

Hadoop Map-Reduce Tutorial

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1. Purpose

This document comprehensively describes all user-facing facets of the Hadoop Map-Reduce framework and serves as a tutorial.

2. Pre-requisites

Ensure that Hadoop is installed, configured and is running. More details:

- Hadoop [Quickstart](#) for first-time users.
- Hadoop [Cluster Setup](#) for large, distributed clusters.

3. Overview

Hadoop Map-Reduce is a software framework for easily writing applications which process vast amounts of data (multi-terabyte data-sets) in-parallel on large clusters (thousands of nodes) of commodity hardware in a reliable, fault-tolerant manner.

A Map-Reduce *job* usually splits the input data-set into independent chunks which are processed by the *map tasks* in a completely parallel manner. The framework sorts the outputs of the maps, which are then input to the *reduce tasks*. Typically both the input and the output of the job are stored in a file-system. The framework takes care of scheduling tasks, monitoring them and re-executes the failed tasks.

Typically the compute nodes and the storage nodes are the same, that is, the Map-Reduce framework and the [Distributed FileSystem](#) are running on the same set of nodes. This configuration allows the framework to effectively schedule tasks on the nodes where data is already present, resulting in very high aggregate bandwidth across the cluster.

The Map-Reduce framework consists of a single master `JobTracker` and one slave `TaskTracker` per cluster-node. The master is responsible for scheduling the jobs' component tasks on the slaves, monitoring them and re-executing the failed tasks. The slaves execute the tasks as directed by the master.

Minimally, applications specify the input/output locations and supply *map* and *reduce* functions via implementations of appropriate interfaces and/or abstract-classes. These, and other job parameters, comprise the *job configuration*. The Hadoop *job client* then submits the job (jar/executable etc.) and configuration to the `JobTracker` which then assumes the responsibility of distributing the software/configuration to the slaves, scheduling tasks and monitoring them, providing status and diagnostic information to the job-client.

Although the Hadoop framework is implemented in Java™, Map-Reduce applications need

not be written in Java.

- [Hadoop Streaming](#) is a utility which allows users to create and run jobs with any executables (e.g. shell utilities) as the mapper and/or the reducer.
- [Hadoop Pipes](#) is a [SWIG](#)- compatible C++ API to implement Map-Reduce applications (non JNITM based).

4. Inputs and Outputs

The Map-Reduce framework operates exclusively on `<key, value>` pairs, that is, the framework views the input to the job as a set of `<key, value>` pairs and produces a set of `<key, value>` pairs as the output of the job, conceivably of different types.

The `key` and `value` classes have to be serializable by the framework and hence need to implement the [Writable](#) interface. Additionally, the `key` classes have to implement the [WritableComparable](#) interface to facilitate sorting by the framework.

Input and Output types of a Map-Reduce job:

(input) `<k1, v1>` -> **map** -> `<k2, v2>` -> **combine** -> `<k2, v2>` -> **reduce** -> `<k3, v3>` (output)

5. Example: WordCount v1.0

Before we jump into the details, let's walk through an example Map-Reduce application to get a flavour for how they work.

WordCount is a simple application that counts the number of occurrences of each word in a given input set.

This works with a [local-standalone](#), [pseudo-distributed](#) or [fully-distributed](#) Hadoop installation.

5.1. Source Code

WordCount.java	
1.	<code>package org.myorg;</code>
2.	
3.	<code>import java.io.IOException;</code>
4.	<code>import java.util.*;</code>
5.	

6.	<code>import org.apache.hadoop.fs.Path;</code>
7.	<code>import org.apache.hadoop.conf.*;</code>
8.	<code>import org.apache.hadoop.io.*;</code>
9.	<code>import org.apache.hadoop.mapred.*;</code>
10.	<code>import org.apache.hadoop.util.*;</code>
11.	
12.	<code>public class WordCount {</code>
13.	
14.	<code> public static class Map extends MapReduceBase implements Mapper<LongWritable, Text, Text, IntWritable> {</code>
15.	<code> private final static IntWritable one = new IntWritable(1);</code>
16.	<code> private Text word = new Text();</code>
17.	
18.	<code> public void map(LongWritable key, Text value, OutputCollector<Text, IntWritable> output, Reporter reporter) throws IOException {</code>
19.	<code> String line = value.toString();</code>
20.	<code> StringTokenizer tokenizer = new StringTokenizer(line);</code>
21.	<code> while (tokenizer.hasMoreTokens()) {</code>
22.	<code> word.set(tokenizer.nextToken());</code>
23.	<code> output.collect(word, one);</code>
24.	<code> }</code>
25.	<code> }</code>
26.	<code> }</code>

27.	
28.	<code>public static class Reduce extends MapReduceBase implements Reducer<Text, IntWritable, Text, IntWritable> {</code>
29.	<code>public void reduce(Text key, Iterator<IntWritable> values, OutputCollector<Text, IntWritable> output, Reporter reporter) throws IOException {</code>
30.	<code>int sum = 0;</code>
31.	<code>while (values.hasNext()) {</code>
32.	<code>sum += values.next().get();</code>
33.	<code>}</code>
34.	<code>output.collect(key, new IntWritable(sum));</code>
35.	<code>}</code>
36.	<code>}</code>
37.	
38.	<code>public static void main(String[] args) throws Exception {</code>
39.	<code>JobConf conf = new JobConf(WordCount.class);</code>
40.	<code>conf.setJobName("wordcount");</code>
41.	
42.	<code>conf.setOutputKeyClass(Text.class);</code>
43.	<code>conf.setOutputValueClass(IntWritable.class);</code>
44.	
45.	<code>conf.setMapperClass(Map.class);</code>
46.	

	<code>conf.setCombinerClass(Reduce.class);</code>
47.	<code>conf.setReducerClass(Reduce.class);</code>
48.	
49.	<code>conf.setInputFormat(TextInputFormat.class);</code>
50.	<code>conf.setOutputFormat(TextOutputFormat.class);</code>
51.	
52.	<code>conf.setInputPath(new Path(args[0]));</code>
53.	<code>conf.setOutputPath(new Path(args[1]));</code>
54.	
55.	<code>JobClient.runJob(conf);</code>
57.	<code>}</code>
58.	<code>}</code>
59.	

5.2. Usage

Assuming HADOOP_HOME is the root of the installation and HADOOP_VERSION is the Hadoop version installed, compile WordCount.java and create a jar:

```
$ mkdir wordcount_classes
$ javac -classpath
${HADOOP_HOME}/hadoop-${HADOOP_VERSION}-core.jar -d
wordcount_classes WordCount.java
$ jar -cvf /usr/joe/wordcount.jar -C wordcount_classes/ .
```

Assuming that:

- /usr/joe/wordcount/input - input directory in HDFS
- /usr/joe/wordcount/output - output directory in HDFS

Sample text-files as input:

```
$ bin/hadoop dfs -ls /usr/joe/wordcount/input/  
/usr/joe/wordcount/input/file01  
/usr/joe/wordcount/input/file02  
$ bin/hadoop dfs -cat /usr/joe/wordcount/input/file01  
Hello World Bye World  
$ bin/hadoop dfs -cat /usr/joe/wordcount/input/file02  
Hello Hadoop Goodbye Hadoop
```

Run the application:

```
$ bin/hadoop jar /usr/joe/wordcount.jar org.myorg.WordCount  
/usr/joe/wordcount/input /usr/joe/wordcount/output
```

Output:

```
$ bin/hadoop dfs -cat /usr/joe/wordcount/output/part-00000  
Bye 1  
Goodbye 1  
Hadoop 2  
Hello 2  
World 2
```

5.3. Walk-through

The WordCount application is quite straight-forward.

The Mapper implementation (lines 14-26), via the map method (lines 18-25), processes one line at a time, as provided by the specified TextInputFormat (line 49). It then splits the line into tokens separated by whitespaces, via the StringTokenizer, and emits a key-value pair of < <word>, 1>.

For the given sample input the first map emits:

```
< Hello, 1>  
< World, 1>  
< Bye, 1>  
< World, 1>
```

The second map emits:

```
< Hello, 1>  
< Hadoop, 1>  
< Goodbye, 1>  
< Hadoop, 1>
```

We'll learn more about the number of maps spawned for a given job, and how to control them in a fine-grained manner, a bit later in the tutorial.

`WordCount` also specifies a `combiner` (line 46). Hence, the output of each map is passed through the local combiner (which is same as the `Reducer` as per the job configuration) for local aggregation, after being sorted on the *keys*.

The output of the first map:

```
< Bye, 1>
< Hello, 1>
< World, 2>
```

The output of the second map:

```
< Goodbye, 1>
< Hadoop, 2>
< Hello, 1>
```

The `Reducer` implementation (lines 28-36), via the `reduce` method (lines 29-35) just sums up the values, which are the occurrence counts for each key (i.e. words in this example).

Thus the output of the job is:

```
< Bye, 1>
< Goodbye, 1>
< Hadoop, 2>
< Hello, 2>
< World, 2>
```

The `run` method specifies various facets of the job, such as the input/output paths (passed via the command line), key/value types, input/output formats etc., in the `JobConf`. It then calls the `JobClient.runJob` (line 55) to submit the and monitor its progress.

We'll learn more about `JobConf`, `JobClient`, `Tool` and other interfaces and classes a bit later in the tutorial.

6. Map-Reduce - User Interfaces

This section provides a reasonable amount of detail on every user-facing aspect of the Map-Reduce framework. This should help users implement, configure and tune their jobs in a fine-grained manner. However, please note that the javadoc for each class/interface remains the most comprehensive documentation available; this is only meant to be a tutorial.

Let us first take the `Mapper` and `Reducer` interfaces. Applications typically implement them to provide the `map` and `reduce` methods.

We will then discuss other core interfaces including `JobConf`, `JobClient`, `Partitioner`, `OutputCollector`, `Reporter`, `InputFormat`, `OutputFormat` and others.

Finally, we will wrap up by discussing some useful features of the framework such as the `DistributedCache`, `IsolationRunner` etc.

6.1. Payload

Applications typically implement the `Mapper` and `Reducer` interfaces to provide the `map` and `reduce` methods. These form the core of the job.

6.1.1. Mapper

[Mapper](#) maps input key/value pairs to a set of intermediate key/value pairs.

Maps are the individual tasks that transform input records into intermediate records. The transformed intermediate records do not need to be of the same type as the input records. A given input pair may map to zero or many output pairs.

The Hadoop Map-Reduce framework spawns one map task for each `InputSplit` generated by the `InputFormat` for the job.

Overall, `Mapper` implementations are passed the `JobConf` for the job via the [JobConfigurable.configure\(JobConf\)](#) method and override it to initialize themselves. The framework then calls [map\(WritableComparable, Writable, OutputCollector, Reporter\)](#) for each key/value pair in the `InputSplit` for that task. Applications can then override the [Closeable.close\(\)](#) method to perform any required cleanup.

Output pairs do not need to be of the same types as input pairs. A given input pair may map to zero or many output pairs. Output pairs are collected with calls to [OutputCollector.collect\(WritableComparable, Writable\)](#).

Applications can use the `Reporter` to report progress, set application-level status messages and update `Counters`, or just indicate that they are alive.

All intermediate values associated with a given output key are subsequently grouped by the framework, and passed to the `Reducer(s)` to determine the final output. Users can control the grouping by specifying a `Comparator` via [JobConf.setOutputKeyComparatorClass\(Class\)](#).

The `Mapper` outputs are sorted and then partitioned per `Reducer`. The total number of partitions is the same as the number of reduce tasks for the job. Users can control which keys

(and hence records) go to which Reducer by implementing a custom `Partitioner`.

Users can optionally specify a combiner, via [JobConf.setCombinerClass\(Class\)](#), to perform local aggregation of the intermediate outputs, which helps to cut down the amount of data transferred from the Mapper to the Reducer.

The intermediate, sorted outputs are always stored in files of [SequenceFile](#) format. Applications can control if, and how, the intermediate outputs are to be compressed and the [CompressionCodec](#) to be used via the `JobConf`.

6.1.1.1. How Many Maps?

The number of maps is usually driven by the total size of the inputs, that is, the total number of blocks of the input files.

The right level of parallelism for maps seems to be around 10-100 maps per-node, although it has been set up to 300 maps for very cpu-light map tasks. Task setup takes awhile, so it is best if the maps take at least a minute to execute.

Thus, if you expect 10TB of input data and have a blocksize of 128MB, you'll end up with 82,000 maps, unless [setNumMapTasks\(int\)](#) (which only provides a hint to the framework) is used to set it even higher.

6.1.2. Reducer

[Reducer](#) reduces a set of intermediate values which share a key to a smaller set of values.

The number of reduces for the job is set by the user via [JobConf.setNumReduceTasks\(int\)](#).

Overall, `Reducer` implementations are passed the `JobConf` for the job via the [JobConfigurable.configure\(JobConf\)](#) method and can override it to initialize themselves. The framework then calls [reduce\(WritableComparable, Iterator, OutputCollector, Reporter\)](#) method for each <key, (list of values)> pair in the grouped inputs. Applications can then override the [Closeable.close\(\)](#) method to perform any required cleanup.

Reducer has 3 primary phases: shuffle, sort and reduce.

6.1.2.1. Shuffle

Input to the `Reducer` is the sorted output of the mappers. In this phase the framework fetches the relevant partition of the output of all the mappers, via HTTP.

6.1.2.2. Sort

The framework groups Reducer inputs by keys (since different mappers may have output the same key) in this stage.

The shuffle and sort phases occur simultaneously; while map-outputs are being fetched they are merged.

Secondary Sort

If equivalence rules for grouping the intermediate keys are required to be different from those for grouping keys before reduction, then one may specify a `Comparator` via [JobConf.setOutputValueGroupingComparator\(Class\)](#). Since [JobConf.setOutputKeyComparatorClass\(Class\)](#) can be used to control how intermediate keys are grouped, these can be used in conjunction to simulate *secondary sort on values*.

6.1.2.3. Reduce

In this phase the [reduce\(WritableComparable, Iterator, OutputCollector, Reporter\)](#) method is called for each `<key, (list of values)>` pair in the grouped inputs.

The output of the reduce task is typically written to the [FileSystem](#) via [OutputCollector.collect\(WritableComparable, Writable\)](#).

Applications can use the `Reporter` to report progress, set application-level status messages and update `Counters`, or just indicate that they are alive.

The output of the Reducer is *not sorted*.

6.1.2.4. How Many Reduces?

The right number of reduces seems to be 0.95 or 1.75 multiplied by (*<no. of nodes> * mapred.tasktracker.reduce.tasks.maximum*).

With 0.95 all of the reduces can launch immediately and start transferring map outputs as the maps finish. With 1.75 the faster nodes will finish their first round of reduces and launch a second wave of reduces doing a much better job of load balancing.

Increasing the number of reduces increases the framework overhead, but increases load balancing and lowers the cost of failures.

The scaling factors above are slightly less than whole numbers to reserve a few reduce slots in the framework for speculative-tasks and failed tasks.

6.1.2.5. Reducer NONE

It is legal to set the number of reduce-tasks to *zero* if no reduction is desired.

In this case the outputs of the map-tasks go directly to the `FileSystem`, into the output path set by [setOutputPath\(Path\)](#). The framework does not sort the map-outputs before writing them out to the `FileSystem`.

6.1.3. Partitioner

[Partitioner](#) partitions the key space.

Partitioner controls the partitioning of the keys of the intermediate map-outputs. The key (or a subset of the key) is used to derive the partition, typically by a *hash function*. The total number of partitions is the same as the number of reduce tasks for the job. Hence this controls which of the *m* reduce tasks the intermediate key (and hence the record) is sent to for reduction.

[HashPartitioner](#) is the default `Partitioner`.

6.1.4. Reporter

[Reporter](#) is a facility for Map-Reduce applications to report progress, set application-level status messages and update `Counters`.

`Mapper` and `Reducer` implementations can use the `Reporter` to report progress or just indicate that they are alive. In scenarios where the application takes a significant amount of time to process individual key/value pairs, this is crucial since the framework might assume that the task has timed-out and kill that task. Another way to avoid this is to set the configuration parameter `mapred.task.timeout` to a high-enough value (or even set it to *zero* for no time-outs).

Applications can also update `Counters` using the `Reporter`.

6.1.5. OutputCollector

[OutputCollector](#) is a generalization of the facility provided by the Map-Reduce framework to collect data output by the `Mapper` or the `Reducer` (either the intermediate outputs or the output of the job).

Hadoop Map-Reduce comes bundled with a [library](#) of generally useful mappers, reducers, and partitioners.

6.2. Job Configuration

[JobConf](#) represents a Map-Reduce job configuration.

JobConf is the primary interface for a user to describe a map-reduce job to the Hadoop framework for execution. The framework tries to faithfully execute the job as described by JobConf, however:

- Some configuration parameters may have been marked as [final](#) by administrators and hence cannot be altered.
- While some job parameters are straight-forward to set (e.g. [setNumReduceTasks\(int\)](#)), other parameters interact subtly with the rest of the framework and/or job configuration and are more complex to set (e.g. [setNumMapTasks\(int\)](#)).

JobConf is typically used to specify the Mapper, combiner (if any), Partitioner, Reducer, InputFormat and OutputFormat implementations. JobConf also indicates the set of input files ([setInputPath\(Path\)](#)/[addInputPath\(Path\)](#)) and where the output files should be written ([setOutputPath\(Path\)](#)).

Optionally, JobConf is used to specify other advanced facets of the job such as the Comparator to be used, files to be put in the DistributedCache, whether intermediate and/or job outputs are to be compressed (and how), debugging via user-provided scripts ([setMapDebugScript\(String\)](#)/[setReduceDebugScript\(String\)](#)), whether job tasks can be executed in a *speculative* manner ([setMapSpeculativeExecution\(boolean\)](#)/[setReduceSpeculativeExecution\(boolean\)](#)), maximum number of attempts per task ([setMaxMapAttempts\(int\)](#)/[setMaxReduceAttempts\(int\)](#)), percentage of tasks failure which can be tolerated by the job ([setMaxMapTaskFailuresPercent\(int\)](#)/[setMaxReduceTaskFailuresPercent\(int\)](#)) etc.

Of course, users can use [set\(String, String\)](#)/[get\(String, String\)](#) to set/get arbitrary parameters needed by applications. However, use the DistributedCache for large amounts of (read-only) data.

6.3. Task Execution & Environment

The TaskTracker executes the Mapper/ Reducer *task* as a child process in a separate jvm.

The child-task inherits the environment of the parent TaskTracker. The user can specify additional options to the child-jvm via the `mapred.child.java.opts` configuration parameter in the JobConf such as non-standard paths for the run-time linker to search shared libraries via `-Djava.library.path=<>` etc. If the `mapred.child.java.opts` contains the symbol `@taskid@` it is interpolated with value of `taskid` of the map/reduce task.

Here is an example with multiple arguments and substitutions, showing jvm GC logging, and start of a passwordless JVM JMX agent so that it can connect with jconsole and the likes to watch child memory, threads and get thread dumps. It also sets the maximum heap-size of the child jvm to 512MB and adds an additional path to the `java.library.path` of the child-jvm.

```
<property>
  <name>mapred.child.java.opts</name>
  <value>
    -Xmx512M -Djava.library.path=/home/mycompany/lib
  -verbose:gc -Xloggc:/tmp/@taskid@.gc
    -Dcom.sun.management.jmxremote.authenticate=false
  -Dcom.sun.management.jmxremote.ssl=false
  </value>
</property>
```

The [DistributedCache](#) can also be used as a rudimentary software distribution mechanism for use in the map and/or reduce tasks. It can be used to distribute both jars and native libraries. The [DistributedCache.addArchiveToClassPath\(Path, Configuration\)](#) or [DistributedCache.addFileToClassPath\(Path, Configuration\)](#) api can be used to cache files/jars and also add them to the *classpath* of child-jvm. Similarly the facility provided by the `DistributedCache` where-in it symlinks the cached files into the working directory of the task can be used to distribute native libraries and load them. The underlying detail is that child-jvm always has its *current working directory* added to the `java.library.path` and hence the cached libraries can be loaded via [System.loadLibrary](#) or [System.load](#).

6.4. Job Submission and Monitoring

[JobClient](#) is the primary interface by which user-job interacts with the `JobTracker`.

`JobClient` provides facilities to submit jobs, track their progress, access component-tasks' reports/logs, get the Map-Reduce cluster's status information and so on.

The job submission process involves:

1. Checking the input and output specifications of the job.
2. Computing the `InputSplit` values for the job.
3. Setting up the requisite accounting information for the `DistributedCache` of the job, if necessary.
4. Copying the job's jar and configuration to the map-reduce system directory on the `FileSystem`.
5. Submitting the job to the `JobTracker` and optionally monitoring it's status.

Job history files are also logged to user specified directory `hadoop.job.history.user.location` which defaults to job output directory. The files are stored in "`_logs/history/`" in the specified directory. Hence, by default they will be in `mapred.output.dir/_logs/history`. User can stop logging by giving the value `none` for `hadoop.job.history.user.location`

User can view logs in specified directory using the following command

```
$ bin/hadoop job -history output-dir
```

This will start a stand alone jetty on the client and load history jsp's. It will display the port where the server is up at. The server will be up for 30 minutes. User has to use `http://hostname:port` to view the history. User can also provide http bind address using `mapred.job.history.http.bindAddress`

User can use [OutputLogFilter](#) to filter log files from the output directory listing.

Normally the user creates the application, describes various facets of the job via `JobConf`, and then uses the `JobClient` to submit the job and monitor its progress.

6.4.1. Job Control

Users may need to chain map-reduce jobs to accomplish complex tasks which cannot be done via a single map-reduce job. This is fairly easy since the output of the job typically goes to distributed file-system, and the output, in turn, can be used as the input for the next job.

However, this also means that the onus on ensuring jobs are complete (success/failure) lies squarely on the clients. In such cases, the various job-control options are:

- [runJob\(JobConf\)](#) : Submits the job and returns only after the job has completed.
- [submitJob\(JobConf\)](#) : Only submits the job, then poll the returned handle to the [RunningJob](#) to query status and make scheduling decisions.
- [JobConf.setJobEndNotificationURI\(String\)](#) : Sets up a notification upon job-completion, thus avoiding polling.

6.5. Job Input

[InputFormat](#) describes the input-specification for a Map-Reduce job.

The Map-Reduce framework relies on the `InputFormat` of the job to:

1. Validate the input-specification of the job.
2. Split-up the input file(s) into logical `InputSplit` instances, each of which is then assigned to an individual `Mapper`.
3. Provide the `RecordReader` implementation used to glean input records from the logical `InputSplit` for processing by the `Mapper`.

The default behavior of file-based `InputFormat` implementations, typically sub-classes of [FileInputFormat](#), is to split the input into *logical* `InputSplit` instances based on the total size, in bytes, of the input files. However, the `FileSystem` blocksize of the input files is treated as an upper bound for input splits. A lower bound on the split size can be set via `mapred.min.split.size`.

Clearly, logical splits based on input-size is insufficient for many applications since record boundaries must be respected. In such cases, the application should implement a `RecordReader`, who is responsible for respecting record-boundaries and presents a record-oriented view of the logical `InputSplit` to the individual task.

[TextInputFormat](#) is the default `InputFormat`.

If `TextInputFormat` is the `InputFormat` for a given job, the framework detects input-files with the `.gz` and `.lzo` extensions and automatically decompresses them using the appropriate `CompressionCodec`. However, it must be noted that compressed files with the above extensions cannot be *split* and each compressed file is processed in its entirety by a single mapper.

6.5.1. InputSplit

[InputSplit](#) represents the data to be processed by an individual Mapper.

Typically `InputSplit` presents a byte-oriented view of the input, and it is the responsibility of `RecordReader` to process and present a record-oriented view.

[FileSplit](#) is the default `InputSplit`. It sets `map.input.file` to the path of the input file for the logical split.

6.5.2. RecordReader

[RecordReader](#) reads `<key, value>` pairs from an `InputSplit`.

Typically the `RecordReader` converts the byte-oriented view of the input, provided by the `InputSplit`, and presents a record-oriented to the Mapper implementations for processing. `RecordReader` thus assumes the responsibility of processing record boundaries and presents the tasks with keys and values.

6.6. Job Output

[OutputFormat](#) describes the output-specification for a Map-Reduce job.

The Map-Reduce framework relies on the `OutputFormat` of the job to:

1. Validate the output-specification of the job; for example, check that the output directory doesn't already exist.
2. Provide the `RecordWriter` implementation used to write the output files of the job. Output files are stored in a `FileSystem`.

`TextOutputFormat` is the default `OutputFormat`.

6.6.1. Task Side-Effect Files

In some applications, component tasks need to create and/or write to side-files, which differ from the actual job-output files.

In such cases there could be issues with two instances of the same Mapper or Reducer running simultaneously (for example, speculative tasks) trying to open and/or write to the same file (path) on the `FileSystem`. Hence the application-writer will have to pick unique names per task-attempt (using the taskid, say `task_200709221812_0001_m_000000_0`), not just per task.

To avoid these issues the Map-Reduce framework maintains a special `${mapred.output.dir}/_${taskid}` sub-directory for each task-attempt on the `FileSystem` where the output of the task-attempt is stored. On successful completion of the task-attempt, the files in the `${mapred.output.dir}/_${taskid}` (only) are *promoted* to `${mapred.output.dir}`. Of course, the framework discards the sub-directory of unsuccessful task-attempts. This process is completely transparent to the application.

The application-writer can take advantage of this feature by creating any side-files required in `${mapred.output.dir}` during execution of a task via [JobConf.getOutputPath\(\)](#), and the framework will promote them similarly for succesful task-attempts, thus eliminating the need to pick unique paths per task-attempt.

6.6.2. RecordWriter

[RecordWriter](#) writes the output `<key, value>` pairs to an output file.

`RecordWriter` implementations write the job outputs to the `FileSystem`.

6.7. Other Useful Features

6.7.1. Counters

`Counters` represent global counters, defined either by the Map-Reduce framework or applications. Each `Counter` can be of any `Enum` type. Counters of a particular `Enum` are

bunched into groups of type `Counters.Group`.

Applications can define arbitrary `Counters` (of type `Enum`) and update them via [Reporter.incrCounter\(Enum, long\)](#) in the map and/or reduce methods. These counters are then globally aggregated by the framework.

6.7.2. DistributedCache

[DistributedCache](#) distributes application-specific, large, read-only files efficiently.

`DistributedCache` is a facility provided by the Map-Reduce framework to cache files (text, archives, jars and so on) needed by applications.

Applications specify the files to be cached via urls (`hdfs://` or `http://`) in the `JobConf`. The `DistributedCache` assumes that the files specified via `hdfs://` urls are already present on the `FileSystem`.

The framework will copy the necessary files to the slave node before any tasks for the job are executed on that node. Its efficiency stems from the fact that the files are only copied once per job and the ability to cache archives which are un-archived on the slaves.

`DistributedCache` tracks the modification timestamps of the cached files. Clearly the cache files should not be modified by the application or externally while the job is executing.

`DistributedCache` can be used to distribute simple, read-only data/text files and more complex types such as archives and jars. Archives (zip files) are *un-archived* at the slave nodes. Optionally users can also direct the `DistributedCache` to *symlink* the cached file(s) into the current working directory of the task via the [DistributedCache.createSymlink\(Path, Configuration\)](#) api. Files have *execution permissions* set.

6.7.3. Tool

The [Tool](#) interface supports the handling of generic Hadoop command-line options.

`Tool` is the standard for any Map-Reduce tool or application. The application should delegate the handling of standard command-line options to [GenericOptionsParser](#) via [ToolRunner.run\(Tool, String\[\]\)](#) and only handle its custom arguments.

The generic Hadoop command-line options are:

```
-conf <configuration file>
-D <property=value>
-fs <local|namenode:port>
-jt <local|jobtracker:port>
```

6.7.4. IsolationRunner

[IsolationRunner](#) is a utility to help debug Map-Reduce programs.

To use the `IsolationRunner`, first set `keep.failed.tasks.files` to `true` (also see `keep.tasks.files.pattern`).

Next, go to the node on which the failed task ran and go to the TaskTracker's local directory and run the `IsolationRunner`:

```
$ cd <local path>/taskTracker/${taskid}/work
$ bin/hadoop org.apache.hadoop.mapred.IsolationRunner
../job.xml
```

`IsolationRunner` will run the failed task in a single jvm, which can be in the debugger, over precisely the same input.

6.7.5. JobControl

[JobControl](#) is a utility which encapsulates a set of Map-Reduce jobs and their dependencies.

6.7.6. Data Compression

Hadoop Map-Reduce provides facilities for the application-writer to specify compression for both intermediate map-outputs and the job-outputs i.e. output of the reduces. It also comes bundled with [CompressionCodec](#) implementations for the [zlib](#) and [lzo](#) compression algorithms. The [gzip](#) file format is also supported.

Hadoop also provides native implementations of the above compression codecs for reasons of both performance (zlib) and non-availability of Java libraries (lzo). More details on their usage and availability are available [here](#).

6.7.6.1. Intermediate Outputs

Applications can control compression of intermediate map-outputs via the [JobConf.setCompressMapOutput\(boolean\)](#) api and the `CompressionCodec` to be used via the [JobConf.setMapOutputCompressorClass\(Class\)](#) api. Since the intermediate map-outputs are always stored in the [SequenceFile](#) format, the [SequenceFile.CompressionType](#) (i.e. [RECORD](#) / [BLOCK](#) - defaults to `RECORD`) can be specified via the [JobConf.setMapOutputCompressionType\(SequenceFile.CompressionType\)](#) api.

6.7.6.2. Job Outputs

Applications can control compression of job-outputs via the [OutputFormatBase.setCompressOutput\(JobConf, boolean\)](#) api and the CompressionCodec to be used can be specified via the [OutputFormatBase.setOutputCompressorClass\(JobConf, Class\)](#) api.

If the job outputs are to be stored in the [SequenceFileOutputFormat](#), the required `SequenceFile.CompressionType` (i.e. RECORD / BLOCK - defaults to RECORD) can be specified via the [SequenceFileOutputFormat.setOutputCompressionType\(JobConf, SequenceFile.CompressionType\)](#) api.

7. Example: WordCount v2.0

Here is a more complete WordCount which uses many of the features provided by the Map-Reduce framework we discussed so far.

This needs the HDFS to be up and running, especially for the DistributedCache-related features. Hence it only works with a [pseudo-distributed](#) or [fully-distributed](#) Hadoop installation.

7.1. Source Code

WordCount.java	
1.	<code>package org.myorg;</code>
2.	
3.	<code>import java.io.*;</code>
4.	<code>import java.util.*;</code>
5.	
6.	<code>import org.apache.hadoop.fs.Path;</code>
7.	<code>import org.apache.hadoop.filecache.DistributedCache;</code>
8.	<code>import org.apache.hadoop.conf.*;</code>
9.	<code>import org.apache.hadoop.io.*;</code>
10.	<code>import org.apache.hadoop.mapred.*;</code>
11.	<code>import org.apache.hadoop.util.*;</code>
12.	

13.	<code>public class WordCount extends Configured implements Tool {</code>
14.	
15.	<code>public static class Map extends MapReduceBase implements Mapper<LongWritable, Text, Text, IntWritable> {</code>
16.	
17.	<code>static enum Counters { INPUT_WORDS }</code>
18.	
19.	<code>private final static IntWritable one = new IntWritable(1);</code>
20.	<code>private Text word = new Text();</code>
21.	
22.	<code>private boolean caseSensitive = true;</code>
23.	<code>private Set<String> patternsToSkip = new HashSet<String>();</code>
24.	
25.	<code>private long numRecords = 0;</code>
26.	<code>private String inputFile;</code>
27.	
28.	<code>public void configure(JobConf job) {</code>
29.	<code>caseSensitive = job.getBoolean("wordcount.case.sensitive", true);</code>
30.	<code>inputFile = job.get("map.input.file");</code>
31.	

32.	<code>if (job.getBoolean("wordcount.skip.patterns", false)) {</code>
33.	<code>Path[] patternsFiles = new Path[0];</code>
34.	<code>try {</code>
35.	<code>patternsFiles = DistributedCache.getLocalCacheFiles(job);</code>
36.	<code>} catch (IOException ioe) {</code>
37.	<code>System.err.println("Caught exception while getting cached files: " + StringUtils.stringifyException(ioe));</code>
38.	<code>}</code>
39.	<code>for (Path patternsFile : patternsFiles) {</code>
40.	<code>parseSkipFile(patternsFile);</code>
41.	<code>}</code>
42.	<code>}</code>
43.	<code>}</code>
44.	
45.	<code>private void parseSkipFile(Path patternsFile) {</code>
46.	<code>try {</code>
47.	<code>BufferedReader fis = new BufferedReader(new FileReader(patternsFile.toString()));</code>
48.	<code>String pattern = null;</code>
49.	<code>while ((pattern = fis.readLine()) != null) {</code>
50.	<code>patternsToSkip.add(pattern);</code>
51.	<code>}</code>

52.	<code>} catch (IOException ioe) {</code>
53.	<code> System.err.println("Caught exception while parsing the cached file '" + patternsFile + "' : " + StringUtils.stringifyException(ioe));</code>
54.	<code>}</code>
55.	<code>}</code>
56.	
57.	<code> public void map(LongWritable key, Text value, OutputCollector<Text, IntWritable> output, Reporter reporter) throws IOException {</code>
58.	<code> String line = (caseSensitive) ? value.toString() : value.toString().toLowerCase();</code>
59.	
60.	<code> for (String pattern : patternsToSkip) {</code>
61.	<code> line = line.replaceAll(pattern, "");</code>
62.	<code> }</code>
63.	
64.	<code> StringTokenizer tokenizer = new StringTokenizer(line);</code>
65.	<code> while (tokenizer.hasMoreTokens()) {</code>
66.	<code> word.set(tokenizer.nextToken());</code>
67.	<code> output.collect(word, one);</code>
68.	<code> reporter.incrCounter(Counters.INPUT_WORDS, 1);</code>
69.	<code> }</code>

70.	
71.	<code>if ((++numRecords % 100) == 0) {</code>
72.	<code> reporter.setStatus("Finished processing " + numRecords + " records " + "from the input file: " + inputFile);</code>
73.	<code>}</code>
74.	<code>}</code>
75.	<code>}</code>
76.	
77.	<code>public static class Reduce extends MapReduceBase implements Reducer<Text, IntWritable, Text, IntWritable> {</code>
78.	<code> public void reduce(Text key, Iterator<IntWritable> values, OutputCollector<Text, IntWritable> output, Reporter reporter) throws IOException {</code>
79.	<code> int sum = 0;</code>
80.	<code> while (values.hasNext()) {</code>
81.	<code> sum += values.next().get();</code>
82.	<code> }</code>
83.	<code> output.collect(key, new IntWritable(sum));</code>
84.	<code> }</code>
85.	<code>}</code>
86.	
87.	<code>public int run(String[] args) throws Exception {</code>
88.	<code> JobConf conf = new JobConf(getConf(), WordCount.class);</code>

89.	<code>conf.setJobName("wordcount");</code>
90.	
91.	<code>conf.setOutputKeyClass(Text.class);</code>
92.	<code>conf.setOutputValueClass(IntWritable.class);</code>
93.	
94.	<code>conf.setMapperClass(Map.class);</code>
95.	<code>conf.setCombinerClass(Reduce.class);</code>
96.	<code>conf.setReducerClass(Reduce.class);</code>
97.	
98.	<code>conf.setInputFormat(TextInputFormat.class);</code>
99.	<code>conf.setOutputFormat(TextOutputFormat.class);</code>
100.	
101.	<code>List<String> other_args = new ArrayList<String>();</code>
102.	<code>for (int i=0; i < args.length; ++i) {</code>
103.	<code>if ("-skip".equals(args[i])) {</code>
104.	<code>DistributedCache.addCacheFile(new Path(args[++i]).toUri(), conf);</code>
105.	<code>conf.setBoolean("wordcount.skip.patterns", true);</code>
106.	<code>} else {</code>
107.	<code>other_args.add(args[i]);</code>
108.	<code>}</code>

109.	}
110.	
111.	<code>conf.setInputPath(new Path(other_args.get(0)));</code>
112.	<code>conf.setOutputPath(new Path(other_args.get(1)));</code>
113.	
114.	<code>JobClient.runJob(conf);</code>
115.	<code>return 0;</code>
116.	}
117.	
118.	<code>public static void main(String[] args) throws Exception {</code>
119.	<code>int res = ToolRunner.run(new Configuration(), new WordCount(), args);</code>
120.	<code>System.exit(res);</code>
121.	}
122.	}
123.	

7.2. Sample Runs

Sample text-files as input:

```
$ bin/hadoop dfs -ls /usr/joe/wordcount/input/
/usr/joe/wordcount/input/file01
/usr/joe/wordcount/input/file02
$ bin/hadoop dfs -cat /usr/joe/wordcount/input/file01
Hello World, Bye World!
$ bin/hadoop dfs -cat /usr/joe/wordcount/input/file02
Hello Hadoop, Goodbye to hadoop.
```

Run the application:

```
$ bin/hadoop jar /usr/joe/wordcount.jar org.myorg.WordCount
/usr/joe/wordcount/input /usr/joe/wordcount/output
```

Output:

```
$ bin/hadoop dfs -cat /usr/joe/wordcount/output/part-00000
Bye 1
Goodbye 1
Hadoop, 1
Hello 2
World! 1
World, 1
hadoop. 1
to 1
```

Notice that the inputs differ from the first version we looked at, and how they affect the outputs.

Now, lets plug-in a pattern-file which lists the word-patterns to be ignored, via the DistributedCache.

```
$ hadoop dfs -cat /user/joe/wordcount/patterns.txt
\.
\,
\!
to
```

Run it again, this time with more options:

```
$ bin/hadoop jar /usr/joe/wordcount.jar org.myorg.WordCount
-Dwordcount.case.sensitive=true /usr/joe/wordcount/input
/usr/joe/wordcount/output -skip
/user/joe/wordcount/patterns.txt
```

As expected, the output:

```
$ bin/hadoop dfs -cat /usr/joe/wordcount/output/part-00000
Bye 1
Goodbye 1
Hadoop 1
Hello 2
World 2
hadoop 1
```

Run it once more, this time switch-off case-sensitivity:

```
$ bin/hadoop jar /usr/joe/wordcount.jar org.myorg.WordCount
-Dwordcount.case.sensitive=false /usr/joe/wordcount/input
/usr/joe/wordcount/output -skip
/user/joe/wordcount/patterns.txt
```

Sure enough, the output:

```
$ bin/hadoop dfs -cat /usr/joe/wordcount/output/part-00000
bye 1
goodbye 1
hadoop 2
hello 2
world 2
```

7.3. Highlights

The second version of WordCount improves upon the previous one by using some features offered by the Map-Reduce framework:

- Demonstrates how applications can access configuration parameters in the `configure` method of the Mapper (and Reducer) implementations (lines 28-43).
- Demonstrates how the `DistributedCache` can be used to distribute read-only data needed by the jobs. Here it allows the user to specify word-patterns to skip while counting (line 104).
- Demonstrates the utility of the `Tool` interface and the `GenericOptionsParser` to handle generic Hadoop command-line options (lines 87-116, 119).
- Demonstrates how applications can use `Counters` (line 68) and how they can set application-specific status information via the `Reporter` instance passed to the `map` (and `reduce`) method (line 72).

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