacting a running job.

Big Data Formats

Data comes in many varied formats:

- Avro
 - Avro stores the data definition in JSON format making it easy to read and interpret
- Parquet
 - Parquet is an open source, binary, column-oriented data file format designed for efficient data storage and retrieval
- ORC
 - The Optimized Row Columnar (ORC) file format provides a highly efficient way to store Hive data.
- Text files (log data, CSV, ...)
- XML
- JSON
- JDBC (read/write from/to relational tables)
- ...

Parquet Files

[Apache Parquet](#) is a columnar file format that supports block level compression and is optimized for query performance as it allows selection of 10 or less columns from from 50+ columns records.

Apache Spark can read/write from/to Parquet data format.

Parquet is a columnar open source storage format that can efficiently store nested data which is

widely used in Hadoop and Spark.

Characteristics of Parquet:

- Free and open source file format.
- Language agnostic.
- Column-based format - files are organized by column, rather than by row, which saves storage space and speeds up analytics queries.
- Used for analytics (OLAP) use cases, typically in conjunction with traditional OLTP databases.
- Highly efficient data compression and decompression.
- Supports complex data types and advanced nested data structures.

Benefits of Parquet:

- Good for storing big data of any kind (structured data tables, images, videos, documents).
- Saves on cloud storage space by using highly efficient column-wise compression, and flexible encoding schemes for columns with different data types.
- Increased data throughput and performance using techniques like data skipping, whereby queries that fetch specific column values need not read the entire row of data.

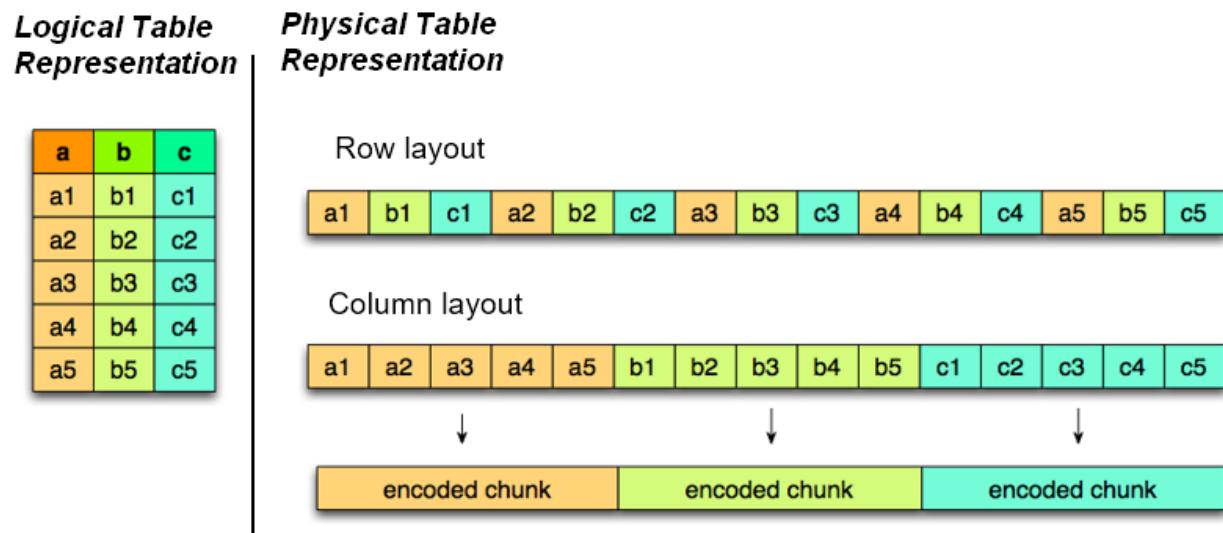
Spark Format Showdown		File Format		
		CSV	JSON	Parquet
A t t r i b u t e	Columnar	No	No	Yes
	Compressable	Yes	Yes	Yes
	Splittable	Yes*	Yes**	Yes
	Human Readable	Yes	Yes	No
	Nestable	No	Yes	Yes
	Complex Data Structures	No	Yes	Yes
	Default Schema: Named columns	Manual	Automatic (full read)	Automatic (instant)
	Default Schema: Data Types	Manual (full read)	Automatic (full read)	Automatic (instant)

Columnar vs. Row Oriented Databases

Columnar databases have become the popular choice for storing analytical data workloads. In a nutshell, Column oriented databases, store all values from each column together whereas row oriented databases store all the values in a row together.

If you need to read MANY rows but only a FEW columns, then Column-Oriented databases are

the way to go. If you need to read a FEW rows but MANY columns then row oriented databases are better suited.



Tez

[Apache Tez](#) (which implements MapReduce paradigm) is a framework to create high performance applications for batch and data processing. YARN of Apache Hadoop coordinates with it to provide the developer framework and API for writing applications of batch workloads.

The Tez is aimed at building an application framework which allows for a complex directed-acyclic-graph (DAG) of tasks for processing data. It is currently built atop Apache Hadoop YARN.

Apache HBase

[Apache HBase](#) is an open source, non-relational, distributed database running in conjunction with Hadoop. HBase can support billions of data points.

Features of HBase:

- HBase is linearly scalable.
- It has automatic failure support.
- It provides consistent read and writes.
- It integrates with Hadoop, both as a source and a destination.
- It has easy Java API for client.
- It provides data replication across clusters.

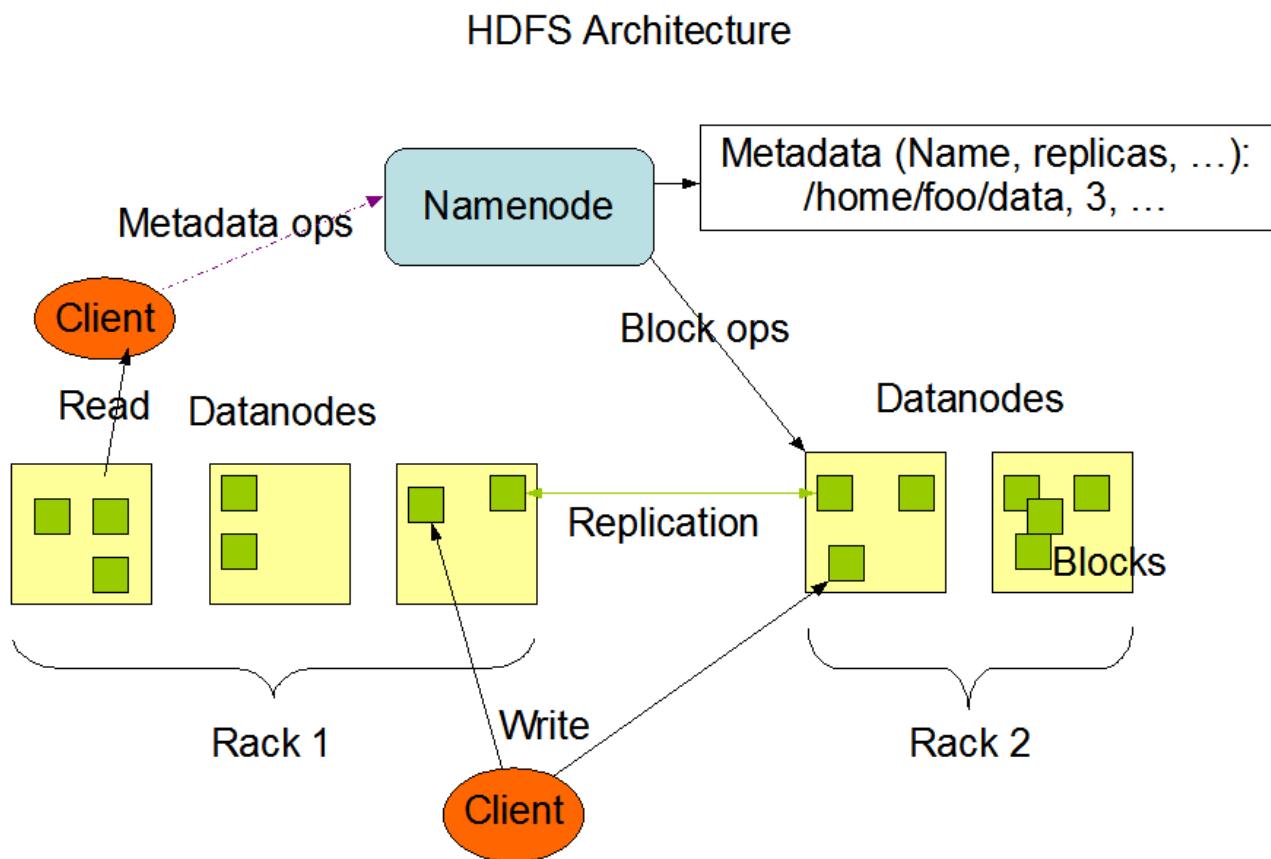
Google Bigtable

According to Google: [Google Bigtable](#) is an HBase-compatible, enterprise-grade NoSQL database service with single-digit millisecond latency, limitless scale, and 99.999% availability for large analytical and operational workloads.

Bigtable is a fully managed wide-column and key-value NoSQL database service for large analytical and operational workloads as part of the Google Cloud portfolio.

HDFS

[HDFS](#) (Hadoop Distributed File System) is a distributed file system designed to run on commodity hardware. You can place huge amount of data in HDFS. You can create new files or directories. You can delete files, but you can not edit/update files in place.



Features of HDFS:

- Data replication. This is used to ensure that the data is always available and prevents data loss

- Fault tolerance and reliability
 - High availability
 - Scalability
 - High throughput
 - Data locality
- HDFS General format:

```
1 | hdfs://<host>:<port>/folder_1/.../folde_n/file
```

- HDFS Example:

```
1 | hdfs://localhost:8020/data/2023-01-07/samples.txt
```

Amazon S3

Amazon Simple Storage Service (Amazon S3) is an object storage service that offers industry-leading scalability, data availability, security, and performance. Customers of all sizes and industries can use Amazon S3 to store and protect any amount of data for a range of use cases, such as data lakes, websites, mobile applications, backup and restore, archive, enterprise applications, IoT devices, and big data analytics. Amazon S3 provides management features so that you can optimize, organize, and configure access to your data to meet your specific business, organizational, and compliance requirements.

Objects are the fundamental entities stored in Amazon S3. Objects are stored as:

- General format:

```
1 | s3://<bucket-name>/folder_1/.../folde_n/file
```

- Example:

```
1 | s3://my_bucket_name/data/2023-01-07/samples.txt
```

Amazon Athena

The Amazon Athena is widely used and is defined as an interactive query service that makes it

easy to analyze data in Amazon S3 using the standard SQL.

- Amazon Athena is serverless, so there is no infrastructure to manage, and users pay only for the queries that they run.
- Amazon Athena is easy to use and simply point to users' data in Amazon S3, define the schema, and start querying using standard SQL.
- Most results are delivered within seconds. With Athena, there's no need for complex ETL jobs to prepare user's data for the analysis and this makes it easy for anyone with SQL skills to quickly analyze large-scale datasets.
- Amazon Athena is out-of-the-box integrated with the AWS Glue Data Catalog allowing users to create the unified metadata repository across various services, crawl data sources to discover schemas and populate their Catalog with new and modified table and partition definitions, and maintain the schema versioning.
- Amazon Athena is the serverless data query tool which means it is scalable and cost-effective at the same time. Usually, customers are charged on a pay per query basis which further translates to the number of queries that are executed at a given time.
- The normal charge for scanning 1TB of data from S3 is 5 USD and although it looks quite a small amount at a first glance when users have multiple queries running on hundreds and thousands of GB of data, the price might get out of control at times.

Google BigQuery

- BigQuery is a serverless and cost-effective enterprise data warehouse.
- BigQuery supports the Google Standard SQL dialect, but a legacy SQL dialect is also available.
- BigQuery has built-in machine learning and BI that works across clouds, and scales with your data.
- BigQuery is a fully managed enterprise data warehouse that helps you manage and analyze your data with built-in features like machine learning, geospatial analysis, and business intelligence.
- BigQuery's query engine can run SQL queries on terabytes of data within seconds, and petabytes within minutes. BigQuery gives you this performance without the need to maintain the infrastructure or rebuild or create indexes. BigQuery's speed and scalability

make it suitable for use in processing huge datasets.

- BigQuery storage: BigQuery stores data using a columnar storage format that is optimized for analytical queries. BigQuery presents data in tables, rows, and columns and provides full support for database transaction semantics (ACID). BigQuery storage is automatically replicated across multiple locations to provide high availability.
- With Google Cloud's pay-as-you-go pricing structure, you only pay for the services you use.

Commodity server/hardware

Commodity hardware (computer), sometimes known as off-the-shelf server/hardware, is a computer device or IT component that is relatively inexpensive, widely available and basically interchangeable with other hardware of its type. Since commodity hardware is not expensive, it is used in building/creating clusters for big data computing (scale-out architecture). Commodity hardware is often deployed for high availability and disaster recovery purposes.

Fault Tolerance and Data Replication.

Fault-tolerance is the ability of a system to continue to run when a component of the system (such as a server node, disk, ...) fails.

HDFS is designed to reliably store very large files across machines in a large cluster. It stores each file as a sequence of blocks; all blocks in a file except the last block are the same size. The blocks of a file are replicated for fault tolerance.

Block size can be configured. For example, let block size to be 512MB. Now, let's place a file (sample.txt) of 1800MB in HDFS:

```
1 | 1800MB = 512MB (Block-1) + 512MB (Block-2) + 512MB (Block-3) + 264MB (Block-4)
2 | Lets denote
3 |     Block-1 by B1
4 |     Block-2 by B2
5 |     Block-3 by B3
6 |     Block-4 by B4
```

Note that the last block has only 264MB of useful data.

Let's say, we have a cluster of 6 nodes (one master and 5 worker nodes {W1, W2, W3, W4, W5})

and master does not store any data), also assume that the replication factor is 2, therefore, blocks will be placed as:

1	W1: B1, B4
2	W2: B2, B3
3	W3: B3, B1
4	W4: B4
5	W5: B2

Fault Tolerance: if replication factor is N , then $(N-1)$ nodes can safely fail without a job fails.

High-Performance-Computing (HPC)

Using supercomputers to solve highly complex and advanced computing problems. This is a scale-up architecture and not a scale-out architecture.

Hadoop and Spark use scale-out architectures.

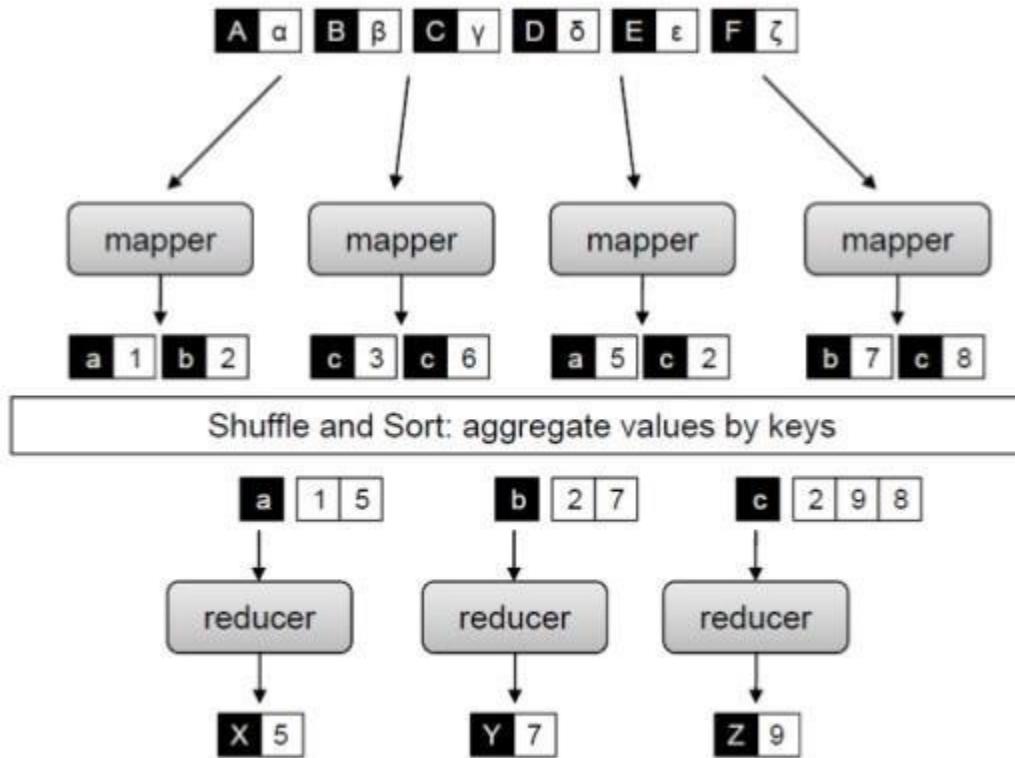
History of MapReduce

MapReduce was developed by Google back in 2004 by Jeffery Dean and Sanjay Ghemawat of Google (Dean & Ghemawat, 2004). In their paper, “MAPREDUCE: SIMPLIFIED DATA PROCESSING ON LARGE CLUSTERS,” and was inspired by the `map()` and `reduce()` functions commonly used in functional programming. At that time, Google’s proprietary MapReduce system ran on the Google File System (GFS). Apache Hadoop is an open-source implementation of Google’s MapReduce.

MapReduce

Mapreduce is a software framework for processing vast amounts of data. MapReduce is a parallel programming model for processing data on a distributed system. MapReduce is a programming model and an associated implementation for processing and generating big data sets with a parallel, distributed algorithm on a cluster.

Abstract MapReduce Framework



In a nutshell, MapReduce provides 3 functions to analyze huge amounts of data:

- `map()` provided by programmer: process the records of the data set:

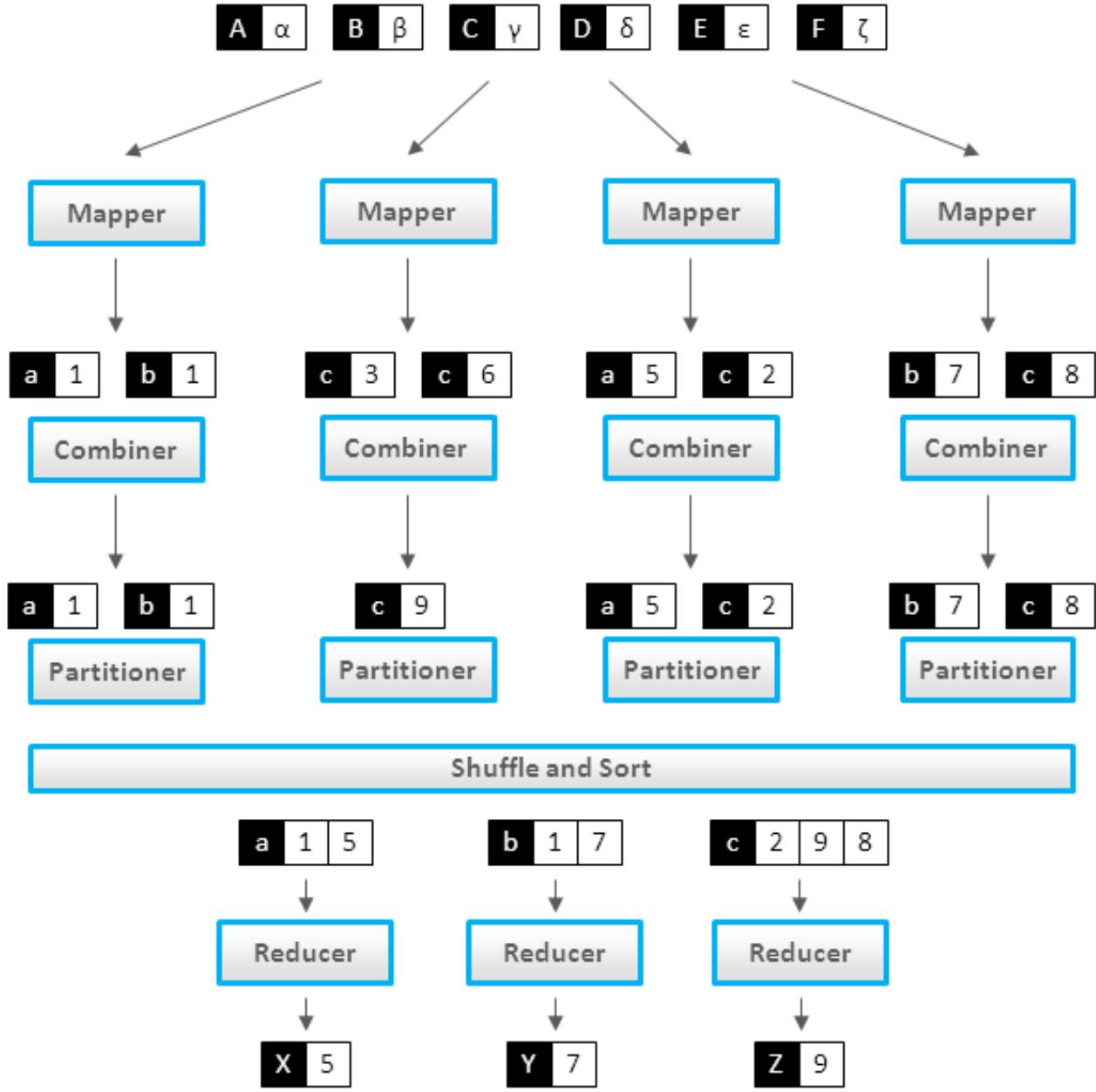
```
1 # key: partition number of record number, which might be ignored
2 # or the “key” might refer to the offset address for each record
3 # value : an actual input record
4 map(key, value) -> {(K2, V2), ...}
5
6 NOTE: If a mapper does not emit any (K2, V2), then it
7 means that the input record is filtered out.
```

- `reduce()` provided by programmer: merges the output from mappers:

```
1 # key: unique key as K2
2 # values : [v1, v2, ...], values associated by K2
3 # the order of values {v1, v2, ...} are undefined.
4 reduce(key, values) -> {(K3, V3), ...}
5
6 NOTE: If a reducer does not emit any (K3, V3), then it
7 means that the key (as K2) is filtered out.
```

- `combine()` provided by programmer [optional]
 - Mini-Reducer
 - Optimizes the result sets from the mappers before sending them to the reducers

The following image illustrates the basic concepts of mappers, combiners, and reducers in MapReduce paradigm.



The genie/magic/power of MapReduce is a Sort & Shuffle phase (provided by MapReduce implementation), which groups keys generated by all mappers. For example, if all mappers have created the following `(key, value)` pairs:

```

1 | (C, 4), (C, 5),
2 | (A, 2), (A, 3),
3 | (B, 1), (B, 2), (B, 3), (B, 1),
4 | (D, 7)
  
```

then Sort & Shuffle phase creates the following `(key, value)` pairs (not in any particular

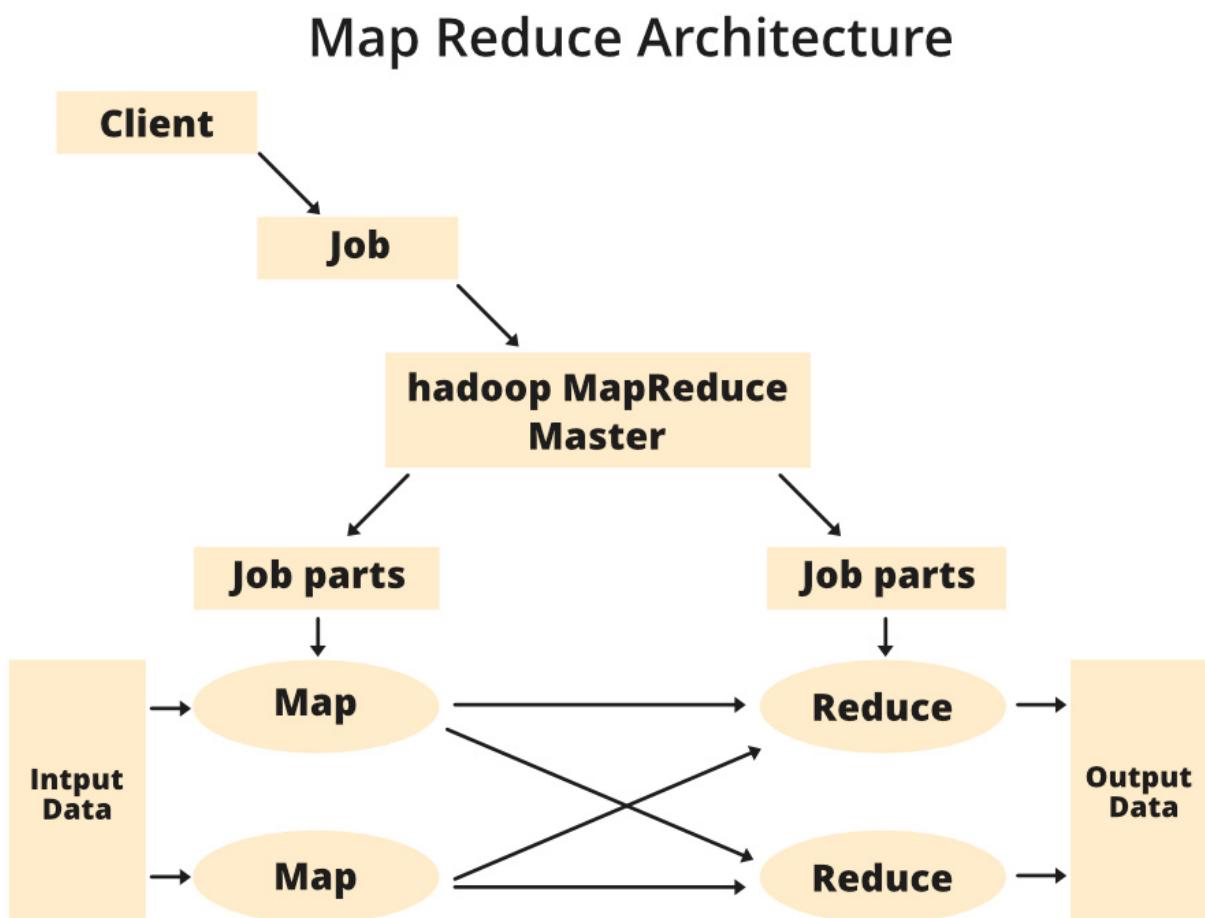
order) to be consumed by reducers:

```
1 | (A, [2, 3])
2 | (B, [1, 2, 3, 1])
3 | (C, [4, 5])
4 | (D, [7])
```

Options for MapReduce implementation:

- Hadoop (slow and complex) is an implementation of MapReduce.
- Spark (fast and simple) is a superset implementation of MapReduce.

Mapreduce Architecture



Components of MapReduce Architecture:

- **Client:** The MapReduce client is the one who brings the Job to the MapReduce for processing. There can be multiple clients available that continuously send jobs for processing to the Hadoop MapReduce Manager.
- **Job:** The MapReduce Job is the actual work that the client wanted to do which is comprised of so many smaller tasks that the client wants to process or execute.
- **Hadoop/MapReduce Master:** It divides the particular job into subsequent job-parts.
- **Job-Parts:** The task or sub-jobs that are obtained after dividing the main job. The result of all the job-parts combined to produce the final output.
- **Input Data:** The data set that is fed to the MapReduce for processing.
- **Output Data:** The final result is obtained after the processing.

MapReduce Task:

The **MapReduce Task** is mainly divided into 3 phases i.e. Map phase, Sort & Shuffle pahse and Reduce phase.

- **Map:** As the name suggests its main use is to map the input data in (key, value) pairs. The input to the map may be a (key, value) pair where the key can be the id of some kind of address (mostly ignored by the mapper) and value is the actual value (a single record of input) that it keeps. The `map()` function will be executed in its memory repository on each of these input (key, value) pairs and generates the intermediate (key2, value2) pairs. The `map()` is provided by a programmer.
- **Sort & Shuffle:** The input to this pahse is the output of all mappers as (key2, value2) pairs. The main function of Sort & Shuffle phase is to group the keys (key2 as output of mappers) by their associated values: therefore, Sort & Shuffle will create a set of:

```
1 | (key2, [v1, v2, v3, ...])
```

which will be fed as input to the reducers. In MapReduce paradigm, **Sort & Shuffle** is handled by the MapReduce implementation and it is so called the genie of the MapReduce paradigm. A programmer does not write any code for the **Sort & Shuffle** phase.

For example, for a MapReduce job, if all mappers have created the following `(key, value)` pairs (with 3 distinct keys as `{A, B, C}`) :

```
1 | (A, 2), (A, 3)
2 | (B, 4), (B, 5), (B, 6), (B, 7)
3 | (C, 8)
```

Then **Sort & Shuffle** phase will produce the following output (which will be sent as input to the reducers – note the values are not sorted in any order at all):

```
1 | (A, [2, 3])
2 | (C, [8])
3 | (B, [7, 4, 5, 6])
```

- **Reduce:** The intermediate (key, value) pairs that work as input for Reducer are shuffled and sort and send to the `reduce()` function. Reducer aggregate or group the data based on its `(key, value)` pair as per the reducer algorithm written by the developer.

For the example, listed above, 3 reducers will be executed (in parallel):

```
1 | reduce(A, [2, 3])
2 | reduce(C, [8])
3 | reduce(B, [7, 4, 5, 6])
```

where each reducer can generate any number of new `(key3, value3)` pairs.

What is an Example of a Mapper in MapReduce

Imagine that you have records, which describe values for genes and each record is identified as:

```
1 | <gene_id><, ><value_1><, ><value_2>
```

Sample records might be:

```
1 | INS,1.1,1.4
2 | INSR,1.7,1.2
```

Suppose the goal is to find the median value for the smaller of the two gene values. Therefore we need to produce `(key, value)` pairs such that `key` is a `gene_id` and value is minimum of `<value_1>` and `<value_2>`.

The following pseudo-code will accomplish the mapper task:

```
1 # key: record number or offset of a record number
2 # key will be ignored since we do not need it
3 # value: an actual record with the format of:
4 # <gene_id><,><value_1><,><value_2>
5 map(key, value) {
6     # tokenize input record
7     tokens = value.split(",")
8     gene_id = tokens[0]
9     value_1 = double(tokens[1])
10    value_2 = double(tokens[2])
11    minimum = min(value_1, value_2)
12    # now emit output of the mapper:
13    emit(gene_id, minimum)
14 }
```

For example, if we had the following input:

```
1 INS,1.3,1.5
2 INS,1.1,1.4
3 INSR,1.7,1.2
4 INS,1.6,1.0
5 INSR,0.7,1.2
```

Then output of mappers will be:

```
1 (INS, 1.3)
2 (INS, 1.1)
3 (INSR, 1.2)
4 (INS, 1.0)
5 (INSR, 0.7)
```

Note that, for the preceding mappers output, the Sort & Shuffle phase will produce the following (key, values) pairs to be consumed by the reducers.

```
1 (INS, [1.3, 1.1, 1.0])
2 (INSR, [1.2, 0.7])
```

What is an Example of a Reducer in MapReduce

Imagine that mappers have produced the following output: (key, value) where key is a gene_id and value is an associated gene value:

```
1 | (INS, 1.3)
2 | (INS, 1.1)
3 | (INSR, 1.2)
4 | (INS, 1.0)
5 | (INSR, 0.7)
```

Note that, for the preceding mappers output, the Sort & Shuffle phase will produce the following (key, values) pairs to be consumed by the reducers.

```
1 | (INS, [1.3, 1.1, 1.0])
2 | (INSR, [1.2, 0.7])
```

Now, assume that the goal of reducers is to find the median of values per key (as a gene_id). For simplicity, we assume that there exists a `median()` function, which accepts a list of values and computes the median of given values.

```
1 | # key: a unique gene_id
2 | # values: Iterable<Double> (i.e., as a list of values)
3 | reduce(key, values) {
4 |     median_value = median(values)
5 |     # now output final (key, value)
6 |     emit(key, median_value)
7 | }
```

Therefore, with this reducer, reducers will create the following (key, value) pairs:

```
1 | (INS, 1.1)
2 | (INSR, 0.95)
```

What is an Example of a Combiner in MapReduce

Consider a classic word count program in MapReduce. Let's Consider 3 partitions with mappers

output:

	Partition-1	Partition-2	Partition-3
1	=====	=====	=====
2	(A, 1)	(A, 1)	(C, 1)
3	(A, 1)	(B, 1)	(C, 1)
4	(B, 1)	(B, 1)	(C, 1)
5	(B, 1)	(C, 1)	(C, 1)
6	(B, 1)		(B, 1)
7			

Without a combiner, Sort & Shuffle will output the following (for all partitions):

1	(A, [1, 1, 1])
2	(B, [1, 1, 1, 1, 1, 1])
3	(C, [1, 1, 1, 1, 1])

With a combiner, Sort & Shuffle will output the following (for all partitions):

1	(A, [2, 1])
2	(B, [3, 2, 1])
3	(C, [1, 4])

As you can see, with a combiner, values are combined for the same key on a partition-by-partition basis. In MapReduce, combiners are mini-reducer optimizations and they reduce network traffic by combining many values into a single value.

Partition

Data can be partitioned into smaller logical units. These units are called partitions. In big data, partitions are used as a unit of parallelism.

For example, in a nutshell, Apache spark partitions your data and then each partition is executed by an executor.

For example, given a data size of `80,000,000,000` records, this data can be partitioned into `80,000` chunks, where each chunk/partition will have about `1000,000` records. Then in a transformation (such as mapper, filter, ...) these partitions can be processed in parallel. The maximum parallelism for this example is `80,000`. If the cluster does not have `80,000` points of parallelism, then some of the partitions will be queued for parallelism.

In MapReduce, input is partitioned and then passed to mappers (so that the mappers can be run in parallel).

In Apache Spark, a programmer can control the partitioning data (by using `coalesce()`, ...) and hence controlling parallelism.

Spark examples:

- `RDD.coalesce(numPartitions: int, shuffle: bool = False)` : return a new RDD that is reduced into `numPartitions` partitions.
- `DataFrame.coalesce(numPartitions: int)` : returns a new DataFrame that has exactly `numPartitions` partitions.

Parallel computing

[Parallel computing](#) (also called concurrent computing) is a type of computation in which many calculations or processes are carried out simultaneously (at the same time). Large problems can often be divided into smaller ones, which can then be solved at the same time. There are several different forms of parallel computing: bit-level, instruction-level, data, and task parallelism. Parallelism has long been employed in high-performance computing, ... parallel computing has become the dominant paradigm in computer architecture, mainly in the form of multi-core processors.

MapReduce and Spark employs parallelism by data partitioning.

How does MapReduce work?

A MapReduce system (an implementation of MapReduce model) is usually composed of three steps (even though it's generalized as the combination of Map and Reduce operations/functions). The MapReduce operations are:

- **Map:** The input data is first split (partitioned) into smaller blocks. For example, the Hadoop framework then decides how many mappers to use, based on the size of the data to be processed and the memory block available on each mapper server. Each block is then assigned to a mapper for processing. Each 'worker' node applies the map function to the local data, and writes the output to temporary storage. The primary (master) node ensures that only a single copy of the redundant input data is processed.

```
1 | map(key, value) -> { (K2, V2), ...}
```

- **Shuffle, combine and partition:** worker nodes redistribute data based on the output keys (produced by the map function), such that all data belonging to one key is located on the same worker node. As an optional process the combiner (a reducer) can run individually on each mapper server to reduce the data on each mapper even further making reducing the data footprint and shuffling and sorting easier. Partition (not optional) is the process that decides how the data has to be presented to the reducer and also assigns it to a particular reducer. Sort & Shuffle output (note that mappers have created N unique keys – such as K2):

```
1 | (key_1, [V_11, V_12, ...])
2 | ...
3 | (key_N, [V_N1, V_N2, ...])
```

- **Reduce:** A reducer cannot start while a mapper is still in progress. Worker nodes process each group of (key, value) pairs output data, in parallel to produce (key,value) pairs as output. All the map output values that have the same key are assigned to a single reducer, which then aggregates the values for that key. Unlike the map function which is mandatory to filter and sort the initial data, the reduce function is optional.

Word Count in MapReduce

Given a set of text documents (as input), Word Count algorithm finds frequencies of unique words in input. The `map()` and `reduce()` functions are provided as a **pseudo-code**.

- Mapper function

```
1 | # key: partition number, record number, offset in input file, ignored.
2 | # value: an actual input record
3 | map(key, value) {
4 |   words = value.split(" ")
5 |   for w in words {
6 |     emit(w, 1)
7 |   }
8 | }
```

- Reducer function (long version)

```

1 # key: a unique word
2 # values: Iterable<Integer>
3 reduce(key, values) {
4     total = 0
5     for n in values {
6         total += n
7     }
8     emit(key, total)
9 }
```

- Reducer function (short version)

```

1 # key: a unique word
2 # values: Iterable<Integer>
3 reduce(key, values) {
4     total = sum(values)
5     emit(key, total)
6 }
```

- Combiner function (short version)

```

1 # key: a unique word
2 # values: Iterable<Integer>
3 combine(key, values) {
4     total = sum(values)
5     emit(key, total)
6 }
```

Finding Average in MapReduce

Given a set of *geneid(s)* and *genewvalue(s)* (as input), the average algorithm finds average of gene values per gene_id for canceric genes. Assume that the input is formatted as:

```

1 <gene_id_as_string>,><gene_value_as_double>,><cancer-or-benign>
2
3 where <cancer-or-benign> has value as {"cancer", "benign"}
```

The `map()` and `reduce()` functions are provided as a **pseudo-code**.

- Mapper function

```

1 # key: partition number, record number, offset in input file, ignored.
2 # value: an actual input record as:
3 # <gene_id_as_string>,><gene_value_as_double>,><cancer-or-benign>
4 map(key, value) {
5     tokens = value.split(",")
6     gene_id = tokens[0]
7     gene_value = tokens[1]
8     status = tokens[2]
9     if (status == "cancer" ) {
10        emit(gene_id, gene_value)
11    }
12 }
```

- Reducer function (long version)

```

1 # key: a unique gene_id
2 # values: Iterable<double>
3 reduce(key, values) {
4     total = 0
5     count = 0
6     for v in values {
7         total += v
8         count += 1
9     }
10    avg = total / count
11    emit(key, avg)
12 }
```

- Reducer function (short version)

```

1 # key: a unique gene_id
2 # values: Iterable<double>
3 reduce(key, values) {
4     total = sum(values)
5     count = len(values)
6     avg = total / count
7     emit(key, avg)
8 }
```

To have a combiner function, we have to change the output of mappers (since avg of avg is not an avg). This means that avg function is a commutative, but not associative. Changing output of mappers will make it commutative and associative.

Commutative means that:

```
1 |     avg(a, b) = avg(b, a)
```

Associative means that:

```
1 |     avg(avg(a, b), c) = avg(a, avg(b, c))
```

For details on commutative and associative properties refer to [Data Algorithms with Spark](#).

- Revised Mapper function

```
1 | # key: partition number, record number, offset in input file, ignored.
2 | # value: an actual input record as:
3 | # <gene_id_as_string>,><gene_value_as_double>,><cancer-or-benign>
4 | map(key, value) {
5 |     tokens = value.split(",")
6 |     gene_id = tokens[0]
7 |     gene_value = tokens[1]
8 |     status = tokens[2]
9 |     if (status == "cancer" ) {
10 |         # revised mapper output
11 |         emit(gene_id, (gene_value, 1))
12 |     }
13 | }
```

- Combiner function

```

1 # key: a unique gene_id
2 # values: Iterable<(double, Integer)>
3 combine(key, values) {
4     total = 0
5     count = 0
6     for v in values {
7         # v = (double, integer)
8         # v = (sum, count)
9         total += v[0]
10        count += v[1]
11    }
12    # note the combiner does not calculate avg
13    emit(key, (total, count))
14}

```

- Reducer function

```

1 # key: a unique gene_id
2 # values: Iterable<(double, Integer)>
3 combine(key, values) {
4     total = 0
5     count = 0
6     for v in values {
7         # v = (double, integer)
8         # v = (sum, count)
9         total += v[0]
10        count += v[1]
11    }
12    # calculate avg
13    avg = total / count
14    emit(key, avg)
15}

```

What is an Associative Law

An associative operation:

```

1 | f: X x X -> X

```

is a binary operation such that for all `a, b, c` in `X`:

```
1 | f(a, f(b, c)) = f(f(a, b), c)
```

For example, + (addition) is an associative function because

```
1 | (a + (b + c)) = ((a + b) + c)
```

For example, * (multiplication) is an associative function because

```
1 | (a * (b * c)) = ((a * b) * c)
```

While, - (subtraction) is not an associative function because

```
1 | (4 - (6 - 3)) != ((4 - 6) - 3)  
2 | (4 - 3) != (-2 - 3)  
3 | 1 != -5
```

While average operation is not an associative function.

```
1 | FACT: avg(1, 2, 3) = 2  
2 |  
3 | avg(1, avg(2, 3)) != avg(avg(1, 2), 3)  
4 | avg(1, 2.5) != avg(1.5, 3)  
5 | 1.75 != 2.25
```

What is a Commutative Law

A commutative function f is a function that takes multiple inputs from a set X and produces an output that does not depend on the ordering of the inputs. For example, the binary operation $+$ is commutative, because $2 + 5 = 5 + 2$. Function f is commutative if the following property holds:

```
1 | f(a, b) = f(b, a)
```

While, - (subtraction) is not an commutative function because

$$\begin{array}{l|l} 1 & 2 - 4 \neq 4 - 2 \\ 2 & -2 \neq 2 \end{array}$$

Monoid

Monoids are algebraic structures. A monoid M is a triplet (X, f, i) , where

- X is a set
- f is an associative binary operator
- i is an identity element in X

The monoid axioms (which govern the behavior of f) are as follows.

1. (Closure) For all a, b in X , $f(a, b)$ and $f(b, a)$ is also in X .
2. (Associativity) For all a, b, c in X :

$$1 \mid f(a, f(b, c)) = f(f(a, b), c)$$

3. (Identity) There is an i in X such that, for all a in X :

$$1 \mid f(a, i) = f(i, a) = a$$

Monoid Examples

Example-1

Let X denotes non-negative integer numbers.

- Let $+$ be an addition function, then $M(X, +, 0)$ is a monoid.
- Let $*$ be an multiplication function, then $M(X, *, 1)$ is a monoid.

Example-2

Let S denote a set of strings including an empty string (`" "`) of length zero, and `||` denote a concatenation operator,

Then $M(S, ||, "")$ is a monoid.

Non Monoid Examples

Then $M(X, -, 0)$ is not a monoid, since binary subtraction function is not an associative function.

Then $M(X, /, 1)$ is not a monoid, since binary division function is not an associative function.

Then $M(X, \text{AVG}, 0)$ is not a monoid, since AVG (an average function) is not an associative function.

Monoids as a Design Principle for Efficient MapReduce Algorithms

According to [Jimmy Lin](#): “it is well known that since the sort/shuffle stage in MapReduce is costly, local aggregation is one important principle to designing efficient algorithms. This short paper represents an attempt to more clearly articulate this design principle in terms of monoids, which generalizes the use of combiners and the in-mapper combining pattern.”

For example, in Spark (using PySpark), in a distributed computing environment, we can not write the following transformation to find average of integer numbers per key:

```
1 |     # rdd: RDD[(String, Integer)] : RDD[(key, value)]
2 |     # The Following Transformation is WRONG
3 |     avg_per_key = rdd.reduceByKey(lambda x, y: (x+y) / 2)
```

This will not work, because average of average is not an average. In Spark, `RDD.reduceByKey()` merges the values for each key using an **associative** and **commutative** reduce function. Average function is not an associative function.

How to fix this problem? Make it a Monoid:

```

1   # rdd: RDD[(String, Integer)] : RDD[(key, value)]
2   # convert (key, value) into (key, (value, 1))
3   # rdd2 elements will be monoidic structures for addition +
4   rdd2 = rdd.mapValues(lambda v: (v, 1))
5   # rdd2: RDD[(String, (Integer, Integer))] : RDD[(key, (sum, count))]
6
7   # find (sum, count) per key: a Monoid
8   sum_count_per_key = rdd2.reduceByKey(
9       lambda x, y: (x[0]+y[0], x[1]+y[1])
10
11
12   # find average per key
13   # v : (sum, count)
14   avg_per_key = sum_count_per_key.mapValues(
15       lambda v: float(v[0]) / v[1]
16

```

Note that by mapping `(key, value)` to `(key, (value, 1))` we make addition of values such as `(sum, count)` to be a monoid. Consider the following two partitions:

	Partition-1	Partition-2
1	(A, 1)	
2	(A, 2)	(A, 3)

By mapping `(key, value)` to `(key, (value, 1))`, we will have (as `rdd2`):

	Partition-1	Partition-2
1	(A, (1, 1))	
2	(A, (2, 1))	(A, (3, 1))

Then `sum_count_per_key` RDD will hold:

	Partition-1	Partition-2
1	(A, (3, 2))	(A, (3, 1))

Finally, `avg_per_key` RDD will produce the final value per key: `(A, 2)`.

What Does it Mean that "Average of Average is Not

an Average”

In distributed computing environments (such as MapReduce, Hadoop, Spark, ...) correctness of algorithms are very very important. Let's say, we have only 2 partitions:

	Partition-1	Partition-2
1	(A, 1)	(A, 3)
2	(A, 2)	
3		

and we want to calculate the average per key. Looking at these partitions, the average of `(1, 2, 3)` will be exactly `2.0`. But since we are in a distributed environment (operations/functions are done on data partitions), then the average will be calculated per partition:

```
1 Partition-1: avg(1, 2) = 1.5
2 Partition-2: avg(3) = 3.0
3
4 avg(Partition-1, Partition-2) = (1.5 + 3.0) / 2 = 2.25
5
6 ==> which is NOT the correct average we were expecting.
```

To fix this problem, we can change the output of mappers; new revised output is as:

```
(key, (sum, count)) :
```

	Partition-1	Partition-2
1	(A, (1, 1))	(A, (3, 1))
2	(A, (2, 1))	

Now, let's calculate average:

Advantages of MapReduce

Is there any benefit in using MapReduce paradigm? With MapReduce, developers do not need to write code for parallelism, distributing data, or other complex coding tasks because those are already built into the model. This alone shortens analytical programming time.

The following are advantages of MapReduce:

- Scalability
- Flexibility
- Security and authentication
- Faster processing of data
- Very simple programming model
- Availability and resilient nature
- Fault tolerance

What is a MapReduce Job

Job – A program is an execution of a Mapper and Reducer across a dataset. Minimally, a MapReduce job will have the following components:

- Input path: identifies input directories and files
- Output path: identifies a directory where the outputs will be written
- Mapper: a `map()` function
- Reducer: a `reduce()` function
- Combiner: a `combine()` function [optional]

Disadvantages of MapReduce

- Rigid `Map-and-then-Reduce` programming paradigm
 - low level API
 - must use `map()`, `reduce()` one or more times to solve a problem
 - join operation is not supported
 - complex: have to write lots of code
 - one type of reduction is supported: GROUP BY KEY
- Disk I/O (makes it slow)
- Read/Write Intensive (does not utilize in-memory computing)

- Java Focused
 - have to write lots of lines of code to do some simple map and then reduce functions
 - API is a low level

What the MapReduce's Job Flow

1-InputFormat: Splits input into `(key_1, value_1)` pairs and passes them to mappers. When Hadoop submits a job, it splits the input data logically (Input splits) and these are processed by each Mapper. The number of Mappers is equal to the number of input splits created. Hadoop's `InputFormat.getSplits()` function is responsible for generating the input splits which uses each split as input for each mapper job.

2-Mapper: `map(key_1, value_1)` emits a set of `(key_2, value_2)` pairs. If a mapper does not emit any `(key, value)` pairs, then it means that `(key_1, value_1)` is filtered out (for example, tossing out the invalid/bad records).

3-Combiner: [optional] `combine(key_2, [value_2, ...])` emits `(key_2, value_22)`. The combiner might emit no (key, value) pair if there is a filtering algorithm (based on the key (i.e., `key_2` and its associated values)).

Note that `value_22` is an aggregated value for `[value_2, ...]`

4-Sort & Shuffle: Group by keys of mappers with their associated values. If output of all mappers/combiners are:

1	<code>(K_1, v_1), (K_1, v_2), (K_1, v_3), ...,</code>
2	<code>(K_2, t_1), (K_2, t_2), (K_2, t_3), ...,</code>
3	<code>...</code>
4	<code>(K_n, a_1), (K_n, a_2), (K_n, a_3), ...</code>

Then output of Sort & Shuffle will be (which will be fed as an input to reducers as `(key, values)` :

1	<code>(K_1, [v_1, v_2, v_3, ...])</code>
2	<code>(K_2, [t_1, t_2, t_3, ...])</code>
3	<code>...</code>
4	<code>(K_n, [a_1, a_2, a_3, ...])</code>

5-Reducer: We will have `n` reducers, since we have `n` unique keys. All these reducers can run in parallel (if we have enough resources).

`reduce(key, values)` will emit a set of `(key_3, value_3)` pairs and eventually they are written to output. Note that reducer key will be one of `{K_1, K_2, ..., K_n}`.

6-OutputFormat: Responsible for writing `(key_3, value_3)` pairs to output medium. Note that some of the reducers might not emit any `(key_3, value_3)` pairs: this means that the reducer is filtering out some keys based on the associated values (for example, if the median of the values is less than 10, then filter out).

Hadoop vs. Spark

Feature	Hadoop	Spark
Data Processing	Provides batch processing	Provides both batch processing and stream processing
Memory usage	Disk-bound	Uses large amounts of RAM
Security	Better security features	Basic security is provided
Fault Tolerance	Replication is used for fault tolerance	RDD and various data storage models are used for fault tolerance.
Graph Processing	Must develop custom algorithms	Comes with a graph computation library called GraphX and external library as GraphFrames
Ease of Use	Difficult to use	Easier to use
Powerful API	Low level API	High level API
Real-time	Batch only	Batch and Interactive and Stream
Interactive data processing	Not supported	Supported by PySpark, ...
Speed	SLOW: Hadoop's MapReduce model reads and writes from a disk, thus it slows down the processing speed.	FAST: Spark reduces the number of read/write cycles to disk and stores intermediate data in memory, hence faster-processing speed.

Latency	It is high latency computing framework.	It is a low latency computing and can process data interactively
Machine Learning API	Not supported	Supported by ML Library
Data Source Support	Limited	Extensive
Storage	Has HDFS (Hadoop Distributed File System)	Does not have a storage system, but may use S3 and HDFS and many other data sources and storages
MapReduce	Implements MapReduce	Implements superset of MapReduce and beyond
Join Operation	Does not support Join directly	Has extensive API for Join

Apache Spark

In a nutshell, we can say that Apache Spark is the most active open big data tool reshaping the big data market. [Apache Spark](#) is an engine for large-scale data analytics. Spark is a multi-language (Java, Scala, Python, R, SQL) engine for executing data engineering, data science, and machine learning on single-node machines or clusters. Spark implements superset of MapReduce paradigm and uses memory/RAM as much as possible and can run up to 100 times faster than Hadoop. Spark is considered the successor of Hadoop/Mapreduce and has addressed many problems of Hadoop.

With using Spark, developers do not need to write code for parallelism, distributing data, or other complex coding tasks because those are already built into the spark engine. This alone shortens analytical programming time.

Apache Spark is one of the best alternatives to Hadoop and currently is the defacto standard for big data analytics. Spark offers simple API and provides high-level mappers, filters, and reducers.

Spark's architecture consists of two main components:

- Drivers - convert the user's code into tasks to be distributed across worker nodes
- Executors - run on those nodes and carry out the tasks assigned to them

PySpark is an interface for Spark in Python. PySpark has two main data abstractions:

- RDD (Resilient Distributed Dataset)
 - low-level
 - immutable
 - partitioned
 - can represent billions of data points
 - for unstructured and semi-structured data
- DataFrame
 - high-level
 - immutable
 - partitioned
 - can represent billions of rows with named columns
 - for structured and semi-structured data

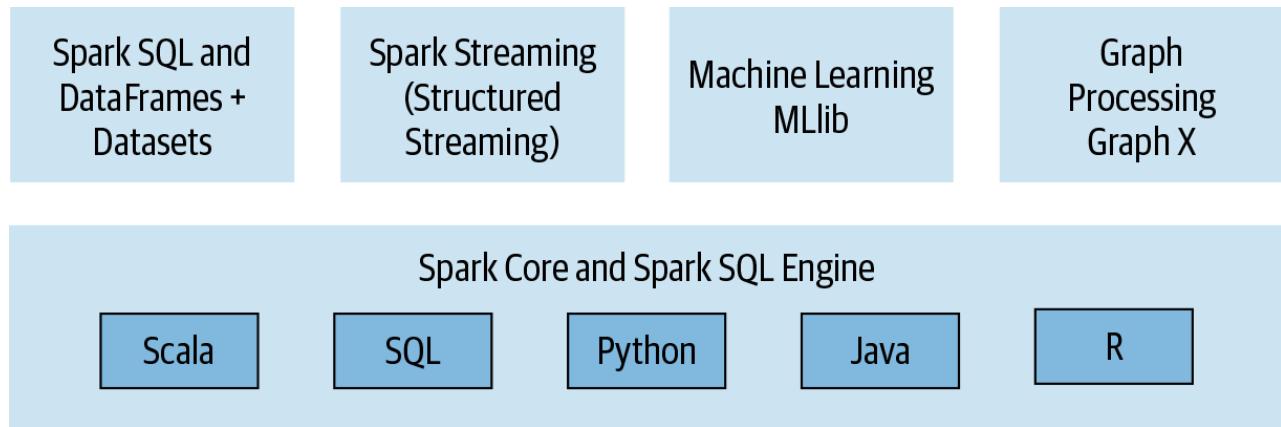
Spark addresses many problems of hadoop:

- provides in-memory computing
- provides simple, powerful, and high-level transformations
- provides join operations for RDDs and DataFrames
- You do not need to write too many lines of a code to solve a big data problem

Apache Spark Components

Apache Spark provides:

- Core components: RDDs, DataFrames, SQL
- Data Streaming
- Machine Learning
- Graph Processing (GraphX and GrahFrames)
- Multi-language support (Python, Java, Scala, R, SQL)



Apache Spark in Large-Scale Sorting

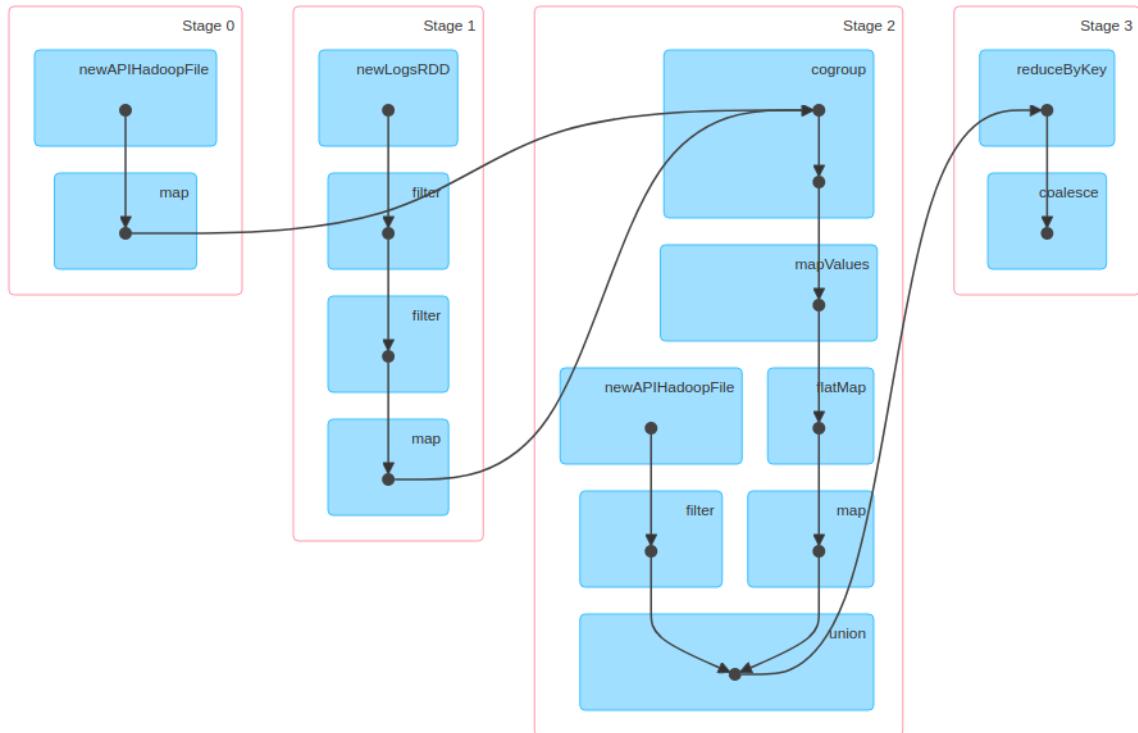
[Spark Officially Sets a New Record in Large-Scale Sorting](#). Databricks team sorted 100 TB of data on disk in 23 minutes. In comparison, the previous world record set by Hadoop MapReduce used 2100 machines and took 72 minutes. This means that Apache Spark sorted the same data 3X faster using 10X fewer machines. All the sorting took place on disk (HDFS), without using Spark's in-memory cache.

	Hadoop MR Record	Spark Record	Spark 1PB
Data Size	102.5 TB	100 TB	1000 TB
Elapsed Time	72 mins	23 mins	234 mins
# Nodes	2100	206	190
# Cores	50400 physical	6592 virtualized	6080 virtualized
Cluster disk throughput	3150 GB/s (est.)	618 GB/s	570 GB/s
Sort Benchmark Daytona Rules	Yes	Yes	No
Network	dedicated data center, 10Gbps	virtualized (EC2) 10Gbps network	virtualized (EC2) 10Gbps network
Sort rate	1.42 TB/min	4.27 TB/min	4.27 TB/min
Sort rate/node	0.67 GB/min	20.7 GB/min	22.5 GB/min

DAG in Spark

Spark DAG (directed acyclic graph) is the strict generalization of the MapReduce model. The DAG operations can do better global optimization than the other systems like MapReduce. The

Apache Spark DAG allows a user to dive into the stage and further expand on detail on any stage.

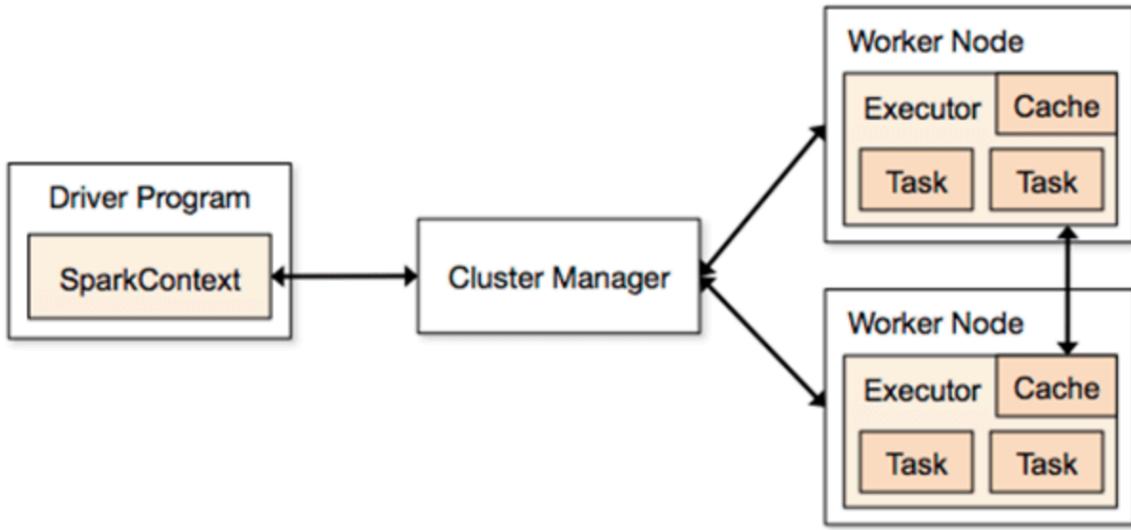


DAG in Spark is a set of vertices and edges, where vertices represent the RDDs and the edges represent the Operation to be applied on RDD. In Spark DAG, every edge directs from earlier to later in the sequence. On the calling of Action, the created DAG submits to DAG Scheduler which further splits the graph into the stages of the task.

By using [Spark Web UI](#), you can view Spark jobs and their associated DAGs.

Spark Concepts and Key Terms

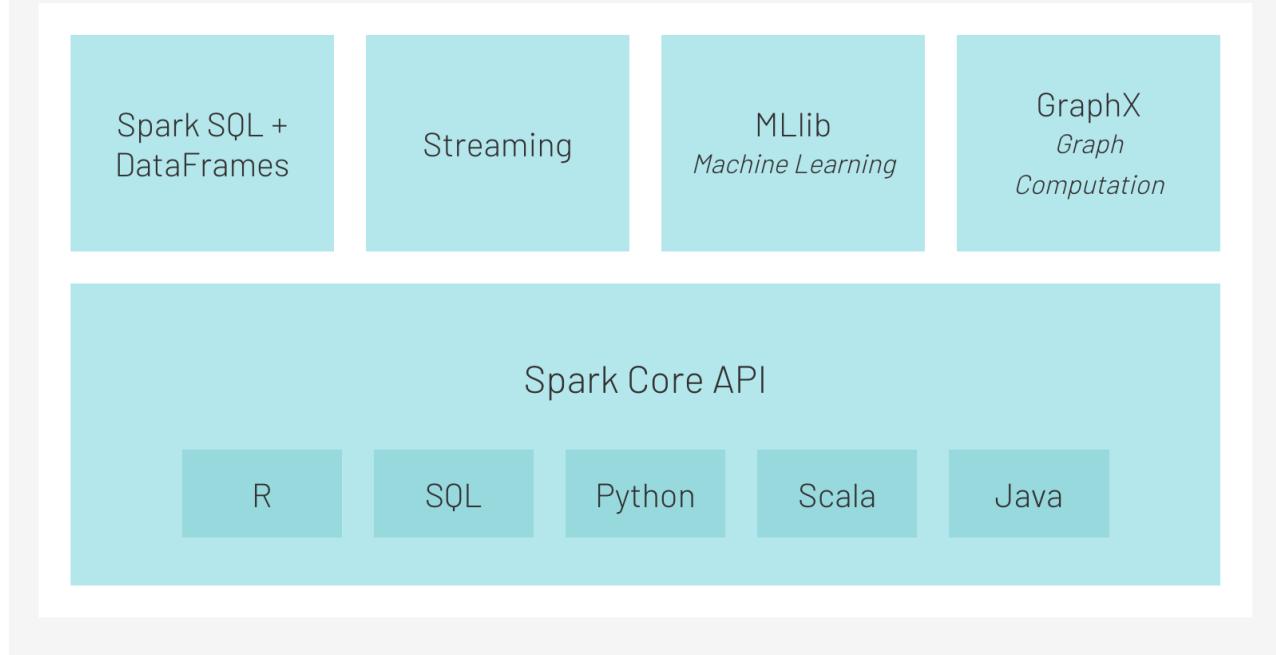
- [Spark Architecture](#)



- [Spark Cluster](#): a collection of machines or nodes in the public cloud or on-premise in a private data center on which Spark is installed. Among those machines are Spark workers, a Spark Master (also a cluster manager in a Standalone mode), and at least one Spark Driver.
- [Spark Master](#): As the name suggests, a Spark Master JVM acts as a cluster manager in a Standalone deployment mode to which Spark workers register themselves as part of a quorum. Depending on the deployment mode, it acts as a resource manager and decides where and how many Executors to launch, and on what Spark workers in the cluster.
- [Spark Worker](#): Upon receiving instructions from Spark Master, the Spark worker JVM launches Executors on the worker on behalf of the Spark Driver. Spark applications, decomposed into units of tasks, are executed on each worker's Executor. In short, the worker's job is to only launch an Executor on behalf of the master.
- [Spark Executor](#): A Spark Executor is a JVM container with an allocated amount of cores and memory on which Spark runs its tasks. Each worker node launches its own Spark Executor, with a configurable number of cores (or threads). Besides executing Spark tasks, an Executor also stores and caches all data partitions in its memory.
- [Spark Driver](#): Once it gets information from the Spark Master of all the workers in the cluster and where they are, the driver program distributes Spark tasks to each worker's Executor. The driver also receives computed results from each Executor's tasks.
- Task: A unit of work that will be sent to one executor.

Apache Spark Ecosystem

Apache Spark Ecosystem



What are the main components of Spark ecosystem?

Components of Apache Spark (EcoSystem):

- **Spark Core:** Spark Core is the underlying general execution engine for the Spark platform that all other functionality is built on top of. It provides in-memory computing capabilities to deliver speed, a generalized execution model to support a wide variety of applications, and Java, Scala, and Python APIs for ease of development.
- **Spark SQL + DataFrames:** Many data scientists, analysts, and general business intelligence users rely on interactive SQL queries for exploring data. Spark SQL is a Spark module for structured data processing. It provides a programming abstraction called `DataFrames` and can also act as distributed SQL query engine. It enables unmodified Hadoop Hive queries to run up to 100x faster on existing deployments and data. It also provides powerful integration with the rest of the Spark ecosystem (e.g., integrating SQL query processing with machine learning).
- **Spark Streaming:** Many applications need the ability to process and analyze not only batch data, but also streams of new data in real-time. Running on top of Spark, Spark Streaming enables powerful interactive and analytical applications across both streaming and historical data, while inheriting Spark's ease of use and fault tolerance characteristics.

It readily integrates with a wide variety of popular data sources, including HDFS, Flume, Kafka, and Twitter.

- **MLlib (Machine learning library)**: Machine learning has quickly emerged as a critical piece in mining Big Data for actionable insights. Built on top of Spark, MLlib is a scalable machine learning library that delivers both high-quality algorithms (e.g., multiple iterations to increase accuracy) and blazing speed (up to 100x faster than MapReduce). The library is usable in Java, Scala, and Python as part of Spark applications, so that you can include it in complete workflows.
- **GraphX**: GraphX is a graph computation engine built on top of Spark that enables users to interactively build, transform and reason about graph structured data at scale. It comes complete with a library of common algorithms. Note that GraphX is not available for PySpark, but you may use an external graph library called GraphFrames (which is a DataFrame based solution).

Spark as a superset of MapReduce

Spark is a true successor of MapReduce and maintains MapReduce's linear scalability and fault tolerance, but extends it in 7 important ways:

1. Spark does not rely on a low-level and rigid `map-then-reduce` workflow. Spark's engine can execute a more general Directed Acyclic Graph (DAG) of operators. This means that in situations where MapReduce must write out intermediate results to the distributed file system (such as HDFS and S3), Spark can pass them directly to the next step in the pipeline. Rather than writing many `map-then-reduce` jobs, in Spark, you can use transformations in any order to have an optimized solution.
2. Spark complements its computational capability with a simple and rich set of transformations and actions that enable users to express computation more naturally. Powerful and simple API (as a set of functions) are provided for various tasks including numerical computation, datetime processing and string manipulation.
3. Spark extends its predecessors (such as Hadoop) with in-memory processing. MapReduce uses disk I/O (which is slow), but Spark uses in-memory computing as much as possible and it can be up to 100 times faster than MapReduce implementations. This means that future steps that want to deal with the same data set need not recompute it or reload it from disk. Spark is well suited for highly iterative algorithms as well as adhoc queries.
4. Spark offers interactive environment (for example using PySpark interactively) for testing

and debugging data transformations.

5. Spark offers extensive Machine Learning libraries (Hadoop/MapReduce does not have this capability)
6. Spark offers extensive graph API by GraphX (built-in) and GraphFrames (as an external library).
7. Spark Streaming is an extension of the core Spark API that allows data engineers and data scientists to process real-time data from various sources including (but not limited to) Kafka, Flume, and Amazon Kinesis. This processed data can be pushed out to file systems, databases, and live dashboards.

What is an Spark RDD

Spark's RDD (full name in PySpark as: `pyspark.RDD`) is a Resilient Distributed Dataset (`RDD`), the basic abstraction in Spark. RDD represents an immutable, partitioned collection of elements that can be operated on in parallel. Basically, an RDD represents your data (as a collection, text files, databases, Parquet files, JSON, CSV files, ...). Once your data is represented as an RDD, then you call apply transformations (such as filters, mappers, and reducers) to your RDD and create new RDDs.

An RDD can be created from many data sources such as Python collections, text files, CSV files, log files, JSON, ...

An RDD is more suitable to unstructured and semi-structured data (while a DataFrame is more suitable to structured and semi-structured data).

What are Spark Mappers?

Spark offers comprehensive mapper functions for RDDs and DataFrames. Spark `map()` is a transformation operation that is used to apply the transformation on every element of RDD, DataFrame, and Dataset and finally returns a new RDD/Dataset respectively.

Mappers for RDDs:

- `RDD.map()`
 - 1-to-1 mapping
 - maps an RDD (source) element to a single RDD (target) element

- `RDD.flatMap()`
 - 1-to-many mapping
 - maps an RDD (source) element to multiple RDD (target) elements
- `RDD.mapPartitions()`
 - many-to-1 mapping
 - maps a single partition (comprised of many elements) into a single RDD (target) element

Mappers for DataFrames:

Mappers for Spark Dataframes can be handled by two means:

- Using direct DataFrame's API
- Using SQL on a table (a DataFrame can be registered as a table or rows with named columns)

What are Spark Reducers?

The reducer function receives an intermediate key and a set of associated values (not sorted in any order). It processes these values and generates output as `(key, value)` pairs by grouping values for each key. Example of reduction will be:

Let `key` denotes a key and `values` denotes a set of values for a given `key`, then the following are example of reducers:

- Given a `(key, values)`, find average of values for a given key
- Given a `(key, values)`, find median of values for a given key
- Given a `(key, values)`, find `(minimum, maximum)` of values for a given key

Spark offers comprehensive reducer functions for RDDs and DataFrames.

Reducers for RDDs:

- `RDD.groupByKey()`
- `RDD.reduceByKey()`
- `RDD.combineByKey()`
- `RDD.aggregateByKey()`

Reducers for DataFrames:

Reductions for Spark Dataframes can be handled by two means:

- Using `DataFrame.groupBy()`
- Using SQL's **GROUP BY** on a table (a DataFrame can be registered as a table or rows with named columns)

Data Structure

In computer science, a data structure is a data organization, management, and storage format that is usually chosen for efficient access to data.

There are numerous types of data structures, generally built upon simpler primitive data types. Well known examples are:

- Array
- Set
- Stack
- Linked List
- Double Linked List
- Record
- Tuples
- Hash tables
- Graphs
- Tables
- Tree
- Binary tree

Difference between Spark's Action and Transformation

A Spark transformation (such as `map()`, `filter()`, `reduceByKey()`, ...) applies to a source RDD and creates a new target RDD. While, an action (such as `collect()`, `save()`, ...) applies to a source RDD and creates a non-RDD element (such as a number or another data structure).

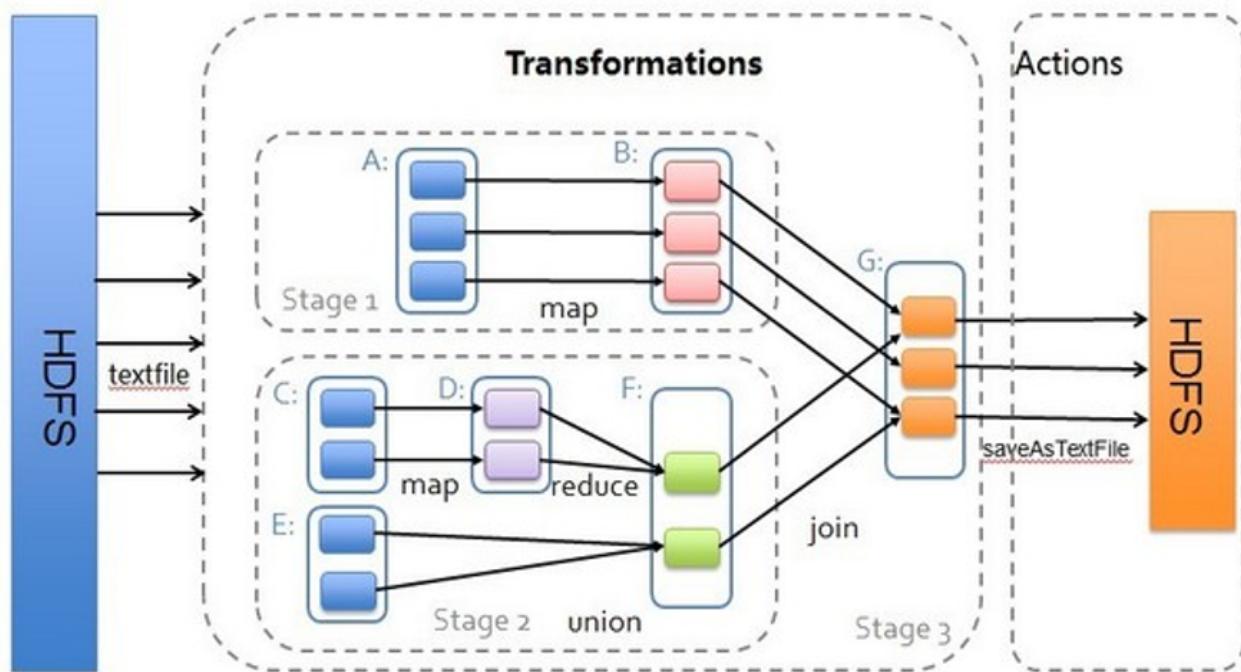
In Spark, if a function returns a DataFrame, Dataset, or RDD, it is a transformation. If it returns anything else or does not return a value at all (or returns Unit in the case of Scala API), it is an action.

What is Lineage In Spark?

Spark RDDs are immutable (READ-ONLY) distributed collection of elements of your data that can be stored in memory or disk across a cluster of machines. The data is partitioned across machines in your cluster that can be operated in parallel with a low-level API that offers transformations and actions. RDDs are fault tolerant as they track data lineage information to rebuild lost data automatically on failure.

What are Spark operations/functions?

Two types of Spark RDD operations are: Transformations and Actions.



- **Transformation:** a transformation is a function that produces new/target RDDs from the source/existing RDDs
 - Transformation: `source_rdd --> target_rdd`
 - `map()` , `filter()` , `flatMap()` , `mapPartitions()`
 - `groupByKey()` , `reduceByKey()` , `combineByKey()`
 - ...

- **Action:** when we want to work with the actual dataset, at that point Action is performed. For RDD, anction is defined as the Spark operations that return raw values. In other words, any of the RDD functions that return other than the `RDD[T]` is considered an action in the spark programming.
 - `Action: source_rdd --> NONE_rdd`
 - `collect()`
 - `count()`
 - `...`

The Spark Programming Model

Spark programming starts with a data set (which can be represented as an RDD or a DataFame), usually residing in some form of distributed, persistent storage like Amazon S3 or Hadoop HDFS. Writing a Spark program typically consists of a few related steps:

1. Define a set of transformations on the input data set.
2. Invoke actions that output the transformed data sets to persistent storage or return results to the driver's local memory.
3. Run local computations that operate on the results computed in a distributed fashion.

These can help you decide what transformations and actions to undertake next.

What is Lazy Binding In Spark?

Lazy binding/evaluation in Spark means that the execution of **transformations** will not start until an **action** is triggered.

In programming language theory, lazy evaluation, or call-by-need, is an evaluation strategy which delays the evaluation of an expression until its value is needed (non-strict evaluation) and which also avoids repeated evaluations (sharing).

Difference between `reduceByKey()` and `combineByKey()`

- `reduceByKey()`

`RDD.reduceByKey()` merges the values for each key using an **associative** and

commutative reduce function. This will also perform the merging locally on each mapper before sending results to a reducer, similarly to a “combiner” in MapReduce.

This can be expressed as:

```
1 | reduceByKey: RDD[(K, V)] -> RDD[(K, V)]
```

- `combineByKey()`

```
1 | combineByKey: RDD[(K, V)] -> RDD[(K, C)]
2 | # where V and C can be different types
```

`RDD.combineByKey()` is a generic function to combine the elements for each key using a custom set of aggregation functions. `RDD.combineByKey()` turns an `RDD[(K, V)]` into a result of type `RDD[(K, C)]`, for a “combined type” `C`.

```
1 | # rdd : RDD[(K, V)]
2 | # rdd2: RDD[(K, C)]
3 | # where V and C can be different types
4 | rdd2 = rdd.combineByKey(create_combiner, merge_value, merge_combiners)
```

For `combineByKey()`, users provide three functions:

- `create_combiner`, which turns a `V` into a `C` (e.g., creates a one-element list as type `C`)

```
1 | create_combiner: V --> C
```

- `merge_value`, to merge a `V` into a `C` (e.g., adds it to the end of a list)

```
1 | merge_value: C x V --> C
```

- `merge_combiners`, to combine two `C's` into a single one (e.g., merges the lists)

```
1 | merge_combiners: C x C --> C
```

This can be expressed as:

```
1     combineByKey: RDD[(K, V)] --> RDD[(K, C)]
2
3     where V and C can be the same or different
```

What is an example of `RDD.combineByKey()` ?

Combine all of values per key.

```
1 # combineByKey: RDD[(String, Integer)] --> RDD[(String, [Integer])]
2
3 rdd = sc.parallelize([('a', 1), ('b', 7), ('a', 2), ('a', 3), ('b', 8), ('z',
4
5
6 # V --> C
7 def to_list(a):
8     return [a]
9
10 # C x V --> C
11 def append(a, b):
12     a.append(b)
13     return a
14
15 # C x C --> C
16 def extend(a, b):
17     a.extend(b)
18     return a
19
20 # rdd: RDD[(String, Integer)]
21 # rdd2: RDD[(String, [Integer])]
22 rdd2 = rdd.combineByKey(to_list, append, extend)
23 rdd2.collect()
24
25 [
26     ('z', [5]),
27     ('a', [1, 2, 3]),
28     ('b', [7, 8])
29 ]
30
31 # Note that values of keys does not need to be sorted
```

What is an example of `RDD.reduceByKey()` ?

Find maximum of values per key.

```
1 # reduceByKey: RDD[(String, Integer)] --> RDD[(String, Integer)]
2
3 rdd = sc.parallelize([('a', 1), ('b', 7), ('a', 2), ('a', 3), ('b', 8), ('z',
4
5
6 # rdd: RDD[(String, Integer)]
7 # rdd2: RDD[(String, Integer)]
8 rdd2 = rdd.reduceByKey(lambda x, y: max(x, y))
9 rdd2.collect()
10
11 [
12     ('z', 5),
13     ('a', 3),
14     ('b', 8)
15 ]
```

What is an example of `RDD.groupByKey()` ?

Combine/Group values per key.

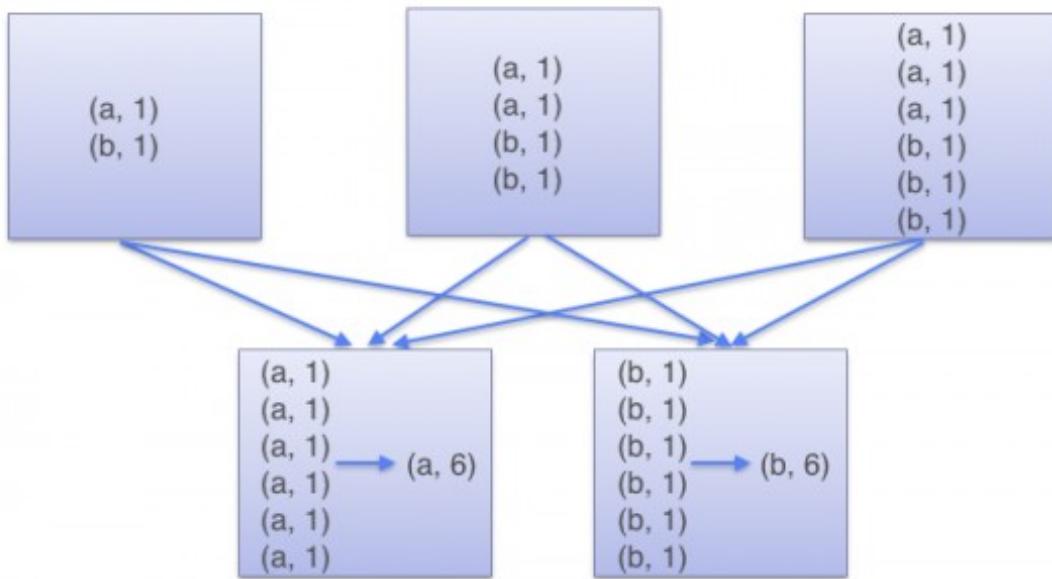
```
1 # reduceByKey: RDD[(String, Integer)] --> RDD[(String, [Integer])]
2
3 rdd = sc.parallelize([('a', 1), ('b', 7), ('a', 2), ('a', 3), ('b', 8), ('z',
4
5
6 # rdd: RDD[(String, Integer)]
7 # rdd2: RDD[(String, [Integer])]
8 rdd2 = rdd.groupByKey()
9 rdd2.collect()
10
11 [
12     ('z', [5]),
13     ('a', [1, 2, 3]),
14     ('b', [7, 8])
15 ]
```

Difference of `RDD.groupByKey()` and `RDD.reduceByKey()`

Both `reduceByKey()` and `groupByKey()` result in wide transformations which means both triggers a shuffle operation. The key difference between `reduceByKey()` and `groupByKey()` is that `reduceByKey()` does a map side combine and `groupByKey()` does not do a map side combine. Overall, `reduceByKey()` is optimized with a map side combine. Note that the reducer function for the `reduceByKey()` must be associative and commutative.

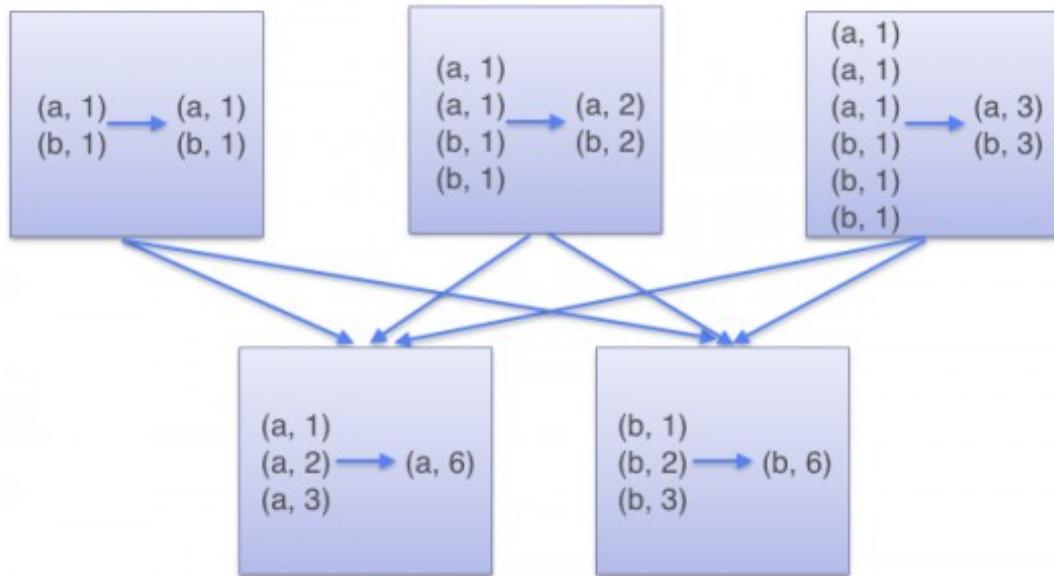
- `groupByKey: RDD[(K, V)] --> RDD[(K, [V])]`

GroupByKey



- `reduceByKey: RDD[(K, V)] --> RDD[(K, V)]`

ReduceByKey



What is a DataFrame?

A DataFrame is a data structure that organizes data into a 2-dimensional table of rows and columns, much like a spreadsheet or a relational table. DataFrames are one of the most common data structures used in modern data analytics because they are a flexible and intuitive way of storing and working with data.

Python DataFrame Example

DataFrame is a 2-dimensional mutable labeled data structure with columns of potentially different types. You can think of it like a spreadsheet or SQL table, or a dict of Series objects. It is generally the most commonly used `Pandas` object. A `Pandas` DataFrame is a 2-dimensional data structure, like a 2-dimensional array, or a table with rows and columns. The number of rows for `Pandas` DataFrame is mutable and limited to the computer and memory where it resides.

```

1 import pandas as pd
2
3 data = {
4     "calories": [100, 200, 300],
5     "duration": [50, 60, 70]
6 }
7
8 #load data into a DataFrame object:
9 df = pd.DataFrame(data)
10
11 print(df)
12
13 # Result:
14
15      calories  duration
16      0         100        50
17      1         200        60
18      2         300        70

```

Spark DataFrame Example

Like an RDD, a DataFrame is an immutable distributed collection of data. Unlike an RDD, data is organized into named columns, like a table in a relational database.

In Spark, a DataFrame is a distributed collection of data grouped into named columns. Spark's DataFrame is immutable and can have billions of rows. A DataFrame is equivalent to a relational table in Spark SQL, and can be created using various functions in `SparkSession` :

```

1 # PySpark code:
2
3 input_path = "..."
4 # spark: as a SparkSession object
5 people = spark.read.parquet(input_path)

```

Once created, it can be manipulated using the various domain-specific-language (DSL) functions or you may use `SQL` to execute queries against DataFrame (registered as a table).

A more concrete example:

```
1 # PySpark code:  
2  
3 # To create DataFrame using SparkSession  
4 input_path_people = "..."  
5 people = spark.read.parquet(input_path_people)  
6 input_path_dept = "..."  
7 department = spark.read.parquet(input_path_dept)  
8  
9 result = people.filter(people.age > 30) \  
10 .join(department, people.deptId == department.id) \  
11 .groupBy(department.name, "gender") \  
12 .agg({"salary": "avg", "age": "max"})
```

What is an Spark DataFrame?

Spark's DataFrame (full name as: `pyspark.sql.DataFrame`) is an immutable and distributed collection of data grouped into named columns. Once your DataFrame is created, then your DataFrame can be manipulated and transformed into another DataFrame by DataFrame's native API and SQL.

A DataFrame can be created from Python collections, relational databases, Parquet files, JSON, CSV files, ...).

DataFrame is more suitable to structured and semi-structured data (while an RDD is more suitable to unstructured and semi-structured data).

Spark RDD Example

An Spark RDD can represent billions of elements.

```
1      >>> sc
2      <SparkContext master=local[*] appName=PySparkShell>
3      >>> sc.version
4      '3.3.1'
5      >>> numbers = sc.parallelize(range(0,1000))
6      >>> numbers
7      PythonRDD[1] at RDD at PythonRDD.scala:53
8      >>> numbers.count()
9      1000
10     >>> numbers.take(5)
11     [0, 1, 2, 3, 4]
12     >>> numbers.getNumPartitions()
13     16
14     >>> total = numbers.reduce(lambda x, y: x+y)
15     >>> total
16     499500
```

Spark DataFrame Example

A Spark DataFrame can represent billions of rows of named columns.

```
1      >>> records = [("alex", 23), ("jane", 24), ("mia", 33)]
2      >>> spark
3      <pyspark.sql.session.SparkSession object at 0x12469e6e0>
4      >>> spark.version
5      '3.3.1'
6      >>> df = spark.createDataFrame(records, ["name", "age"])
7      >>> df.show()
8      +---+---+
9      | name | age |
10     +---+---+
11     | alex | 23 |
12     | jane | 24 |
13     | mia | 33 |
14     +---+---+
15
16     >>> df.printSchema()
17     root
18     |-- name: string (nullable = true)
19     |-- age: long (nullable = true)
```

Join Operation in MapReduce

The MapReduce paradigm does not have a direct join API. But the join can be implemented as a set of custom mappers and reducers.

Below, an inner join is presented for MapReduce:

Let R be a relation as (K, a_1, a_2, \dots) , where K is a key and a_1, a_2, \dots are additional attributes of R , which we denote it as (K, A) , where A denotes attributes (a_1, a_2, \dots) .

Let S be a relation as (K, b_1, b_2, \dots) , where K is a key and b_1, b_2, \dots are additional attributes of S , which we denote it as (K, B) , where B denotes attributes (b_1, b_2, \dots) .

We want to implement $R.join(S)$, which will return $(K, (a, b))$, where (K, a) is in R and (K, b) is in S .

Step-1: Map relation R: inject the name of relation into an output value as:

```
1 | input (K, a)
2 | output: (K, ("R", a))
```

Step-2: Map relation S: inject the name of relation into an output value as:

```
1 | input (K, b)
2 | output: (K, ("S", b))
```

Step-3: Merge outputs of Step-1 and Step-2 into $/tmp/merged_input/$, which will be used as an input path for Step-4 (as an identity mapper):

Step-4: is an identity mapper:

```
1 | # key: as K
2 | # value as: ("R", a) OR ("S", b)
3 | map(key, value) {
4 |     emit(key, value)
5 | }
```

Step-4.5: Sort & Shuffle (provided by MapReduce implementation): will create (key, value) pairs

as:

```
1 | (K, Iterable<(relation, attribute)>
```

where `K` is the common key of `R` and `S`, relation is either “R” or “S”, and attribute is either `a` in `A` or `b` in `B`.

Step-5: Reducer

```

1  # key as K is the common key of R and S
2  # values : Iterable<(relation, attribute)>
3  reduce(key, values) {
4      # create two lists: one for R and another one for S
5      R_list = []
6      S_list = []
7
8      # iterate values and update R_list and S_list
9      for pair in values {
10          relation = pair[0]
11          attribute = pair[1]
12          if (relation == "R") {
13              R_list.append(attribute)
14          }
15          else {
16              # relation == "S"
17              S_list.append(attribute)
18          }
19      } #end-for
20
21      # drop keys, which are not common
22      if (len(R_list) == 0) or (len(S_list) == 0) {
23          # no join, no common attributes
24          return
25      }
26
27      # Process common keys
28      # Both lists are non-empty:
29      # len(R_list) > 0) AND len(S_list) > 0
30      # perform a cartesian product of R and S
31      for a in R_list {
32          for b in S_list {
33              emit (key, (a, b))
34          }
35      }
36  } # end-reduce

```

Note that the left-join and right-join operations can be implemented by revising the reducer function.

Example: Demo Inner Join

Relation R:

1	(x, 1)
2	(x, 2)
3	(y, 3)
4	(y, 4)
5	(z, 5)

Relation S:

1	(x, 22)
2	(x, 33)
3	(y, 44)
4	(p, 55)
5	(p, 66)
6	(p, 77)

Step-1: output:

1	(x, ("R", 1))
2	(x, ("R", 2))
3	(y, ("R", 3))
4	(y, ("R", 4))
5	(z, ("R", 5))

Step-2: output:

1	(x, ("S", 22))
2	(x, ("S", 33))
3	(y, ("S", 44))
4	(p, ("S", 55))
5	(p, ("S", 66))
6	(p, ("S", 77))

Step-3: combine outputs of Step-1 and Step-2:

```
1   (x, ("R", 1))
2   (x, ("R", 2))
3   (y, ("R", 3))
4   (y, ("R", 4))
5   (z, ("R", 5))
6   (x, ("S", 22))
7   (x, ("S", 33))
8   (y, ("S", 44))
9   (p, ("S", 55))
10  (p, ("S", 66))
11  (p, ("S", 77))
```

Step-4: Identity Mapper output:

```
1   (x, ("R", 1))
2   (x, ("R", 2))
3   (y, ("R", 3))
4   (y, ("R", 4))
5   (z, ("R", 5))
6   (x, ("S", 22))
7   (x, ("S", 33))
8   (y, ("S", 44))
9   (p, ("S", 55))
10  (p, ("S", 66))
11  (p, ("S", 77))
```

Step-4.5: Sort & Shuffle output:

```
1   (x, [("R", 1), ("R", 2), ("S", 22), ("S", 33)])
2   (y, [("R", 3), ("R", 4), ("S", 44)])
3   (z, [("R", 5)])
4   (p, [("S", 55), ("S", 66), ("S", 77)])
```

Step-5: Reducer output:

```
1 | (x, (1, 22))
2 | (x, (1, 33))
3 | (x, (2, 22))
4 | (x, (2, 33))
5 | (y, (3, 44))
6 | (y, (4, 44))
```

Join Operation in Spark

Spark has an extensive support for join operation.

Join in RDD

Let A be an `RDD[(K, V)]` and B be an `RDD[(K, U)]`, then `A.join(B)` will return a new RDD (call it as C) as `RDD[(K, (V, U))]`. Each pair of C elements will be returned as a `(k, (v, u))` tuple, where `(k, v)` is in A and `(k, u)` is in B. Spark performs a hash join across the cluster.

Example:

```
1 | # sc : SparkContext
2 | x = sc.parallelize([('a', 1), ('b', 4), ('c', 6), ('c', 7)])
3 | y = sc.parallelize([('a', 2), ('a', 3), ('c', 8), ('d', 9)])
4 | x.join(y).collect()
5 |
6 | [
7 |     ('a', (1, 2)),
8 |     ('a', (1, 3)),
9 |     ('c', (6, 8)),
10 |    ('c', (7, 8))
11 | ]
```

Join in DataFrame

```

1 # PySpark API:
2
3 DataFrame.join(other: pyspark.sql.dataframe.DataFrame,
4                 on: Union[str, List[str],
5                           pyspark.sql.column.Column,
6                           List[pyspark.sql.column.Column], None] = None,
7                 how: Optional[str] = None)
8                         → pyspark.sql.dataframe.DataFrame
9
10 Joins with another DataFrame, using the given join expression.

```

Example: inner join

```

1 # SparkSession available as 'spark'.
2 >>> emp = [(1, "alex", "100", 33000), \
3 ...      (2, "rose", "200", 44000), \
4 ...      (3, "bob", "100", 61000), \
5 ...      (4, "james", "100", 42000), \
6 ...      (5, "betty", "400", 35000), \
7 ...      (6, "ali", "300", 66000) \
8 ... ]
9 >>> emp_columns = ["emp_id", "name", "dept_id", "salary"]
10 >>> emp_df = spark.createDataFrame(data=emp, schema = emp_columns)
11 >>>
12 >>> emp_df.show()
13 +---+---+---+---+
14 |emp_id| name|dept_id|salary|
15 +---+---+---+---+
16 | 1| alex| 100| 33000|
17 | 2| rose| 200| 44000|
18 | 3| bob| 100| 61000|
19 | 4| james| 100| 42000|
20 | 5| betty| 400| 35000|
21 | 6| ali| 300| 66000|
22 +---+---+---+---+
23
24 >>> dept = [("Finance", 100), \
25 ...      ("Marketing", 200), \
26 ...      ("Sales", 300), \
27 ...      ("IT", 400) \
28 ... ]
29 >>> dept_columns = ["dept_name", "dept_id"]
30 >>> dept_df = spark.createDataFrame(data=dept, schema = dept_columns)

```

```

31 >>> dept_df.show()
32 +-----+-----+
33 |dept_name|dept_id|
34 +-----+-----+
35 |  Finance|    100|
36 |Marketing|    200|
37 |   Sales|    300|
38 |     IT|    400|
39 +-----+-----+
40
41 >>> joined = emp_df.join(dept_df, emp_df.dept_id == dept_df.dept_id, "inner")
42 >>> joined.show()
43 +-----+-----+-----+-----+-----+
44 |emp_id| name|dept_id|salary|dept_name|dept_id|
45 +-----+-----+-----+-----+-----+
46 |    1| alex|    100| 33000| Finance|    100|
47 |    3| bob|    100| 61000| Finance|    100|
48 |    4|james|    100| 42000| Finance|    100|
49 |    2| rose|    200| 44000| Marketing|    200|
50 |    6| ali|    300| 66000|   Sales|    300|
51 |    5|betty|    400| 35000|      IT|    400|
52 +-----+-----+-----+-----+
53
54 >>> joined = emp_df.join(dept_df, emp_df.dept_id == dept_df.dept_id, "inner"
55 .drop(dept_df.dept_id)
56 >>> joined.show()
57 +-----+-----+-----+-----+
58 |emp_id| name|dept_id|salary|dept_name|
59 +-----+-----+-----+-----+
60 |    1| alex|    100| 33000| Finance|
61 |    3| bob|    100| 61000| Finance|
62 |    4|james|    100| 42000| Finance|
63 |    2| rose|    200| 44000| Marketing|
64 |    6| ali|    300| 66000|   Sales|
65 |    5|betty|    400| 35000|      IT|
66 +-----+-----+-----+-----+

```

Spark Partitioning

A [partition in spark](#) is an atomic chunk of data (logical division of data) stored on a node in the cluster. Partitions are basic units of parallelism in Apache Spark. RDDs and DataFrames in Apache Spark are collection of partitions.

Data (represented as an RDD or DataFrame) partitioning in Spark helps achieve more parallelism. For example, if your RDD/DataFrame is partitioned into 100 chunks/partitions, then for `RDD.map()`, there is a chance of running 100 mappers in parallel/concurrently (at the same time). Therefore, Spark RDDs and DataFrames are stored in partitions and operated in parallel.

For example, in PySpark you can get the current number/length/size of partitions by running `RDD.getNumPartitions()`.

Physical Data Partitioning

Physical Data Partitioning is a technique used in data warehouses and big data query engines.

Physical Data Partitioning is a way to organize a very large data into several smaller data based on one or multiple columns (partition key, for example, continent, country, date, state e.t.c).

The main point of Physical Data Partitioning is to analyze slice of a data rather than the whole data. For example, if we have a temperature data for 7 continents, and we are going to query data based on the continent name, then to reduce the query time, we can partition data by the continent name: this enables us to query slice of a data (such as:

`continent_name = asia`) rather than the whole data. When we physically partition data, we create separate folder (or directory) per partitioned column.

In Spark, for Physical Data Partitioning, you may use

`pyspark.sql.DataFrameWriter.partitionBy()`.

PySpark Example:

```
1 | output_path = "...target-output-path..."  
2 | df.write.partitionBy('continent')\  
3 |   .parquet(output_path)
```

For example, given a DataFrame as:

```
1 | DataFrame(continent, country, city, temprature)
```

Then partitioning by `continent`, the following physical folders/directories will be created (for example, if we had data for 7 continents, then 7 folders will be created):

```
1 <output_path>
2   |
3     +----- continent=Asia    --- <data-for-asia>
4   |
5     +----- continent=Europe --- <data-for-europe>
6   |
7     + ...
```

For details, refer to [Physical Data Partitioning tutorial](#).

GraphFrames

[GraphFrames](#) is an external package for Apache Spark which provides DataFrame-based Graphs. It provides high-level APIs in Scala, Java, and Python. It aims to provide both the functionality of GraphX (included in Spark API) and extended functionality taking advantage of Spark DataFrames. This extended functionality includes motif finding, DataFrame-based serialization, and highly expressive graph queries.

GraphFrames are to DataFrames as GraphX is to RDDs.

To build a graph, you build 2 DataFrames (one for vertices and another one for the edges) and then glue them together to create a graph:

```
1 # each node is identified by "id" and an optional attributes
2 # vertices: DataFrame(id, ...)
3
4 # each edge is identified by (src, dst) and an optional attributes
5 # where src and dst are node ids
6 # edges: DataFrame(src, dst, ...)
7
8 # import required GraphFrame library
9 from graphframes import GraphFrame
10
11 # create a new directed graph
12 graph = GraphFrame(vertices, edges)
```

Example of a GraphFrame

This example shows how to build a directed graph using graphframes API.

To invoke PySpark with GraphFrames:

```
1 % # define the home directory for Spark
2 % export SPARK_HOME=/home/spark-3.2.0
3 % # import graphframes library into PySpark and invoke interactive PySpark:
4 % $SPARK_HOME/bin/pyspark --packages graphframes:graphframes:0.8.2-spark3.2-s
5 Python 3.8.9 (default, Mar 30 2022, 13:51:17)
6 ...
7 Welcome to
8
9   _\ _/ \ _ \ _ \ _ \ _ \ _ \
10  / \ _ \ _ \ _ \ _ \ _ \ _ \
11  / _ \ _ \ _ \ _ \ _ \ _ \ _ \
12  / _ \
13
14 Using Python version 3.8.9 (default, Mar 30 2022 13:51:17)
15 Spark context Web UI available at http://10.0.0.234:4040
16 Spark context available as 'sc' (master = local[*], app id = local-1650670391)
17 SparkSession available as 'spark'.
18 >>>
```

Then PySpark is ready to use GraphFrames API:

```
1 >>># create list of nodes
2 >>> vert_list = [("a", "Alice", 34),
3 ...           ("b", "Bob", 36),
4 ...           ("c", "Charlie", 30)]
5 >>>
6 >>># define column names for a node
7 >>> column_names_nodes = ["id", "name", "age"]
8 >>>
9 >>># create vertices_df as a Spark DataFrame
10 >>> vertices_df = spark.createDataFrame(
11 ...     vert_list,
12 ...     column_names_nodes
13 ... )
14
15 >>>
16 >>># create list of edges
17 >>> edge_list = [("a", "b", "friend"),
18 ...                 ("b", "c", "follow"),
19 ...                 ("c", "b", "follow")]
```

```

20 >>>
21 >>> # define column names for an edge
22 >>> column_names_edges = ["src", "dst", "relationship"]
23 >>>
24 >>> # create edges_df as a Spark DataFrame
25 >>> edges_df = spark.createDataFrame(
26 ...         edge_list,
27 ...         column_names_edges
28 ... )
29 >>>
30 >>> # import required libraries
31 >>> from graphframes import GraphFrame
32 >>>
33 >>> # build a graph using GraphFrame library
34 >>> graph = GraphFrame(vertices_df, edges_df)
35 >>>
36 >>> # examine built graph
37 >>> graph
38 GraphFrame(
39     v:[id: string, name: string ... 1 more field],
40     e:[src: string, dst: string ... 1 more field]
41 )
42 >>>
43 >>> # access vertices of a graph
44 >>> graph.vertices.show()
45 +---+-----+---+
46 | id|    name|age|
47 +---+-----+---+
48 | a| Alice| 34|
49 | b| Bob| 36|
50 | c|Charlie| 30|
51 +---+-----+---+
52
53 >>> # access edges of a graph
54 >>> graph.edges.show()
55 +---+-----+---+
56 |src|dst|relationship|
57 +---+-----+---+
58 | a| b| friend|
59 | b| c| follow|
60 | c| b| follow|
61 +---+-----+---+

```

Advantages of using Spark

- **Speed:** for large scale data analysis and processing, Spark is 100 times faster than Hadoop. This is achieved by:
 - Modern architecture, better ECO system
 - Provides parallelism with simple and powerful API
 - Utilizing In-Memory (RAM) processing architecture
- **Ease of Use:** Spark provides simple and powerful APIs for working with big data sets. Spark offers over 100 high-level operators and transformations that makes creating parallel programs a breeze
- **Advanced Analytics:** Spark implements superset of MapReduce paradigm. Spark does much more than `map-then-reduce` of MapReduce paradigm. Sparks offers Machine Learning, Graph processing, streaming data, and SQL queries.
- **Dynamic:** Spark allows simple creation of parallel applications. Spark offers over 100 high-level operators, transformations, and actions.
- **Multilingual:** Python, Java, Scala, R, and SQL are supported by Spark
- **Simple and Powerful:** Because of its low-latency in-memory data processing capacity, Spark can handle a wide range of analytics problems. Spark has an extensive libraries for Machine Learning and Graph analytics at a scale
- **Open-Source:** Spark is an open-source and hosted by Apache Software Foundation.

GraphX

[GraphX](#) is Apache Spark's API (RDD-based) for graphs and graph-parallel computation, with a built-in library of common algorithms. GraphX has API for Java and Scala, but does not have an API for Python (therefore, PySpark does not support GraphX, but PySpark supports GraphFrames).

Cluster

Cluster is a group of servers on a network that are configured to work together. A server is either a master node or a worker node. A cluster may have a master node and many worker nodes. In a nutshell, a master node acts as a cluster manager.

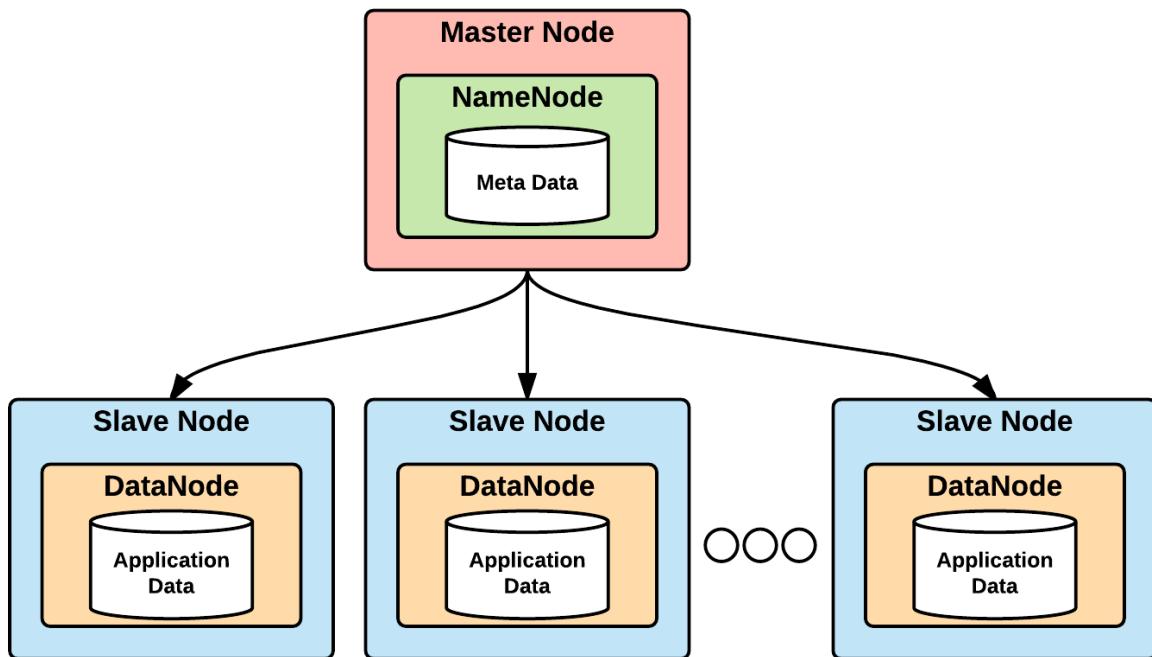
A cluster may have one (or two) master nodes and many worker nodes. For example, a cluster of 15 nodes: one master and 14 worker nodes. Another example: a cluster of 101 nodes: one master and 100 worker nodes.

A cluster may be used for running many jobs (Spark and MapReduce jobs) at the same time.

Master node

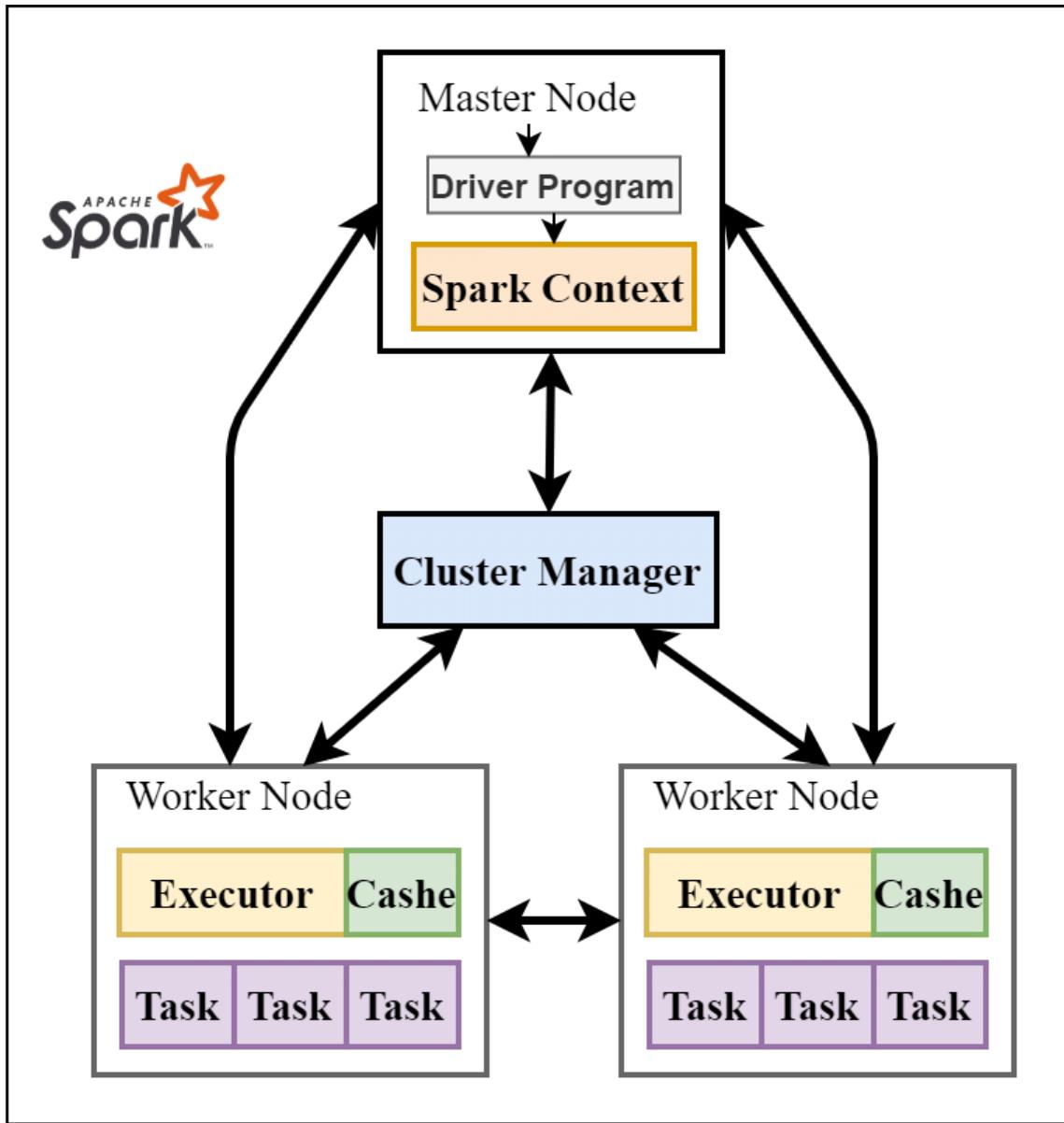
In Hadoop, Master nodes (set of one or more nodes) are responsible for storing data in HDFS and overseeing key operations, such as running parallel computations on the data using MapReduce. The worker nodes comprise most of the virtual machines in a Hadoop cluster, and perform the job of storing the data and running computations.

Hadoop-Master-Worker: the following images shows Hadoop's master node and worker nodes.



In Spark, the master node contains driver program, which drives the application by creating Spark context object. Spark context object works with cluster manager to manage different jobs. Worker nodes job is to execute the tasks and return the results to Master node.

Spark-Master-Worker: the following images shows master node and 2 worker nodes.



Worker node

In Hadoop, the worker nodes comprise most of the virtual machines in a Hadoop cluster, and perform the job of storing the data and running computations. Each worker node runs the DataNode and TaskTracker services, which are used to receive the instructions from the master nodes.

In Spark, worker node is ny node that can run application code in the cluster. Executor is a process launched for an application on a worker node, that runs tasks and keeps data in memory or disk storage across them. Each application has its own executors.

Cluster computing

Cluster computing is a collection of tightly or loosely connected computers that work together so that they act as a single entity. The connected computers execute operations all together thus creating the idea of a single system. The clusters are generally connected through fast local area networks (LANs). A cluster computing is comprised of a one or more masters (manager for the whole cluster) and many worker nodes. For example, a cluster computer may have a single master node (which might not participate in tasks such as mappers and reducers) and 100 worker nodes (which actively participate in carrying tasks such as mappers and reducers). A small cluster might have one master node and 5 worker nodes. Large clusters might have hundreds or thousands of worker nodes.

Concurrency

Performing and executing multiple tasks and processes at the same time. Let's define 5 tasks {T1, T2, T3, T4, T5} where each will take 10 seconds. If we execute these 5 tasks in sequence, then it will take about 50 seconds, while if we execute all of them in parallel, then the whole thing will take about 10 seconds. Cluster computing enables concurrency and parallelism.

Histogram

A graphical representation of the distribution of a set of numeric data, usually a vertical bar graph

Structured data

Structured data — typically categorized as quantitative data — is highly organized and easily decipherable by machine learning algorithms. Developed by IBM in 1974, structured query language (SQL) is the programming language used to manage structured data. By using a relational (SQL) database, business users can quickly input, search and manipulate structured data. In structured data, each record has a precise record format. Structured data is identifiable as it is organized in structure like rows and columns.

Structured data is data that has a predefined data model or is organized in a predefined way.

Unstructured data

In the modern world of big data, unstructured data is the most abundant. It's so prolific because unstructured data could be anything: media, imaging, audio, sensor data, log data, text data, and much more. Unstructured simply means that it is datasets (typical large collections of files) that aren't stored in a structured database format. Unstructured data has an internal structure, but it's not predefined through data models. It might be human generated, or machine generated in a textual or a non-textual format. Unstructured data is regarded as data that is in general text heavy, but may also contain dates, numbers and facts.

Unstructured data is data that does not have a predefined data model or is not organized in a predefined way.

Correlation analysis

The analysis of data to determine a relationship between variables and whether that relationship is negative (-1.00) or positive $(+1.00)$.

Data aggregation tools

The process of transforming scattered data from numerous sources into a single new one.

Data analyst

Someone analysing, modelling, cleaning or processing data

Database

A digital collection of data stored via a certain technique. In computing, a database is an organized collection of data (rows or objects) stored and accessed electronically.

Database Management System

Collecting, storing and providing access of data.

Data cleansing

The process of reviewing and revising data in order to delete duplicates, correct errors and provide consistency

Data mining

The process of finding certain patterns or information from data sets. Data Mining is done for purposes like Market Analysis, determining customer purchase pattern, financial planning, fraud detection, etc.

Data mining is a study of extracting useful information from structured/unstructured data taken from various sources. This is done usually for

1. Mining for frequent patterns
2. Mining for associations
3. Mining for correlations
4. Mining for clusters
5. Mining for predictive analysis

Data virtualization

A data integration process in order to gain more insights. Usually it involves databases, applications, file systems, websites, big data techniques, etc.)

De-identification

Same as anonymization; ensuring a person cannot be identified through the data

ETL (Extract, Transform and Load)

ETL is a process in a database and data warehousing meaning extracting the data from various sources, transforming it to fit operational needs and loading it into the database or some storage. For example, processing DNA data, creating output records in specific Parquet format and loading it to Amazon S3 is an ETL process.

- Extract: the process of reading data from a database or data sources
- Transform: the process of conversion of extracted data in the desired form so that it can be put into another database.
- Load: the process of writing data into the target database to data source

Failover

Switching automatically to a different server or node should one fail Fault-tolerant design – a system designed to continue working even if certain parts fail Feature - a piece of measurable information about something, for example features you might store about a set of people, are age, gender and income.

Graph Databases

Graph databases are purpose-built to store and navigate relationships. Relationships are first-class citizens in graph databases, and most of the value of graph databases is derived from these relationships. Graph databases use nodes to store data entities, and edges to store relationships between entities. An edge always has a start node, end node, type, and direction, and an edge can describe parent-child relationships, actions, ownership, and the like. There is no limit to the number and kind of relationships a node can have.

Grid computing

Connecting different computer systems from various location, often via the cloud, to reach a common goal

Key-Value Databases

Key-Value Databases store data with a primary key, a uniquely identifiable record, which makes easy and fast to look up. The data stored in a Key-Value is normally some kind of primitive of the programming language. As a dictionary, for example, Redis allows you to set and retrieve pairs of keys and values. Think of a “key” as a unique identifier (string, integer, etc.) and a “value” as whatever data you want to associate with that key. Values can be strings, integers, floats, booleans, binary, lists, arrays, dates, and more.

(key, value)

The `(key, value)` notation is used in many places (such as Spark) and in MapReduce Paradigm. In MapReduce paradigm everything works as a `(key, value)`. Note that the `key` and `value` can be

- simple data type: such as String, Integer, Double, ...

- combined data types: tuples, structures, arrays, lists, ...

In MapReduce, `map()` and `reduce()` use `(key, value)` pairs:

The Map output types should match the input types of the Reduce as shown below:

```
1 # mapper can emit 0, 1, 2, ... of (K2, V2)
2 map(K1, V1) -> { (K2, V2) }
3
4 # reducer can emit 0, 1, 2, ... of (K3, V3)
5 # K2 is a unique key from mapper's outputs
6 # [V2, ...] are all values associated with key K2
7 reduce(K2, [V2, ...]) -> { (K3, V3) }
```

In Spark, using RDDs, a source RDD must be in `(key, value)` form before we can apply reduction transformations such as `groupByKey()`, `reduceByKey()`, and `combineByKey()`.

Java

[Java](#) is a programming language and computing platform first released by Sun Microsystems in 1995. It has evolved from humble beginnings to power a large share of today's digital world, by providing the reliable platform upon which many services and applications are built. New, innovative products and digital services designed for the future continue to rely on Java, as well.

Python

[Python](#) is a programming language that lets you work quickly and integrate systems more effectively. Python is an interpreted, object-oriented (not fully) programming language that's gained popularity for big data professionals due to its readability and clarity of syntax. Python is relatively easy to learn and highly portable, as its statements can be interpreted in several operating systems.

JavaScript

A scripting language designed in the mid-1990s for embedding logic in web pages, but which later evolved into a more general-purpose development language.

In-memory

A database management system stores data on the main memory instead of the disk, resulting in very fast processing, storing and loading of the data Internet of Things – ordinary devices that are connected to the internet at any time anywhere via sensors

Latency

A measure of time delayed in a system

Location data

GPS data describing a geographical location

Machine Learning

Part of artificial intelligence where machines learn from what they are doing and become better over time. Apache Spark offers a comprehensive Machine Learning library for big data. In a nutshell, Machine learning is an application of AI that enables systems to learn and improve from experience without being explicitly programmed.

There are many ML packages for experimentation:

- [scikit-learn - Machine Learning in Python](#)
- [Apache Spark Machine Learning](#)

Internet of Things

Internet of things, IoT, in short, is a conception of connecting devices, such as house lighting, heating or even fridges to a common network. It allows storing big amounts of data, which can later be used in real-time analytics. This term is also connected with a smart home, a concept of controlling house with phone etc.

According to Wiki: [The Internet of things \(IoT\)](#) describes physical objects (or groups of such objects) with sensors, processing ability, software and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks. Internet of things has been considered a misnomer because devices do not need to be connected to the public internet, they only need to be connected to a network and be

individually addressable.

Metadata

Data about data; gives information about what the data is about.

For example, author, date created, date modified and file size are examples of very basic document file metadata.

Table definition for a relational table is an example of metadata.

Natural Language Processing (NLP)

A field of computer science involved with interactions between computers and human languages.

Open source software for NLP: [The Stanford Natural Language Processing](#)

Network analysis

Viewing relationships among the nodes in terms of the network or graph theory, meaning analysing connections between nodes in a network and the strength of the ties.

Workflow

A graphical representation of a set of events, tasks, and decisions that define a business process (example: vacation approval process in a company; purchase approval process). You use the developer tool to add objects to a workflow and to connect the objects with sequence flows. The Data Integration Service uses the instructions configured in the workflow to run the objects.

Schema

In computer programming, a schema (pronounced **SKEE-mah**) is the organization or structure for a database, while in artificial intelligence (AI) a schema is a formal expression of an inference rule. For the former, the activity of data modeling leads to a schema.

- Example, Database schema:

```
1 | CREATE TABLE product (
2 |   id INT AUTO_INCREMENT PRIMARY KEY,
3 |   product_name VARCHAR(50) NOT NULL,
4 |   price VARCHAR(7) NOT NULL,
5 |   quantity INT NOT NULL
6 | )
```

- Example, DataFrame schema in PySpark

```
1 | from pyspark.sql.types import StructType, StructField
2 | from pyspark.sql.types import StringType, IntegerType
3 |
4 | schema = StructType([
5 |   StructField("first_name", StringType(), True), \
6 |   StructField("last_name", StringType(), True), \
7 |   StructField("emp_id", StringType(), True), \
8 |   StructField("gender", StringType(), True), \
9 |   StructField("salary", IntegerType(), True)
10 | ])
```

Difference between Tuple and List in Python

The primary difference between tuples and lists is that tuples are **immutable** as opposed to lists which are **mutable**. Therefore, it is possible to change a list but not a tuple. The contents of a tuple cannot change once they have been created in Python due to the immutability of tuples.

Examples in Python3:

```
1 # create a tuple
2 >>> t3 = (10, 20, 40)
3 >>> t3
4 (10, 20, 40)
5
6 # create a list
7 >>> l3 = [10, 20, 40]
8 >>> l3
9 [10, 20, 40]
10
11 # add an element to a list
12 >>> l3.append(500)
13 >>> l3
14 [10, 20, 40, 500]
15
16 # add an element to a tuple
17 >>> t3.append(600)
18 Traceback (most recent call last):
19   File "<stdin>", line 1, in <module>
20     AttributeError: 'tuple' object has no attribute 'append'
```

Object Databases

An object database store data in the form of objects, as used by object-oriented programming. They are different from relational or graph databases and most of them offer a query language that allows object to be found with a declarative programming approach.

Pattern Recognition

Pattern Recognition identifies patterns in data via algorithms to make predictions of new data coming from the same source.

Predictive analysis

Analysis within big data to help predict how someone will behave in the (near) future. It uses a variety of different data sets such as historical, transactional, or social profile data to identify risks and opportunities.

Privacy

To seclude certain data / information about oneself that is deemed personal Public data – public information or data sets that were created with public funding

Query

Asking for information to answer a certain question

Regression analysis

To define the dependency between variables. It assumes a one-way causal effect from one variable to the response of another variable.

Real-time data

Data that is created, processed, stored, analysed and visualized within milliseconds

Scripting

The use of a computer language where your program, or script, can be run directly with no need to first compile it to binary code. Semi-structured data - a form a structured data that does not have a formal structure like structured data. It does however have tags or other markers to enforce hierarchy of records.

Sentiment Analysis

Using algorithms to find out how people feel about certain topics or events

SQL

A programming language for retrieving data from a relational database. Also, SQL is used to retrieve data from big data by translating query into mappers, filters, and reducers.

SQL is a standard language for accessing and manipulating databases (relational and non-relational).

What is SQL?

- SQL stands for Structured Query Language
- SQL lets you access and manipulate databases
- SQL became a standard of the American National Standards Institute (ANSI) in 1986, and of the International Organization for Standardization (ISO) in 1987

What Can SQL do?

- SQL can execute queries against a database
- SQL can retrieve data from a database
- SQL can insert records in a database
- SQL can update records in a database
- SQL can delete records from a database
- SQL can create new databases
- SQL can create new tables in a database
- SQL can create stored procedures in a database
- SQL can create views in a database
- SQL can set permissions on tables, procedures, and views

Time series analysis

Analysing well-defined data obtained through repeated measurements of time. The data has to be well defined and measured at successive points in time spaced at identical time intervals.

Variability

It means that the meaning of the data can change (rapidly). In (almost) the same tweets for example a word can have a totally different meaning

What are the 4 Vs of Big Data?

- Volume (i.e., the size of the dataset)
- Velocity (i.e., rate of flow)
- Variety (i.e., data from multiple repositories, domains, or types)
- Veracity (i.e., refers to the accuracy of the data)

Variety

Data today comes in many different formats: structured data, semi-structured data, unstructured

data and even complex structured data

Velocity

The speed at which the data is created, stored, analysed and visualized

Veracity

Ensuring that the data is correct as well as the analyses performed on the data are correct.

Volume

The amount of data, ranging from megabytes to gigabytes to petabytes to ...

XML Databases

XML Databases allow data to be stored in XML format. The data stored in an XML database can be queried, exported and serialized into any format needed.

Big Data Scientist

Someone who is able to develop the distributed algorithms to make sense out of big data

Classification analysis

A systematic process for obtaining important and relevant information about data, also meta data called; data about data.

Cloud computing

A distributed computing system over a network used for storing data off-premises. This can include ETL, data storage, application development, and data analytics. Examples: Amazon Cloud and Google Cloud.

Cloud computing is one of the must-known big data terms. It is a new paradigm computing system which offers visualization of computing resources to run over the standard remote server for storing data and provides IaaS, PaaS, and SaaS. Cloud Computing provides IT resources

such as Infrastructure, software, platform, database, storage and so on as services. Flexible scaling, rapid elasticity, resource pooling, on-demand self-service are some of its services.

Distributed computing

Distributed computing is a computing system in which components located on networked computers communicate and coordinate their actions by passing messages.

Clustering analysis

Cluster analysis or clustering is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense) to each other than to those in other groups (clusters).

Database-as-a-Service

A database hosted in the cloud on a pay per use basis, for example Amazon Web Services

Database Management System (DBMS)

Database Management System is software that collects data and provides access to it in an organized layout. It creates and manages the database. DBMS provides programmers and users a well-organized process to create, update, retrieve, and manage data.

Distributed File System

Systems that offer simplified, highly available access to storing, analysing and processing data; examples are:

- Hadoop Distributed File System (HDFS)
- Amazon S3 (a distributed object storage system)

Document Store Databases

A document-oriented database that is especially designed to store, manage and retrieve documents, also known as semi structured data.

NoSQL

NoSQL sometimes referred to as ‘Not only SQL’ as it is a database that doesn’t adhere to traditional relational database structures. It is more consistent and can achieve higher availability and horizontal scaling. NoSQL is an approach to database design that can accommodate a wide variety of data models, including key-value, document, columnar and graph formats. NoSQL, which stands for “not only SQL,” is an alternative to traditional relational databases in which data is placed in tables and data schema is carefully designed before the database is built. NoSQL databases are especially useful for working with large sets of distributed data.

Scala

A software programming language that blends object-oriented methods with functional programming capabilities. This allows it to support a more concise programming style which reduces the amount of code that developers need to write. Another benefit is that Scala features, which operate well in smaller programs, also scale up effectively when introduced into more complex environments.

Columnar Database

A database that stores data column by column instead of the row is known as the column-oriented database.

Data Analyst

The data analyst is responsible for collecting, processing, and performing statistical analysis of data. A data analyst discovers the ways how this data can be used to help the organization in making better business decisions. It is one of the big data terms that define a big data career. Data analyst works with end business users to define the types of the analytical report required in business.

Data Scientist

Data Scientist is also a big data term that defines a big data career. A data scientist is a practitioner of data science. He is proficient in mathematics, statistics, computer science, and/or data visualization who establish data models and algorithms for complex problems to solve them.

Data Model and Data Modelling

Data Model is a starting phase of a database designing and usually consists of attributes, entity types, integrity rules, relationships and definitions of objects.

Data modeling is the process of creating a data model for an information system by using certain formal techniques. Data modeling is used to define and analyze the requirement of data for supporting business processes.

Hive

Hive is an open source Hadoop-based data warehouse software project for providing data summarization, analysis, and query. Users can write queries in the SQL-like language known as HiveQL. Hadoop is a framework which handles large datasets in the distributed computing environment.

Load Balancing

Load balancing is a tool which distributes the amount of workload between two or more computers over a computer network so that work gets completed in small time as all users desire to be served faster. It is the main reason for computer server clustering and it can be applied with software or hardware or with the combination of both.

Load balancing refers to distributing workload across multiple computers or servers in order to achieve optimal results and utilization of the system

Log File

A log file is the special type of file that allows users keeping the record of events occurred or the operating system or conversation between the users or any running software.

Log file is a file automatically created by a computer program to record events that occur while operational.

Parallel Processing

It is the capability of a system to perform the execution of multiple tasks simultaneously (at the same time)

In parallel processing, we take in multiple different forms of information at the same time. This is especially important in vision. For example, when you see a bus coming towards you, you see its color, shape, depth, and motion all at once.

Parallel processing is a method in computing of running two or more processors (CPUs) to handle separate parts of an overall task. Breaking up different parts of a task among multiple processors will help reduce the amount of time to run a program.

For example, Spark uses Resilient Distributed Datasets (RDD) to perform parallel processing across a cluster or computer processors.

Server (or node)

The server is a virtual or physical computer that receives requests related to the software application and thus sends these requests over a network. It is the common big data term used almost in all the big data technologies.

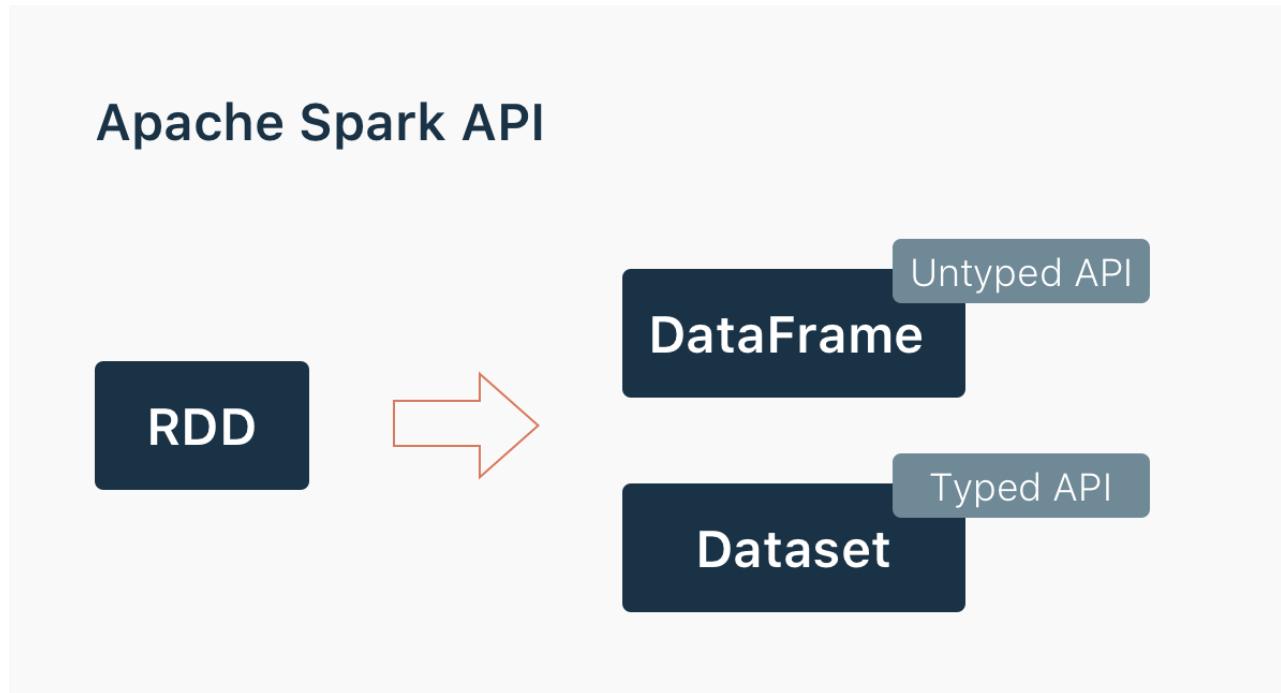
Abstraction layer

A translation layer that transforms high-level requests into low-level functions and actions. Data abstraction sees the essential details needed to perform a function removed, leaving behind the complex, unnecessary data in the system. The complex, unneeded data is hidden from the client, and a simplified representation is presented. A typical example of an abstraction layer is an API (application programming interface) between an application and an operating system.

For example, Spark offers three types of data abstractions (it means that your data can be represented in RDD, DataFrame, and Dataset):

- **RDD** (supported by PySpark)
- **DataFrame** (supported by PySpark)
- Dataset (not supported by PySpark)

Apache Spark API



Cloud

Cloud technology, or The Cloud as it is often referred to, is a network of servers that users access via the internet and the applications and software that run on those servers. Cloud computing has removed the need for companies to manage physical data servers or run software applications on their own devices - meaning that users can now access files from almost any location or device.

The cloud is made possible through virtualisation - a technology that mimics a physical server but in virtual, digital form, A.K.A virtual machine.

Data ingestion

Data ingestion is the process of moving data from various sources into a central repository such as a data warehouse where it can be stored, accessed, analysed, and used by an organisation.

Common examples of data ingestion include:

- Move data from DNA laboratory to a data warehouse then analyze with variant analyzer.
- Capture data from a Twitter feed for real-time sentiment analysis.
- Acquire data for training machine learning models and experimentation.

Data warehouse

A centralised repository of information that enterprises can use to support business intelligence (BI) activities such as analytics. Data warehouses typically integrate historical data from various sources.

It is a system that stores data in order to analyze and process it in the future. The source of data can vary, depending on its purpose. Data can be uploaded from the company's CRM (Customer relationship management) systems as well as imported from external files or databases.

For big data, these are the data warehouse platforms on the market:

- Snowflake
- Google BigQuery
- Amazon Redshift
- Amazon Athena
- Azure Synapse Analytics
- IBM Db2 Warehouse
- Firebolt

Open-source

Open-source refers to the availability of certain types of code to be used, redistributed and even modified for free by other developers. This decentralised software development model encourages collaboration and peer production.

The most popular open-source software is from [Apache](#).

Prime examples of open-source products are:

- Apache HTTP Server
- Apache Hadoop
- Apache Spark

Relational database

The `relational` term here refers to the relations (also commonly referred to as tables) in the database - the tables and their relationships to each other. The tables 'relate' to each other. It is these relations (tables) and their relationships that make it `relational`.

A relational database exists to house and identify data items that have pre-defined relationships with one another. Relational databases can be used to gain insights into data in relation to other data via sets of tables with columns and rows. In a relational database, each row in the table has a unique ID referred to as a key.

What do you mean by relational database? a relational database is a collection of information (stored as rows) that organizes data in predefined relationships where data is stored in one or more tables (or “relations”) of columns and rows, making it easy to see and understand how different data structures relate to each other.

There are 3 different types of relations in the database:

- one-to-one
- one-to-many
- many-to-many

RDBMS

- RDBMS stands for Relational DataBase Management System. The following are examples of system, which implement RDBMS:
 - Oracle database
 - MySQL
 - MariaDB
 - PostgreSQL
 - Microsoft SQL Server
- It is a database, which stores data in a structured format using rows and columns
- RDBMS is a multi-tenant and can manage many databases, where each database may have many tables
- RDBMS is built in such a way to respond to SQL queries in seconds
- With RDBMS, you can create databases, and within a database, you can create tables, which you may insert/update/delete/query records
- The relational structure makes it possible to run queries against many tables
- SQL (structured query language) is the standard programming language used to access database

How does Hadoop perform Input Splits?

The Hadoop's `InputFormat<K, V>` is responsible to provide the input splits. The `InputFormat<K, V>` describes the input-specification for a MapReduce job. The interface `InputFormat`'s full name is `org.apache.hadoop.mapred.InputFormat<K, V>`.

According to Hadoop: the MapReduce framework relies on the `InputFormat` of the job to:

1. Validate the input-specification of the job.
2. Split-up the input file(s) into logical `InputSplit` (s), each of which is then assigned to an individual Mapper.
3. Provide the `RecordReader` implementation to be used to glean input records from the logical `InputSplit` for processing by the Mapper.

The `InputFormat` interface has 2 functions:

```
1 // 1. Get the RecordReader for the given InputSplit.  
2     RecordReader<K,V>    getRecordReader(InputSplit split, JobConf job, Reporter reporter)  
3  
4 // 2. Logically split the set of input files for the job.  
5     InputSplit[]    getSplits(JobConf job, int numSplits)
```

In general, if you have N nodes, the HDFS will distribute the input file(s) over all these N nodes. If you start a job, there will be N mappers by default. The mapper on a machine will process the part of the data that is stored on this node.

MapReduce/Hadoop data processing is driven by this concept of input splits. The number of input splits that are calculated for a specific application determines the number of mapper tasks.

The number of maps is usually driven by the number of DFS blocks in the input files. Each of these mapper tasks is assigned, where possible, to a worker node where the input split (`InputSplit`) is stored. The Resource Manager does its best to ensure that input splits are processed locally (for optimization purposes).

Sort & Shuffle function in MapReduce/Hadoop

Shuffle phase in Hadoop transfers the map output (in the form of `(key, value)` pairs) from

Mapper to a Reducer in MapReduce. Sort phase in MapReduce covers the merging and sorting of mappers outputs. Data from the mapper are grouped by the `key`, split among reducers and sorted by the key. Every reducer obtains all values associated with the same `key`.

For example, if there were 3 input chunks/splits, (and each chunk go to a different server) then mappers create `(key, value)` pairs per split (also called partitions), consider all of the output from all of the mappers:

	Partition-1	Partition-2	Partition-3
1	(A, 1)	(A, 5)	(A, 9)
2	(A, 3)	(B, 6)	(C, 20)
3	(B, 4)	(C, 10)	(C, 30)
4	(B, 7)	(D, 50)	
5			
6	(A, 100)		

Then the output of Sort & Shuffle phase will be (note that the values of keys are not sorted):

1	(A, [1, 3, 9, 5, 100])
2	(B, [4, 7, 6])
3	(C, [10, 20, 30])
4	(D, [50])

Output of Sort & Shuffle phase will be input to reducers.

Therefore, Sort & Shuffle creates its outputs in the following form:

1	(key, [v_1, v_2, ..., v_n])
---	-----------------------------

where all mappers have created:

1	(key, v_1),
2	(key, v_2),
3	...
4	(key, v_n)

NoSQL Database

NoSQL databases (aka “not only SQL”) are non-tabular databases and store data differently

than relational tables. NoSQL databases come in a variety of types. Redis, HBase, CouchDB and MongoDB, ... are examples of NoSQL databases.

PySpark

What is PySpark? PySpark is the Python API for Apache Spark, an open source, distributed computing framework and set of libraries for near-real-time, large-scale data processing. If you're already familiar with Python and libraries such as Pandas, then PySpark is a good language to learn to create more scalable analyses and pipelines. According to [Spark documentation](#): “PySpark is an interface for Apache Spark in Python. It not only allows you to write Spark applications using Python APIs, but also provides the PySpark shell for interactively analyzing your data in a distributed environment. PySpark supports most of Spark's features such as Spark SQL, DataFrame, Streaming, MLlib (Machine Learning) and Spark Core.”

PySpark Data Abstractions:

PySpark supports two types of data abstractions:

- RDDs
- DataFrames

PySpark Documentation:

- [PySpark Documentation](#)

PySpark Usage:

PySpark can be used in two modes (The `SPARK_HOME` is an environment variable which denotes the directory/folder where Spark is installed):

- Interactive mode: by invoking:

```
1 | ${SPARK_HOME}/bin/pyspark
```

- Batch mode: by invoking

```
1 | ${SPARK_HOME}/bin/spark-submit <pyspark-program> [optional-parameters]
```

PySpark Graph Analysis:

You may use [GraphFrames](#) package to build and analyze graphs at scale.

Boolean Predicate

A Boolean predicate returns the truth value of a Boolean expression (boolean-expression: an expression that returns the Boolean value: `True` or `False`).

For example, in Spark, `RDD.filter(f: Callable[[T], bool])` returns a new RDD containing only the elements that satisfy a boolean predicate.

For example, a Python function is a boolean predicate if it only returns `True` or `False` .

Cartesian Product

In mathematics, specifically set theory, the Cartesian product of two sets `A` and `B`, denoted $A \times B$, is the set of all ordered pairs (a, b) where `a` is in `A` and `b` is in `B`

```
1 | A x B = {(a,b) / a in A and b in B }
```

Cartesian Product in Python:

```
1 | >>> A = [1, 2, 3]
2 | >>> B = [4, 5]
3 | >>> cartesian_product = [(a, b) for a in A for b in B]
4 | >>> cartesian_product
5 | [(1, 4), (1, 5), (2, 4), (2, 5), (3, 4), (3, 5)]
```

Cartesian Product in PySpark:

```
1 | # sc as SparkContext
2 | rdd = sc.parallelize([1, 2, 3])
3 | rdd2 = sc.parallelize([4, 5])
4 | rdd.cartesian(rdd2).collect()
5 | [(1, 4), (1, 5), (2, 4), (2, 5), (3, 4), (3, 5)]
```

Python Lambda

A lambda function is a small anonymous function.

A lambda function can take any number of arguments, but can only have one expression.

You should use lambda functions when an anonymous function is required for a short period of time. You should use the lambda function to create simple expressions. For example, expressions that do not include complex structures such as `if-else`, `for-loops`, and so on.

Syntax:

```
1 | lambda argument(s) : expression
```

where

- `lambda` is a keyword in Python for defining the anonymous function.
- `expression` is the code you want to execute in the lambda function.

Example:

```
1 | x = lambda a: a + 10
2 | print(x(5))
3 | 15
4 |
5 | x = lambda a, b, c : a + b + c
6 | print(x(2, 3, 4))
7 | 9
8 |
9 | def my_func(n):
10|     return lambda a : a * n
11|
12| my_tripler = my_func(3)
13| print(my_tripler(11))
14| 33
15|
16| my_list = [1, 2, 3, 4, 5, 6, 7, 8, 9]
17| list(filter(lambda x: x % 2 == 0, my_list))
18| [2, 4, 6, 8]
```

Data transformation

Data transformation is the process to convert data from one form to the other.

Note that data transformation in Python is sequential (and can handle small to medium size data)

and single threaded, while in PySpark, data is partitioned and processed in parallel and there is no limit on the size of data.

Data transformation in Python:

```
1 | >>> A = [1, 2, 3]
2 | >>> B = [x*x for x in A]
3 | >>> B
4 | [1, 4, 9]
```

Data transformation in Python using map():

```
1 | >>> map(lambda n: n * 2, [1, 2, 3, 4, 5])
2 | [2, 4, 6, 8, 10]
```

Data transformation in Python using filter():

```
1 | >>> strs = ['apple', 'and', 'a', 'donut']
2 | >>>
3 | >>> list(filter(lambda s: len(s) > 3, strs))
4 | ['apple', 'donut']
```

Data transformation in PySpark using map():

```
1 | # sc as SparkContext
2 | rdd = sc.parallelize([1, 2, 3, 4])
3 | rdd.map(lambda x: x * x).collect()
4 | [1, 4, 9, 16]
```

Data transformation in PySpark using filter():

```
1 | # sc as SparkContext
2 | rdd = sc.parallelize([1, 2, 3, 4])
3 | rdd.filter(lambda x: x > 2).collect()
4 | [3, 4]
```

Data transformation in PySpark using flatMap():

```

1 # sc as SparkContext
2 >>> rdd = sc.parallelize([ [1, 2, 3, 9], [], [4, 5, 6] ])
3 >>> rdd.count()
4 3
5 >>> rdd.collect()
6 [[1, 2, 3, 9], [], [4, 5, 6]]
7 >>> rdd2 = rdd.flatMap(lambda x: x)
8 >>> rdd2.count()
9 7
10 >>> rdd2.collect()
11 [1, 2, 3, 9, 4, 5, 6]

```

Data Curation

Curation is the process of validating and managing discovered metadata of a data source so that the metadata is fit for use and reporting. Data curation is the process of creating, organizing and maintaining data sets so they can be accessed and used by people looking for information. It involves collecting, structuring, indexing and cataloging data for users in an organization, group or the general public.

What is Bioinformatics?

- Bioinformatics is a mutually beneficial collaboration between Biology and Computer Science (CS).
- For CS, Biology provides a motivation for studying new challenging problems and developing new algorithms.
- For Biology, CS offers effective and cheap (as *in silico* experiments are typically cheaper than wet-lab ones) solutions to many tough problems

spark-packages.org

spark-packages.org is a community package index to track the growing number of open source packages and libraries that work with Apache Spark. Spark Packages makes it easy for users to find, discuss, rate, and install packages for any version of Spark and makes it easy for developers to contribute packages.

For example, GraphFrames package can be located [here](#).

References

1. [Data Algorithms with Spark by Mahmoud Parsian](#)
2. [Data Algorithms by Mahmoud Parsian](#)
3. [Monoidify! Monoids as a Design Principle for Efficient MapReduce Algorithms by Jimmy Lin](#)
4. [Google's MapReduce Programming Model — Revisited by Ralf Lammel](#)
5. [MapReduce: Simplified Data Processing on Large Clusters Jeffrey Dean and Sanjay Ghemawat](#)
6. [Data-Intensive Text Processing with MapReduce by Jimmy Lin and Chris Dyer](#)
7. [MapReduce Design Patterns by Donald Miner, Adam Shook](#)
8. [Hadoop: The Definitive Guide, 4th Edition by Tom White](#)
9. [Learning Spark, 2nd Edition by Jules S. Damji, Brooke Wenig, Tathagata Das, Denny Lee](#)
10. [Mining of Massive Datasets by Jure Leskovec, Anand Rajaraman, Jeff Ullman](#)
11. [Chapter 2, MapReduce and the New Software Stack by Jeff Ullman](#)
12. [A Very Brief Introduction to MapReduce by Diana MacLean](#)
13. [Apache Hadoop MapReduce Tutorial, 2022-07-29](#)
14. [Big Data Glossary by Pete Warden, 2011, O'Reilly](#)
15. [What is Lineage In Spark?](#)
16. [RDD lineage in Spark: ToDebugString Method](#)
17. [Lazy Evaluation in Apache Spark](#)
18. [Advanced Analytics with PySpark by Akash Tandon, Sandy Ryza, Uri Laserson, Sean Owen, and Josh Wills](#)
19. [8 Steps for a Developer to Learn Apache Spark with Delta Lake by Databricks](#)
20. [Apache Spark Key Terms, Explained](#)
21. [How Data Partitioning in Spark helps achieve more parallelism?](#)

22. [Apache Spark Officially Sets a New Record in Large-Scale Sorting](#)
 23. [Understanding Parquet and its Optimization Opportunities](#)
 24. [Columnar Vs. Row Oriented Databases - The Basics](#)
 25. [What is Parquet by Databricks](#)
 26. [Spark File Format Showdown – CSV vs JSON vs Parquet by Garren Staubli](#)
 27. [Introduction to SQL](#)
 28. [What are the 4 Vs of Big Data? by Bernard Marr](#)
 29. [NIST Big Data Interoperability Framework: Volume 1, Definitions](#)
 30. [Python Guide by Nick Parlante](#)
 31. [What is Big Data Engineering? : A Comprehensive Guide 101](#)
 32. [What is an Algorithm? Definition, Types, Complexity, Examples](#)
 33. [7 Algorithms Every Programmer Should Know](#)
 34. [Best 7 Types Of Algorithms You Should Know](#)
 35. [List of Algorithms in Computer Programming](#)
-

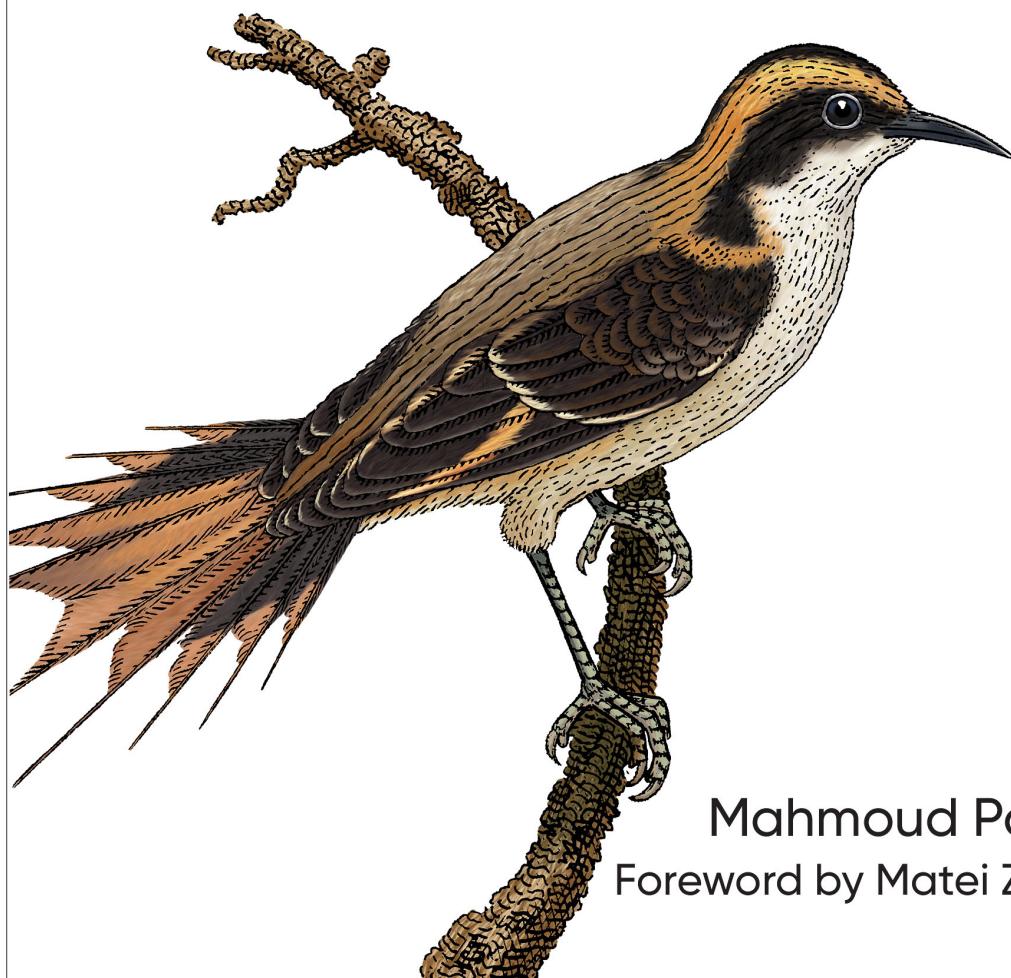
Mahmoud Parsian's List of Books:

Data Algorithms with Spark

O'REILLY®

Data Algorithms with Spark

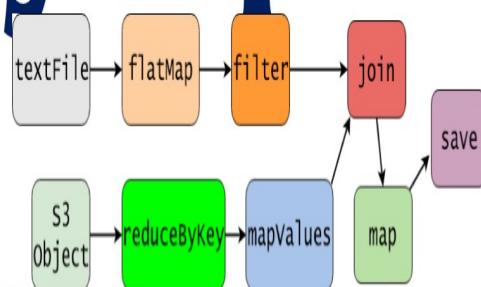
Recipes and Design Patterns for Scaling Up
Using PySpark



Mahmoud Parsian
Foreword by Matei Zaharia

PySpark Algorithms

PySpark



Algorithms

Mahmoud Parsian

Ph.D. in Computer Science

Data Algorithms

O'REILLY®



Data Algorithms

RECIPES FOR SCALING UP WITH HADOOP AND SPARK

Mahmoud Parsian