STAT679
Computing for Data Science and Statistics

Lecture 16: Hadoop and the `mrjob` package

Some slides adapted from C. Budak (UMichigan)

Recap

Previous lecture: Hadoop/MapReduce framework in general

This lecture: actually doing things

In particular: `mrjob` Python package

- https://mrjob.readthedocs.io/en/latest/
- **Installation:** `pip install mrjob` (or conda, or install from source...)

Recap: Basic concepts

Mapper: takes a (key,value) pair as input

Outputs zero or more (key,value) pairs

Outputs grouped by key

Combiner: takes a key and a subset of values for that key as input

Outputs zero or more (key,value) pairs

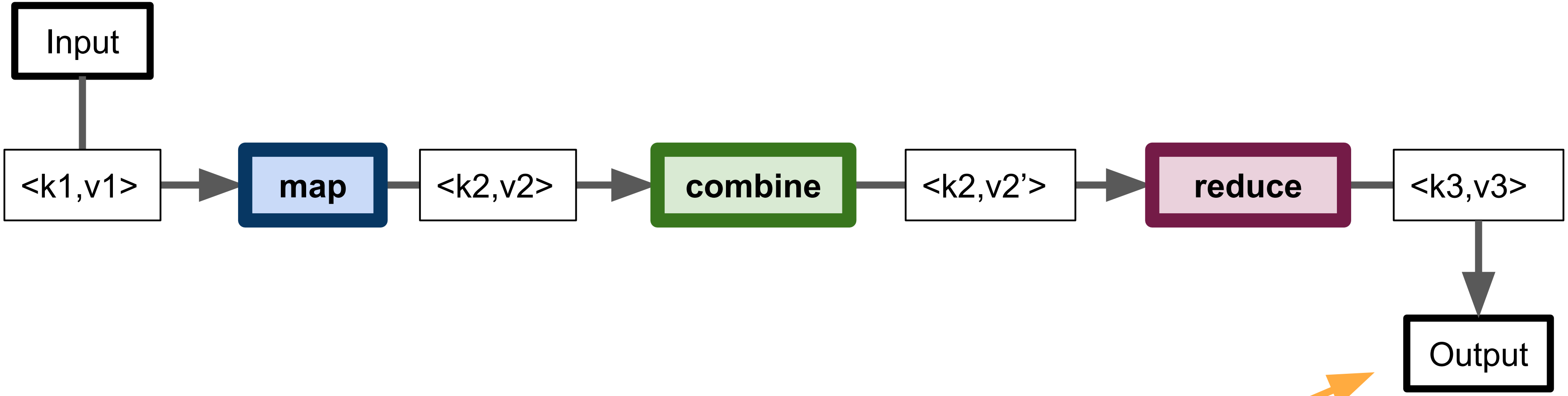
Runs after the mapper, only on a slice of the data

Must be **idempotent**

Reducer: takes a key and **all** values for that key as input

Outputs zero or more (key,value) pairs

Recap: a prototypical MapReduce program



Input

<k1,v1>

map

<k2,v2>

combine

<k2,v2’>

reduce

<k3,v3>

Output

Note: this output could be made the input to another MR program.

Recap: Basic concepts

Step: One sequence of map, combine, reduce

All three are optional, but must have at least one!

Node: a computing unit (e.g., a server in a rack)

Job tracker: a single node in charge of coordinating a Hadoop job

Assigns tasks to worker nodes

Worker node: a node that performs actual computations in Hadoop

e.g., computes the Map and Reduce functions

Python `mrjob` package

Developed at Yelp for simplifying/prototyping MapReduce jobs

https://engineeringblog.yelp.com/2010/10/mrjob-distributed-computing-for-everybody.html

`mrjob` acts like a wrapper around **Hadoop Streaming**

Hadoop Streaming makes Hadoop computing model available to languages other than Java

But `mrjob` can also be run without a Hadoop instance at all!

e.g., locally on your machine

Why use `mrjob`?

Fast prototyping

- Can run locally without a Hadoop cluster...
- ...but can also run atop Hadoop or Spark

Much simpler interface than Java Hadoop

Sensible error messages

- i.e., usually there’s a Python traceback error if something goes wrong
- Because everything runs “in Python”

`MRJob.{mapper, combiner, reducer}`

MRJob.mapper(*key*, *value*)

key – parsed from input; **value** – parsed from input.

Yields zero or more tuples of (out_key, out_value).

MRJob.combiner(*key*, *values*)

key – yielded by mapper; **value** – generator yielding all values from node corresponding to key.

Yields one or more tuples of (out_key, out_value)

MRJob.reducer(*key*, *values*)

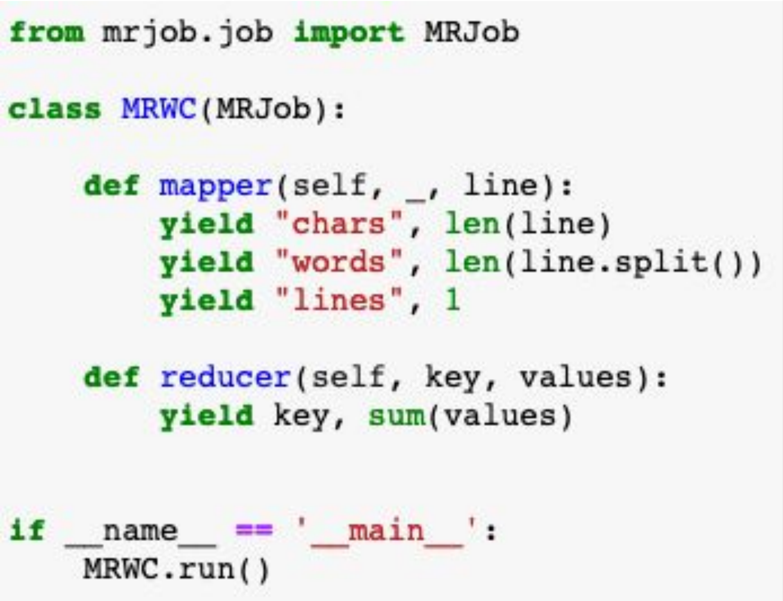
key – key yielded by mapper; **value** – generator yielding all values from corresponding to key.

Yields one or more tuples of (out_key, out_value)

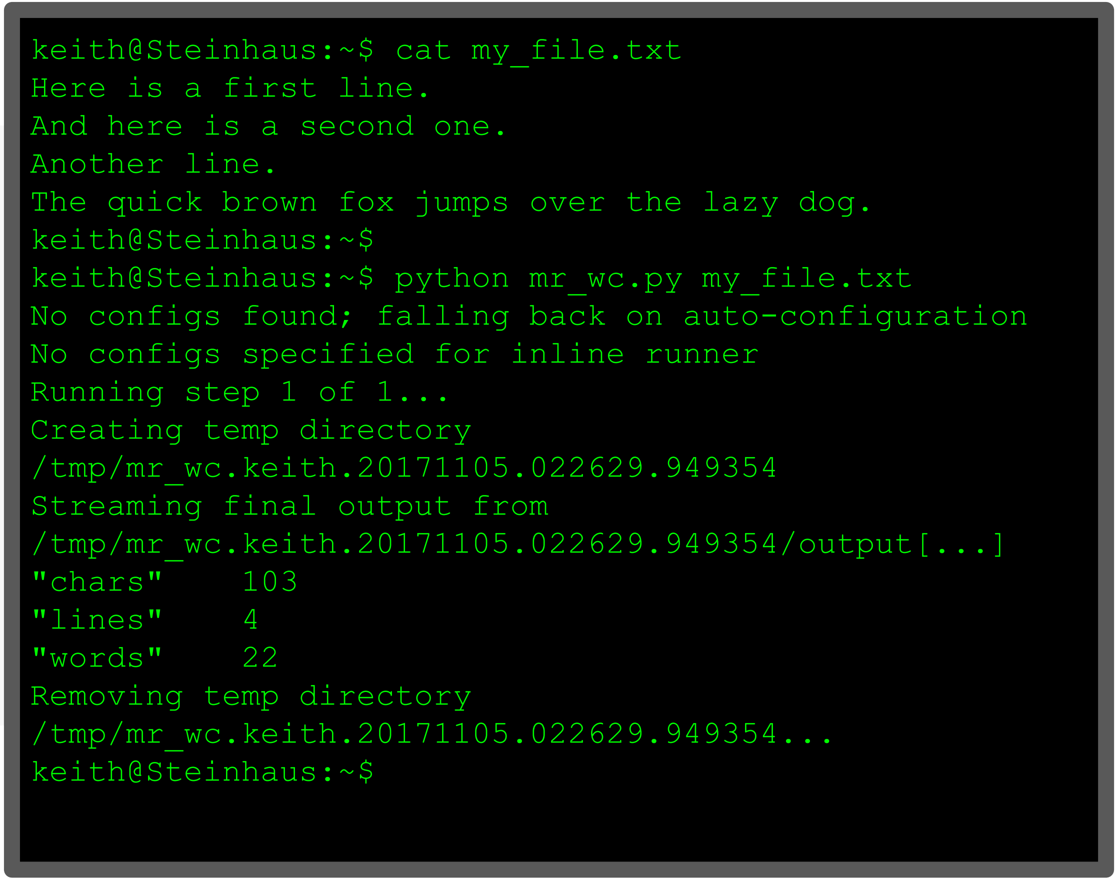
Details: https://mrjob.readthedocs.io/en/latest/guides/writing-mrjobs.html

Basic `mrjob` script

mr_wc.py



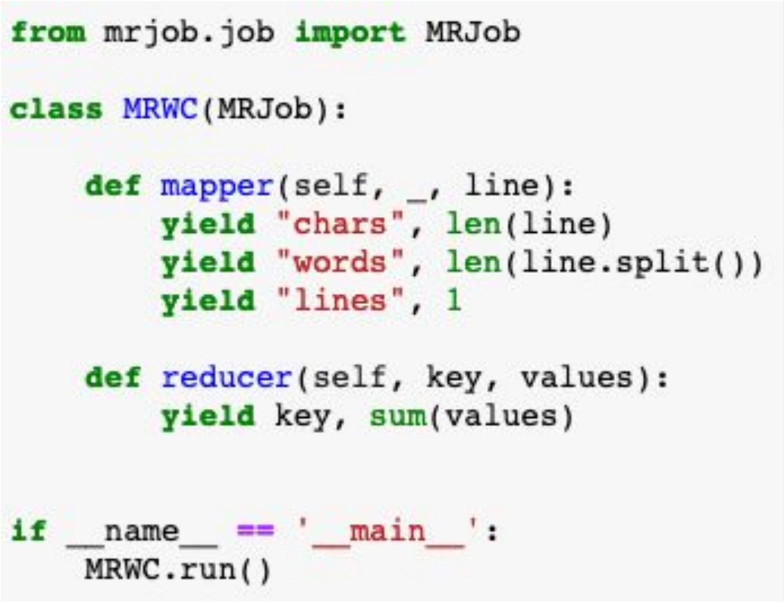
```python
from mrjob.job import MRJob

class MRWC(MRJob):

    def mapper(self, _, line):
        yield "chars", len(line)
        yield "words", len(line.split())
        yield "lines", 1

    def reducer(self, key, values):
        yield key, sum(values)


if __name__ == '__main__':
    MRWC.run()
```



```
keith@Steinhaus:~$ cat my_file.txt
Here is a first line.
And here is a second one.
Another line.
The quick brown fox jumps over the lazy dog.
keith@Steinhaus:~$
keith@Steinhaus:~$ python mr_wc.py my_file.txt
No configs found; falling back on auto-configuration
No configs specified for inline runner
Running step 1 of 1...
Creating temp directory
/tmp/mr_wc.keith.20171105.022629.949354
Streaming final output from
/tmp/mr_wc.keith.20171105.022629.949354/output[...]
"chars"    103
"lines"    4
"words"    22
Removing temp directory
/tmp/mr_wc.keith.20171105.022629.949354...
keith@Steinhaus:~$
```

Basic `mrjob` script

mr_wc.py



```python
from mrjob.job import MRJob

class MRWC(MRJob):

    def mapper(self, _, line):
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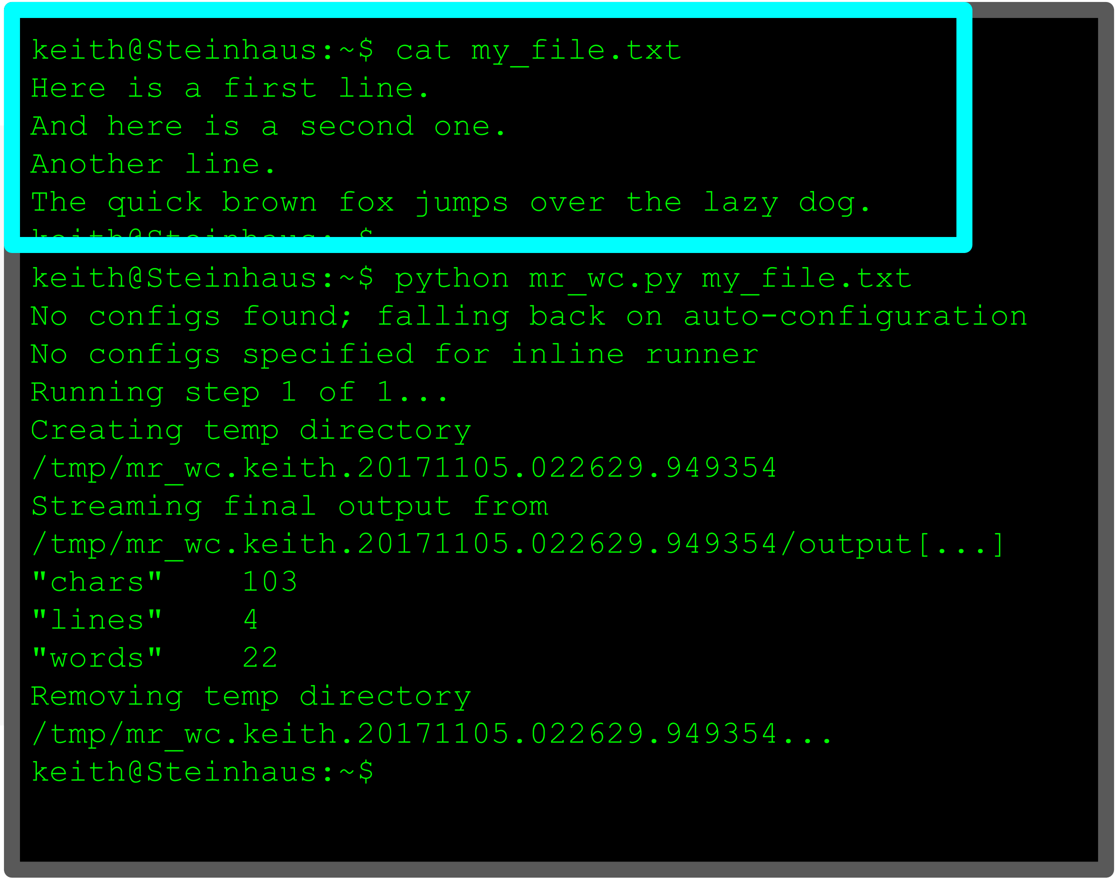
        yield "words", len(line.split())
        yield "lines", 1

    def reducer(self, key, values):
        yield key, sum(values)


if __name__ == '__main__':
    MRWC.run()
```

Contents of our example file.



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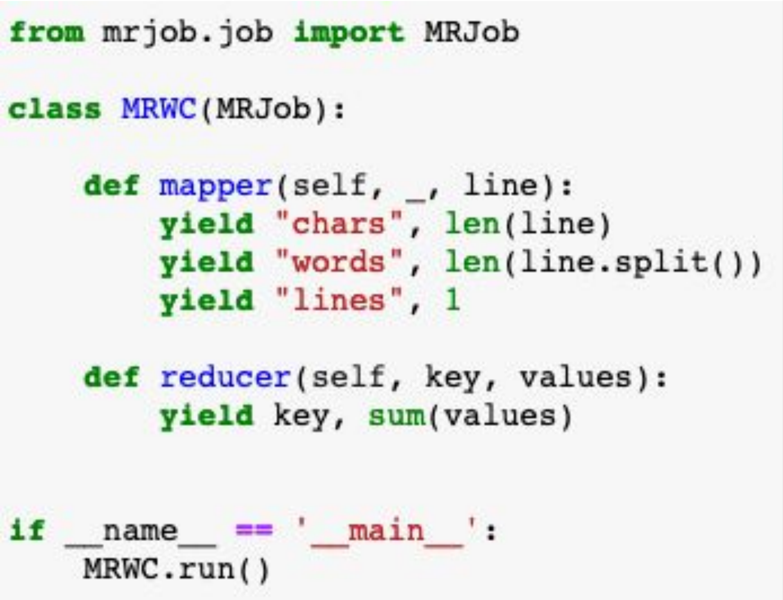
keith@Steinhaus:~$
```

Basic `mrjob` script

mr_wc.py



```
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class MRWC(MRJob):

    def mapper(self, _, line):
        yield "chars", len(line)
        yield "words", len(line.split())
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    def reducer(self, key, values):
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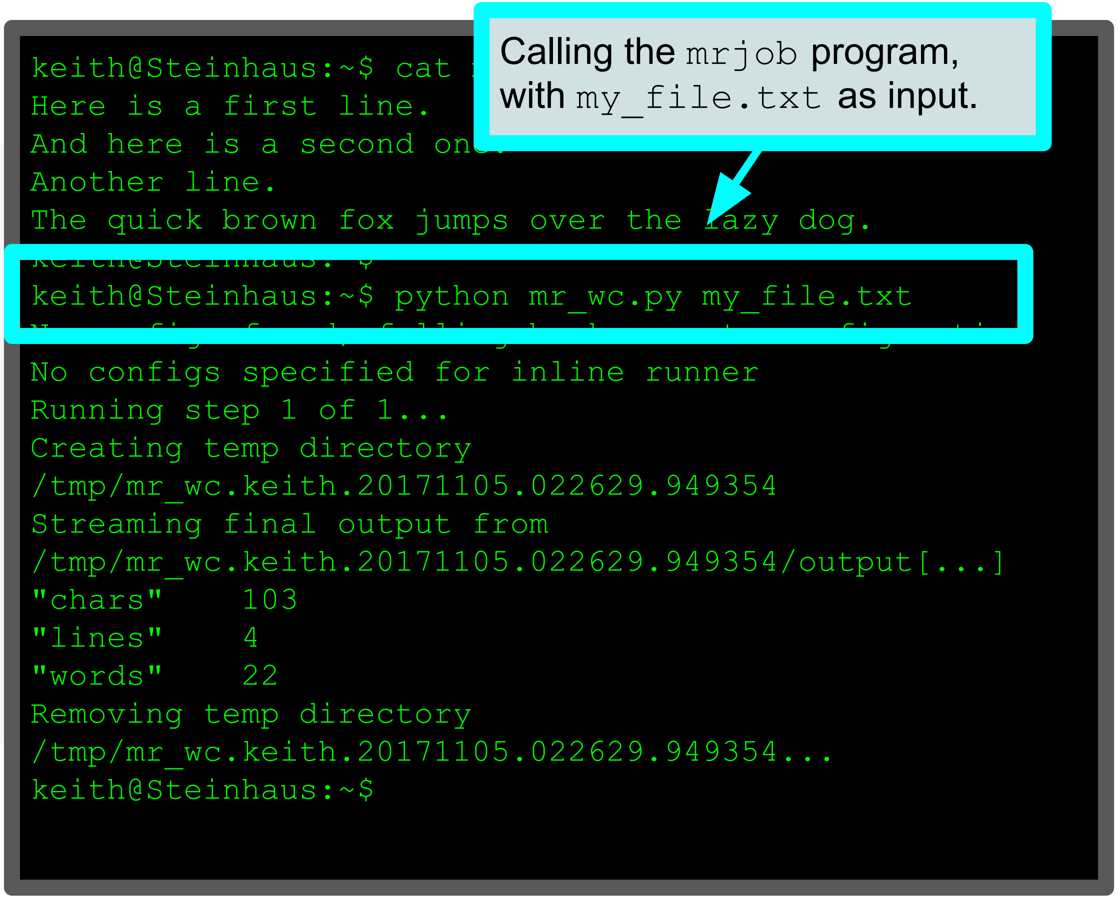
if __name__ == '__main__':
    MRWC.run()
```



```
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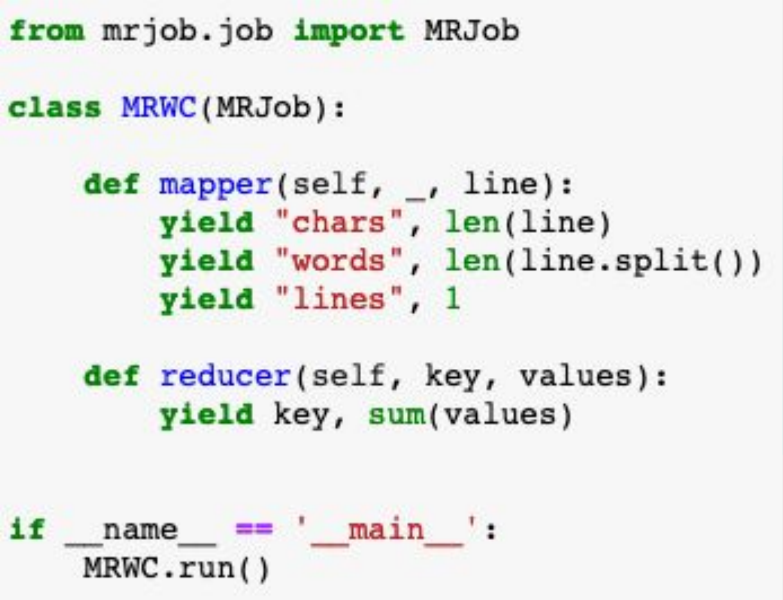
Removing temp directory
/tmp/mr_wc.keith.20171105.022629.949354...
keith@Steinhaus:~$
```

Calling the `mrjob` program, with `my_file.txt` as input.

Basic `mrjob` script

mr_wc.py



```python
from mrjob.job import MRJob

class MRWC(MRJob):

    def mapper(self, _, line):
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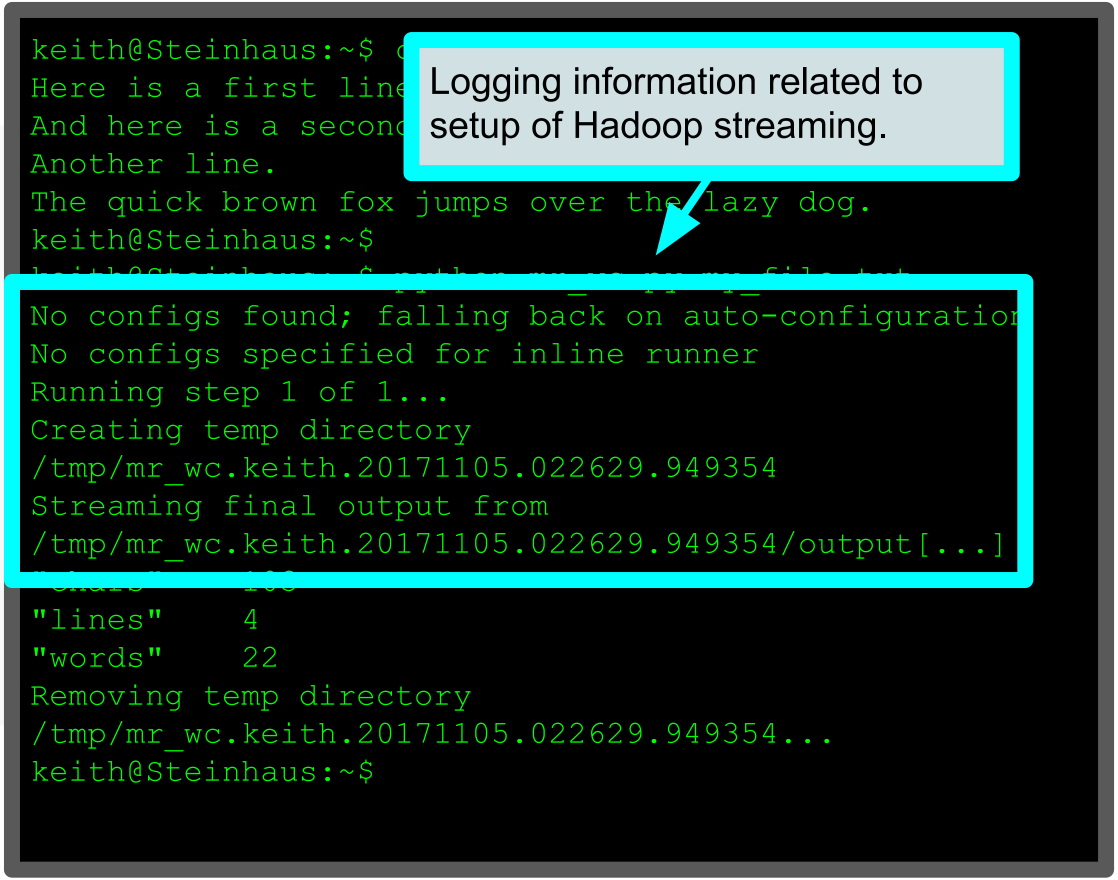
    def reducer(self, key, values):
        yield key, sum(values)


if __name__ == '__main__':
    MRWC.run()
```



```
keith@Steinhaus:~$ c
Here is a first line
And here is a second
Another line.
The quick brown fox jumps over the lazy dog.
keith@Steinhaus:~$
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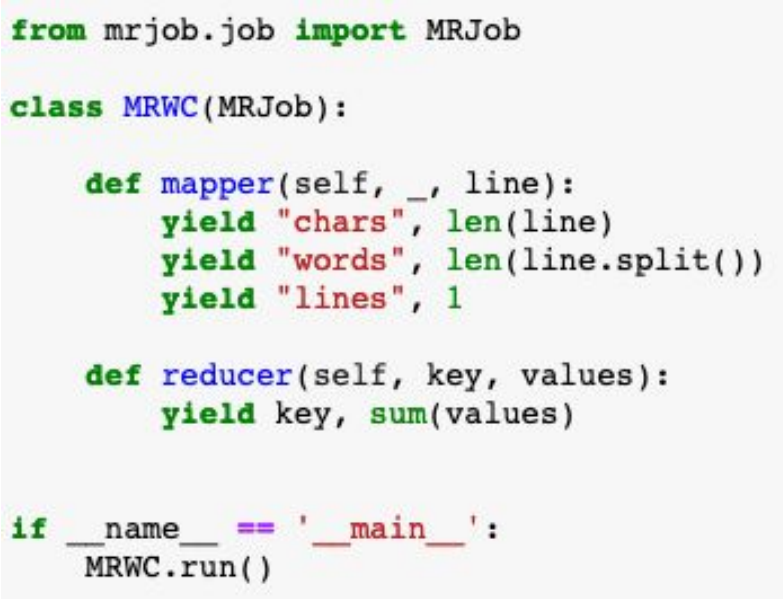
"chars"     103
"lines"     4
"words"     22
Removing temp directory
/tmp/mr_wc.keith.20171105.022629.949354...
keith@Steinhaus:~$
```

Logging information related to setup of Hadoop streaming.

Basic `mrjob` script

mr_wc.py



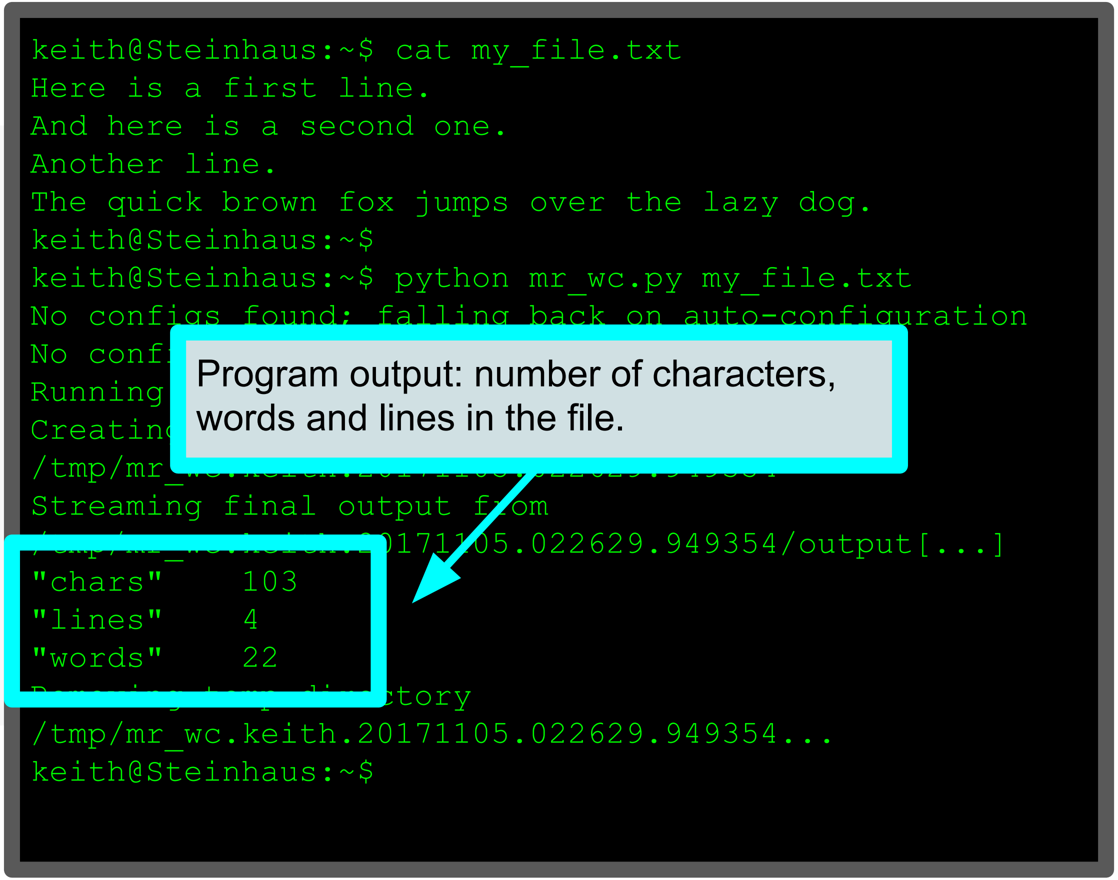
```
from mrjob.job import MRJob

class MRWC(MRJob):

    def mapper(self, _, line):
        yield "chars", len(line)
        yield "words", len(line.split())
        yield "lines", 1

    def reducer(self, key, values):
        yield key, sum(values)


if __name__ == '__main__':
    MRWC.run()
```



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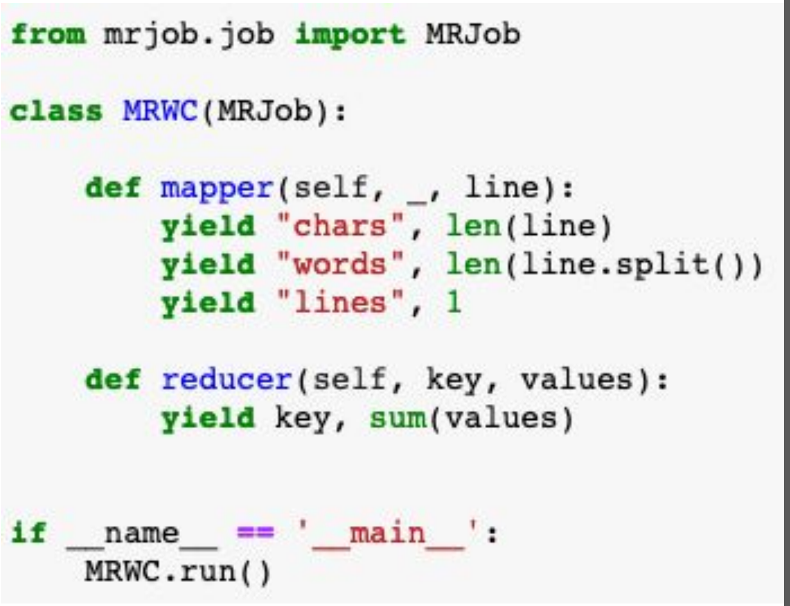
Removing temp directory
/tmp/mr_wc.keith.20171105.022629.949354...
keith@Steinhaus:~$
```

Program output: number of characters, words and lines in the file.

Basic `mrjob` script

mr_wc.py



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class MRWC(MRJob):

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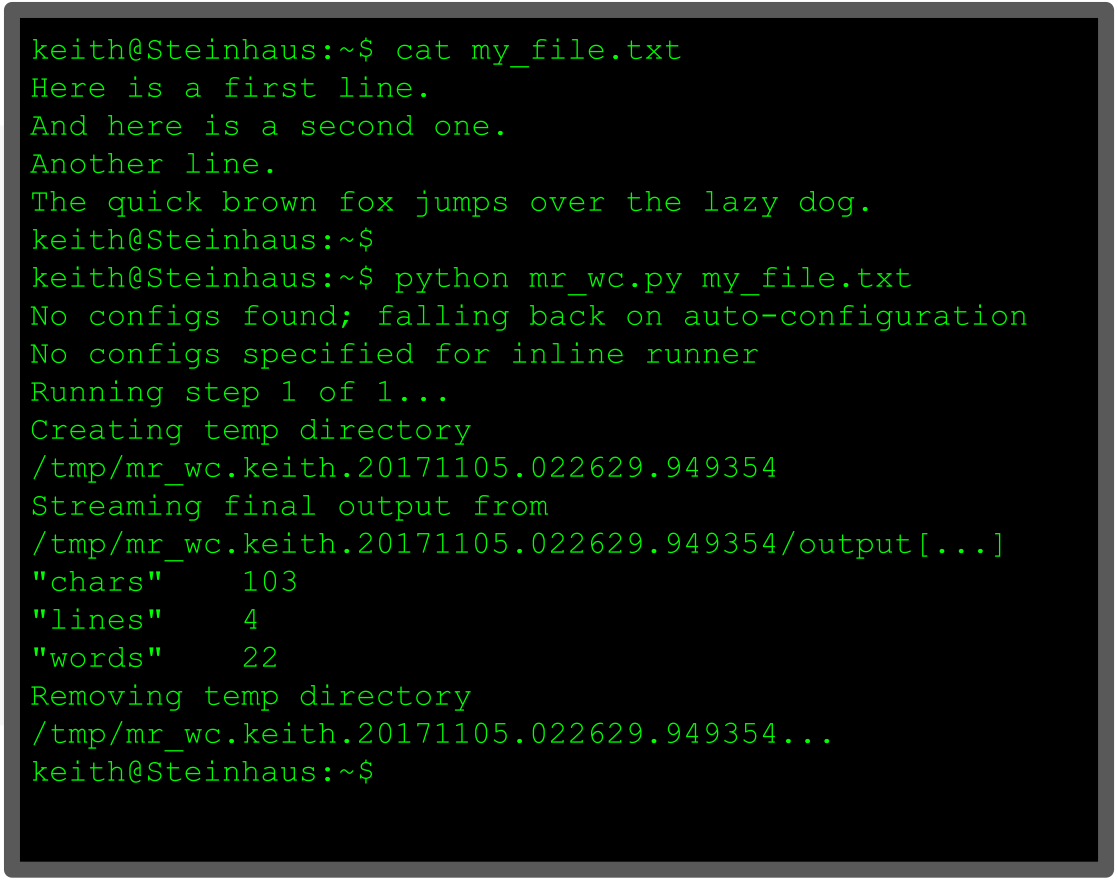
        yield key, sum(values)


if __name__ == '__main__':
    MRWC.run()
```



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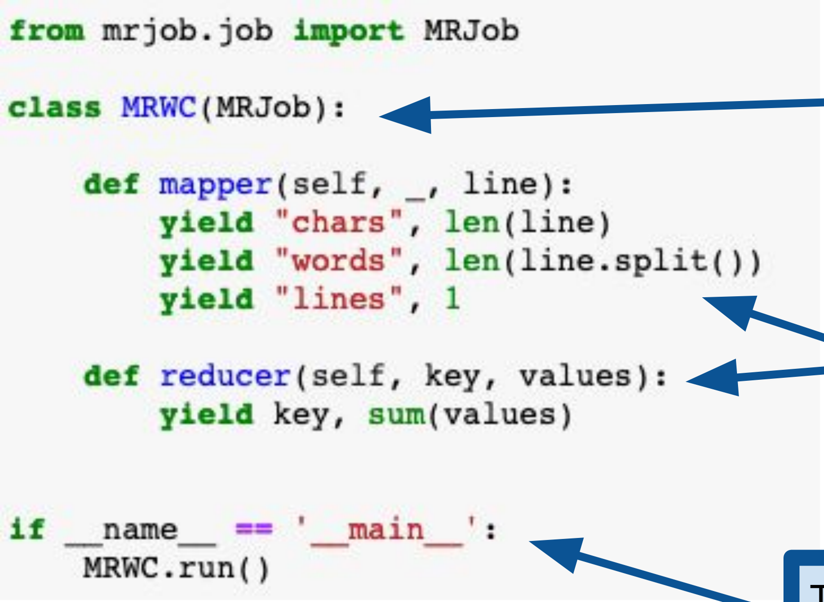
keith@Steinhaus:~$
```

Basic `mrjob` script

This is a MapReduce job that counts the number of characters, words, and lines in a file.

mr_wc.py



```python
from mrjob.job import MRJob

class MRWC(MRJob):

    def mapper(self, _, line):
        yield "chars", len(line)
        yield "words", len(line.split())
        yield "lines", 1

    def reducer(self, key, values):
        yield key, sum(values)


if __name__ == '__main__':
    MRWC.run()
```

Each mrjob program you write requires defining a class, which extends the MRJob class.

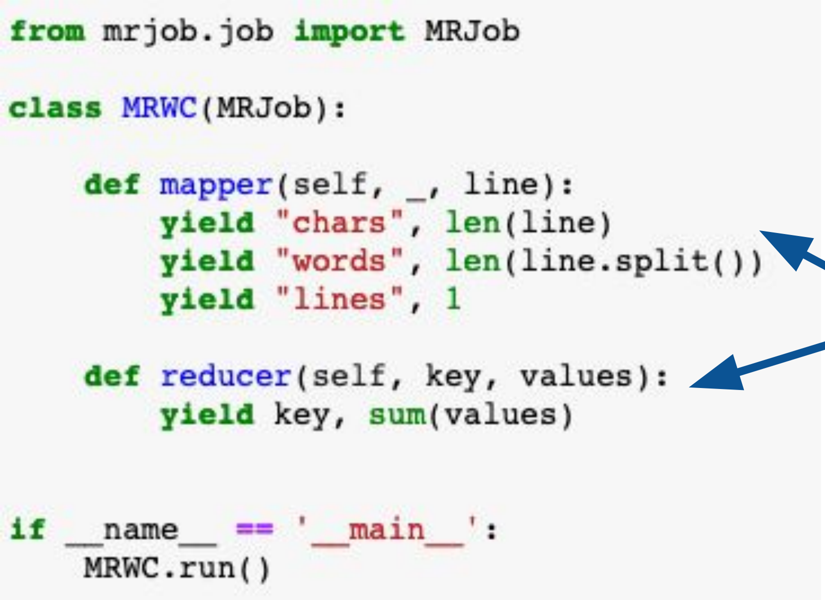
These mapper and reducer methods are precisely the Map and Reduce operations in our job. Recall the difference between the **yield** keyword and the **return** keyword.

This if-statement will run precisely when we call this script from the command line.

Basic `mrjob` script

This is a MapReduce job that counts the number of characters, words, and lines in a file.

mr_wc.py



```python
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class MRWC(MRJob):

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        yield "words", len(line.split())
        yield "lines", 1

    def reducer(self, key, values):
        yield key, sum(values)


if __name__ == '__main__':
    MRWC.run()
```
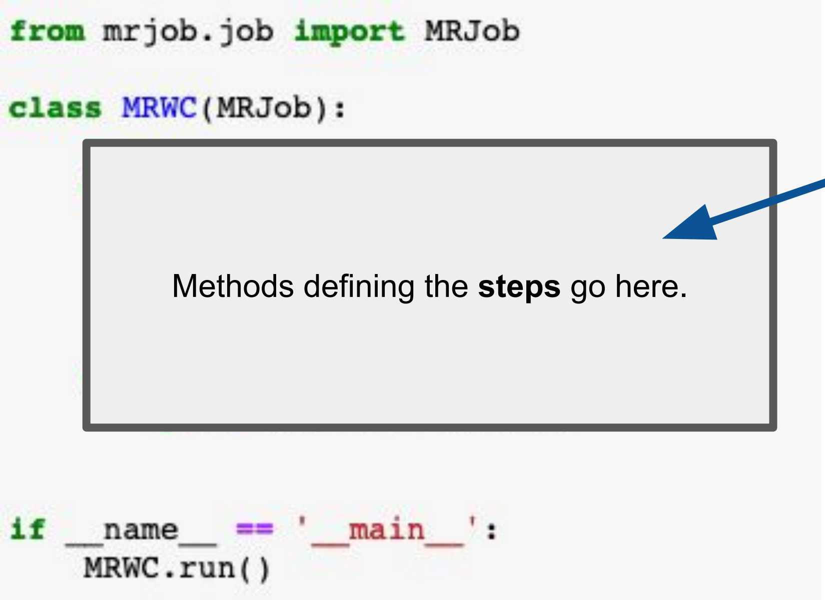

MRJob class already provides a method `run()`, which MRWordFrequencyCount inherits, but we need to define at least one of `mapper`, `reducer` or `combiner`.

Basic `mrjob` script

This is a MapReduce job that counts the number of characters, words, and lines in a file.

mr_wc.py



```
from mrjob.job import MRJob

class MRWC(MRJob):



if __name__ == '__main__':
    MRWC.run()
```

Methods defining the **steps** go here.

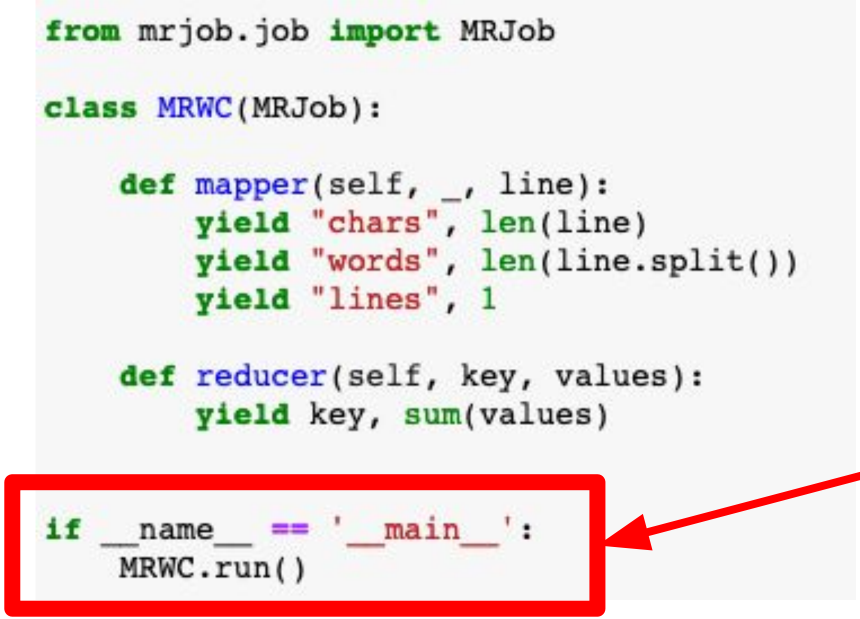
In `mrjob`, an `MRJob` object implements one or more steps of a MapReduce program. Recall that a step is a single Map->Reduce->Combine chain. All three are optional, but must have at least one in each step.

If we have more than one step, then we have to do a bit more work… (we'll come back to this)

Basic `mrjob` script

This is a MapReduce job that counts the number of characters, words, and lines in a file.

mr_wc.py



```python
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class MRWC(MRJob):

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        yield "chars", len(line)
        yield "words", len(line.split())
        yield "lines", 1

    def reducer(self, key, values):
        yield key, sum(values)


if __name__ == '__main__':
    MRWC.run()
```
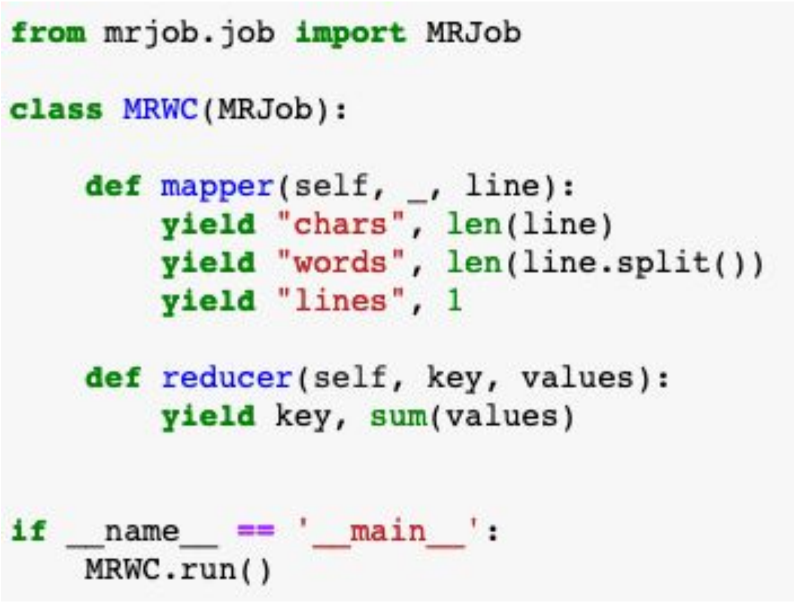

Warning: do not forget these two lines, or else your script will not run!

Basic `mrjob` script: recap

mr_wc.py



```
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if __name__ == '__main__':
    MRWC.run()
```

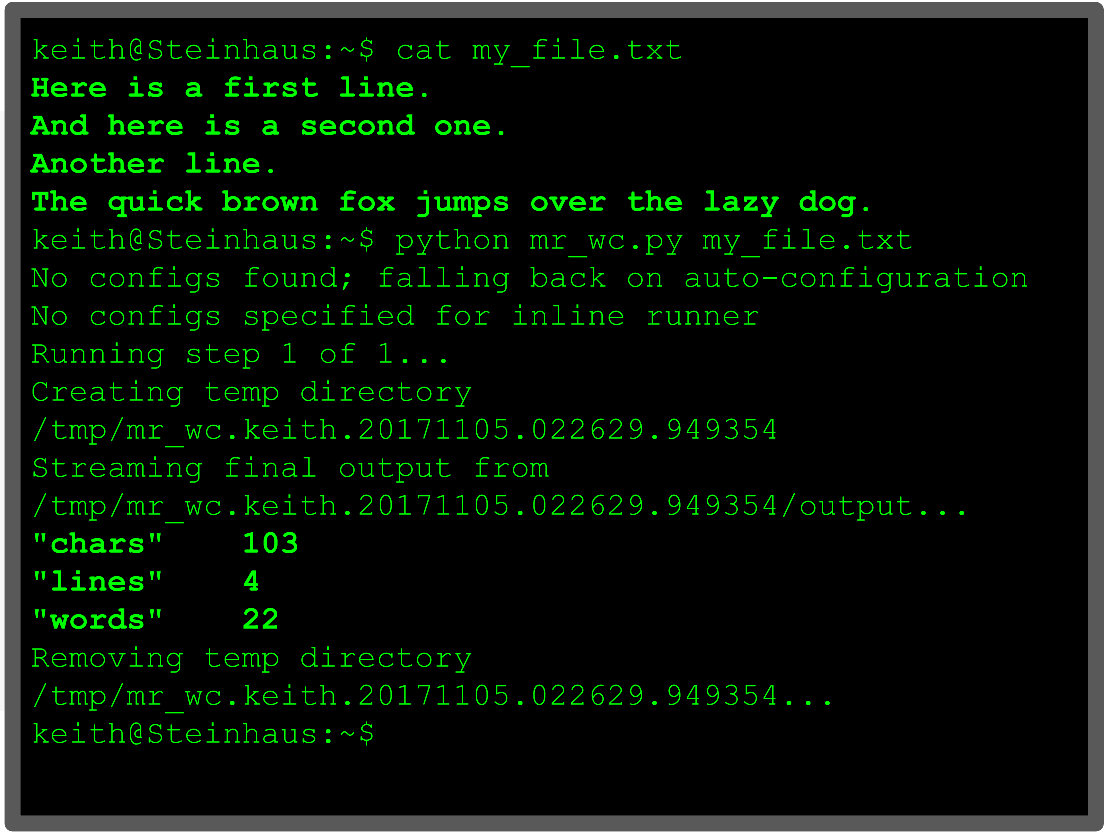

```
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Here is a first line.
And here is a second one.
Another line.
The quick brown fox jumps over the lazy dog.
keith@Steinhaus:~$ python mr_wc.py my_file.txt
No configs found; falling back on auto-configuration
No configs specified for inline runner
Running step 1 of 1...
Creating temp directory
/tmp/mr_wc.keith.20171105.022629.949354
Streaming final output from
/tmp/mr_wc.keith.20171105.022629.949354/output...
"chars"    103
"lines"    4
"words"    22
Removing temp directory
/tmp/mr_wc.keith.20171105.022629.949354...
keith@Steinhaus:~$
```
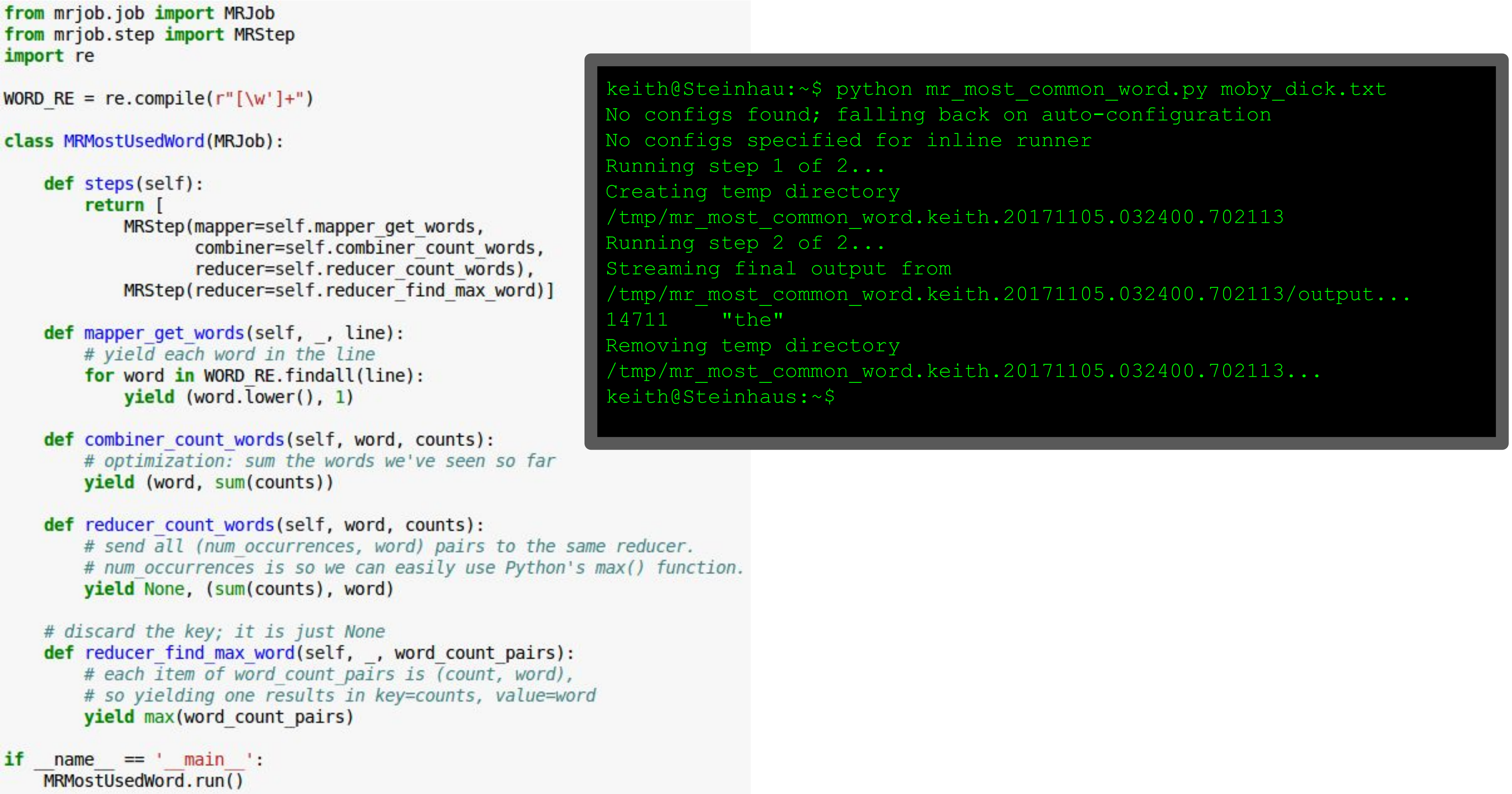
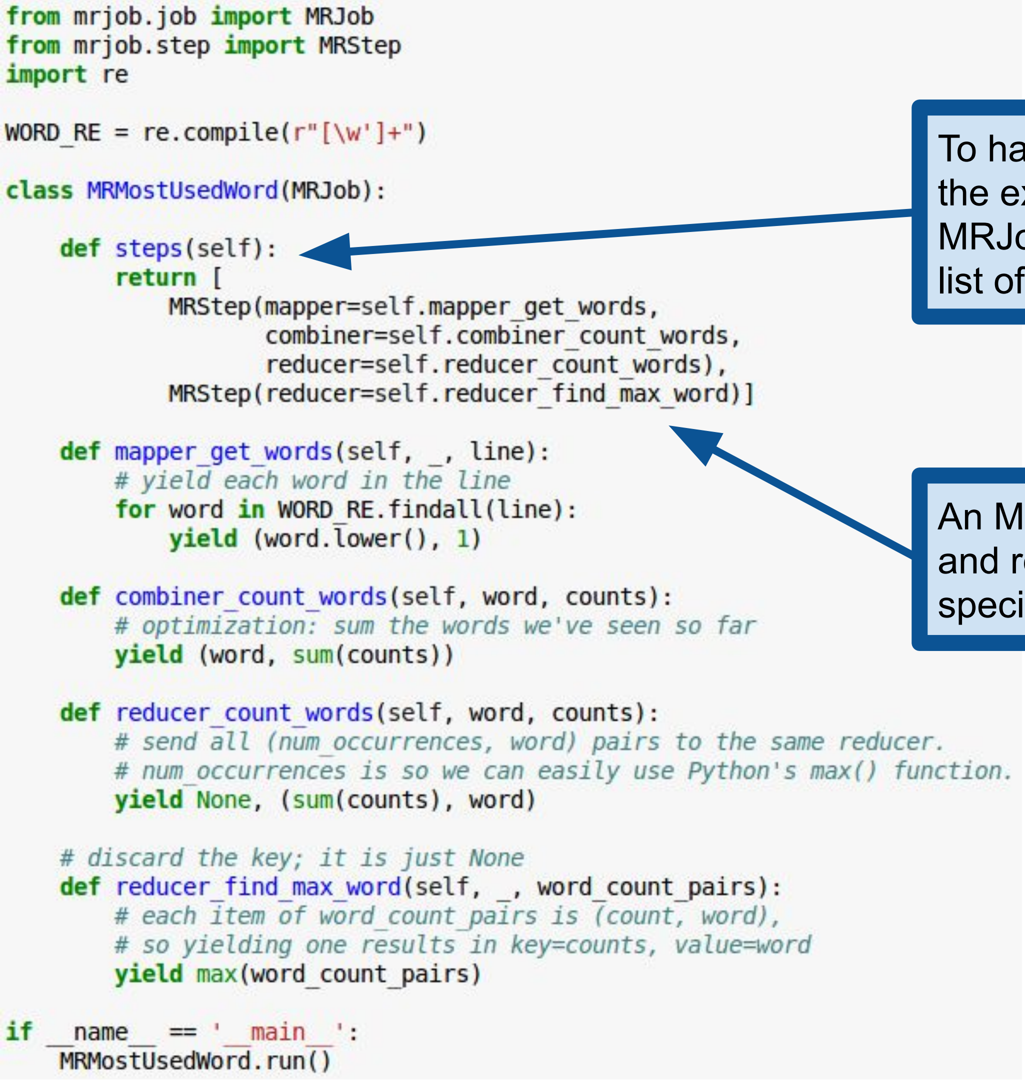

More complicated jobs: multiple steps



```python
from mrjob.job import MRJob
from mrjob.step import MRStep
import re

WORD_RE = re.compile(r"[\w']+")

class MRMostUsedWord(MRJob):

    def steps(self):
        return [
            MRStep(mapper=self.mapper_get_words,
                   combiner=self.combiner_count_words,
                   reducer=self.reducer_count_words),
            MRStep(reducer=self.reducer_find_max_word)]

    def mapper_get_words(self, _, line):
        # yield each word in the line
        for word in WORD_RE.findall(line):
            yield (word.lower(), 1)

    def combiner_count_words(self, word, counts):
        # optimization: sum the words we've seen so far
        yield (word, sum(counts))

    def reducer_count_words(self, word, counts):
        # send all (num_occurrences, word) pairs to the same reducer.
        # num_occurrences is so we can easily use Python's max() function.
        yield None, (sum(counts), word)

    # discard the key; it is just None
    def reducer_find_max_word(self, _, word_count_pairs):
        # each item of word_count_pairs is (count, word),
        # so yielding one results in key=counts, value=word
        yield max(word_count_pairs)

if __name__ == '__main__':
    MRMostUsedWord.run()
```

```
keith@Steinhau:~$ python mr_most_common_word.py moby_dick.txt
No configs found; falling back on auto-configuration
No configs specified for inline runner
Running step 1 of 2...
Creating temp directory
/tmp/mr_most_common_word.keith.20171105.032400.702113
Running step 2 of 2...
Streaming final output from
/tmp/mr_most_common_word.keith.20171105.032400.702113/output...
14711	"the"
Removing temp directory
/tmp/mr_most_common_word.keith.20171105.032400.702113...
keith@Steinhaus:~$
```



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                   combiner=self.combiner_count_words,
                   reducer=self.reducer_count_words),
            MRStep(reducer=self.reducer_find_max_word)]

    def mapper_get_words(self, _, line):
        # yield each word in the line
        for word in WORD_RE.findall(line):
            yield (word.lower(), 1)

    def combiner_count_words(self, word, counts):
        # optimization: sum the words we've seen so far
        yield (word, sum(counts))

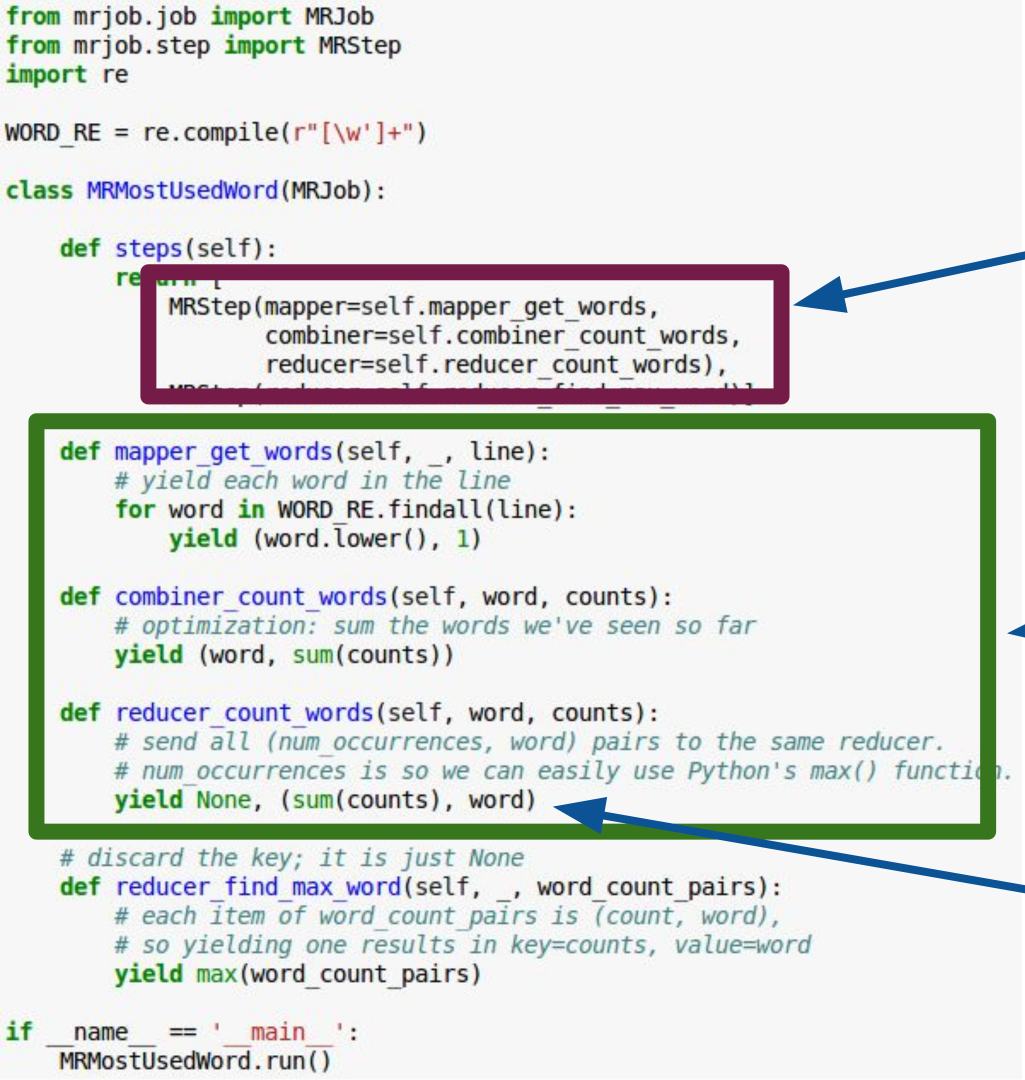
    def reducer_count_words(self, word, counts):
        # send all (num_occurrences, word) pairs to the same reducer.
        # num_occurrences is so we can easily use Python's max() function.
        yield None, (sum(counts), word)

    # discard the key; it is just None
    def reducer_find_max_word(self, _, word_count_pairs):
        # each item of word_count_pairs is (count, word),
        # so yielding one results in key=counts, value=word
        yield max(word_count_pairs)

if __name__ == '__main__':
    MRMostUsedWord.run()
```

To have more than one step, we need to override the existing definition of the method `steps()` in MRJob. The new `steps()` method must return a list of MRStep objects.

An MRStep object specifies a mapper, combiner and reducer. All three are optional, but must specify at least one.



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from mrjob.job import MRJob
from mrjob.step import MRStep
import re

WORD_RE = re.compile(r"[\w']+")

class MRMostUsedWord(MRJob):

    def steps(self):
        return [
            MRStep(mapper=self.mapper_get_words,
                   combiner=self.combiner_count_words,
                   reducer=self.reducer_count_words),
            MRStep(reducer=self.reducer_find_max_word)]

    def mapper_get_words(self, _, line):
        # yield each word in the line
        for word in WORD_RE.findall(line):
            yield (word.lower(), 1)

    def combiner_count_words(self, word, counts):
        # optimization: sum the words we've seen so far
        yield (word, sum(counts))

    def reducer_count_words(self, word, counts):
        # send all (num_occurrences, word) pairs to the same reducer.
        # num_occurrences is so we can easily use Python's max() function.
        yield None, (sum(counts), word)

    # discard the key; it is just None
    def reducer_find_max_word(self, _, word_count_pairs):
        # each item of word_count_pairs is (count, word),
        # so yielding one results in key=counts, value=word
        yield max(word_count_pairs)

if __name__ == '__main__':
    MRMostUsedWord.run()
```
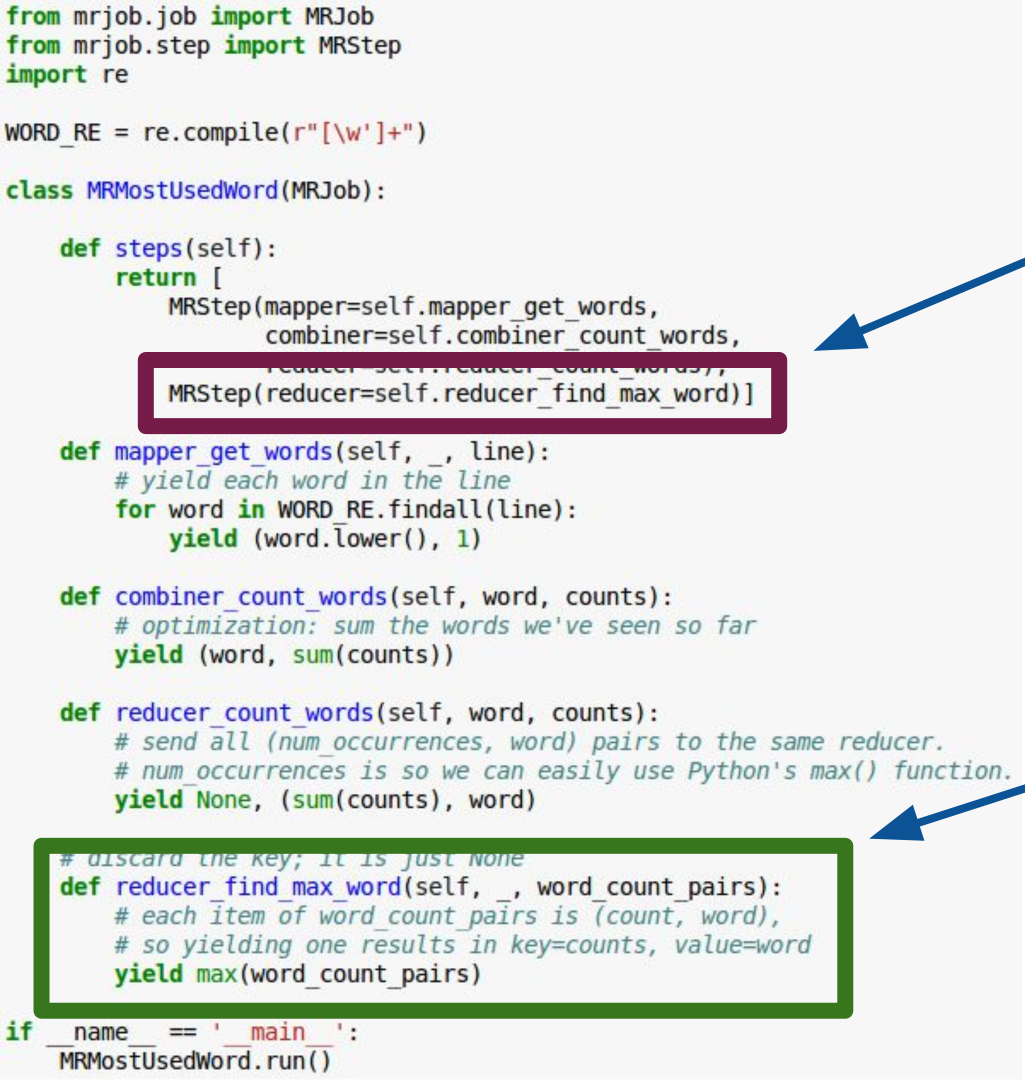

First step: count words

This pattern should look familiar. It implements word counting.

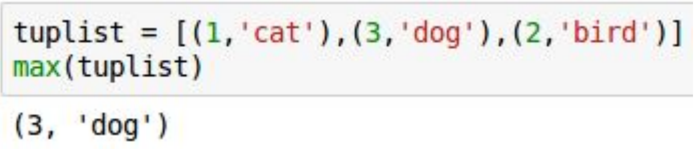
One key difference, because this reducer output is going to be the input to another step.



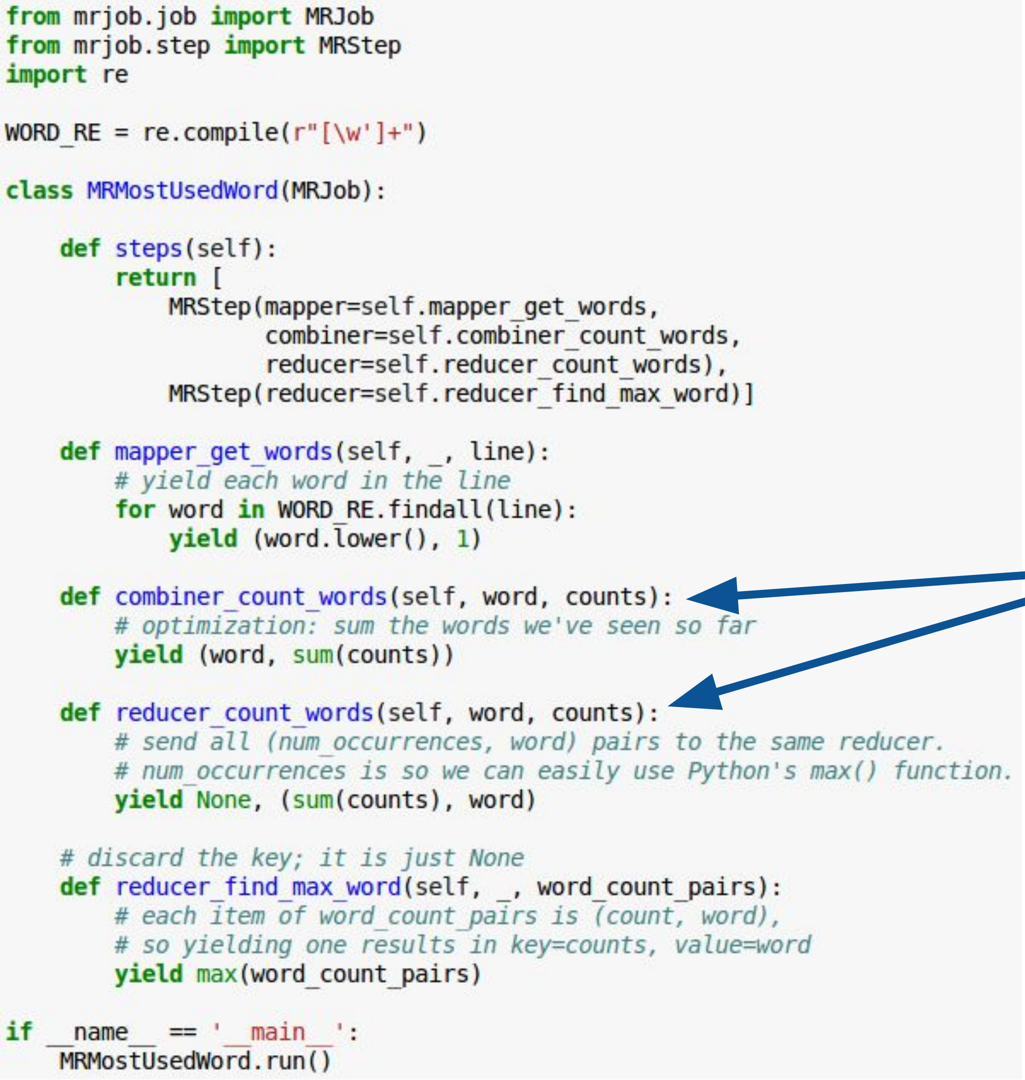
```
from mrjob.job import MRJob
from mrjob.step import MRStep
import re

WORD_RE = re.compile(r"[\w']+")

class MRMostUsedWord(MRJob):

    def steps(self):
        return [
            MRStep(mapper=self.mapper_get_words,
                   combiner=self.combiner_count_words,
                   reducer=self.reducer_count_words),
            MRStep(reducer=self.reducer_find_max_word)]

    def mapper_get_words(self, _, line):
        # yield each word in the line
        for word in WORD_RE.findall(line):
            yield (word.lower(), 1)

    def combiner_count_words(self, word, counts):
        # optimization: sum the words we've seen so far
        yield (word, sum(counts))

    def reducer_count_words(self, word, counts):
        # send all (num_occurrences, word) pairs to the same reducer.
        # num_occurrences is so we can easily use Python's max() function.
        yield None, (sum(counts), word)

    # discard the key; it is just None
    def reducer_find_max_word(self, _, word_count_pairs):
        # each item of word_count_pairs is (count, word),
        # so yielding one results in key=counts, value=word
        yield max(word_count_pairs)

if __name__ == '__main__':
    MRMostUsedWord.run()
```

Second step: find the largest count.

Note: `word_count_pairs` is like a list of pairs. Refer to how Python `max` works on a list of tuples.



```
tuplist = [(1,'cat'),(3,'dog'),(2,'bird')]
max(tuplist)

(3, 'dog')
```

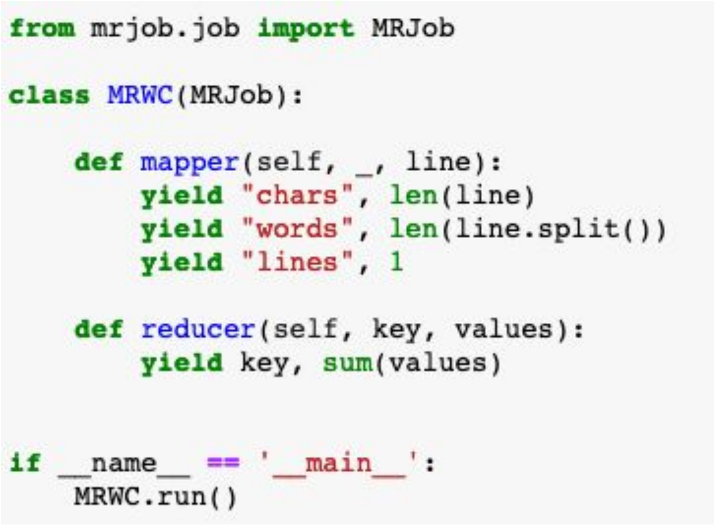


```python
from mrjob.job import MRJob
from mrjob.step import MRStep
import re

WORD_RE = re.compile(r"[\w']+")

class MRMostUsedWord(MRJob):

    def steps(self):
        return [
            MRStep(mapper=self.mapper_get_words,
                   combiner=self.combiner_count_words,
                   reducer=self.reducer_count_words),
            MRStep(reducer=self.reducer_find_max_word)]

    def mapper_get_words(self, _, line):
        # yield each word in the line
        for word in WORD_RE.findall(line):
            yield (word.lower(), 1)

    def combiner_count_words(self, word, counts):
        # optimization: sum the words we've seen so far
        yield (word, sum(counts))

    def reducer_count_words(self, word, counts):
        # send all (num_occurrences, word) pairs to the same reducer.
        # num_occurrences is so we can easily use Python's max() function.
        yield None, (sum(counts), word)

    # discard the key; it is just None
    def reducer_find_max_word(self, _, word_count_pairs):
        # each item of word_count_pairs is (count, word),
        # so yielding one results in key=counts, value=word
        yield max(word_count_pairs)

if __name__ == '__main__':
    MRMostUsedWord.run()
```

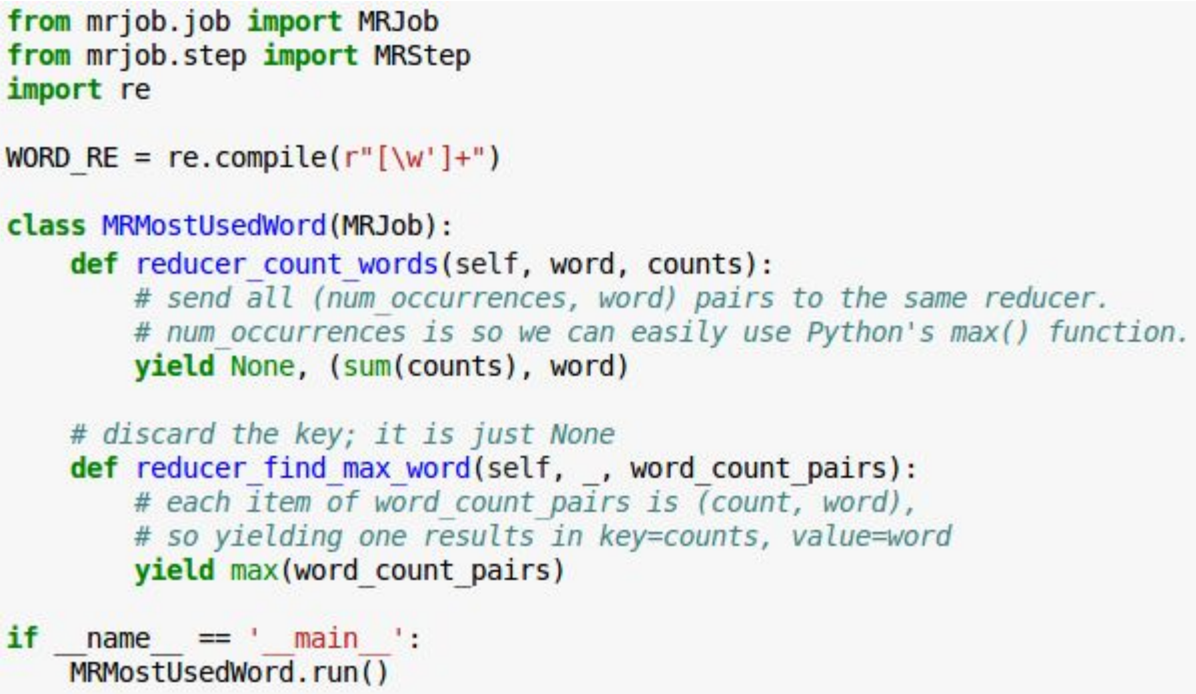
Note: combiner and reducer are the same operation in this example, provided we ignore the fact that reducer has a special output format

More complicated reducers: Python’s `reduce`

So far our reducers have used Python built-in functions `sum` and `max`



```python
from mrjob.job import MRJob

class MRWC(MRJob):

    def mapper(self, _, line):
        yield "chars", len(line)
        yield "words", len(line.split())
        yield "lines", 1

    def reducer(self, key, values):
        yield key, sum(values)


if __name__ == '__main__':
    MRWC.run()
```



```python
from mrjob.job import MRJob
from mrjob.step import MRStep
import re

WORD_RE = re.compile(r"[\w']+")

class MRMostUsedWord(MRJob):
    def reducer_count_words(self, word, counts):
        # send all (num_occurrences, word) pairs to the same reducer.
        # num_occurrences is so we can easily use Python's max() function.
        yield None, (sum(counts), word)

    # discard the key; it is just None
    def reducer_find_max_word(self, _, word_count_pairs):
        # each item of word_count_pairs is (count, word),
        # so yielding one results in key=counts, value=word
        yield max(word_count_pairs)

if __name__ == '__main__':
    MRMostUsedWord.run()
```

More complicated reducers: Python’s `reduce`

So far our reducers have used Python built-in functions `sum` and `max`

What if I want to multiply the values instead of `sum`?

Python does not have `product()` function analogous to `sum()`...

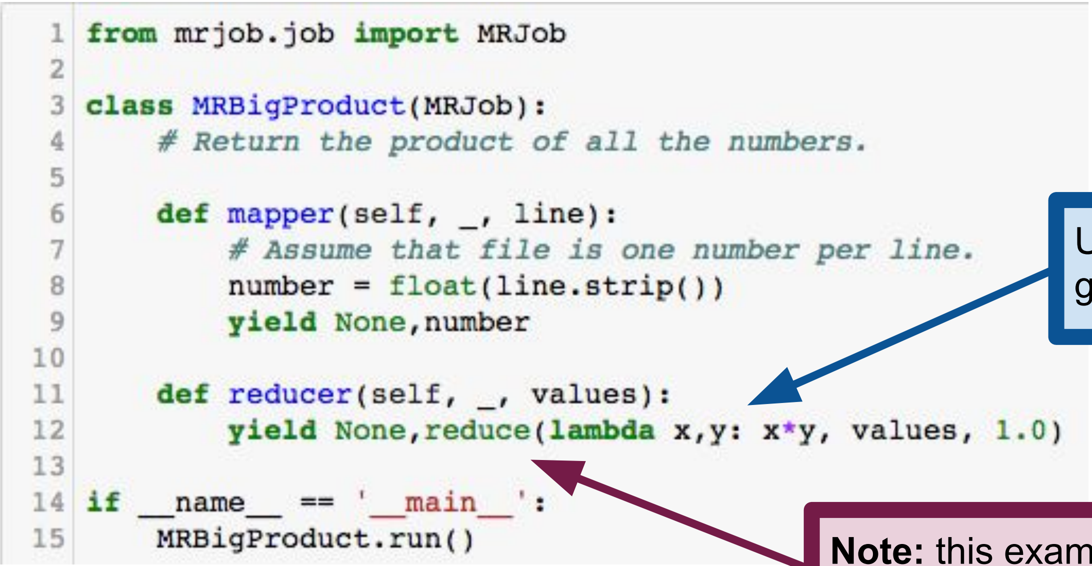
What if my values aren’t numbers, but I have a sum defined on them?

e.g., tuples representing vectors

Want `(a,b)+(x,y)=(a+x,b+y)`, but tuples don’t support this addition

Solution: use `functools.reduce`

More complicated reducers: Python’s `reduce`

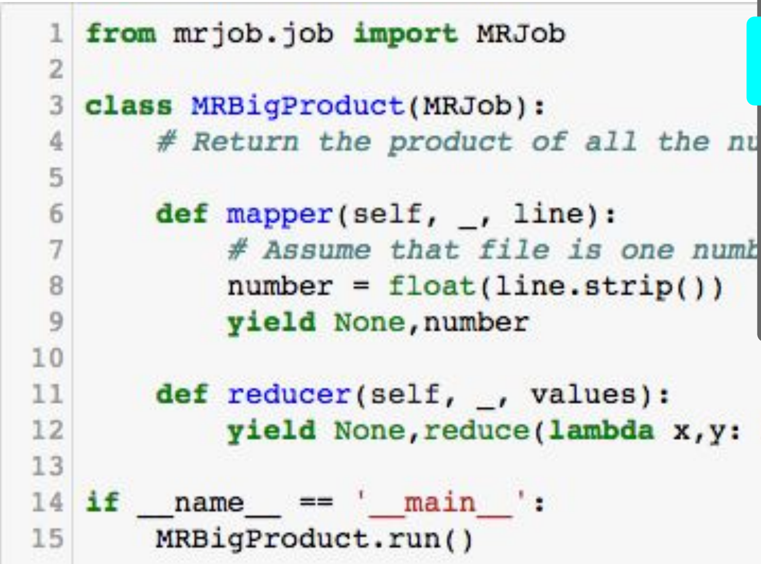


```python
from mrjob.job import MRJob

class MRBigProduct(MRJob):
    # Return the product of all the numbers.

    def mapper(self, _, line):
        # Assume that file is one number per line.
        number = float(line.strip())
        yield None,number

    def reducer(self, _, values):
        yield None,reduce(lambda x,y: x*y, values, 1.0)

if __name__ == '__main__':
    MRBigProduct.run()
```

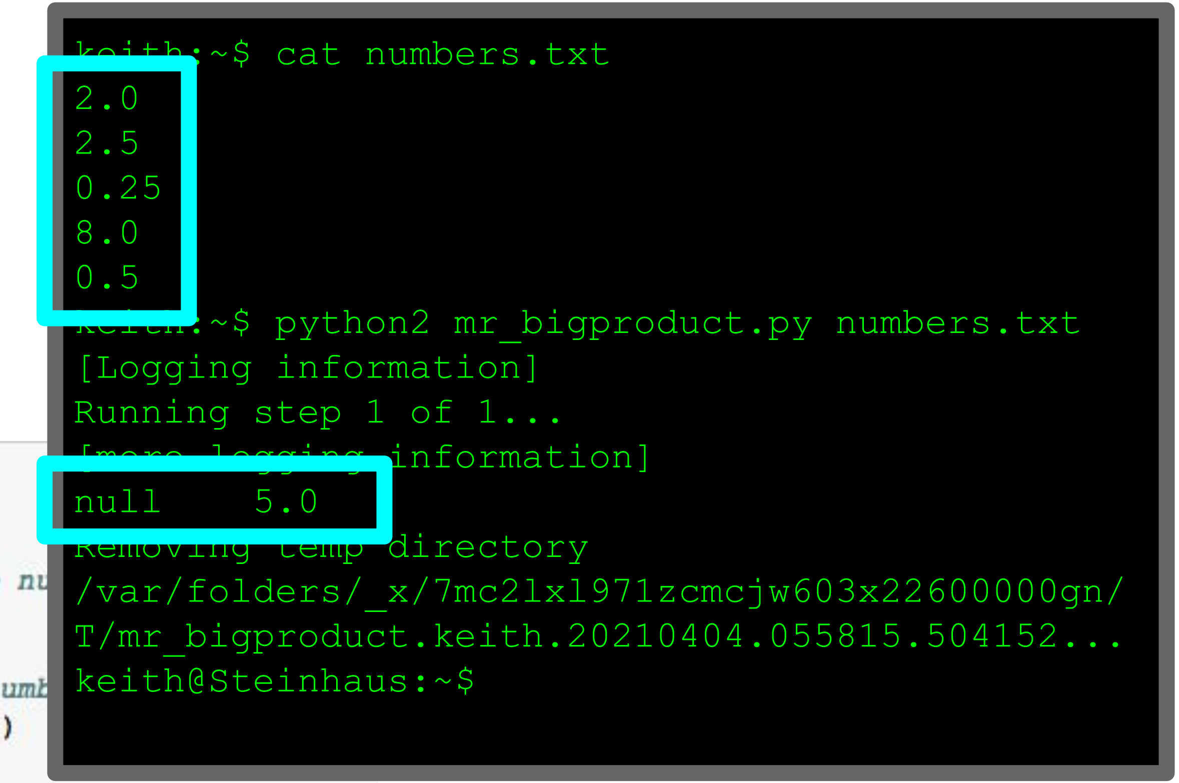
Using `reduce` and `lambda`, we can get just about any reducer we want.

Note: this example was run in Python 2. You’ll need to import `functools` to do this in Python 3.

Note: numbers are successfully extracted from input and multiplied with one another.



```python
from mrjob.job import MRJob

class MRBigProduct(MRJob):
    # Return the product of all the nu

    def mapper(self, _, line):
        # Assume that file is one numb
        number = float(line.strip())
        yield None,number

    def reducer(self, _, values):
        yield None,reduce(lambda x,y: x*y, values, 1.0)

if __name__ == '__main__':
    MRBigProduct.run()
```



```
keith:~$ cat numbers.txt
2.0
2.5
0.25
8.0
0.5
keith:~$ python2 mr_bigproduct.py numbers.txt
[Logging information]
Running step 1 of 1...
[more logging information]
null    5.0
Removing temp directory
/var/folders/_x/7mc21x1971zcmcjw603x22600000gn/
T/mr_bigproduct.keith.20210404.055815.504152...
keith@Steinhaus:~$
```

Running `mrjob` on a Hadoop cluster

We’ve already seen how to run `mrjob` from the command line.

Previous examples emulated Hadoop

But no actual Hadoop instance was running!

That’s fine for prototyping and testing…

...but **how do I actually run it on a Hadoop cluster?**

We need access to a computer cluster!
This semester, we will use Google Cloud Platform.

Overview: Google Cloud

Google Cloud Platform (GCP) is Google's distributed computing service

- Cloud computing: rent computers (and storage) by the minute
- ML tools (e.g., support for TensorFlow and related tools)
- Large-scale database (e.g., HDFS and HBase for Hadoop)

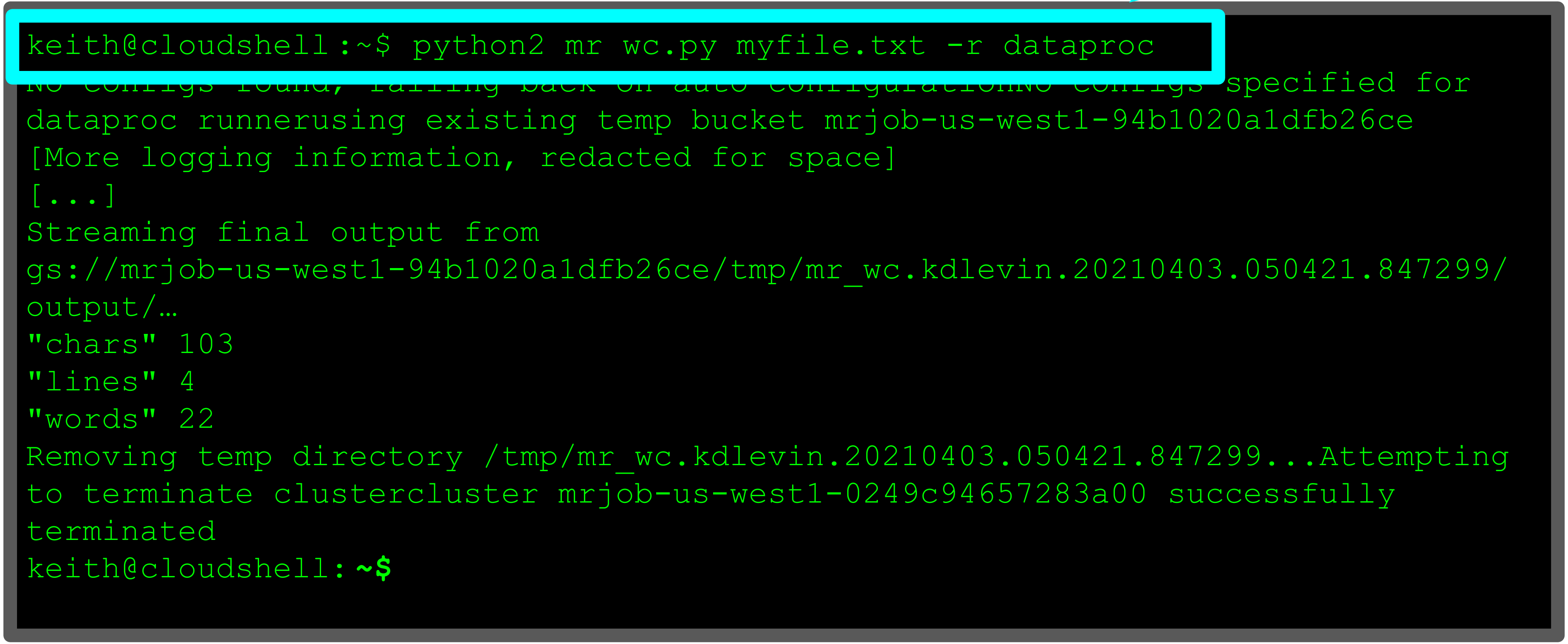
Dataproc: Google's service for running Apache Hadoop jobs

Homework 11 will walk you through the process of running your `mrjob` program on a GCP Dataproc cluster (i.e., Hadoop server).

Step 1: access Google Cloud console, which gives a terminal in which to interact with Google Cloud. https://console.cloud.google.com/

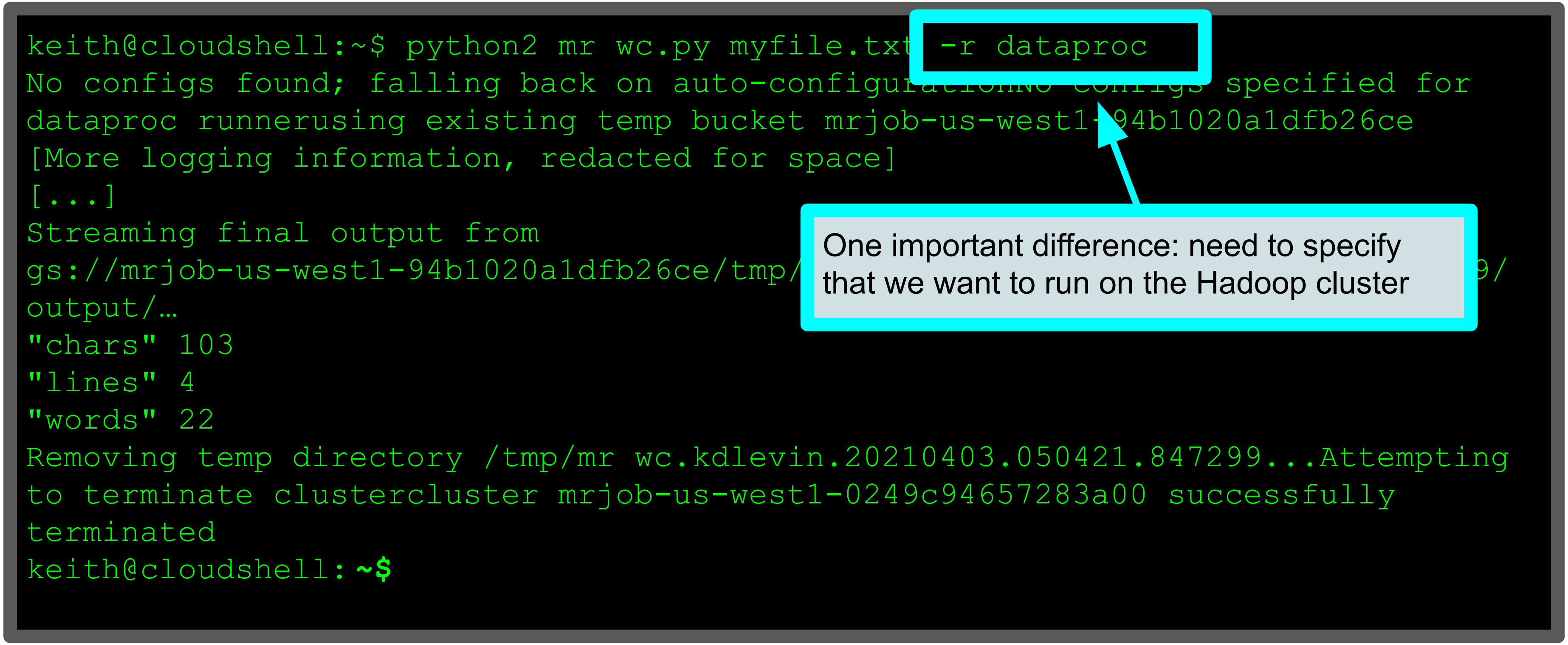
Running mrjob on a cluster

On a compute cluster, we call mrjob just like on our local machine.



```
keith@cloudshell:~$ python2 mr wc.py myfile.txt -r dataproc
No configs found; falling back on auto configurationNo configs specified for
dataproc runnerusing existing temp bucket mrjob-us-west1-94b1020a1dfb26ce
[More logging information, redacted for space]
[...]
Streaming final output from
gs://mrjob-us-west1-94b1020a1dfb26ce/tmp/mr_wc.kdlevin.20210403.050421.847299/
output/…
"chars" 103
"lines" 4
"words" 22
Removing temp directory /tmp/mr_wc.kdlevin.20210403.050421.847299...Attempting
to terminate clustercluster mrjob-us-west1-0249c94657283a00 successfully
terminated
keith@cloudshell:~$
```

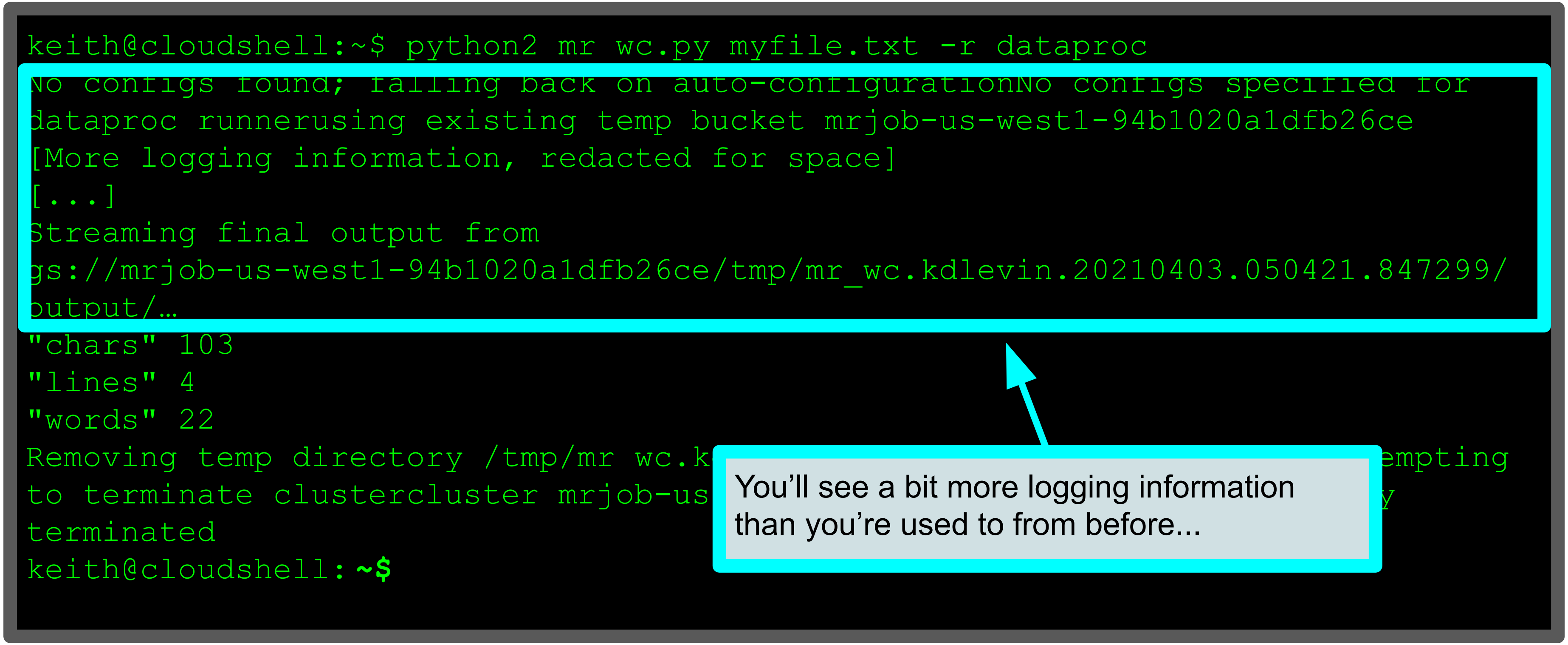
Running mrjob on a cluster



```
keith@cloudshell:~$ python2 mr wc.py myfile.txt -r dataproc
No configs found; falling back on auto-configurationNo configs specified for
dataproc runnerusing existing temp bucket mrjob-us-west1-94b1020a1dfb26ce
[More logging information, redacted for space]
[...]
Streaming final output from
gs://mrjob-us-west1-94b1020a1dfb26ce/tmp/                                  9/
output/…
"chars" 103
"lines" 4
"words" 22
Removing temp directory /tmp/mr wc.kdlevin.20210403.050421.847299...Attempting
to terminate clustercluster mrjob-us-west1-0249c94657283a00 successfully
terminated
keith@cloudshell:~$
```

One important difference: need to specify that we want to run on the Hadoop cluster

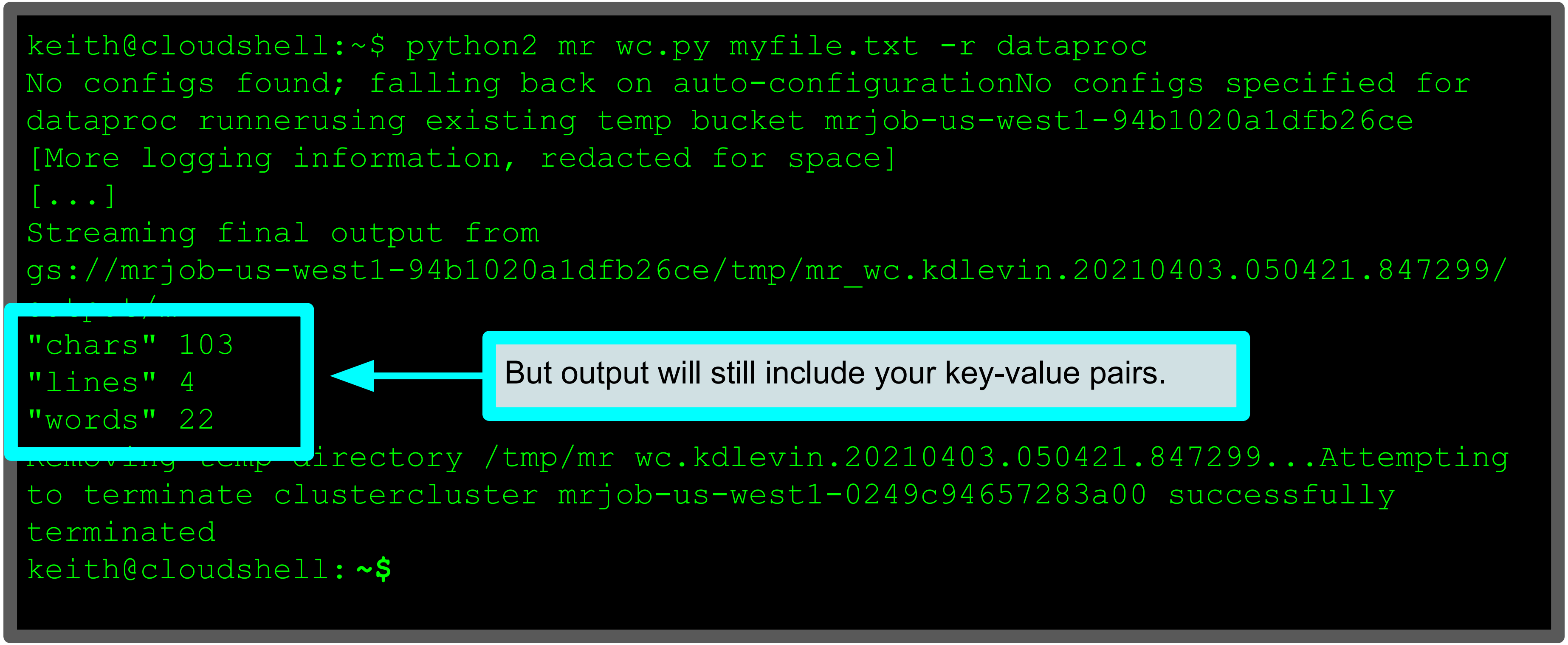
Running `mrjob` on a cluster



```
keith@cloudshell:~$ python2 mr wc.py myfile.txt -r dataproc
No configs found; falling back on auto-configurationNo configs specified for
dataproc runnerusing existing temp bucket mrjob-us-west1-94b1020a1dfb26ce
[More logging information, redacted for space]
[...]
Streaming final output from
gs://mrjob-us-west1-94b1020a1dfb26ce/tmp/mr_wc.kdlevin.20210403.050421.847299/
output/…
"chars" 103
"lines" 4
"words" 22
Removing temp directory /tmp/mr wc.k                                   empting
to terminate clustercluster mrjob-us                                 y
terminated
keith@cloudshell:~$
```

You’ll see a bit more logging information than you’re used to from before...

Running `mrjob` on a cluster



```
keith@cloudshell:~$ python2 mr wc.py myfile.txt -r dataproc
No configs found; falling back on auto-configurationNo configs specified for
dataproc runnerusing existing temp bucket mrjob-us-west1-94b1020a1dfb26ce
[More logging information, redacted for space]
[...]
Streaming final output from
gs://mrjob-us-west1-94b1020a1dfb26ce/tmp/mr_wc.kdlevin.20210403.050421.847299/
output/...
"chars" 103
"lines" 4
"words" 22
Removing temp directory /tmp/mr wc.kdlevin.20210403.050421.847299...Attempting
to terminate clustercluster mrjob-us-west1-0249c94657283a00 successfully
terminated
keith@cloudshell:~$
```

But output will still include your key-value pairs.

`mrjob` hides complexity of MapReduce

We need only define mapper, reducer, combiner

Package handles everything else

Most importantly, interacting with Hadoop

But `mrjob` does provide powerful tools for specifying Hadoop configuration

https://mrjob.readthedocs.io/en/latest/guides/configs-hadoopy-runners.html

You don't have to worry about any of this in this course, but you should be aware of it in case you need it in the future.

`mrjob`: protocols

`mrjob` assumes that all data is “newline-delimited bytes”

- That is, newlines separate lines of input
- Each line is a single unit to be processed in isolation
    - (e.g., a line of words to count, an entry in a database, etc)

`mrjob` handles inputs and outputs via **protocols**

- **Protocol** is an object that has `read()` and `write()` methods
- `read()`: convert bytes to (key,value) pairs
- `write()`: convert (key,value) pairs to bytes

mrjob: protocols

Controlled by setting three variables in config file mrjob.conf:

INPUT_PROTOCOL, INTERNAL_PROTOCOL, OUTPUT_PROTOCOL

Defaults:

```
INPUT_PROTOCOL = mrjob.protocol.RawValueProtocol
INTERNAL_PROTOCOL = mrjob.protocol.JSONProtocol
OUTPUT_PROTOCOL = mrjob.protocol.JSONProtocol
```

Again, you don't have to worry about this in this course, but you should be aware of it.

Data passed around internally via JSON. This is precisely the kind of thing that JSON is good for.