# How to write MapReduce programs in Hadoop

# Hadoop implementation of MapReduce

# MapReduce and Hadoop

- Designers/Developers focus on the definition of the Map and Reduce functions (i.e., **m** and **r**)
  - No need to manage the distributed execution of the map, shuffle and sort, and reduce phases
- The Hadoop framework coordinates the execution of the MapReduce program
  - Parallel execution of the map and reduce phases
  - Execution of the shuffle and sort phase
  - Scheduling of the subtasks
  - Synchronization

# MapReduce programs

- The programming language 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

- 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)

# Terminology

- (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
  - 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

# Driver

- 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
  - Configures the job
  - Submits the job to the Hadoop Cluster
  - "Coordinates" the work flow of the application
  - Runs on the client machine
    - i.e., it does not run on the cluster

# Mapper

- The Mapper
  - Is an instance of the Mapper class
  - "Implements" the map phase
  - Is characterized by the map(…) method
    - Processes the (key, value) pairs of the input file and emits (key, value) pairs
    - Is invoked one time for each input (key, value) pair
  - Runs on the cluster

# Reducer

- The Reducer
  - Is an instance of the Reduce class
  - "Implements" the reduce phase
  - Is characterized by the reduce(…) method
    - Processes (key, [list of values]) pairs and emits (key, value) pairs
    - Is invoked one time for each distinct key
  - Runs on the cluster

# Hadoop implementation of the MapReduce phases

- 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
  - 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)
- Intermediate results
  - Are aggregated by means of a shuffle and sort procedure
  - A set of (key, [list of values]) pairs is generated
    - One (key, [list of values]) for each distinct key

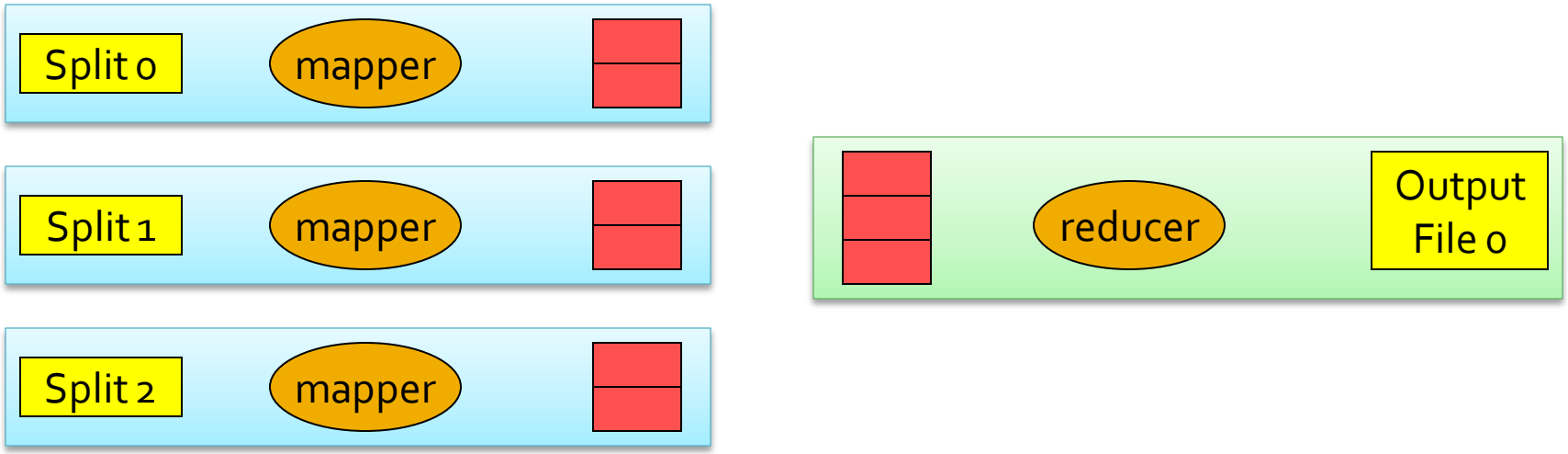
# Hadoop implementation of the MapReduce phases

- The reduce method of the Reduder
  - Is applied over each (key, [list of values]) pair
  - 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:
  - They are not stored on the distributed files system
  - They are stored locally to the node producing or processing them

# Hadoop implementation of the MapReduce phases

- 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
  - And a user-specified number of Reducers
    - Each reducer is associated with a set of keys
      - 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

# MapReduce data flow with a single reducer



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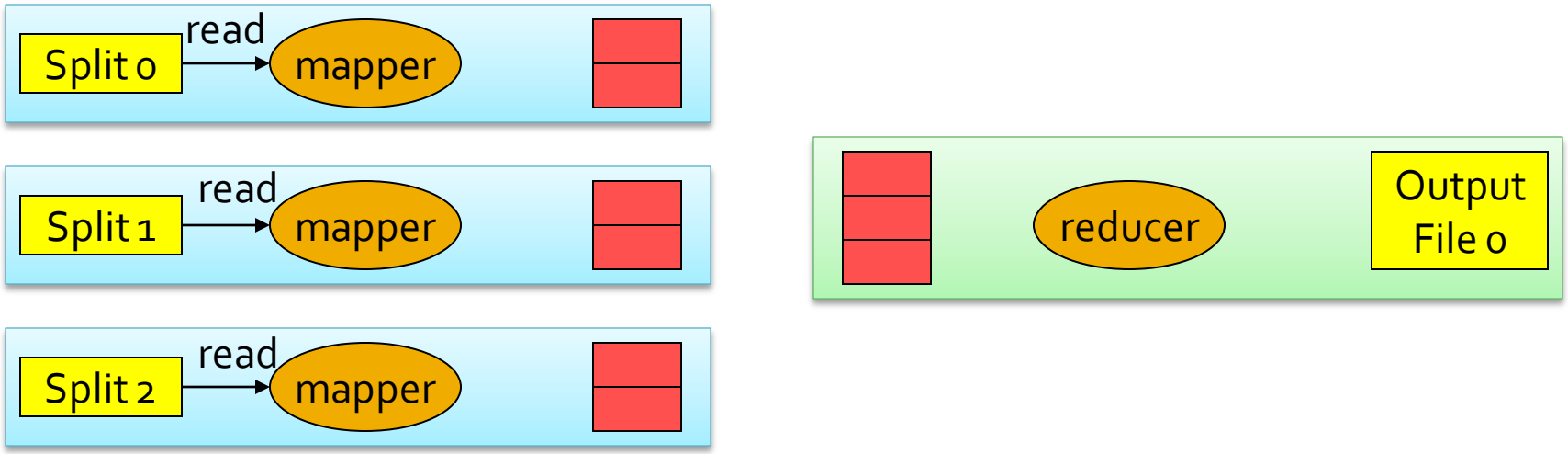
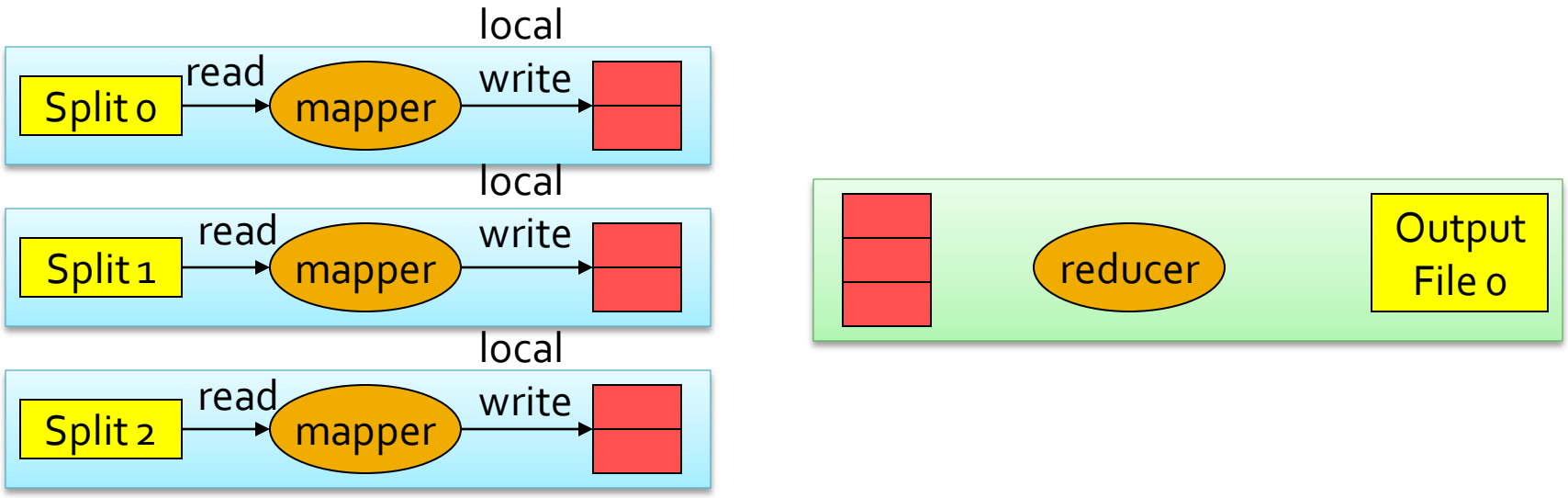
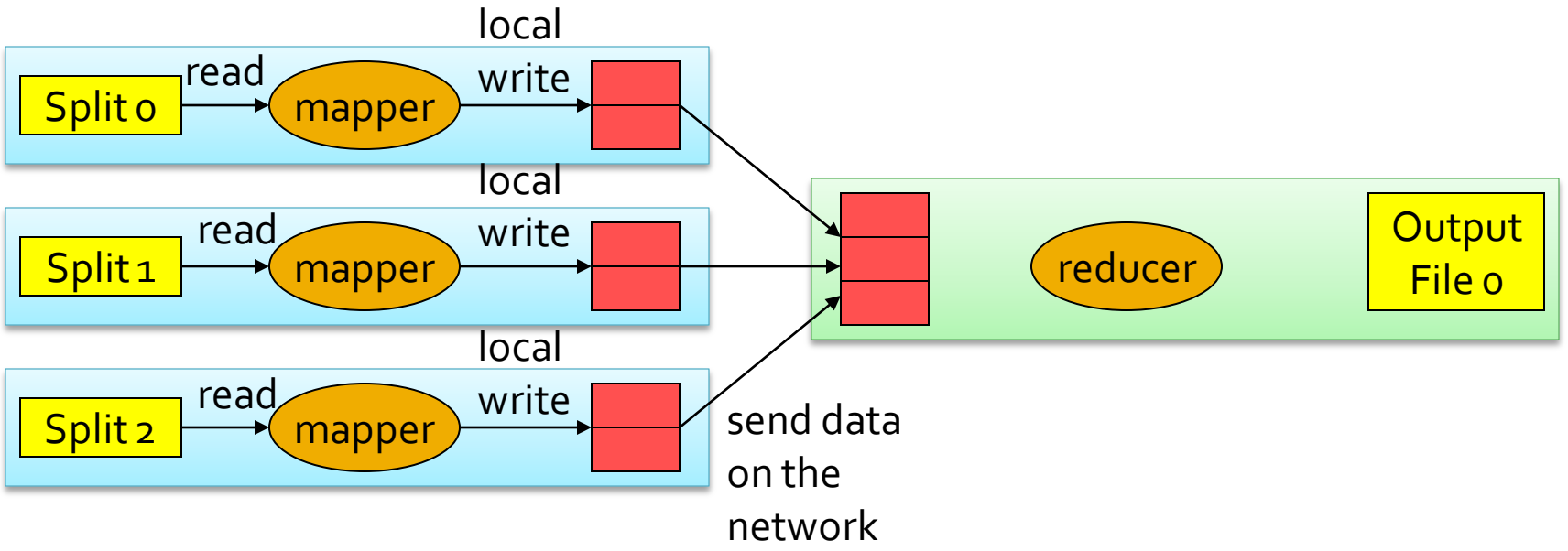


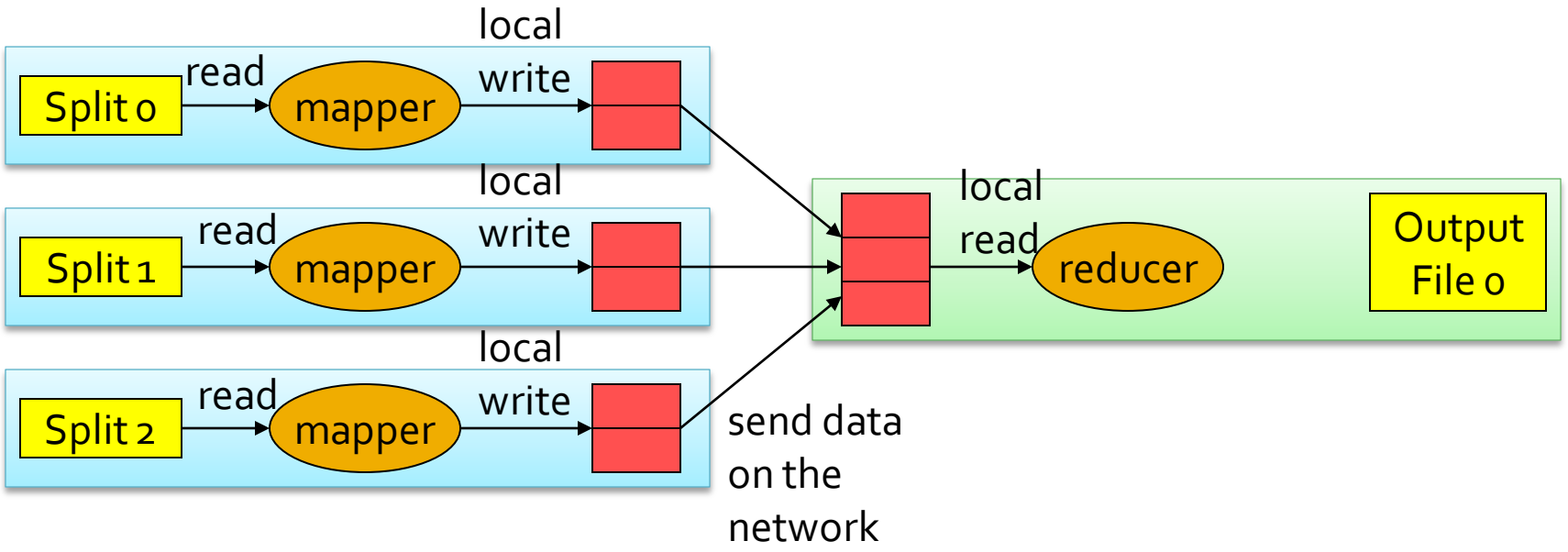
# MapReduce data flow with a single reducer



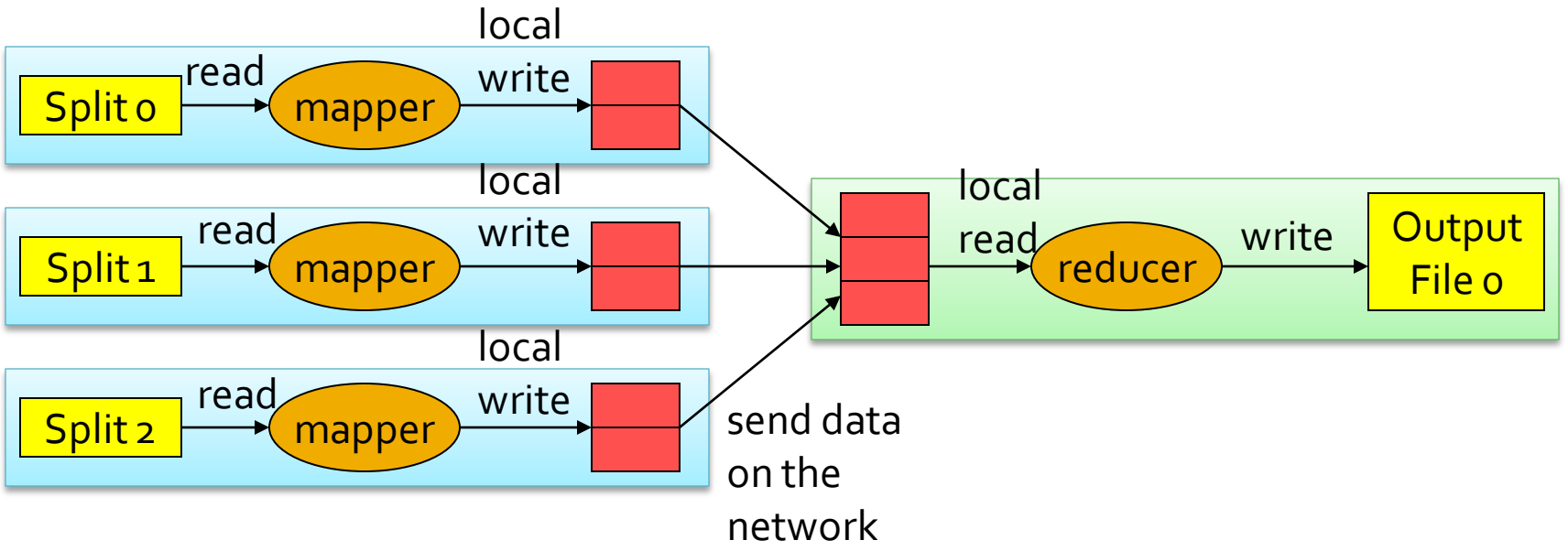
# MapReduce data flow with a single reducer



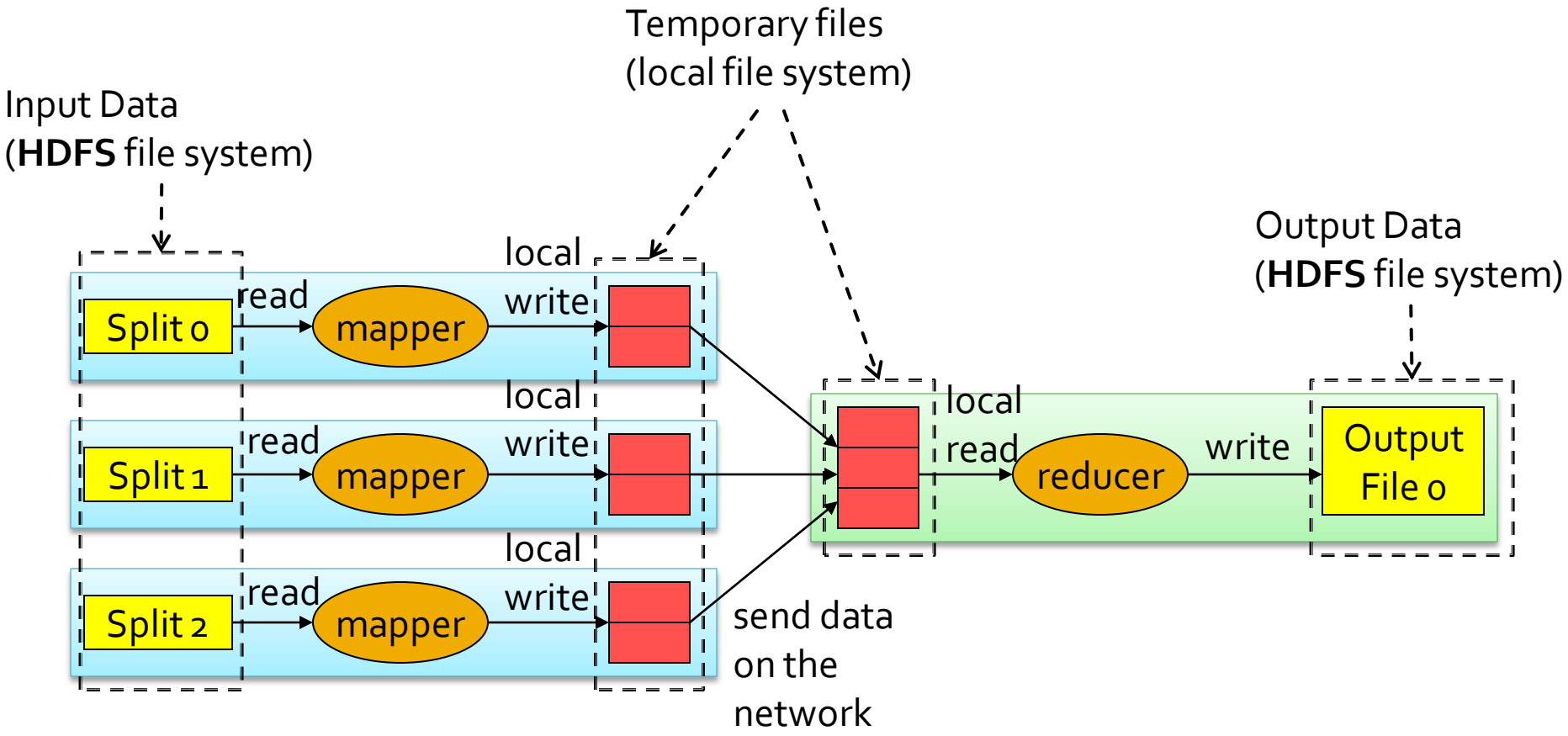
# MapReduce data flow with a single reducer



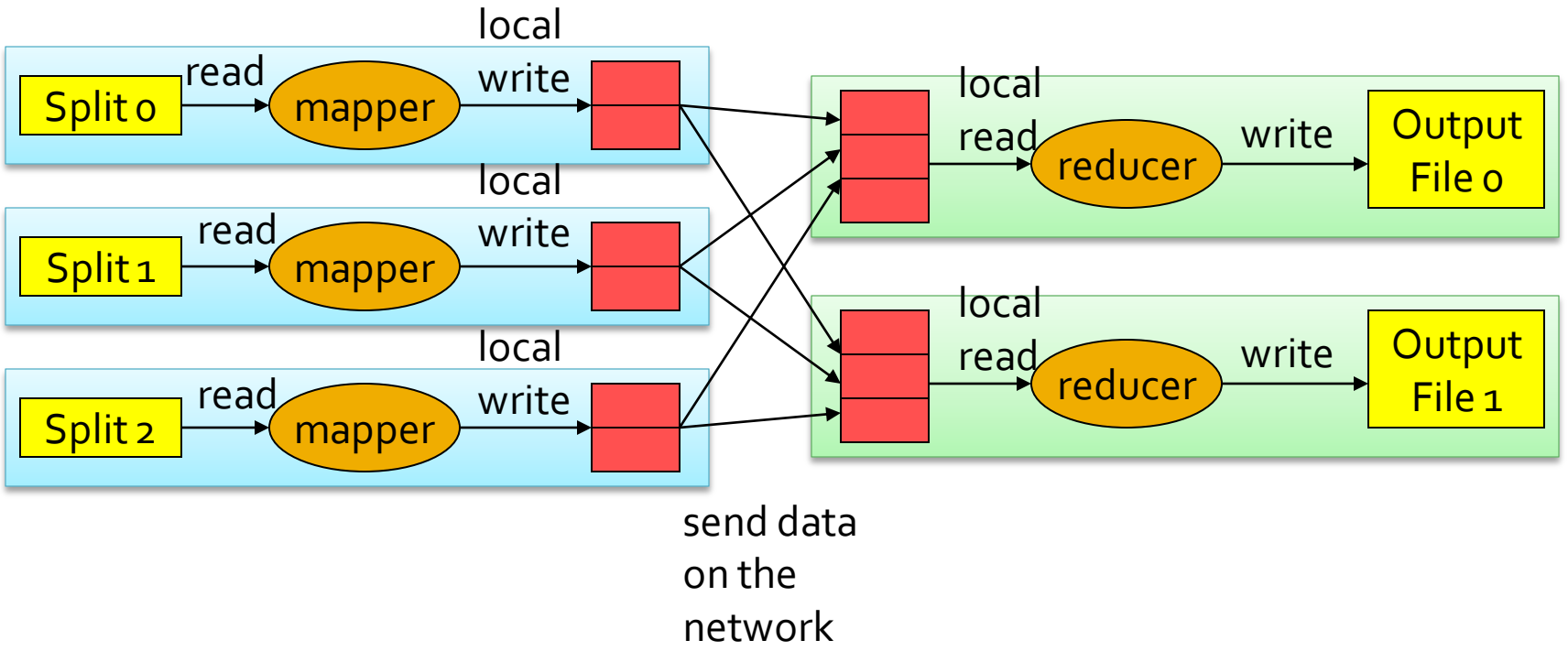
# MapReduce data flow with a single reducer



# MapReduce data flow with a single reducer

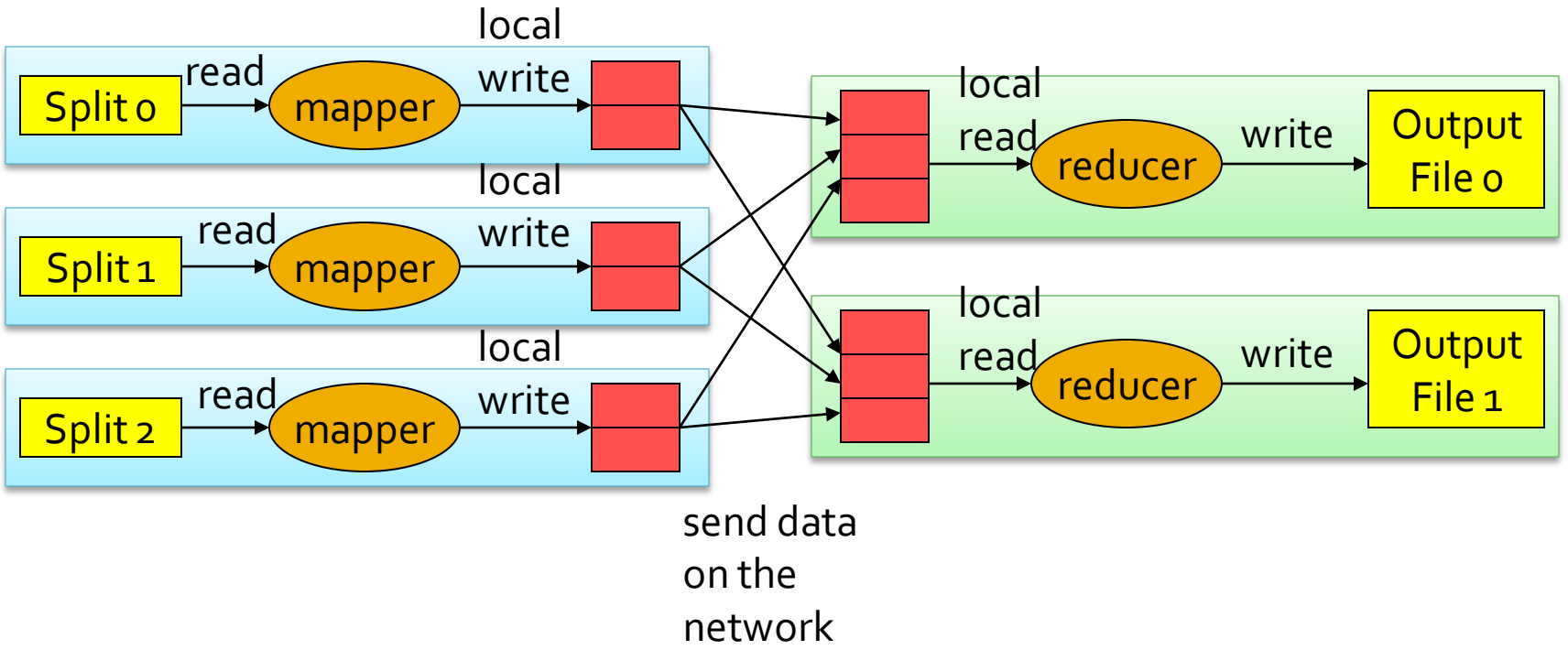


# MapReduce data flow with multiple reducers

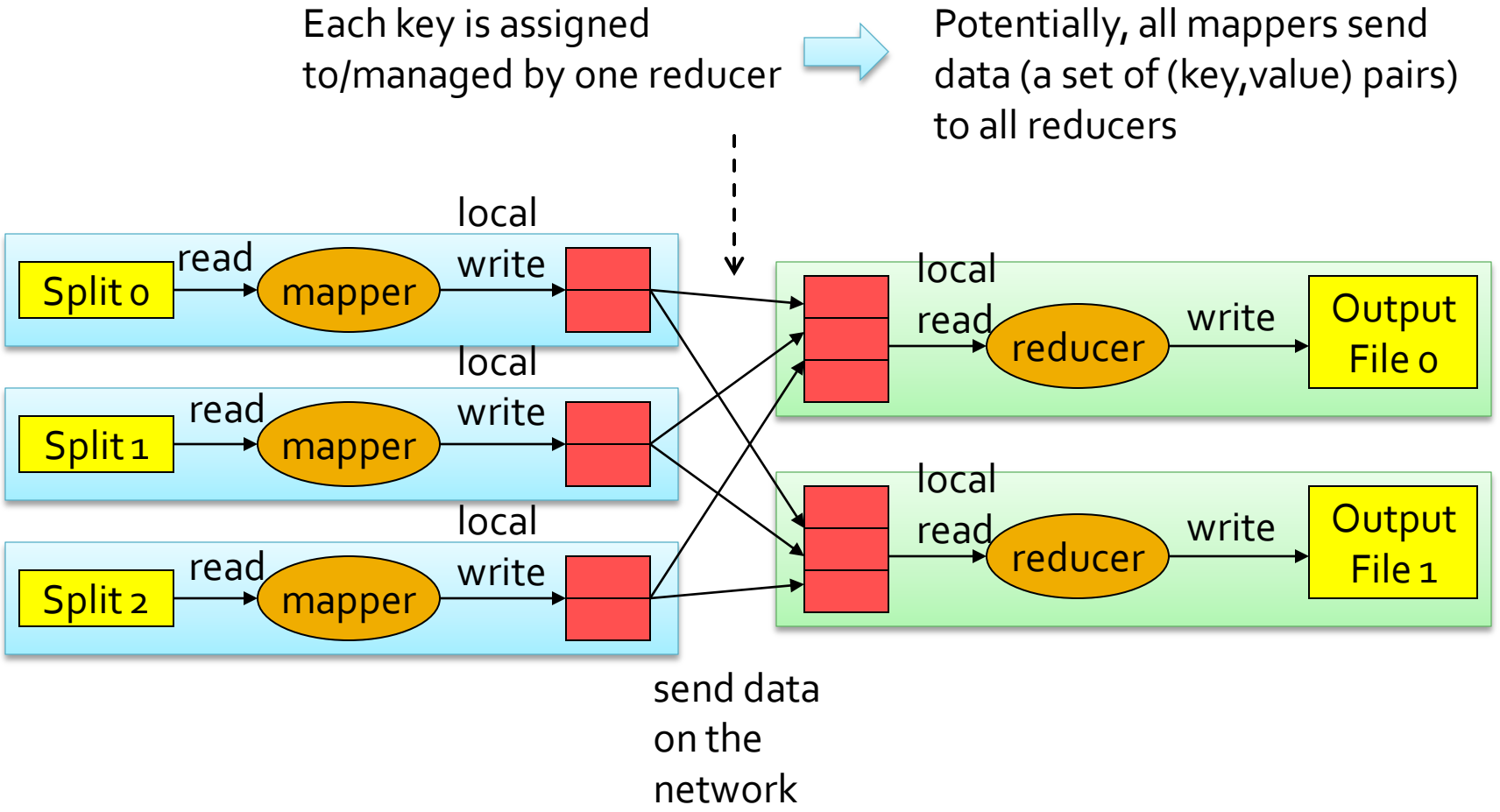


# MapReduce data flow with multiple reducers

Each key is assigned to/managed by one reducer



# MapReduce data flow with multiple reducers



# MapReduce programs - Driver

- The Driver class extends the org.apache.hadoop.conf.Configured class and implements the org.apache.hadoop.util.Tool interface
  - You can write a Driver class that does not extend Configured and does not implement Tool
    - However, you need to manage some low level details related to some command line parameters in that case
- The designer/developer implements the **main**(…) and **run**(…) methods

# MapReduce programs - Driver

- The run(…) method
  - Configures the job
    - Name of the Job
    - Job Input format
    - Job Output format
    - Mapper class
      - Name of the class
      - Type of its input (key, value) pairs
      - Type of its output (key, value) pairs

# MapReduce programs - Driver

- Reducer class
  - Name of the class
  - Type of its input (key, value) pairs
  - Type of its output (key, value) pairs
- Number of reducers

# MapReduce programs - Mapper

- The Mapper class extends the org.apache.hadoop.mapreduce.Mapper class
  - The org.apache.hadoop.mapreduce.Mapper class
    - 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

# MapReduce programs - Mapper

- 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

# MapReduce programs - Reducer

- The Reducer class extends the org.apache.hadoop.mapreduce.Reducer class
  - The org.apache.hadoop.mapreduce.Reducer class
    - 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)

# MapReduce programs - Reducer

- 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

# MapReduce 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
  - Etc

# MapReduce Data Types

- 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

# MapReduce Data Types

- Developers can define new data types by implementing the org.apache.hadoop.io.Writable and/or org.apache.hadoop.io.WritableComparable interfaces
  - It is useful for managing complex data types

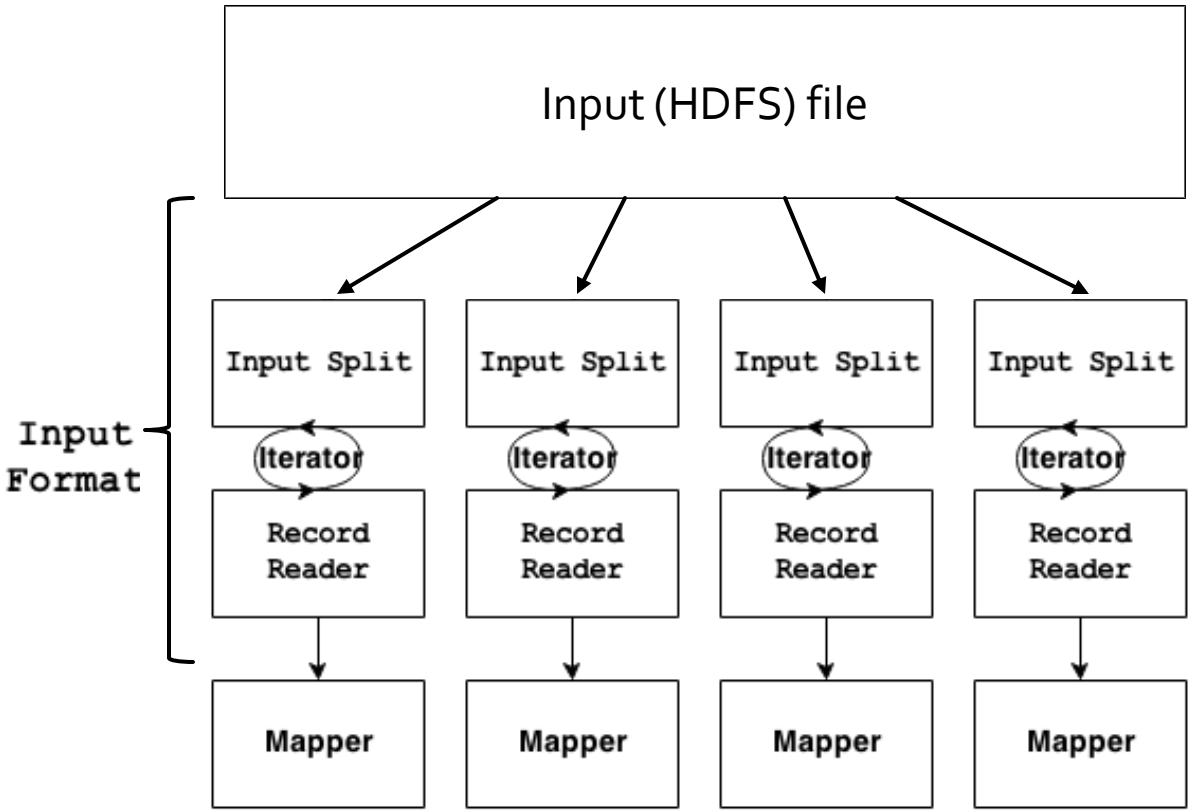
# InputFormat

- The input of the MapReduce program is an HDFS file (or an HDFS folder)
- While 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

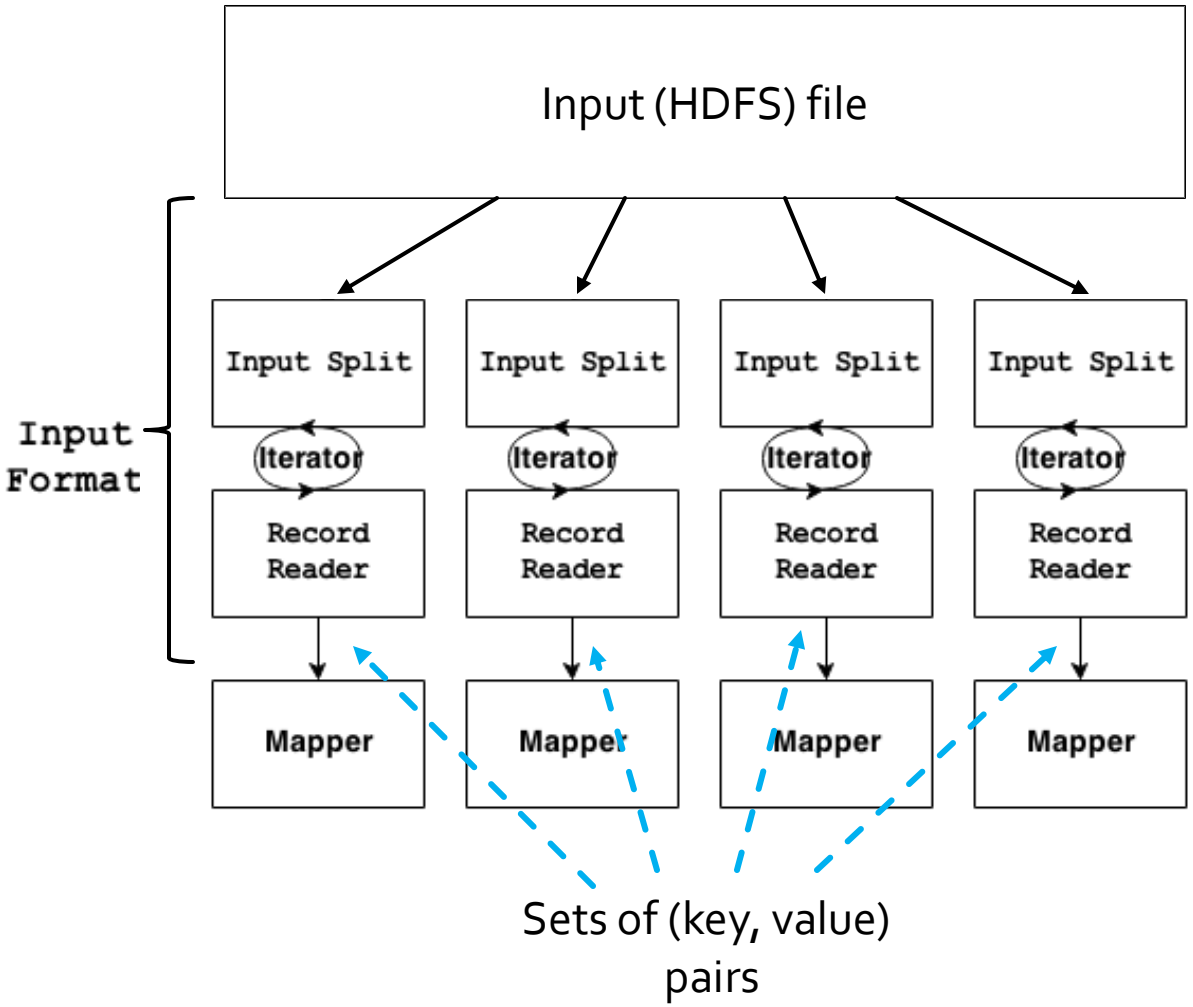
# InputFormat

- 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 input split 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

# Getting Data to the Mapper



# Getting Data to the Mapper



# Reading Data

- 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

# InputFormat

- A set of predefined classes extending the InputFormat abstract class are available for standard input file formats
  - TextInputFormat
    - An InputFormat for plain text files
  - KeyValueTextInputFormat
    - Another InputFormat for plain text files
  - SequenceFileInputFormat
    - An InputFormat for sequential/binary files
  - ….

# TextInputFormat

- TextInputFormat
  - An InputFormat for plain text files
  - Files are broken into lines
    - 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

# TextInputFormat example

**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.")

# KeyValueTextInputFormat

- KeyValueTextInputFormat
  - An InputFormat for plain text files
    - Each line of the file must have the format

      key<separator>value
    - The default separator is tab (\t)
  - Files are broken into lines
    - Either linefeed or carriage-return are used to signal end of line
    - 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

# KeyValueTextInputFormat

**Input HDFS file**

10125\tMister John\n
10236\tMiss Jenny\n
1\tMister Donald Duck\n

**(key, value) pairs generated by using KeyValueTextInputFormat**

(10125, “Mister John”)
(10236, “Miss Jenny”)
(1, “Mister Donald Duck”)

# OutputFormat

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

# OutputFormat

- 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
  - ….

# TextOutputFormat

- TextOutputFormat
  - An OutputFormat for plain text files
  - For each output (key, value) pair TextOutputFormat writes one line in the output file
  - The format of each output line is

    key\tvalue\n

# Structure of a MapReduce program in Hadoop

# Basic structure of a MapReduce program - Driver (1)

```
/* Set package */
package it.polito.bigdata.hadoop.mypackage;

/* Import libraries */
import java.io.IOException;

import org.apache.hadoop.mapreduce.Job;
import org.apache.hadoop.util.Tool;
import org.apache.hadoop.util.ToolRunner;
import org.apache.hadoop.conf.Configuration;
import org.apache.hadoop.conf.Configured;
Import org.apache.hadoop.io.*;
import org.apache.hadoop.mapreduce.lib.input.TextInputFormat;
import org.apache.hadoop.mapreduce.lib.output.TextOutputFormat;
.....
```

# Basic structure of a MapReduce program - Driver (2)

```
/* Driver class */
public class MapReduceAppDriver extends Configured implements
    Tool {
 @Override
 public int run(String[] args) throws Exception {
    /* variables */
    int exitCode;
    .....

    // Parse parameters
    numberOfReducers = Integer.parseInt(args[0]);
    inputPath = new Path(args[1]);
    outputDir = new Path(args[2]);
    ....
```

# Basic structure of a MapReduce program - Driver (3)

```
// Define and configure a new job
Configuration conf = this.getConf();
Job job = Job.getInstance(conf);

// Assign a name to the job
job.setJobName("My First MapReduce program");
```

# Basic structure of a MapReduce program - Driver (4)

```
// Set path of the input file/folder (if it is a folder, the job reads all
the files in the specified folder) for this job
FileInputFormat.addInputPath(job, inputPath);

// Set path of the output folder for this job
FileOutputFormat.setOutputPath(job, outputDir);

// Set input format
// TextInputFormat = textual files
job.setInputFormatClass(TextInputFormat.class);

// Set job output format
job.setOutputFormatClass(TextOutputFormat.class);
```

# Basic structure of a MapReduce program - Driver (5)

```
// Specify the class of the Driver for this job
job.setJarByClass(MapReduceAppDriver .class);

// Set mapper class
job.setMapperClass(MyMapperClass.class);

// Set map output key and value classes
job.setMapOutputKeyClass(output key type.class);
job.setMapOutputValueClass(output value type.class);
```

# Basic structure of a MapReduce program - Driver (6)

```
// Set reduce class
job.setReducerClass(MyReducerClass.class);

// Set reduce output key and value classes
job.setOutputKeyClass(output key type.class);
job.setOutputValueClass(output value type.class);

// Set number of reducers
job.setNumReduceTasks(numberOfReducers);
```

# Basic structure of a MapReduce program - Driver (7)

```
    // Execute the job and wait for completion
    if (job.waitForCompletion(true)==true)
        exitCode=0;
    else
        exitCode=1;
    return exitCode;
}   // End of the run method
```

# Basic structure of a MapReduce program - Driver (8)

```
/* main method of the driver class   */
   public static void main(String args[]) throws Exception {
    /* Exploit the ToolRunner class to "configure" and run the
       Hadoop application */

    int res = ToolRunner.run(new Configuration(),
                                  new MapReduceAppDriver(), args);

    System.exit(res);
 } // End of the main method

} // End of public class MapReduceAppDriver
```

# Basic structure of a MapReduce program - Mapper (1)

```
/* Set package */
package it.polito.bigdata.hadoop.mypackage;

/* Import libraries */
import java.io.IOException;

import org.apache.hadoop.mapreduce.Mapper;
import org.apache.hadoop.io.*;
.....
```

# Basic structure of a MapReduce program - Mapper (2)

```
/* Mapper Class */
class myMapperClass extends Mapper<
                    MapperInputKeyType,      // Input key type (must be
    consistent with the InputFormat class specified in the Driver)
                    MapperInputValueType,    // Input value type (must be
    consistent with the InputFormat class specified in the Driver)
                    MapperOutputKeyType,     // Output key type
                    MapperOutputValueType> // Output value type
{
```

# Basic structure of a MapReduce program - Mapper (3)

```
/* Implementation of the map method */
protected void map(
        MapperInputKeyType key,          // Input key
        MapperInputValueType value,      // Input value
        Context context) throws IOException, InterruptedException {

        /* Process the input (key, value) pair and
           emit a set of (key,value) pairs.
           context.write(..) is used to emit (key, value) pairs
           context.write(new outputkey, new outputvalue); */
    } // End of the map method

} // End of class myMapperClass
```

# Basic structure of a MapReduce program - Reducer (1)

```
/* Set package */
package it.polito.bigdata.hadoop.mypackage;

/* Import libraries */
import java.io.IOException;

import org.apache.hadoop.mapreduce.Reducer;
Import org.apache.hadoop.io.*;
.....
```

# Basic structure of a MapReduce program - Reducer (2)

```
/* Reducer Class */
class myReducerClass extends Reducer<
                    ReducerInputKeyType,     // Input key type (must be
    consistent with the OutputKeyType of the Mapper)
                    ReducerInputValueType,    // Input value type (must be
    consistent with the OutputValueType of the Mapper)
                    ReducerOutputKeyType,    // Output key type (must be
    consistent with the OutputFormat class specified in the Driver)
                    ReducerOutputValueType> // Output value type (must
    be consistent with the OutputFormat class specified in the Driver)
{
```

# Basic structure of a MapReduce program - Reducer (3)

```
/* Implementation of the reduce method */
protected void reduce(
      ReducerInputKeyType key,                    // Input key
      Iterable<ReducerInputValueType> values, // Input values (list of values)
      Context context) throws IOException, InterruptedException {

      /* Process the input (key, [list of values]) pair and
         emit a set of (key,value) pairs.
         context.write(..) is used to emit (key, value) pairs
         context.write(new outputkey, new outputvalue); */
} // End of the reduce method

} // End of class myReducerClass
```

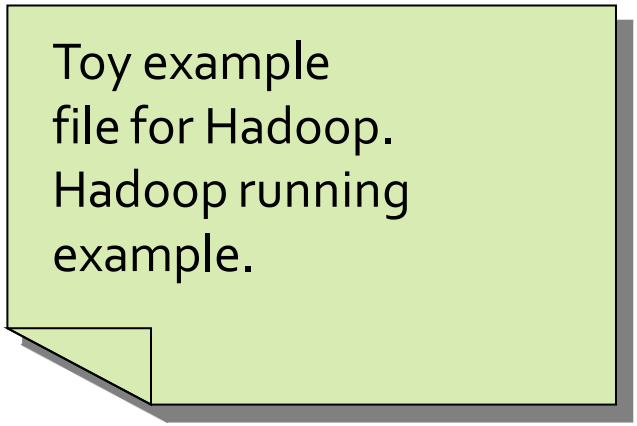
# MapReduce programs in Hadoop: Word Count Example

# Word Count Example

- Word count problem
  - Input: (unstructured) textual file
    - 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

# Word Count Example

- Input file




- Output pairs

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

# Word Count Example - Driver (1)

```
/* Set package */
package it.polito.bigdata.hadoop.wordcount;

/* Import libraries */
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.Text;
import org.apache.hadoop.mapreduce.Job;
import org.apache.hadoop.mapreduce.lib.input.FileInputFormat;
import org.apache.hadoop.mapreduce.lib.input.TextInputFormat;
import org.apache.hadoop.mapreduce.lib.output.FileOutputFormat;
import org.apache.hadoop.mapreduce.lib.output.TextOutputFormat;
import org.apache.hadoop.util.Tool;
import org.apache.hadoop.util.ToolRunner;
```

# Word Count Example - Driver (2)

```
/* Driver class */
public class WordCount extends Configured implements Tool {
  @Override
  public int run(String[] args) throws Exception {

    Path inputPath;
    Path outputDir;
    int numberOfReducers;
    int exitCode;

    // Parse input parameters
    numberOfReducers = Integer.parseInt(args[0]);
    inputPath = new Path(args[1]);
    outputDir = new Path(args[2]);
```

# Word Count Example - Driver (3)

```
// Define and configure a new job
Configuration conf = this.getConf();
Job job = Job.getInstance(conf);

// Assign a name to the job
job.setJobName("WordCounter");
```

# Word Count Example - Driver (4)

```
// Set path of the input file/folder (if it is a folder, the job reads all the files
in the specified folder) for this job
FileInputFormat.addInputPath(job, inputPath);

// Set path of the output folder for this job
FileOutputFormat.setOutputPath(job, outputDir);

// Set input format
// TextInputFormat = textual files
job.setInputFormatClass(TextInputFormat.class);

// Set job output format
job.setOutputFormatClass(TextOutputFormat.class);
```

# Word Count Example - Driver (5)

```
// Specify the class of the Driver for this job
job.setJarByClass(WordCount.class);

// Set mapper class
job.setMapperClass(WordCountMapper.class);

// Set map output key and value classes
job.setMapOutputKeyClass(Text.class);
job.setMapOutputValueClass(IntWritable.class);
```

# Word Count Example - Driver (6)

```
// Set reduce class
job.setReducerClass(WordCountReducer.class);

// Set reduce output key and value classes
job.setOutputKeyClass(Text.class);
job.setOutputValueClass(IntWritable.class);

// Set number of reducers
job.setNumReduceTasks(numberOfReducers);
```

# Word Count Example - Driver (7)

```
    // Execute the job and wait for completion
    if (job.waitForCompletion(true)==true)
            exitCode=0;
    else
            exitCode=1;
    return exitCode;
}   // End of the run method
```

# Word Count Example - Driver (8)

```
/* main method of the driver class   */
   public static void main(String args[]) throws Exception {
     /* Exploit the ToolRunner class to "configure" and run the
        Hadoop application */

     int res = ToolRunner.run(new Configuration(),
                              new WordCount(), args);

     System.exit(res);
  } // End of the main method

} // End of public class WordCount
```

# Word Count Example - Mapper (1)

```
/* Set package */
package it.polito.bigdata.hadoop.wordcount;

/* Import libraries */
import java.io.IOException;

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

# Word Count Example - Mapper (2)

```
/* Mapper Class */
class WordCountMapper extends Mapper<
            LongWritable,  // Input key type
            Text,          // Input value type
            Text,          // Output key type
            IntWritable>   // Output value type
{
    /* Implementation of the map method */
    protected void map(
        LongWritable key,   // Input key type
        Text value,         // Input value type
        Context context) throws IOException, InterruptedException {
```

# Word Count Example - Mapper (3)

```
        // Split each sentence in words. Use whitespace(s) as delimiter
        // The split method returns an array of strings
        String[] words = value.toString().split("\\s+");

        // Iterate over the set of words
        for(String word : words) {
          // Transform word case
          String cleanedWord = word.toLowerCase();

          // emit one pair (word, 1) for each input word
          context.write(new Text(cleanedWord), new IntWritable(1));
        }
    } // End map method

} // End of class WordCountMapper
```

# Word Count Example - Reducer (1)

```
/* Set package */
package it.polito.bigdata.hadoop.wordcount;

/* Import libraries */
import java.io.IOException;

import org.apache.hadoop.io.IntWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.mapreduce.Reducer;
```

# Word Count Example - Reducer (2)

```
/* Reducer Class */
class WordCountReducer extends Reducer<
        Text,                   // Input key type
        IntWritable,            // Input value type
        Text,                   // Output key type
        IntWritable>            // Output value type
{
    /* Implementation of the reduce method */
    protected void reduce(
        Text key, // Input key type
        Iterable<IntWritable> values, // Input value type
        Context context) throws IOException, InterruptedException {
```

# Word Count Example - Reducer (3)

```
/* Implementation of the reduce method */
protected void reduce(
        Text key, // Input key type
        Iterable<IntWritable> values, // Input value type
        Context context) throws IOException, InterruptedException {
                int occurrances = 0;

                // Iterate over the set of values and sum them
                for (IntWritable value : values) {
                        occurrances = occurrances + value.get();
                }
                // Emit the total number of occurrences of the current word
                context.write(key, new IntWritable(occurrances));
        } // End reduce method
} // End of class WordCountReducer
```

# Combiner

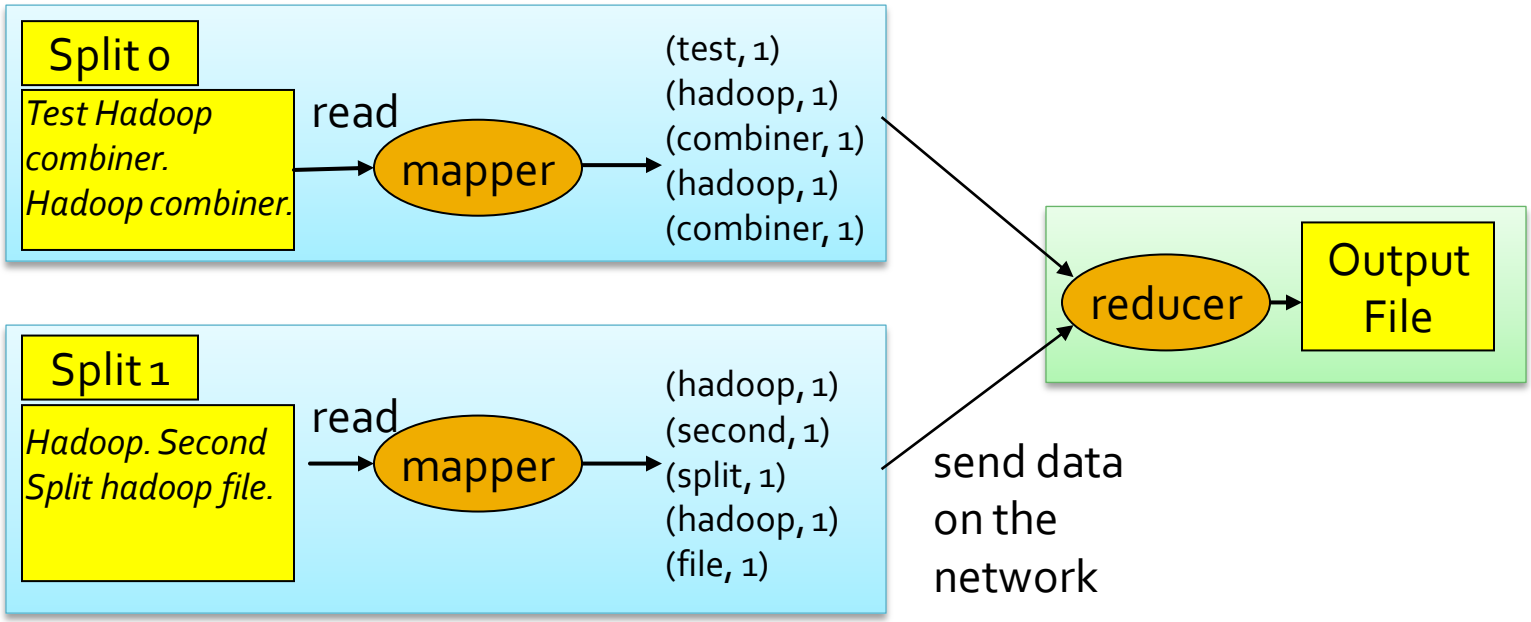
# Combiner

- "Standard" MapReduce applications
  - The (key,value) pairs emitted by the Mappers are sent to the Reducers through the network
- Some "pre-aggregations" could be performed to limit the amount of network data by using Combiners (also called "mini-reducers")

# Combiner – Word count example

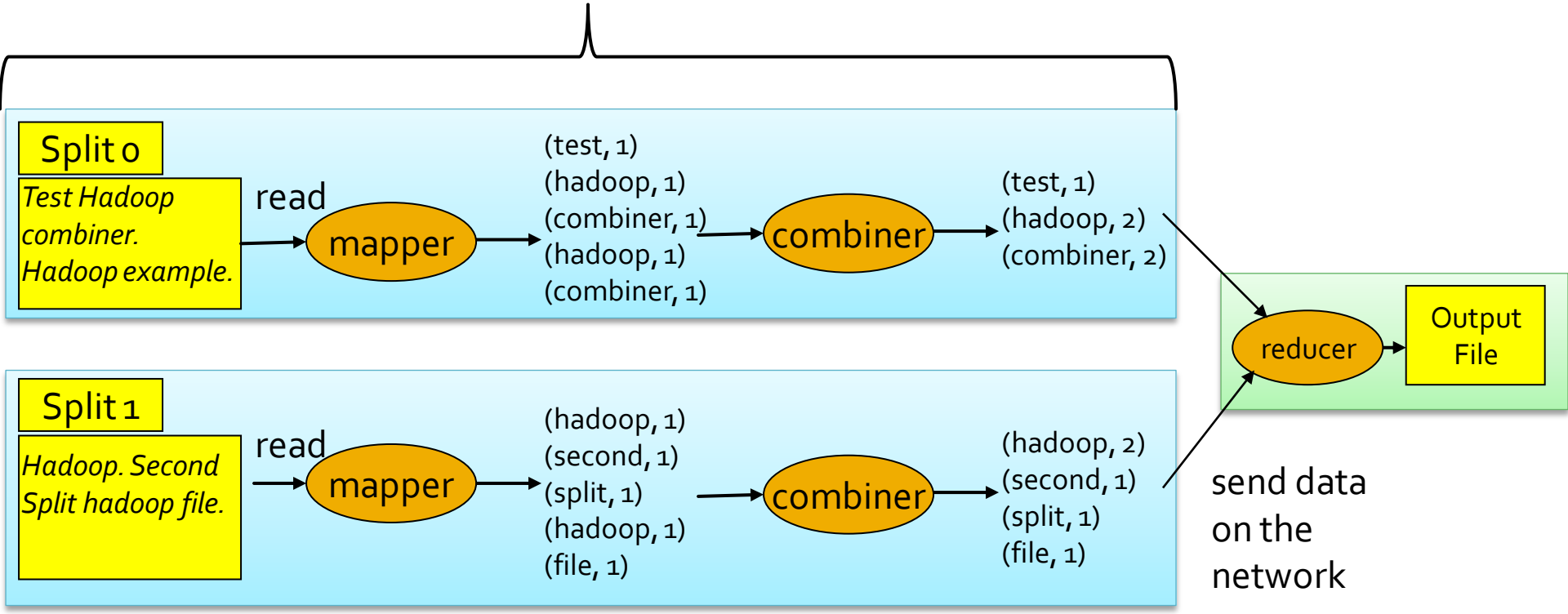
- Consider the standard word count problem
- Suppose the input file is split in two input splits
  - Hence, two Mappers are instantiated (one for each split)

# Word count example without combiner



# Word count example with combiner

The combiner is **locally** called on the output (key, value) pairs of the mapper (it works on data stored in the main-memory or on the local hard disks)



# Combiner

- MapReduce applications with **Combiners**
  - 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
    - Combiners perform "pre-aggregations" to limit the amount of network data generated by each cluster node

# Combiner

- **Combiners** work only if the **reduce function** is **commutative** and **associative**
- The **execution** of combiners **is not guaranteed**
  - Hadoop may or **may not execute** a **combiner**
    - The decision is taken at runtime by Hadoop and you cannot check it in your code
  - Your **MapReduce job** **should not depend on** the **Combiner execution**

# Combiner

- The Combiner
  - Is an instance of the org.apache.hadoop.mapreduce.Reducer class
    - There is not a specific combiner-template class
  - "Implements" a pre-reduce phase that aggregates the pairs emitted in each node by Mappers
  - Is characterized by the reduce(…) method
    - Processes (key, [list of values]) pairs and emits (key, value) pairs
  - Runs on the cluster

# MapReduce programs - Combiner

- The Combiner class extends the org.apache.hadoop.mapreduce.Reducer class
  - The org.apache.hadoop.mapreduce.Reducer class
    - Is a generic type/generic class
    - With four type parameters: input key type, input value type, output key type, output value type
  - i.e., Combiners and Reducers extend the same class
- The designer/developer implements the **reduce**(…) method
  - It is automatically called by Hadoop for each (key, [list of values]) pair obtained by aggregating the local output of a Mapper

# MapReduce programs - Combiner

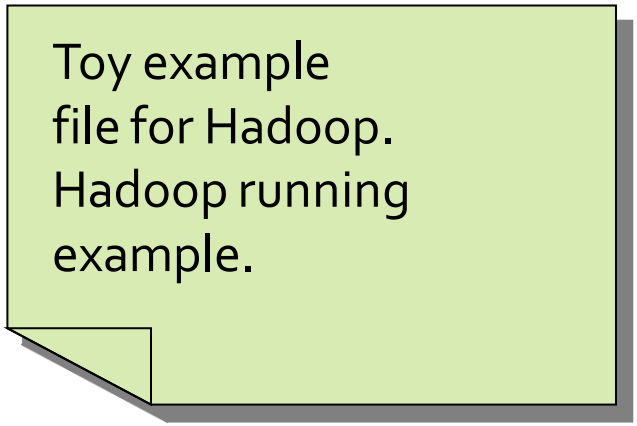
- The Combiner class is specified by using the job.setCombinerClass() method in the run method of the Driver
  - i.e., in the job configuration part of the code

# Word Count Example with Combiner

- Word count problem
  - Input: (unstructured) textual file
    - 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

# Word Count Example with Combiner

- Input file




- Output pairs

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

# Word Count Example with Combiner

- Differences with the solution without combiner
  - 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
      - It emits partial results (local number of occurrences for each word) from each cluster node that is used to run our application

# Word Count Example with Combiner - Driver (1)

```
/* Set package */
package it.polito.bigdata.hadoop.wordcount;

/* Import libraries */
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.Text;
import org.apache.hadoop.mapreduce.Job;
import org.apache.hadoop.mapreduce.lib.input.FileInputFormat;
import org.apache.hadoop.mapreduce.lib.input.TextInputFormat;
import org.apache.hadoop.mapreduce.lib.output.FileOutputFormat;
import org.apache.hadoop.mapreduce.lib.output.TextOutputFormat;
import org.apache.hadoop.util.Tool;
import org.apache.hadoop.util.ToolRunner;
```

# Word Count Example with Combiner - Driver (2)

```
/* Driver class */
public class WordCount extends Configured implements Tool {
  @Override
  public int run(String[] args) throws Exception {

    Path inputPath;
    Path outputDir;
    int numberOfReducers;
    int exitCode;

    // Parse input parameters
    numberOfReducers = Integer.parseInt(args[0]);
    inputPath = new Path(args[1]);
    outputDir = new Path(args[2]);
```

# Word Count Example with Combiner - Driver (3)

```
// Define and configure a new job
Configuration conf = this.getConf();
Job job = Job.getInstance(conf);

// Assign a name to the job
job.setJobName("WordCounter");
```

# Word Count Example with Combiner - Driver (4)

```
// Set path of the input file/folder (if it is a folder, the job reads all the files in the specified folder) for this job
FileInputFormat.addInputPath(job, inputPath);

// Set path of the output folder for this job
FileOutputFormat.setOutputPath(job, outputDir);

// Set input format
// TextInputFormat = textual files
job.setInputFormatClass(TextInputFormat.class);

// Set job output format
job.setOutputFormatClass(TextOutputFormat.class);
```

# Word Count Example with Combiner - Driver (5)

```
// Specify the class of the Driver for this job
job.setJarByClass(WordCount.class);

// Set mapper class
job.setMapperClass(WordCountMapper.class);

// Set map output key and value classes
job.setMapOutputKeyClass(Text.class);
job.setMapOutputValueClass(IntWritable.class);
```

# Word Count Example with Combiner - Driver (6)

```
// Set reduce class
job.setReducerClass(WordCountReducer.class);

// Set reduce output key and value classes
job.setOutputKeyClass(Text.class);
job.setOutputValueClass(IntWritable.class);

// Set number of reducers
job.setNumReduceTasks(numberOfReducers);

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

# Word Count Example with Combiner - Driver (7)

```
    // Execute the job and wait for completion
    if (job.waitForCompletion(true)==true)
            exitCode=0;
    else
            exitCode=1;
    return exitCode;
}   // End of the run method
```

# Word Count Example with Combiner - Driver (8)

```
/* main method of the driver class   */
   public static void main(String args[]) throws Exception {
     /* Exploit the ToolRunner class to "configure" and run the
        Hadoop application */

     int res = ToolRunner.run(new Configuration(),
                              new WordCount(), args);

     System.exit(res);
  } // End of the main method

} // End of public class WordCount
```

# Word Count Example with Combiner - Mapper (1)

```
/* Set package */
package it.polito.bigdata.hadoop.wordcount;

/* Import libraries */
import java.io.IOException;

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

# Word Count Example with Combiner - Mapper (2)

```
/* Mapper Class */
class WordCountMapper extends Mapper<
            LongWritable,  // Input key type
            Text,          // Input value type
            Text,          // Output key type
            IntWritable>   // Output value type
{
    /* Implementation of the map method */
    protected void map(
        LongWritable key,   // Input key type
        Text value,         // Input value type
        Context context) throws IOException, InterruptedException {
```

# Word Count Example with Combiner - Mapper (3)

```
        // Split each sentence in words. Use whitespace(s) as delimiter
        // The split method returns an array of strings
        String[] words = value.toString().split("\\s+");

        // Iterate over the set of words
        for(String word : words) {
          // Transform word case
          String cleanedWord = word.toLowerCase();

          // emit one pair (word, 1) for each input word
          context.write(new Text(cleanedWord), new IntWritable(1));
        }
    } // End map method

} // End of class WordCountMapper
```

# Word Count Example with Combiner - Combiner (1)

```
/* Set package */
package it.polito.bigdata.hadoop.wordcount;

/* Import libraries */
import java.io.IOException;

import org.apache.hadoop.io.IntWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.mapreduce.Reducer;
```

# Word Count Example with Combiner - Combiner (2)

```
/* Combiner Class */
class WordCountCombiner extends Reducer<
        Text,                   // Input key type
        IntWritable,            // Input value type
        Text,                   // Output key type
        IntWritable>            // Output value type
{
    /* Implementation of the reduce method */
    protected void reduce(
        Text key, // Input key type
        Iterable<IntWritable> values, // Input value type
        Context context) throws IOException, InterruptedException {
```

# Word Count Example with Combiner - Combiner (3)

```
/* Implementation of the reduce method */
protected void reduce(
        Text key, // Input key type
        Iterable<IntWritable> values, // Input value type
        Context context) throws IOException, InterruptedException {
                int occurrances = 0;

                // Iterate over the set of values and sum them
                for (IntWritable value : values) {
                        occurrances = occurrances + value.get();
                }
                // Emit the total number of occurrences of the current word
                context.write(key, new IntWritable(occurrances));
        } // End reduce method
} // End of class WordCountCombiner
```

# Word Count Example with Combiner - Reducer (1)

```
/* Set package */
package it.polito.bigdata.hadoop.wordcount;

/* Import libraries */
import java.io.IOException;

import org.apache.hadoop.io.IntWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.mapreduce.Reducer;
```

# Word Count Example with Combiner - Reducer (2)

```
/* Reducer Class */
class WordCountReducer extends Reducer<
        Text,                   // Input key type
        IntWritable,            // Input value type
        Text,                   // Output key type
        IntWritable>            // Output value type
{
    /* Implementation of the reduce method */
    protected void reduce(
        Text key, // Input key type
        Iterable<IntWritable> values, // Input value type
        Context context) throws IOException, InterruptedException {
```

# Word Count Example with Combiner - Reducer (3)

```
/* Implementation of the reduce method */
protected void reduce(
        Text key, // Input key type
        Iterable<IntWritable> values, // Input value type
        Context context) throws IOException, InterruptedException {
                int occurrances = 0;

                // Iterate over the set of values and sum them
                for (IntWritable value : values) {
                        occurrances = occurrances + value.get();
                }
                // Emit the total number of occurrences of the current word
                context.write(key, new IntWritable(occurrances));
        } // End reduce method
} // End of class WordCountReducer
```

# Word Count Example with Combiner

- The reducer and the combiner classes perform the same computation (the reduce method of the two classes is the same)
- We do not really need two different classes
  - We can simply specify that WordCountReducer is also the combiner class
    - In the driver

      job.setCombinerClass(WordCountReducer.class);
  - In 99% of the Hadoop applications the same class can be used to implement both combiner and reducer

# Personalized Data Types

# Personalized Data Types and Values

- 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
  - 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()

# Personalized Data Types - Example

- Suppose to be interested in "complex" values composed of two parts:
  - a counter (int)
  - a sum (float)
- An ad-hoc Data Type can be used to implement this complex data type in Hadoop

# Personalized Data Types - Example (1)

```
package it.polito.bigdata.hadoop.combinerexample;
import java.io.DataInput;
import java.io.DataOutput;
import java.io.IOException;

public class SumAndCountWritable implements
    org.apache.hadoop.io.Writable {
    /* Private variables */
    private float sum = 0;
    private int count = 0;
```

# Personalized Data Types - Example (2)

```
/* Methods to get and set private variables of the class */
public float getSum() {
        return sum;
}

public void setSum(float sumValue) {
        sum=sumValue;
}

public int getCount() {
        return count;
}

public void setCount(int countValue) {
        count=countValue;
}
```

# Personalized Data Types - Example (3)

```
/* Methods to serialize and deserialize the contents of the
instances of this class */
@Override  /* Serialize the fields of this object to out */
public void write(DataOutput out) throws IOException {
      out.writeFloat(sum);
      out.writeInt(count);
}

@Override /* Deserialize the fields of this object from in */
public void readFields(DataInput in) throws IOException {
      sum=in.readFloat();
      count=in.readInt();
}
```

# Personalized Data Types - Example (4)

```
/* Specify how to convert the contents of the instances of this
class to a String
* Useful to specify how to store/write the content of this class
* in a textual file */
public String toString()
{
      String formattedString=
                        new String("sum="+sum+",count="+count);

      return formattedString;
}

}
```

# Personalized Data Types and 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
  - Because keys must be compared/sorted
    - Implement the compareTo() method
  - And split in groups
    - Implement the hashCode() method

# Sharing parameters among Driver, Mappers, and Reducers

# 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
- Personalized (property-name, property-value) pairs can be specified in the driver
  - They can be used to share some parameters of the application with mappers and reducers

# Sharing parameters among Driver, Mappers, and Reducers

- Personalized (property-name, property-value) pairs are useful to shared small (**constant**) properties that are available only during the execution of the program
  - The driver set them
  - Mappers and Reducers can access them
    - Their values **cannot be modified by mappers and reducers**

# Sharing parameters among Driver, Mappers, and Reducers

- In the driver
  - Configuration conf = this.getConf();
    - Retrieve the configuration object
  - conf.set("*property-name*", "*value*");
    - Set personalized properties
- In the Mapper and/or Reducer
  - context.getConfiguration().get("*property-name*")
    - This method returns a String containing the value of the specified property

# Counters

# Counters

- Hadoop provides a set of basic, built-in, counters to store some statistics about jobs, mappers, reducers
  - E.g., number of input and output records (i.e., pairs)
  - E.g., number of transmitted bytes
- Ad-hoc, user-defined, counters can be defined to compute global "statistics" associated with the goal of the application

# User-defined Counters

- User-defined counters
  - Are defined by means of Java enum
    - Each application can define an arbitrary number of enums
  - Are incremented in the Mappers and Reducers
  - The global/final value of each counter is available at the end of the job
    - It is stored/printed by the Driver (at the end of the execution of the job)

# User-defined Counters

- The name of the enum is the group name
  - Each enum as a number of "fields"
- The enum's fields are the counter names
- In mappers and/or reduces counters are incremented by using the increment() method
  - context.getCounter(countername).increment(value);

# User-defined Counters

- The getCounters() and findCounter() methods are used by the Driver to retrieve the final values of the counters

# User-defined Dynamic Counters

- 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

# Example of user-defined counters

- In the driver

```
public static enum COUNTERS {
   ERROR_COUNT,
   MISSING_FIELDS_RECORD_COUNT
}
```

  - This enum defines two counters
    - COUNTERS.ERROR_COUNT
    - COUNTERS.MISSING_FIELDS_RECORD_COUNT

# Example of user-defined counters

- This example increments the COUNTERS.ERROR_COUNT counter
  - In the mapper or the reducer

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

# Example of user-defined counters

- This example retrieves the final value of the COUNTERS.ERROR_COUNT counter

- In the driver

```
Counter errorCounter =
job.getCounters().findCounter(COUNTERS.ERROR
_COUNT);
```

# Map-only job

# 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
  - The reduce phase is avoided
  - Also the shuffle and sort phase is not executed
  - The output of the map job is directly stored in HDFS
    - i.e., the set of pairs emitted by the map phase is already the final output

# Map-only job

- Implementation of a Map-only job
  - Implement the map method
  - Set the number of reducers to 0 during the configuration of the job (in the driver)
    - job.setNumReduceTasks(0);

# In-Mapper combiner

# Setup and cleanup method

- Mapper classes are also characterized by a setup and a cleanup method
  - They are empty if they are not overridden
- 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
  - In-mapper variables are used to maintain in-mapper statistics and preserve the state (locally for each mapper) within and across calls to the map method

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

# Setup and cleanup method

- 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-Mapper Combiners

- In-Mapper Combiners, a possible improvement over "standard" Combiners
  - Initialize a set of in-mapper variables during the instance of the Mapper
    - Initialize them 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

# In-Mapper Combiners

- 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

# In-Mapper Combiners

- The in-mapper variables are used to perform the work of the combiner in the mapper
  - It can allow improving the overall performance of the application
  - But **pay attention** to the amount of **used main memory**
    - Each mapper can 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)

# In-Mapper Combiner – Word count Pseudo code

```
class MAPPER
        method setup
                A ← new AssociativeArray

        method map(offset key, line l)
                for all word w ∈ line l do
                        A{w} ← A{w} + 1

        method cleanup
        for all word w ∈ A do
                EMIT(term w , count A{w})
```

# In-Mapper Combiner – Word count Pseudo code

```
class MAPPER
    method setup
        A ← new AssociativeArray

    method map(offset key, line l)
        for all word w ∈ line l do
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Invoked **one time** for each mapper

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# In-Mapper Combiner – Word count Pseudo code

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        for all word w ∈ line l do
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    method cleanup
    for all word w ∈ A do
        EMIT(term w , count A{w})
```

Invoked **one time** for each mapper

Invoked **multiple times** for each mapper

Invoked **one time** for each mapper