Writing An Hadoop MapReduce Program In Python

In this tutorial I will describe how to write a simple MapReduce program for Hadoop in thePython programming language.

Motivation

Even though the Hadoop framework is written in Java, programs for Hadoop need not to be coded in Java but can also be developed in other languages like Python or C++ (the latter since version 0.14.1). However, Hadoop's documentation and the most prominent Python example on the Hadoop website could make you think that you *must* translate your Python code using Jython into a Java jar file. Obviously, this is not very convenient and can even be problematic if you depend on Python features not provided by Jython. Another issue of the Jython approach is the overhead of writing your Python program in such a way that it can interact with Hadoop – just have a look at the example in `$HADOOP_HOME/src/examples/python/WordCount.py` and you see what I mean.

That said, the ground is now prepared for the purpose of this tutorial: writing a Hadoop MapReduce program in a more Pythonic way, i.e. in a way you should be familiar with.

What we want to do

We will write a simple MapReduce program (see also the MapReduce article on Wikipedia) for Hadoop in Python but *without* using Jython to translate our code to Java jar files.

Our program will mimick the WordCount, i.e. it reads text files and counts how often words occur. The input is text files and the output is text files, each line of which contains a word and the count of how often it occured, separated by a tab.

> Note: You can also use programming languages other than Python such as Perl or Ruby with the "technique" described in this tutorial.

Prerequisites

You should have an Hadoop cluster up and running because we will get our hands dirty. If you don't have a cluster yet, my following tutorials might help you to build one. The tutorials are tailored to Ubuntu Linux but the information does also apply to other Linux/Unix variants.

- Running Hadoop On Ubuntu Linux (Single-Node Cluster) – How to set up a *pseudo-distributed*, *single-node* Hadoop cluster backed by the Hadoop Distributed File System (HDFS)
- Running Hadoop On Ubuntu Linux (Multi-Node Cluster) – How to set up a *distributed*, *multi-node* Hadoop cluster backed by the Hadoop Distributed File System (HDFS)

Python MapReduce Code

The "trick" behind the following Python code is that we will use the Hadoop Streaming API (see also the corresponding wiki entry) for helping us passing data between our Map and Reduce code via `STDIN` (standard input) and `STDOUT` (standard output). We will simply use Python's `sys.stdin` to read input data and print our own output to `sys.stdout`. That's all we need to do because Hadoop Streaming will take care of everything else!

Map step: mapper.py

Save the following code in the file `/home/hduser/mapper.py`. It will read data from `STDIN`, split it into words and output a list of lines mapping words to their (intermediate) counts to `STDOUT`. The Map script will not compute an (intermediate) sum of a word's occurrences though. Instead, it will output `<word> 1` tuples immediately – even though a specific word might occur multiple times in the input. In our case we let the subsequent Reduce step do the final sum count. Of course, you can change this behavior in your own scripts as you please, but we will keep it like that in this tutorial because of didactic reasons. :-)

Make sure the file has execution permission (`chmod +x /home/hduser/mapper.py` should do the trick) or you will run into problems.

```
#!/usr/bin/env python
"""mapper.py"""

import sys

# input comes from STDIN (standard input)
for line in sys.stdin:
    # remove leading and trailing whitespace
    line = line.strip()
    # split the line into words
    words = line.split()
    # increase counters
    for word in words:
        # write the results to STDOUT (standard output);
        # what we output here will be the input for the
        # Reduce step, i.e. the input for reducer.py
        #
        # tab-delimited; the trivial word count is 1
        print '%s\t%s' % (word, 1)
```

Reduce step: reducer.py

Save the following code in the file `/home/hduser/reducer.py`. It will read the results of `mapper.py` from `STDIN` (so the output format of `mapper.py` and the expected input format

of `reducer.py` must match) and sum the occurrences of each word to a final count, and then output its results to `STDOUT`.

Make sure the file has execution permission (`chmod +x /home/hduser/reducer.py` should do the trick) or you will run into problems.

```
#!/usr/bin/env python
"""reducer.py"""

from operator import itemgetter
import sys

current_word = None
current_count = 0
word = None

# input comes from STDIN
for line in sys.stdin:
    # remove leading and trailing whitespace
    line = line.strip()

    # parse the input we got from mapper.py
    word, count = line.split('\t', 1)

    # convert count (currently a string) to int
    try:
        count = int(count)
    except ValueError:
        # count was not a number, so silently
        # ignore/discard this line
        continue

    # this IF-switch only works because Hadoop sorts map output
    # by key (here: word) before it is passed to the reducer
    if current_word == word:
        current_count += count
    else:
        if current_word:
            # write result to STDOUT
            print '%s\t%s' % (current_word, current_count)
        current_count = count
        current_word = word

# do not forget to output the last word if needed!
if current_word == word:
    print '%s\t%s' % (current_word, current_count)
```

Test your code (cat data | map | sort | reduce)

I recommend to test your `mapper.py` and `reducer.py` scripts locally before using them in a MapReduce job. Otherwise your jobs might successfully complete but there will be no job result data at all or not the results you would have expected. If that happens, most likely it was you (or me) who screwed up.

Here are some ideas on how to test the functionality of the Map and Reduce scripts.

```
# Test mapper.py and reducer.py locally first

# very basic test
hduser@ubuntu:~$ echo "foo foo quux labs foo bar quux" | /home/hduser/mapper.py
foo     1
foo     1
quux    1
labs    1
foo     1
bar     1
quux    1

hduser@ubuntu:~$ echo "foo foo quux labs foo bar quux" | /home/hduser/mapper.py | sort
bar     1
foo     3
labs    1
quux    2

# using one of the ebooks as example input
# (see below on where to get the ebooks)
hduser@ubuntu:~$ cat /tmp/gutenberg/20417-8.txt | /home/hduser/mapper.py
 The     1
 Project 1
 Gutenberg       1
 EBook   1
 of      1
 [...]
 (you get the idea)
```

Running the Python Code on Hadoop

Download example input data

We will use three ebooks from Project Gutenberg for this example:

- The Outline of Science, Vol. 1 (of 4) by J. Arthur Thomson
- The Notebooks of Leonardo Da Vinci
- Ulysses by James Joyce

Download each ebook as text files in `Plain Text UTF-8` encoding and store the files in a local temporary directory of choice, for example `/tmp/gutenberg`.

```
hduser@ubuntu:~$ ls -l /tmp/gutenberg/
total 3604
-rw-r--r-- 1 hduser hadoop  674566 Feb  3 10:17 pg20417.txt
-rw-r--r-- 1 hduser hadoop 1573112 Feb  3 10:18 pg4300.txt
-rw-r--r-- 1 hduser hadoop 1423801 Feb  3 10:18 pg5000.txt
hduser@ubuntu:~$
```

Copy local example data to HDFS

Before we run the actual MapReduce job, we must first copy the files from our local file system to Hadoop's HDFS.

```
hduser@ubuntu:/usr/local/hadoop$ bin/hadoop dfs -copyFromLocal /tmp/gutenberg /user/hd
hduser@ubuntu:/usr/local/hadoop$ bin/hadoop dfs -ls
Found 1 items
drwxr-xr-x   - hduser supergroup          0 2010-05-08 17:40 /user/hduser/gutenberg
hduser@ubuntu:/usr/local/hadoop$ bin/hadoop dfs -ls /user/hduser/gutenberg
Found 3 items
-rw-r--r--   3 hduser supergroup     674566 2011-03-10 11:38 /user/hduser/gutenberg/pg
-rw-r--r--   3 hduser supergroup    1573112 2011-03-10 11:38 /user/hduser/gutenberg/pg
-rw-r--r--   3 hduser supergroup    1423801 2011-03-10 11:38 /user/hduser/gutenberg/pg
hduser@ubuntu:/usr/local/hadoop$
```

Run the MapReduce job

Now that everything is prepared, we can finally run our Python MapReduce job on the Hadoop cluster. As I said above, we leverage the Hadoop Streaming API for helping us passing data between our Map and Reduce code via `STDIN` and `STDOUT`.

```
hduser@ubuntu:/usr/local/hadoop$ bin/hadoop jar contrib/streaming/hadoop-*streaming*.j
-file /home/hduser/mapper.py    -mapper /home/hduser/mapper.py \
-file /home/hduser/reducer.py   -reducer /home/hduser/reducer.py \
-input /user/hduser/gutenberg/* -output /user/hduser/gutenberg-output
```

If you want to modify some Hadoop settings on the fly like increasing the number of Reduce tasks, you can use the `-D` option:

```
hduser@ubuntu:/usr/local/hadoop$ bin/hadoop jar contrib/streaming/hadoop-*streaming*.j
```

> Note about `mapred.map.tasks`: Hadoop does not honor mapred.map.tasks beyond considering it a hint. But it accepts the user specified `mapred.reduce.tasks` and doesn't manipulate that. You cannot force `mapred.map.tasks` but can specify `mapred.reduce.tasks`.

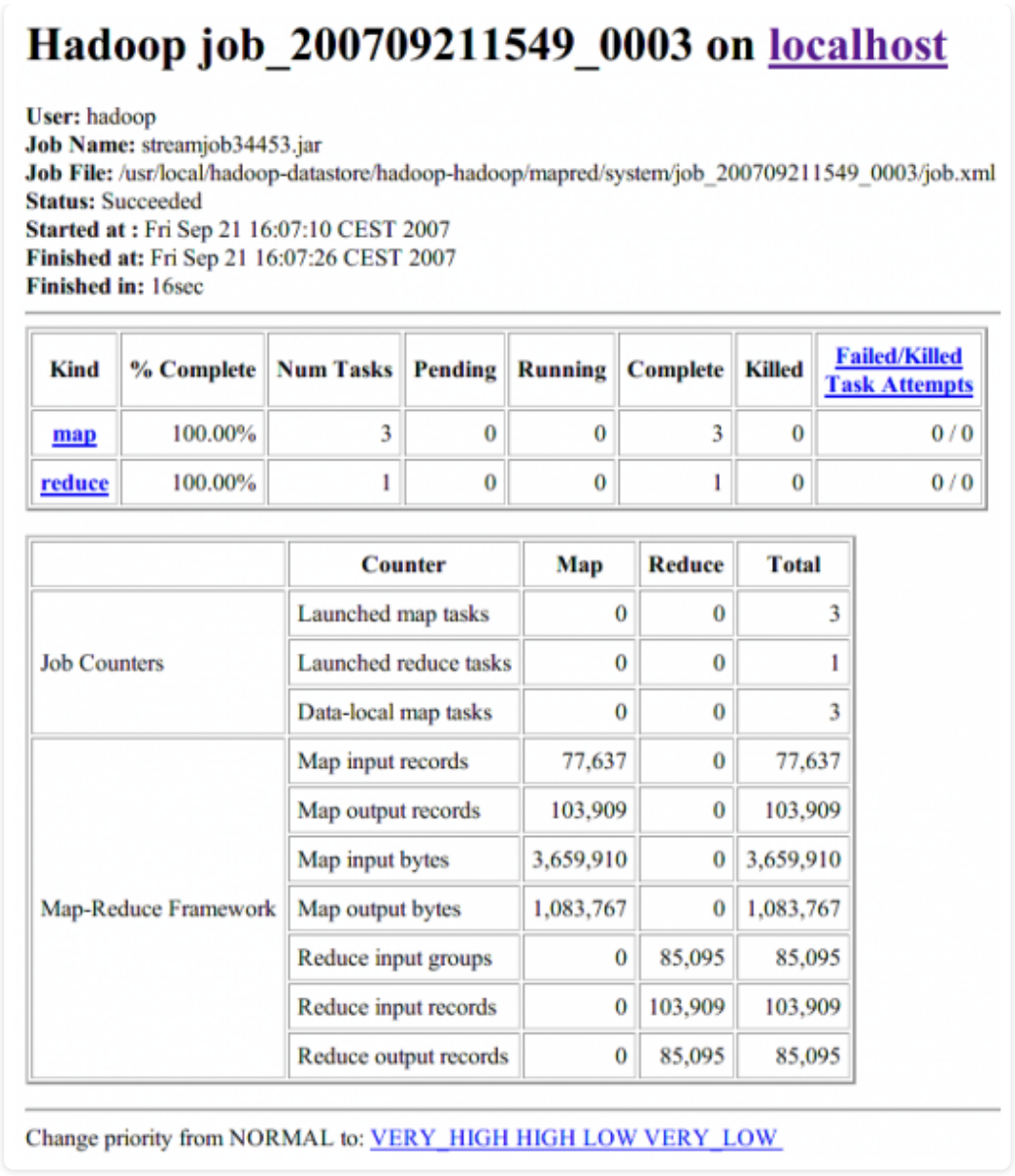
The job will read all the files in the HDFS directory `/user/hduser/gutenberg`, process it, and store the results in the HDFS directory `/user/hduser/gutenberg-output`. In general Hadoop will create one output file per reducer; in our case however it will only create a single file because the input files are very small.

Example output of the previous command in the console:

```
hduser@ubuntu:/usr/local/hadoop$ bin/hadoop jar contrib/streaming/hadoop-*streaming*.j
 additionalConfSpec_:null
```

```
 null=@@@userJobConfProps_.get(stream.shipped.hadoopstreaming
 packageJobJar: [/app/hadoop/tmp/hadoop-unjar54543/]
 [] /tmp/streamjob54544.jar tmpDir=null
 [...] INFO mapred.FileInputFormat: Total input paths to process : 7
 [...] INFO streaming.StreamJob: getLocalDirs(): [/app/hadoop/tmp/mapred/local]
 [...] INFO streaming.StreamJob: Running job: job_200803031615_0021
 [...]
 [...] INFO streaming.StreamJob:  map 0%  reduce 0%
 [...] INFO streaming.StreamJob:  map 43%  reduce 0%
 [...] INFO streaming.StreamJob:  map 86%  reduce 0%
 [...] INFO streaming.StreamJob:  map 100%  reduce 0%
 [...] INFO streaming.StreamJob:  map 100%  reduce 33%
 [...] INFO streaming.StreamJob:  map 100%  reduce 70%
 [...] INFO streaming.StreamJob:  map 100%  reduce 77%
 [...] INFO streaming.StreamJob:  map 100%  reduce 100%
 [...] INFO streaming.StreamJob: Job complete: job_200803031615_0021
 [...] INFO streaming.StreamJob: Output: /user/hduser/gutenberg-output
hduser@ubuntu:/usr/local/hadoop$
```

As you can see in the output above, Hadoop also provides a basic web interface for statistics and information. When the Hadoop cluster is running, open http://localhost:50030/ in a browser and have a look around. Here's a screenshot of the Hadoop web interface for the job we just ran.



Hadoop job_200709211549_0003 on localhost

User: hadoop
Job Name: streamjob34453.jar
Job File: /usr/local/hadoop-datastore/hadoop-hadoop/mapred/system/job_200709211549_0003/job.xml
Status: Succeeded
Started at : Fri Sep 21 16:07:10 CEST 2007
Finished at: Fri Sep 21 16:07:26 CEST 2007
Finished in: 16sec

Kind	% Complete	Num Tasks	Pending	Running	Complete	Killed	Failed/Killed Task Attempts
map	100.00%	3	0	0	3	0	0 / 0
reduce	100.00%	1	0	0	1	0	0 / 0

	Counter	Map	Reduce	Total
Job Counters	Launched map tasks	0	0	3
	Launched reduce tasks	0	0	1
	Data-local map tasks	0	0	3
Map-Reduce Framework	Map input records	77,637	0	77,637
	Map output records	103,909	0	103,909
	Map input bytes	3,659,910	0	3,659,910
	Map output bytes	1,083,767	0	1,083,767
	Reduce input groups	0	85,095	85,095
	Reduce input records	0	103,909	103,909
	Reduce output records	0	85,095	85,095

Change priority from NORMAL to: VERY_HIGH HIGH LOW VERY_LOW

Figure 1: A screenshot of Hadoop's JobTracker web interface, showing the details of the MapReduce job we just ran

Check if the result is successfully stored in HDFS directory `/user/hduser/gutenberg-output`:

```
hduser@ubuntu:/usr/local/hadoop$ bin/hadoop dfs -ls /user/hduser/gutenberg-output
Found 1 items
/user/hduser/gutenberg-output/part-00000     &lt;r 1&gt;   903193  2007-09-21 13:00
hduser@ubuntu:/usr/local/hadoop$
```

You can then inspect the contents of the file with the `dfs -cat` command:

```
hduser@ubuntu:/usr/local/hadoop$ bin/hadoop dfs -cat /user/hduser/gutenberg-output/par
"(Lo)cra"       1
"1490   1
"1498," 1
"35"    1
"40,"   1
```

```
"A      2
"AS-IS".        2
"A_     1
"Absoluti       1
[...]
hduser@ubuntu:/usr/local/hadoop$
```

Note that in this specific output above the quote signs (`"`) enclosing the words have not been inserted by Hadoop. They are the result of how our Python code splits words, and in this case it matched the beginning of a quote in the ebook texts. Just inspect the `part-00000` file further to see it for yourself.

Improved Mapper and Reducer code: using Python iterators and generators

The Mapper and Reducer examples above should have given you an idea of how to create your first MapReduce application. The focus was code simplicity and ease of understanding, particularly for beginners of the Python programming language. In a real-world application however, you might want to optimize your code by using Python iterators and generators (an even better introduction in PDF).

Generally speaking, iterators and generators (functions that create iterators, for example with Python's `yield` statement) have the advantage that an element of a sequence is not produced until you actually need it. This can help a lot in terms of computational expensiveness or memory consumption depending on the task at hand.

> Note: The following Map and Reduce scripts will only work "correctly" when being run in the Hadoop context, i.e. as Mapper and Reducer in a MapReduce job. This means that running the naive test command "cat DATA | ./mapper.py | sort -k1,1 | ./reducer.py" will not work correctly anymore because some functionality is intentionally outsourced to Hadoop.

Precisely, we compute the sum of a word's occurrences, e.g. `("foo", 4)`, only if by chance the same word (`foo`) appears multiple times in succession. In the majority of cases, however, we let the Hadoop group the (key, value) pairs between the Map and the Reduce step because Hadoop is more efficient in this regard than our simple Python scripts.

mapper.py

```
#!/usr/bin/env python
"""A more advanced Mapper, using Python iterators and generators."""

import sys

def read_input(file):
    for line in file:
        # split the line into words
        yield line.split()

def main(separator='\t'):
```

```
    # input comes from STDIN (standard input)
    data = read_input(sys.stdin)
    for words in data:
        # write the results to STDOUT (standard output);
        # what we output here will be the input for the
        # Reduce step, i.e. the input for reducer.py
        #
        # tab-delimited; the trivial word count is 1
        for word in words:
            print '%s%s%d' % (word, separator, 1)

if __name__ == "__main__":
    main()
```

reducer.py

```
#!/usr/bin/env python
"""A more advanced Reducer, using Python iterators and generators."""

from itertools import groupby
from operator import itemgetter
import sys

def read_mapper_output(file, separator='\t'):
    for line in file:
        yield line.rstrip().split(separator, 1)

def main(separator='\t'):
    # input comes from STDIN (standard input)
    data = read_mapper_output(sys.stdin, separator=separator)
    # groupby groups multiple word-count pairs by word,
    # and creates an iterator that returns consecutive keys and their group:
    #   current_word - string containing a word (the key)
    #   group - iterator yielding all ["&lt;current_word&gt;", "&lt;count&gt;"] items
    for current_word, group in groupby(data, itemgetter(0)):
        try:
            total_count = sum(int(count) for current_word, count in group)
            print "%s%s%d" % (current_word, separator, total_count)
        except ValueError:
            # count was not a number, so silently discard this item
            pass

if __name__ == "__main__":
    main()
```

Related Links

From yours truly:

- Running Hadoop On Ubuntu Linux (Single-Node Cluster)
- Running Hadoop On Ubuntu Linux (Multi-Node Cluster)