Parallel Computing - Hadoop

Chapter 10 from "Data Science and Big Data Analytics: Discovering, Analyzing, Visualizing and Presenting Data"
1st Edition by EMC Education Services

Reference: "Hadoop: The Definitive Guide" by Tom White.

Ka-Chun Wong, Department of Computer Science, City University of Hong Kong
Charles Tappert Seidenberg, School of CSIS, Pace University

Google Origins

2003

The Google File System

Sanjay Ghemawat, Howard Gobioff, and Shun-Tak Leung
Google*

→ hadoop HDFS

2004

MapReduce: Simplified Data Processing on Large Clusters

Jeffrey Dean and Sanjay Ghemawat
jeff@google.com, sanjay@google.com
Google, Inc.

→ hadoop Map Reduce

2006

Bigtable: A Distributed Storage System for Structured Data

Fay Chang, Jeffrey Dean, Sanjay Ghemawat, Wilson C. Hsieh, Deborah A. Wallach
Mike Burrows, Tushar Chandra, Andrew Fikes, Robert E. Gruber
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Google, Inc.

Abstract

gtable is a distributed storage system for managing tured data that is designed to scale to a very large petabytes of data across thousands of commodity rs. Many projects at Google store data in Bigtable, ding web indexing, Google Earth, and Google Fi- e. These applications place very different demands igtable, both in terms of data size (from URLs to

achieved scalability and high performance, but Big provides a different interface than such systems. Big does not support a full relational data model; inste provides clients with a simple data model that sup dynamic control over data layout and format, an lows clients to reason about the locality properties o data represented in the underlying storage. Data i dexed using row and column names that can be arbi strings. Bigtable also treats data as uninterpreted str

→ APACHE HBASE

By Nalini Venkatasubramanian

Apache Hadoop

- **Hadoop:**
  - an open-source software framework that supports data-intensive distributed applications, licensed under the Apache license.

- **Goals / Requirements:**
  - Abstract and facilitate the storage and processing of large and/or rapidly growing data sets
    - Structured and non-structured data
    - Simple programming models
  - High scalability and availability
  - Use commodity (cheap!) hardware with little redundancy
  - Fault-tolerance
  - More computation rather than data

By Nalini Venkatasubramanian

Contents

10.1 Analytics for Unstructured Data

- These slides document some key technologies and tools related to the Apache Hadoop software library
  - Hadoop stores data in a distributed system
  - Hadoop implements a parallel programming model (or paradigm) known as MapReduce
  - Hadoop ecosystem tools
    - Pig
    - Hive
    - Hbase
    - ……

10.1 Analytics for Unstructured Data
10.1.1 Use Cases

- IBM Watson – Jeopardy playing machine
  - To educate Watson, Hadoop was utilized to process data sources
    - Encyclopedias, dictionaries, news wire feeds, literature, Wikipedia, etc.
- LinkedIn – network of over 250 million users in 200 countries
  - Hadoop is used to process daily transaction logs, examine users' activities, feed extracted data back to production systems, restructure the data, develop and test analytic models
- Yahoo! – large Hadoop deployment
  - Search index creation and maintenance, Webpage content optimization, spam filters, etc.

Hadoop clusters

Yahoo: First Use Case in 2008
As of 2013, Hadoop adoption had become widespread: more than half of the Fortune 50 companies used Hadoop.[ref]

- We have ~20,000 machines running Hadoop
- Our largest clusters are currently 2000 nodes
- Several petabytes of user data (compressed, unreplicated)
- We run hundreds of thousands of jobs every month

10.1 Analytics for Unstructured Data
10.1.2 MapReduce

- The MapReduce model (or paradigm) breaks a large task into smaller tasks, runs the tasks in parallel, and consolidates the outputs of the individual tasks into the final output
- Map
  - Applies an operation to a piece of data
  - Provides some intermediate output
- Reduce
  - Consolidates the intermediate outputs from the map step
  - Provides the final output
- Each step uses key/value pairs (i.e. <key, value>) as the data format between input and output

10.1 Analytics for Unstructured Data
10.1.2 MapReduce

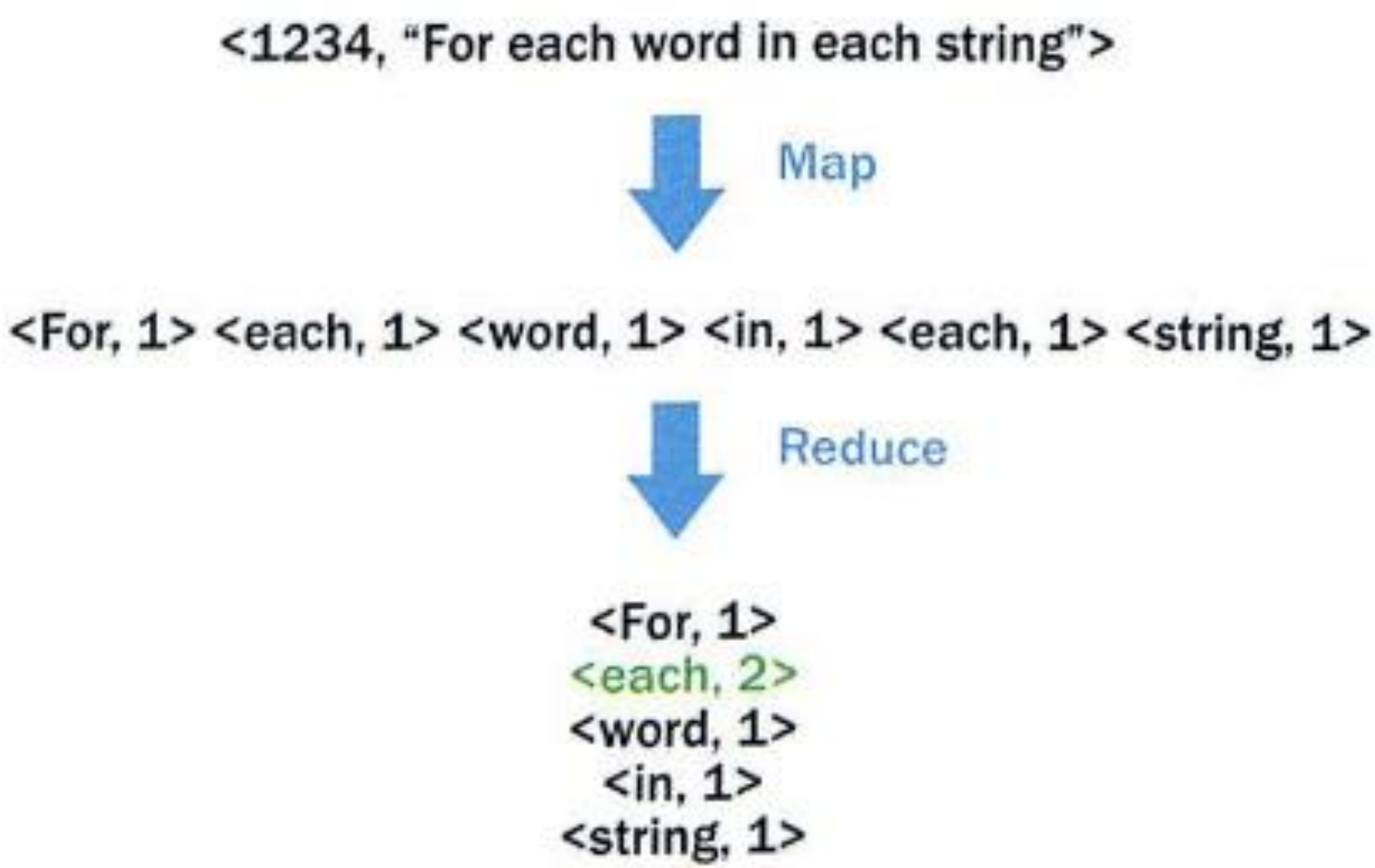
- MapReduce provides
  - Automatic parallelization and distribution
  - I/O scheduling
    - Load balancing
    - Network and data transfer optimization
  - Fault tolerance
    - Handling of machine failures
- Main Philosophy: **Scale out, not up!**
    - Large number of **commodity servers** as opposed to some high end specialized servers

Apache Hadoop:
Open source implementation of MapReduce

By **Cristiana Amza**

10.1 Analytics for Unstructured Data
10.1.2 MapReduce

MapReduce word count example



10.1 Analytics for Unstructured Data
10.1.2 MapReduce

Example 1

see bob throw

see spot run

see	1
bob	1
throw	1
see	1
spot	1
run	1

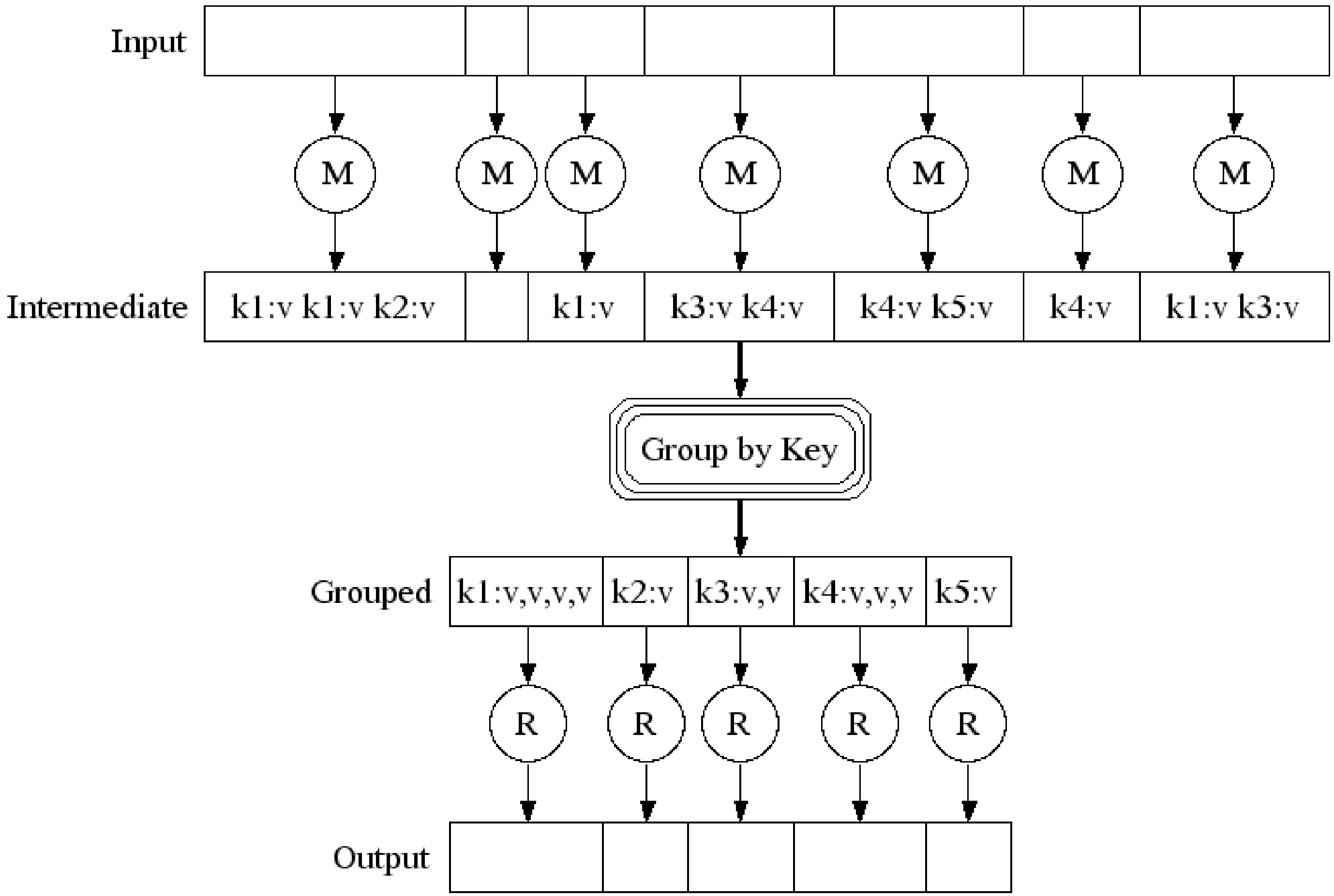
bob	1
run	1
see	2
spot	1
throw	1

Can we do word count in parallel?

By Shivnath Babu

10.1 Analytics for Unstructured Data
10.1.2 MapReduce

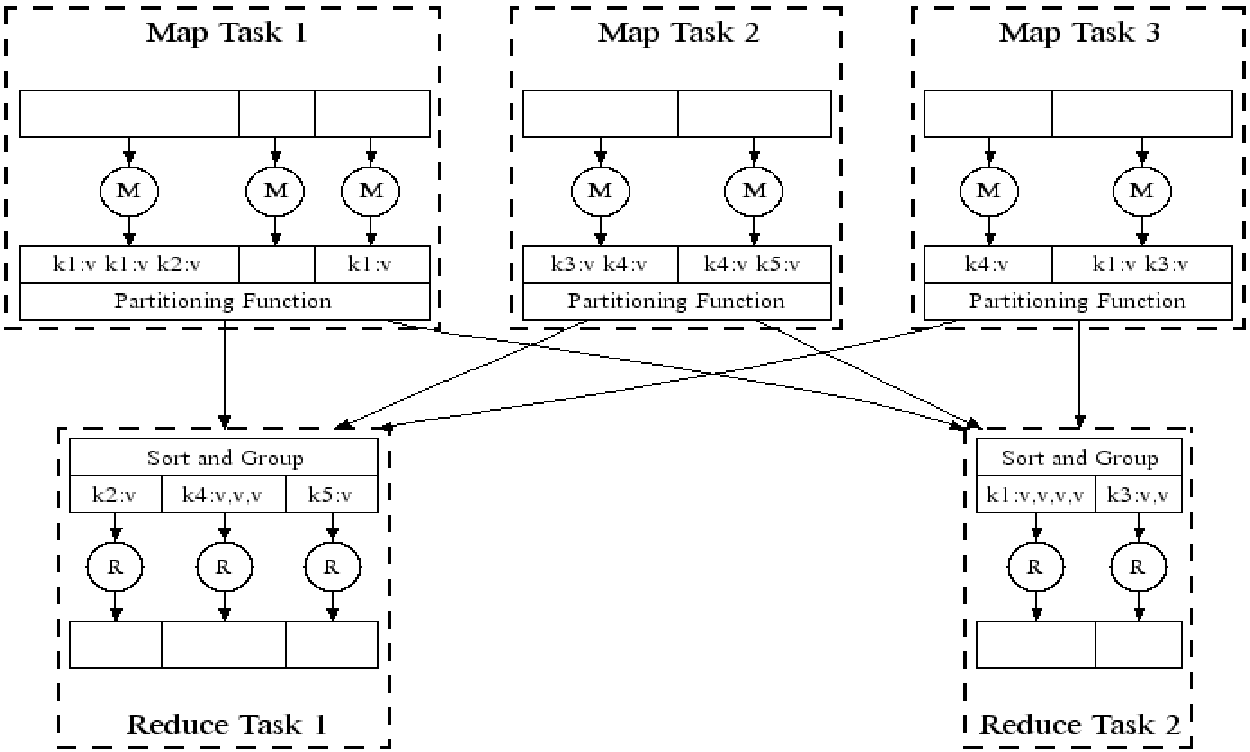
Example 2



By Shivnath Babu

10.1 Analytics for Unstructured Data
10.1.2 MapReduce

Example 2



Handles failures automatically, e.g., restarts tasks if a node fails; runs multiples copies of the same task to avoid a slow task slowing down the whole job

By Shivnath Babu

10.1 Analytics for Unstructured Data
10.1.2 MapReduce

- Failures are norms in commodity hardware
  - **Worker** failure
    - Detect failure via periodic heartbeats
    - Re-execute in-progress map/reduce tasks
  - **Master** failure
    - Single point of failure; Resume from Execution Log
- **Robust**
  - Google's experience: lost 1600 of 1800 machines once!, but finished fine

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

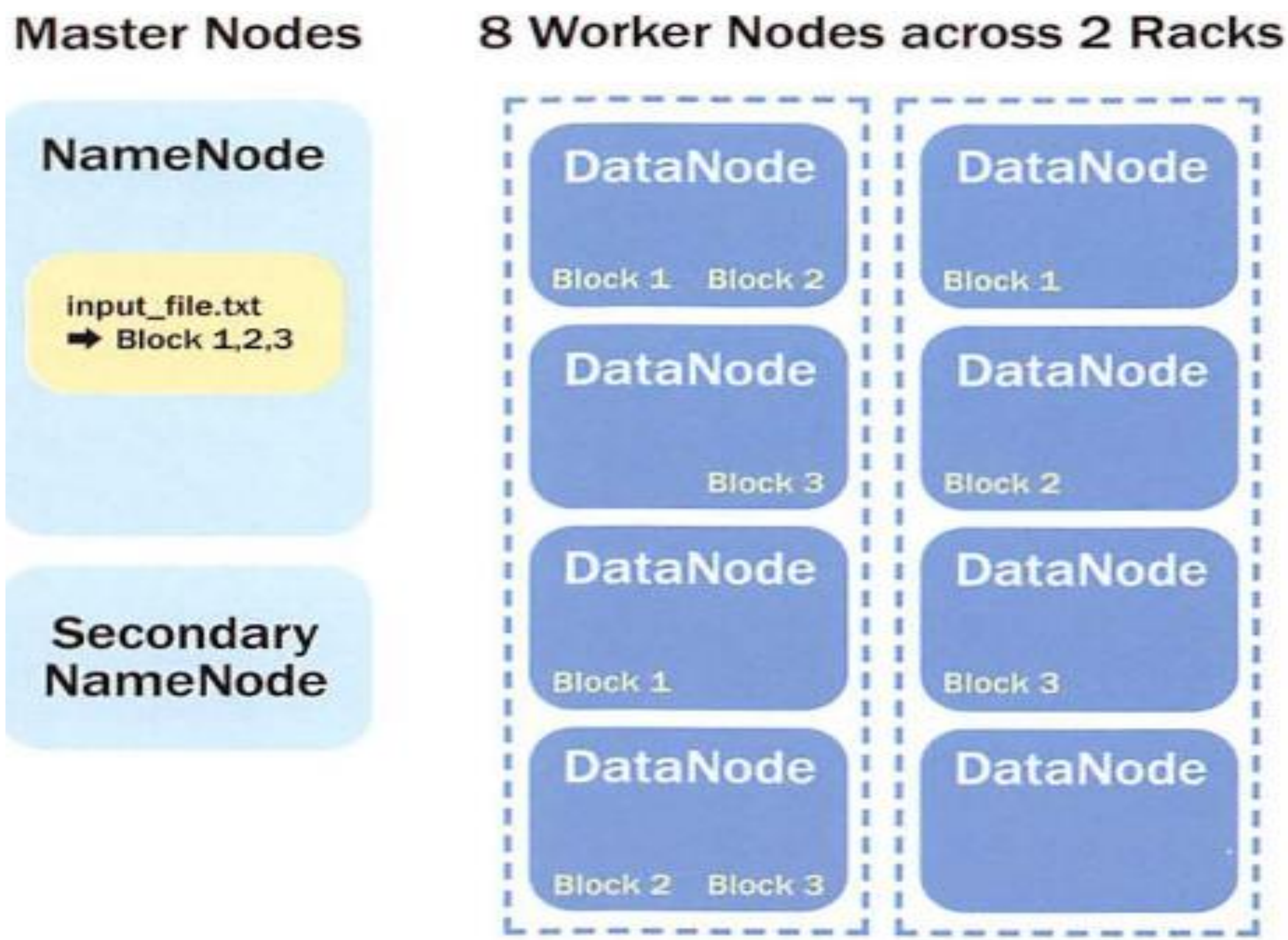
- MapReduce is a distributed programming model (or paradigm) for automatic penalization in Hadoop
- Executing an MapReduce job, Hadoop automatically handles:
  - Job scheduling based on system's workload (i.e. load balancing)
  - Input data spread across cluster of machines (i.e. IO handling)
  - Map step spread across distributed system (i.e. communications)
  - Intermediate outputs collected and distributed for reduce step
  - Final output made available to another user, another application, or another MapReduce job (i.e. IO handling)

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

- Hadoop Distributed File System (HDFS)
  - File system that distributes data across a cluster to take advantage of the parallel processing of MapReduce
  - HDFS uses three Java daemons (background processors)
    1. NameNode – determines and tracks where various blocks of data are stored
    2. DataNode – manages the data stored on each machine
    3. Secondary NameNode – performs some of the NameNode tasks to reduce the load on NameNode

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

- Structuring a MapReduce Job in Hadoop



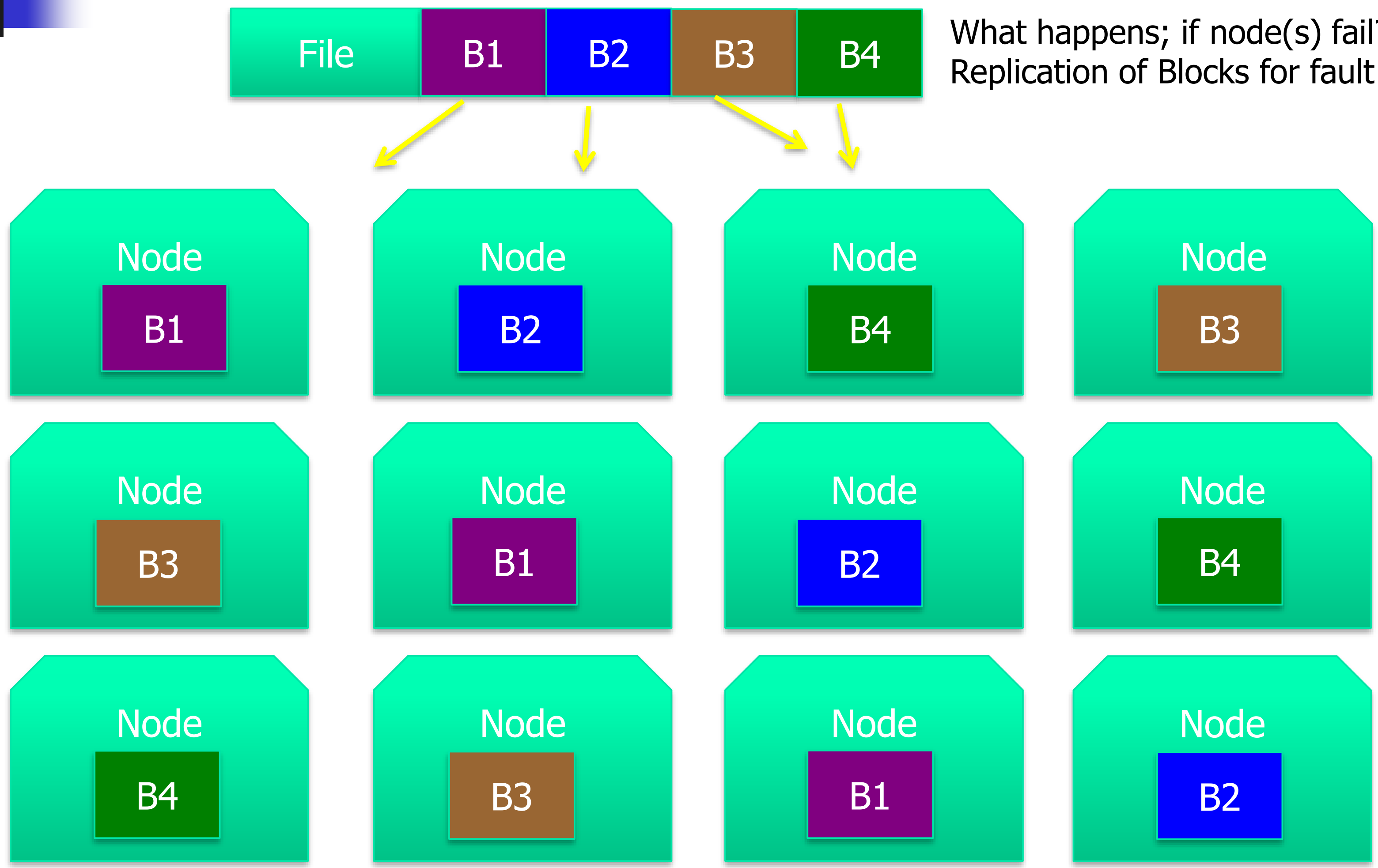
A file stored in HDFS

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

- HDFS files are divided into blocks
  - Block is the basic unit of read/write
  - Its default size is 64MB
    - The size could be adjusted (128MB)
  - It makes HDFS good for storing big data files
- HDFS blocks are replicated multiple times
  - One block stored at multiple locations (also at different racks) for usually 3 times
  - This makes HDFS storage fault tolerant and faster to read

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

What happens; if node(s) fail?
Replication of Blocks for fault tolerance



10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

- Structuring a MapReduce Job in Hadoop
  - A typical MapReduce Java program has three classes
    - Driver
      - provides details such as input file locations, names of mapper and reducer classes, location of reduce class output, etc.
    - Mapper
      - provides computing logic to process each data block
    - Reducer
      - aggregates the data provided by the mapper

In Java

File Edit Options Buffers Tools Java Help

```java
public class WordCount {

  public static class Map extends MapReduceBase implements
                 Mapper<LongWritable, Text, Text, IntWritable> {
    private final static IntWritable one = new IntWritable(1);
    private Text word = new Text();

    public void map(LongWritable key, Text value, OutputCollector<Text, IntWritable>
                  output, Reporter reporter) throws IOException {
      String line = value.toString();
      StringTokenizer tokenizer = new StringTokenizer(line);
      while (tokenizer.hasMoreTokens()) {
        word.set(tokenizer.nextToken());
        output.collect(word, one);
  }}}

  public static class Reduce extends MapReduceBase implements
                 Reducer<Text, IntWritable, Text, IntWritable> {
    public void reduce(Text key, Iterator<IntWritable> values, OutputCollector<Text,
                  IntWritable> output, Reporter reporter) throws IOException {
      int sum = 0;
      while (values.hasNext()) { sum += values.next().get(); }
      output.collect(key, new IntWritable(sum));
  }}

  public static void main(String[] args) throws Exception {
    JobConf conf = new JobConf(WordCount.class);
    conf.setJobName("wordcount");
    conf.setOutputKeyClass(Text.class);
    conf.setOutputValueClass(IntWritable.class);
    conf.setMapperClass(Map.class);
    conf.setCombinerClass(Reduce.class);
    conf.setReducerClass(Reduce.class);
    conf.setInputFormat(TextInputFormat.class);
    conf.setOutputFormat(TextOutputFormat.class);
    FileInputFormat.setInputPaths(conf, new Path(args[0]));
    FileOutputFormat.setOutputPath(conf, new Path(args[1]));

    JobClient.runJob(conf);
  }}
```

```
--:---  mapreduce.java   All L9    (Java/l Abbrev)----------------------------------------
Wrote /home/shivnath/Desktop/mapreduce.java
```

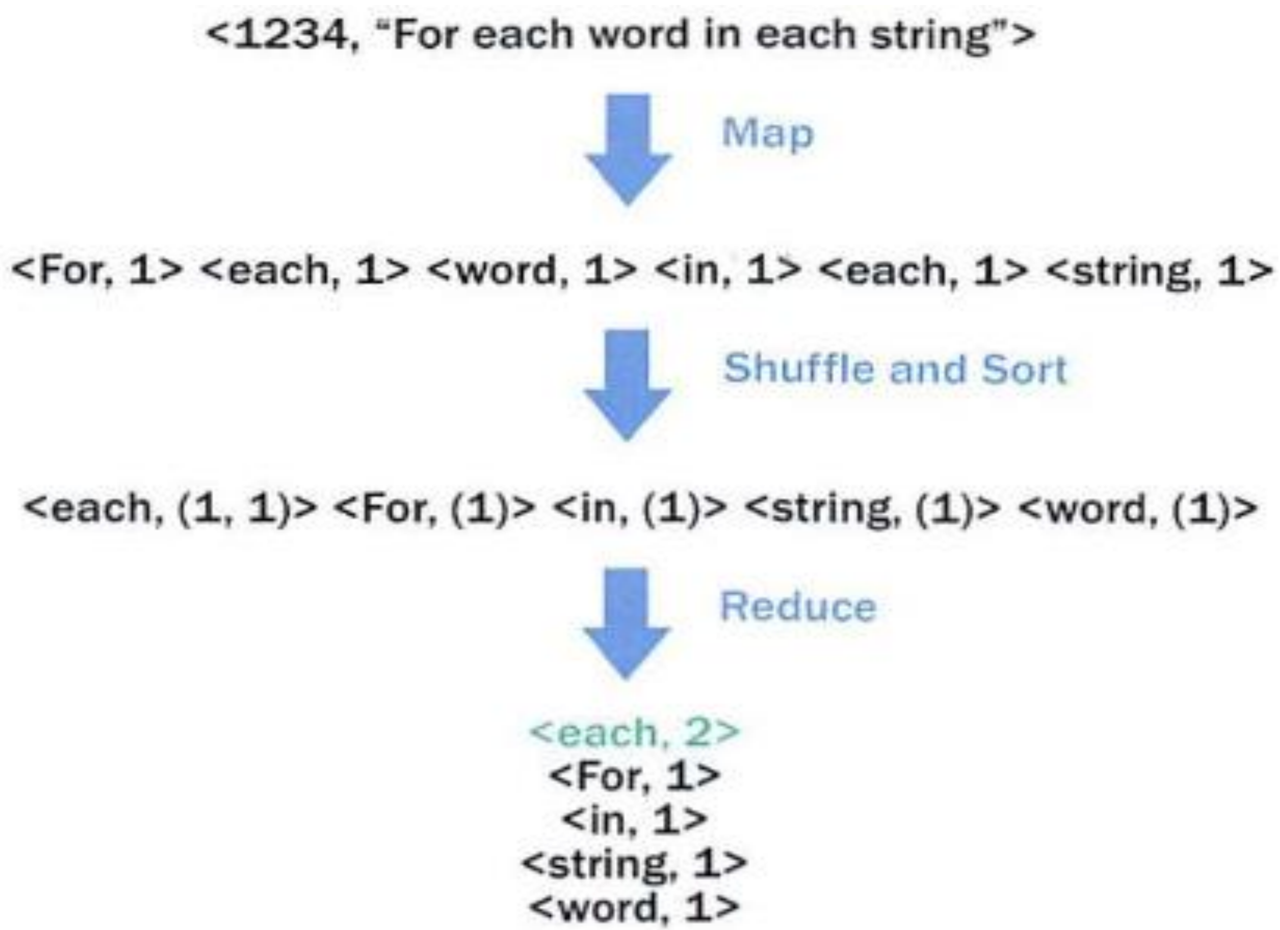
Map function

Reduce function

Run this program as a MapReduce job

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

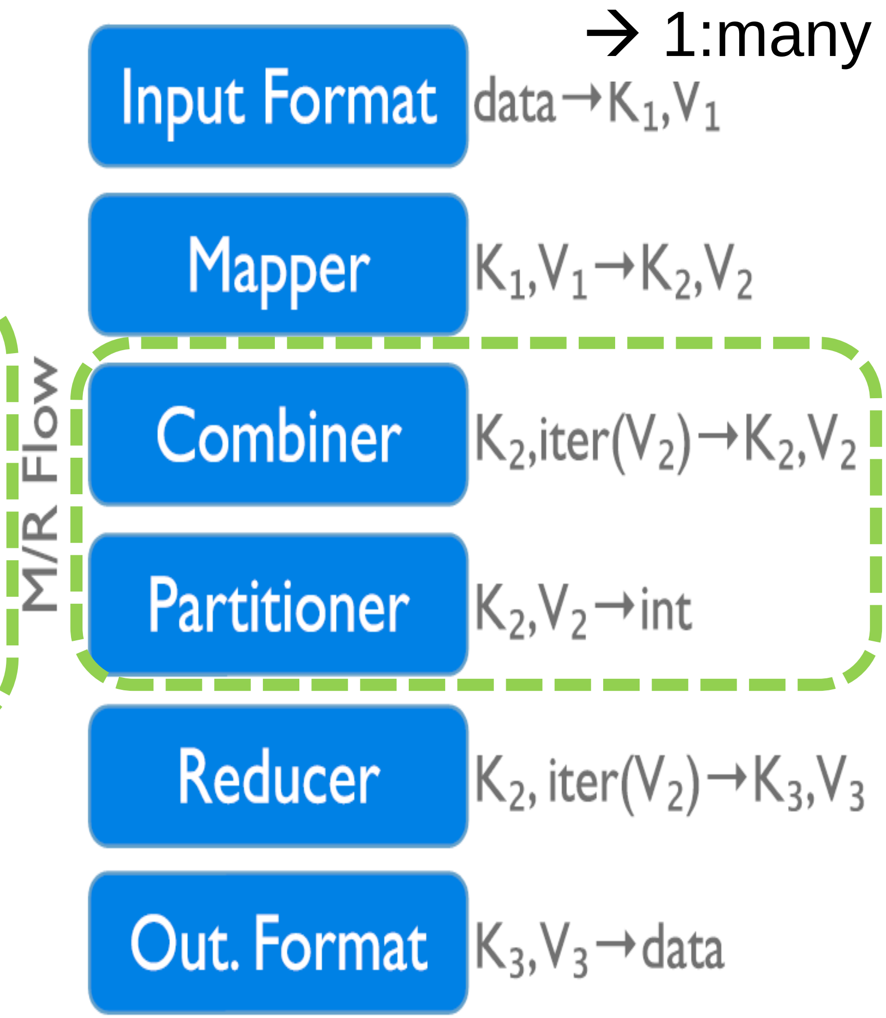
- Structuring a MapReduce Job



Shuffle and Sort

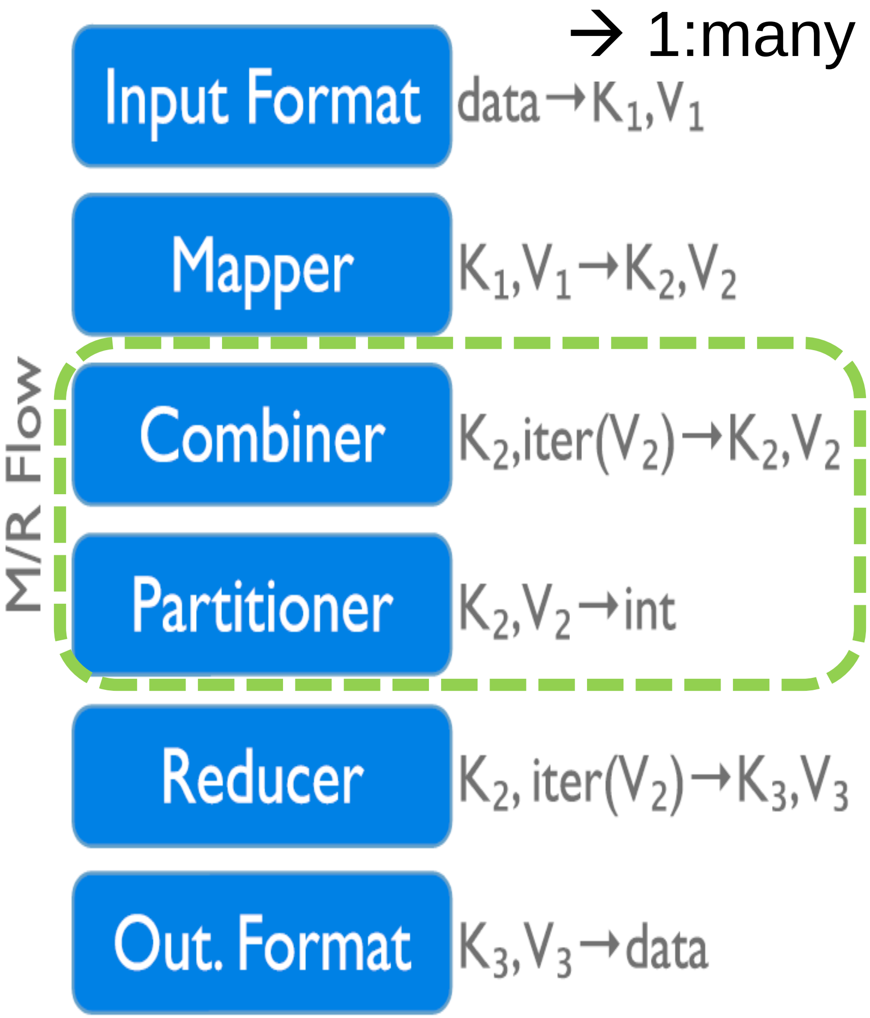
MapReduce Functions in Hadoop

- InputFormat
- Map function
- Combiner
  - Sorting & Merging
- Partitioner
  - Shuffling
- Reduce function
- OutputFormat

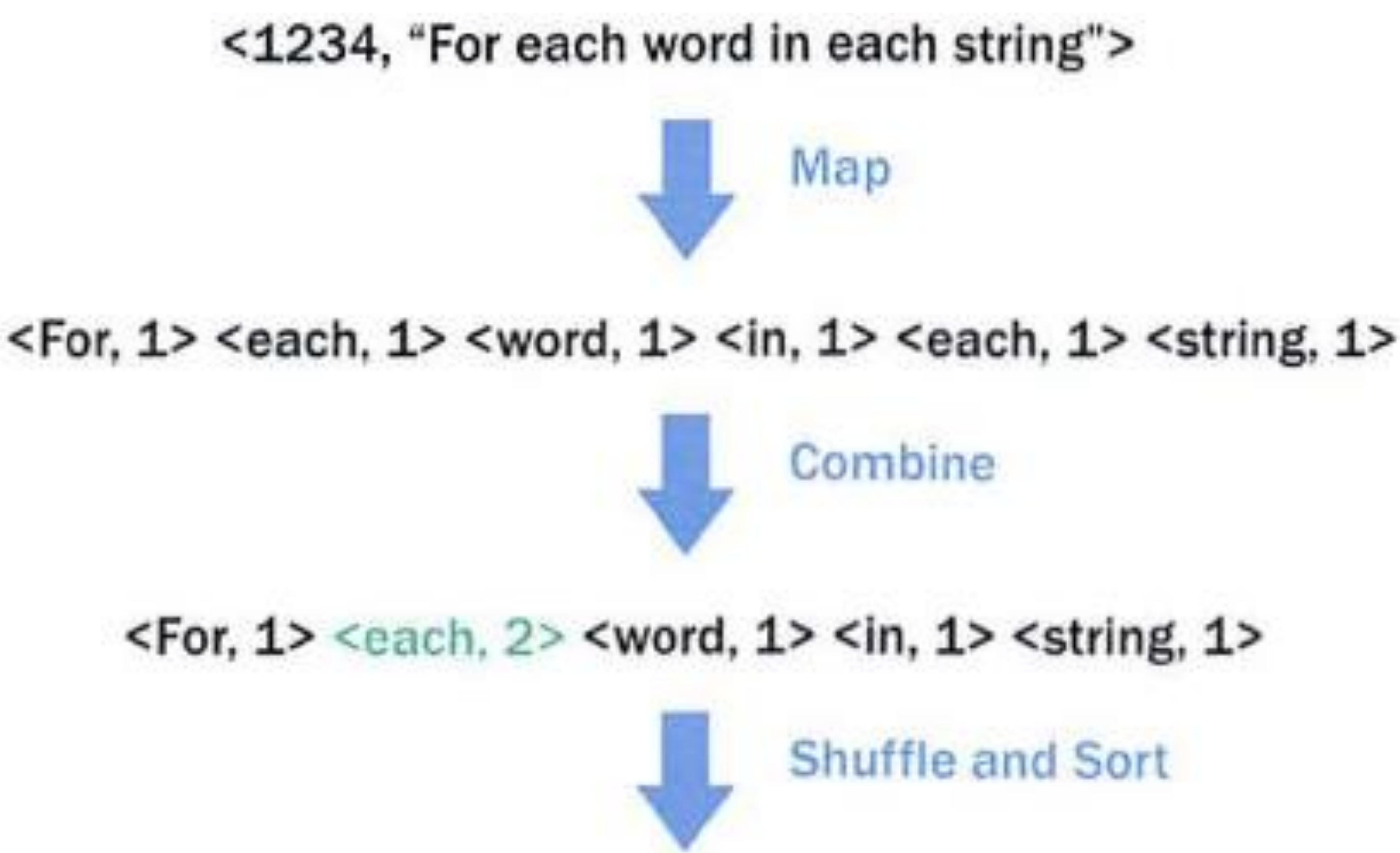


MapReduce Functions in Hadoop

- Optional Functions:
- Combiner:
  - "Mini-reducers" that run in memory after the map phase.
  - Used as an optimization to reduce network traffic.
- Partitioner
  - Often a simple hash of the key, e.g., hash(k') mod n .
  - Divides up key space for parallel reduce operations.

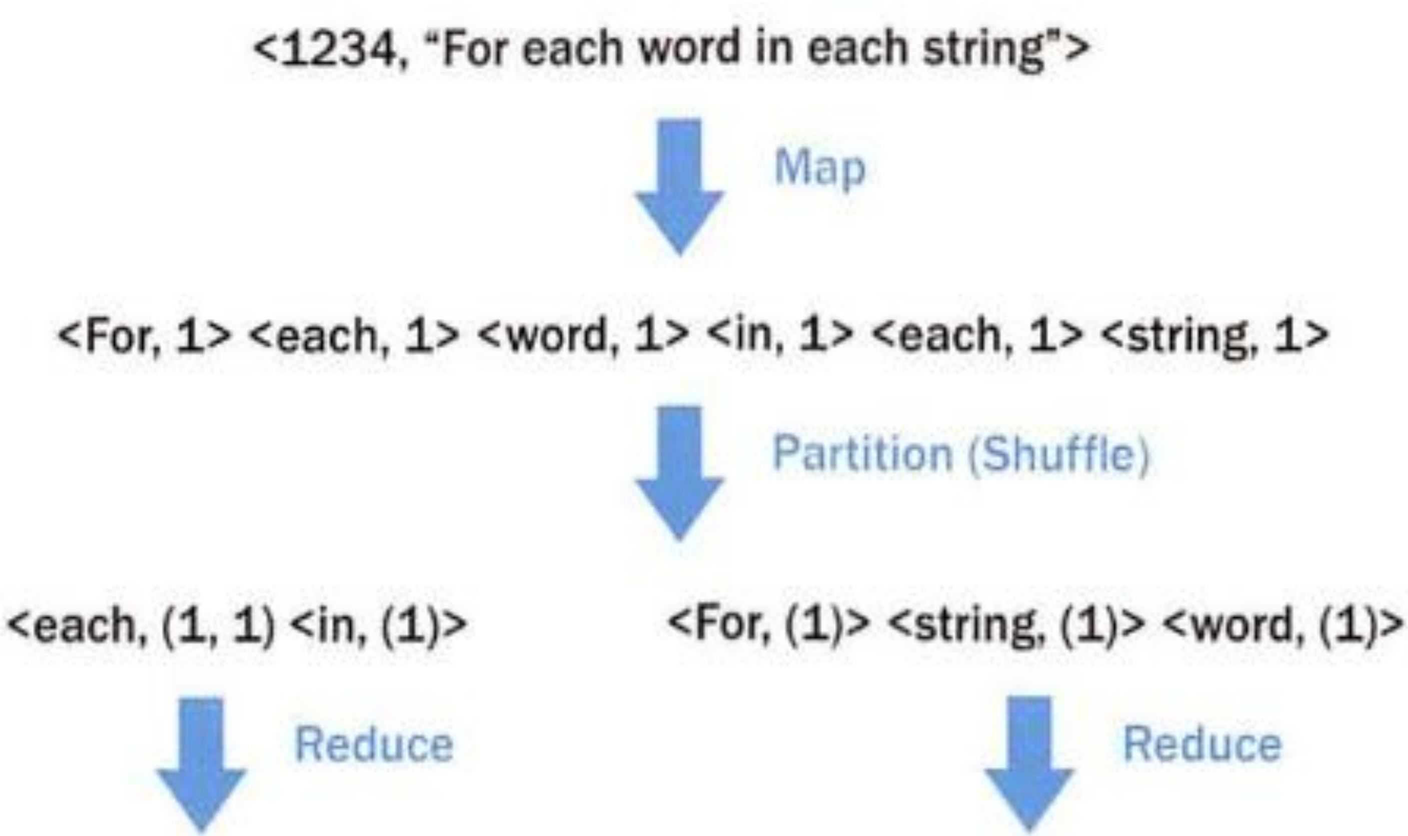


10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop



using a combiner

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop



using a partitioner

Job Configuration Parameters

File Edit Options Buffers Tools SGML Help

```xml
<?xml version="1.0"?>
<?xml-stylesheet type="text/xsl" href="configuration.xsl"?>
<configuration>

<property>
  <name>mapred.reduce.tasks</name>
  <value>1</value>
  <description>The default number of reduce tasks
             per job</description>
</property>

<property>
  <name>io.sort.factor</name>
  <value>10</value>
  <description>Number of streams to merge at once
             while sorting</description>
</property>

<property>
  <name>io.sort.record.percent</name>
  <value>0.05</value>
  <description>Percentage of io.sort.mb dedicated to
             tracking record boundaries</description>
</property>

</configuration>
```

-U:--- conf.xml All L9 (XML)------------------------

- 190+ parameters in Hadoop
- Set manually or defaults are used
- http://hadoop.apache.org/docs/r1.2.1/api/org/apache/hadoop/conf/Configuration.html

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

- Developing and Executing a Hadoop MapReduce Program
- Common practice is to use an IDE tool such as Eclipse
- The MapReduce program consists of three Java files
  - Driver code, mapper code, and reducer code
- Java code is compiled and stored in a JAR file and executed against the specified HDFS input files

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

```
public class ProjectionMapper extends Mapper<LongWritable, Text, Text, LongWritable> {
  private Text word = new Text();
  private LongWritable count = new LongWritable();

  @Override
  protected void map(LongWritable key, Text value, Context context)
      throws IOException, InterruptedException {
    // value is tab separated values: word, year, occurrences, #books, #pages
    // we project out (word, occurrences) so we can sum over all years
    String[] split = value.toString().split("\t+");
    word.set(split[0]);
    if (split.length > 2) {
      try {
        count.set(Long.parseLong(split[2]));
        context.write(word, count);
      } catch (NumberFormatException e) {
        // cannot parse - ignore
      }
    }
  }
}
```

("dobbs", 20)
("dobbs", 22)
("doctor", 545525)
("doctor", 668666)

```
package com.tom_e_white.drdobbs.mapreduce;

import org.apache.hadoop.io.LongWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.mapreduce.Mapper;

import java.io.IOException;
```


http://www.drdobbs.com/database/hadoop-writing-and-running-your-first-pr/240153197 (Expired)

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

```
public class LongSumReducer<KEY> extends Reducer<KEY, LongWritable, KEY,LongWritable> {

  private LongWritable result = new LongWritable();

  public void reduce(KEY key, Iterable<LongWritable> values,
                   Context context) throws IOException, InterruptedException {
    long sum = 0;
    for (LongWritable val : values) {
      sum += val.get();
    }
    result.set(sum);
    context.write(key, result);
  }

}
```

("dobbs", 42)
("doctor", 1214191)

```
package org.apache.hadoop.mapreduce.lib.reduce;

import java.io.IOException;
import org.apache.hadoop.io.LongWritable;
import org.apache.hadoop.mapreduce.Reducer;
```


http://www.drdobbs.com/database/hadoop-writing-and-running-your-first-pr/240153197 (Expired)

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

```java
public class AggregateJob extends Configured implements Tool {

  @Override
  public int run(String[] args) throws Exception {
    Job job = new Job(getConf());
    job.setJarByClass(getClass());
    job.setJobName(getClass().getSimpleName());

    FileInputFormat.addInputPath(job, new Path(args[0]));
    FileOutputFormat.setOutputPath(job, new Path(args[1]));

    job.setMapperClass(ProjectionMapper.class);
    job.setCombinerClass(LongSumReducer.class);
    job.setReducerClass(LongSumReducer.class);

    job.setOutputKeyClass(Text.class);
    job.setOutputValueClass(LongWritable.class);

    return job.waitForCompletion(true) ? 0 : 1;
  }

  public static void main(String[] args) throws Exception {
    int rc = ToolRunner.run(new AggregateJob(), args);
    System.exit(rc);
  }
}
```

```java
package com.tom_e_white.drdobbs.mapreduce;

import org.apache.hadoop.conf.Configured;
import org.apache.hadoop.fs.Path;
import org.apache.hadoop.io.LongWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.mapreduce.Job;
import org.apache.hadoop.mapreduce.lib.input.FileInputFormat;
import org.apache.hadoop.mapreduce.lib.output.FileOutputFormat;
import org.apache.hadoop.mapreduce.lib.reduce.LongSumReducer;
import org.apache.hadoop.util.Tool;
import org.apache.hadoop.util.ToolRunner;
```

http://www.drdobbs.com/database/hadoop-writing-and-running-your-first-pr/240153197 (Expired)

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

https://docs.oracle.com/javase/tutorial/deployment/jar/build.html

```
% hadoop com.sun.tools.javac.Main *.java
% jar cf Example.jar *.class
```

https://hadoop.apache.org/docs/r1.0.4/commands_manual.html#jar

```
% hadoop jar Example.jar \
  com.tom_e_white.drdobbs.mapreduce.AggregateJob data output
```

(**AggregateJob** highlighted)

```
% cat output/part-r-00000
dobbs     42
doctor    1214191
```

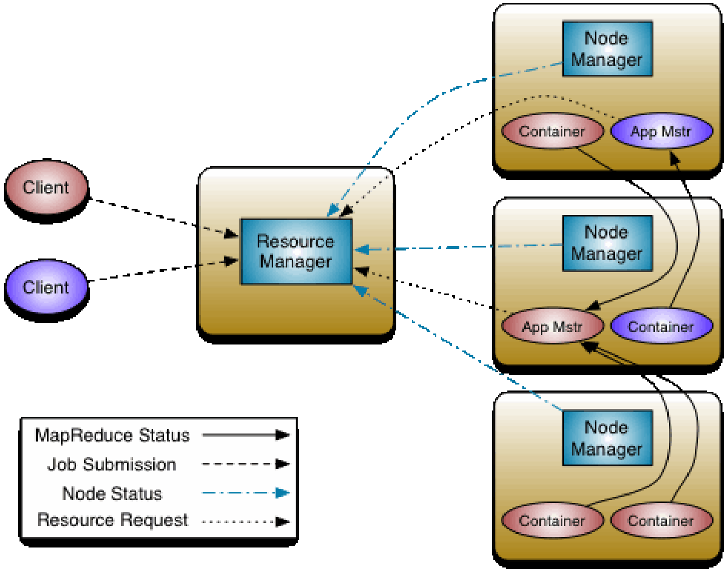
```
% hadoop fs -copyFromLocal data data
```

```
% hadoop jar Example.jar \
  com.tom_e_white.drdobbs.mapreduce.AggregateJob \
  -D fs.default.name=hdfs://localhost:8020 \
  -D mapred.job.tracker=localhost:8021 \
  data output
% hadoop fs -cat output/part-r-00000
dobbs     42
doctor    1214191
```


http://www.drdobbs.com/database/hadoop-writing-and-running-your-first-pr/240153197 (Expired)

10.1 Analytics for Unstructured Data
10.1.3 Apache Hadoop

- **Yet Another Resource Negotiator (YARN)**
- The fundamental idea of YARN is to split up the functionalities of resource management and job scheduling/monitoring into separate daemons. The idea is to have a global ResourceManager (*RM*) and per-application ApplicationMaster (*AM*). An application is either a single job or a DAG of jobs.
- The ResourceManager and the NodeManager form the data-computation framework. The ResourceManager is the ultimate authority that arbitrates resources among all the applications in the system. The NodeManager is the per-machine framework agent who is responsible for containers, monitoring their resource usage (cpu, memory, disk, network) and reporting the same to the ResourceManager/Scheduler.



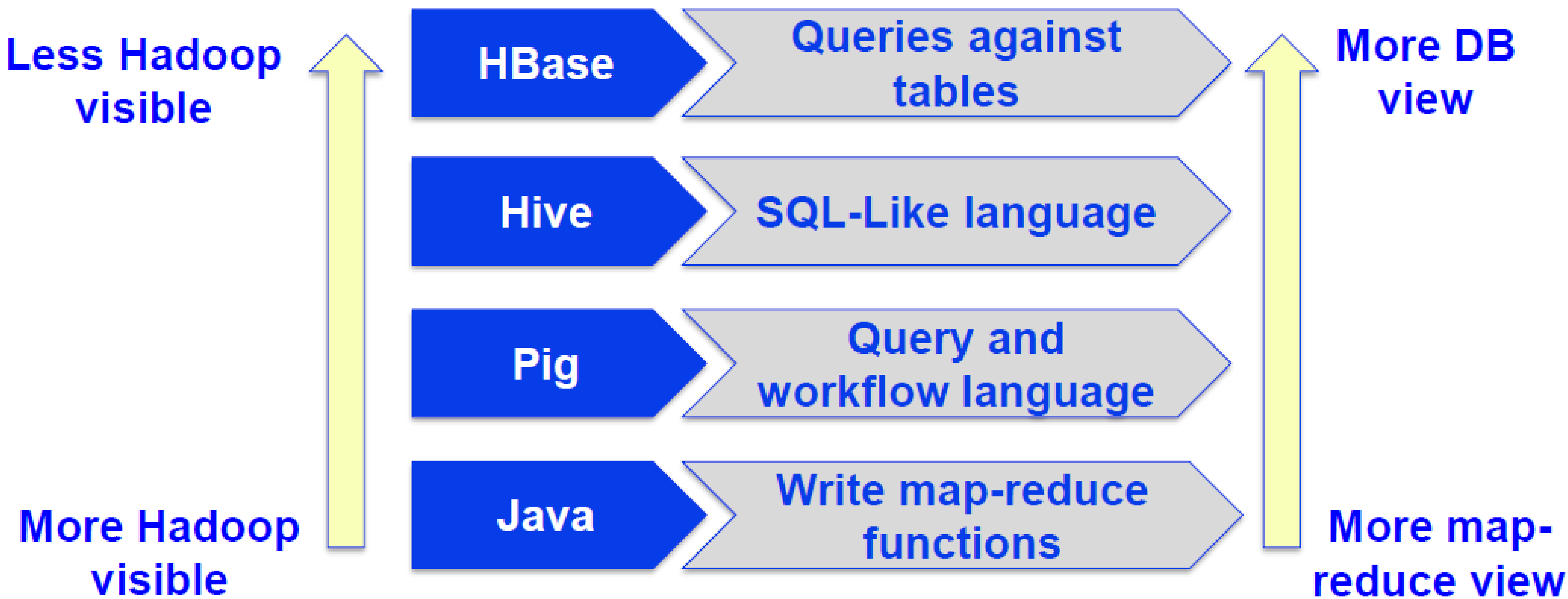
Details: https://hadoop.apache.org/docs/current/hadoop-yarn/hadoop-yarn-site/YARN.html

Lecture Break

10.2 The Hadoop Ecosystem

- Tools have been developed to make Hadoop easier to use and provide additional functionalities and features
  - Pig – provides a high-level data-flow programming language
  - Hive – provides SQL-like access
  - HBase – provides real-time reads and writes
  - ……

10.2 The Hadoop Ecosystem



10.2 The Hadoop Ecosystem
10.2.1 Pig

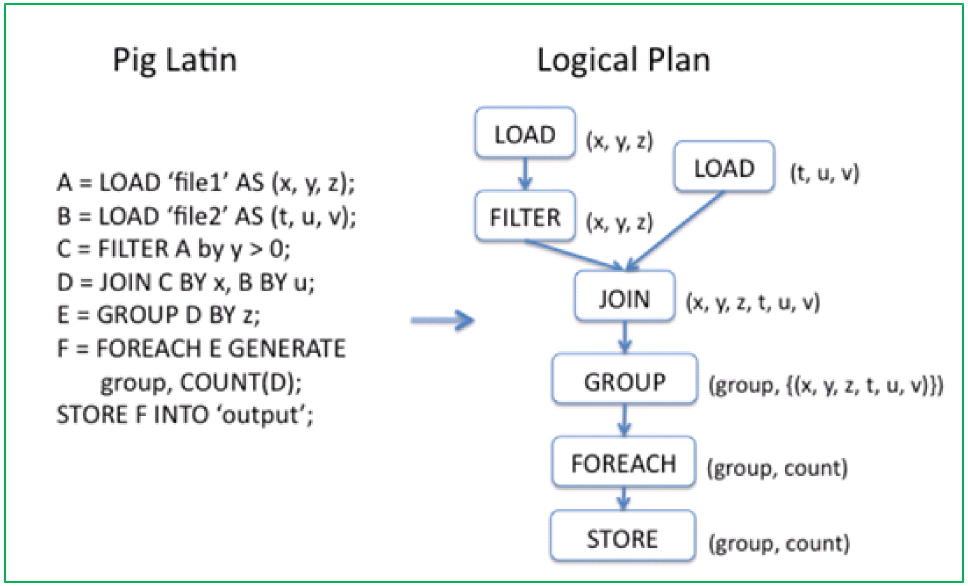
- Pig consists of
  - A data flow language called **Pig Latin**
  - An environment to execute the Pig code
- Example of Pig commands (in Hadoop)

```
$ pig
grunt> records  =  LOAD '/user/customer.txt' AS
                     (cust_id:INT, first_name:CHARARRAY,
                    last_name:CHARARRAY,
                    email_address:CHARARRAY);
grunt> filtered_records = FILTER records
                    BY email_address matches '.*@isp.com'
grunt> STORE filtered_records INTO '/user/isp_customers';
grunt> quit
$
```

10.2 The Hadoop Ecosystem
10.2.1 Pig

- Framework for analyzing large un-structured and semi-structured data on top of Hadoop.

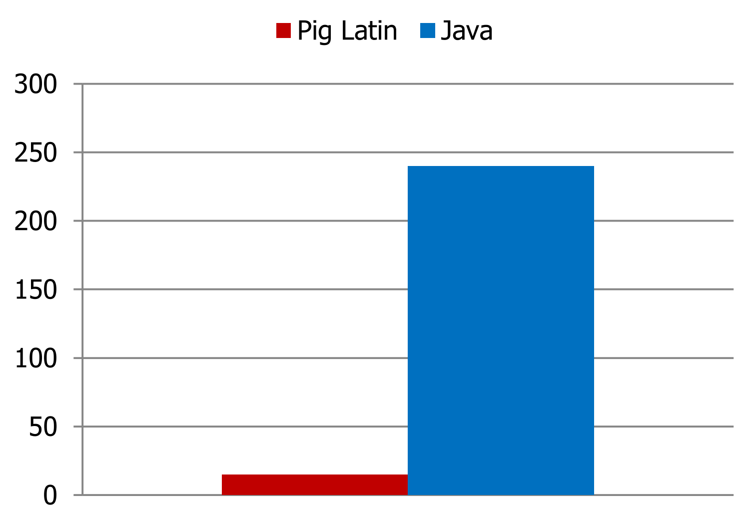
The Pig engine parses and compiles Pig Latin scripts into MapReduce jobs run on top of Hadoop.
Pig Latin is a data processing language; the high level language interface for Hadoop.



By Hui Li, Judy Qiu, Adam Kawa

10.2 The Hadoop Ecosystem
10.2.1 Pig

- Faster development
  - Fewer lines of code (Writing map reduce like writing SQL queries)
  - Re-use others' code (e.g. PiggyBank)
- One test: Find the top 5 words with highest frequencies
  - 10 lines of Pig Latin V.S 200 lines in Java
  - 15 minutes in Pig Latin V.S 4 hours in Java



By Hui Li, Judy Qiu, Adam Kawa

10.2 The Hadoop Ecosystem
10.2.1 Pig

- Word Count using MapReduce

```java
import java.io.IOException;
import java.util.ArrayList;
import java.util.Iterator;
import java.util.List;
import java.util.StringTokenizer;

import org.apache.hadoop.conf.Configuration;
import org.apache.hadoop.conf.Configured;
import org.apache.hadoop.fs.Path;
import org.apache.hadoop.io.IntWritable;
import org.apache.hadoop.io.LongWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.mapred.FileInputFormat;
import org.apache.hadoop.mapred.FileOutputFormat;
import org.apache.hadoop.mapred.JobClient;
import org.apache.hadoop.mapred.JobConf;
import org.apache.hadoop.mapred.MapReduceBase;
import org.apache.hadoop.mapred.Mapper;
import org.apache.hadoop.mapred.OutputCollector;
import org.apache.hadoop.mapred.Reducer;
import org.apache.hadoop.mapred.Reporter;
import org.apache.hadoop.util.Tool;
import org.apache.hadoop.util.ToolRunner;

public class WordCount extends Configured implements Tool {

  public static class MapClass extends MapReduceBase
    implements Mapper<LongWritable, Text, Text, IntWritable> {

    private final static IntWritable one = new IntWritable(1);
    private Text word = new Text();

    public void map(LongWritable key, Text value,
                    OutputCollector<Text, IntWritable> output,
                    Reporter reporter) throws IOException {
      String line = value.toString();
      StringTokenizer itr = new StringTokenizer(line);
      while (itr.hasMoreTokens()) {
        word.set(itr.nextToken());
        output.collect(word, one);
      }
    }
  }

  public static class Reduce extends MapReduceBase
    implements Reducer<Text, IntWritable, Text, IntWritable> {

    public void reduce(Text key, Iterator<IntWritable> values,
                       OutputCollector<Text, IntWritable> output,
                       Reporter reporter) throws IOException {
      int sum = 0;
      while (values.hasNext()) {
        sum += values.next().get();
      }
      output.collect(key, new IntWritable(sum));
    }
  }
```

```java
  public int run(String[] args) throws Exception {
    JobConf conf = new JobConf(getConf(), WordCount.class);
    conf.setJobName("wordcount");

    conf.setOutputKeyClass(Text.class);
    conf.setOutputValueClass(IntWritable.class);

    conf.setMapperClass(MapClass.class);
    conf.setCombinerClass(Reduce.class);
    conf.setReducerClass(Reduce.class);

    List<String> other_args = new ArrayList<String>();
    for(int i=0; i < args.length; ++i) {
      try {
        if ("-m".equals(args[i])) {
          conf.setNumMapTasks(Integer.parseInt(args[++i]));
        } else if ("-r".equals(args[i])) {
          conf.setNumReduceTasks(Integer.parseInt(args[++i]));
        } else {
          other_args.add(args[i]);
        }
      } catch (NumberFormatException except) {
        System.out.println("ERROR: Integer expected instead of " + args[i]);
        return printUsage();
      } catch (ArrayIndexOutOfBoundsException except) {
        System.out.println("ERROR: Required parameter missing from " +
                           args[i-1]);
        return printUsage();
      }
    }
    // Make sure there are exactly 2 parameters left.
    if (other_args.size() != 2) {
      System.out.println("ERROR: Wrong number of parameters: " +
                         other_args.size() + " instead of 2.");
      return printUsage();
    }
    FileInputFormat.setInputPaths(conf, other_args.get(0));
    FileOutputFormat.setOutputPath(conf, new Path(other_args.get(1)));
    JobClient.runJob(conf);
    return 0;
  }

  public static void main(String[] args) throws Exception {
    int res = ToolRunner.run(new Configuration(), new WordCount(), args);
    System.exit(res);
  }
}
```

10.2 The Hadoop Ecosystem
10.2.1 Pig

- Word Count using Pig

```
Lines=LOAD 'input/hadoop.log' AS (line: chararray);
Words = FOREACH Lines GENERATE  FLATTEN(TOKENIZE(line)) AS word;
Groups = GROUP Words BY word;
Counts = FOREACH Groups GENERATE  group, COUNT(Words);
Results = ORDER Words BY Counts DESC;
Top5 = LIMIT Results 5;
STORE Top5 INTO /output/top5words;
```

10.2 The Hadoop Ecosystem
10.2.1 Pig

- User-Defined Functions (UDFs) can be written to take advantage of the combiner
- Four join implementations are built and available
- Writing load and store functions is easy if an InputFormat and OutputFormat exist
- Multi-query: pig will combine certain types of operations together in a single pipeline to reduce the number of times data is scanned.
- “Order by” provides total ordering across reducers in a balanced way
- Piggybank, a collection of user contributed UDFs
  https://cwiki.apache.org/confluence/display/PIG/PiggyBank

10.2 The Hadoop Ecosystem
10.2.1 Pig

- 70% of production jobs at Yahoo
  - 10k per day
- Twitter, LinkedIn, Ebay, AOL,…
- Used to
  - Process web logs
  - Build user behavior models
  - Process images
  - Build maps of the web
  - Do research on large data sets

By Hui Li, Judy Qiu, Adam Kawa

10.2 The Hadoop Ecosystem
10.2.1 Pig

- Data Types
  - Scalar Types:
    - Int, long, float, double, boolean, null, chararray, bytearray;
  - Complex Types:
    - A Field is a piece of data
    - A Tuple is an ordered set of fields
    - A Bag is a collection of tuples
    - A Relation is an outer bag
  - Samples:
    - Tuple → Row in Database
      - (0002576169, Tome, 20, 4.0)
    - Relation,Bag → Table or View in Database

      {(0002576169 , Tome, 20, 4.0),
      (0002576170, Mike, 20, 3.6),
      (0002576171 Lucy, 19, 4.0), …. }

By Hui Li, Judy Qiu, Adam Kawa

10.2 The Hadoop Ecosystem
10.2.1 Pig

- Loading data
  - LOAD loads input data
  - Lines=LOAD 'input/access.log' AS (line: chararray);
- Projection
  - FOREACH … GENERATE … (similar to SELECT)
  - takes a set of expressions and applies them to every record.
- Grouping
  - GROUP collects together records with the same key
- Dump/Store
  - DUMP displays results to screen, STORE save results to file system
- Aggregation
  - AVG, COUNT, MAX, MIN, SUM

10.2 The Hadoop Ecosystem
10.2.1 Pig

- Pig Data Loader
  - PigStorage: loads/stores relations using field-delimited text format

```
(1,John,18,4.0F)
(2,Mary,19,3.8F)
(3,Bill,20,3.9F)
```

```
students = load 'student.txt' using PigStorage('\t')
                    as (studentid: int, name:chararray, age:int, gpa:double);
```

  - TextLoader: loads relations from a plain-text format
  - BinStorage:loads/stores relations from or to binary files
  - PigDump: stores relations by writing the toString() representation of tuples, one per line

By Hui Li, Judy Qiu, Adam Kawa

10.2 The Hadoop Ecosystem
10.2.1 Pig

- Foreach ... Generate
  - The Foreach ... Generate statement iterates over the members of a bag

```
studentid = FOREACH  students  GENERATE  studentid, name;
```

  - The result of a Foreach is another bag
  - Elements are named as in the input bag

By Hui Li, Judy Qiu, Adam Kawa

10.2 The Hadoop Ecosystem
10.2.1 Pig

Eval	Load/Store	Math	String	DateTime
AVG	BinStorage()	ABS	INDEXOF	AddDuration
CONCAT	JsonLoader	CEIL	LAST_ INDEX_OF	CurrentTime
COUNT	JsonStorage	COS, ACOS	LCFORST	DaysBetween
COUNT_STAR	PigDump	EXP	LOWER	GetDay
DIFF	PigStorage	FLOOR	REGEX_ EXTRACT	GetHour
IsEmpty	TextLoader	LOG, LOG10	REPLACE	GetMinute
MAX	HBaseStorage	RANDOM	STRSPLIT	GetMonth
MIN		ROUND	SUBSTRING	GetWeek
SIZE		SIN, ASIN	TRIM	GetWeekYear
SUM		SQRT	UCFIRST	GetYear
TOKENIZE		TAN, ATAN	UPPER	MinutesBetween
				SubtractDuration
				ToDate

10.2 The Hadoop Ecosystem
10.2.1 Pig

- How to run Pig Latin scripts
  - Local mode
    - Local host and local file system is used
    - Neither Hadoop nor HDFS is required
    - Useful for prototyping and debugging
  - MapReduce mode
    - Run on a Hadoop cluster and HDFS
  - Batch mode - run a script directly
    - Pig –x local my_pig_script.pig
    - Pig –x mapreduce my_pig_script.pig
  - Interactive mode use the Pig shell to run script
    - Grunt> Lines = LOAD '/input/input.txt' AS (line:chararray);
    - Grunt> Unique = DISTINCT Lines;
    - Grunt> DUMP Unique;

10.2 The Hadoop Ecosystem
10.2.1 Pig

- Find the top 10 most visited pages in each category

Visits

User	Url	Time
Amy	cnn.com	8:00
Amy	bbc.com	10:00
Amy	flickr.com	10:05
Fred	cnn.com	12:00

⋮

Url Info

Url	Category	PageRank
cnn.com	News	0.9
bbc.com	News	0.8
flickr.com	Photos	0.7
espn.com	Sports	0.9

⋮

from Yahoo Research

10.2 The Hadoop Ecosystem
10.2.1 Pig

- Find the top 10 most visited pages in each category

'/data/visits'

User	Url	Time
Amy	cnn.com	8:00
Amy	bbc.com	10:00
Amy	flickr.com	10:05
Fred	cnn.com	12:00

'/data/urlInfo'

Url	Category	PageRank
cnn.com	News	0.9
bbc.com	News	0.8
flickr.com	Photos	0.7
espn.com	Sports	0.9

from Yahoo Research

Load Visits

Group by url

Foreach url generate count

Load Url Info

Join on url

Group by category

Foreach category generate top10 urls

10.2 The Hadoop Ecosystem
10.2.1 Pig

```
visits          = load '/data/visits' as (user, url, time);
gVisits         = group visits by url;
visitCounts     = foreach gVisits generate url, count(visits);

urlInfo         = load '/data/urlInfo' as (url, category, pRank);
visitCounts     = join visitCounts by url, urlInfo by url;
// select * from visitCounts v,urlInfo u where v.url = u.url
gCategories     = group visitCounts by category;
topUrls         = foreach gCategories generate top(visitCounts,10);

store topUrls into '/data/topUrls';
```

from Yahoo Research

10.2 The Hadoop Ecosystem
10.2.2 Hive

- The Hive language, Hive Query Language (HiveQL), resembles SQL rather than a scripting language
- Example Hive code

```
hive> create table customer (
                    cust_id bigint,
                    first_name string,
                    last_name  string,
                    email_address  string)
                    row format delimited
                    fields terminated by '\t';
```

10.2 The Hadoop Ecosystem
10.2.2 Hive

- Yahoo worked on Pig to facilitate application deployment on Hadoop.
  - Their need mainly was focused on processing unstructured data into structured data.
- Simultaneously, Facebook started working on deploying warehouse solutions on Hadoop that resulted in Hive.
  - The size of data being collected and analyzed in industry for business intelligence (BI) is growing rapidly making traditional warehousing solution prohibitively expensive.

Based on Facebook Team's paper

10.2 The Hadoop Ecosystem
10.2.2 Hive

- MapReduce is very low level and requires programmers to write custom programs.
- HIVE supports queries expressed in SQL-like language called HiveQL which are compiled into MR jobs that are executed on Hadoop.
- Hive also allows MR scripts
- It also includes MetaStore that contains schemas and statistics that are useful for data explorations, query optimization, and query compilation.
- At Facebook, Hive warehouse contains tens of thousands of tables; it stores over 700TB and is used for reporting and ad-hoc analyses by 200 Facebook employees.

Based on Facebook Team's paper

10.2 The Hadoop Ecosystem
10.2.2 Hive

- Hive structures data into well-understood database concepts such as: tables, rows, cols, partitions
- It supports primitive types: integers, floats, doubles, and strings
- Hive also supports:
  - associative arrays: map<key-type, value-type>
  - Lists: list<element type>
  - Structs: struct<file name: file type…>
- SerDe: serialize and deserialized API is used to move data in and out of tables

Based on Facebook Team's paper

10.2 The Hadoop Ecosystem
10.2.2 Hive

- Query Language (HiveQL)
  - Subset of SQL
  - Meta-data queries
  - Limited equality and join predicates

Based on Facebook Team's paper

10.2 The Hadoop Ecosystem
10.2.2 Hive

- CREATE TABLE docs (line STRING);
- LOAD DATA INPATH 'hdfs://localhost:9000/user/hduser/employee123.txt' OVERWRITE INTO TABLE docs;
- CREATE TABLE word_counts AS
- SELECT word, count(1) AS count FROM
- (SELECT explode(split(line, '\\s')) AS word FROM docs) w
- GROUP BY word
- ORDER BY word;

http://hive.praveendeshmane.co.in/hive/hive-wordcount-hiveQL-execution.jsp

10.2 The Hadoop Ecosystem
10.2.2 Hive

- Hive and Hadoop are extensively used in Facebook for different kinds of operations.
- 700 TB = 2.1Petabyte after replication!

https://www.facebook.com/notes/facebook-engineering/hive-a-petabyte-scale-data-warehouse-using-hadoop/89508453919/

https://web.archive.org/web/20110728063630/http://www.sfbayacm.org/wp/wp-content/uploads/2010/01/sig_2010_v21.pdf

Based on Facebook Team's paper

10.2 The Hadoop Ecosystem Pig vs Hive

Pig	Hive
Procedural Data Flow Language	Declarative SQLish Language
For Programming	For Reporting
Mainly used by Programmers	Mainly used by Data Analysts
Operates on the client side of a cluster.	Operates on the server side of a cluster.
Does not have a dedicated metadata database.	Makes use of exact variation of dedicated SQL DDL language by defining tables beforehand.
Pig is SQL like but varies to a great extent.	Directly leverages SQL and is easy to learn for database experts.

https://www.dezyre.com/article/difference-between-pig-and-hive-the-two-key-components-of-hadoop-ecosystem/79

10.2 The Hadoop Ecosystem
10.2.3 HBase

- HBase is an **open-source**, **distributed**, **column-oriented** database built on top of HDFS based on Google BigTable.
- A distributed NoSQL data store that can scale horizontally to 1,000s of commodity servers and petabytes of indexed storage.
- Designed to operate on top of the Hadoop distributed file system (HDFS) or Kosmos File System (KFS, aka Cloudstore) for scalability, fault tolerance, and high availability.

10.2 The Hadoop Ecosystem
10.2.3 HBase

- **Columns in HBase:**
  - Columns are known as column qualifiers
  - Column qualifiers are organized into column families
  - Column families conceptually organize column qualifiers into groups that have the same access patterns
  - Column families must be defined when a table is created
  - The number of column qualifiers in a column family is dynamic and can be defined as needed, giving HBase flexibility for dealing with unstructured data
  - The number of column families should be limited to no more than two or three families for storage efficiency

https://jcsites.juniata.edu/faculty/rhodes/smui/syllabus.htm

10.2 The Hadoop Ecosystem
10.2.3 HBase

- **Column Examples in HBase:**

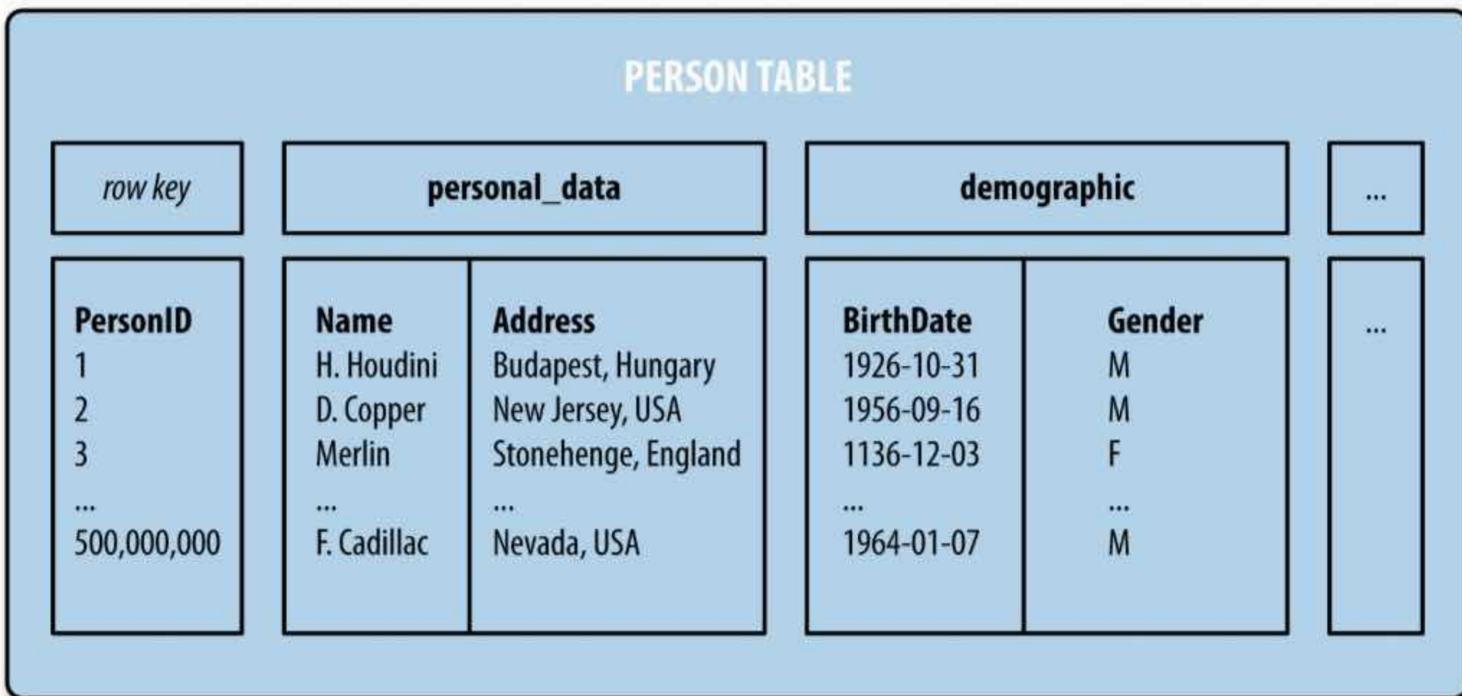


Figure 6-1. Census data as an HBase schema

https://jcsites.juniata.edu/faculty/rhodes/smui/syllabus.htm

10.2 The Hadoop Ecosystem
10.2.3 HBase

- HBase provides **random read and write access** to huge datasets for basic database operations in a key-value fashion.

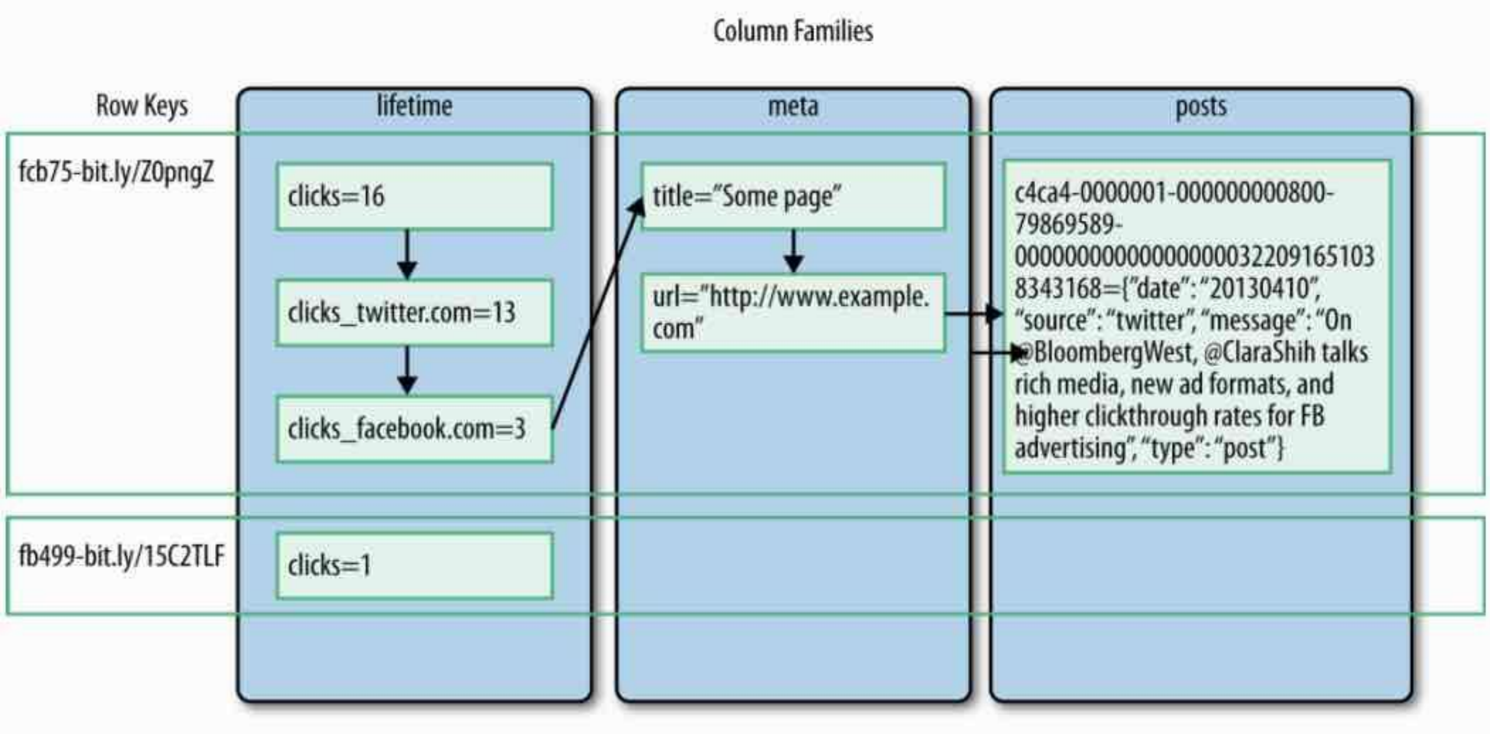


Figure 6-2. Social media events with sparse columns

https://jcsites.juniata.edu/faculty/rhodes/smui/syllabus.htm

HBase Data Example

```
HTable table = …
Text row = new Text("enclosure1");
Text col1 = new Text("animal:type");
Text col2 = new Text("animal:size");
BatchUpdate update = new BatchUpdate(row);
update.put(col1, "lion".getBytes("UTF-8"));
update.put(col2, "big".getBytes("UTF-8));
table.commit(update);
```

```
update = new BatchUpdate(row);
update.put(col1, "zebra".getBytes("UTF-8"));
table.commit(update);
```

Row	Timestamp	Column family: animal:	
		animal:type	animal:size
enclosure1	t2	**zebra**	
	t1	**lion**	**big**
…	…	…	…

HBase Data Example

Retrieve a cell

Cell = table.getRow(“enclosure1”).getColumn(“animal:type”).getValue();

Retrieve a row

RowResult = table.getRow(“enclosure1”);

Scan through a range of rows

Scanner s = table.getScanner(new String[] { “animal:type” });

Row	Timestamp	Column family: animal:	
		animal:type	animal:size
enclosure1	t2	zebra	
	t1	lion	big
…	…	…	…

10.2 The Hadoop Ecosystem
10.2.3 HBase

HBase	HDFS
HBase is a database built on top of the HDFS.	HDFS is a distributed file system suitable for storing large files.
HBase provides fast lookups for large tables.	HDFS does not support fast individual record lookups.
It provides low latency access to single rows from billions of records (Random access).	It provides high latency in batch processing; no concept of batch processing.
HBase internally uses Hash tables and provides random access, and it stores the data in indexed HDFS files for faster lookups.	It provides only sequential access of data.

https://www.tutorialspoint.com/hbase/hbase_overview.htm

10.2 The Hadoop Ecosystem
10.2.3 HBase

HBase	RDBMS
HBase is schema-less, it does not have the concept of fixed columns schema; defines only column families.	An RDBMS is governed by its schema, which describes the whole structure of tables.
It is built for wide tables. HBase is horizontally scalable.	It is thin and built for narrow tables. Hard to scale across many columns.
No transactions exist in HBase.	RDBMS is transactional.
It has de-normalized data tables.	It has normalized data.
It is good for semi-structured as well as structured data.	It is good for structured data.

https://jcsites.juniata.edu/faculty/rhodes/smui/syllabus.htm

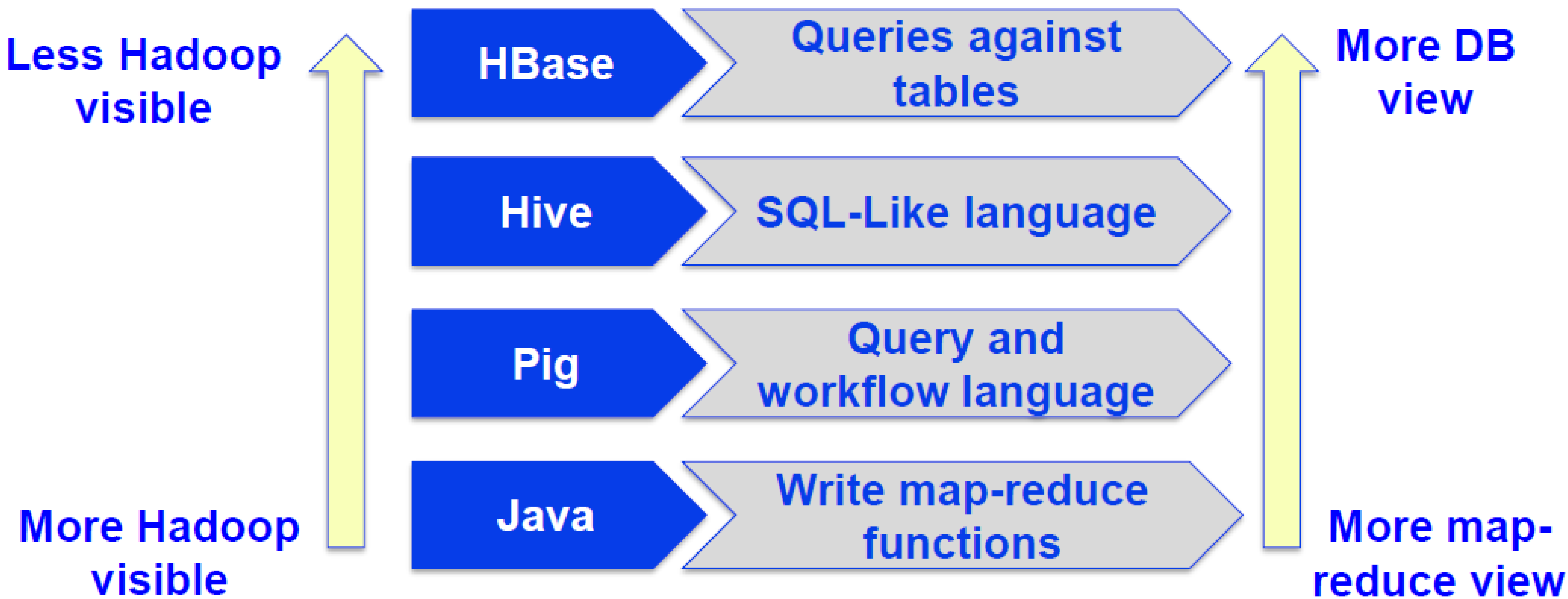
10.2 The Hadoop Ecosystem
10.2.3 HBase

- Advantages:
  - Automatic partitioning
  - Linear and automatic scaling with new nodes
  - Commodity hardware
  - Fault tolerance
  - Batch processing
  - Random read and write operations
  - Table cells are stored with UTC timestamps

10.2 The Hadoop Ecosystem
10.2.3 HBase

- Disadvantages:
  - We cannot expect completely to use HBase as a replacement for traditional models. Some of the traditional features cannot be supported by HBase
  - HBase cannot perform functions like SQL. It doesn't support SQL structure, so it does not contain any query optimizer
  - HBase is CPU and Memory intensive with large sequential input or output access while Map Reduce jobs are primarily input or output bound with fixed memory. HBase integrated with Map-reduce jobs will result in unpredictable latencies

10.2 The Hadoop Ecosystem



https://www.csd.uoc.gr/~hy562/lectures17/MRHadoop18.pdf

References

- Original paper (https://doi.org/10.1145/1327452.1327492)
- On Wikipedia (http://en.wikipedia.org/wiki/MapReduce)
- Hadoop – MapReduce in Java (https://hadoop.apache.org/docs/stable/hadoop-mapreduce-client/hadoop-mapreduce-client-core/MapReduceTutorial.html)

References

1. Apache Hadoop: http://hadoop.apache.org

2. Dean, J. and Ghemawat, S. 2008. **MapReduce: simplified data processing on large clusters.** *Communication of ACM* 51, 1 (Jan. 2008), 107-113.

3. Chapter 10 from "Data Science and Big Data Analytics: Discovering, Analyzing, Visualizing and Presenting Data" 1st Edition by EMC Education Services
4. "Hadoop: The Definitive Guide" by Tom White.

Summary

- 10.1 Analytics for Unstructured Data
  - 10.1.1 Use Cases
  - 10.1.2 MapReduce
  - 10.1.3 Apache Hadoop
- 10.2 The Hadoop Ecosystem
  - 10.2.1 Pig
  - 10.2.2 Hive
  - 10.2.3 HBase
- Summary

END

- The `Partitioner` interface defines the `getPartition()` method
  - Input: a *key*, a *value* and the number of partitions
  - Output: a partition id for the given *key*, *value* pair
- The default `Partitioner` is the `HashPartitioner`:

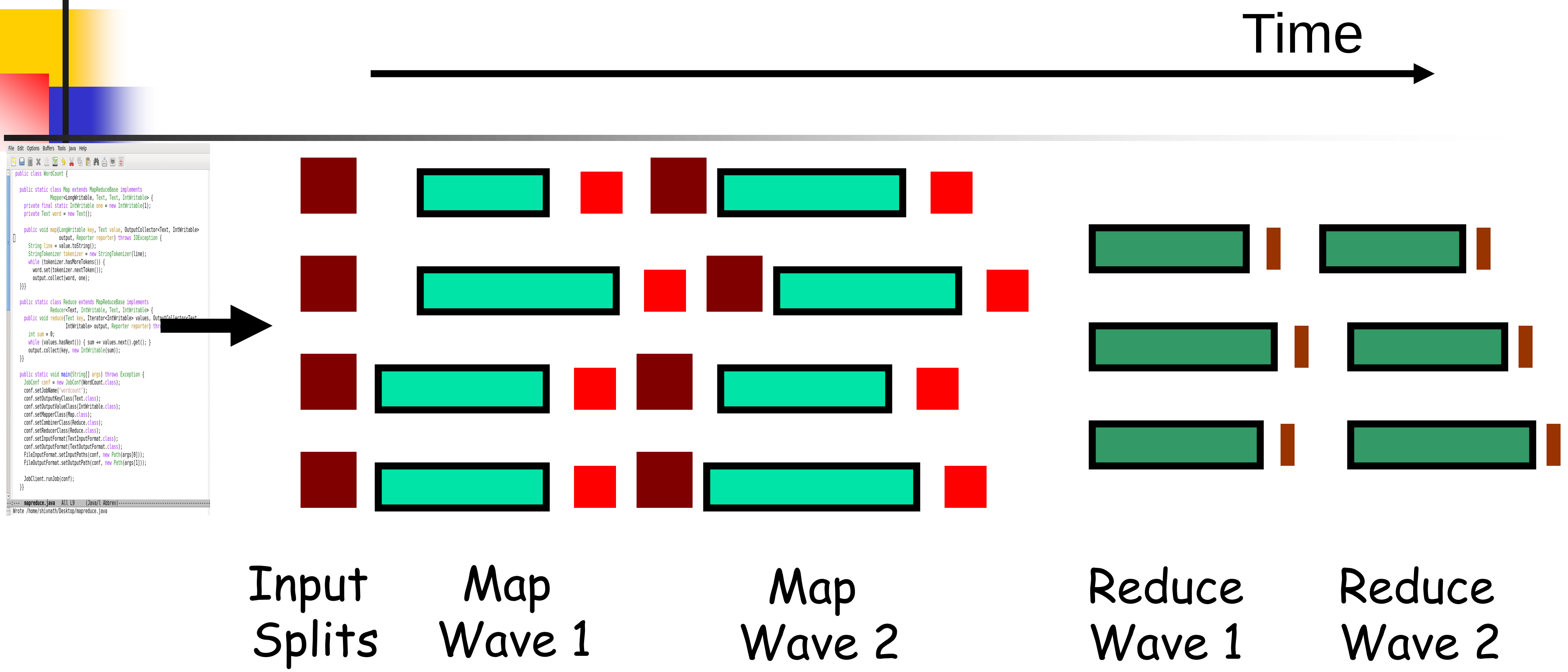
```
int getPartition(K key, V value, int numPartitions) {
    return key.hashCode() % numPartitions;
}
```

Key	key.hashCode()	partitionId (0-2)
hello	12847	1
world	23874	0
map	82375	1
reduce	12839	2

numPartitions = 3

https://www.csd.uoc.gr/~hy562/lectures17/MRHadoop18.pdf

Lifecycle of a MapReduce Job



By Shivnath Babu

10.1 Analytics for Unstructured Data 10.1.3 Apache Hadoop

```
% tar zxf hadoop-1.0.4.tar.gz
% export HADOOP_HOME=$(pwd)/hadoop-1.0.4
% $HADOOP_HOME/bin/hadoop version
Hadoop 1.0.4
```

In another directory, checkout the Git repository that accompanies this example:

```
% git clone git://github.com/tomwhite/hadoop-drdobbs.git
% cd hadoop-drdobbs
% mvn install
```

The repository contains a small amount of sample data for testing:

```
% cat data/*.tsv
dobbs   2007    20      18      15
dobbs   2008    22      20      12
doctor  2007    545525  366136  57313
doctor  2008    668666  446034  72694
```

http://www.drdobbs.com/database/hadoop-writing-and-running-your-first-pr/240153197

10.3 NoSQL

- NoSQL = Not only Structured Query Language
- Four major categories of NoSQL tools
  - Key/value stores – contains data (the value) accessed by the key
  - Document stores – good when the value of the key/value pair is a file
  - Column family stores – good for sparse datasets
  - Graph stores – good for items and relationships between them
    - Social networks like Facebook and LinkedIn

10.3 NoSQL

- Examples of NoSQL Data Stores

Category	Data Store	Website
Key/Value	Redis	redis.io
	Voldemort	www.project-voldemort.com/voldemort
Document	CouchDB	couchdb.apache.org
	MongoDB	www.mongodb.org
Column family	Cassandra	cassandra.apache.org
	HBase	hbase.apache.org/
Graph	FlockDB	github.com/twitter/flockdb
	Neo4j	www.neo4j.org