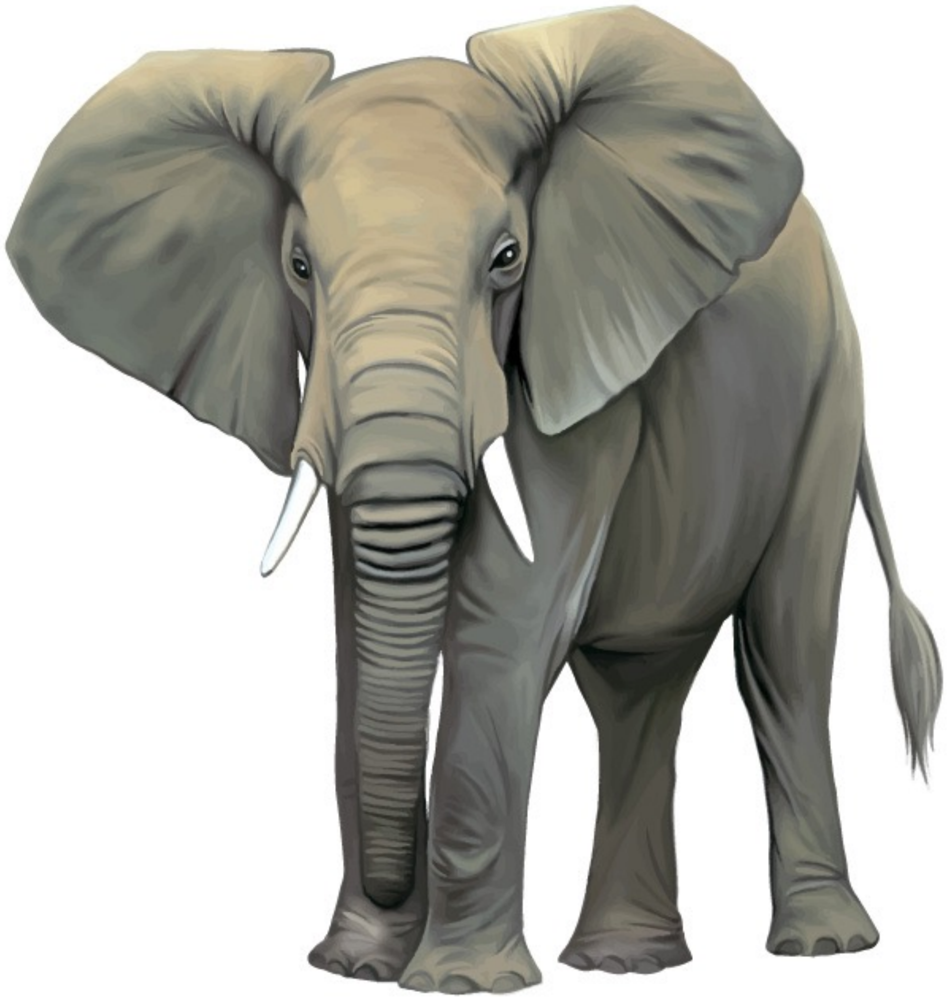
Hadoop



Sudsanguan Ngamsuriyaroj
Ekasit Kijsipongse
Ittipon Rassameeroj

Semester 1/2022

Topics

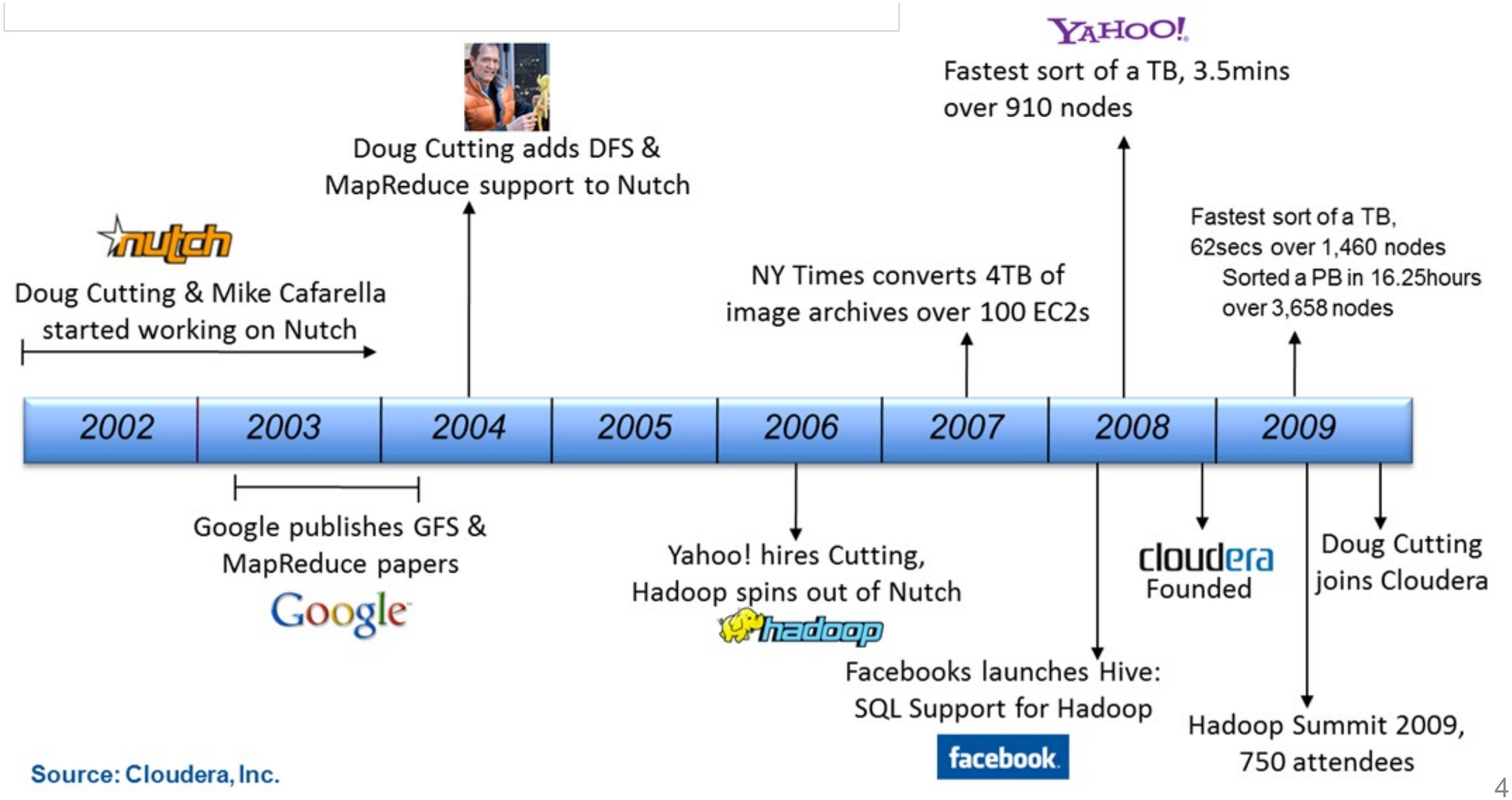
- What is Hadoop
- Hadoop Distributed File System
- Hadoop MapReduce
- Programming in MapReduce
- Hadoop Ecosystem

What is hadoop

- How to process Big data with reasonable cost and time?
- Hadoop is an open-source software that supports Big data applications, licensed under the Apache v2 license
- Design Principles
  - Facilitate the storage and processing of large and/or rapidly growing data sets, both structured and non-structured data
  - Simple programming models
  - Optimized for large and very large data
  - Highly scalable
  - Use commodity (cheap!) hardware
  - Fault-tolerance
  - Move computation rather than data

Hadoop History

- Starting by Cutting at Yahoo based on Google's publication in 2003 and 2004
- Developers works at several organizations, e.g facebook, Cloudera, Yahoo



Doug Cutting & Mike Cafarella started working on Nutch

Google publishes GFS & MapReduce papers

Doug Cutting adds DFS & MapReduce support to Nutch

Yahoo! hires Cutting, Hadoop spins out of Nutch

NY Times converts 4TB of image archives over 100 EC2s

Facebooks launches Hive: SQL Support for Hadoop

Fastest sort of a TB, 3.5mins over 910 nodes

cloudera Founded

Fastest sort of a TB, 62secs over 1,460 nodes

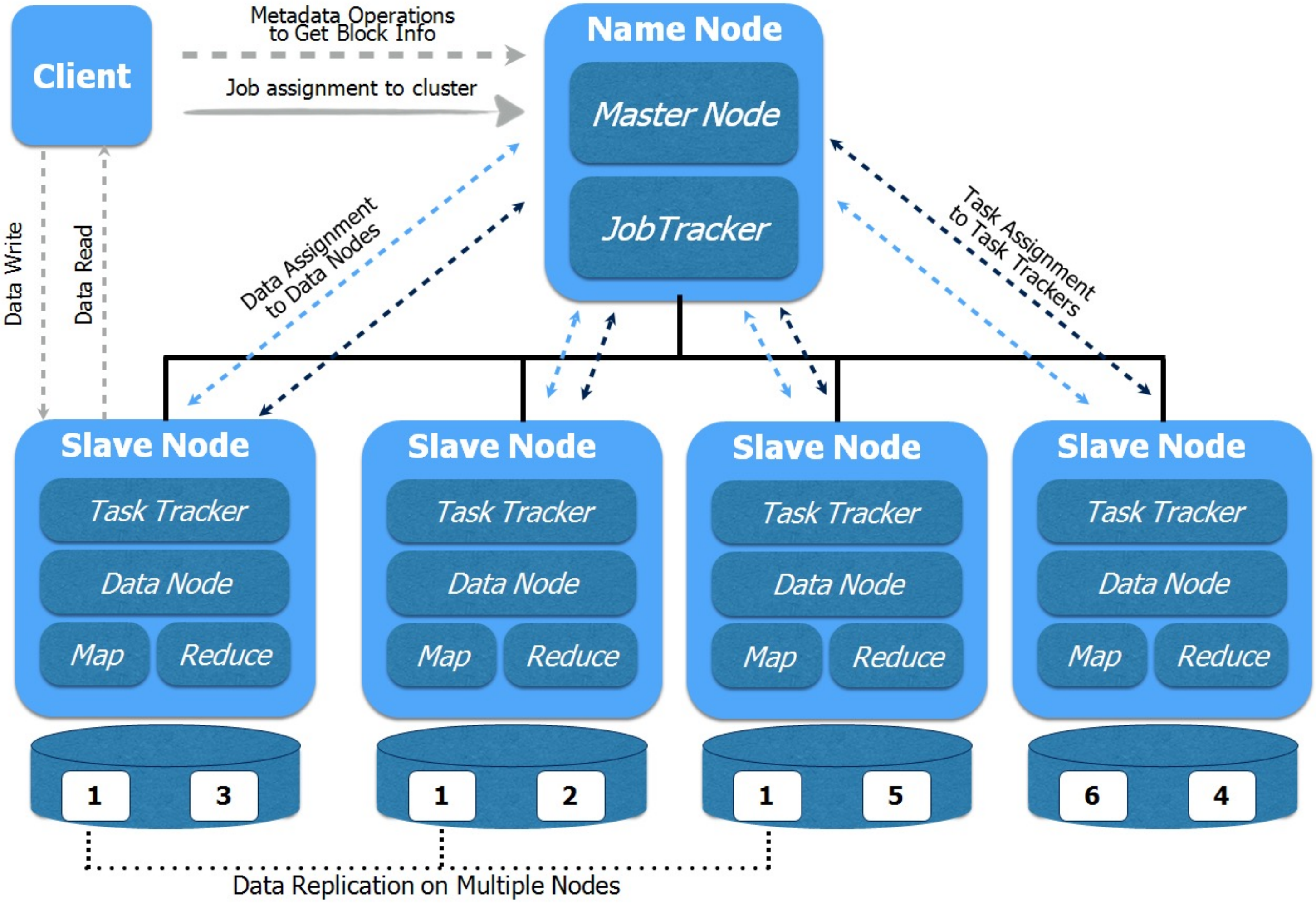
Sorted a PB in 16.25hours over 3,658 nodes

Doug Cutting joins Cloudera

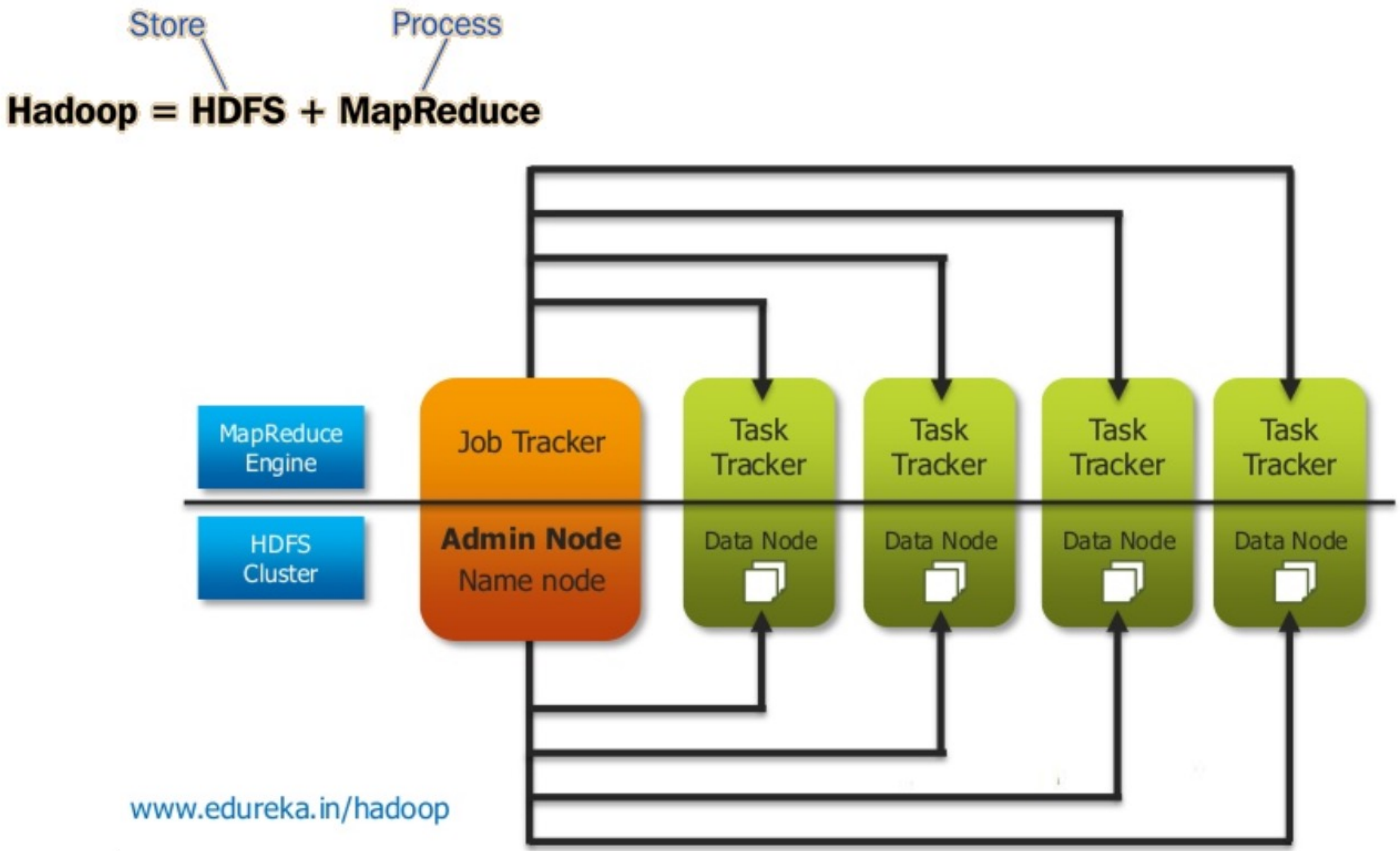
Hadoop Summit 2009, 750 attendees

Source: Cloudera, Inc.

Batch Processing in Hadoop



Hadoop Core Architecture

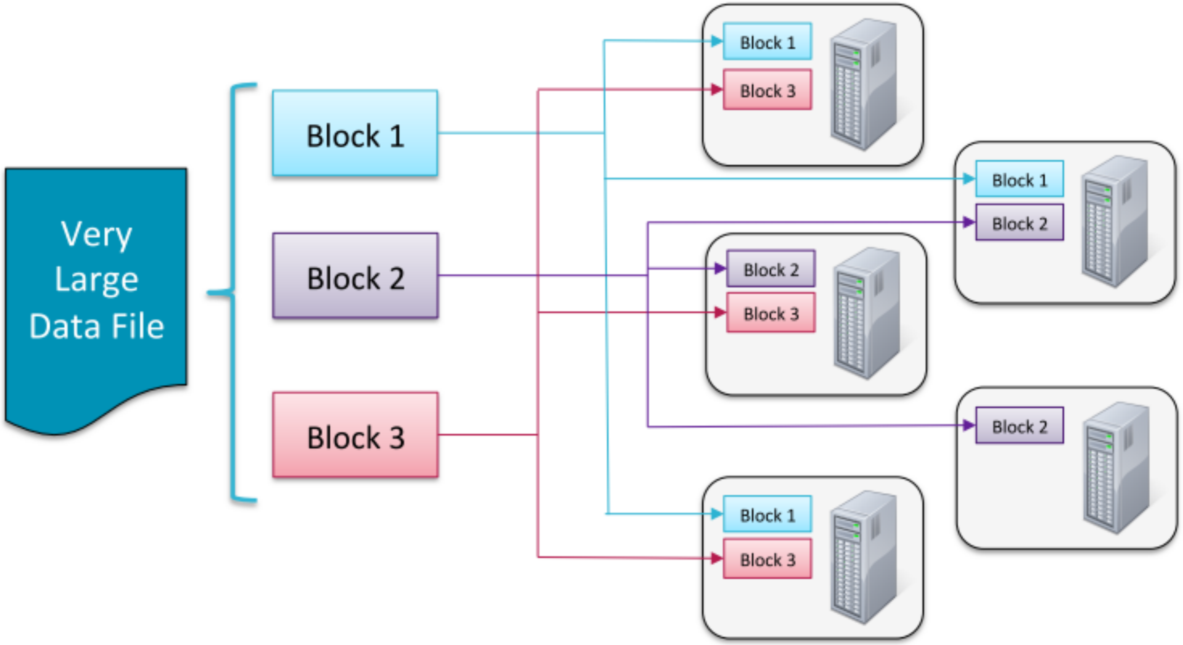


Hadoop Distributed File System (HDFS)

- Very Large Distributed File System (not Databases)
  - 10K nodes, 100 million files, 10 PB
- Assumes Commodity Hardware
  - Files are replicated to handle hardware failure
  - Detect failures and recovers from them
- Optimized for Large Streaming Reads of Files
  - Provides very high aggregate bandwidth
- Files are broken up into blocks
  - Typically 64MB block size
- Each block replicated on multiple DataNodes
- Not support random write! (only created and appended)

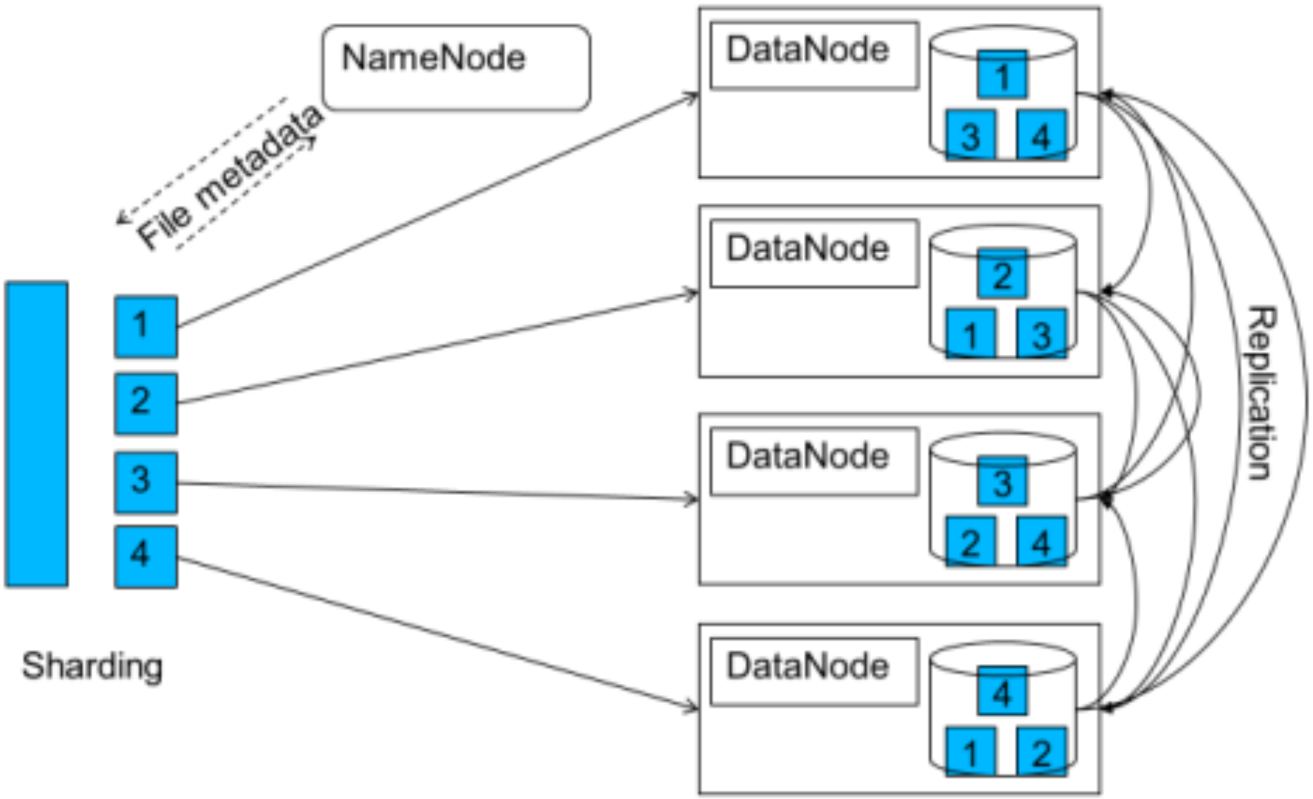
How Files are Stored

- Files are split into blocks and distributed to datanodes
- Each block is replicated to multiple nodes (default to 3)



HDFS Architecture

- NameNode + DataNode



Namenode

- Maintains the HDFS namespace, filesystem tree and metadata
- Maintains the mapping from each file to the list of blockIDs where the file is
- Metadata mapping is maintained in memory as well as persisted on disk
- Maintains in memory the locations of each block. (Block to datanode mapping)
- Memory requirement: ~150 bytes/file
- Issues instructions to datanode to create/replicate/delete blocks

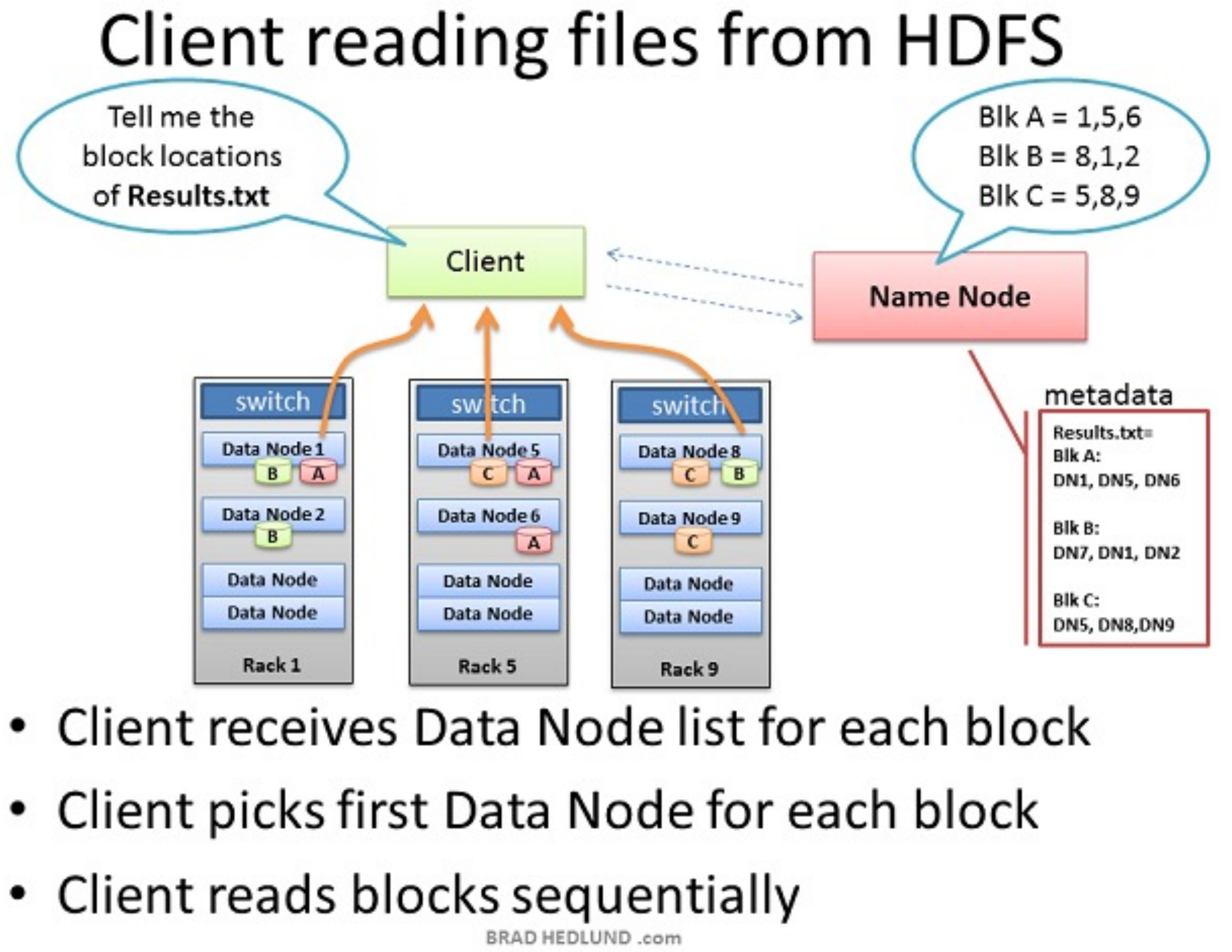
Datanodes

- Serve as storage for data blocks
- No metadata
- Report all blocks to namenode at startup (BlockReport)
- Sends periodic "heartbeat" to Namenode
- Serves read, write requests, performs block creation, deletion, and replication upon instruction from Namenode
- User data never flows through the NameNode

Replication and Rack-awareness

- Replication in Hadoop is at the block level
- Each block of data will be replicated to multiple machines to prevent the failure of one machine from losing all copies of data
- Unfortunate if all copies of data happened to be located on machines in the same rack, and that rack experiences a failure?
- Replication is "Rack-aware"
- Reading and writing on HDFS also makes use of rack-awareness

Reading Files from HDFS



Client reading files from HDFS

- Client receives Data Node list for each block
- Client picks first Data Node for each block
- Client reads blocks sequentially

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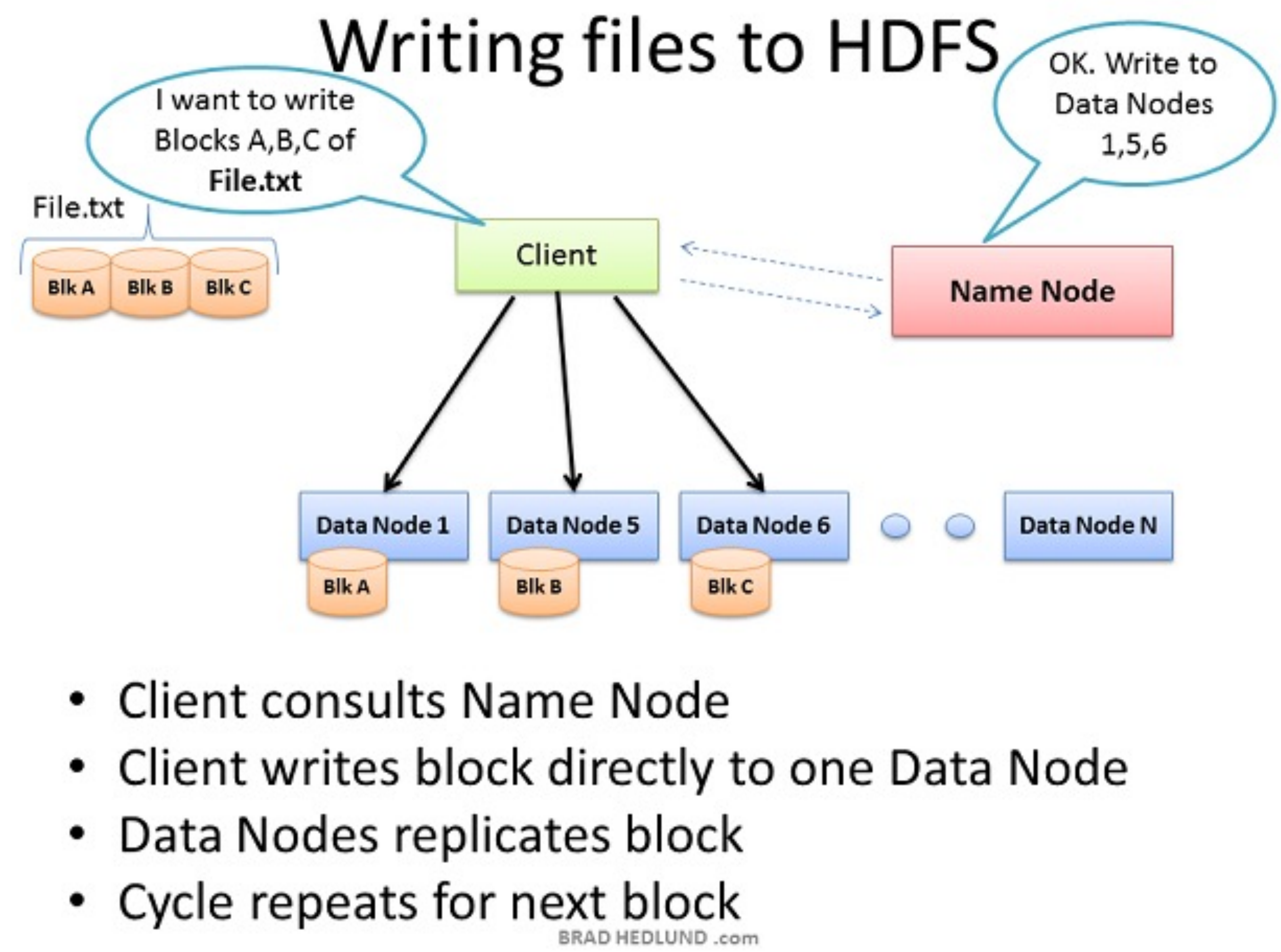
Writing Files to HDFS



Writing files to HDFS

- Client consults Name Node
- Client writes block directly to one Data Node
- Data Nodes replicates block
- Cycle repeats for next block

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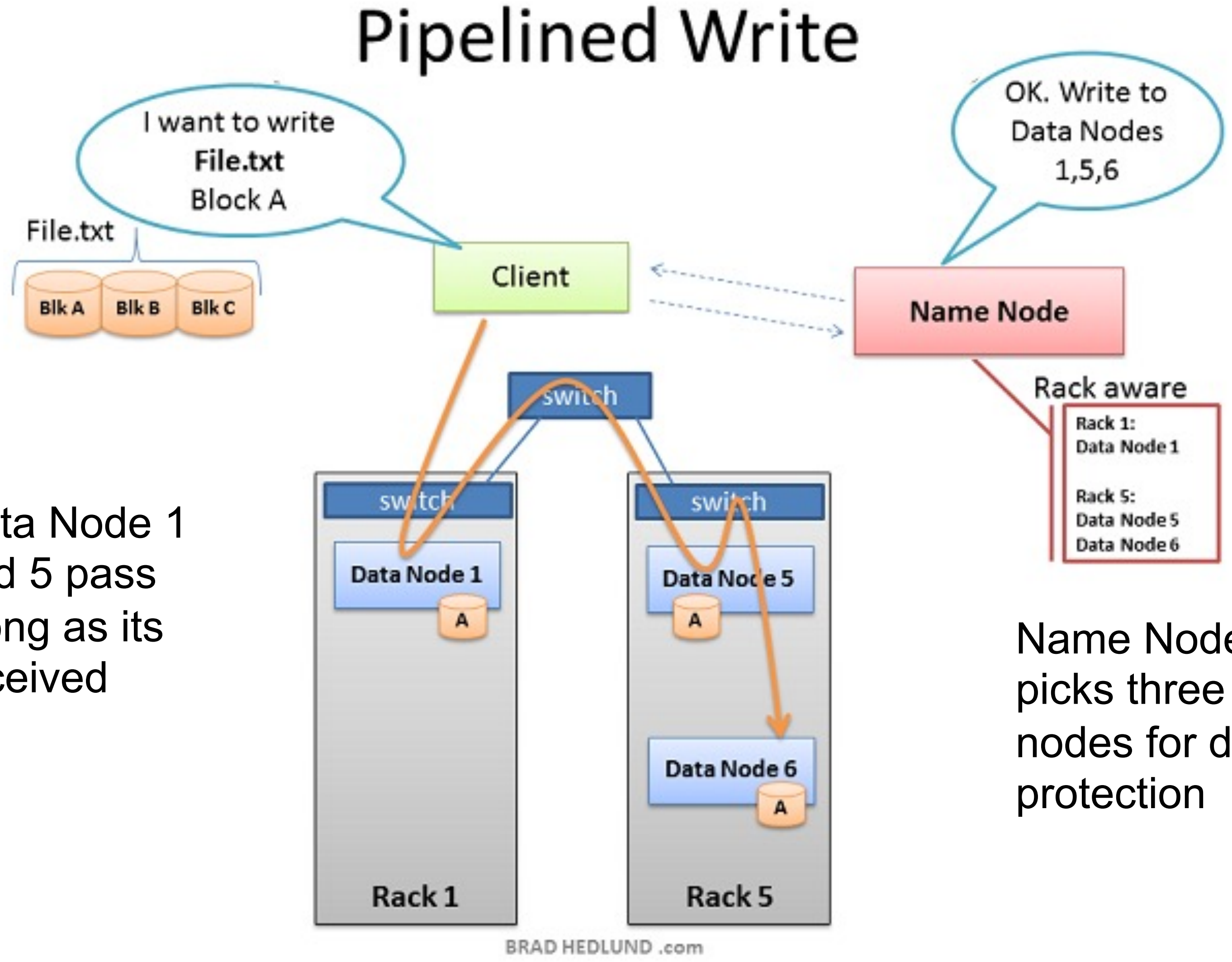
Pipelined Write

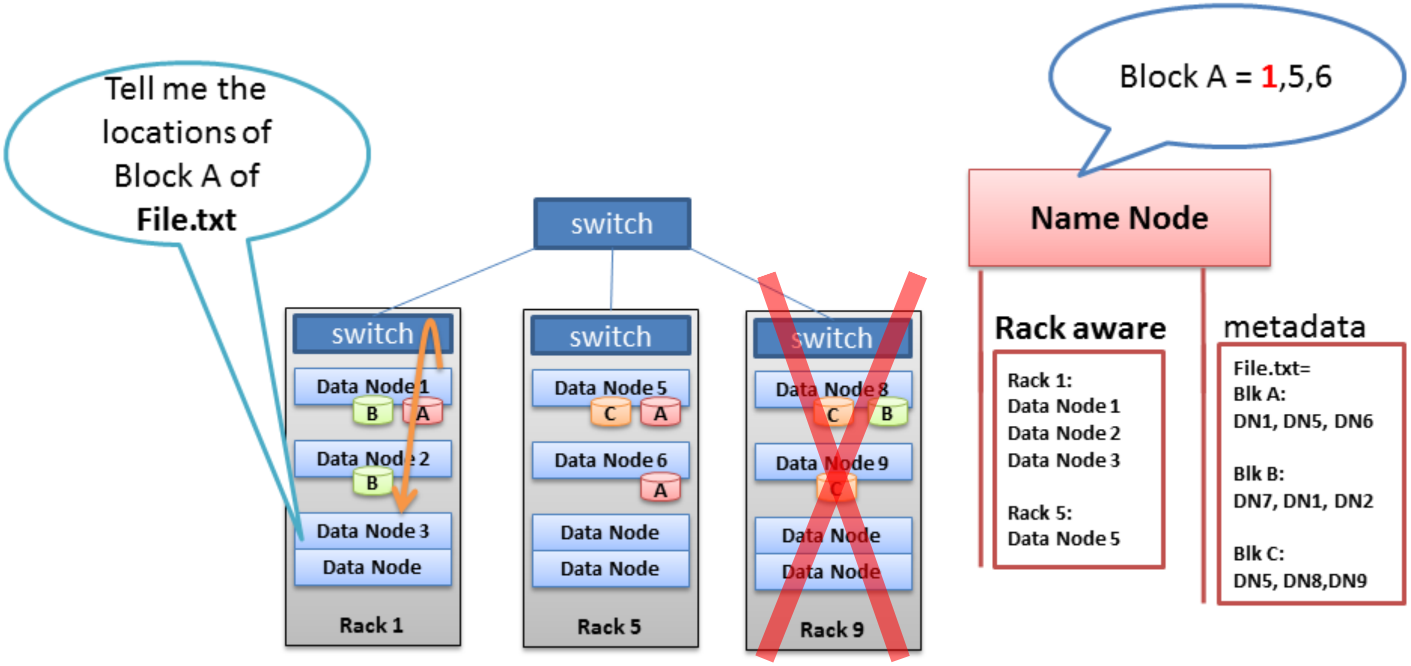


Data Node 1 and 5 pass along as its received

Name Node picks three nodes for data protection

Fault-Tolerance

- Never lose data even if an entire rack fails



- Name Node provides rack local Nodes first
- Leverage in-rack bandwidth, single hop

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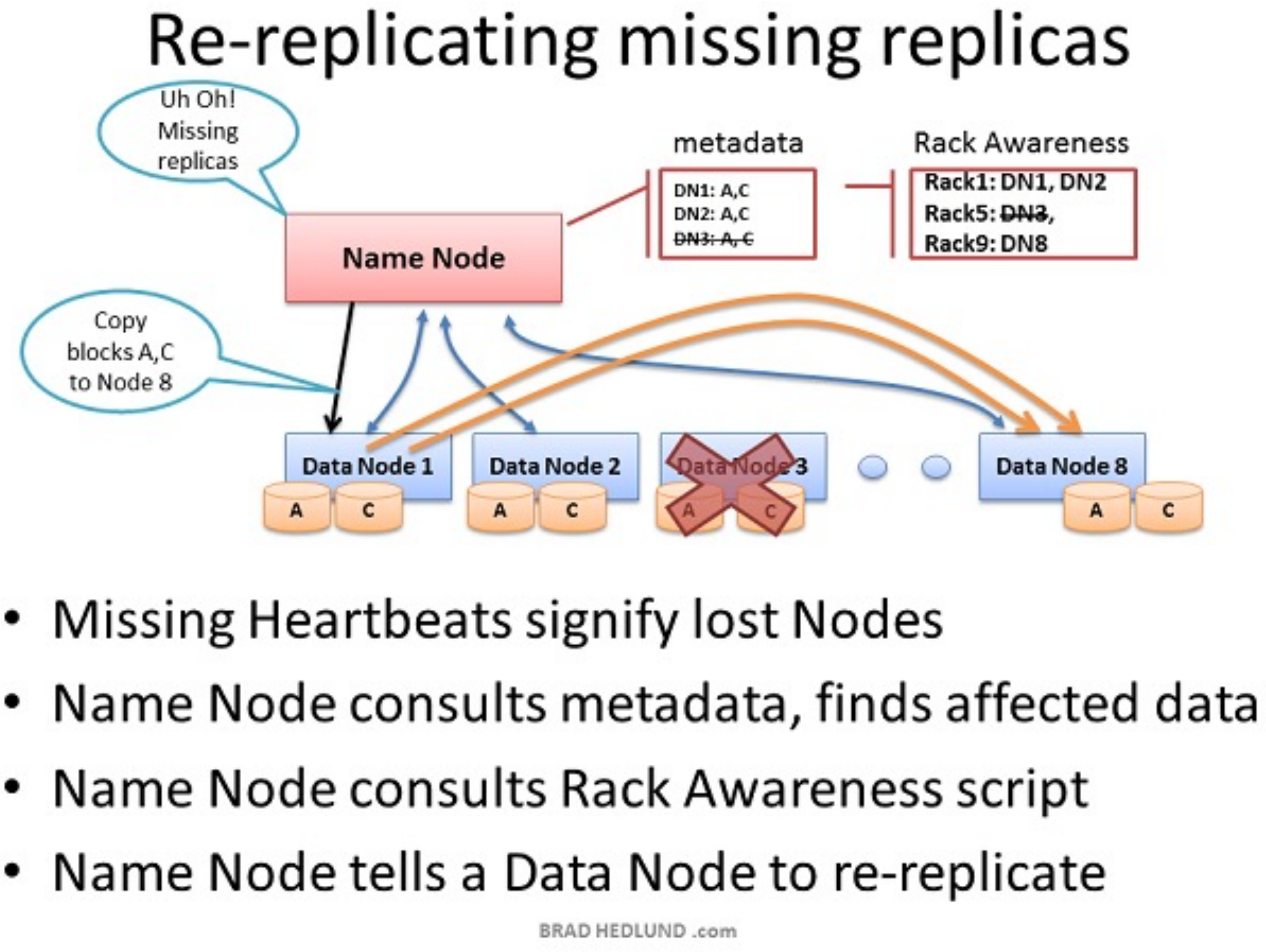
Recover from Fault



Re-replicating missing replicas

- Missing Heartbeats signify lost Nodes
- Name Node consults metadata, finds affected data
- Name Node consults Rack Awareness script
- Name Node tells a Data Node to re-replicate

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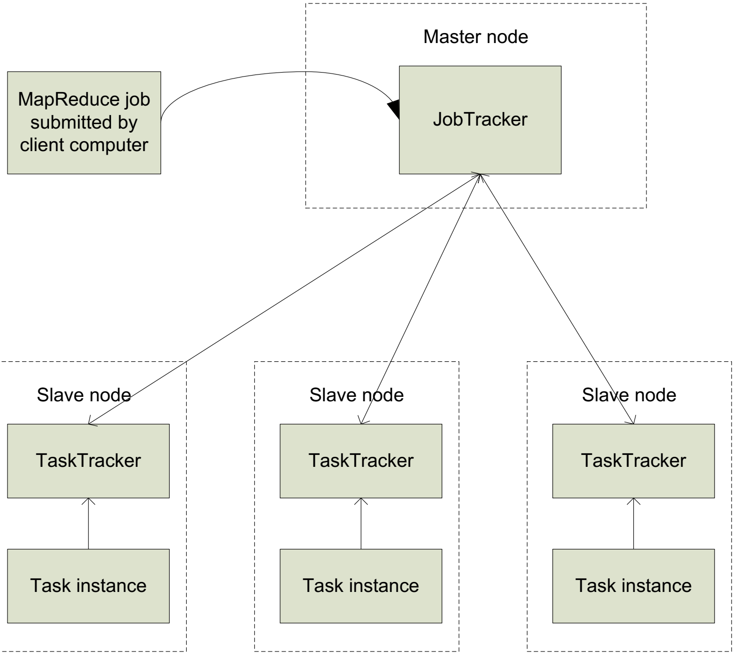
MapReduce

- Pioneered by Google to processes 20 petabytes of data per day
- Simple parallel programming model designed for processing **large datasets** on a large cluster of machines
    - scalability and fault-tolerance
- Programmer specifies two functions: **Map** and **Reduce** functions.
- Input & Output: each a set of **key/value** pairs
- Many real world tasks are expressible in this model

- MPI is designed for numerical applications

MapReduce Architecture

- **Master** node runs **JobTracker**, which accepts Job requests from clients and sends tasks to **TaskTrackers**
- TaskTracker runs on **slave** nodes
- TaskTracker forks separate process for task instances

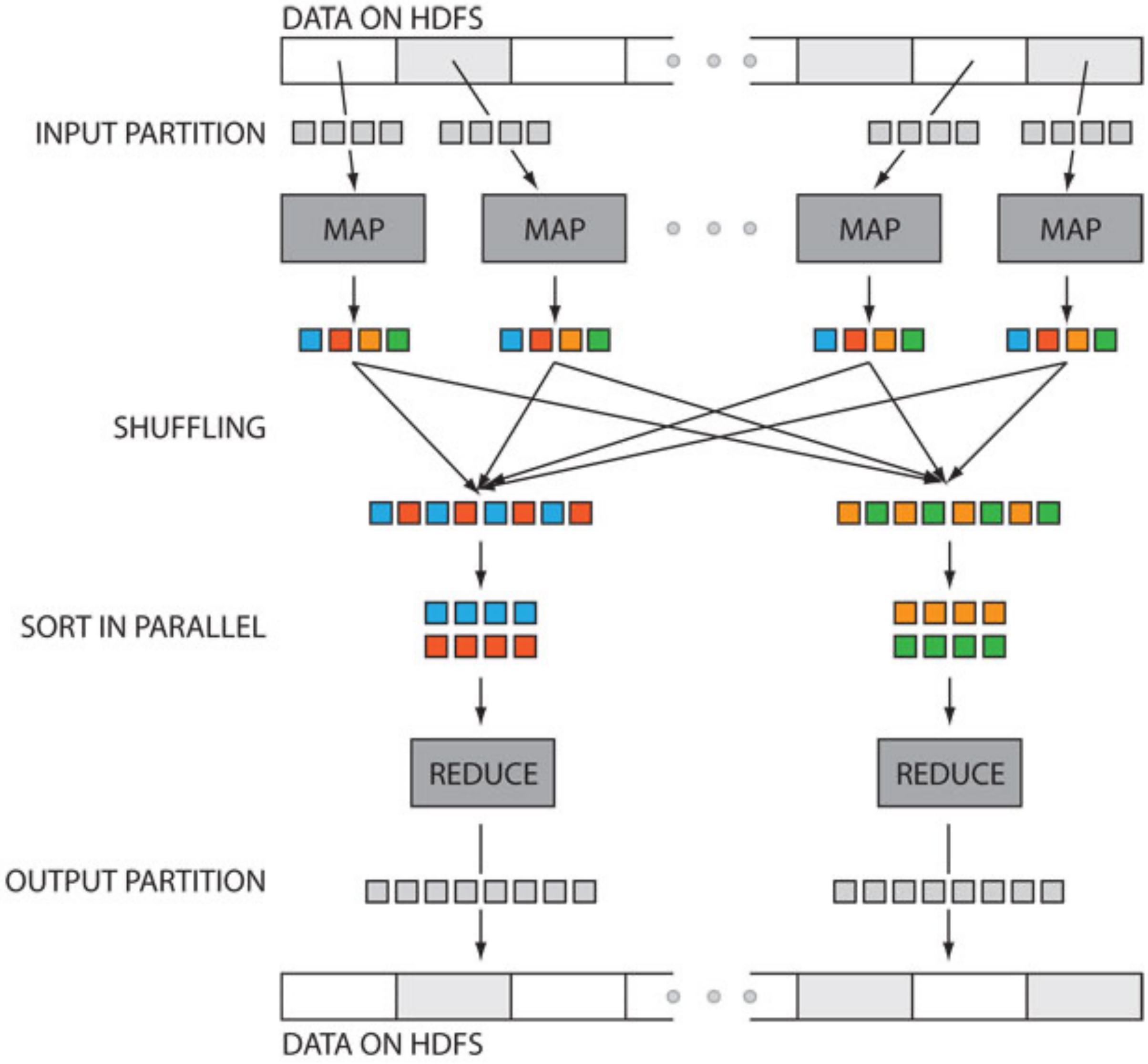


How Jobs are Executed

- **The Mapper**
  - Each Map task (typically) operates on a single HDFS block
  - Map tasks(usually) run on the node where the block is stored
- **Shuffle and Sort**
  - Intermediate data from all mappers are split
  - Then, consolidate and sort intermediate data to reducers
  - Happens after all Map tasks are complete and before Reduce tasks start
- **The Reducer**
  - Operates on shuffled/sorted intermediate data (Map task output)
  - Produces final output

Map
Shuffle and Sort
Reduce

How Jobs are Executed



MapReduce Input/Output

- Input is a set of key/value (k1,v1) pairs
- Map converts each input to intermediate data

  map(k1,v1) → list (k2,v2)
- Intermediate data are a list of (k2,v2) pairs
- Then, intermediate data are grouped by key
- Reduce collects and converts intermediate data into output

  reduce(k2, list (v2)) → (k3,v3)
- Output is the list of (k3,v3) pairs
- Key cannot be null, but value can

- Example: Count word frequency in text files

Wordcount Example

Input

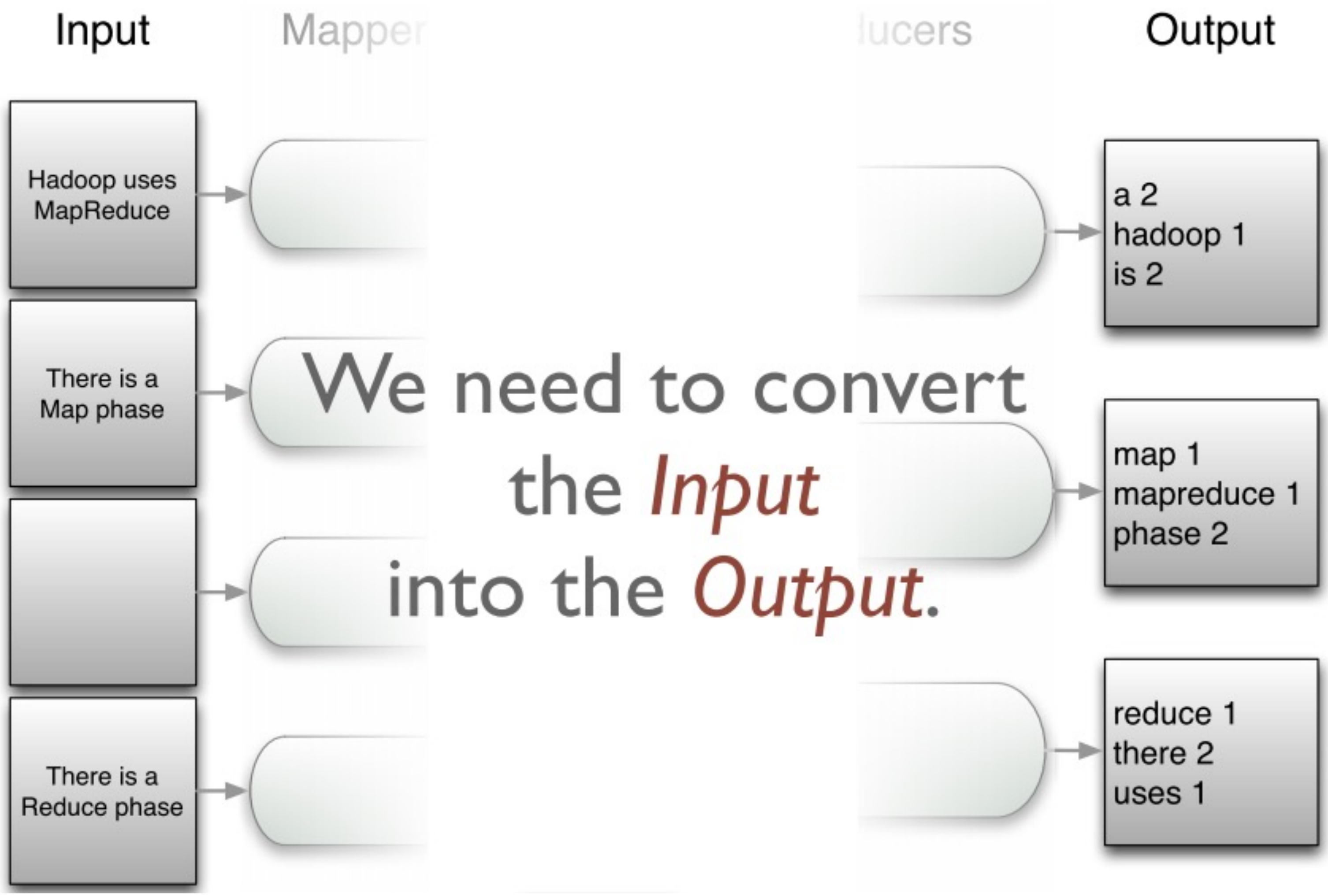
```
Line1   Hadoop uses MapReduce
Line2   There is a Map phrase
Line3
Line4   There is a Reduce phrase
```

Output

```
a 2
hadoop 1
is 2
map 1
mapreduce 1
phrase 2
reduce 1
there 2
uses 1
```

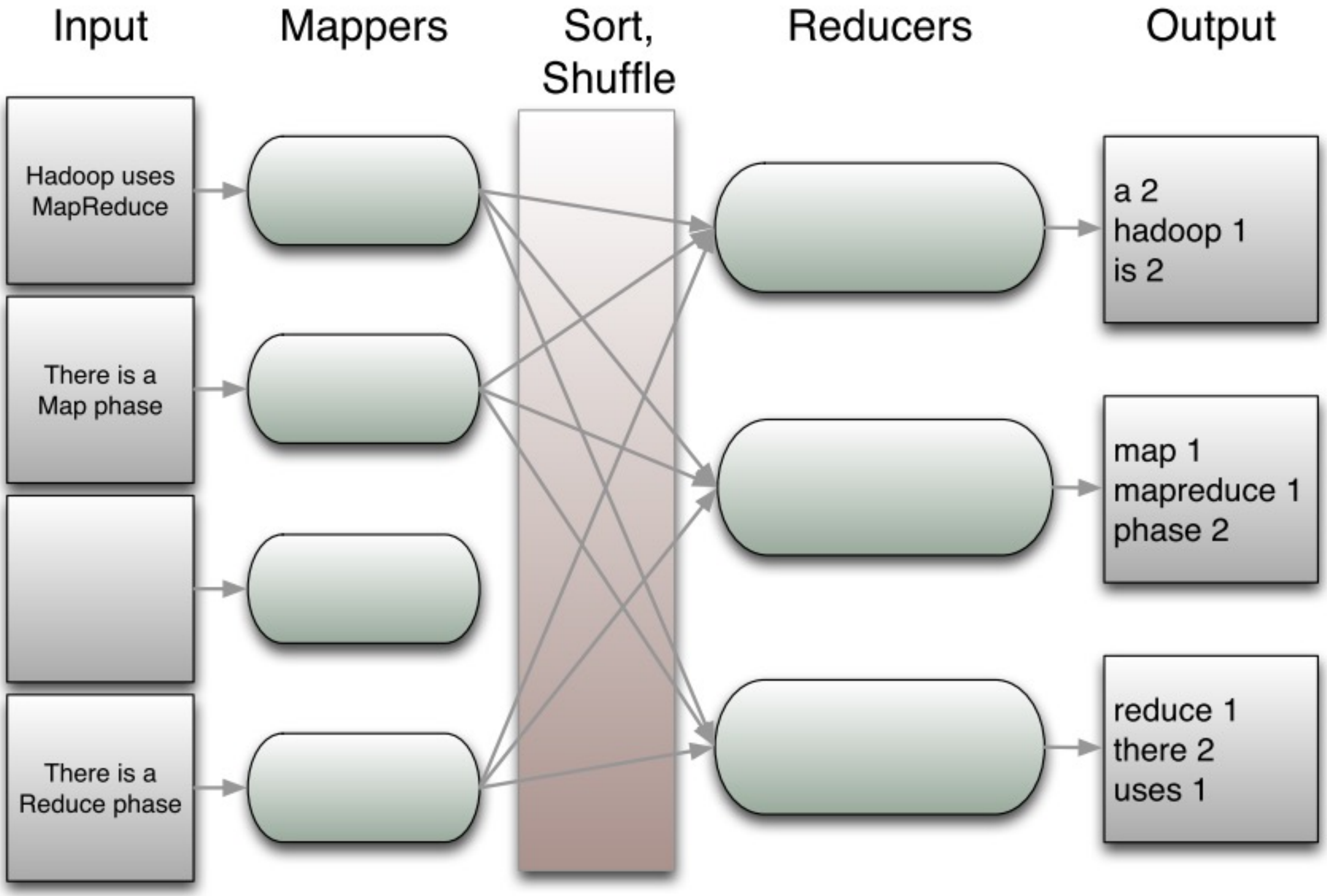
(This example ignores case sensitive)

Wordcount Example

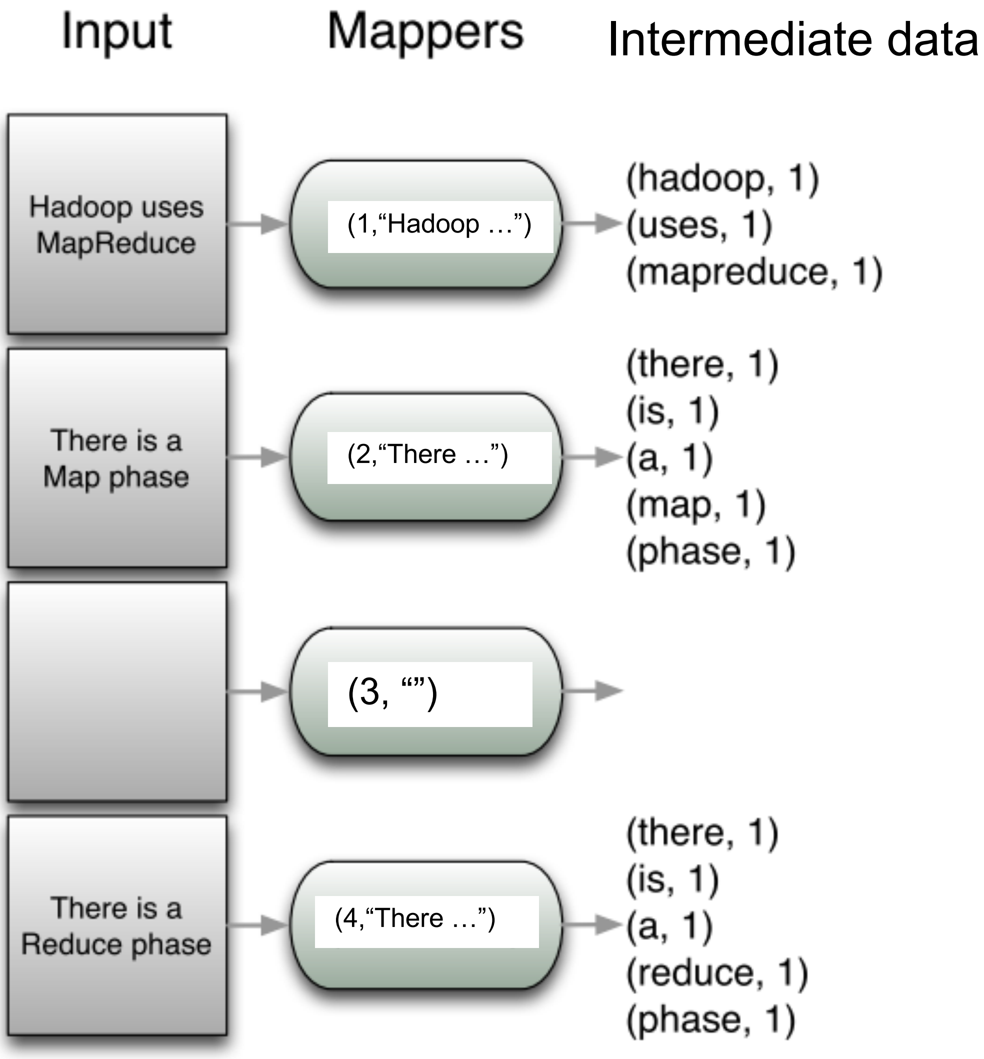


We need to convert the *Input* into the *Output*.

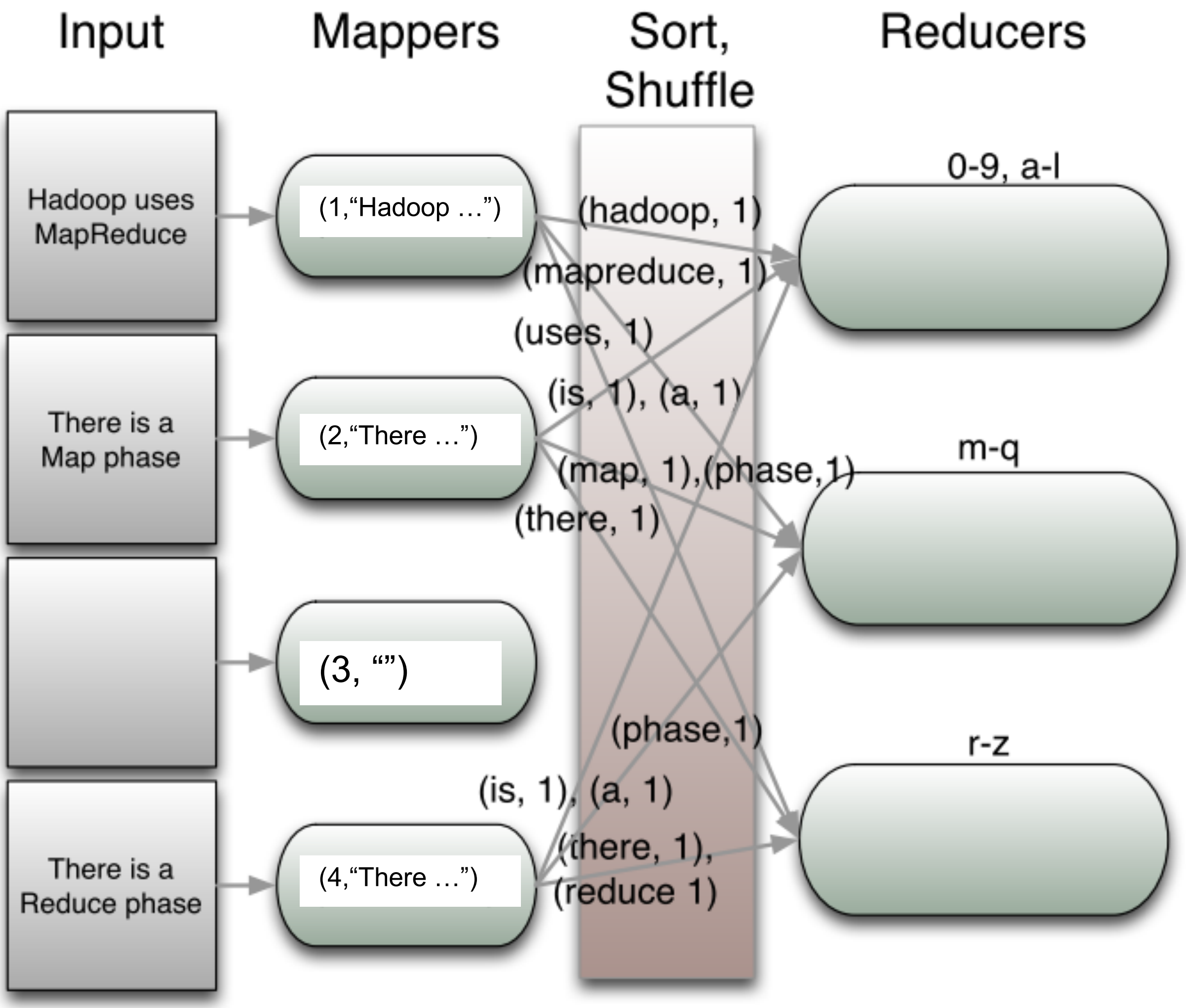
Wordcount Example



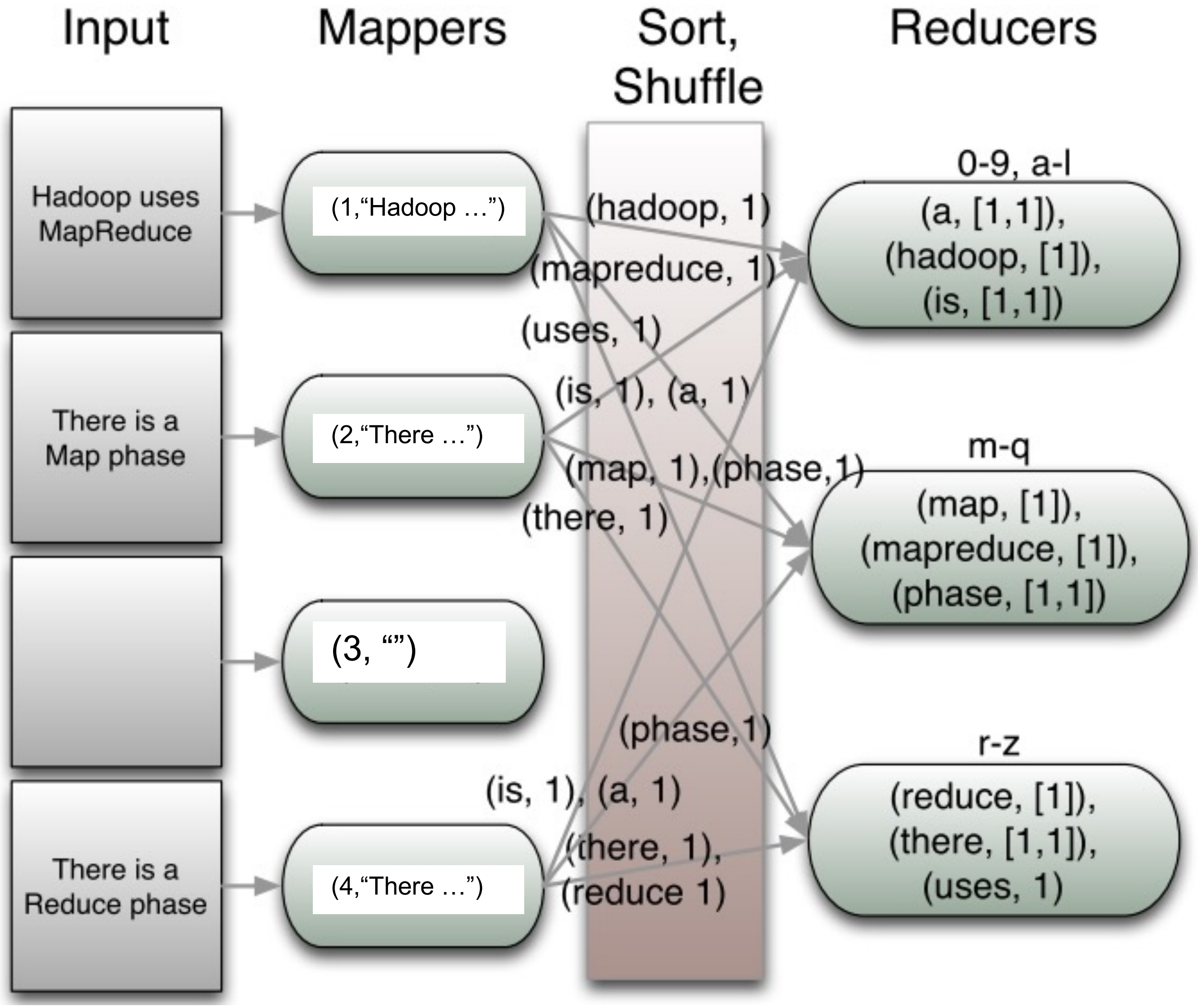
Wordcount Example



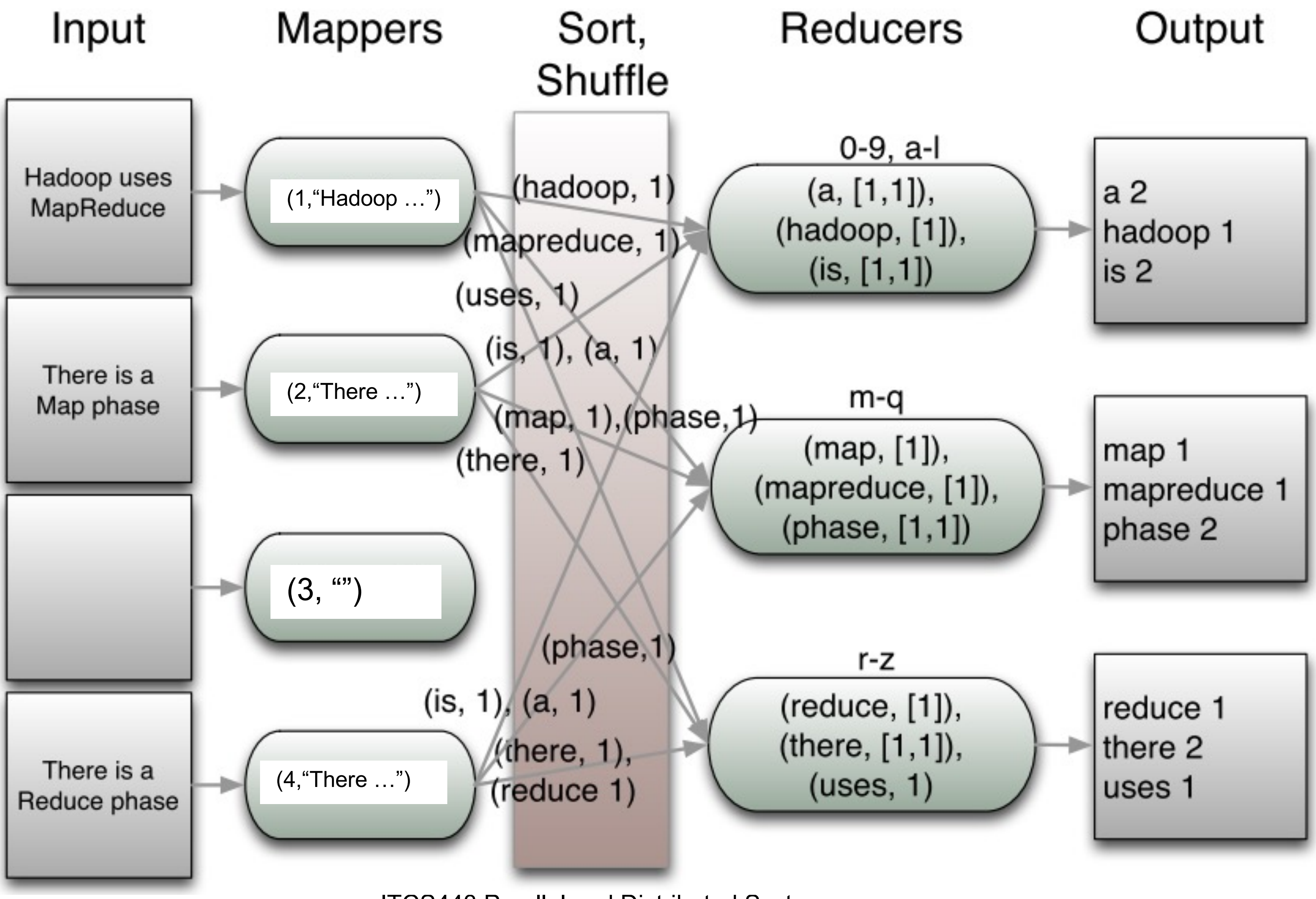
Wordcount Example



Wordcount Example



Wordcount Example



MapReduce Programming Model

For every input line (record), call a map function on the line.

Map:

- Accepts *input* key/value pair
- Emits *intermediate* key/value pairs

For every distinct intermediate key, call a reduce function

Reduce :

- Merges all *intermediate* key/value pairs with the same intermediate key
- Emits *output* key/value pairs (usually one)

Wordcount’s Map and Reduce Functions (Pseudo Code)

```
map(key, value):                              // For 1st line: key = 1, value = “hadoop uses mapreduce”
        // key: line number
        // value: line content
        for each word w in split(value,” ”)  ←  Split returns an array of words
              Emit(w, 1);                     // Split() returns [“hadoop“, “uses”, “mapreduce”]
        end for
                                              // Emit(“hadoop”,1)
                                              // Emit(“uses”, 1)
                                              // Emit(“mapreduce”,1)
```

```
reduce(key, values[ ]):                       // For 1st group: key = “a”, value = [1,1]
       // key: a word
       // values: a list of 1 for the same word
       sum = 0;
       for each v in values
             sum += v;
       end for
       Emit(key, sum);                        // Emit(“a”,2)
```

Mean Temperature Example

- From data collected since 2010 until now, find the mean temperature of each month
- Input data has two columns: YYYYMMDDhhmm, Celsius
- Output has two columns and 12 rows each for a month

```
201001010000,25.0
201001010015,24.5
201001010030,24.0
201001010045,24.0
201001010100,23.5
201001010115,23.0
     …
201512312345,27.0
```

Mean’s Map and Reduce Functions

```
map(key, value):
        // key: line number
        // value: line of datetime and degree
        (datetime,degree) = split(value,”,”)
        month = substring(datetime,4,2)
        Emit(month, degree);
```

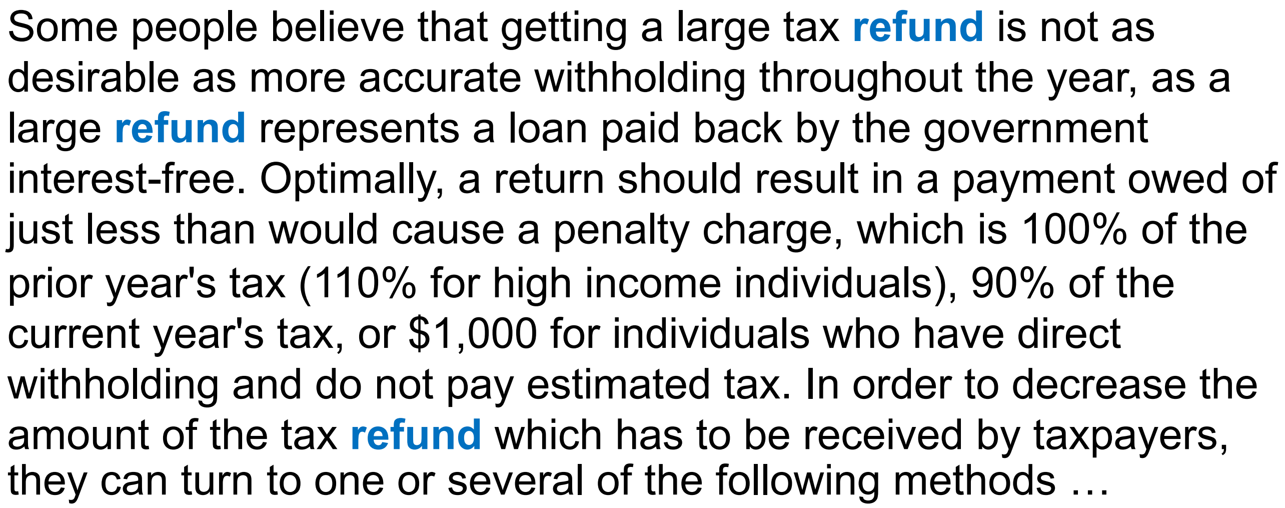
Split to array and then assign the first and second elements to datetime and degree

```
// For the first 2 lines
// Emit (“01”, “25.0”)
// (“01”, “24.5”)
```

```
reduce(key, values[ ]):          // For 1st group: key=“01” , value = [“25.0”, “24.5”. …]
        // key: a month
        // values: a list of temperatures in the same month
        sum = 0, count=0;
        for each v in values
              sum += v;
              count += 1;
        end for
        Emit(key, sum/count);
```

Searching Keyword Example

- Example: Check if a specific keyword "*refund*" exists in a large text file



Some people believe that getting a large tax **refund** is not as desirable as more accurate withholding throughout the year, as a large **refund** represents a loan paid back by the government interest-free. Optimally, a return should result in a payment owed of just less than would cause a penalty charge, which is 100% of the prior year's tax (110% for high income individuals), 90% of the current year's tax, or $1,000 for individuals who have direct withholding and do not pay estimated tax. In order to decrease the amount of the tax **refund** which has to be received by taxpayers, they can turn to one or several of the following methods …

Searching’s Map and Reduce Functions

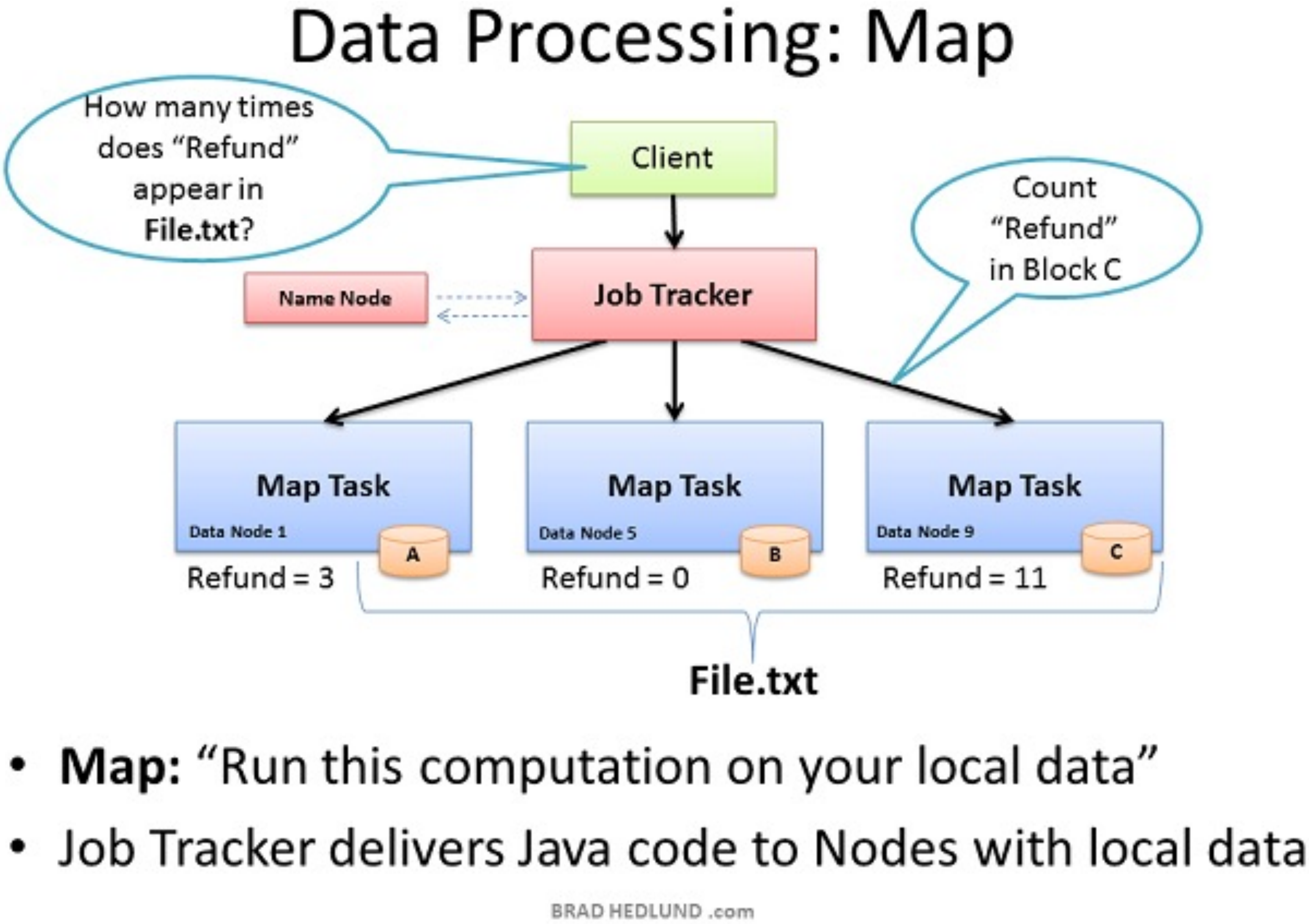
```
map(key, value):
    // key: line number
    // value: line of text
    count = 0
    for each word w in split(value,” ”)
        if (w equals ”refund”) count += 1
    end for
    Emit(“refund”,count)      // 0 means not found
```

```
reduce(key, values[ ]):
    // key: word ”refund”
    // values: a list of frequencies for the word “refund” in each line
    sum = 0;
    for each v in values
        sum += v;
    end for
    Emit(key, sum);   // If output has sum > 0, found
```

Hadoop Job Scheduling

- Input files are divided into blocks (default to HDFS blocks)
- A map task is created for each block
- JobTracker finds the location of block from NameNode
- JobTracker selects a node to run a map task
- Data aware scheduling
  - A map task is scheduled to run at the node where data block is located
  - Otherwise, a map task is scheduled to run at the node close to the data block

Data Aware Scheduling in Map Tasks



Data Processing: Map

How many times does "Refund" appear in **File.txt?**

Client

Job Tracker

Name Node

Count "Refund" in Block C

Map Task
Data Node 1
A
Refund = 3

Map Task
Data Node 5
B
Refund = 0

Map Task
Data Node 9
C
Refund = 11

File.txt

- **Map:** "Run this computation on your local data"
- Job Tracker delivers Java code to Nodes with local data

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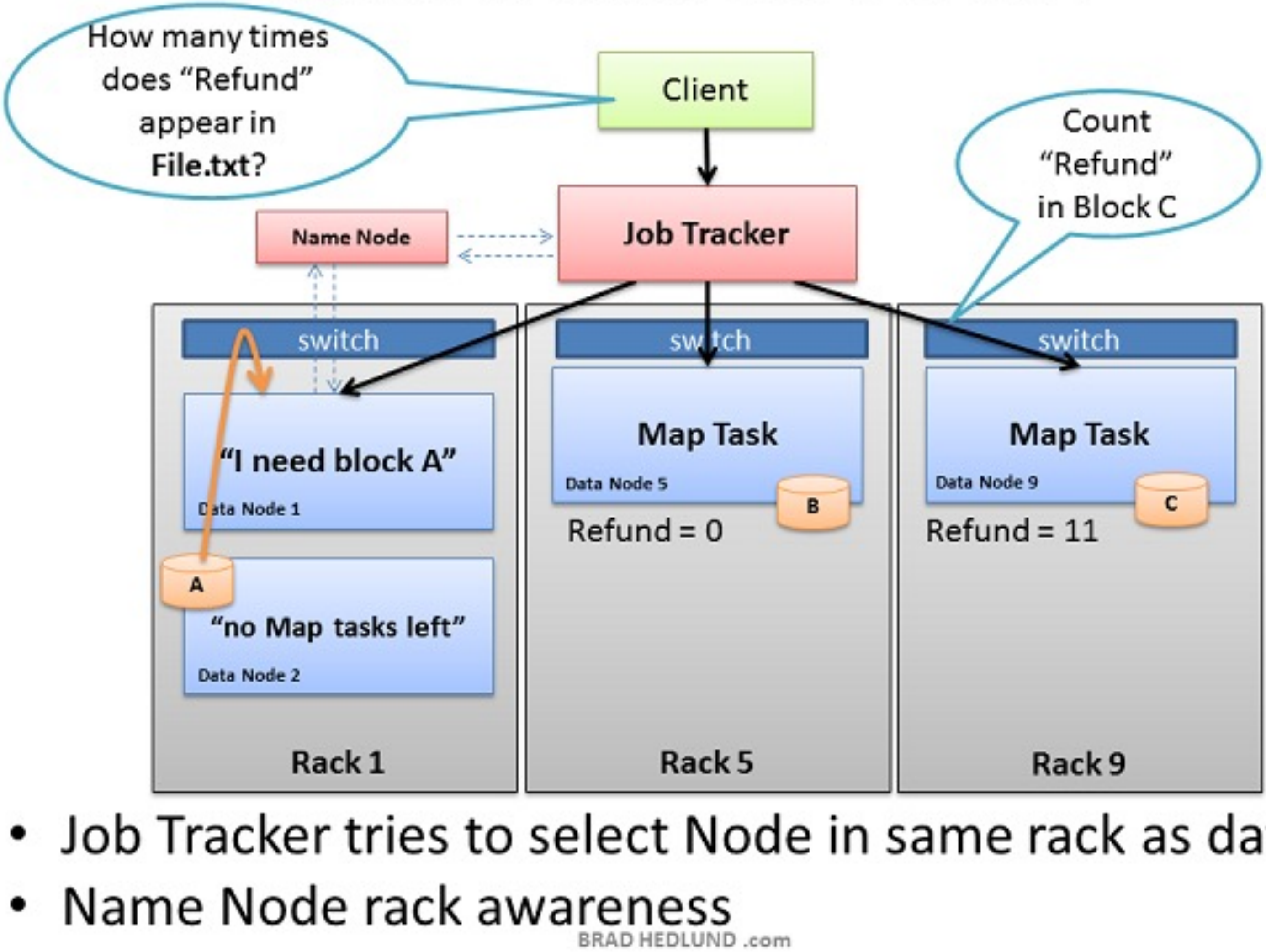
What if data isn't local?

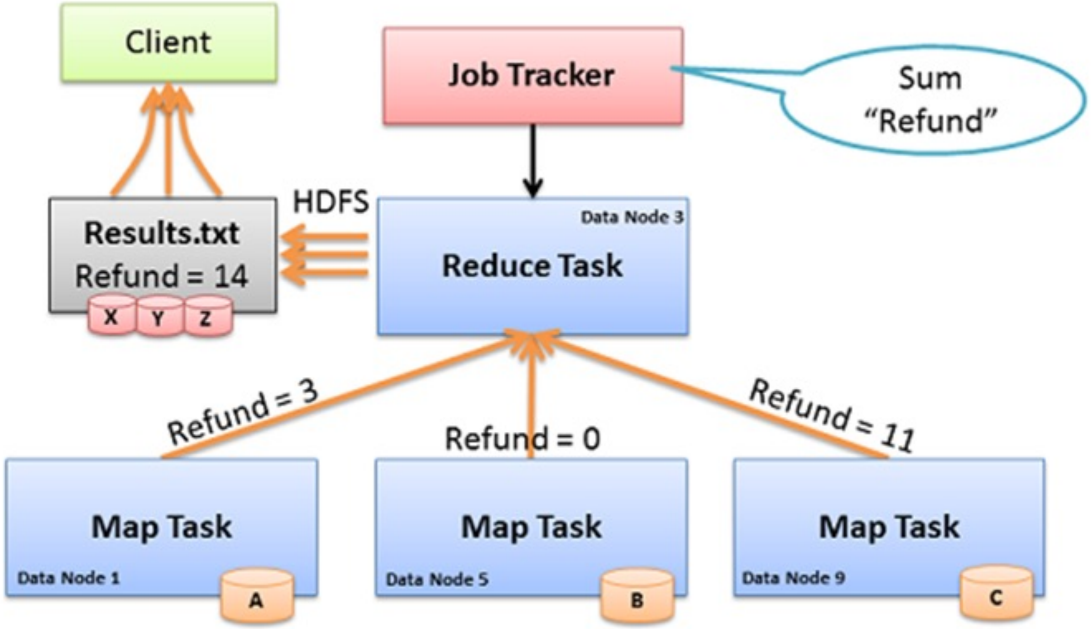


- Job Tracker tries to select Node in same rack as data
- Name Node rack awareness

Reduce Task Scheduling

- Reduce tasks are placed at random nodes
- The intermediate data from mappers are split to each reducer based on the **hash or range partition** of the intermediate key
- For wordcount example, with 2 reducers, using range partition, words begin with a-m is assigned to reducer1, and n-z is assigned to reducer2
- Each reduce task collects intermediate data of the assigned keys from all mappers

Data Processing: Reduce



- **Reduce:** "Run this computation across Map results"
- Map Tasks send output data to Reducer over the network
- Reduce Task data output written to HDFS

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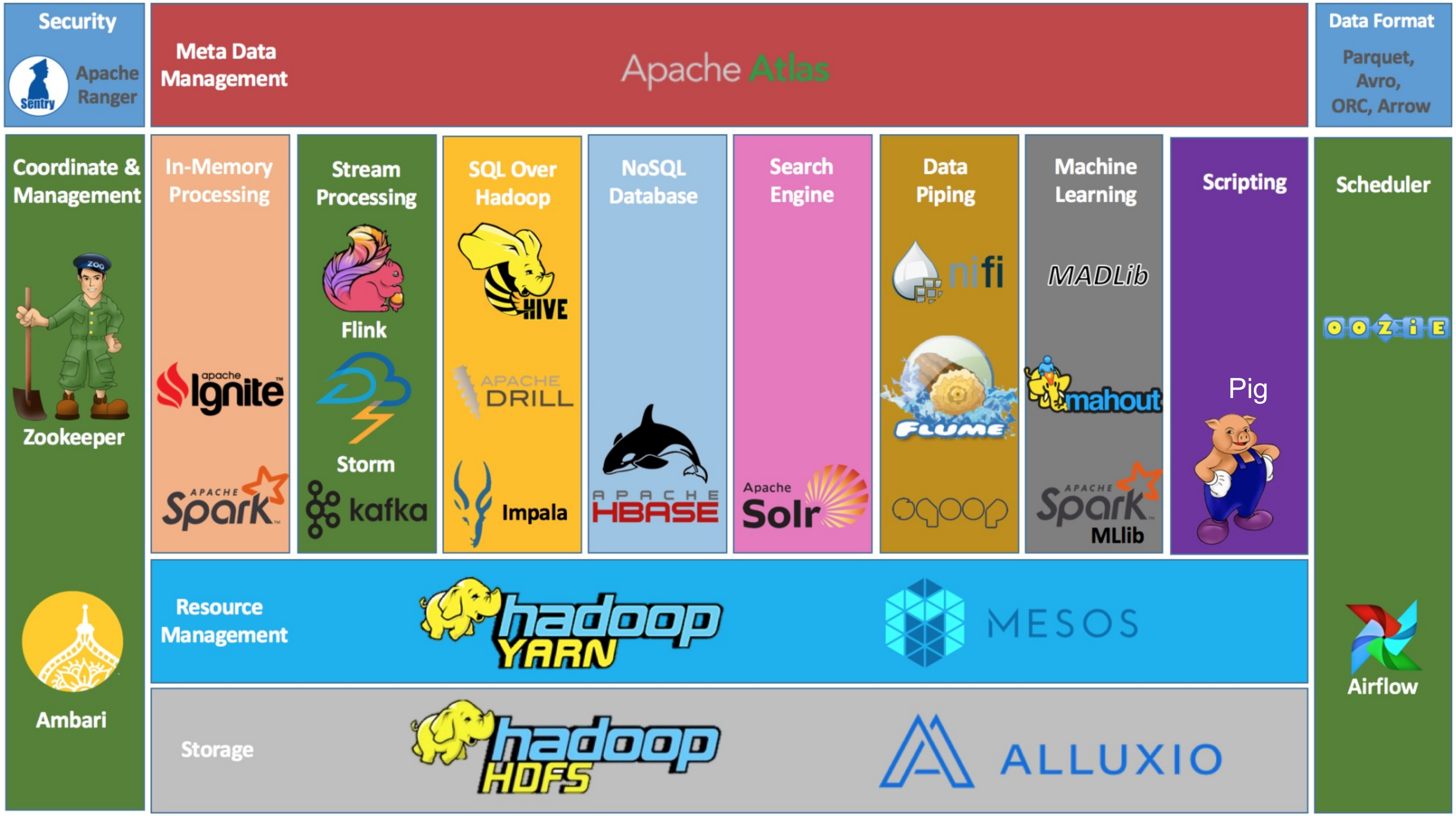
Hadoop Ecosystem



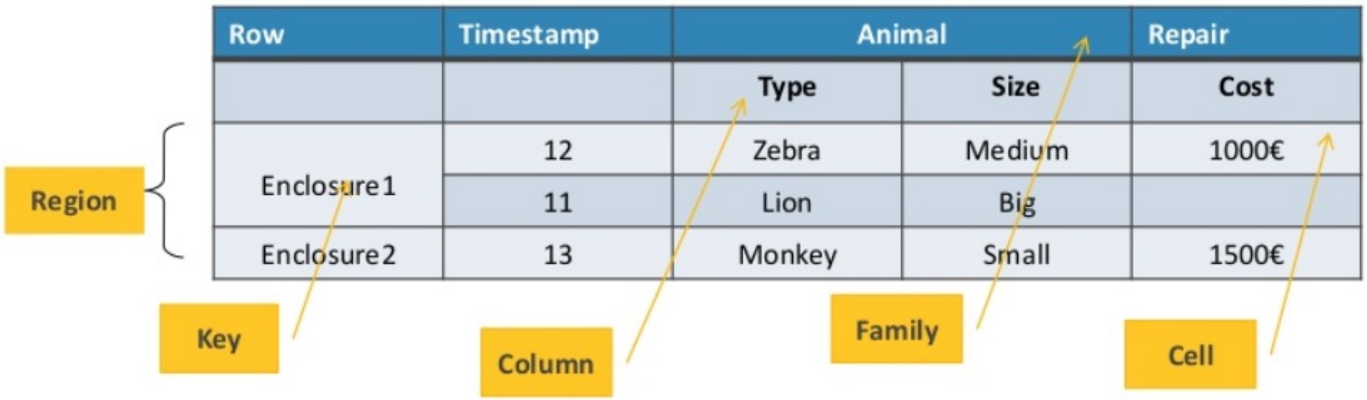
HBASE

- A NoSQL datastore

- Clone of Big Table (Google)
- Implemented in Java (Clients : Java, C++, Ruby...)
- Data is stored "Column-oriented"
- Distributed over many servers
- Tolerant of machine failure
- Layered over HDFS
- Strong consistency

- It's not a relational database (No joins)
- Sparse data – nulls are stored for free
- Semi-structured or unstructured data
- Data changes through time
- Versioned data
- Scalable – Goal of billions of rows x millions of columns

Table - Example

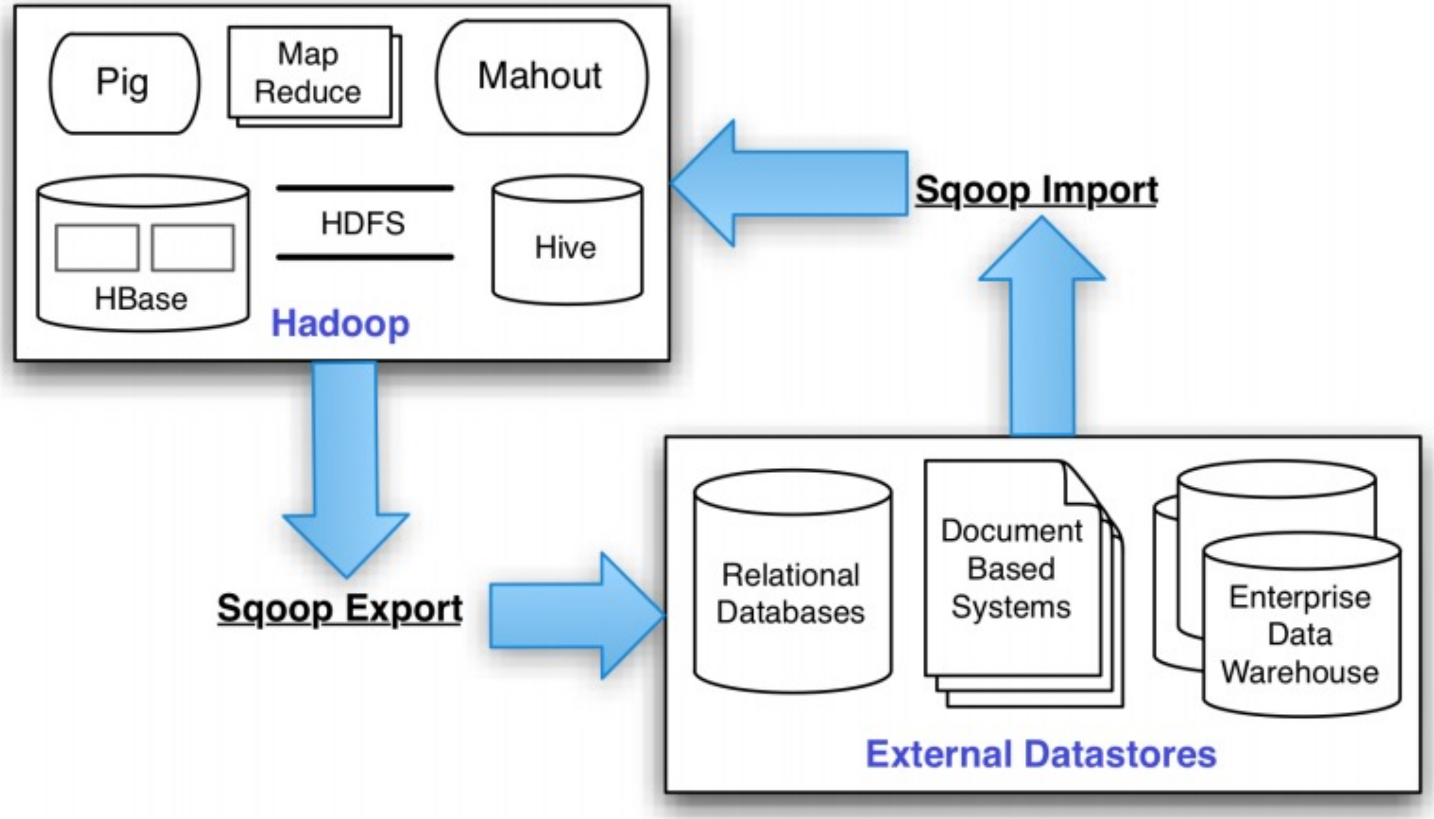


Row	Timestamp	Animal		Repair
		Type	Size	Cost
Enclosure1	12	Zebra	Medium	1000€
	11	Lion	Big	
Enclosure2	13	Monkey	Small	1500€

(Table, Row_Key, Family, Column, Timestamp) = Cell (Value)

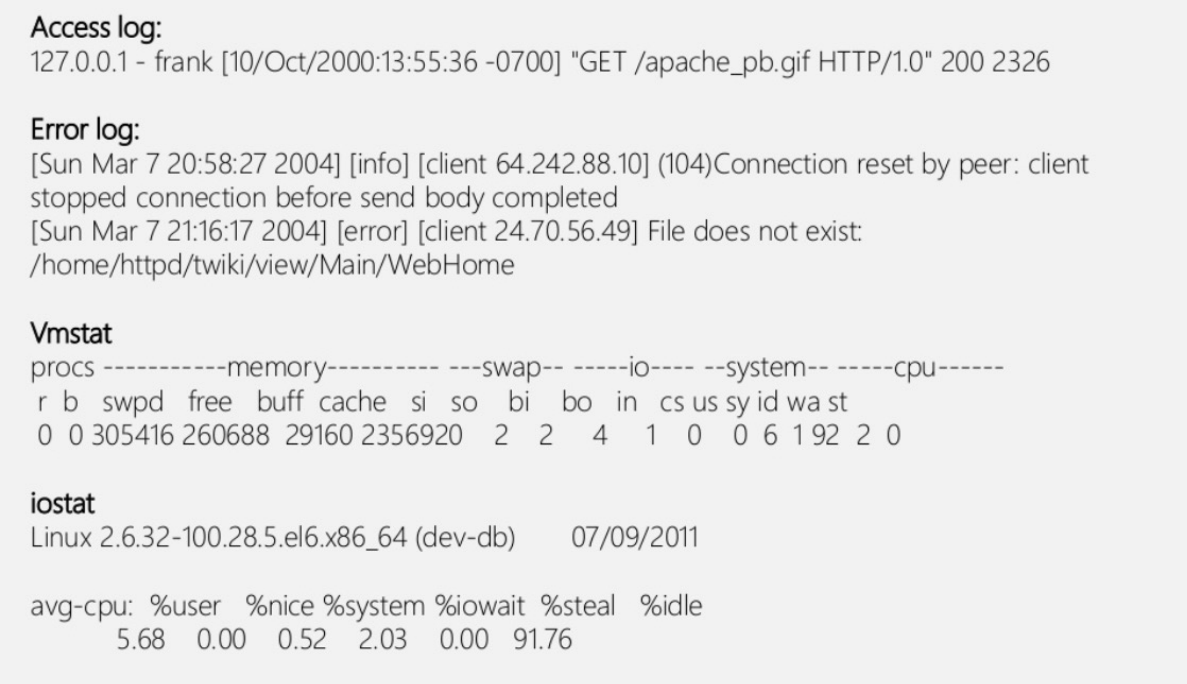
Sqoop

- A tool for data import/export between Hadoop and RDBMS

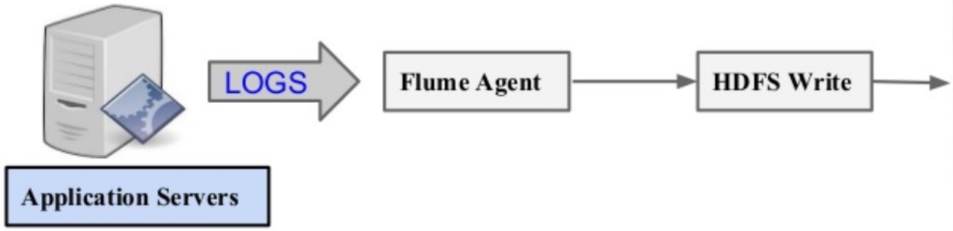


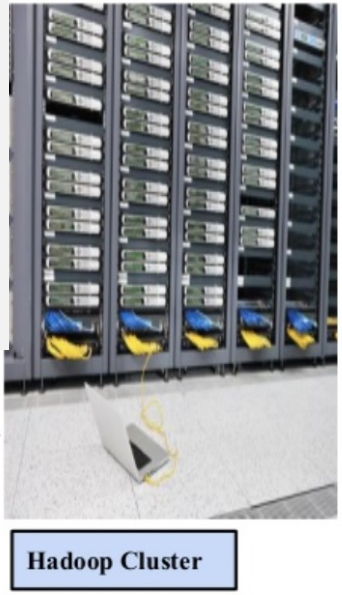
Flume

- Move large amount of streaming event (log data) into Hadoop



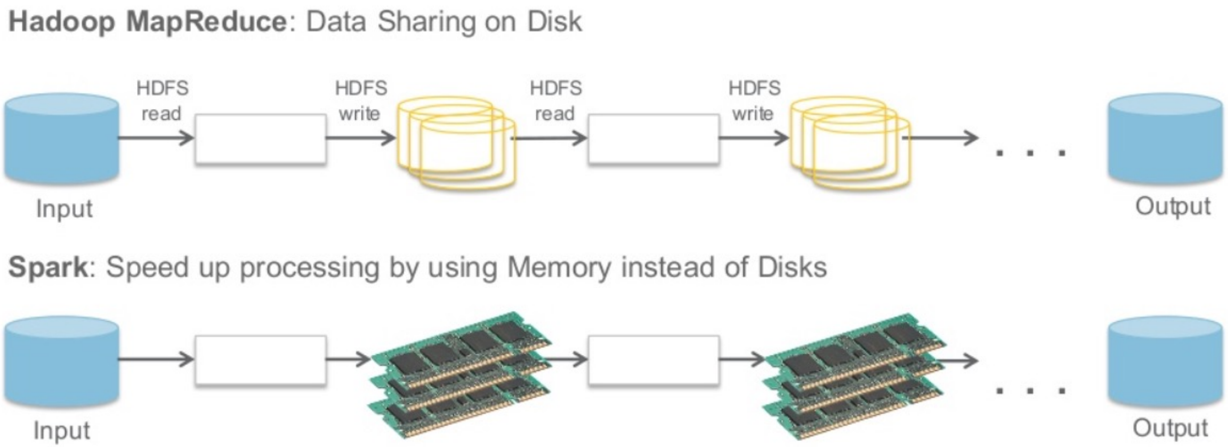
```
Access log:
127.0.0.1 - frank [10/Oct/2000:13:55:36 -0700] "GET /apache_pb.gif HTTP/1.0" 200 2326

Error log:
[Sun Mar 7 20:58:27 2004] [info] [client 64.242.88.10] (104)Connection reset by peer: client
stopped connection before send body completed
[Sun Mar 7 21:16:17 2004] [error] [client 24.70.56.49] File does not exist:
/home/httpd/twiki/view/Main/WebHome

Vmstat
procs -----------memory---------- ---swap-- -----io---- --system-- -----cpu------
 r  b   swpd   free   buff  cache   si   so    bi    bo   in   cs us sy id wa st
 0  0 305416 260688  29160 2356920    2    2     4     1    0    0  6  1 92  2  0

iostat
Linux 2.6.32-100.28.5.el6.x86_64 (dev-db)       07/09/2011

avg-cpu:  %user   %nice %system %iowait  %steal   %idle
           5.68    0.00    0.52    2.03    0.00   91.76
```





Spark

- Supersede Hadoop MapReduce
- Can utilize both in-memory and disk storage



Hadoop MapReduce: Data Sharing on Disk

Spark: Speed up processing by using Memory instead of Disks

- More operations than map/reduce
- Support Scala, Java, Python, R
- Scale from a single node to a cluster

Hive

- Hive is an SQL-like interface to Hadoop

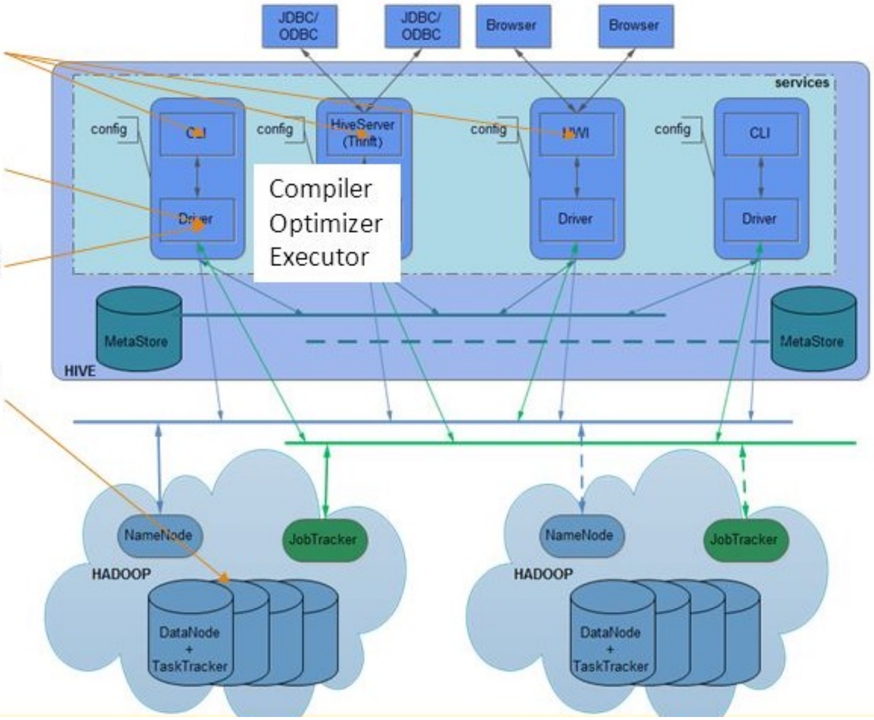
```
SELECT * FROM purchases WHERE price > 10000 ORDER BY
storeid
```

1. User issues SQL Query

2. Hive parses and plans query

3. Query converted to Map-Reduce

4. Map-Reduce run by Hadoop



Compiler
Optimizer
Executor

Additional References

- https://hadoop.apache.org/
- http://biforbeginners.blogspot.com/2012/08/hadoop-basics.html

Q & A