Hadoop MapReduce

What Is MapReduce?

- **MapReduce is a method for distributing a task across multiple nodes**
- **Each node processes data stored on that node**
  - Where possible
- **Consists of two phases:**
  - Map
  - Reduce

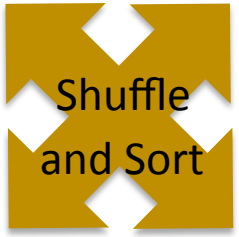
MapReduce: Terminology

- **A *job* is a 'full program'**
  - A complete execution of Mappers and Reducers over a dataset
  - In MapReduce 2, the term *application* is often used in place of 'job'
- **A *task* is the execution of a single Mapper or Reducer over a slice of data**
- **A *task attempt* is a particular instance of an attempt to execute a task**
  - There will be at least as many task attempts as there are tasks
  - If a task attempt fails, another will be started by the JobTracker
  - *Speculative execution* (see later) can also result in more task attempts than completed tasks

Hadoop Components: MapReduce

- **The Mapper**
  - Each Map task (typically) operates on a single HDFS block
  - Map tasks (usually) run on the node where the block is stored

- **Shuffle and Sort**
  - Sorts and consolidates intermediate data from all mappers
  - Happens as Map tasks complete and before Reduce tasks start



- **The Reducer**
  - Operates on shuffled/sorted intermediate data (Map task output)
  - Produces final output

Example: Word Count

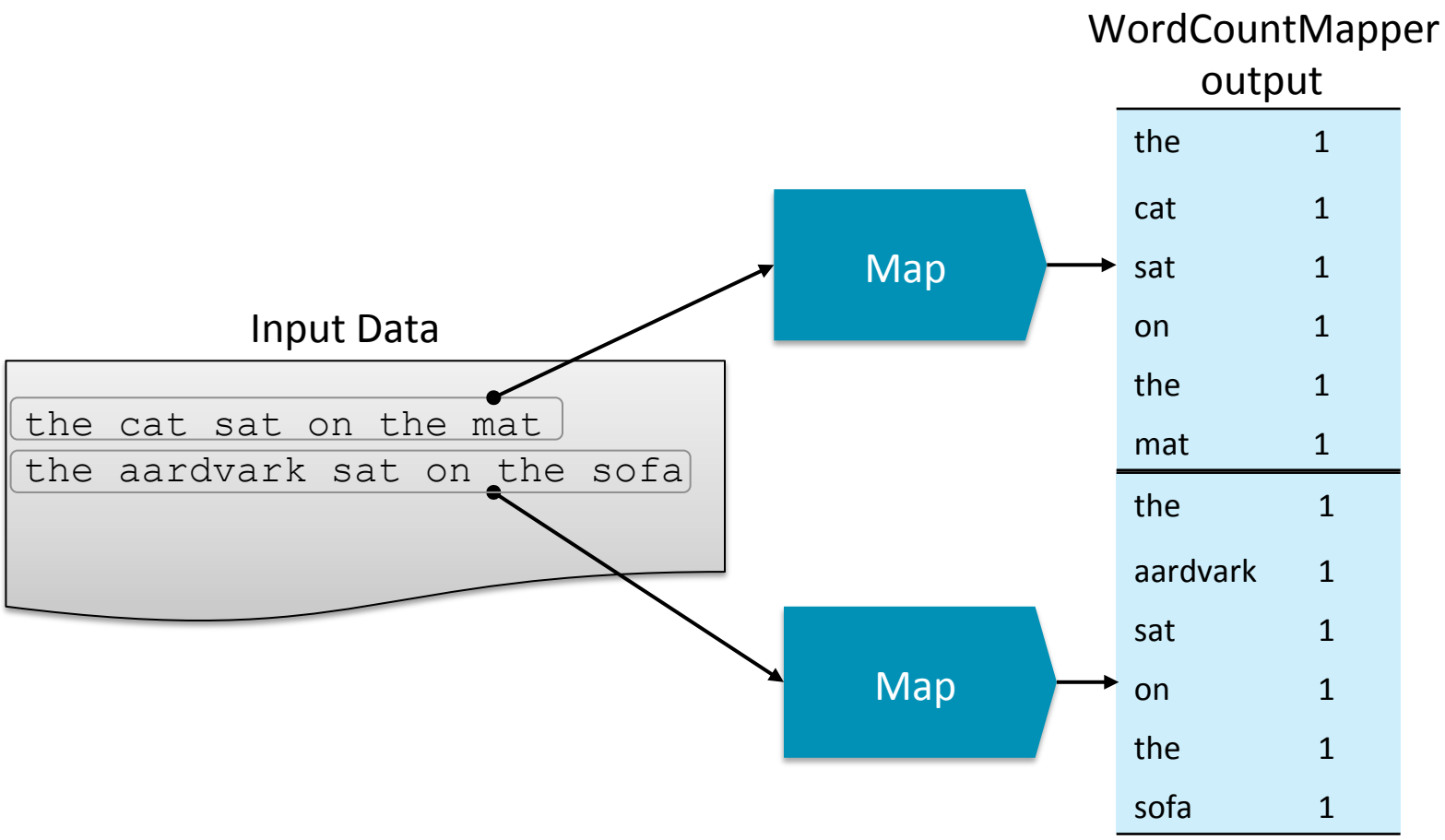
Input Data

```
the cat sat on the mat
the aardvark sat on the sofa
```

Result

aardvark	1
cat	1
mat	1
on	2
sat	2
sofa	1
the	4

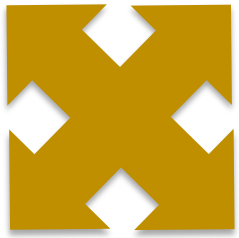
Example: The WordCount Mapper



Example: Shuffle & Sort

Mapper Output

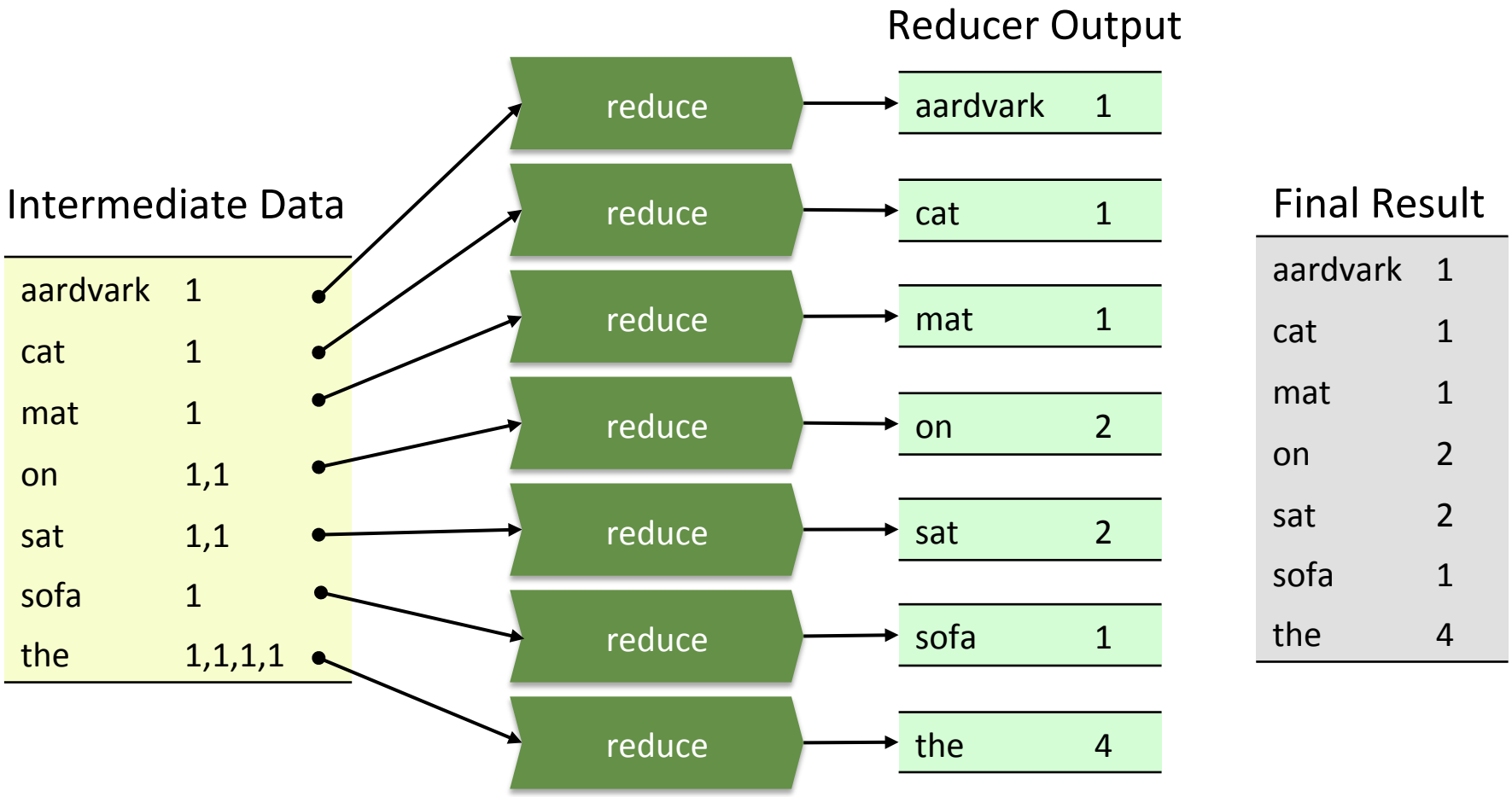
the	1
cat	1
sat	1
on	1
the	1
mat	1
the	1
aardvark	1
sat	1
on	1
the	1
sofa	1



Intermediate Data

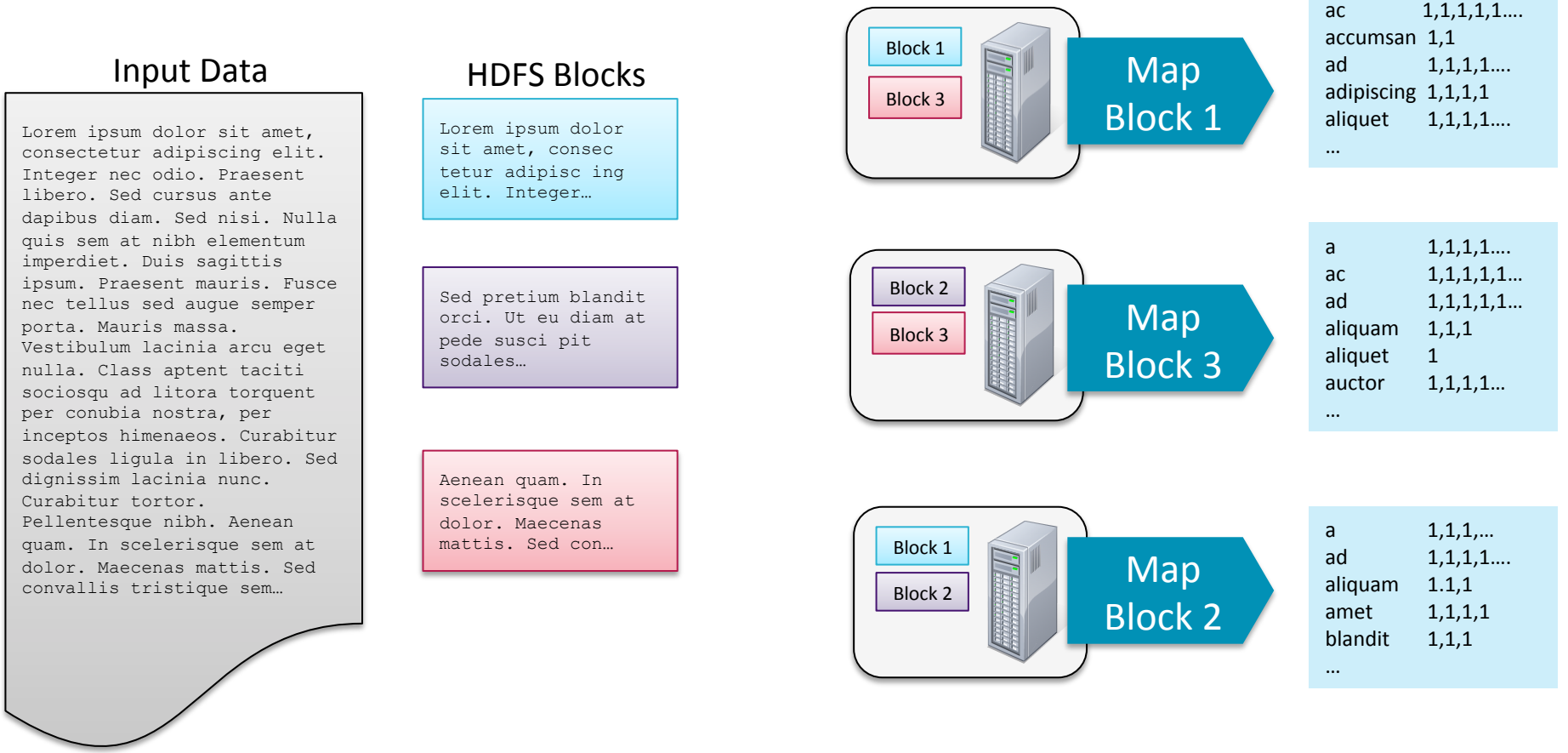
aardvark	1
cat	1
mat	1
on	1,1
sat	1,1
sofa	1
the	1,1,1,1

Example: SumReducer



Mappers Run in Parallel

- **Hadoop runs Map tasks on the slave node where the block is stored (when possible)**
  - Many Mappers can run in parallel
  - Minimizes network traffic



MapReduce: The Mapper

- **Hadoop attempts to ensure that Mappers run on nodes which hold their portion of the data locally, to avoid network traffic**
  - Multiple Mappers run in parallel, each processing a portion of the input data
- **The Mapper reads data in the form of key/value pairs**
  - The Mapper may use or completely ignore the input key
  - For example, a standard pattern is to read one line of a file at a time
    - The key is the byte offset into the file at which the line starts
    - The value is the contents of the line itself
    - Typically the key is considered irrelevant
- **If the Mapper writes anything out, the output must be in the form of key/value pairs**

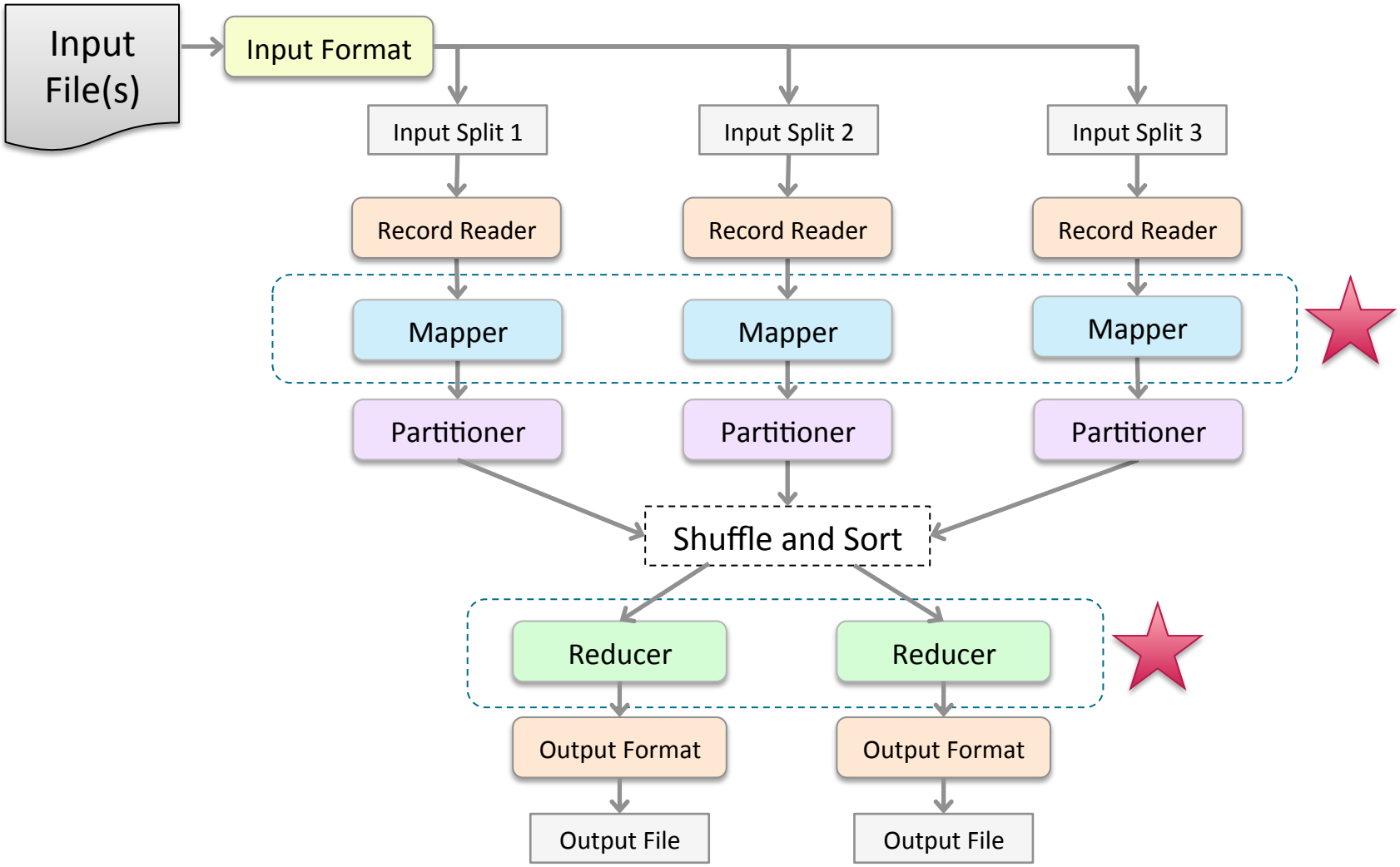
MapReduce: The Reducer

- **After the Map phase is over, all intermediate values for a given intermediate key are combined together into a list**
- **This list is given to a Reducer**
  - There may be a single Reducer, or multiple Reducers
  - All values associated with a particular intermediate key are guaranteed to go to the same Reducer
  - The intermediate keys, and their value lists, are passed to the Reducer in sorted key order
  - This step is known as the 'shuffle and sort'
- **The Reducer outputs zero or more final key/value pairs**
  - These are written to HDFS
  - In practice, the Reducer usually emits a single key/value pair for each input key

Why Do We Care About Counting Words?

- **Word count is challenging over massive amounts of data**
  - Using a single compute node would be too time-consuming
  - Using distributed nodes requires moving data
  - Number of unique words can easily exceed available memory
    - Would need to store to disk
- **Statistics are simple aggregate functions**
  - Distributive in nature
  - e.g., max, min, sum, count
- **MapReduce breaks complex tasks down into smaller elements which can be executed in parallel**
- **Many common tasks are very similar to word count**
  - e.g., log file analysis

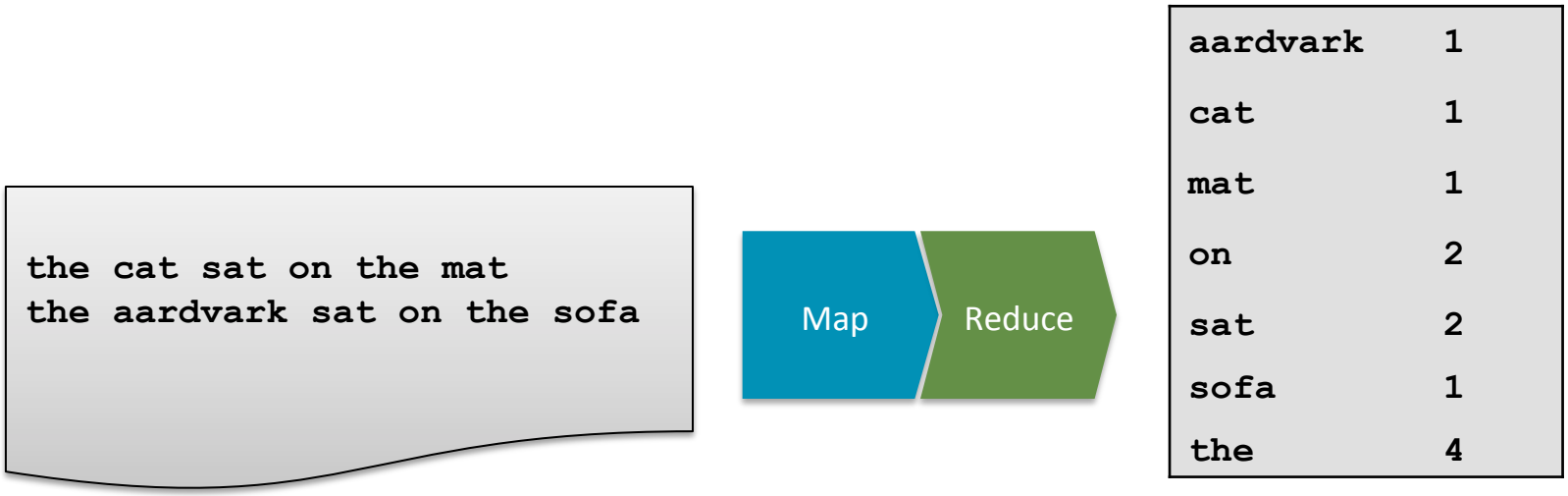
Review: The MapReduce Flow



A Sample MapReduce Program: WordCount

Let's have a look at the code for WordCount

- This will demonstrate the Hadoop API



Our MapReduce Program: WordCount

- **To inves(gate the API, we will dissect the WordCount program**

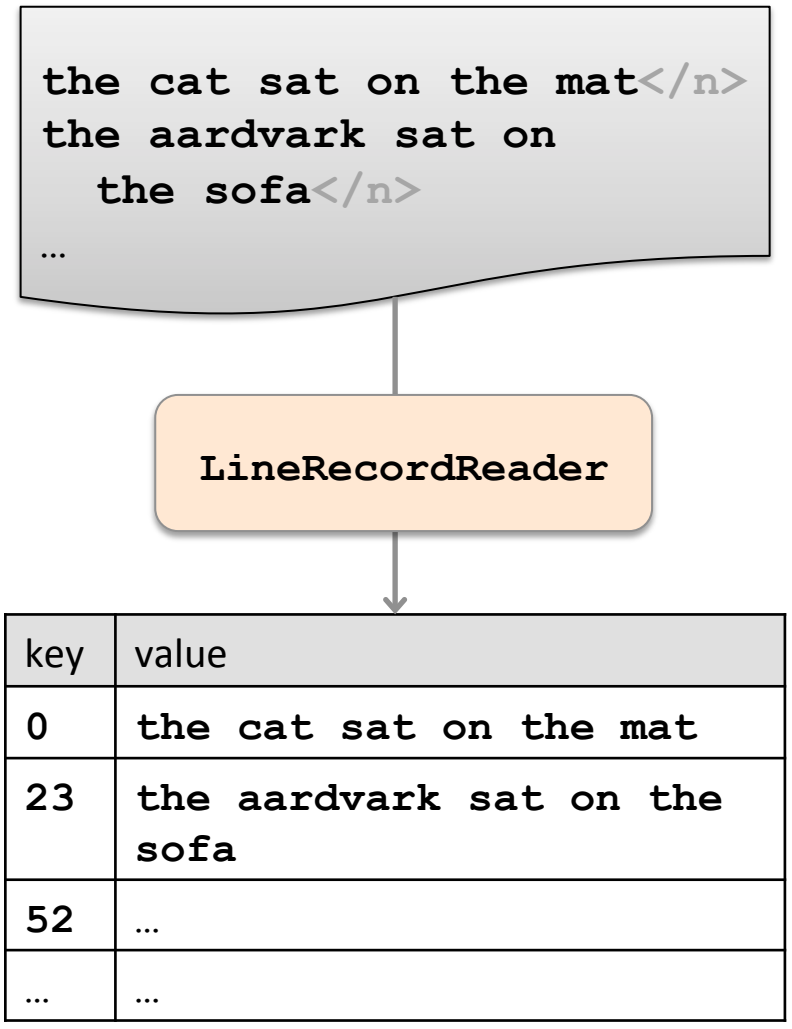
- **This consists of three portions**
  - The driver code
    - Code that runs on the client to configure and submit the job
  - The Mapper
  - The Reducer
- **Before we look at the code, we need to cover some basic Hadoop API concepts**

Getting Data to the Mapper

- **The data passed to the Mapper is specified by an *InputFormat***
  - Specified in the driver code
  - Defines the location of the input data
    - Typically a file or directory
  - Determines how to split the input data into *input splits*
    - Each Mapper deals with a single input split
  - Creates a RecordReader object
    - RecordReader parses the input data into key/value pairs to pass to the Mapper

Example: `TextInputFormat`

- **`TextInputFormat`**
  - The default
  - Creates `LineRecordReader` objects
  - Treats each `\n`-terminated line of a file as a value
  - Key is the byte offset of that line within the file



key	value
0	the cat sat on the mat
23	the aardvark sat on the sofa
52	…
…	…

Other Standard InputFormats

- **`FileInputFormat`**
  - Abstract base class used for all file-based InputFormats
- **`KeyValueTextInputFormat`**
  - Maps `\n`-terminated lines as 'key [*separator*] value'
    - By default, [*separator*] is a tab
- **`SequenceFileInputFormat`**
  - Binary file of (key, value) pairs with some additional metadata
- **`SequenceFileAsTextInputFormat`**
  - Similar, but maps (`key.toString()`, `value.toString()`)

Keys and Values are Objects

- **Keys and values in Hadoop are Java `Objects`**
  - Not primitives
- **Values are objects which implement `Writable`**
- **Keys are objects which implement `WritableComparable`**

What is `Writable`?

- **The `Writable` interface makes serialization quick and easy for Hadoop**
- **Any value's type must implement the `Writable` interface**
- **Hadoop defines its own 'box classes' for strings, integers, and so on**
  - `IntWritable` for ints
  - `LongWritable` for longs
  - `FloatWritable` for floats
  - `DoubleWritable` for doubles
  - `Text` for strings
  - Etc.

What is `WritableComparable`?

- **A `WritableComparable` is a `Writable` which is also `Comparable`**
  - Two `WritableComparable`s can be compared against each other to determine their 'order'
  - Keys must be `WritableComparable`s because they are passed to the Reducer in sorted order
  - We will talk more about `WritableComparable`s later
- **Note that despite their names, all Hadoop box classes implement both `Writable` and `WritableComparable`**
  - For example, `IntWritable` is actually a `WritableComparable`

The Driver: Complete Code

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

public class WordCount extends Configured implements Tool {

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

  public int run(String[] args) throws Exception {
    if (args.length != 2) {
      System.out.printf(
          "Usage: %s [generic options] <input dir> <output dir>\n", getClass().getSimpleName());
      return -1;
    }
    Job job = new Job(getConf());
    job.setJarByClass(WordCount.class);
    job.setJobName("Word Count");

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

    job.setMapperClass(WordMapper.class);
    job.setReducerClass(SumReducer.class);
    job.setMapOutputKeyClass(Text.class);
    job.setMapOutputValueClass(IntWritable.class);

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

    boolean success = job.waitForCompletion(true);
    return success ? 0 : 1;
  }
}
```

Driver Class Definition

```
public class WordCount extends Configured implements Tool {

  public static void ma
    int exitCode = Tool
    System.exit(exitCo
  }

  public int run(String

    if (args.length != 2
      System.out.printf(
          "Usage: %s [generic options] <input dir> <output dir>\n", getClass().getSimpleName());
      return -1;
    }
    Job job = new Job(getConf());
    job.setJarByClass(WordCount.class); job.setJobName("Word Count");

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

    job.setMapperClass(WordMapper.class);
    job.setReducerClass(SumReducer.class);
    job.setMapOutputKeyClass(Text.class);
    job.setMapOutputValueClass(IntWritable.class);

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

    boolean success = job.waitForCompletion(true);
    return success ? 0 : 1;
  }
}
```

The driver class implements the `Tool` interface and extends the `Configured` class.

Main Method

```
public class WordCount extends Configured implements Tool {

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

  public int run(String
   if (args.length !=
     System.out.printf
         "Usage: %s [ge
     return -1;
   }
   Job job = new Job(getConf());
   job.setJarByClass(WordCount.class);
   job.setJobName("Word Count");

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

   job.setMapperClass(WordMapper.class);
   job.setReducerClass(SumReducer.class);
   job.setMapOutputKeyClass(Text.class);
   job.setMapOutputValueClass(IntWritable.class);

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

   ...
```

The driver `main` method calls `ToolRunner.run`.

Run Method

```
public class WordCount

   public static void
     int exitCode = To
           new WordCo
     System.exit(exitC
   }
```

The driver `run` method creates, configures, and submits the job.

```
public int run(String[] args) throws Exception {
  if (args.length != 2) {
   System.out.printf(
       "Usage: %s [generic options] <input dir> <output dir>\n", getClass().getSimpleName());
   return -1;
   }
  Job job = new Job(getConf());
  job.setJarByClass(WordCount.class);
  job.setJobName("Word Count");

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

  ...
```

Creating a New `Job` Object

- **The `Job` class allows you to set configuration options for your MapReduce job**
  - The classes to be used for your Mapper and Reducer
  - The input and output directories
  - Many other options
- **Any options not explicitly set in your driver code will be read from your Hadoop configuration files**
  - Usually located in `/etc/hadoop/conf`
- **Any options not specified in your configuration files will use Hadoop's default values**
- **You can also use the `Job` object to submit the job, control its execution, and query its state**

Configuring the Job: Specifying the InputFormat

- **The default InputFormat (`TextInputFormat`) will be used unless you specify otherwise**
- **To use an InputFormat other than the default, use e.g.**

```
job.setInputFormatClass(KeyValueTextInputFormat.class)
```

Configuring the Job: Determining Which Files To Read

- **By default, `FileInputFormat.setInputPaths()` will read all files from a specified directory and send them to Mappers**
  - Exceptions: items whose names begin with a period (`.`) or underscore (`_`)
  - Globs can be specified to restrict input
    - For example, `/2010/*/01/*`
- **Alternatively, `FileInputFormat.addInputPath()` can be called multiple times, specifying a single file or directory each time**
- **More advanced filtering can be performed by implementing a `PathFilter`**
  - Interface with a method named `accept`
    - Takes a path to a file, returns `true` or `false` depending on whether or not the file should be processed

Configuring the Job: Specifying Final Output With OutputFormat

- **`FileOutputFormat.setOutputPath()` specifies the directory to which the Reducers will write their final output**
- **The driver can also specify the format of the output data**
  - Default is a plain text file
  - Could be explicitly written as `job.setOutputFormatClass(TextOutputFormat.class)`
- **We will discuss OutputFormats in more depth in a later chapter**

Configuring the Job: Specifying the Mapper and Reducer Classes

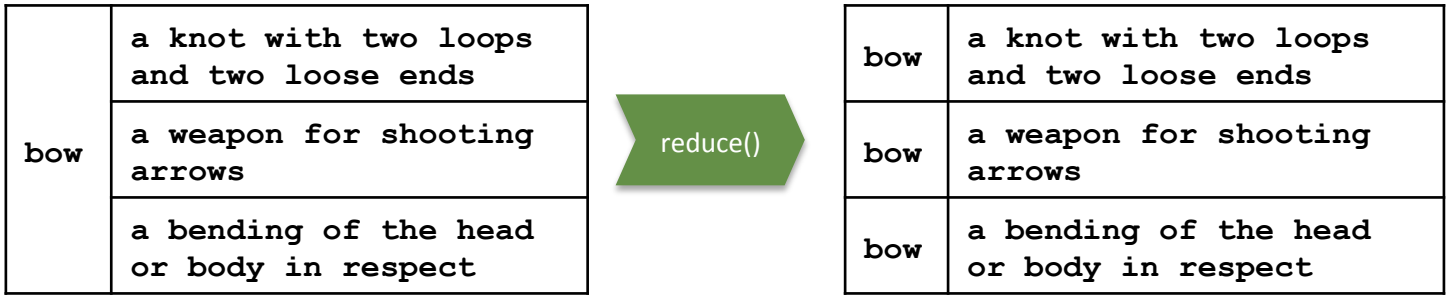
```
public class WordCount {
  public static void main(String[] args) throws Exception {
    if (args.length != 2) {
      System.out.printf("Usage: WordCount <input dir> <output dir>\n");
      System.exit(-1);
    }
    Job job = new Job();
    job.setJarByClass(WordCount.class);
    job.setJobName("Word Count");

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

    job.setMapperClass(WordMapper.class);
    job.setReducerClass(SumReducer.class);

    job
    job

    job
    job

    boolean success = job.waitForCompletion(true);
    System.exit(success ? 0 : 1);
  }
}
```

Give the `Job` object information about which classes are to be instantiated as the Mapper and Reducer.

Default Mapper and Reducer Classes

- **Setting the Mapper and Reducer classes is optional**
- **If not set in your driver code, Hadoop uses its defaults**
  - **`IdentityMapper`**

  - **`IdentityReducer`**



Configuring the Job: Specifying the Intermediate Data Types

```
public class WordCount {
  public static void main(String[] args) throws Exception {
    if (args.length != 2) {
      System.out.printf("Usage: WordCount <input dir> <output dir>\n");
      System.exit(-1);
    }
    Job job = new Job();
    job.setJarByClass(WordCount.class);
    job.setJobName("Word Count");

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

    job.setMapperClass(WordMapper.class);
    job.setReducerClass(SumReducer.class);

    job.setMapOutputKeyClass(Text.class);
    job.setMapOutputValueClass(IntWritable.class);

    j
    j

    b
    S
  }
}
```

Specify the types for the intermediate output keys and values produced by the Mapper.

Configuring the Job: Specifying the Final Output Data Types

```
public class WordCount {
  public static void main(String[] args) throws Exception {
    if (args.length != 2) {
      System.out.printf("Usage: WordCount <input dir> <output dir>\n");
      System.exit(-1);
    }
    Job job = new Job();
    job.setJarByClass(WordCount.class);
    job.setJobName("Word Count");

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

    job.setMapperClass(WordMapper.class);
    j
    j
    j

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

    boolean success = job.waitForCompletion(true);
    System.exit(success ? 0 : 1);
  }
}
```

Specify the types for the Reducer's output keys and values.

Running The Job (1)

```
public class WordCount {
  public static void main(String[] args) throws Exception {
    if (args.length != 2) {
      System.out.printf("Usage: WordCount <input dir> <output dir>\n");
      System.exit(-1);
    }
    Job job = new Job();
    job.setJarByClass(WordCount.class);
    job.setJobName("Word Count");

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

    boolean success = job.waitForCompletion(true);
    System.exit(success ? 0 : 1);
  }
}
```

Start the job and wait for it to complete. Parameter is a Boolean, specifying verbosity: if true, display progress to the user. Finally, exit with a return code.

Running The Job

- **There are two ways to run your MapReduce job:**
  - `job.waitForCompletion()`
    - Blocks (waits for the job to complete before continuing)
  - `job.submit()`
    - Does not block (driver code continues as the job is running)
- **The client determines the proper division of input data into InputSplits, and then sends the job information to the JobTracker daemon on the cluster**

ToolRunner Command Line Options

- **ToolRunner allows the user to specify configuration options on the command line**
- **Commonly used to specify Hadoop properties using the `-D` flag**
  - Will override any default or site properties in the configuration
  - But will *not* override those set in the driver code

```
$ hadoop jar myjar.jar MyDriver \
-D mapred.reduce.tasks=10 myinputdir myoutputdir
```

- **Note that `-D` options must appear before any additional program arguments**
- **Can specify an XML configuration file with `-conf`**
- **Can specify the default filesystem with `-fs` *`uri`***
  - Shortcut for `-D fs.default.name=`*`uri`*

The Mapper: Complete Code

```
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;

public class WordMapper extends Mapper<LongWritable, Text, Text,
IntWritable> {
  @Override
  public void map(LongWritable key, Text value, Context context)
      throws IOException, InterruptedException {

    String line = value.toString();

    for (String word : line.split("\\W+")) {
      if (word.length() > 0) {

        context.write(new Text(word), new IntWritable(1));
      }
    }
  }
}
```

The Mapper: Class Declaration (1)

```
public class WordMapper extends Mapper<LongWritable, Text, Text, IntWritable>
{
  @Overr
  public
      th

    String line = value.toString();

    for (String word : line.split("\\W+")) {
      if (word.length() > 0) {

        context.write(new Text(word), new IntWritable(1));
      }
    }
  }
}
```

Mapper classes extend the `Mapper` base class.

The Mapper: Class Declaration (2)

```
public class WordMapper extends Mapper<LongWritable, Text, Text, IntWritable>
{
  @Override
  public void map(LongWritable key, Text
      throws IOException, InterruptedException {

    Str

    for
      i

    }
  }
}
```

Input key and value types

Intermediate key and value types

Specify generic types that declare four type parameters: the input key and value types, and the output (intermediate) key and value types. Keys must be `WritableComparable`, and values must be `Writable`.

The `map` Method

```
public class WordMapper extends Mapper<LongWritable, Text, Text, IntWritable>
{
  @Override
  public void map(LongWritable key, Text value, Context context)
      throws IOException, InterruptedException {

    String

    for (St
      if (w

        con
      }
    }
  }
}
```

The `map` method is passed a key, a value, and a `Context` object. The `Context` is used to write the intermediate data. It also contains information about the job's configuration.

The `map` Method: Processing The Line (1)

```
public class WordMapper extends Mapper<LongWritable, Text, Text, IntWritable>
{
  @Override
  public void map(LongWritable key, Text value, Context context)
      throws IOException, InterruptedException {

    String line = value.toString();

    for
      if
        context.write(new Text(word), new IntWritable(1));
      }
    }
  }
}
```

`value` is a `Text` object, so retrieve the string it contains.

The `map` Method: Processing The Line (2)

```
public class WordMapper extends Mapper<LongWritable, Text, Text, IntWritable>
{
  @Override
  public void map(LongWritable key, Text value, Context context)
      throws IOException, InterruptedException {

    String line = value.toString();

    for (String word : line.split("\\W+")) {
      if (word.length() > 0) {

        cont
      }
    }
  }
}
```

Split the string up into words using a regular expression with non-alphanumeric characters as the delimiter, and then loop through the words.

The `map` Method: Outputting Intermediate Data

```
public class WordMapper extends Mapper<LongWritable, Text, Text, IntWritable>
{
  @Ov
  pub
      context.write(new Text(word), new IntWritable(1));
    }
  }
}
```

To emit a (key, value) pair, call the `write` method of the `Context` object. The key will be the word itself, the value will be the number 1. Recall that the output key must be a `WritableComparable`, and the value must be a `Writable`.

The Reducer: Complete Code

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

public class SumReducer extends Reducer<Text, IntWritable, Text, IntWritable>
{

  @Override
  public void reduce(Text key, Iterable<IntWritable> values, Context context)
      throws IOException, InterruptedException {

    int wordCount = 0;

    for (IntWritable value : values) {
      wordCount += value.get();
    }

    context.write(key, new IntWritable(wordCount));
  }
}
```

The Reducer: Class Declaration

```
public class SumReducer extends Reducer<Text, IntWritable, Text, IntWritable>
{

  @Override
  public void reduce(Text key, Iterable<
      throws IOException, InterruptedException {

    int

    for
      wo
    }

    cont
  }
}
```

Intermediate key and value types

Output key and value types

Reducer classes extend the `Reducer` base class. The four generic type parameters are: input (intermediate) key and value types, and final output key and value types.

The `reduce` Method

```
public class SumReducer extends Reducer<Text, IntWritable, Text, IntWritable>
{

  @Override
  public void reduce(Text key, Iterable<IntWritable> values, Context context)
      throws IOException, InterruptedException {

    int wordC

    for (IntW
      wordCou
    }

    context.w
  }
}
```

The `reduce` method receives a key and an `Iterable` collection of objects (which are the values emitted from the Mappers for that key); it also receives a `Context` object.

The `reduce` Method: Processing The Values

```
public class SumReducer extends Reducer<Text, IntWritable, Text, IntWritable>
{

  @Override
  public void reduce(Text key, Iterable<IntWritable> values, Context context)
      throws IOException, InterruptedException {

    int wordCount = 0;

    for (IntWritable value : values) {
      wordCount += value.get();
    }

    cont
  }
}
```

We use the Java for-each syntax to step through all the elements in the collection. In our example, we are merely adding all the values together. We use `value.get()` to retrieve the actual numeric value each time.

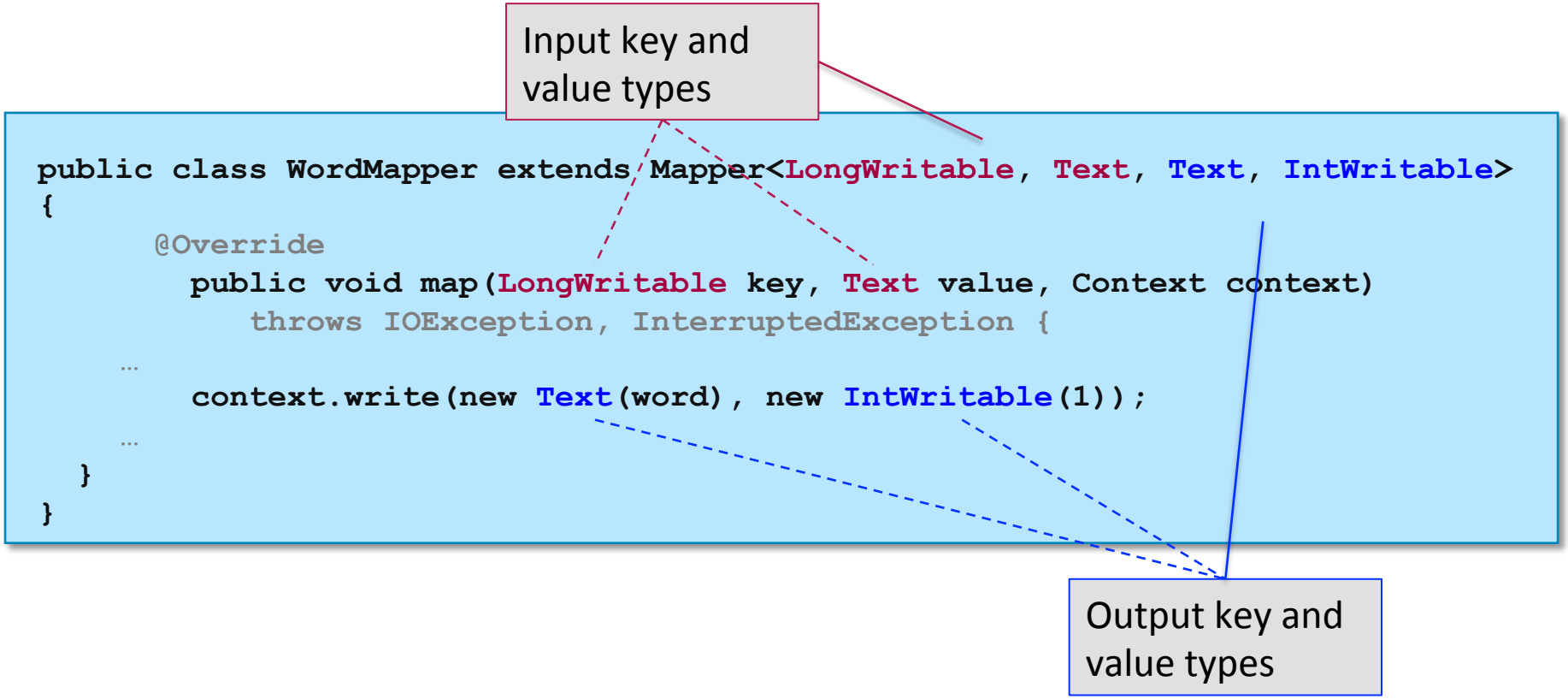
The `reduce` Method: Writing The Final Output

```
public class SumReducer extends Reducer<Text, IntWritable, Text, IntWritable>
{

  @Override
  public void reduce(Text key, Iterable<IntWritable> values, Context context)
      throws IOException, InterruptedException {

    int

    for
      wo
    }

    context.write(key, new IntWritable(wordCount));
  }
}
```

Finally, we write the output key-value pair to HDFS using the `write` method of our `Context` object.

Ensure Types Match (1)

- **Mappers and Reducers declare input and output type parameters**
- **These must match the types used in the class**



Ensure Types Match (2)

- **Output types must also match those set in the driver**

```
public class WordMapper extends Mapper<LongWritable,
Text, Text, IntWritable> {
    …
}
```

Mapper

```
public class WordCount {
  public static void main(String[] args) throws Exception {
    …
    job.setMapOutputKeyClass(Text.class);
    job.setMapOutputValueClass(IntWritable.class);

    job.setOutputKeyClass(Text.class);
    job.setOutputValueClass(IntWritable.class);
    …
```

driver code

```
public class SumReducer extends Reducer<Text,
IntWritable, Text, IntWritable> {
…
}
```

Reducer

What Is The Old API?

- **When Hadoop 0.20 was released, a 'New API' was introduced**
  - Designed to make the API easier to evolve in the future
  - Favors abstract classes over interfaces
- **Some developers still use the Old API**
  - Until CDH4, the New API was not absolutely feature-complete
- **All the code examples in this course use the New API**

New API vs. Old API: Some Key Differences (1)

New API	Old API
`import org.apache.hadoop.mapreduce.*`	`import org.apache.hadoop.mapred.*`

Driver code:
`Configuration conf = new Configuration();`
`Job job = new Job(conf);`
`job.setJarByClass(Driver.class);`
`job.setSomeProperty(...);`
`...`
`job.waitForCompletion(true);`
	Driver code:
	`JobConf conf = new JobConf(Driver.class);`
	`conf.setSomeProperty(...);`
	`...`
	`JobClient.runJob(conf);`

Mapper:
`public class MyMapper extends Mapper {`
`  public void map(Keytype k, Valuetype v,`
`  Context c) {`
`  ...`
`  c.write(key, val);`
`  }`
`}`
	Mapper:
	`public class MyMapper extends MapReduceBase`
	`  implements Mapper {`
	`  public void map(Keytype k, Valuetype v,`
	`  OutputCollector o, Reporter r) {`
	`  ...`
	`  o.collect(key, val);`
	`  }`
	`}`

New API vs. Old API: Some Key Differences (2)

New API	Old API

Reducer:
 	
`public class MyReducer extends Reducer {`
 	
`  public void reduce(Keytype k,`
`  Iterable<Valuetype> v, Context c) {`
`  for(Valuetype eachval : v) {`
`  // process eachval`
`  c.write(key, val);`
`  }`
`  }`
`}`
	Reducer:
	
	`public class MyReducer extends MapReduceBase`
	`  implements Reducer {`
	
	`  public void reduce(Keytype k,`
	`  Iterator<Valuetype> v,`
	`  OutputCollector o, Reporter r) {`
	`  while(v.hasnext()) {`
	`  // process v.next()`
	`  o.collect(key, val);`
	`  }`
	`  }`
	`}`

`setup(Context c)` **(See later)**	`configure(JobConf job)`
`cleanup(Context c)` **(See later)**	`close()`

MRv1 vs MRv2, Old API vs New API

- **There is a lot of confusion about the New and Old APIs, and MapReduce version 1 and MapReduce version 2**
- **The chart below should clarify what is available with each version of MapReduce**

	Old API	New API
MapReduce v1	✔	✔
MapReduce v2	✔	✔

- **Summary: Code using either the Old API or the New API will run under MRv1 and MRv2**

The `setup` Method

- **It is common to want your Mapper or Reducer to execute some code before the `map` or `reduce` method is called for the first time**
  - Initialize data structures
  - Read data from an external file
  - Set parameters
- **The `setup` method is run before the `map` or `reduce` method is called for the first time**

```
public void setup(Context context)
```

The `cleanup` Method

- **Similarly, you may wish to perform some action(s) after all the records have been processed by your Mapper or Reducer**
- **The `cleanup` method is called before the Mapper or Reducer terminates**

```
public void cleanup(Context context) throws
    IOException, InterruptedException
```

Passing Parameters

```
public class MyDriverClass {
    public int main(String[] args) throws Exception {
        Configuration conf = new Configuration();
        conf.setInt ("paramname",value);
        Job job = new Job(conf);
        ...
        boolean success = job.waitForCompletion(true);
        return success ? 0 : 1;
    }
}
```

```
public class MyMapper extends Mapper {

    public void setup(Context context) {
          Configuration conf = context.getConfiguration();
            int myParam = conf.getInt("paramname", 0);
            ...
    }
    public void map...
}
```

Reuse of Objects is Good Practice (1)

- **It is generally good practice to reuse objects**
  - Instead of creating many new objects
- **Example: Our original WordCount Mapper code**

```
public class WordMapper extends Mapper<LongWritable, Text, Text, IntWritable>
{
  @Override
  public void map(LongWritable key, Text value, Context context)
      throws IOException, InterruptedException {

    Strin

    for (
      if

        context.write(new Text(word), new IntWritable(1));
      }
    }
  }
}
```

Each time the `map()` method is called, we create a new `Text` object and a new `IntWritable` object.

Reuse of Objects is Good Practice (2)

- **Instead, this is better practice:**

```
public class WordMapper extends Mapper<LongWritable, Text, Text, IntWritable>
{
 private final static IntWritable one = new IntWritable(1);
 private Text wordObject = new Text();

 @Overr
  publi
      t

    String line = value.toString();

    for (String word : line.split("\\W+")) {
      if (word.length() > 0) {
        wordObject.set(word);
        context.write(wordObject, one);
      }
    }
  }
}
```

Create objects for the key and value outside of your `map()` method

Reuse of Objects is Good Practice (3)

- **Instead, this is better practice:**

```
public class WordMapper extends Mapper<LongWritable, Text, Text, IntWritable>
{
 private final static IntWritable one = new IntWritable(1);
 private Text wordObject = new Text();

 @Ov
  pu

    if (word.length() > 0) {
      wordObject.set(word);
      context.write(wordObject, one);
    }
  }
 }
}
```

Within the `map()` method, populate the objects and write them out. Hadoop will take care of serializing the data so it is perfectly safe to re-use the objects.

Object Reuse: Caution!

- **Hadoop re-uses objects all the time**
- **For example, each time the Reducer is passed a new value, the same object is reused**
- **This can cause subtle bugs in your code**
  - For example, if you build a list of value objects in the Reducer, each element of the list will point to the same underlying object
    - Unless you do a deep copy

Map-Only MapReduce Jobs

- **There are many types of job where only a Mapper is needed**
- **Examples:**
  - Image processing
  - File format conversion
  - Input data sampling
  - ETL

Creating Map-Only Jobs

- **To create a Map-only job, set the number of Reducers to 0 in your Driver code**

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

- **Call the `Job.setOutputKeyClass` and `Job.setOutputValueClass` methods to specify the output types**
  - *Not* the `Job.setMapOutputKeyClass` and `Job.setMapOutputValueClass` methods
- **Anything written using the `Context.write` method in the Mapper will be written to HDFS**
  - Rather than written as intermediate data
  - One file per Mapper will be written

How Many Reducers Do You Need?

- **An important consideration when creating your job is to determine the number of Reducers specified**
- **Default is a single Reducer**
- **With a single Reducer, one task receives *all* keys in sorted order**
  - This is sometimes advantageous if the output must be in completely sorted order
  - Can cause significant problems if there is a large amount of intermediate data
    - Node on which the Reducer is running may not have enough disk space to hold all intermediate data
    - The Reducer will take a long time to run

Jobs Which Require a Single Reducer

- **If a job needs to output a file where all keys are listed in sorted order, a single Reducer must be used**
- **Alternatively, the `TotalOrderPartitioner` can be used**
  - Uses an externally generated file which contains information about intermediate key distribution
  - Partitions data such that all keys which go to the first Reducer are smaller than any which go to the second, etc
  - In this way, multiple Reducers can be used
  - Concatenating the Reducers' output files results in a totally ordered list

Jobs Which Require a Fixed Number of Reducers

- **Some jobs will require a specific number of Reducers**
- **Example: a job must output one file per day of the week**
  - Key will be the weekday
  - Seven Reducers will be specified
  - A Partitioner will be written which sends one key to each Reducer

Jobs With a Variable Number of Reducers (1)

- **Many jobs can be run with a variable number of Reducers**
- **Developer must decide how many to specify**
  - Each Reducer should get a reasonable amount of intermediate data, but not too much
  - Chicken-and-egg problem
- **Typical way to determine how many Reducers to specify:**
  - Test the job with a relatively small test data set
  - Extrapolate to calculate the amount of intermediate data expected from the 'real' input data
  - Use that to calculate the number of Reducers which should be specified

Jobs With a Variable Number of Reducers (2)

- **Note: you should take into account the number of Reduce slots likely to be available on the cluster**
  - If your job requires one more Reduce slot than there are available, a second 'wave' of Reducers will run
    - Consisting just of that single Reducer
    - Potentially doubling the amount of time spent on the Reduce phase
  - In this case, increasing the number of Reducers further may cut down the time spent in the Reduce phase
    - Two or more waves will run, but the Reducers in each wave will have to process less data