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Designers and developers focus on the definition of the Map and Reduce functions (i.e.,  $m$  and  $r$ ), and they don't need to manage the distributed execution of the map, shuffle and sort, and reduce phases. Indeed, the Hadoop framework coordinates the execution of the MapReduce program, managing:

- the parallel execution of the map and reduce phases
- the execution of the shuffle and sort phase
- the scheduling of the subtasks
- the synchronization

## 1 The components: summary

The programming language to use to give instructions to Hadoop is Java. A Hadoop MapReduce program consists of three main parts:

- Driver
- Mapper
- Reducer

Each part is “implemented” by means of a specific class.

### Terminology

Term	Definition
Driver class	The class containing the method/code that coordinates the configuration of the job and the “workflow” of the application
Mapper class	A class “implementing” the map function
Reducer class	A class “implementing” the reduce function
Driver	Instance of the Driver class (i.e., an object)
Mapper	Instance of the Mapper class (i.e., an object)
Reducer	Instance of the Reducer class (i.e., an object)
(Hadoop) Job	Execution/run of a MapReduce code over a data set
Task	Execution/run of a Mapper (Map task) or a Reducer (Reduce task) on a slice of data. Notice that there may be many tasks for each job

Input split	Fixed-size piece of the input data. Usually each split has approximately the same size of a HDFS block/chunk
-------------	--

---

## 1.1 Driver (instance)

The Driver is characterized by the `main()` method, which accepts arguments from the command line (i.e., it is the entry point of the application). Also, it has a `run()` method

- It configures the job
- It submits the job to the Hadoop Cluster
- It “coordinates” the work flow of the application
- It runs on the client machine (i.e., it does not run on the cluster)

## 1.2 Mapper (instance)

The Mapper is an instance of the `Mapper` class.

- It “implements” the map phase;
- It is characterized by the `map()` method, which processes the (`key`, `value`) pairs of the input file and emits (`key`, `value`) pairs and is invoked one time for each input (`key`, `value`) pair;
- It runs on the cluster.

### Tip

The Driver will try to create one Mapper instance for each input block, pushing to the maximum parallelization possible.

## 1.3 Reducer (instance)

The Reducer is an instance of the `Reduce` class.

- It “implements” the reduce phase;
- It is characterized by the `reduce()` method, which processes (`key`, [`list of values`]) pairs and emits (`key`, `value`) pairs and is invoked one time for each distinct key;
- It runs on the cluster.

# 2 Hadoop implementation of the MapReduce phases

The main characteristics Hadoop implementation of the MapReduce are the following

- The input `key-value` pairs are read from the HDFS file system.
- The map method of the Mapper is invoked over each input `key-value` pair, and emits a set of intermediate `key-value` pairs that are stored in the local file system of the computing server (they are not stored in HDFS).

- The intermediate results are aggregated by means of a shuffle and sort procedure, and a set of (key, [list of values]) pairs is generated. Notice that one (key, [list of values]) for each distinct key.
- The reduce method of the Reducer is applied over each (key, [list of values]) pair, and emits a set of key-value pairs that are stored in HDFS (the final result of the MapReduce application).
- Intermediate key-value pairs are transient, which means that they are not stored on the distributed files system, while they are stored locally to the node producing or processing them.
- In order to parallelize the work/the job, Hadoop executes a set of tasks in parallel
  - It instantiates one Mapper (Task) for each input split
  - It instantiates a user-specified number of Reducers: each reducer is associated with a set of keys, and it receives and processes all the key-value pairs associated with its set of keys
- Mappers and Reducers are executed on the nodes/servers of the clusters

Figure 1: MapReduce data flow with a single reducer

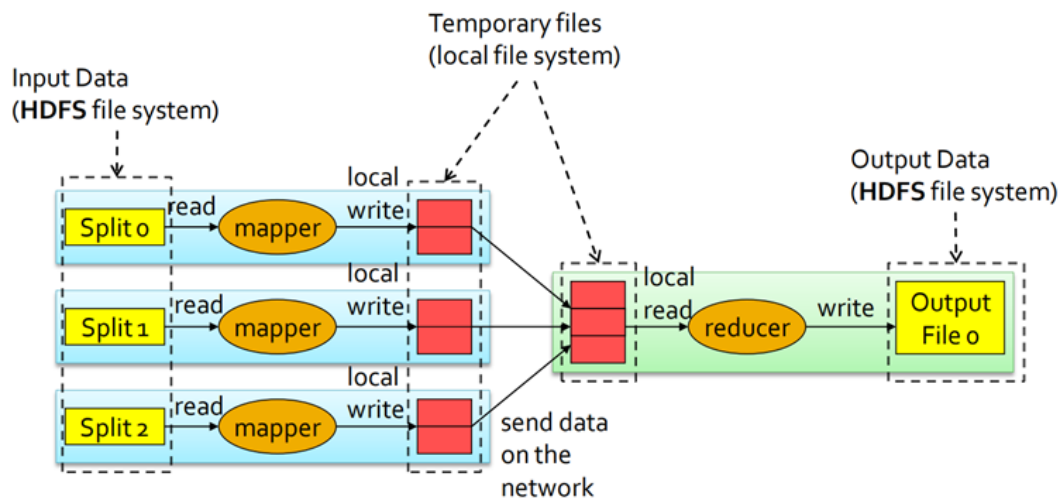
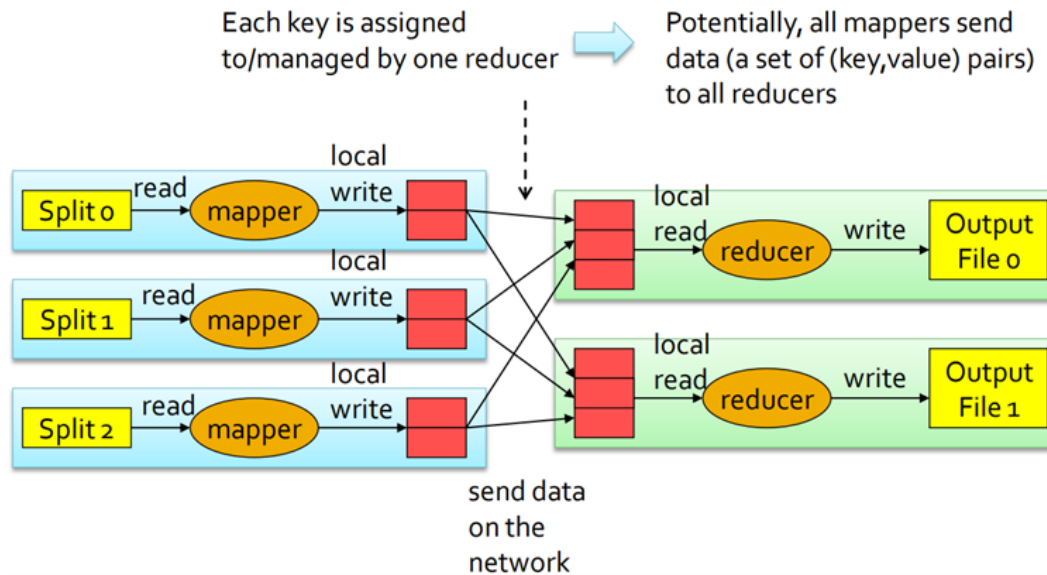


Figure 2: MapReduce data flow with multiple reducers



## 2.1 Driver class

The Driver class extends the `org.apache.hadoop.conf.Configured` class and implements the `org.apache.hadoop.util.Tool` interface <sup>1</sup>.

It is possible to write a Driver class that does not extend `Configured` and does not implement `Tool`, however some low level details related to some command line parameters must be managed in that case.

The designer/developer implements the `main()` and `run()` methods.

The `run()` method configures the job, defining

- The name of the Job
- The job Input format
- The job Output format
- The Mapper class
  - Name of the class
  - Type of its input (key, value) pairs
  - Type of its output (key, value) pairs
- The Reducer class
  - Name of the class
  - Type of its input (key, value) pairs
  - Type of its output (key, value) pairs
- The Number of Reducers <sup>2</sup>

<sup>1</sup>An **interface** is like a template of a class, defining which methods must be implemented to be compliant with the interface

<sup>2</sup>Setting the number of Reducers is a balancing problem: having more Reducers decreases the time to aggregate the data, however it also increases the overhead needed to instantiate the Reducers

## 2.2 Mapper class

The Mapper class extends the

```
1 org.apache.hadoop.mapreduce.Mapper
```

class which is a generic type/generic class with four type parameters:

- input key type
- input value type
- output key type
- output value type

The designer/developer implements the `map()` method, that is automatically called by the framework for each (`key`, `value`) pair of the input file.

The `map()` method

- Processes its input (`key`, `value`) pairs by using standard Java code
- Emits (`key`, `value`) pairs by using the `context.write(key, value)` method

## 2.3 Reducer class

The Reducer class extends the

```
1 org.apache.hadoop.mapreduce.Reducer
```

class, which is a generic type/generic class with four type parameters:

- input key type
- input value type
- output key type
- output value type

The designer/developer implements the `reduce()` method, that is automatically called by the framework for each (`key`, [`list of values`]) pair obtained by aggregating the output of the mapper(s).

The `reduce()` method

- Processes its input (`key`, [`list of values`]) pairs by using standard Java code
- Emits (`key`, `value`) pairs by using the `context.write(key, value)` method

## 2.4 Data Types

Hadoop has its own basic data types optimized for network serialization

- `org.apache.hadoop.io.Text`: like Java String
- `org.apache.hadoop.io.IntWritable`: like Java Integer
- `org.apache.hadoop.io.LongWritable`: like Java Long
- `org.apache.hadoop.io.FloatWritable`: like Java Float
- ...

The basic Hadoop data types implement the `org.apache.hadoop.io.Writable` and `org.apache.hadoop.io.WritableComparable` interfaces

- All classes (data types) used to represent **keys** are instances of `WritableComparable`: keys must be “comparable” for supporting the sort and shuffle phase
- All classes (data types) used to represent **values** are instances of `Writable`: usually, they are also instances of `WritableComparable` even if it is not indispensable

Developers can define new data types by implementing the `org.apache.hadoop.io.Writable` and/or `org.apache.hadoop.io.WritableComparable` interfaces, allowing to manage complex data types.

## 2.5 Input: InputFormat

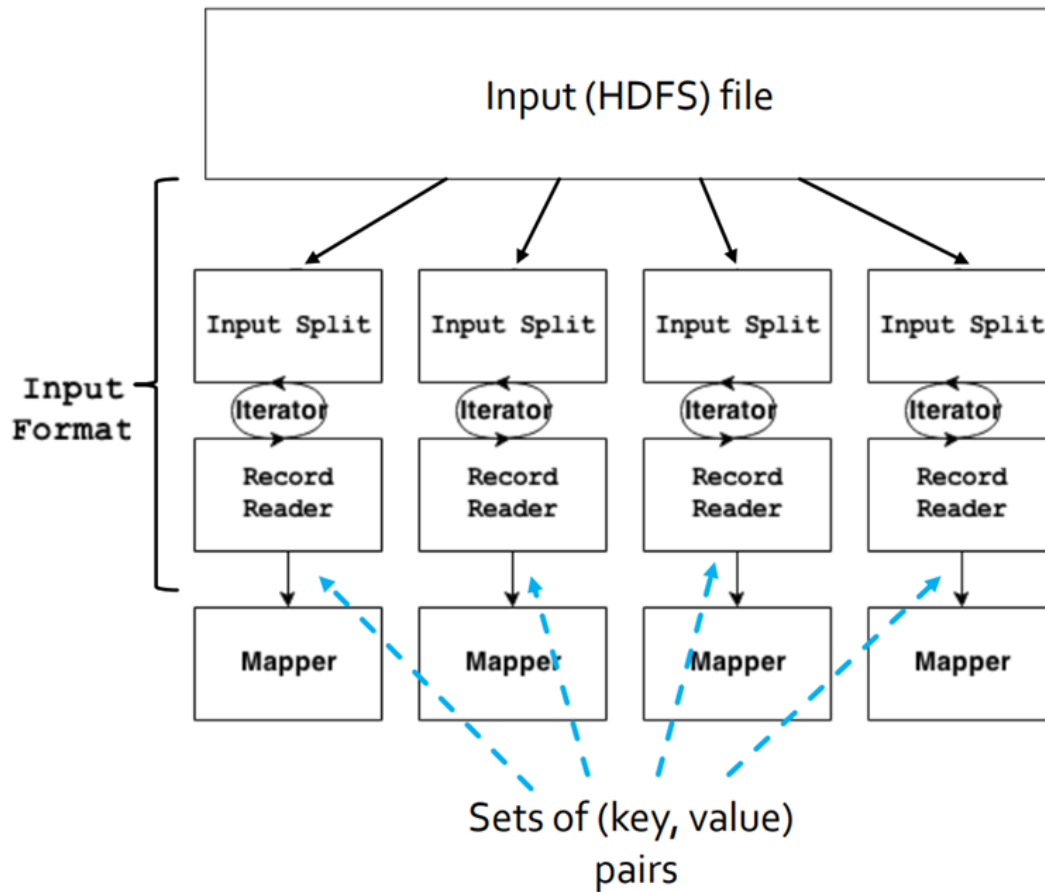
The input of the MapReduce program is an HDFS file (or an HDFS folder), but the input of the Mapper is a set of (**key**, **value**) pairs.

The classes extending the `org.apache.hadoop.mapreduce.InputFormat` abstract class are used to read the input data and “logically transform” the input HDFS file in a set of (**key**, **value**) pairs.

`InputFormat` describes the input-format specification for a MapReduce application and processes the input file(s). The `InputFormat` class is used to

- Read input data and validate the compliance of the input file with the expected input-format
- Split the input file(s) into logical Input Splits, each of which is then assigned to an individual Mapper
- Provide the `RecordReader` implementation to be used to divide the logical input split in a set of (**key**, **value**) pairs (also called records) for the mapper

Figure 3: Getting data to the Mapper



`InputFormat` identifies partitions of the data that form an input split

- Each input split is a (reference to a) part of the input file processed by a single mapper
- Each split is divided into records, and the mapper processes one record (i.e., a **(key,value)** pair) at a time

A set of predefined classes extending the `InputFormat` abstract class are available for standard input file formats

- `TextInputFormat`: `InputFormat` for plain text files
- `KeyValueTextInputFormat`: another `InputFormat` for plain text files
- `SequenceFileInputFormat`: an `InputFormat` for sequential/binary files
- ...

### 2.5.1 `TextInputFormat`

`TextInputFormat` is an `InputFormat` for plain text files. Files are broken into lines, where either linefeed or carriage-return are used to signal end of line. One pair **(key, value)** is emitted for each line of the file:



- Key is the position (offset) of the line in the file
- Value is the content of the line

### **i** Example

Figure 4: Getting data to the Mapper

#### Input HDFS file

Toy example file for Hadoop.\n  
Hadoop running example.\n  
TextinputFormat is used to split data.\n



#### (key, value) pairs generated by using TextInputFormat

(0, "Toy example file for Hadoop.")  
(31, "Hadoop running example.")  
(56, "TextinputFormat is used to split data.")

### 2.5.2 KeyValueTextInputFormat

KeyValueTextInputFormat is an InputFormat for plain text files, where each line must have the format

```
key<separator>value
```

and the default separator is tab (`\t`).

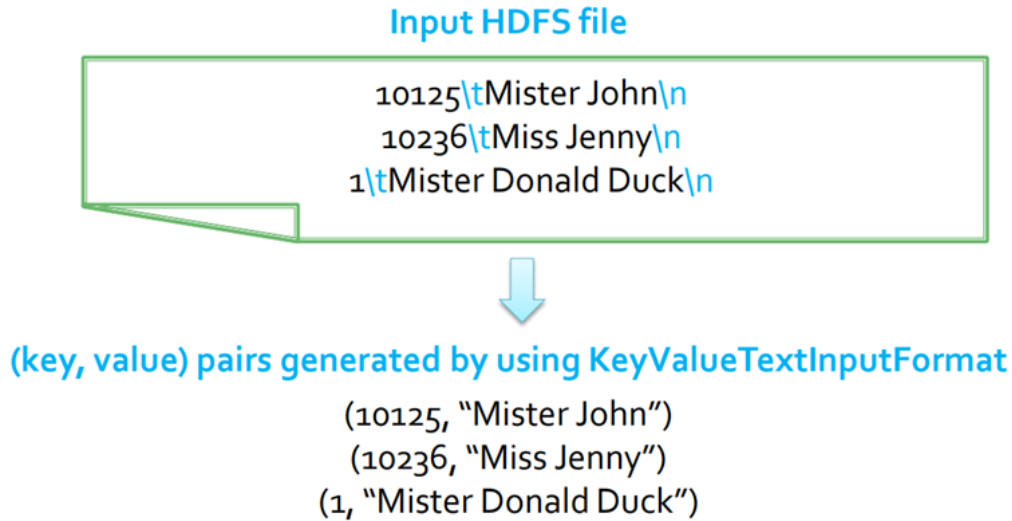
Files are broken into lines, and either linefeed or carriage-return are used to signal end of line, and each line is split into key and value parts by considering the separator symbol/character.

One pair (`key`, `value`) is emitted for each line of the file

- Key is the text preceding the separator
- Value is the text following the separator

**i** Example

Figure 5: Getting data to the Mapper



## 2.6 Output: OutputFormat

The classes extending the `org.apache.hadoop.mapreduce.OutputFormat` abstract class are used to write the output of the MapReduce program in HDFS.

A set of predefined classes extending the `OutputFormat` abstract class are available for standard output file formats

- `TextOutputFormat`: an `OutputFormat` for plain text files
- `SequenceFileOutputFormat`: an `OutputFormat` for sequential/binary files
- ...

### 2.6.1 TextOutputFormat

`TextOutputFormat` is an `OutputFormat` for plain text files: for each output (key, value) pair, `TextOutputFormat` writes one line in the output file. In particular, the format of each output line is

```
"key\tvalue\n"
```

## 3 Structure of a MapReduce program in Hadoop

Always start from these templates. The parts of the code that should be changed to customize the Hadoop application are highlighted using notes.

### 3.1 Driver

```

1  /* Set package */ // # <1>
2  package it.polito.bigdata.hadoop.mypackage;
3
4  /* Import libraries */
5  import java.io.IOException;
6
7  import org.apache.hadoop.mapreduce.Job;
8  import org.apache.hadoop.util.Tool;
9  import org.apache.hadoop.util.ToolRunner;
10 import org.apache.hadoop.conf.Configuration;
11 import org.apache.hadoop.conf.Configured;
12 import org.apache.hadoop.io.*;
13 import org.apache.hadoop.mapreduce.lib.input.TextInputFormat;
14 import org.apache.hadoop.mapreduce.lib.output.TextOutputFormat;
15
16 /* Driver class */
17 public class MapReduceAppDriver extends Configured implements Tool { // # <2>
18     @Override
19     public int run(String[] args) throws Exception {
20         /* variables */
21         int exitCode;
22         //...
23
24         // Parse parameters
25         numberOfReducers = Integer.parseInt(args[0]); // Number of instances of the Reducer class
26         inputPath = new Path(args[1]); // Can be the path to a folder or to a file. If this is a file, it will be read
27         outputDir = new Path(args[2]); // This is always the path to a folder
28
29         // Define and configure a new job
30         Configuration conf = this.getConf(); // Create a configuration object to design in it the job
31         Job job = Job.getInstance(conf); // Creation of the job, that is the application instance
32
33         // Assign a name to the job
34         job.setJobName("My First MapReduce program"); // # <3>
35
36         // Set path of the input file/folder (if it is a folder, the job reads all the files in it)
37         FileInputFormat.addInputPath(job, inputPath);
38
39         // Set path of the output folder for this job
40         FileOutputFormat.setOutputPath(job, outputDir);
41
42         // Set input format
43         // TextInputFormat = textual files; the input types are (keys: LongWritable, values: text)
44         // KeyValueTextInputFormat = textual files; the input types are (keys: text, values: text)

```

```

45     job.setInputFormatClass(TextInputFormat.class); // This class also includes the inform
46
47     // Set job output format
48     job.setOutputFormatClass(TextOutputFormat.class); // # <5>
49
50     // Specify the class of the Driver for this job
51     job.setJarByClass(MapReduceAppDriver.class); // # <6>
52
53     // Set mapper class
54     job.setMapperClass(MyMapperClass.class); // # <7>
55
56     // Set map output key and value classes; these are also the key - value types of the r
57     job.setMapOutputKeyClass(output key type.class); // where type changes depending on th
58     job.setMapOutputValueClass(output value type.class); // # <9>
59
60     // Set reduce class
61     job.setReducerClass(MyReducerClass.class); // # <10>
62
63     // Set reduce output key and value classes
64     job.setOutputKeyClass(output key type.class); // # <11>
65     job.setOutputValueClass(output value type.class); // # <12>
66
67     // Set number of reducers
68     job.setNumReduceTasks(numberOfReducers);
69
70     // Execute the job and wait for completion
71     if (job.waitForCompletion(true)==true) // with this method the application is run
72         exitCode=0;
73     else
74         exitCode=1;
75     return exitCode;
76 } // End of the run method
77
78 /* main method of the driver class */
79 public static void main(String args[]) throws Exception { // This part of the code is alwa
80     /* Exploit the ToolRunner class to "configure" and run the Hadoop application */
81     int res = ToolRunner.run(
82         new Configuration(),
83         new MapReduceAppDriver(), // # <13>
84         args
85     );
86     System.exit(res);
87 } // End of the main method
88 } // End of public class MapReduceAppDriver

```

1. mypackage
2. MapReduceAppDriver

3. "My First MapReduce program"
4. TextInputFormat
5. TextInputFormat
6. MapReduceAppDriver
7. MyMapperClass
8. output value type
9. output value type
10. MyReducerClass
11. output value type
12. output value type
13. MapReduceAppDriver

## 3.2 Mapper

```
1  /* Set package */
2  package it.polito.bigdata.hadoop.mypackage; // # <1>
3
4  /* Import libraries */
5  import java.io.IOException;
6
7  import org.apache.hadoop.mapreduce.Mapper;
8  import org.apache.hadoop.io.*;
9
10 /* Mapper Class */
11 class myMapperClass extends Mapper< // Mapper is a template // # <2>
12     MapperInputKeyType, // Input key type (must be consistent with the InputFormat class specification)
13     MapperInputValueType, // Input value type (must be consistent with the InputFormat class specification)
14     MapperOutputKeyType, // Output key type // # <5>
15     MapperOutputValueType // Output value type // # <6>
16 >{
17     /* Implementation of the map method */
18     protected void map(
19         MapperInputKeyType key, // Input key // # <7>
20         MapperInputValueType value, // Input value // # <8>
21         Context context // This is an object containing the write method, that has to be invoked
22     ) throws IOException, InterruptedException {
23
24         /*
25         Process the input (key, value) pair and emit a set of (key,value) pairs.
26         context.write(...) is used to emit (key, value) pairs context.write(new outputkey, new outputvalue);
27         */
28
29         context.write(new outputkey, new outputvalue); // # <9>
30         // Notice context.write(...) has to be invoked a number of times equal to the number of pairs
31
32         // In the mapper instance also setup and cleanup methods can be implemented, but are not required
```

```

33
34     } // End of the map method
35 } // End of class myMapperClass

```

1. mypackage
2. myMapperClass
3. MapperInputKeyType
4. MapperInputValueType
5. MapperOutputKeyType
6. MapperOutputValueType
7. MapperInputKeyType
8. MapperInputValueType
9. outputkey and outputvalue

### 3.3 Reducer

```

1  /* Set package */
2  package it.polito.bigdata.hadoop.mypackage; // # <1>
3
4  /* Import libraries */
5  import java.io.IOException;
6  import org.apache.hadoop.mapreduce.Reducer;
7  import org.apache.hadoop.io.*;
8
9  /* Reducer Class */
10 class myReducerClass extends Reducer< // Reducer is a template // # <2>
11     ReducerInputKeyType, // Input key type (must be consistent with the OutputKeyType of the M
12     ReducerInputValueType, // Input value type (must be consistent with the OutputValueType of
13     ReducerOutputKeyType, // Output key type (must be consistent with the OutputFormat class s
14     ReducerOutputValueType // Output value type (must be consistent with the OutputFormat class
15 >{
16     /* Implementation of the reduce method */
17     protected void reduce(
18         ReducerInputKeyType key, // Input key // # <7>
19         Iterable<ReducerInputValueType> values, // Input values (list of values). Notice that s
20         Context context
21     ) throws IOException, InterruptedException {
22
23         /*
24         Process the input (key, [list of values]) pair and emit a set of (key,value) pairs.
25         context.write(...) is used to emit (key, value) pairs context.write(new outputkey, new
26         */
27
28         context.write(new outputkey, new outputvalue); // # <9>
29         // Notice context.write(...) has to be invoked a number of times equal to the number o
30         // "new" has to be always specified

```

```

31
32     } // End of the reduce method
33 } // End of class myReducerClass

```

1. mypackage
2. myReducerClass
3. ReducerInputKeyType
4. ReducerInputValueType
5. ReducerOutputKeyType
6. ReducerOutputValueType
7. ReducerInputKeyType
8. ReducerInputValueType
9. outputkey and outputvalue

### 3.4 Example of a MapReduce program in Hadoop: Word Count

The Word count problem consists of

- Input: (unstructured) textual file, where each line of the input file can contains a set of words
- Output: number of occurrences of each word appearing in the input file
- Parameters/arguments of the application:
  - `args[0]`: number of instances of the reducer
  - `args[1]`: path of the input file
  - `args[2]`: path of the output folder

#### **i** Word Count input and output examples

##### **Input file**

Toy example file for Hadoop. Hadoop running example.

##### **Output file**

```

(toy,1)
(example,2)
(file,1)
(for,1)
(hadoop,2)
(running,1)

```

### 3.4.1 Driver

```

1  /* Set package */
2  package it.polito.bigdata.hadoop.wordcount;
3
4  /* Import libraries */
5  import org.apache.hadoop.conf.Configuration;
6  import org.apache.hadoop.conf.Configured;
7  import org.apache.hadoop.fs.Path;
8  import org.apache.hadoop.io.IntWritable;
9  import org.apache.hadoop.io.Text;
10 import org.apache.hadoop.mapreduce.Job;
11 import org.apache.hadoop.mapreduce.lib.input.FileInputFormat;
12 import org.apache.hadoop.mapreduce.lib.input.TextInputFormat;
13 import org.apache.hadoop.mapreduce.lib.output.FileOutputFormat;
14 import org.apache.hadoop.mapreduce.lib.output.TextOutputFormat;
15 import org.apache.hadoop.util.Tool;
16 import org.apache.hadoop.util.ToolRunner;
17
18 /* Driver class */
19 public class WordCount extends Configured implements Tool {
20     @Override
21     public int run(String[] args) throws Exception {
22         Path inputPath;
23         Path outputDir;
24         int numberOfReducers;
25         int exitCode;
26
27         // Parse input parameters
28         numberOfReducers = Integer.parseInt(args[0]);
29         inputPath = new Path(args[1]);
30         outputDir = new Path(args[2]);
31
32         // Define and configure a new job
33         Configuration conf = this.getConf();
34         Job job = Job.getInstance(conf);
35
36         // Assign a name to the job
37         job.setJobName("WordCounter");
38
39         // Set path of the input file/folder (if it is a folder, the job reads all the files in it)
40         FileInputFormat.addInputPath(job, inputPath);
41
42         // Set path of the output folder for this job
43         FileOutputFormat.setOutputPath(job, outputDir);
44

```



```
45     // Set input format
46     // TextInputFormat = textual files
47     job.setInputFormatClass(TextInputFormat.class);
48
49     // Set job output format
50     job.setOutputFormatClass(TextOutputFormat.class);
51
52     // Specify the class of the Driver for this job
53     job.setJarByClass(WordCount.class);
54
55     // Set mapper class
56     job.setMapperClass(WordCountMapper.class);
57
58     // Set map output key and value classes
59     job.setMapOutputKeyClass(Text.class);
60     job.setMapOutputValueClass(IntWritable.class);
61
62     // Set reduce class
63     job.setReducerClass(WordCountReducer.class);
64
65     // Set reduce output key and value classes
66     job.setOutputKeyClass(Text.class);
67     job.setOutputValueClass(IntWritable.class);
68
69     // Set number of reducers
70     job.setNumReduceTasks(numberOfReducers);
71
72     // Execute the job and wait for completion
73     if (job.waitForCompletion(true)==true)
74         exitCode=0;
75     else
76         exitCode=1;
77     return exitCode;
78 } // End of the run method
79
80 /* main method of the driver class */
81 public static void main(String args[]) throws Exception {
82
83     /* Exploit the ToolRunner class to "configure" and run the
84     Hadoop application */
85
86     intres = ToolRunner.run(
87         new Configuration(),
88         new WordCount(),
89         args
90     );
```

```

91     System.exit(res);
92 } // End of the main method
93 } // End of public class WordCount

```

### 3.4.2 Mapper

```

1  /* Set package */
2  package it.polito.bigdata.hadoop.wordcount;
3
4  /* Import libraries */
5  import java.io.IOException;
6  import org.apache.hadoop.io.IntWritable;
7  import org.apache.hadoop.io.LongWritable;
8  import org.apache.hadoop.io.Text;
9  import org.apache.hadoop.mapreduce.Mapper;
10
11 /* MapperClass */
12 class WordCountMapper extends Mapper<
13     LongWritable, // Input key type
14     Text, // Input value type
15     Text, // Output key type
16     IntWritable // Output value type
17 >{
18     /* Implementation of the map method */
19     protected void map(
20         LongWritable key, // Input key type
21         Text value, // Input value type
22         Context context
23     ) throws IOException, InterruptedException {
24         // Split each sentence in words. Use whitespace(s) as delimiter
25         // The split method returns an array of strings
26         String[] words = value.toString().split("\\s+");
27
28         // Iterate over the set of words
29         for(String word : words) {
30             // Transform word case
31             String cleanedWord = word.toLowerCase();
32
33             // emit one pair (word, 1) for each input word
34             context.write(new Text(cleanedWord), new IntWritable(1));
35         }
36     } // End map method
37 } // End of class WordCountMapper

```

### 3.4.3 Reducer

```

1  /* Set package */
2  package it.polito.bigdata.hadoop.wordcount;
3
4  /* Import libraries */
5  import java.io.IOException;
6  import org.apache.hadoop.io.IntWritable;
7  import org.apache.hadoop.io.Text;
8  import org.apache.hadoop.mapreduce.Reducer;
9
10 /* Reducer Class */
11 class WordCountReducer extends Reducer<
12 Text, // Input key type
13 IntWritable, // Input value type
14 Text, // Output key type
15 IntWritable // Output value type
16 >{
17     /* Implementation of the reduce method */
18     protected void reduce(
19         Text key, // Input key type
20         Iterable<IntWritable> values, // Input value type
21         Context context
22     ) throws IOException, InterruptedException{
23         int occurrences= 0;
24
25         // Iterate over the set of values and sum them
26         for (IntWritable value : values) {
27             occurrences = occurrences+ value.get();
28         }
29
30         // Emit the total number of occurrences of the current word
31         context.write(key, new IntWritable(occurrences));
32     } // End reduce method
33 } // End of class WordCountReducer

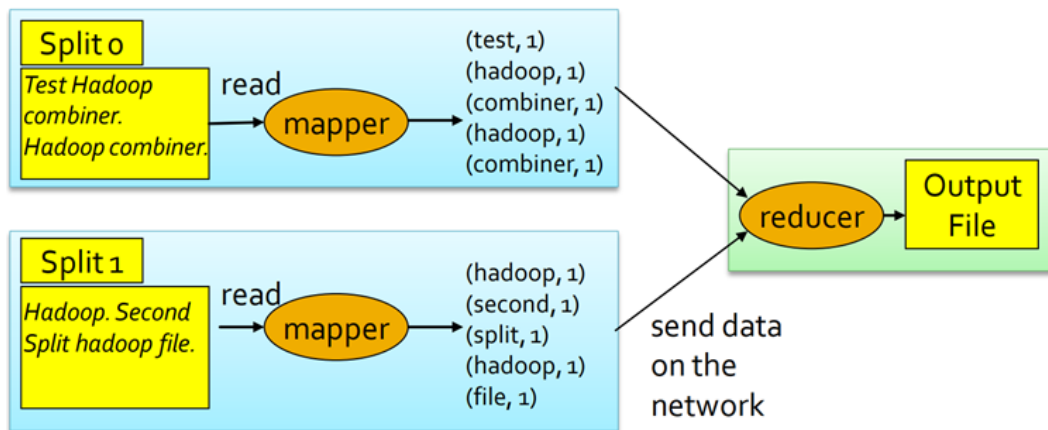
```

## 4 Combiner

In standard MapReduce applications, the (key,value) pairs emitted by the Mappers are sent to the Reducers through the network. However, some pre-aggregations could be performed to limit the amount of network data by using Combiners (also called “minireducers”).

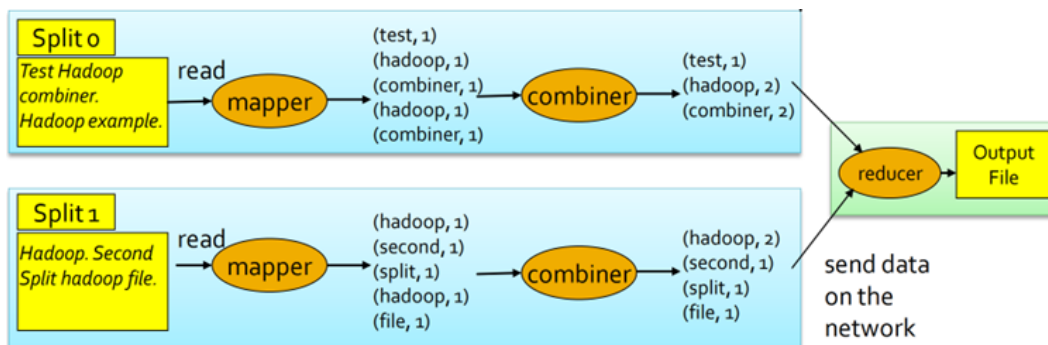
Consider the standard word count problem, and suppose that the input file is split in two input splits, hence, two Mappers are instantiated (one for each split).

Figure 6: Word count without Combiner



A combiner can be locally called on the output (key, value) pairs of each mapper (it works on data stored in the main-memory or on the local hard disks) to pre-aggregate data, reducing the data moving through the network.

Figure 7: Word count with Combiner



So, in MapReduce applications that include Combiners after the Mappers, the (key, value) pairs emitted by the Mappers are analyzed in main-memory (or on the local disk) and aggregated by the Combiners. Each Combiner pre-aggregates the values associated with the pairs emitted by the Mappers of a cluster node, limiting the amount of network data generated by each cluster node.

### ! Combiner scope of application

- Combiners work only if the reduce function is **commutative** and **associative**.
- The execution of combiners is not guaranteed: Hadoop decides at runtime if executing a combiner, and so the user cannot be sure of the combiner execution just by checking the code. Because of this, the developer/designer should write MapReduce jobs whose successful executions **do not depend** on whether the Combiner is executed.

## 4.1 Combiner (instance)

The Combiner is an instance of the `org.apache.hadoop.mapreduce.Reducer` class. Notice that there is not a specific combiner-template class.

- It “implements” a pre-reduce phase that aggregates the pairs emitted in each node by Mappers
- It is characterized by the `reduce()` method
- It processes (`key`, [`list of values`]) pairs and emits (`key`, `value`) pairs
- It runs on the cluster

## 4.2 Combiner class

The Combiner class extends the `org.apache.hadoop.mapreduce.Reducer` class, that is a generic type/generic class with four type parameters:

- input key type
- input value type
- output key type
- output value type

Notice that the output data types are the same as the input data types.

Combiners and Reducers extend the **same class**, and the designer/developer implements the `reduce()` method also for the Combiner instances. The Combiner is automatically called by Hadoop for each (`key`, [`list of values`]) pair obtained by aggregating the local output of a Mapper.

The Combiner class is specified by using the `job.setCombinerClass()` method in the `run` method of the Driver (i.e., in the job configuration part of the code).

## 4.3 Example: adding the Combiner to the Word Count problem

Consider the word count problem (see Section 3.4 for details), to add the combiner to solution seen before:

- Specify the combiner class in the Driver
- Define the Combiner class. The reduce method of the combiner aggregates local pairs emitted by the mappers of a single cluster node, and emits partial results (local number of occurrences for each word) from each cluster node that is used to run the application.

### 4.3.1 Specify combiner class in the Driver

Add the call to the combiner class in the Driver, before the `return` around line 68

```
1      // Set combiner class
2      job.setCombinerClass(WordCountCombiner.class);
```

### 4.3.2 Define the Combiner class

```

1  /* Set package */
2  package it.polito.bigdata.hadoop.wordcount;
3
4  /* Import libraries */
5  import java.io.IOException;
6  import org.apache.hadoop.io.IntWritable;
7  import org.apache.hadoop.io.Text;
8  import org.apache.hadoop.mapreduce.Reducer;
9
10 /* Combiner Class */
11 class WordCountCombiner extends Reducer<
12     Text, // Input key type
13     IntWritable, // Input value type
14     Text, // Output key type
15     IntWritable // Output value type
16 >{
17     /* Implementation of the reduce method */
18     protected void reduce(
19         Text key, // Input key type
20         Iterable<IntWritable> values, // Input value type
21         Context context
22     ) throws IOException, InterruptedException{
23         int occurrences= 0;
24         // Iterate over the set of values and sum them
25         for (IntWritable value : values) {
26             occurrences = occurrences+ value.get();
27         }
28         // Emit the total number of occurrences of the current word
29         context.write(key, new IntWritable(occurrences));
30     } // End reduce method
31 } // End of class WordCountCombiner

```

## 4.4 Final thoughts

The reducer and the combiner classes perform the same computation (the reduce method of the two classes is the same). Indeed, the developer/designer does not really need two different classes: he can simply specify that WordCountReducer is also the combiner class, for example by adding in the driver

```

1      // Set combiner class
2      job.setCombinerClass(WordCountReducer.class);
3      // "WordCountReducer.class" instead of "WordCountCombiner.class"

```

In 99% of the Hadoop applications the same class can be used to implement both combiner and reducer.

## 5 Personalized Data Types

Personalized Data Types are useful when the **value** of a key-value pair is a **complex data type**. Personalized Data Types are defined by implementing the `org.apache.hadoop.io.Writable` interface. To properly serialize the input-output data, the following methods must be implemented

- `public void readFields(DataInput in)`
- `public void write(DataOutput out)`

To properly format the output of the job usually also the following method is “redefined”

- `public String toString()`

Suppose to be interested in complex values composed of two parts, such as a counter (int) and a sum (float). In this case, an ad-hoc Data Type can be used to implement this complex data type in Hadoop.

### 5.1 Example

```

1  /* Set package */
2
3  package it.polito.bigdata.hadoop.combinerexample;
4  import java.io.DataInput;
5  import java.io.DataOutput;
6  import java.io.IOException;
7  public class SumAndCountWritable implements
8  org.apache.hadoop.io.Writable {
9      /* Private variables */
10     private float sum = 0;
11     private int count = 0;
12
13     /* Methods to get and set private variables of the class */
14     public float getSum() {
15         return sum;
16     }
17
18     public void setSum(float sumValue) {
19         sum=sumValue;
20     }
21
22     public int getCount() {
23         return count;
24     }
25
26     public void setCount(int countValue) {
27         count=countValue;
28     }
29

```

```

30     /* Methods to serialize and deserialize the contents of the
31     instances of this class */
32     @Override /* Serialize the fields of this object to out */
33     public void write(DataOutput out) throws IOException {
34         out.writeFloat(sum);
35         out.writeInt(count);
36     }
37
38     @Override /* Deserialize the fields of this object from in */
39     public void readFields(DataInput in) throws IOException {
40         sum=in.readFloat();
41         count=in.readInt();
42     }
43
44     /* Specify how to convert the contents of the instances of this
45     class to a String
46     * Useful to specify how to store/write the content of this class
47     * in a textual file */
48     public String toString()
49     {
50         String formattedString=
51         new String("sum="+sum+",count="+count);
52         return formattedString;
53     }
54 }

```

## 5.2 Complex keys

Personalized Data Types can be used also to manage complex **keys**. In that case the Personalized Data Type must implement the `org.apache.hadoop.io.WritableComparable` interface, since keys must be

- compared/sorted: it is possible by implementing the `compareTo()` method
- split in groups: it is possible by implementing the `hashCode()` method

## 6 Sharing parameters among Driver, Mappers, and Reducers

The configuration object is used to share the (basic) configuration of the Hadoop environment across the driver, the mappers and the reducers of the application/job. It stores a list of (property-name, property-value) pairs.

Also, personalized (property-name, property-value) pairs can be specified in the driver, and they can be used to share some parameters of the application with mappers and reducers. The personalized (property-name, property-value) pairs are useful to define shared small (constant) properties that are available only during the execution of the program. The driver sets these parameters, and Mappers and Reducers can access them, however they cannot modify them.



## 6.1 How to use these parameters

In the driver

1. Retrieve the configuration object

```
1 Configuration conf = this.getConf();
```

2. Set personalized properties

```
1 conf.set("property-name", "value");
```

In the Mapper and/or Reducer

```
1 context.getConfiguration().get("property-name")
```

This method returns a String containing the value of the specified property.

## 7 Counters

Hadoop provides a set of basic, built-in, counters to store some statistics about jobs, mappers, reducers, for example

- number of input and output records (i.e., pairs)
- number of transmitted bytes

Also other ad-hoc, user-defined, counters can be defined to compute global “statistics” associated with the goal of the application.

### 7.1 User-defined counters

User-defined counters are defined by means of Java **enum**, and each application can define an arbitrary number of enums. The name of the **enum** is the group name, and each **enum** has a number of “fields”, which are the counter names.

Counters are incremented in the Mappers and Reducers by using the **increment()** method

```
1 context.getCounter(countername).increment(value);
```

The global/final value of each counter, which is available at the end of the job, is then stored/printed by the Driver (at the end of the execution of the job). Driver can retrieve the final values of the counters using the **getCounters()** and **findCounter()** methods.

User-defined counters can be also defined on the fly by using the method **incrCounter("group name", "counter name", value)**. Dynamic counters are useful when the set of counters is unknown at design time.

## 7.2 Example: use the counters

In the driver, add

```
1 public static enum COUNTERS {  
2     ERROR_COUNT,  
3     MISSING_FIELDS_RECORD_COUNT  
4 }
```

This enum defines two counters

- COUNTERS.ERROR\_COUNT
- COUNTERS.MISSING\_FIELDS\_RECORD\_COUNT

To increment the COUNTERS.ERROR\_COUNT counter in the mapper or the reducer, use

```
1 context.getCounter(COUNTERS.ERROR_COUNT).increment(1);
```

To retrieve the final value of the COUNTERS.ERROR\_COUNT counter in the driver, use

```
1 Counter errorCounter = job.getCounters().findCounter(COUNTERS.ERROR_COUNT);
```

## 8 Map-only job

In some applications, all the work can be performed by the mapper(s) (e.g., record filtering applications): Hadoop allows executing Map-only jobs, avoiding the reduce phase, and also the shuffle and sort phase.

The output of the map job is directly stored in HDFS, since the set of pairs emitted by the map phase is already the final output.

### 8.1 Implementation of a Map-only job

To implement a Map-only job

- Implement the map method
- Set the number of reducers to 0 during the configuration of the job (in the driver), writing

```
1 job.setNumReduceTasks(0);
```

## 9 In-Mapper combiner

Mapper classes are also characterized by a setup and a cleanup method, which are empty if they are not overridden.

## 9.1 Setup method

The setup method is called once for each mapper prior to the many calls of the map method. It can be used to set the values of in-mapper variables, which are used to maintain in-mapper statistics and preserve the state (locally for each mapper) within and across calls to the map method.

## 9.2 Cleanup method

The map method, invoked many times, updates the value of the in-mapper variables. Each mapper (each instance of the mapper class) has its own copy of the in-mapper variables.

The cleanup method is called once for each mapper after the many calls to the map method, and it can be used to emit (**key,value**) pairs based on the values of the in-mapper variables/statistics.

Also the reducer classes are characterized by a setup and a cleanup method.

- The setup method is called once for each reducer prior to the many calls of the reduce method.
- The cleanup method is called once for each reducer after the many calls of the reduce method.

In-MapperCombiners are a possible improvement over “standard” Combiners

- Initialize a set of in-mapper variables during the instance of the Mapper, in the setup method of the mapper;
- Update the in-mapper variables/statistics in the map method. Usually, no (key,value) pairs are emitted in the map method of an in-mapper combiner.

After all the input records (input (**key, value**) pairs) of a mapper have been analyzed by the map method, emit the output (**key, value**) pairs of the mapper: (**key, value**) pairs are emitted in the cleanup method of the mapper based on the values of the in-mapper variables

The in-mapper variables are used to perform the work of the combiner in the mapper, allowing to improve the overall performance of the application. However, pay attention to the amount of used main memory: each mapper may use a limited amount of main-memory, hence in-mapper variables should be “small” (at least smaller than the maximum amount of memory assigned to each mapper).

## 9.3 In-Mapper combiner: Word count pseudocode

```
1  class MAPPER
2      method setup
3          A = new AssociativeArray
4      method map(offset key, line l)
5          for all word w   line l do
6              A{w} = A{w} + 1
7      method cleanup
8          for all word w in A do
9              EMIT(term w , count A{w})
```

## 10 Maven project

### 10.1 Structure

- *src* folder: contains the source code. May contain subfolders, but the important point is that it must contain the java files
  - DriverBigData.java
  - MapperBigData.java
  - ReducerBigData.java
- *target* folder:
  - *.jar* file: useful to run the application on the cluster. It's the java archive that collects the three classes of the Hadoop application
- *pom.xml* file: used to configure the Hadoop application

### 10.2 How to run the project

Using Eclipse

- select the Driver *.java* file
- Right click
- Click “Run As”
- If the arguments have already been set:
  - Click “Java Application”
- Otherwise
  - Click “Run Configurations”, to set the arguments
  - Go to “Arguments” section, and write the arguments. The arguments are
    - \* the number of reducers: 2
    - \* the (relative) path of the input folder `example_data`
    - \* the (relative) path of the output folder `example_data_output`

2 `example_data example_data_output`

The output files are

- an empty file “\_SUCCESS”, if the application run successfully
- one file for each reducer instance: the intersection between the sets of words in each file is empty, which means that all the same words were processed by the same Reducer. For this reason the output is always a folder and not a single file.

### 10.3 How to create a .jar file from the project

Using Eclipse, to create a .jar file from the project to run the project on the cluster

- Right click on the project name (e.g., “MapReduceProject”)
- Click “Runs As”
- Click “Maven build...”
- In “Goals” write “package”
- Click “Run”

### 10.4 How to run the .jar in the BigData@Polito cluster

- Go to <https://jupyter.polito.it/> (i.e., the server gateway) and connect using the credentials
- Copy the .jar file on server
- Upload the input data in the HDFS
- Use the terminal to run the .jar, using the `hadoop` command

```
1  hadoop jar Exercise1-1.0.0.jar \  
2  it.polito.bigdata.hadoop.exercise1.DriverBigData \  
3  2 example_data example_data_output
```

In this configuration there are 3 file systems

- The local file system on the personal PC
- The local file system on the gateway server
- The distributed file system on the Hadoop cluster (the interface to manage it is <https://bigdatalab.polito.it/hue>)