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Python

tools for big data



**UNIVERSITÉ
RENNES 2**

Publisher

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Chapter 1

Git

Git is a free and open source distributed version control system designed to handle everything from small to very large projects with speed and efficiency.

Official website <https://git-scm.com>

1.1 GitHub

- Web-based hosting service for version control using Git.
- Offers all of the distributed version control and source code management (SCM) functionality of Git as well as adding its own features.
- Provides access control and several collaboration features such as bug tracking, feature requests, task management, and wikis for every project.
- Github is the largest host of source code in the world.

1.2 About SCM

- Records changes to a file or set of files over time.
- You can recall specific versions later.
- You can use it with nearly any type of file on a computer.
- This is the better way to collaborate on the same document.
- Every change is committed with an author and a date.
- Figures are downloaded from [Pro Git book](#).
- "Become a git guru" tutorial (<https://www.atlassian.com/git/tutorials>).

1.3 Local Version Control System

- Collaboration is not really possible.

1.4 Distributed Version Control Systems

- Clients fully mirror the repository.
- You can collaborate with different groups of people in different ways simultaneously within the same project.
- No need of network connection.
- Multiple backups.

1.5 Configure Git

Settings are saved on the computer for all your git repositories.

```
git config --global user.name "Prenom Nom"
git config --global user.email "prenom.nom@univ-rennes2.fr"
```

1.6 Cloning the repository

```
git clone ssh://svmass2/git/big-data.git
```

or

```
git clone https://github.com/pnavaro/big-data.git
```

To save your work locally create a branch

```
git checkout -b my_branch
```

1.7 Four File status in the repository

1.8 Git Workflow

1.9 Locally saving your modifications

Get your files status

```
In [1]: %%bash
        git status
```

On branch master

Your branch is up to date with 'origin/master'.

Untracked files:

(use "git add <file>..." to include in what will be committed)

```
../doit.db.dat
../spark-3.0.0-bin-hadoop2.7.tgz
../spark-3.0.0-bin-hadoop2.7/
```

nothing added to commit but untracked files present (use "git add" to track)

1.10 Add the modified file to the index

```
git add your_notebook_copy.ipynb
```

Checking which files are ready to be committed.

```
In [2]: %%bash
        git status
```

On branch master

Your branch is up to date with 'origin/master'.

Untracked files:

(use "git add <file>..." to include in what will be committed)

```
../.doit.db.dat
../spark-3.0.0-bin-hadoop2.7.tgz
../spark-3.0.0-bin-hadoop2.7/
```

nothing added to commit but untracked files present (use "git add" to track)

Now save your work, the branch is local.

```
git commit -m 'Some modifications'
```

1.11 Updating from the Repository

If the master branch has changed. To get all new updates :

```
In [3]: %%bash
        git pull origin master
```

Already up to date.

warning: Pulling without specifying how to reconcile divergent branches is discouraged. You can squelch this message by running one of the following commands sometime before your next pull:

```
git config pull.rebase false # merge (the default strategy)
git config pull.rebase true  # rebase
git config pull.ff only      # fast-forward only
```

You can replace "git config" with "git config --global" to set a default preference for all repositories. You can also pass --rebase, --no-rebase, or --ff-only on the command line to override the configured default per invocation.

```
From https://github.com/pnavaro/big-data
* branch                master      -> FETCH_HEAD
```

1.12 Solve conflicts

- If you have some conflicts, no problem just do :

```
git checkout notebook.ipynb
```

It will give you back the original version of notebook.ipynb

- If you have big troubles, you can do

```
git reset --hard
```

Be careful with this last command, you remove uncommitted changes.

1.13 Git through IDE

- Install bash-completion and source git-prompt.sh.
- Use Gui tools:
 - [GitHub Desktop](#)
 - [Sourcetree](#)
 - [GitKraken](#)
- VCS plugin of IDE
 - [RStudio](#)
 - [Eclipse](#)
 - [JetBrains](#)

Chapter 2

Installation with conda

2.1 Install [Anaconda](#) (large) or [Miniconda](#) (small)

2.2 Open a terminal (Linux/MacOSX) or a Anaconda prompt (Windows)

2.3 Create a new conda environment from file

```
cd big-data
conda env create
```

[Conda envs documentation.](#)

2.4 Activate the new environment (for all students)

Activating the conda environment will change your shell's prompt to show what virtual environment you're using, and modify the environment so that running python will get you that particular version and installation of Python.

You must do this everytime you open a new terminal

2.5 Install the kernel for jupyter

```
python -m ipykernel install --user \
    --name big-data
```


Chapter 3

Jupyter



3.1 Launch Jupyter server

```
jupyter notebook
```

- Go to notebooks folder
- Open the file 03.JupyterQuickStart.ipynb

3.2 Make a Copy

Before modifying the notebook, make a copy of it. Go to to **File** menu on the top left of the notebook and click on **Make a Copy...**

3.3 Jupyter Notebook

Jupyter notebook, formerly known as the IPython notebook, is a flexible tool that helps you create readable analyses, as you can keep code, images, comments, formulae and plots together.

Jupyter is quite extensible, supports many programming languages and is easily hosted on your computer or on almost any server — you only need to have ssh or http access. Best of all, it's completely free.

The name Jupyter is an indirect acronym of the three core languages it was designed for: **J**ulia, **PY**thon, and **R**

3.4 Keyboard Shortcuts

- To access keyboard shortcuts, use the command palette: **Cmd + Shift + P**
- **Esc** will take you into command mode where you can navigate around your notebook with arrow keys.
- While in command mode:
- **A** to insert a new cell above the current cell, **B** to insert a new cell below.
- **M** to change the current cell to Markdown, **Y** to change it back to code
- **D + D** (press the key twice) to delete the current cell

3.5 Easy links to documentation

- **Shift + Tab** will also show you the Docstring

```
In [1]: dict
```

```
Out[1]: dict
```

3.6 Magic commands

```
In [2]: %lsmagic
```

```
Out[2]: Available line magics:
```

```
%alias %alias_magic %autoawait %autocall %automagic %autosave %bookmark %cat %cd %clear
```

```
Available cell magics:
```

```
%%! %%HTML %%SVG %%bash %%capture %%debug %%file %%html %%javascript %%js %%latex %%
```

```
Automagic is ON, % prefix IS NOT needed for line magics.
```

```
In [3]: %ls
```

01-GitBasics.ipynb	book-017.dat	book-054.dat	book-091.dat
02-Installation.ipynb	book-018.dat	book-055.dat	book-092.dat
03-JupyterQuickStart.ipynb	book-019.dat	book-056.dat	book-093.dat
04-WordCount.ipynb	book-020.dat	book-057.dat	book-094.dat
05-MapReduce.ipynb	book-021.dat	book-058.dat	book-095.dat
06-ParallelComputation.ipynb	book-022.dat	book-059.dat	book-096.dat
07-AsynchronousProcessing.ipynb	book-023.dat	book-060.dat	book-097.dat
08-DaskDelayed.ipynb	book-024.dat	book-061.dat	book-098.dat
09-DaskBag.ipynb	book-025.dat	book-062.dat	book-099.dat
10-PandasSeries.ipynb	book-026.dat	book-063.dat	data/
11-PandaDataframes.ipynb	book-027.dat	book-064.dat	fibonacci.py
12-PySpark.ipynb	book-028.dat	book-065.dat	images/
13-UnixCommands.ipynb	book-029.dat	book-066.dat	log
14-Hadoop.ipynb	book-030.dat	book-067.dat	mapper.py*
15-HadoopFileFormats.ipynb	book-031.dat	book-068.dat	pmap.py
16-DaskDataframes.ipynb	book-032.dat	book-069.dat	reducer.py*
17-SparkDataFrames.ipynb	book-033.dat	book-070.dat	sample00.txt
18-NYCTaxiCabTripDask.ipynb	book-034.dat	book-071.dat	sample01.txt
19-NYCTaxiCabTripSpark.ipynb	book-035.dat	book-072.dat	sample02.txt
Makefile	book-036.dat	book-073.dat	sample03.txt

book-000.dat	book-037.dat	book-074.dat	sample04.txt
book-001.dat	book-038.dat	book-075.dat	sample05.txt
book-002.dat	book-039.dat	book-076.dat	sample06.txt
book-003.dat	book-040.dat	book-077.dat	sample07.txt
book-004.dat	book-041.dat	book-078.dat	sample08.txt
book-005.dat	book-042.dat	book-079.dat	sample09.txt
book-006.dat	book-043.dat	book-080.dat	sample10.txt
book-007.dat	book-044.dat	book-081.dat	sample11.txt
book-008.dat	book-045.dat	book-082.dat	sample12.txt
book-009.dat	book-046.dat	book-083.dat	sample13.txt
book-010.dat	book-047.dat	book-084.dat	sample14.txt
book-011.dat	book-048.dat	book-085.dat	sample15.txt
book-012.dat	book-049.dat	book-086.dat	sample16.txt
book-013.dat	book-050.dat	book-087.dat	sample17.txt
book-014.dat	book-051.dat	book-088.dat	sample18.txt
book-015.dat	book-052.dat	book-089.dat	sample19.txt
book-016.dat	book-053.dat	book-090.dat	test_stdin.py

```
In [4]: %%file sample.txt
```

```
write the cell content to the file sample.txt.
The file is created when you run this cell.
```

Writing sample.txt

```
In [5]: %cat sample.txt
```

```
write the cell content to the file sample.txt.
The file is created when you run this cell.
```

```
In [6]: %%file fibonacci.py
```

```
f1, f2 = 1, 1
for n in range(10):
    print(f1, end=',')
    f1, f2 = f2, f1+f2
```

Overwriting fibonacci.py

```
In [7]: %run fibonacci.py
```

```
1,1,2,3,5,8,13,21,34,55,
```

```
In [8]: # %load fibonacci.py
```

```
f1, f2 = 1, 1
for n in range(10):
    print(f1, end=',')
    f1, f2 = f2, f1+f2
```

```
1,1,2,3,5,8,13,21,34,55,
```

```
In [9]: %%time
        f1, f2 = 1, 1
        for n in range(10):
            print(f1, end=',')
            f1, f2 = f2, f1+f2
        print()

1,1,2,3,5,8,13,21,34,55,
CPU times: user 339 µs, sys: 52 µs, total: 391 µs
Wall time: 256 µs
```

3.7 Installing Python Packages from a Jupyter Notebook

3.7.1 Install a conda package in the current Jupyter kernel

Example with package `numpy` from *conda-forge*

```
%conda install -c conda-forge lorem
```

Chapter 4

Wordcount

- [Wikipedia](#)
- Word count example reads text files and counts how often words occur.
- Word count is commonly used by translators to determine the price for the translation job.
- This is the "Hello World" program of Big Data.

Some recommendations: - *Don't google too much, ask me or use the python documentation through `help` function.* - *Do not try to find a clever or optimized solution, do something that works before.* - *Please don't get the solution from your colleagues* - *Notebooks will be updated next week with solutions*

4.1 Create sample text file

```
In [1]: from lorem import text

        with open("sample.txt", "w") as f:
            for i in range(10000):
                f.write(text())
```

4.1.1 Exercise 4.1

Write a python program that counts the number of lines, words and characters in that file.

```
In [2]: %%bash
        wc sample.txt
        du -h sample.txt

69756 2009622 14199532 sample.txt
14M      sample.txt
```

- Compute number of lines

```
In [3]: with open("sample.txt") as f:
        lines = list(f)

        nlines = len(lines)
        nlines
```

```
Out[3]: 69757
```

- Compute number of words

```
In [4]: nwords = sum([len(line.split()) for line in lines])
        nwords
```

```
Out[4]: 2009622
```

```
In [5]: nchars = 0
        for line in lines:
            words = line.split()
            nchars += sum([len(word) for word in line.split()])

        nchars
```

```
Out[5]: 12155033
```

- `set` gives the list of unique elements from words list.

```
In [6]: s = set(words)
        s
```

```
Out[6]: {'Adipisci',
        'Amet',
        'Consectetur',
        'Modi',
        'Quaerat',
        'Quiquia',
        'adipisci',
        'adipisci.',
        'aliquam',
        'amet',
        'consectetur',
        'dolor',
        'dolore',
        'dolorem',
        'eius',
        'est',
        'est.',
        'ipsum',
        'modi',
        'neque.',
        'numquam',
        'porro',
        'quaerat',
        'quaerat.',
        'quisquam',
        'tempora',
        'tempora.',
        'ut',
        'velit.',
        'voluptatem'}
```

4.1.2 Exercise 4.2

Create a function called `map_words` that take a file name as argument and return a lists containing all words as items.

```
map_words("sample.txt")[:5] # first five words
['adipisci', 'adipisci', 'adipisci', 'adipisci', 'adipisci']
```

```
In [7]: def map_words(filename):
        """ take a file name as argument and return a
           lists containing all words as item
           """
        with open(filename) as f:
            data = f.read().lower().replace('.', ' ')

        return sorted(data.split())

map_words("sample.txt")[:5]

Out[7]: ['adipisci', 'adipisci', 'adipisci', 'adipisci', 'adipisci']
```

4.2 Sorting a dictionary by value

By default, if you use `sorted` function on a `dict`, it will use keys to sort it. To sort by values, you can use `operator.itemgetter(1)` Return a callable object that fetches item from its operand using the operand's `__getitem__` method. It could be used to sort results.

```
In [8]: import operator
        fruits = [('apple', 3), ('banana', 2), ('pear', 5), ('orange', 1)]
        getcount = operator.itemgetter(1)
        dict(sorted(fruits, key=getcount))
```

```
Out[8]: {'orange': 1, 'banana': 2, 'apple': 3, 'pear': 5}
```

`sorted` function has also a `reverse` optional argument.

```
In [9]: dict(sorted(fruits, key=getcount, reverse=True))
```

```
Out[9]: {'pear': 5, 'apple': 3, 'banana': 2, 'orange': 1}
```

4.2.1 Exercise 4.3

Create a function `reduce` to reduce the list of words returned by `map_words` and return a dictionary containing all words as keys and number of occurrences as values.

```
wordcount('sample.txt')
{'tempora': 2, 'non': 1, 'quisquam': 1, 'amet': 1, 'sit': 1}
```

```
In [10]: def reduce(sorted_words):
        " Compute word occurrences from sorted list of words"

        res = {}
        current_word = None
        for word in sorted_words:
            if word == current_word:
                res[word] += 1
            else:
                res[word] = 1
                current_word = word
        return dict(sorted(res.items(), key=lambda v:v[1], reverse=True))

reduce(map_words("sample.txt"))
```

```
Out[10]: {'dolor': 75483,
          'aliquam': 75312,
          'numquam': 75269,
```

```

'quaerat': 75180,
'non': 75089,
'ipsum': 75010,
'sed': 74958,
'voluptatem': 74943,
'porro': 74911,
'etincidunt': 74902,
'neque': 74863,
'sit': 74834,
'velit': 74785,
'est': 74771,
'adipisci': 74695,
'consectetur': 74653,
'modi': 74650,
'amet': 74632,
'labore': 74591,
'eius': 74568,
'magnam': 74565,
'quisquam': 74554,
'dolorem': 74541,
'quiquia': 74534,
'ut': 74522,
'dolore': 74467,
'tempora': 74339}

```

- reduce function using python exception KeyError

```

In [11]: def reduce(sorted_words):
    " Compute word occurrences from sorted list of words"

    res = {}
    for word in sorted_words:
        try:
            res[word] += 1
        except KeyError:
            res[word] = 1

    return dict(sorted(res.items(), key=lambda v:v[1], reverse=True))

reduce(map_words("sample.txt"))

```

```

Out[11]: {'dolor': 75483,
'aliquam': 75312,
'numquam': 75269,
'quaerat': 75180,
'non': 75089,
'ipsum': 75010,
'sed': 74958,
'voluptatem': 74943,
'porro': 74911,
'etincidunt': 74902,
'neque': 74863,
'sit': 74834,
'velit': 74785,
'est': 74771,
'adipisci': 74695,

```

```
'consectetur': 74653,
'modi': 74650,
'amet': 74632,
'labore': 74591,
'eius': 74568,
'magnam': 74565,
'quisquam': 74554,
'dolorem': 74541,
'quiquia': 74534,
'ut': 74522,
'dolore': 74467,
'tempora': 74339}
```

You probably notice that this simple function is not easy to implement. Python standard library provides some features that can help.

4.3 Container datatypes

`collections` module implements specialized container datatypes providing alternatives to Python's general purpose built-in containers, `dict`, `list`, `set`, and `tuple`.

- `defaultdict` : dict subclass that calls a factory function to supply missing values
- `Counter` : dict subclass for counting hashable objects

4.3.1 defaultdict

When you implement the `wordcount` function you probably had some problem to append key-value pair to your `dict`. If you try to change the value of a key that is not present in the dict, the key is not automatically created.

You can use a `try-except` flow but the `defaultdict` could be a solution. This container is a `dict` subclass that calls a factory function to supply missing values. For example, using `list` as the `default_factory`, it is easy to group a sequence of key-value pairs into a dictionary of lists:

```
In [12]: from collections import defaultdict
s = [('yellow', 1), ('blue', 2), ('yellow', 3), ('blue', 4), ('red', 1)]
d = defaultdict(list)
for k, v in s:
    d[k].append(v)

dict(d)
```

```
Out[12]: {'yellow': [1, 3], 'blue': [2, 4], 'red': [1]}
```

4.3.2 Exercise 4.4

- Modify the `reduce` function you wrote above by using a `defaultdict` with the most suitable factory.

```
In [13]: from collections import defaultdict

def reduce(sorted_words):
    " Reduce version using defaultdict, we use factory `int`"
    res = defaultdict(int)
    for word in sorted_words:
        res[word] += 1

    return dict(sorted(res.items(), key=lambda v:v[1], reverse=True))

reduce(map_words("sample.txt"))
```


4.3.4 Exercise 4.5

Use a `Counter` object to count words occurrences in the sample text file.

```
In [18]: from collections import Counter

def wordcounter(filename):

    " Wordcount function using the Counter type from collections"

    with open(filename) as f:
        data = f.read()

    c = Counter(data.lower().replace(".", " ").split())
    return dict(c.most_common())

wordcounter("sample.txt")

Out[18]: {'dolor': 75483,
          'aliquam': 75312,
          'numquam': 75269,
          'quaerat': 75180,
          'non': 75089,
          'ipsum': 75010,
          'sed': 74958,
          'voluptatem': 74943,
          'porro': 74911,
          'etincidunt': 74902,
          'neque': 74863,
          'sit': 74834,
          'velit': 74785,
          'est': 74771,
          'adipisci': 74695,
          'consectetur': 74653,
          'modi': 74650,
          'amet': 74632,
          'labore': 74591,
          'eius': 74568,
          'magnam': 74565,
          'quisquam': 74554,
          'dolorem': 74541,
          'quiquia': 74534,
          'ut': 74522,
          'dolore': 74467,
          'tempora': 74339}
```

The `Counter` class is similar to bags or multisets in some Python libraries or other languages. We will see later how to use `Counter`-like objects in a parallel context.

4.4 Process multiple files

- Create several files containing `lorem` text named `'sample01.txt'`, `'sample02.txt'`...
- If you process these files you return multiple dictionaries.
- You have to loop over them to sum occurrences and return the resulted dict. To iterate on specific mappings, Python standard library provides some useful features in `itertools` module.
- `itertools.chain(*mapped_values)` could be used for treating consecutive sequences as a single sequence.

```
In [19]: import itertools, operator
fruits = [('apple', 3), ('banana', 2), ('pear', 5), ('orange', 1)]
vegetables = [('endive', 2), ('spinach', 1), ('celery', 5), ('carrot', 4)]
getcount = operator.itemgetter(1)
dict(sorted(itertools.chain(fruits,vegetables), key=getcount))
```

```
Out[19]: {'orange': 1,
          'spinach': 1,
          'banana': 2,
          'endive': 2,
          'apple': 3,
          'carrot': 4,
          'pear': 5,
          'celery': 5}
```

4.4.1 Exercise 4.6

- Write the program that creates files, processes and use `itertools.chain` to get the merged word count dictionary.

```
In [20]: import lorem

         for i in range(4): # write 4 sample text files
             with open(f"sample{i:02d}.txt", "w") as f:
                 f.write(lorem.text())

In [21]: from glob import glob

         samples = glob("*.txt")

In [22]: from itertools import chain

         words1 = map_words("sample01.txt")
         words2 = map_words("sample02.txt")

         reduce(chain(words1,words2)) # word count on two files

Out[22]: {'aliquam': 23,
          'eius': 23,
          'porro': 22,
          'quiquia': 21,
          'sit': 21,
          'est': 20,
          'magnam': 20,
          'modi': 20,
          'sed': 19,
          'tempora': 19,
          'consectetur': 18,
          'adipisci': 17,
          'numquam': 17,
          'quisquam': 17,
          'neque': 16,
          'non': 16,
          'dolore': 15,
          'voluptatem': 15,
          'ut': 14,
          'velit': 14,
```

```
'amet': 13,
'ipsum': 13,
'labore': 13,
'dolor': 12,
'dolorem': 12,
'quaerat': 12,
'etincidunt': 11}
```

- wordcount on a list of files

```
In [23]: from itertools import chain
         from glob import glob
```

```
         reduce(chain(*[map_words(file) for file in glob("sample0*.txt")]))
```

```
Out[23]: {'tempora': 102,
          'quiquia': 92,
          'quisquam': 92,
          'sit': 91,
          'dolore': 84,
          'etincidunt': 84,
          'ut': 84,
          'modi': 83,
          'adipisci': 82,
          'eius': 82,
          'magnam': 81,
          'dolor': 79,
          'aliquam': 78,
          'porro': 77,
          'dolorem': 76,
          'est': 76,
          'numquam': 76,
          'consectetur': 74,
          'sed': 74,
          'amet': 73,
          'non': 71,
          'voluptatem': 70,
          'ipsum': 69,
          'quaerat': 68,
          'velit': 67,
          'labore': 64,
          'neque': 61}
```

4.4.2 Exercise 4.7

- Create the wordcount function in order to accept several files as arguments and return the result dict.

```
wordcount(file1, file2, file3, ...)
```

[Hint: arbitrary argument lists](#)

- Example of use of arbitrary argument list and arbitrary named arguments.

```
In [24]: def func( *args, **kwargs):
         for arg in args:
             print(arg)
```

```

    print(kwargs)

    func( "3", [1,2], "bonjour", x = 4, y = "y")

```

3
[1, 2]
bonjour
{'x': 4, 'y': 'y'}

```

In [25]: from itertools import chain
        from glob import glob

        def wordcount(*args): # arbitrary argument list

            # MAP
            mapped_values = []
            for filename in args:
                with open(filename) as f:
                    data = f.read()
                    words = data.lower().replace('.', '').strip().split()
                    mapped_values.append(sorted(words))

            # REDUCE
            return reduce(chain(*mapped_values))

        wordcount(*glob("sample0*.txt"))

```

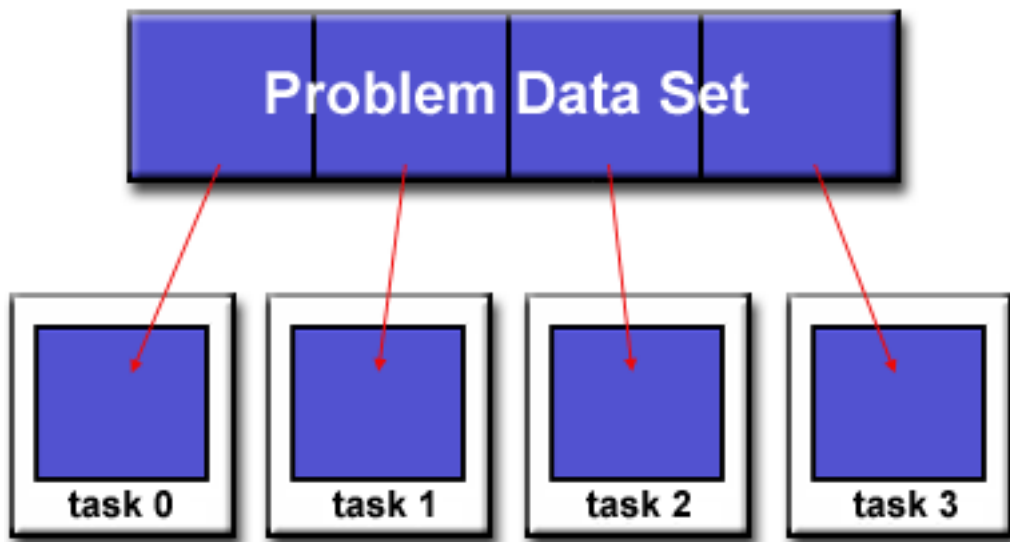
```

Out[25]: {'tempora': 102,
          'quiquia': 92,
          'quisquam': 92,
          'sit': 91,
          'dolore': 84,
          'etincidunt': 84,
          'ut': 84,
          'modi': 83,
          'adipisci': 82,
          'eius': 82,
          'magnam': 81,
          'dolor': 79,
          'aliquam': 78,
          'porro': 77,
          'dolorem': 76,
          'est': 76,
          'numquam': 76,
          'consectetur': 74,
          'sed': 74,
          'amet': 73,
          'non': 71,
          'voluptatem': 70,
          'ipsum': 69,
          'quaerat': 68,
          'velit': 67,
          'labore': 64,
          'neque': 61}

```

Chapter 5

Map Reduce



credits: https://computing.llnl.gov/tutorials/parallel_comp

5.1 map function example

The `map(func, seq)` Python function applies the function `func` to all the elements of the sequence `seq`. It returns a new list with the elements changed by `func`

```
In [1]: def f(x):
        return x * x

        rdd = [2, 6, -3, 7]
        res = map(f, rdd)
        res  # Res is an iterator

Out[1]: <map at 0x7f96642b5550>

In [2]: print(*res)

4 36 9 49
```

```
In [3]: from operator import mul
        rdd1, rdd2 = [2, 6, -3, 7], [1, -4, 5, 3]
        res = map(mul, rdd1, rdd2) # element wise sum of rdd1 and rdd2
```

```
In [4]: print(*res)
```

```
2 -24 -15 21
```

MapReduce Job – Logical View

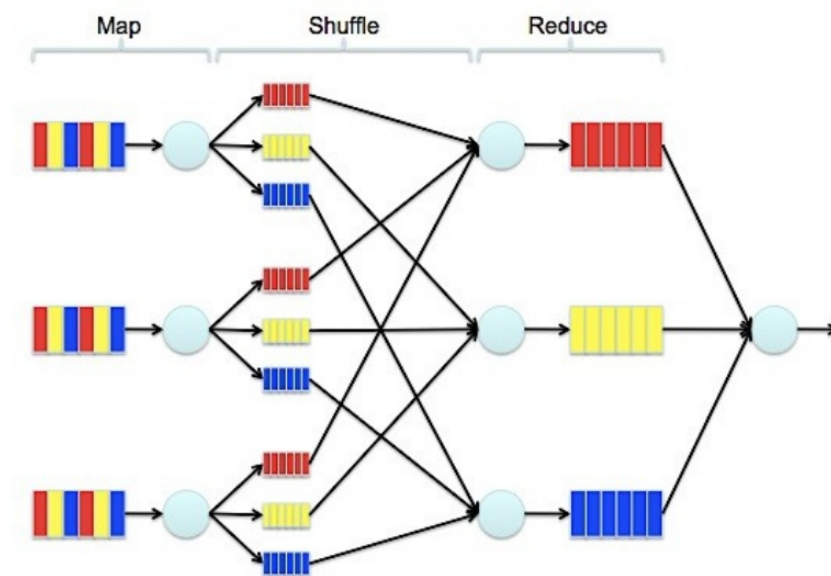


Image from - <http://mm-tom.s3.amazonaws.com/blog/MapReduce.png>

5.2 functools.reduce example

The function `reduce(func, seq)` continually applies the function `func()` to the sequence `seq` and return a single value. For example, `reduce(f, [1, 2, 3, 4, 5])` calculates `f(f(f(f(1,2),3),4),5)`.

```
In [5]: from functools import reduce
        from operator import add

        reduce(mul, rdd) # computes (((1+2)+3)+4)+5)
```

```
Out[5]: -252
```

```
In [6]: p = 1
        for x in rdd:
            p *= x
        p
```

```
Out[6]: -252
```

```
In [7]: def g(x,y):
        return x * y

        reduce(g, rdd)
```

```
Out[7]: -252
```

```
In [8]: p = 1
        for x in rdd:
            p *= x
        p
```

```
Out[8]: -252
```

5.3 Weighted mean and Variance

If the generator of random variable X is discrete with probability mass function $x_1 \mapsto p_1, x_2 \mapsto p_2, \dots, x_n \mapsto p_n$ then

$$\text{Var}(X) = \left(\sum_{i=1}^n p_i x_i^2 \right) - \mu^2,$$

where μ is the average value, i.e.

$$\mu = \sum_{i=1}^n p_i x_i.$$

```
In [9]: X = [5, 1, 2, 3, 1, 2, 5, 4]
        P = [0.05, 0.05, 0.15, 0.05, 0.15, 0.2, 0.1, 0.25]
```

Example of zip

```
In [10]: for x, p in zip(X, P):
        print(f" x = {x} ..... p = {p}")
```

```
x = 5 ... p = 0.05
x = 1 ... p = 0.05
x = 2 ... p = 0.15
x = 3 ... p = 0.05
x = 1 ... p = 0.15
x = 2 ... p = 0.2
x = 5 ... p = 0.1
x = 4 ... p = 0.25
```

```
In [11]: from itertools import zip_longest
```

```
        for x, p in zip_longest(X, [0.1], fillvalue=0.0):
            print(f" x = {x} ..... p = {p}")
```

```
x = 5 ... p = 0.1
x = 1 ... p = 0.0
x = 2 ... p = 0.0
x = 3 ... p = 0.0
x = 1 ... p = 0.0
x = 2 ... p = 0.0
x = 5 ... p = 0.0
x = 4 ... p = 0.0
```

```
In [12]: sum(P)
Out[12]: 0.9999999999999999
```

5.3.1 Exercise 5.1

- Write functions to compute the average value and variance using for loops

```
In [13]: def weighted_mean( X, P):
          return sum([x*p for x, p in zip(X,P)])

          weighted_mean(X,P)

Out[13]: 2.8

In [14]: def variance(X, P):
          mu = weighted_mean(X,P)
          return sum([p*x*x for x,p in zip(X,P)]) - mu**2

          variance(X, P)

Out[14]: 1.96000000000000017
```

5.3.2 Exercise 5.2

- Write functions to compute the average value and variance using `map` and `reduce`

```
In [15]: from operator import add, mul
          from functools import reduce

          def weighted_mean( X, P):
              return reduce(add,map(mul, X, P))

          weighted_mean(X,P)

Out[15]: 2.8

In [16]: def variance(X, P):
          mu = weighted_mean(X,P)
          return reduce(add,map(lambda x,p:p*x*x, X, P)) - mu**2

          variance(X, P)

Out[16]: 1.96000000000000017
```

5.3.3 Examples with filter

```
In [17]: res = filter( lambda p: p > 0.1, P) # select p > 0.1
          print(*res)

0.15 0.15 0.2 0.25

In [18]: res = filter( lambda x: x % 3 == 0, range(15)) # select integer that can be divided by 3
          print(*res)

0 3 6 9 12
```

NB: Exercises above are just made to help to understand map-reduce process. This is a bad way to code a variance in Python. You should use [Numpy](#) instead.

5.4 Wordcount

We will modify the `wordcount` application into a map-reduce process.

The **map** process takes text files as input and breaks it into words. The **reduce** process sums the counts for each word and emits a single key/value with the word and sum.

We need to split the wordcount function we wrote in notebook 04 in order to use map and reduce.

In the following exercises we will implement in Python the Java example described in [Hadoop documentation](#).

5.5 Map - Read file and return a key/value pairs

5.5.1 Exercise 5.3

Write a function `mapper` with a single file name as input that returns a sorted sequence of tuples (word, 1) values.

```
mapper('sample.txt')
[('adipisci', 1), ('adipisci', 1), ('adipisci', 1), ('adipisci', 1), ('adipisci', 1), ('adipisci', 1),
```

```
In [19]: import lorem
          with open('sample.txt', 'w') as f:
              f.write(lorem.text())
```

```
In [20]: def mapper(filename):
            with open(filename) as f:
                data = f.read()

            data = data.strip().replace(".", "").lower().split()

            return sorted([(w,1) for w in data])

mapper("sample.txt")
```

[illegible]

('consectetur', 1),
('consectetur', 1),
('consectetur', 1),
('dolor', 1),
('dolor', 1),
('dolor', 1),
('dolore', 1),
('dolore', 1),
('dolore', 1),
('dolore', 1),
('dolore', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('dolorem', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('eius', 1),
('est', 1),
('est', 1),
('est', 1),
('est', 1),
('est', 1),
('est', 1),
('est', 1),
('est', 1),
('est', 1),
('est', 1),
('etincidunt', 1),
('etincidunt', 1),
('etincidunt', 1),
('etincidunt', 1),
('etincidunt', 1),
('etincidunt', 1).

('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('ipsum', 1),
('labore', 1),
('labore', 1),
('labore', 1),
('labore', 1),
('labore', 1),
('labore', 1),
('labore', 1),
('labore', 1),
('labore', 1),
('labore', 1),
('labore', 1),
('labore', 1),
('magnam', 1),
('magnam', 1),
('magnam', 1),
('magnam', 1),
('magnam', 1),
('magnam', 1),
('magnam', 1),
('magnam', 1),
('magnam', 1),
('magnam', 1),
('modi', 1),
('modi', 1),
('modi', 1),
('modi', 1),
('modi', 1),
('modi', 1),
('modi', 1),
('modi', 1),
('modi', 1),
('modi', 1),
('neque', 1),
('neque', 1),
('neque', 1),
('neque', 1),

```
('neque', 1),
('neque', 1),
('neque', 1),
('neque', 1),
('neque', 1),
('non', 1),
('non', 1),
('non', 1),
('non', 1),
('non', 1),
('non', 1),
('non', 1),
('non', 1),
('non', 1),
('non', 1),
('non', 1),
('non', 1),
('non', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('numquam', 1),
('porro', 1),
('porro', 1),
('porro', 1),
('porro', 1),
('porro', 1),
('quaerat', 1),
('quaerat', 1),
('quaerat', 1),
('quaerat', 1),
('quaerat', 1),
('quaerat', 1),
('quaerat', 1),
('quaerat', 1),
('quaerat', 1),
('quaerat', 1),
('quiquia', 1),
('quiquia', 1),
('quiquia', 1),
('quiquia', 1),
('quiquia', 1),
('quisquam', 1),
('quisquam', 1),
('quisquam', 1),
```

[illegible]

```

('velit', 1),
('velit', 1),
('velit', 1),
('voluptatem', 1),
('voluptatem', 1),
('voluptatem', 1),
('voluptatem', 1),
('voluptatem', 1),
('voluptatem', 1),
('voluptatem', 1),
('voluptatem', 1),
('voluptatem', 1),
('voluptatem', 1)]

```

5.6 Partition

5.6.1 Exercise 5.4

Create a function named `partitioner` that stores the key/value pairs from `mapper` that group (word, 1) pairs into a list as:

```

partitioner(mapper('sample.txt'))
[('adipisci', [1, 1, 1, 1, 1, 1, 1]), ('aliquam', [1, 1, 1, 1, 1, 1, 1]), ('amet', [1, 1, 1, 1],...)]

```

In [21]: `from collections import defaultdict`

```

def partitioner(mapped_values):
    res = defaultdict(list)
    for w, c in mapped_values:
        res[w].append(c)

    return res.items()

```

```

partitioner(mapper('sample.txt'))

```

```

Out[21]: dict_items([('adipisci', [1, 1, 1, 1]), ('aliquam', [1, 1, 1, 1, 1, 1]), ('amet', [1, 1, 1, 1],...)]

```

5.7 Reduce - Sums the counts and returns a single key/value (word, sum).

5.7.1 Exercise 5.5

Write the function `reducer` that read a tuple (word,[1,1,1,...,1]) and sum the occurrences of word to a final count, and then output the tuple (word,occurrences).

```

reducer(('hello', [1, 1, 1, 1, 1]))
('hello', 5)

```

In [22]: `from operator import itemgetter`

```

def reducer( item ):
    w, v = item
    return (w, len(v))

```

```
reducer(('hello', [1,1,1,1,1]))
```

```
Out[22]: ('hello', 5)
```

5.8 Process several files

Let's create 8 files `sample[0-7].txt`. Set most common words at the top of the output list.

```
In [23]: from lorem import text
        for i in range(8):
            with open("sample{0:02d}.txt".format(i), "w") as f:
                f.write(text())
```

```
In [24]: import glob
        files = sorted(glob.glob('sample0*.txt'))
        files
```

```
Out[24]: ['sample00.txt',
          'sample01.txt',
          'sample02.txt',
          'sample03.txt',
          'sample04.txt',
          'sample05.txt',
          'sample06.txt',
          'sample07.txt',
          'sample08.txt',
          'sample09.txt']
```

5.8.1 Exercise 5.6

- Use functions implemented above to count (word, occurrences) by using a for loops over files and partitioned data.

```
In [25]: from itertools import chain

        def wordcount(files):

            mapped_values = [mapper(file) for file in files]

            partitioned_values = partitioner(chain(*mapped_values))

            return sorted([reducer(val) for val in partitioned_values],
                          key = itemgetter(1),
                          reverse = True)

        wordcount(files)
```

```
Out[25]: [('non', 94),
          ('sed', 91),
          ('aliquam', 89),
          ('sit', 87),
          ('voluptatem', 87),
          ('velit', 86),
          ('adipisci', 85),
          ('labore', 84),
          ('neque', 84),
```

```
(('dolorem', 83),
 ('quaerat', 83),
 ('dolor', 82),
 ('etincidunt', 82),
 ('magnam', 82),
 ('amet', 81),
 ('est', 81),
 ('ut', 81),
 ('tempora', 80),
 ('modi', 79),
 ('eius', 78),
 ('quiquia', 78),
 ('quisquam', 78),
 ('consectetur', 76),
 ('dolore', 74),
 ('ipsum', 74),
 ('porro', 72),
 ('numquam', 69])
```

5.8.2 Exercise 5.7

- This time use map function to apply mapper and reducer.

In [26]: `def wordcount(files):`

```
    mapped_values = map(mapper, files)
    partitioned_values = partitioner(chain(*mapped_values))

    return sorted( map(reducer, partitioned_values),
                    key=itemgetter(1),
                    reverse=True)
```

`wordcount(files)`

```
Out[26]: [('non', 94),
 ('sed', 91),
 ('aliquam', 89),
 ('sit', 87),
 ('voluptatem', 87),
 ('velit', 86),
 ('adipisci', 85),
 ('labore', 84),
 ('neque', 84),
 ('dolorem', 83),
 ('quaerat', 83),
 ('dolor', 82),
 ('etincidunt', 82),
 ('magnam', 82),
 ('amet', 81),
 ('est', 81),
 ('ut', 81),
 ('tempora', 80),
 ('modi', 79),
 ('eius', 78),
 ('quiquia', 78),
```



```
('quisquam', 78),  
( 'consectetur', 76),  
( 'dolore', 74),  
( 'ipsum', 74),  
( 'porro', 72),  
( 'numquam', 69)]
```


Chapter 6

Parallel Computation

6.1 Parallel computers

- Multiprocessor/multicore: several processors work on data stored in shared memory
- Cluster: several processor/memory units work together by exchanging data over a network
- Co-processor: a general-purpose processor delegates specific tasks to a special-purpose processor (GPU)

6.2 Parallel Programming

- Decomposition of the complete task into independent subtasks and the data flow between them.
- Distribution of the subtasks over the processors minimizing the total execution time.
- For clusters: distribution of the data over the nodes minimizing the communication time.
- For multiprocessors: optimization of the memory access patterns minimizing waiting times.
- Synchronization of the individual processes.

6.3 MapReduce

```
In [1]: from time import sleep
        def f(x):
            sleep(1)
            return x*x
        L = list(range(8))
        L
```

```
Out[1]: [0, 1, 2, 3, 4, 5, 6, 7]
```

```
In [2]: %time sum(f(x) for x in L)
```

```
CPU times: user 0 ns, sys: 3.27 ms, total: 3.27 ms
Wall time: 8.01 s
```

```
Out[2]: 140
```

```
In [3]: %time sum(map(f,L))
```

```
CPU times: user 0 ns, sys: 3.66 ms, total: 3.66 ms
Wall time: 8.01 s
```

```
Out[3]: 140
```

6.4 Multiprocessing

`multiprocessing` is a package that supports spawning processes.

We can use it to display how many concurrent processes you can launch on your computer.

```
In [4]: from multiprocessing import cpu_count
```

```
        cpu_count()
```

```
Out[4]: 2
```

6.5 Futures

The `concurrent.futures` module provides a high-level interface for asynchronously executing callables.

The asynchronous execution can be performed with: - **threads**, using `ThreadPoolExecutor`, - **separate processes**, using `ProcessPoolExecutor`. Both implement the same interface, which is defined by the abstract `Executor` class.

`concurrent.futures` can't launch **processes** on windows. Windows users must install [loky](#).

```
In [5]: %%file pmap.py
        from concurrent.futures import ProcessPoolExecutor
        from time import sleep, time

        def f(x):
            sleep(1)
            return x*x

        L = list(range(8))

        if __name__ == '__main__':

            begin = time()
            with ProcessPoolExecutor() as pool:

                result = sum(pool.map(f, L))
            end = time()

            print(f"result = {result} and time = {end-begin}")
```

Overwriting `pmap.py`

```
In [6]: import sys
        !{sys.executable} pmap.py
```

```
result = 140 and time = 4.011821985244751
```

- `ProcessPoolExecutor` launches one slave process per physical core on the computer.
- `pool.map` divides the input list into chunks and puts the tasks (function + chunk) on a queue.
- Each slave process takes a task (function + a chunk of data), runs `map(function, chunk)`, and puts the result on a result list.
- `pool.map` on the master process waits until all tasks are handled and returns the concatenation of the result lists.

```
In [7]: %%time
        from concurrent.futures import ThreadPoolExecutor
```

```

with ThreadPoolExecutor() as pool:

    results = sum(pool.map(f, L))

print(results)

```

140

CPU times: user 6.41 ms, sys: 319 µs, total: 6.72 ms

Wall time: 2 s

6.6 Thread and Process: Differences

- A **process** is an instance of a running program.
- **Process** may contain one or more **threads**, but a **thread** cannot contain a **process**.
- **Process** has a self-contained execution environment. It has its own memory space.
- Application running on your computer may be a set of cooperating **processes**.
- **Process** don't share its memory, communication between **processes** implies data serialization.
- A **thread** is made of and exist within a **process**; every **process** has at least one **thread**.
- Multiple **threads** in a **process** share resources, which helps in efficient communication between **threads**.
- **Threads** can be concurrent on a multi-core system, with every core executing the separate **threads** simultaneously.

6.7 The Global Interpreter Lock (GIL)

- The Python interpreter is not thread safe.
- A few critical internal data structures may only be accessed by one thread at a time. Access to them is protected by the GIL.
- Attempts at removing the GIL from Python have failed until now. The main difficulty is maintaining the C API for extension modules.
- Multiprocessing avoids the GIL by having separate processes which each have an independent copy of the interpreter data structures.
- The price to pay: serialization of tasks, arguments, and results.

6.8 Weighted mean and Variance

6.8.1 Exercise 6.1

Use `ThreadPoolExecutor` to parallelized functions written in notebook 05

```

In [8]: X = [5, 1, 2, 3, 1, 2, 5, 4]
        P = [0.05, 0.05, 0.15, 0.05, 0.15, 0.2, 0.1, 0.25]

In [9]: from operator import add, mul
        from functools import reduce
        from concurrent.futures import ThreadPoolExecutor as pool

        def weighted_mean( X, P):

```

```

    with pool() as p:
        w1 = p.map(mul, X, P)

    return reduce(add,w1)

weighted_mean(X,P)

Out[9]: 2.8

In [10]: def variance(X, P):
    mu = weighted_mean(X,P)
    with pool() as p:
        w2 = p.map(lambda x,p:p*x*x, X, P)
    return reduce(add,w2) - mu**2

variance(X, P)

Out[10]: 1.9600000000000017

In [11]: import numpy as np
    x = np.array(X)
    p = np.array(P)
    np.average( x, weights=p)

Out[11]: 2.8

In [12]: var =np.sum(p*x**2) - np.average( x, weights=p)**2
    var

Out[12]: 1.9600000000000017

```

6.9 Wordcount

```

In [13]: from glob import glob
    from collections import defaultdict
    from operator import itemgetter
    from itertools import chain
    from concurrent.futures import ThreadPoolExecutor

    def mapper(filename):
        " split text to list of key/value pairs (word,1)"
        with open(filename) as f:
            data = f.read()

        data = data.strip().replace(".", "").lower().split()

        return sorted([(w,1) for w in data])

    def partitioner(mapped_values):
        """ get lists from mapper and create a dict with
        (word, [1,1,1]) """

        res = defaultdict(list)
        for w, c in mapped_values:
            res[w].append(c)

        return res.items()

```

```
def reducer( item ):
    """ Compute words occurences from dict computed
    by partioner
    """
    w, v = item
    return (w,len(v))
```

6.10 Parallel map

- Let's improve the mapper function by print out inside the function the current process name.

Example

```
In [14]: import multiprocessing as mp
        from concurrent.futures import ThreadPoolExecutor
        #from loky import ProcessPoolExecutor
        def process_name(n):
            " prints out the current process name "
            print(mp.current_process().name)

        with ProcessPoolExecutor() as e:
            _ = e.map(process_name, range(mp.cpu_count()))
```

```
-----

NameError                                Traceback (most recent call last)

<ipython-input-14-2096cf4534b5> in <module>
      6     print(mp.current_process().name)
      7
----> 8 with ProcessPoolExecutor() as e:
      9     _ = e.map(process_name, range(mp.cpu_count()))

NameError: name 'ProcessPoolExecutor' is not defined
```

6.10.1 Exercise 6.2

- Modify the mapper function by adding this print.

```
In [15]: def mapper(filename):
        " split text to list of key/value pairs (word,1)"

        print(f"{mp.current_process().name} : {filename}")
        with open(filename) as f:
            data = f.read()

        data = data.strip().replace(".", "").lower().split()

        return sorted([(w,1) for w in data])
```

6.11 Parallel reduce

- For parallel reduce operation, data must be aligned in a container. We already created a `partitioner` function that returns this container.

6.11.1 Exercise 6.3

Write a parallel program that uses the three functions above using `ProcessPoolExecutor`. It reads all the "sample*.txt" files. Map and reduce steps are parallel.

```
In [16]: from concurrent.futures import ThreadPoolExecutor

def wordcount(files):

    with ThreadPoolExecutor() as e:

        mapped_values = e.map(mapper, files)
        partioned_values = partitioner(chain(*mapped_values))
        occurences = e.map(reducer, partioned_values)

    return sorted(occurences,
                  key=itemgetter(1),
                  reverse=True)

files = glob("sample*.txt")
wordcount(files)
```

```
Out[16]: []
```

6.12 Increase volume of data

Due to the proxy, code above is not runnable on workstations

6.12.1 Getting the data

- [The Latin Library](#) contains a huge collection of freely accessible Latin texts. We get links on the Latin Library's homepage ignoring some links that are not associated with a particular author.

```
In [17]: from bs4 import BeautifulSoup # web scraping library
        from urllib.request import *

base_url = "http://www.thelatinlibrary.com/"
home_content = urlopen(base_url)

soup = BeautifulSoup(home_content, "lxml")
author_page_links = soup.find_all("a")
author_pages = [ap["href"] for i, ap in enumerate(author_page_links) if i < 49]
```

6.12.2 Generate html links

- Create a list of all links pointing to Latin texts. The Latin Library uses a special format which makes it easy to find the corresponding links: All of these links contain the name of the text author.

```
In [18]: ap_content = list()
        for ap in author_pages:
            ap_content.append(urlopen(base_url + ap))
```



```

book_links = list()
for path, content in zip(author_pages, ap_content):
    author_name = path.split(".")[0]
    ap_soup = BeautifulSoup(content, "lxml")
    book_links += ([link for link in ap_soup.find_all("a", {"href": True}) if author_name in link["href"]])

```

6.12.3 Download webpages content

In [19]: `from urllib.error import HTTPError`

```

num_pages = 100

for i, bl in enumerate(book_links[:num_pages]):
    print("Getting content " + str(i + 1) + " of " + str(num_pages), end="\r", flush=True)
    try:
        content = urlopen(base_url + bl["href"]).read()
        with open(f"book-{i:03d}.dat", "wb") as f:
            f.write(content)
    except HTTPError as err:
        print("Unable to retrieve " + bl["href"] + ".")
        continue

```

Getting content 100 of 100

6.12.4 Extract data files

- I already put the content of pages in files named book-*.txt
- You can extract data from the archive by running the cell below

```

import os # library to get directory and file paths
import tarfile # this module makes possible to read and write tar archives

```

```

def extract_data():
    datadir = os.path.join('data', 'latinbooks')
    if not os.path.exists(datadir):
        print("Extracting data...")
        tar_path = os.path.join('data', 'latinbooks.tgz')
        with tarfile.open(tar_path, mode='r:gz') as books:
            books.extractall('data')

```

`extract_data()` *# this function call will extract text files in data/latinbooks*

6.12.5 Read data files

```

In [20]: from glob import glob
        files = glob('book*.dat')
        texts = list()
        for file in files:
            with open(file, 'rb') as f:
                text = f.read()
            texts.append(text)

```

6.12.6 Extract the text from html and split the text at periods to convert it into sentences.

```

In [21]: %%time
        from bs4 import BeautifulSoup

```

```

sentences = list()

for i, text in enumerate(texts):
    print("Document " + str(i + 1) + " of " + str(len(texts)), end="\r", flush=True)
    textSoup = BeautifulSoup(text, "lxml")
    paragraphs = textSoup.find_all("p", attrs={"class":None})
    prepared = ("".join([p.text.strip().lower() for p in paragraphs[1:-1]]))
    for t in prepared.split("."):
        part = "".join([c for c in t if c.isalpha() or c.isspace()])
        sentences.append(part.strip())

# print first and last sentence to check the results
print(sentences[0])
print(sentences[-1])

```

sed nimirum nihil fortuna rennunte licet homini natu dexterum provenire nec consilio prudenti vel reme

CPU times: user 1.49 s, sys: 40.4 ms, total: 1.53 s
 Wall time: 1.48 s

6.12.7 Exercise 6.4

Parallelize this last process using `concurrent.futures`.

```

In [22]: %%time
from bs4 import BeautifulSoup
from concurrent.futures import ThreadPoolExecutor as pool

def sentence_mapper(text):
    sentences = list()
    textSoup = BeautifulSoup(text, "lxml")
    paragraphs = textSoup.find_all("p", attrs={"class":None})
    prepared = ("".join([p.text.strip().lower() for p in paragraphs[1:-1]]))
    for t in prepared.split("."):
        part = "".join([c for c in t if c.isalpha() or c.isspace()])
        sentences.append(part.strip())
    return sentences

# parallel map
with pool(4) as p:

    mapped_sentences = p.map(sentence_mapper, texts)

# reduce
sentences = reduce(add, mapped_sentences )

# print first and last sentence to check the results
print(sentences[0])
print(sentences[-1])

```

sed nimirum nihil fortuna rennunte licet homini natu dexterum provenire nec consilio prudenti vel reme

CPU times: user 2.57 s, sys: 915 ms, total: 3.48 s
 Wall time: 2.57 s

6.13 References

- [Using Conditional Random Fields and Python for Latin word segmentation](#)

Chapter 7

Asynchronous Processing

While many parallel applications can be described as maps, some can be more complex. In this section we look at the asynchronous `concurrent.futures` interface, which provides a simple API for ad-hoc parallelism. This is useful for when your computations don't fit a regular pattern.

7.0.1 `Executor.submit`

The `submit` method starts a computation in a separate thread or process and immediately gives us a `Future` object that refers to the result. At first, the future is pending. Once the function completes the future is finished.

We collect the result of the task with the `.result()` method, which does not return until the results are available.

```
In [1]: %%time
        from time import sleep

        def slowadd(a, b, delay=1):
            sleep(delay)
            return a + b

        slowadd(1,1)

CPU times: user 1.42 ms, sys: 196 µs, total: 1.62 ms
Wall time: 1 s
```

```
Out[1]: 2
```

```
In [2]: from concurrent.futures import ThreadPoolExecutor

        e = ThreadPoolExecutor()
        future = e.submit(slowadd, 1, 2)
        future
```

```
Out[2]: <Future at 0x7f4a49e17160 state=running>
```

```
In [3]: future.result()
```

```
Out[3]: 3
```

7.0.2 Submit many tasks, receive many futures

Because `submit` returns immediately we can submit many tasks all at once and they will execute in parallel.

```
In [4]: %%time
        results = [slowadd(i, i, delay=1) for i in range(8)]
        print(results)
```

```
[0, 2, 4, 6, 8, 10, 12, 14]
```

```
CPU times: user 3.42 ms, sys: 473 µs, total: 3.89 ms
```

```
Wall time: 8.01 s
```

```
In [5]: %%time
        e = ThreadPoolExecutor()
        futures = [e.submit(slowadd, i, i, delay=1) for i in range(8)]
        results = [f.result() for f in futures]
        print(results)
```

```
[0, 2, 4, 6, 8, 10, 12, 14]
```

```
CPU times: user 0 ns, sys: 5.85 ms, total: 5.85 ms
```

```
Wall time: 2 s
```

- Submit fires off a single function call in the background, returning a future.
- When we combine submit with a single for loop we recover the functionality of map.
- When we want to collect our results we replace each of our futures, `f`, with a call to `f.result()`
- We can combine submit with multiple for loops and other general programming to get something more general than map.

7.0.3 Exercise 7.1

Parallelize the following code with `e.submit`

1. Replace the `results` list with a list called `futures`
2. Replace calls to `slowadd` and `slowsub` with `e.submit` calls on those functions
3. At the end, block on the computation by recreating the `results` list by calling `.result()` on each future in the `futures` list.

```
In [6]: %%time
        from time import sleep

        def slowadd(a, b, delay=1):
            sleep(delay)
            return a + b

        def slowsub(a, b, delay=1):
            sleep(delay)
            return a - b

        results = []
        for i in range(4):
            for j in range(4):
                if i < j:
                    results.append(slowadd(i, j, delay=1))
                elif i > j:
                    results.append(slowsub(i, j, delay=1))

        print(results)
```

```
[1, 2, 3, 1, 3, 4, 2, 1, 5, 3, 2, 1]
CPU times: user 4.48 ms, sys: 701 µs, total: 5.18 ms
Wall time: 12 s
```

7.1 Extract daily stock data from google

```
In [7]: import os # library to get directory and file paths
import tarfile # this module makes possible to read and write tar archives

def extract_data(name, where):
    datadir = os.path.join(where, name)
    if not os.path.exists(datadir):
        print("Extracting data...")
        tar_path = os.path.join(where, name+'.tgz')
        with tarfile.open(tar_path, mode='r:gz') as data:
            data.extractall(where)

extract_data('daily-stock', 'data') # this function call will extract json files
```

7.2 Convert data to pandas DataFrames and save it in hdf5 files

HDF5 is a data model, library, and file format for storing and managing data. This format is widely used and is supported by many languages and platforms.

```
In [8]: import json
import pandas as pd
import os, glob

here = os.getcwd()
datadir = os.path.join(here, 'data', 'daily-stock')
filenames = sorted(glob.glob(os.path.join(datadir, '*.json')))
filenames

Out[8]: ['/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aet.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/afl.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aig.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/al.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/amgn.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/avy.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/b.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/bwa.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ge.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hal.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hp.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hpq.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ibm.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jbl.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jpm.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/luv.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/met.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/pcg.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/tgt.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/usb.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/xom.json']
```

7.2.1 Sequential version

```
In [9]: %%time
        from concurrent.futures import ProcessPoolExecutor
        import json
        import pandas as pd

        def load_parse_store(fn):

            with open(fn) as f:
                data = [json.loads(line) for line in f] # load

            df = pd.DataFrame(data) # parse

            out_filename = fn[:-5] + '.h5'
            df.to_hdf(out_filename, '/data') # store
            print("Finished : %s" % (out_filename.split(os.path.sep)[-1]))

            return True

        results = [load_parse_store(file) for file in filenames]

Finished : aet.h5
Finished : afl.h5
Finished : aig.h5
Finished : al.h5
Finished : amgn.h5
Finished : avy.h5
Finished : b.h5
Finished : bwa.h5
Finished : ge.h5
Finished : hal.h5
Finished : hp.h5
Finished : hpq.h5
Finished : ibm.h5
Finished : jbl.h5
Finished : jpm.h5
Finished : luv.h5
Finished : met.h5
Finished : pcg.h5
Finished : tgt.h5
Finished : usb.h5
Finished : xom.h5
CPU times: user 8.04 s, sys: 941 ms, total: 8.98 s
Wall time: 8.85 s
```

7.2.2 Exercise 7.2

Parallelize the loop above using `ThreadPoolExecutor` and `map`.

7.3 Read files and load dataframes.

```
In [10]: filenames = sorted(glob.glob(os.path.join('data', 'daily-stock', '*.h5')))
        series = {}
```



```

for fn in filenames:
    series[fn] = pd.read_hdf(fn)['close']

-----

ValueError                                Traceback (most recent call last)

<ipython-input-10-2dab4a15ac74> in <module>
      2 series = {}
      3 for fn in filenames:
----> 4     series[fn] = pd.read_hdf(fn)['close']

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/io/pytables.py in read_hdf
    400         for group_to_check in groups[1:]:
    401             if not _is_metadata_of(group_to_check, candidate_only_group):
--> 402                 raise ValueError(
    403                     "key must be provided when HDF5 "
    404                     "file contains multiple datasets."

ValueError: key must be provided when HDF5 file contains multiple datasets.

```

7.4 Application

Given our HDF5 files from the last section we want to find the two datasets with the greatest pair-wise correlation. This forces us to consider all $n \times (n - 1)$ possibilities.

```

In [11]: %%time

results = {}

for a in filenames:
    for b in filenames:
        if a != b:
            results[a, b] = series[a].corr(series[b])

((a, b), corr) = max(results.items(), key=lambda kv: kv[1])
print("%s matches with %s with correlation %.f" % (a, b, corr))

-----

KeyError                                Traceback (most recent call last)

<timed exec> in <module>

KeyError: 'data/daily-stock/aet.h5'

```

We use matplotlib to visually inspect the highly correlated timeseries

```
In [12]: %matplotlib inline
import matplotlib.pyplot as plt
plt.figure(figsize=(10, 4))
plt.plot(series[a]/series[a].max())
plt.plot(series[b]/series[b].max())
plt.xticks(visible=False);

-----

KeyError                                Traceback (most recent call last)

<ipython-input-12-1d4fb0c2882b> in <module>
      2 import matplotlib.pyplot as plt
      3 plt.figure(figsize=(10, 4))
----> 4 plt.plot(series[a]/series[a].max())
      5 plt.plot(series[b]/series[b].max())
      6 plt.xticks(visible=False);

KeyError: 'data/daily-stock/aet.h5'
```

<Figure size 720x288 with 0 Axes>

7.5 Analysis

This computation starts out by loading data from disk. We already know how to parallelize it:

```
series = {}
for fn in filenames:
    series[fn] = pd.read_hdf(fn)['x']
```

It follows with a doubly nested for loop with an if statement.

```
results = {}
for a in filenames:
    for b in filenames:
        if a != b:
            results[a, b] = series[a].corr(series[b])
```

It is possible to solve this problem with `map`, but it requires some cleverness. Instead we'll learn `submit`, an interface to start individual function calls asynchronously.

It finishes with a reduction on small data. This part is fast enough.

```
((a, b), corr) = max(results.items(), key=lambda kv: kv[1])
```

```
In [13]: %%time

from concurrent.futures import ThreadPoolExecutor as PoolExecutor

e = PoolExecutor()

def corr(serie_a, serie_b):
```

```

        return serie_a.corr(serie_b)

futures = {}

for a in filenames:
    for b in filenames:
        if a != b:
            futures[a, b] = e.submit( corr, series[a], series[b])

results = {k : f.result() for k, f in futures.items()}

((a, b), corr) = max(results.items(), key=lambda kv: kv[1])
print("%s matches with %s with correlation %f" % (a, b, corr))

-----

KeyError                                Traceback (most recent call last)

<timed exec> in <module>

KeyError: 'data/daily-stock/aet.h5'

```

7.5.1 Exercise 7.3

- Parallelize pair-wise correlations with `e.submit`
- Implement two versions one using Processes, another with Threads by replacing `e` with a `ProcessPoolExecutor`:

Threads

```

from concurrent.futures import ThreadPoolExecutor
e = ThreadPoolExecutor(4)

```

Processes

Be careful, a `ProcessPoolExecutor` does not run in the jupyter notebook cell. You must run your file in a terminal.

```

from concurrent.futures import ProcessPoolExecutor
e = ProcessPoolExecutor(4)

```

- How does performance vary?

7.6 Some conclusions about futures

- `submit` functions can help us to parallelize more complex applications
- It didn't actually speed up the code very much
- Threads and Processes give some performance differences
- This is not very robust.

Chapter 8

Dask

- process data that doesn't fit into memory by breaking it into blocks and specifying task chains
- parallelize execution of tasks across cores and even nodes of a cluster
- move computation to the data rather than the other way around, to minimize communication overheads

<http://dask.pydata.org/en/latest/>

```
In [1]: import dask
        import dask.multiprocessing
```

8.1 Define two slow functions

```
In [2]: from time import sleep

        def slowinc(x, delay=1):
            sleep(delay)
            return x + 1

        def slowadd(x, y, delay=1):
            sleep(delay)
            return x + y
```

```
In [3]: %%time
        x = slowinc(1)
        y = slowinc(2)
        z = slowadd(x, y)
```

CPU times: user 1.61 ms, sys: 233 µs, total: 1.84 ms
Wall time: 3 s

8.2 Parallelize with dask.delayed

- Functions wrapped by `dask.delayed` don't run immediately, but instead put those functions and arguments into a task graph.
- The result is computed separately by calling the `.compute()` method.

```
In [4]: from dask import delayed
```

```
In [5]: x = delayed(slowinc)(1)
        y = delayed(slowinc)(2)
        z = delayed(slowadd)(x, y)
```

```
In [6]: %%time
        z.compute()
```

```
CPU times: user 3.74 ms, sys: 4.05 ms, total: 7.79 ms
Wall time: 2.01 s
```

```
Out[6]: 5
```

8.3 Dask graph

- Contains description of the calculations necessary to produce the result.
- The `z` object is a lazy Delayed object. This object holds everything we need to compute the final result. We can compute the result with `.compute()` as above or we can visualize the task graph for this value with `.visualize()`.

```
In [7]: z.visualize()
```

```
-----

FileNotFoundError                                Traceback (most recent call last)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
165     try:
--> 166         proc = subprocess.Popen(cmd, startupinfo=get_startupinfo(), **kwargs)
167     except OSError as e:

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in __init__(self, args, bufsize
853
--> 854         self._execute_child(args, executable, preexec_fn, close_fds,
855                             pass_fds, cwd, env,

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in _execute_child(self, args, e
1701         err_msg = os.strerror(errno_num)
-> 1702         raise child_exception_type(errno_num, err_msg, err_filename)
1703         raise child_exception_type(err_msg)

FileNotFoundError: [Errno 2] No such file or directory: 'dot'
```

During handling of the above exception, another exception occurred:

```
ExecutableNotFound                                Traceback (most recent call last)

<ipython-input-7-05252b17577d> in <module>
----> 1 z.visualize()

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(self,
91     https://docs.dask.org/en/latest/optimize.html
```

```

92         """
--> 93         return visualize(
94             self,
95             filename=filename,

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(*args
551         raise NotImplementedError("Unknown value color=%s" % color)
552
--> 553     return dot_graph(dsk, filename=filename, **kwargs)
554
555

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in dot_graph(dsk, f
270     """
271     g = to_graphviz(dsk, **kwargs)
--> 272     return graphviz_to_file(g, filename, format)
273
274

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in graphviz_to_file
282         format = "png"
283
--> 284     data = g.pipe(format=format)
285     if not data:
286         raise RuntimeError(

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/files.py in pipe(self,
134         data = text_type(self.source).encode(self._encoding)
135
--> 136         out = backend.pipe(self._engine, format, data,
137                             renderer=renderer, formatter=formatter,
138                             quiet=quiet)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in pipe(eng
244     """
245     cmd, _ = command(engine, format, None, renderer, formatter)
--> 246     out, _ = run(cmd, input=data, capture_output=True, check=True, quiet=quiet)
247     return out
248

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
167     except OSError as e:
168         if e.errno == errno.ENOENT:
--> 169             raise ExecutableNotFound(cmd)
170         else:
171             raise

```

ExecutableNotFound: failed to execute ['dot', '-Tpng'], make sure the Graphviz executables are

8.4 Parallelize a loop

```
In [8]: %%time
data = list(range(8))

results = []

for x in data:
    y = slowinc(x)
    results.append(y)

total = sum(results)
total
```

CPU times: user 3.89 ms, sys: 0 ns, total: 3.89 ms
Wall time: 8.01 s

Out[8]: 36

8.4.1 Exercise 8.1

- Parallelize this by appending the delayed `slowinc` calls to the list `results`.
- Display the graph of `total` computation
- Compute time elapsed for the computation.

```
In [9]: from dask import delayed

futures = []

for x in data:
    y = delayed(slowinc)(x)
    futures.append(y)

total = delayed(sum)(futures)

In [10]: total.visualize()
```

```
-----
FileNotFoundError                                Traceback (most recent call last)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
165     try:
--> 166         proc = subprocess.Popen(cmd, startupinfo=get_startupinfo(), **kwargs)
167         except OSError as e:

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in __init__(self, args, bufsize
853
--> 854         self._execute_child(args, executable, preexec_fn, close_fds,
855                             pass_fds, cwd, env,
```



```

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in _execute_child(self, args, e
1701         err_msg = os.strerror(errno_num)
-> 1702         raise child_exception_type(errno_num, err_msg, err_filename)
1703         raise child_exception_type(err_msg)

```

FileNotFoundError: [Errno 2] No such file or directory: 'dot'

During handling of the above exception, another exception occurred:

```

ExecutableNotFound                                Traceback (most recent call last)

<ipython-input-10-d5fa05822eb0> in <module>
----> 1 total.visualize()

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(self,
  91         https://docs.dask.org/en/latest/optimize.html
  92         """
---> 93         return visualize(
  94             self,
  95             filename=filename,

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(*args
551         raise NotImplementedError("Unknown value color=%s" % color)
552
--> 553         return dot_graph(dsk, filename=filename, **kwargs)
554
555

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in dot_graph(dsk, f
270         """
271         g = to_graphviz(dsk, **kwargs)
--> 272         return graphviz_to_file(g, filename, format)
273
274

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in graphviz_to_file
282         format = "png"
283
--> 284         data = g.pipe(format=format)
285         if not data:
286             raise RuntimeError(

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/files.py in pipe(self,
134         data = text_type(self.source).encode(self._encoding)
135

```

```

--> 136         out = backend.pipe(self._engine, format, data,
137                               renderer=renderer, formatter=formatter,
138                               quiet=quiet)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in pipe(engine,
244     """
245     cmd, _ = command(engine, format, None, renderer, formatter)
--> 246     out, _ = run(cmd, input=data, capture_output=True, check=True, quiet=quiet)
247     return out
248

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
167     except OSError as e:
168         if e.errno == errno.ENOENT:
--> 169             raise ExecutableNotFound(cmd)
170         else:
171             raise

```

ExecutableNotFound: failed to execute ['dot', '-Tpng'], make sure the Graphviz executables are on your system's PATH

```
In [11]: %time total.compute()
```

CPU times: user 6.66 ms, sys: 1.25 ms, total: 7.91 ms

Wall time: 4.01 s

```
Out[11]: 36
```

8.5 Decorator

It is also common to see the delayed function used as a decorator. Same example:

```
In [12]: %%time
```

```

@dask.delayed
def slowinc(x, delay=1):
    sleep(delay)
    return x + 1

@dask.delayed
def slowadd(x, y, delay=1):
    sleep(delay)
    return x + y

x = slowinc(1)
y = slowinc(2)
z = slowadd(x, y)
z.compute()

```

CPU times: user 3.88 ms, sys: 0 ns, total: 3.88 ms

Wall time: 2 s

```
Out[12]: 5
```

8.6 Control flow

- Delay only some functions, running a few of them immediately. This is helpful when those functions are fast and help us to determine what other slower functions we should call.
- In the example below we iterate through a list of inputs. If that input is even then we want to call `half`. If the input is odd then we want to call `odd_process`. This is even decision to call `half` or `odd_process` has to be made immediately (not lazily) in order for our graph-building Python code to proceed.

```
In [13]: from random import randint
import dask.delayed

@dask.delayed
def half(x):
    sleep(1)
    return x // 2

@dask.delayed
def odd_process(x):
    sleep(1)
    return 3*x+1

def is_even(x):
    return not x % 2

data = [randint(0,100) for i in range(8)]
data
```

```
Out[13]: [65, 32, 17, 57, 15, 36, 11, 89]
```

8.6.1 Exercise 8.2

- Parallelize the sequential code above using `dask.delayed`
- You will need to delay some functions, but not all
- Visualize and check the computed result

```
In [14]: results = []
for x in data:
    if is_even(x):
        y = half(x)
    else:
        y = odd_process(x)
    results.append(y)

total = delayed(sum)(results)
total.visualize()
```

FileNotFoundError

Traceback (most recent call last)

```
/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
165     try:
--> 166         proc = subprocess.Popen(cmd, startupinfo=get_startupinfo(), **kwargs)
167     except OSError as e:
```

```

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in __init__(self, args, bufsize
853
--> 854         self._execute_child(args, executable, preexec_fn, close_fds,
855                             pass_fds, cwd, env,

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in _execute_child(self, args, e
1701         err_msg = os.strerror(errno_num)
-> 1702         raise child_exception_type(errno_num, err_msg, err_filename)
1703         raise child_exception_type(err_msg)

```

FileNotFoundError: [Errno 2] No such file or directory: 'dot'

During handling of the above exception, another exception occurred:

```

ExecutableNotFound                                Traceback (most recent call last)

<ipython-input-14-5d36a9a9c848> in <module>
      8
      9 total = delayed(sum)(results)
--> 10 total.visualize()

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(self,
  91         https://docs.dask.org/en/latest/optimize.html
  92         """
--> 93         return visualize(
  94             self,
  95             filename=filename,

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(*args
551         raise NotImplementedError("Unknown value color=%s" % color)
552
--> 553         return dot_graph(dsk, filename=filename, **kwargs)
554
555

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in dot_graph(dsk, f
270         """
271         g = to_graphviz(dsk, **kwargs)
--> 272         return graphviz_to_file(g, filename, format)
273
274

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in graphviz_to_file
282         format = "png"
283
--> 284         data = g.pipe(format=format)

```

```

285     if not data:
286         raise RuntimeError(

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/files.py in pipe(self,
134         data = text_type(self.source).encode(self._encoding)
135
--> 136         out = backend.pipe(self._engine, format, data,
137                             renderer=renderer, formatter=formatter,
138                             quiet=quiet)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in pipe(eng
244     """
245     cmd, _ = command(engine, format, None, renderer, formatter)
--> 246     out, _ = run(cmd, input=data, capture_output=True, check=True, quiet=quiet)
247     return out
248

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
167     except OSError as e:
168         if e.errno == errno.ENOENT:
--> 169             raise ExecutableNotFound(cmd)
170         else:
171             raise

```

ExecutableNotFound: failed to execute ['dot', '-Tpng'], make sure the Graphviz executables are

8.6.2 Exercise 8.3

- Parallelize the hdf5 conversion from json files
- Create a function `convert_to_hdf`
- Use `dask.compute` function on delayed calls of the function created list
- Is it really faster as expected ?

Hint: Read [Delayed Best Practices](#)

```

In [15]: import os # library to get directory and file paths
import tarfile # this module makes possible to read and write tar archives

def extract_data(name, where):
    datadir = os.path.join(where, name)
    if not os.path.exists(datadir):
        print("Extracting data...")
        tar_path = os.path.join(where, name+'.tgz')
        with tarfile.open(tar_path, mode='r:gz') as data:
            data.extractall(where)

extract_data('daily-stock', 'data') # this function call will extract json files

In [16]: import os, sys
from glob import glob
import pandas as pd

```

```

import json

here = os.getcwd() # get the current directory
filenames = sorted(glob(os.path.join(here, 'data', 'daily-stock', '*.json')))

In [17]: def read( fn ):
        with open(fn) as f:
            return [json.loads(line) for line in f]

        def convert(data):
            df = pd.DataFrame(data)

            out_filename = fn[:-5] + '.h5'
            df.to_hdf(out_filename, os.path.join(here, 'data'))
            return

        for fn in filenames:
            data = read( fn)
            convert(data)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/tables/path.py:155: NaturalNameWarning:
  check_attribute_name(name)

In [18]: %ls data/daily-stock/*.h5

data/daily-stock/aet.h5    data/daily-stock/bwa.h5    data/daily-stock/jpm.h5
data/daily-stock/afl.h5    data/daily-stock/ge.h5     data/daily-stock/luv.h5
data/daily-stock/aig.h5    data/daily-stock/hal.h5    data/daily-stock/met.h5
data/daily-stock/al.h5     data/daily-stock/hp.h5     data/daily-stock/pcg.h5
data/daily-stock/amgn.h5   data/daily-stock/hpq.h5    data/daily-stock/tgt.h5
data/daily-stock/avy.h5    data/daily-stock/ibm.h5    data/daily-stock/usb.h5
data/daily-stock/b.h5      data/daily-stock/jbl.h5    data/daily-stock/xom.h5

In [19]: @dask.delayed
        def read( fn ):
            " read json file "
            with open(fn) as f:
                return [json.loads(line) for line in f]

        @dask.delayed
        def convert(data, fn):
            " convert json file to hdf5 file"
            df = pd.DataFrame(data)
            out_filename = fn[:-5] + '.h5'
            df.to_hdf(out_filename, '/data')
            return fn[:-5]

        results = []
        for filename in filenames:
            data = read(filename)
            results.append(convert(data, filename))

In [20]: %time dask.compute(*results)

CPU times: user 8.53 s, sys: 1.09 s, total: 9.62 s
Wall time: 9.16 s

```

```
Out[20]: ('/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aet',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/afl',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aig',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/al',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/amgn',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/avy',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/b',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/bwa',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ge',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hal',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hp',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hpq',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ibm',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jbl',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jpm',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/luv',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/met',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/pcg',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/tgt',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/usb',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/xom')
```


Chapter 9

Dask bag

Dask proposes "big data" collections with a small set of high-level primitives like `map`, `filter`, `groupby`, and `join`. With these common patterns we can often handle computations that are more complex than `map`, but are still structured.

- Dask-bag excels in processing data that can be represented as a sequence of arbitrary inputs ("messy" data)
- When you encounter a set of data with a format that does not enforce strict structure and datatypes.

Related Documentation

- [Bag Documenation](#)
- [Bag API](#)

```
In [1]: data = list(range(1,9))
        data
```

```
Out[1]: [1, 2, 3, 4, 5, 6, 7, 8]
```

```
In [2]: import dask.bag as db

        b = db.from_sequence(data)
```

```
In [3]: b.compute() # Gather results back to local process
```

```
Out[3]: [1, 2, 3, 4, 5, 6, 7, 8]
```

```
In [4]: b.map(lambda x : x//2).compute() # compute length of each element and collect results
```

```
Out[4]: [0, 1, 1, 2, 2, 3, 3, 4]
```

```
In [5]: from time import sleep

        def slow_half( x):
            sleep(1)
            return x // 2

        res = b.map(slow_half)
        res
```

```
Out[5]: dask.bag<slow_half, npartitions=8>
```

```
In [6]: %%time
        res.compute()
```

CPU times: user 11.8 ms, sys: 9.64 ms, total: 21.5 ms
 Wall time: 4.37 s

Out[6]: [0, 1, 1, 2, 2, 3, 3, 4]

In [7]: res.visualize()

```
-----

FileNotFoundError                                Traceback (most recent call last)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
165     try:
--> 166         proc = subprocess.Popen(cmd, startupinfo=get_startupinfo(), **kwargs)
167         except OSError as e:

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in __init__(self, args, bufsize
853
--> 854         self._execute_child(args, executable, preexec_fn, close_fds,
855                             pass_fds, cwd, env,

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in _execute_child(self, args, e
1701         err_msg = os.strerror(errno_num)
-> 1702         raise child_exception_type(errno_num, err_msg, err_filename)
1703         raise child_exception_type(err_msg)

FileNotFoundError: [Errno 2] No such file or directory: 'dot'
```

During handling of the above exception, another exception occurred:

```
ExecutableNotFound                                Traceback (most recent call last)

<ipython-input-7-2dde28612c67> in <module>
----> 1 res.visualize()

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(self,
91     https://docs.dask.org/en/latest/optimize.html
92     """
---> 93     return visualize(
94         self,
95         filename=filename,

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(*args
551         raise NotImplementedError("Unknown value color=%s" % color)
552
--> 553     return dot_graph(dsk, filename=filename, **kwargs)
```

```

554
555

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in dot_graph(dsk, f
270     """
271     g = to_graphviz(dsk, **kwargs)
--> 272     return graphviz_to_file(g, filename, format)
273
274

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in graphviz_to_file
282     format = "png"
283
--> 284     data = g.pipe(format=format)
285     if not data:
286         raise RuntimeError(

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/files.py in pipe(self,
134     data = text_type(self.source).encode(self._encoding)
135
--> 136     out = backend.pipe(self._engine, format, data,
137                        renderer=renderer, formatter=formatter,
138                        quiet=quiet)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in pipe(eng
244     """
245     cmd, _ = command(engine, format, None, renderer, formatter)
--> 246     out, _ = run(cmd, input=data, capture_output=True, check=True, quiet=quiet)
247     return out
248

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
167     except OSError as e:
168         if e.errno == errno.ENOENT:
--> 169             raise ExecutableNotFound(cmd)
170         else:
171             raise

```

ExecutableNotFound: failed to execute ['dot', '-Tpng'], make sure the Graphviz executables are c

In [8]: b.topk

Out[8]: <bound method Bag.topk of dask.bag<from_sequence, npartitions=8>>

In [9]: b.product(b).compute() *# Cartesian product of each pair
of elements in two sequences (or the same sequence in this case)*

Out[9]: [(1, 1),
(1, 2),

(1, 3),
(1, 4),
(1, 5),
(1, 6),
(1, 7),
(1, 8),
(2, 1),
(2, 2),
(2, 3),
(2, 4),
(2, 5),
(2, 6),
(2, 7),
(2, 8),
(3, 1),
(3, 2),
(3, 3),
(3, 4),
(3, 5),
(3, 6),
(3, 7),
(3, 8),
(4, 1),
(4, 2),
(4, 3),
(4, 4),
(4, 5),
(4, 6),
(4, 7),
(4, 8),
(5, 1),
(5, 2),
(5, 3),
(5, 4),
(5, 5),
(5, 6),
(5, 7),
(5, 8),
(6, 1),
(6, 2),
(6, 3),
(6, 4),
(6, 5),
(6, 6),
(6, 7),
(6, 8),
(7, 1),
(7, 2),
(7, 3),
(7, 4),
(7, 5),
(7, 6),
(7, 7),
(7, 8),

```
(8, 1),
(8, 2),
(8, 3),
(8, 4),
(8, 5),
(8, 6),
(8, 7),
(8, 8)]
```

Chain operations to construct more complex computations

```
In [10]: (b.filter(lambda x: x % 2 > 0)
         .product(b)
         .filter(lambda v : v[0] % v[1] == 0 and v[0] != v[1])
         .compute())
```

```
Out[10]: [(3, 1), (5, 1), (7, 1)]
```

```
In [ ]:
```

9.1 Daily stock example

Let's use the bag interface to read the json files containing time series.

Each line is a JSON encoded dictionary with the following keys - timestamp: Day. - close: Stock value at the end of the day. - high: Highest value. - low: Lowest value. - open: Opening price.

```
In [11]: # preparing data
import os # library to get directory and file paths
import tarfile # this module makes possible to read and write tar archives

def extract_data(name, where):
    datadir = os.path.join(where,name)
    if not os.path.exists(datadir):
        print("Extracting data...")
        tar_path = os.path.join(where, name+'.tgz')
        with tarfile.open(tar_path, mode='r:gz') as data:
            data.extractall(where)

extract_data('daily-stock','data') # this function call will extract json files
```

Extracting data...

```
In [12]: %ls data/daily-stock/*.json
```

```
data/daily-stock/aet.json  data/daily-stock/hpq.json
data/daily-stock/afl.json  data/daily-stock/ibm.json
data/daily-stock/aig.json  data/daily-stock/jbl.json
data/daily-stock/al.json   data/daily-stock/jpm.json
data/daily-stock/amgn.json data/daily-stock/luv.json
data/daily-stock/avj.json  data/daily-stock/met.json
data/daily-stock/b.json    data/daily-stock/pcg.json
data/daily-stock/bwa.json  data/daily-stock/tgt.json
data/daily-stock/ge.json   data/daily-stock/usb.json
data/daily-stock/hal.json  data/daily-stock/xom.json
data/daily-stock/hp.json
```

```
In [13]: import dask.bag as db
import json
stocks = db.read_text('data/daily-stock/*.json')
```

```
In [14]: stocks.npartitions
```

```
Out[14]: 22
```

```
In [15]: stocks.visualize()
```

```
-----

FileNotFoundError                                Traceback (most recent call last)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
165     try:
--> 166         proc = subprocess.Popen(cmd, startupinfo=get_startupinfo(), **kwargs)
167     except OSError as e:

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in __init__(self, args, bufsize
853
--> 854         self._execute_child(args, executable, preexec_fn, close_fds,
855                             pass_fds, cwd, env,

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in _execute_child(self, args, e
1701         err_msg = os.strerror(errno_num)
-> 1702         raise child_exception_type(errno_num, err_msg, err_filename)
1703         raise child_exception_type(err_msg)
```

FileNotFoundError: [Errno 2] No such file or directory: 'dot'

During handling of the above exception, another exception occurred:

```
ExecutableNotFound                                Traceback (most recent call last)

<ipython-input-15-a27501b2e8e0> in <module>
----> 1 stocks.visualize()

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(self,
91     https://docs.dask.org/en/latest/optimize.html
92     """
---> 93     return visualize(
94         self,
95         filename=filename,

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(*args
551     raise NotImplementedError("Unknown value color=%s" % color)
552
```

```

--> 553     return dot_graph(dsk, filename=filename, **kwargs)
554
555

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in dot_graph(dsk, f
270     """
271     g = to_graphviz(dsk, **kwargs)
--> 272     return graphviz_to_file(g, filename, format)
273
274

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in graphviz_to_file
282     format = "png"
283
--> 284     data = g.pipe(format=format)
285     if not data:
286         raise RuntimeError(

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/files.py in pipe(self,
134     data = text_type(self.source).encode(self._encoding)
135
--> 136     out = backend.pipe(self._engine, format, data,
137                         renderer=renderer, formatter=formatter,
138                         quiet=quiet)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in pipe(eng
244     """
245     cmd, _ = command(engine, format, None, renderer, formatter)
--> 246     out, _ = run(cmd, input=data, capture_output=True, check=True, quiet=quiet)
247     return out
248

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
167     except OSError as e:
168         if e.errno == errno.ENOENT:
--> 169             raise ExecutableNotFound(cmd)
170         else:
171             raise

```

ExecutableNotFound: failed to execute ['dot', '-Tpng'], make sure the Graphviz executables are c

```

In [16]: import json
         js = stocks.map(json.loads)

```

```

In [17]: import os, sys
         from glob import glob
         import pandas as pd
         import json

```

```

here = os.getcwd() # get the current directory
filenames = sorted(glob(os.path.join(here, 'data', 'daily-stock', '*.json')))
filenames

```

```

Out[17]: ['/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aet.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/afl.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aig.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/al.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/amgn.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/avy.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/b.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/bwa.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ge.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hal.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hp.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hpq.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ibm.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jbl.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jpm.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/luv.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/met.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/pcg.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/tgt.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/usb.json',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/xom.json']

```

```

In [18]: %rm data/daily-stock/*.h5

```

```

rm: cannot remove 'data/daily-stock/*.h5': No such file or directory

```

```

In [19]: from tqdm.notebook import tqdm
         for fn in tqdm(filenames):
             with open(fn) as f:
                 data = [json.loads(line) for line in f]

                 df = pd.DataFrame(data)

                 out_filename = fn[:-5] + '.h5'
                 df.to_hdf(out_filename, '/data')

```

```

HBox(children=(FloatProgress(value=0.0, max=21.0), HTML(value='')))

```

```

In [20]: filenames = sorted(glob(os.path.join(here, 'data', 'daily-stock', '*.h5')))
         filenames

```

```

Out[20]: ['/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aet.h5',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/afl.h5',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aig.h5',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/al.h5',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/amgn.h5',
          '/home/runner/work/big-data/big-data/notebooks/data/daily-stock/avy.h5',

```



```

'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/b.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/bwa.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ge.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hal.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hp.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hpq.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ibm.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jbl.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jpm.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/luv.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/met.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/pgc.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/tgt.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/usb.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/xom.h5']

```

9.1.1 Serial version

```

In [21]: %%time
series = {}
for fn in filenames:    # Simple map over filenames
    series[fn] = pd.read_hdf(fn)['close']

results = {}

for a in filenames:    # Doubly nested loop over the same collection
    for b in filenames:
        if a != b:      # Filter out bad elements
            results[a, b] = series[a].corr(series[b]) # Apply function

((a, b), corr) = max(results.items(), key=lambda kv: kv[1]) # Reduction

```

CPU times: user 827 ms, sys: 59.8 ms, total: 887 ms

Wall time: 886 ms

```
In [22]: a, b, corr
```

```

Out[22]: ('/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aet.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/luv.h5',
0.9413176064560881)

```

9.2 Dask.bag methods

We can construct most of the above computation with the following dask.bag methods:

- `collection.map(function)`: apply function to each element in collection
- `collection.product(collection)`: Create new collection with every pair of inputs
- `collection.filter(predicate)`: Keep only elements of collection that match the predicate function
- `collection.max()`: Compute maximum element

```

In [23]: %%time

import dask.bag as db

b = db.from_sequence(filenames)

```

```

series = b.map(lambda fn: pd.read_hdf(fn)['close'])

corr = (series.product(series)
        .filter(lambda ab: not (ab[0] == ab[1]).all())
        .map(lambda ab: ab[0].corr(ab[1])).max())

```

```

CPU times: user 2.05 ms, sys: 4.36 ms, total: 6.41 ms
Wall time: 6.25 ms

```

```
In [24]: %%time
```

```
result = corr.compute()
```

```

CPU times: user 1.8 s, sys: 522 ms, total: 2.32 s
Wall time: 4.11 s

```

```
In [25]: result
```

```
Out[25]: 0.9413176064560881
```

9.2.1 Wordcount with Dask bag

```
In [26]: import lorem
```

```
lorem.text()
```

```
Out[26]: 'Consectetur voluptatem ut consectetur eius adipisci amet eius. Voluptatem voluptatem quaerat v
```

```
In [27]: import lorem
```

```

for i in range(20):
    with open(f"sample{i:02d}.txt", "w") as f:
        f.write(lorem.text())

```

```
In [28]: %ls *.txt
```

```

sample00.txt  sample04.txt  sample08.txt  sample12.txt  sample16.txt
sample01.txt  sample05.txt  sample09.txt  sample13.txt  sample17.txt
sample02.txt  sample06.txt  sample10.txt  sample14.txt  sample18.txt
sample03.txt  sample07.txt  sample11.txt  sample15.txt  sample19.txt

```

```

In [29]: import glob
        glob.glob('sample*.txt')

```

```

Out[29]: ['sample13.txt',
          'sample01.txt',
          'sample14.txt',
          'sample00.txt',
          'sample17.txt',
          'sample19.txt',
          'sample07.txt',
          'sample09.txt',
          'sample08.txt',
          'sample16.txt',
          'sample02.txt',

```

```

'sample04.txt',
'sample11.txt',
'sample10.txt',
'sample05.txt',
'sample06.txt',
'sample18.txt',
'sample03.txt',
'sample15.txt',
'sample12.txt']

In [30]: import dask.bag as db
import glob
b = db.read_text(glob.glob('sample*.txt'))

wordcount = (b.str.replace(".", "") # remove dots
              .str.lower()          # lower text
              .str.strip()          # remove \n and trailing spaces
              .str.split()          # split into words
              .flatten()            # chain all words lists
              .frequencies()        # compute occurrences
              .topk(10, lambda x: x[1])) # sort and return top 10 words

wordcount.compute() # Run all tasks and return result

Out[30]: [('dolor', 173),
          ('sit', 171),
          ('aliquam', 167),
          ('adipisci', 164),
          ('consectetur', 164),
          ('modi', 163),
          ('magnam', 160),
          ('dolorem', 159),
          ('porro', 158),
          ('sed', 156)]

```

9.3 Genome example

We will use a Dask bag to calculate the frequencies of sequences of five bases, and then sort the sequences into descending order ranked by their frequency.

- First we will define some functions to split the bases into sequences of a certain size

9.3.1 Exercise 9.1

- Implement a function `group_characters(line, n=5)` to group `n` characters together and return a iterator. `line` is a text line in `genome.txt` file.

```

>>> line = "abcdefghijklmno"
>>> for seq in group_character(line, 5):
    print(seq)

```

```

"abcde"
"efghi"
"klmno"

```

- Implement `group_and_split(line)`

```
>>> group_and_split('abcdefghijklmno')
['abcde', 'fghij', 'klmno']
```

- Use the dask bag to compute the frequencies of sequences of five bases.

```
In [31]: from string import ascii_lowercase as alphabet
         alphabet
```

```
Out[31]: 'abcdefghijklmnopqrstuvwxyz'
```

```
In [32]: def reverse(text):
         k = len(text)
         while k > 0:
             k = k-1
             yield text[k]

         reverse_alphabet = reverse(alphabet)
         print(*reverse_alphabet)

z y x w v u t s r q p o n m l k j i h g f e d c b a
```

```
In [33]: class Reverse:

         def __init__(self, data):
             self.data = data
             self.index = len(data)

         def __iter__(self):
             return self

         def __next__(self):
             self.index = self.index-1
             if self.index < 0:
                 raise StopIteration
             else:
                 return self.data[self.index]
```

```
In [34]: class Fibonacci:

         def __init__(self, n):
             self.n = n
             self.f0 = 0
             self.f1 = 1

         def __iter__(self):
             return self

         def __next__(self):
             self.n = self.n - 1
             if self.n < 0:
                 raise StopIteration
             else:
                 self.f0, self.f1 = self.f1, self.f0 + self.f1
                 return self.f1

         print(*Fibonacci(7))
```

```
1 2 3 5 8 13 21
```

```
In [35]: for c in Reverse(alphabet):
         print(c, end="")
```

```
zyxwvutsrqponmlkjihgfedcba
```

```
In [36]:
         for c in reverse(alphabet):
             print(c, end="")
```

```
zyxwvutsrqponmlkjihgfedcba
```

```
In [37]: def group_character( line, n=5):
         bases = ''
         for i, b in enumerate(line):
             bases += b
             if (i+1) % n == 0:
                 yield bases
                 bases = ''
```

```
In [38]: line = "abcdefghijklmno"
         for seq in group_character(line, 5):
             print(seq)
```

```
abcde
fghij
klmno
```

```
In [39]: def group_and_split( line, n):
         return [seq for seq in group_character(line,n)]
```

```
In [40]: %ls data
```

```
daily-stock/      genome04.txt      monthly.land.90S.90N.df_1901-2000mean.dat.txt
daily-stock.tgz   genome05.txt      nucleotide-sample.txt
genome.txt        genome06.txt      nycflights.tar.gz
genome00.txt      genome07.txt      people.json
genome01.txt      irmar.csv         philadelphia-crime-data-2015-ytd.csv
genome02.txt      irmar.json
genome03.txt      latinbooks.tgz
```

```
In [41]: import os
         from glob import glob

         data_path = os.path.join("data")
         with open(os.path.join(data_path, "genome.txt")) as g:
             data = g.read()
             for i in range(8):
                 file = os.path.join(data_path, f"genome{i:02d}.txt")
                 with open(file, "w") as f:
                     f.write(data)

         glob("data/genome0*.txt")
```

```
Out[41]: ['data/genome00.txt',
          'data/genome01.txt',
          'data/genome07.txt',
          'data/genome06.txt',
          'data/genome02.txt',
          'data/genome05.txt',
          'data/genome03.txt',
          'data/genome04.txt']
```

```
In [42]: from operator import itemgetter
```

```
import dask.bag as db
```

```
b = db.read_text("data/genome0*.txt")
```

```
result = (b.filter(lambda line: not line.startswith(">"))
          .map(lambda line: line.strip())
          .map(lambda line : group_and_split(line,5))
          .flatten()
          .frequencies()
          .topk(10,lambda v : v[1]))
```

```
In [43]: result.visualize()
```

```
-----
FileNotFoundError                                Traceback (most recent call last)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
165     try:
--> 166         proc = subprocess.Popen(cmd, startupinfo=get_startupinfo(), **kwargs)
167     except OSError as e:

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in __init__(self, args, bufsize
853
--> 854         self._execute_child(args, executable, preexec_fn, close_fds,
855                             pass_fds, cwd, env,

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in _execute_child(self, args, e
1701         err_msg = os.strerror(errno_num)
-> 1702         raise child_exception_type(errno_num, err_msg, err_filename)
1703         raise child_exception_type(err_msg)
```

```
FileNotFoundError: [Errno 2] No such file or directory: 'dot'
```

During handling of the above exception, another exception occurred:

```
ExecutableNotFound                                Traceback (most recent call last)

<ipython-input-43-dc769738af30> in <module>
```

```

----> 1 result.visualize()

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(self,
    91         https://docs.dask.org/en/latest/optimize.html
    92         """
--> 93         return visualize(
    94             self,
    95             filename=filename,

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(*args
551         raise NotImplementedError("Unknown value color=%s" % color)
552
--> 553     return dot_graph(dsk, filename=filename, **kwargs)
554
555

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in dot_graph(dsk, f
270     """
271     g = to_graphviz(dsk, **kwargs)
--> 272     return graphviz_to_file(g, filename, format)
273
274

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in graphviz_to_file
282         format = "png"
283
--> 284     data = g.pipe(format=format)
285     if not data:
286         raise RuntimeError(

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/files.py in pipe(self,
134         data = text_type(self.source).encode(self._encoding)
135
--> 136         out = backend.pipe(self._engine, format, data,
137                             renderer=renderer, formatter=formatter,
138                             quiet=quiet)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in pipe(eng
244     """
245     cmd, _ = command(engine, format, None, renderer, formatter)
--> 246     out, _ = run(cmd, input=data, capture_output=True, check=True, quiet=quiet)
247     return out
248

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
167     except OSError as e:
168         if e.errno == errno.ENOENT:

```

```
--> 169             raise ExecutableNotFound(cmd)
    170         else:
    171             raise
```

ExecutableNotFound: failed to execute ['dot', '-Tpng'], make sure the Graphviz executables are on your system's path

```
In [44]: result.compute()
```

```
Out[44]: [('CTGTG', 472),
          ('CCCAG', 440),
          ('CCTGG', 416),
          ('AAAAA', 392),
          ('TGCTG', 336),
          ('TGTGT', 328),
          ('CCACC', 312),
          ('GGCTG', 304),
          ('ACCCA', 296),
          ('GGTGG', 296)]
```

9.3.2 Exercise 9.2

The [FASTA](#) file format is used to write several genome sequences.

- Create a function that can read a [FASTA file](#) and compute the frequencies for $n = 5$ of a given sequence.

9.3.3 Exercise 9.3

Write a program that uses the function implemented above to read several FASTA files stored in a Dask bag.

9.4 Some remarks about bag

- Higher level dask collections include functions for common patterns
- Move data to collection, construct lazy computation, trigger at the end
- Use Dask.bag (`product + map`) to handle nested for loop

Bags have the following known limitations

1. Bag operations tend to be slower than array/dataframe computations in the same way that Python tends to be slower than NumPy/Pandas
2. `Bag.groupby` is slow. You should try to use `Bag.foldby` if possible.
3. Check the [API](#)
4. `dask.dataframe` can be faster than `dask.bag`. But sometimes it is easier to load and clean messy data with a bag. We will see later how to transform a bag into a `dask.dataframe` with the [to_dataframe](#) method.

Chapter 10

Pandas Series



- Started by Wes MacKinney with a first release in 2011.
- Based on NumPy, it is the most used library for all things data.
- Motivated by the toolbox in R for manipulating data easily.
- A lot of names in Pandas come from R world.
- It is Open source (BSD)

<https://pandas.pydata.org/>

```
import pandas as pd
```

"Pandas provides high-performance, easy-to-use data structures and data analysis tools in Python"

- Self-describing data structures
- Data loaders to/from common file formats
- Plotting functions
- Basic statistical tools.

```
In [1]: %matplotlib inline
        %config InlineBackend.figure_format = 'retina'
        import pandas as pd
        import numpy as np
        import matplotlib.pyplot as plt
        import seaborn as sns
        sns.set()
        pd.set_option("display.max_rows", 8)
        plt.rcParams['figure.figsize'] = (9, 6)
```

10.1 Series

- A Series contains a one-dimensional array of data, *and* an associated sequence of labels called the *index*.
- The index can contain numeric, string, or date/time values.
- When the index is a time value, the series is a [time series](#).
- The index must be the same length as the data.
- If no index is supplied it is automatically generated as `range(len(data))`.

```
In [2]: pd.Series([1,3,5,np.nan,6,8])
```

```
Out[2]: 0    1.0
        1    3.0
        2    5.0
        3    NaN
        4    6.0
        5    8.0
        dtype: float64
```

```
In [3]: pd.Series(index=pd.period_range('09/11/2017', '09/18/2017', freq="D"))
```

```
<ipython-input-3-579d6b723cc5>:1: DeprecationWarning: The default dtype for empty Series will be 'object' (instead of 'float64')
pd.Series(index=pd.period_range('09/11/2017', '09/18/2017', freq="D"))
```

```
Out[3]: 2017-09-11    NaN
        2017-09-12    NaN
        2017-09-13    NaN
        2017-09-14    NaN
        2017-09-15    NaN
        2017-09-16    NaN
        2017-09-17    NaN
        2017-09-18    NaN
        Freq: D, dtype: float64
```

10.1.1 Exercise

- Create a text with lorem and count word occurrences with a `collections.Counter`. Put the result in a dict.

```
In [4]: from lorem import text
        from collections import Counter
        import operator
```

```
c = Counter(filter(None, text().strip().replace('.', '').replace('\n', ' ').lower().split(' ')))
result = dict(sorted(c.most_common(), key=operator.itemgetter(1), reverse=True))
result
```

```
Out[4]: {'quiquia': 14,
        'aliquam': 13,
        'non': 12,
        'sed': 12,
        'magnam': 10,
        'neque': 9,
        'adipisci': 9,
        'modi': 9,
        'numquam': 9,
        'ipsum': 9,
```

```

'velit': 8,
'eius': 8,
'est': 8,
'tempora': 8,
'dolorem': 8,
'etincidunt': 8,
'quisquam': 8,
'dolor': 7,
'ut': 6,
'voluptatem': 6,
'quaerat': 6,
'porro': 5,
'labore': 5,
'consectetur': 5,
'dolore': 4,
'amet': 4,
'sit': 4}

```

10.1.2 Exercise

- From the results create a Pandas series name `latin_series` with words in alphabetical order as index.

```
In [5]: df = pd.Series(result)
        df
```

```

Out[5]: quiquia      14
        aliquam     13
        non         12
        sed         12
        ..
        consectetur   5
        dolore        4
        amet         4
        sit          4
        Length: 27, dtype: int64

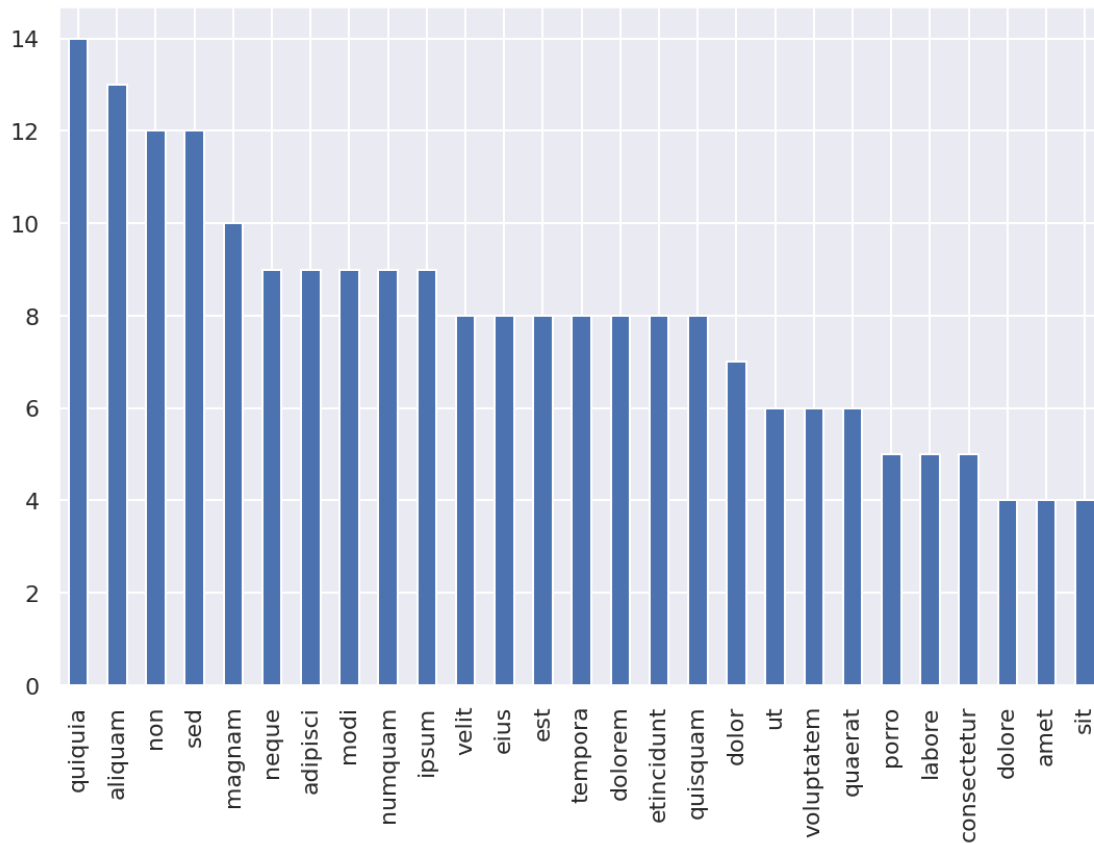
```

10.1.3 Exercise

- Plot the series using 'bar' kind.

```
In [6]: df.plot(kind='bar')
```

```
Out[6]: <AxesSubplot:>
```



10.1.4 Exercise

- Pandas provides explicit functions for indexing `loc` and `iloc`.
 - Use `loc` to display the number of occurrences of 'dolore'.
 - Use `iloc` to display the number of occurrences of the last word in index.

```
In [7]: df.loc['dolore']
```

```
Out[7]: 4
```

```
In [8]: df.iloc[-1]
```

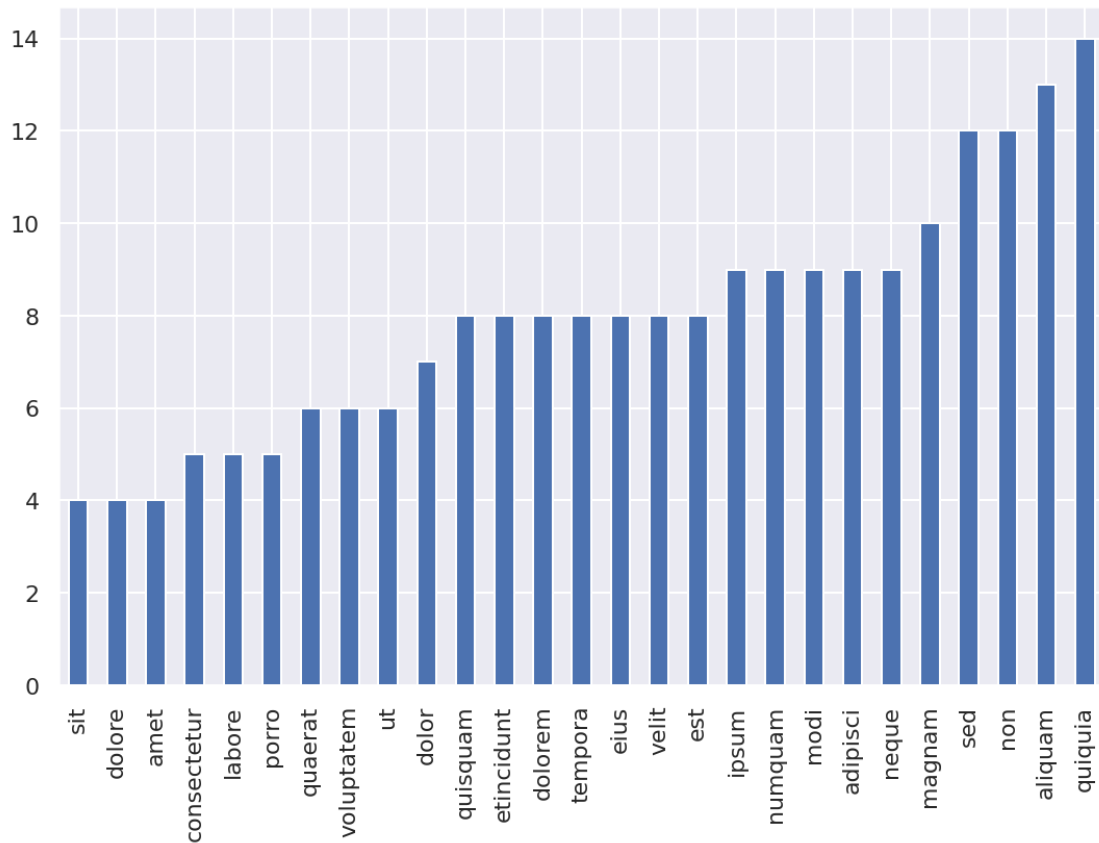
```
Out[8]: 4
```

10.1.5 Exercise

- Sort words by number of occurrences.
- Plot the Series.

```
In [9]: df = df.sort_values()
        df.plot(kind='bar')
```

```
Out[9]: <AxesSubplot:>
```



10.1.6 Full globe temperature between 1901 and 2000.

We read the text file and load the results in a pandas dataframe. In cells below you need to clean the data and convert the dataframe to a time series.

```
In [10]: import os
         here = os.getcwd()

         filename = os.path.join(here, "data", "monthly.land.90S.90N.df_1901-2000mean.dat.txt")

         df = pd.read_table(filename, sep="\s+",
                             names=["year", "month", "mean temp"])
         df
```

```
Out[10]:
```

	year	month	mean temp
0	1880	1	-0.0235
1	1880	2	-0.4936
2	1880	3	-0.6785
3	1880	4	-0.2829
...
1580	2011	9	-999.0000
1581	2011	10	-999.0000
1582	2011	11	-999.0000
1583	2011	12	-999.0000

```
[1584 rows x 3 columns]
```

10.1.7 Exercise

- Insert a third column with value one named "day" with `.insert`.
- convert df index to datetime with `pd.to_datetime` function.
- convert df to Series containing only "mean temp" column.

```
In [11]: df.insert(loc=2,column='day',value=np.ones(len(df)))
df
```

```
Out[11]:
```

	year	month	day	mean temp
0	1880	1	1.0	-0.0235
1	1880	2	1.0	-0.4936
2	1880	3	1.0	-0.6785
3	1880	4	1.0	-0.2829
...
1580	2011	9	1.0	-999.0000
1581	2011	10	1.0	-999.0000
1582	2011	11	1.0	-999.0000
1583	2011	12	1.0	-999.0000

```
[1584 rows x 4 columns]
```

```
In [12]: df.index = pd.to_datetime(df[['year','month','day']])
df
```

```
Out[12]:
```

	year	month	day	mean temp
1880-01-01	1880	1	1.0	-0.0235
1880-02-01	1880	2	1.0	-0.4936
1880-03-01	1880	3	1.0	-0.6785
1880-04-01	1880	4	1.0	-0.2829
...
2011-09-01	2011	9	1.0	-999.0000
2011-10-01	2011	10	1.0	-999.0000
2011-11-01	2011	11	1.0	-999.0000
2011-12-01	2011	12	1.0	-999.0000

```
[1584 rows x 4 columns]
```

```
In [13]: df = df['mean temp']
df
```

```
Out[13]:
```

1880-01-01	-0.0235
1880-02-01	-0.4936
1880-03-01	-0.6785
1880-04-01	-0.2829
...	...
2011-09-01	-999.0000
2011-10-01	-999.0000
2011-11-01	-999.0000
2011-12-01	-999.0000

Name: mean temp, Length: 1584, dtype: float64

```
In [14]: type(df)
```

```
Out[14]: pandas.core.series.Series
```

10.1.8 Exercise

- Display the beginning of the file with `.head`.

```
In [15]: df.head()
```

```
Out[15]: 1880-01-01    -0.0235
         1880-02-01    -0.4936
         1880-03-01    -0.6785
         1880-04-01    -0.2829
         1880-05-01    -0.1261
         Name: mean temp, dtype: float64
```

10.1.9 Exercise

- Display the end of the file with `.tail`.

```
In [16]: df.tail()
```

```
Out[16]: 2011-08-01    -999.0
         2011-09-01    -999.0
         2011-10-01    -999.0
         2011-11-01    -999.0
         2011-12-01    -999.0
         Name: mean temp, dtype: float64
```

In the dataset, -999.00 was used to indicate that there was no value for that year.

10.1.10 Exercise

- Display values equal to -999 with `.values`.
- Replace the missing value (-999.000) by `np.nan`

```
In [17]: df[df.values == -999]
```

```
Out[17]: 2011-07-01    -999.0
         2011-08-01    -999.0
         2011-09-01    -999.0
         2011-10-01    -999.0
         2011-11-01    -999.0
         2011-12-01    -999.0
         Name: mean temp, dtype: float64
```

```
In [18]: df2 = df.copy()
         df2[df == -999.0] = np.nan # For this indexing we need a copy
         df2.tail()
```

```
Out[18]: 2011-08-01    NaN
         2011-09-01    NaN
         2011-10-01    NaN
         2011-11-01    NaN
         2011-12-01    NaN
         Name: mean temp, dtype: float64
```

Once they have been converted to `np.nan`, missing values can be removed (dropped).

10.1.11 Exercise

- Remove missing values with `.dropna`.

```
In [19]: df = df2.dropna()
         df.tail()
```

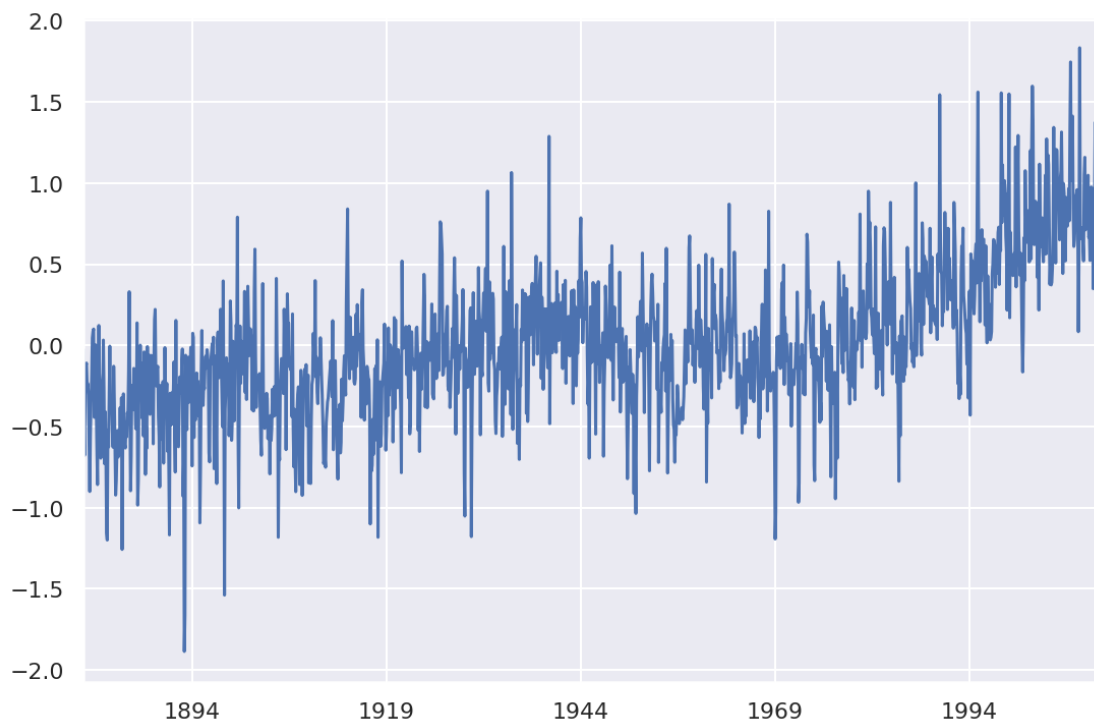
```
Out[19]: 2011-02-01    0.5113
         2011-03-01    0.8618
         2011-04-01    1.0897
         2011-05-01    0.7247
         2011-06-01    0.8550
         Name: mean temp, dtype: float64
```

10.1.12 Exercise

- Generate a basic visualization using `.plot`.

```
In [20]: df.plot()
```

```
Out[20]: <AxesSubplot:>
```



10.1.13 Exercise

Convert `df` index from timestamp to period is more meaningful since it was measured and averaged over the month. Use `to_period` method.

```
In [21]: df = df.to_period('M')
         df
```



```

Out[21]: 1880-01    -0.0235
         1880-02    -0.4936
         1880-03    -0.6785
         1880-04    -0.2829
         ...
         2011-03     0.8618
         2011-04     1.0897
         2011-05     0.7247
         2011-06     0.8550
         Freq: M, Name: mean temp, Length: 1578, dtype: float64

```

10.2 Resampling

Series can be resample, downsample or upsample. - Frequencies can be specified as strings: "us", "ms", "S", "T", "H", "D", "B", "W", "M", "A", "3min", "2h20", ... - More aliases at <http://pandas.pydata.org/pandas-docs/stable/timeseries.html#offset-aliases>

10.2.1 Exercise

- With `resample` method, convert df Series to 10 year blocks:

```

In [22]: df.resample('10A').mean()

Out[22]: 1880    -0.386485
         1890    -0.316798
         1900    -0.256431
         1910    -0.247673
         ...
         1980     0.188519
         1990     0.463572
         2000     0.785452
         2010     0.884700
         Freq: 10A-DEC, Name: mean temp, Length: 14, dtype: float64

```

10.2.2 Saving Work

[HDF5](#) is widely used and one of the most powerful file format to store binary data. It allows to store both Series and DataFrames.

```

In [23]: with pd.HDFStore("data/pandas_series.h5") as writer:
         df.to_hdf(writer, "/temperatures/full_globe")

```

10.2.3 Reloading data

```

In [24]: with pd.HDFStore("data/pandas_series.h5") as store:
         df = store["/temperatures/full_globe"]

```


Chapter 11

Pandas Dataframes

```
In [1]: %matplotlib inline
%config InlineBackend.figure_format = 'retina'
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt

pd.set_option("display.max_rows", 8)
plt.rcParams['figure.figsize'] = (9, 6)
```

11.1 Create a DataFrame

```
In [2]: dates = pd.date_range('20130101', periods=6)
pd.DataFrame(np.random.randn(6,4), index=dates, columns=list('ABCD'))
```

```
Out[2]:
```

	A	B	C	D
2013-01-01	-0.511915	0.421923	0.387521	-0.203787
2013-01-02	1.142739	0.454330	0.644637	1.727555
2013-01-03	-0.084048	-1.323518	0.119985	-0.839457
2013-01-04	-1.464047	2.249301	0.500317	0.391899
2013-01-05	0.014003	-1.656613	-0.773410	0.182633
2013-01-06	0.644069	2.397158	-0.481561	0.729977

```
In [3]: pd.DataFrame({'A' : 1.,
                      'B' : pd.Timestamp('20130102'),
                      'C' : pd.Series(1,index=list(range(4)),dtype='float32'),
                      'D' : np.arange(4,dtype='int32'),
                      'E' : pd.Categorical(["test","train","test","train"]),
                      'F' : 'foo' })
```

```
Out[3]:
```

	A	B	C	D	E	F
0	1.0	2013-01-02	1.0	0	test	foo
1	1.0	2013-01-02	1.0	1	train	foo
2	1.0	2013-01-02	1.0	2	test	foo
3	1.0	2013-01-02	1.0	3	train	foo

11.2 Load Data from CSV File

```
In [4]: url = "https://www.fun-mooc.fr/c4x/agrocampusouest/40001S03/asset/AnaDo_JeuDonnees_TemperatFrance.csv"
french_cities = pd.read_csv(url, delimiter=";", encoding="latin1", index_col=0)
french_cities
```

```
Out[4]:
```

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
Bordeaux	5.6	6.6	10.3	12.8	15.8	19.3	20.9	21.0	18.6	13.8	9.1	
Brest	6.1	5.8	7.8	9.2	11.6	14.4	15.6	16.0	14.7	12.0	9.0	
Clermont	2.6	3.7	7.5	10.3	13.8	17.3	19.4	19.1	16.2	11.2	6.6	
Grenoble	1.5	3.2	7.7	10.6	14.5	17.8	20.1	19.5	16.7	11.4	6.5	
...	
Rennes	4.8	5.3	7.9	10.1	13.1	16.2	17.9	17.8	15.7	11.6	7.8	
Strasbourg	0.4	1.5	5.6	9.8	14.0	17.2	19.0	18.3	15.1	9.5	4.9	
Toulouse	4.7	5.6	9.2	11.6	14.9	18.7	20.9	20.9	18.3	13.3	8.6	
Vichy	2.4	3.4	7.1	9.9	13.6	17.1	19.3	18.8	16.0	11.0	6.6	

	Déce	Lati	Long	Moye	Ampl	Région
Bordeaux	6.2	44.50	-0.34	13.33	15.4	SO
Brest	7.0	48.24	-4.29	10.77	10.2	NO
Clermont	3.6	45.47	3.05	10.94	16.8	SE
Grenoble	2.3	45.10	5.43	10.98	18.6	SE
...
Rennes	5.4	48.05	-1.41	11.13	13.1	NO
Strasbourg	1.3	48.35	7.45	9.72	18.6	NE
Toulouse	5.5	43.36	1.26	12.68	16.2	SO
Vichy	3.4	46.08	3.26	10.72	16.9	SE

[15 rows x 17 columns]

11.3 Viewing Data

```
In [5]: french_cities.head()
```

```
Out[5]:
```

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
Bordeaux	5.6	6.6	10.3	12.8	15.8	19.3	20.9	21.0	18.6	13.8	9.1	
Brest	6.1	5.8	7.8	9.2	11.6	14.4	15.6	16.0	14.7	12.0	9.0	
Clermont	2.6	3.7	7.5	10.3	13.8	17.3	19.4	19.1	16.2	11.2	6.6	
Grenoble	1.5	3.2	7.7	10.6	14.5	17.8	20.1	19.5	16.7	11.4	6.5	
Lille	2.4	2.9	6.0	8.9	12.4	15.3	17.1	17.1	14.7	10.4	6.1	

	Déce	Lati	Long	Moye	Ampl	Région
Bordeaux	6.2	44.50	-0.34	13.33	15.4	SO
Brest	7.0	48.24	-4.29	10.77	10.2	NO
Clermont	3.6	45.47	3.05	10.94	16.8	SE
Grenoble	2.3	45.10	5.43	10.98	18.6	SE
Lille	3.5	50.38	3.04	9.73	14.7	NE

```
In [6]: french_cities.tail()
```

```
Out[6]:
```

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
Paris	3.4	4.1	7.6	10.7	14.3	17.5	19.1	18.7	16.0	11.4	7.1	
Rennes	4.8	5.3	7.9	10.1	13.1	16.2	17.9	17.8	15.7	11.6	7.8	
Strasbourg	0.4	1.5	5.6	9.8	14.0	17.2	19.0	18.3	15.1	9.5	4.9	
Toulouse	4.7	5.6	9.2	11.6	14.9	18.7	20.9	20.9	18.3	13.3	8.6	
Vichy	2.4	3.4	7.1	9.9	13.6	17.1	19.3	18.8	16.0	11.0	6.6	

	Déce	Lati	Long	Moye	Ampl	Région
Paris	4.3	48.52	2.20	11.18	15.7	NE
Rennes	5.4	48.05	-1.41	11.13	13.1	NO

Strasbourg	1.3	48.35	7.45	9.72	18.6	NE
Toulouse	5.5	43.36	1.26	12.68	16.2	SO
Vichy	3.4	46.08	3.26	10.72	16.9	SE

11.4 Index

```
In [7]: french_cities.index
```

```
Out[7]: Index(['Bordeaux', 'Brest', 'Clermont', 'Grenoble', 'Lille', 'Lyon',
              'Marseille', 'Montpellier', 'Nantes', 'Nice', 'Paris', 'Rennes',
              'Strasbourg', 'Toulouse', 'Vichy'],
              dtype='object')
```

We can rename an index by setting its name.

```
In [8]: french_cities.index.name = "City"
        french_cities.head()
```

```
Out[8]:
```

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Bordeaux	5.6	6.6	10.3	12.8	15.8	19.3	20.9	21.0	18.6	13.8	9.1	
Brest	6.1	5.8	7.8	9.2	11.6	14.4	15.6	16.0	14.7	12.0	9.0	
Clermont	2.6	3.7	7.5	10.3	13.8	17.3	19.4	19.1	16.2	11.2	6.6	
Grenoble	1.5	3.2	7.7	10.6	14.5	17.8	20.1	19.5	16.7	11.4	6.5	
Lille	2.4	2.9	6.0	8.9	12.4	15.3	17.1	17.1	14.7	10.4	6.1	

	Déce	Lati	Long	Moye	Ampl	Région
City						
Bordeaux	6.2	44.50	-0.34	13.33	15.4	SO
Brest	7.0	48.24	-4.29	10.77	10.2	NO
Clermont	3.6	45.47	3.05	10.94	16.8	SE
Grenoble	2.3	45.10	5.43	10.98	18.6	SE
Lille	3.5	50.38	3.04	9.73	14.7	NE

11.4.1 Exercise: Rename DataFrame Months in English

```
In [9]: import locale
        import calendar
```

```
locale.setlocale(locale.LC_ALL, 'en_US')
```

```
months = calendar.month_abbr
print(*months)
```

Error

Traceback (most recent call last)

```
<ipython-input-9-e38d847f0b53> in <module>
      2 import calendar
      3
----> 4 locale.setlocale(locale.LC_ALL, 'en_US')
      5
      6 months = calendar.month_abbr
```

```

/usr/share/miniconda3/envs/big-data/lib/python3.8/locale.py in setlocale(category, locale)
606         # convert to string
607         locale = normalize(_build_localename(locale))
--> 608     return _setlocale(category, locale)
609
610 def resetlocale(category=LC_ALL):

```

Error: unsupported locale setting

```

In [10]: french_cities.rename(
        columns={ old : new
                for old, new in zip(french_cities.columns[:12], months[1:])
                if old != new },
        inplace=True)
french_cities.columns

```

NameError Traceback (most recent call last)

```

<ipython-input-10-39c4d54b672b> in <module>
      1 french_cities.rename(
      2     columns={ old : new
----> 3         for old, new in zip(french_cities.columns[:12], months[1:])
      4         if old != new },
      5     inplace=True)

```

NameError: name 'months' is not defined

```

In [11]: french_cities.rename(columns={'Moye': 'Mean'}, inplace=True)

```

```

In [12]: french_cities

```

```

Out[12]:

```

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Bordeaux	5.6	6.6	10.3	12.8	15.8	19.3	20.9	21.0	18.6	13.8	9.1	
Brest	6.1	5.8	7.8	9.2	11.6	14.4	15.6	16.0	14.7	12.0	9.0	
Clermont	2.6	3.7	7.5	10.3	13.8	17.3	19.4	19.1	16.2	11.2	6.6	
Grenoble	1.5	3.2	7.7	10.6	14.5	17.8	20.1	19.5	16.7	11.4	6.5	
...	
Rennes	4.8	5.3	7.9	10.1	13.1	16.2	17.9	17.8	15.7	11.6	7.8	
Strasbourg	0.4	1.5	5.6	9.8	14.0	17.2	19.0	18.3	15.1	9.5	4.9	
Toulouse	4.7	5.6	9.2	11.6	14.9	18.7	20.9	20.9	18.3	13.3	8.6	
Vichy	2.4	3.4	7.1	9.9	13.6	17.1	19.3	18.8	16.0	11.0	6.6	

	Déce	Lati	Long	Mean	Ampl	Région
City						
Bordeaux	6.2	44.50	-0.34	13.33	15.4	SO
Brest	7.0	48.24	-4.29	10.77	10.2	NO
Clermont	3.6	45.47	3.05	10.94	16.8	SE

Grenoble	2.3	45.10	5.43	10.98	18.6	SE
...
Rennes	5.4	48.05	-1.41	11.13	13.1	NO
Strasbourg	1.3	48.35	7.45	9.72	18.6	NE
Toulouse	5.5	43.36	1.26	12.68	16.2	SO
Vichy	3.4	46.08	3.26	10.72	16.9	SE

[15 rows x 7 columns]

11.5 From a local or remote HTML file

We can download and extract data about mean sea level stations around the world from the [PSMSL website](http://www.psmsl.org/).

```
In [13]: # Needs `lxml`, `beautifulSoup4` and `html5lib` python packages
table_list = pd.read_html("http://www.psmsl.org/data/obtaining/")
```

```
In [14]: # there is 1 table on that page which contains metadata about the stations where
# sea levels are recorded
local_sea_level_stations = table_list[0]
local_sea_level_stations
```

```
Out[14]:
```

	Station Name	ID	Lat.	Lon.	GLOSS ID	Country	\
0	BREST	1	48.383	-4.495	242.0	FRA	
1	SWINOUJSCIE	2	53.917	14.233	NaN	POL	
2	SHEERNESS	3	51.446	0.743	NaN	GBR	
3	HOLYHEAD	5	53.314	-4.620	NaN	GBR	
...
1544	SUVA-B	2356	-18.133	178.428	NaN	FJI	
1545	SYDNEY PORT JACKSON	2358	-33.826	151.259	NaN	AUS	
1546	ARKO	2359	58.484	16.961	NaN	SWE	
1547	UDDEVALLA	2360	58.348	11.895	NaN	SWE	

	Date	Coastline	Station
0	07/08/2019	190	91
1	19/10/2001	110	92
2	06/06/2019	170	101
3	06/06/2019	170	191
...
1544	28/01/2020	742	14
1545	13/06/2019	680	138
1546	12/09/2019	50	112
1547	12/09/2019	50	22

[1548 rows x 4 columns]

11.6 Indexing on DataFrames

```
In [15]: french_cities['Lati'] # DF [] accesses columns (Series)
```

```
Out[15]: City
Bordeaux    44.50
Brest       48.24
Clermont    45.47
Grenoble    45.10
```

```

...
Rennes      48.05
Strasbourg  48.35
Toulouse    43.36
Vichy       46.08
Name: Lati, Length: 15, dtype: float64

```

.loc and .iloc allow to access individual values, slices or masked selections:

```
In [16]: french_cities.loc['Rennes', "Sep"]
```

```

-----

KeyError                                Traceback (most recent call last)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexes/base.py in
2888         try:
-> 2889             return self._engine.get_loc(casted_key)
2890         except KeyError as err:

pandas/_libs/index.pyx in pandas._libs.index.IndexEngine.get_loc()

pandas/_libs/index.pyx in pandas._libs.index.IndexEngine.get_loc()

pandas/_libs/hashtable_class_helper.pxi in pandas._libs.hashtable.PyObjectHashTable.get_item()

pandas/_libs/hashtable_class_helper.pxi in pandas._libs.hashtable.PyObjectHashTable.get_item()

KeyError: 'Sep'

```

The above exception was the direct cause of the following exception:

```

KeyError                                Traceback (most recent call last)

<ipython-input-16-766b5d3b5de4> in <module>
----> 1 french_cities.loc['Rennes', "Sep"]

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in __ge
871         # AttributeError for IntervalTree get_value
872         pass
-> 873         return self._getitem_tuple(key)
874     else:
875         # we by definition only have the 0th axis

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _get

```



```

1042     def _getitem_tuple(self, tup: Tuple):
1043         try:
-> 1044             return self._getitem_lowerdim(tup)
1045         except IndexError:
1046             pass

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _geti
808         return section
809         # This is an elided recursive call to iloc/loc
--> 810         return getattr(section, self.name)[new_key]
811
812         raise IndexError("not applicable")

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in __ge
877
878         maybe_callable = com.apply_if_callable(key, self.obj)
--> 879         return self._getitem_axis(maybe_callable, axis=axis)
880
881     def _is_scalar_access(self, key: Tuple):

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _geti
1108         # fall thru to straight lookup
1109         self._validate_key(key, axis)
-> 1110         return self._get_label(key, axis=axis)
1111
1112     def _get_slice_axis(self, slice_obj: slice, axis: int):

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _geti
1057     def _get_label(self, label, axis: int):
1058         # GH#5667 this will fail if the label is not present in the axis.
-> 1059         return self.obj.xs(label, axis=axis)
1060
1061     def _handle_lowerdim_multi_index_axis0(self, tup: Tuple):

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/generic.py in xs(se
3480         loc, new_index = self.index.get_loc_level(key, drop_level=drop_level)
3481     else:
-> 3482         loc = self.index.get_loc(key)
3483
3484         if isinstance(loc, np.ndarray):

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexes/base.py in g
2889         return self._engine.get_loc(casted_key)
2890     except KeyError as err:
-> 2891         raise KeyError(key) from err
2892
2893     if tolerance is not None:

```

```
KeyError: 'Sep'
```

```
In [17]: french_cities.loc['Rennes', ["Sep", "Dec"]]
```

```
-----

KeyError                                Traceback (most recent call last)

<ipython-input-17-988685453654> in <module>
----> 1 french_cities.loc['Rennes', ["Sep", "Dec"]]

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in __getitem__
871         # AttributeError for IntervalTree get_value
872         pass
--> 873         return self._getitem_tuple(key)
874     else:
875         # we by definition only have the 0th axis

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _getitem_tuple
1042     def _getitem_tuple(self, tup: Tuple):
1043         try:
-> 1044             return self._getitem_lowerdim(tup)
1045         except IndexingError:
1046             pass

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _getitem_lowerdim
808         return section
809         # This is an elided recursive call to iloc/loc
--> 810         return getattr(section, self.name)[new_key]
811
812         raise IndexingError("not applicable")

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _getitem_tuple
877
878         maybe_callable = com.apply_if_callable(key, self.obj)
--> 879         return self._getitem_axis(maybe_callable, axis=axis)
880
881     def _is_scalar_access(self, key: Tuple):

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _getitem_tuple
1097         raise ValueError("Cannot index with multidimensional key")
1098
-> 1099         return self._getitem_iterable(key, axis=axis)
1100
1101         # nested tuple slicing
```

```

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _geti
1035
1036     # A collection of keys
-> 1037     keyarr, indexer = self._get_listlike_indexer(key, axis, raise_missing=False)
1038     return self.obj._reindex_with_indexers(
1039         {axis: [keyarr, indexer]}, copy=True, allow_dups=True

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _geti
1252         keyarr, indexer, new_indexer = ax._reindex_non_unique(keyarr)
1253
-> 1254     self._validate_read_indexer(keyarr, indexer, axis, raise_missing=raise_missing)
1255     return keyarr, indexer
1256

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _val
1296         if missing == len(indexer):
1297             axis_name = self.obj._get_axis_name(axis)
-> 1298             raise KeyError(f"None of [{key}] are in the [{axis_name}]")
1299
1300         # We (temporarily) allow for some missing keys with .loc, except in

```

```
KeyError: "None of [Index(['Sep', 'Dec'], dtype='object')] are in the [index]"
```

```
In [18]: french_cities.loc['Rennes', "Sep":"Dec"]
```

```

-----

KeyError                                Traceback (most recent call last)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexes/base.py in g
2888         try:
-> 2889             return self._engine.get_loc(casted_key)
2890         except KeyError as err:

pandas/_libs/index.pyx in pandas._libs.index.IndexEngine.get_loc()

pandas/_libs/index.pyx in pandas._libs.index.IndexEngine.get_loc()

pandas/_libs/hashtable_class_helper.pxi in pandas._libs.hashtable.PyObjectHashTable.get_item()

pandas/_libs/hashtable_class_helper.pxi in pandas._libs.hashtable.PyObjectHashTable.get_item()

KeyError: 'Sep'

```

The above exception was the direct cause of the following exception:

```

KeyError                                Traceback (most recent call last)

<ipython-input-18-9347c35b6c44> in <module>
----> 1 french_cities.loc['Rennes', "Sep":"Dec"]

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in __getitem__
871         # AttributeError for IntervalTree get_value
872         pass
--> 873         return self._getitem_tuple(key)
874     else:
875         # we by definition only have the 0th axis

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _getitem_tuple
1042     def _getitem_tuple(self, tup: Tuple):
1043         try:
-> 1044             return self._getitem_lowerdim(tup)
1045         except IndexingError:
1046             pass

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _getitem_lowerdim
808         return section
809         # This is an elided recursive call to iloc/loc
--> 810         return getattr(section, self.name)[new_key]
811
812         raise IndexingError("not applicable")

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _getitem_iat
877
878         maybe_callable = com.apply_if_callable(key, self.obj)
--> 879         return self._getitem_axis(maybe_callable, axis=axis)
880
881     def _is_scalar_access(self, key: Tuple):

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _getitem_iat
1086         if isinstance(key, slice):
1087             self._validate_key(key, axis)
-> 1088             return self._get_slice_axis(key, axis=axis)
1089         elif com.is_bool_indexer(key):
1090             return self._getbool_axis(key, axis=axis)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexing.py in _getitem_iat
1120
1121         labels = obj._get_axis(axis)
-> 1122         indexer = labels.slice_indexer(
1123             slice_obj.start, slice_obj.stop, slice_obj.step, kind="loc"

```

```

1124         )

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexes/base.py in
4958         slice(1, 3, None)
4959         """
-> 4960         start_slice, end_slice = self.slice_locs(start, end, step=step, kind=kind)
4961
4962         # return a slice

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexes/base.py in
5159         start_slice = None
5160         if start is not None:
-> 5161             start_slice = self.get_slice_bound(start, "left", kind)
5162         if start_slice is None:
5163             start_slice = 0

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexes/base.py in
5081         except ValueError:
5082             # raise the original KeyError
-> 5083             raise err
5084
5085         if isinstance(slc, np.ndarray):

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexes/base.py in
5075         # we need to look up the label
5076         try:
-> 5077             slc = self.get_loc(label)
5078         except KeyError as err:
5079             try:

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexes/base.py in
2889         return self._engine.get_loc(casted_key)
2890         except KeyError as err:
-> 2891             raise KeyError(key) from err
2892
2893         if tolerance is not None:

KeyError: 'Sep'

```

11.7 Masking

```

In [19]: mask = [True, False] * 6 + 5 * [False]
         print(french_cities.iloc[:, mask])

```

	Janv	Mars	Mai	juil	Sept	Nove
City						
Bordeaux	5.6	10.3	15.8	20.9	18.6	9.1

Brest	6.1	7.8	11.6	15.6	14.7	9.0
Clermont	2.6	7.5	13.8	19.4	16.2	6.6
Grenoble	1.5	7.7	14.5	20.1	16.7	6.5
...
Rennes	4.8	7.9	13.1	17.9	15.7	7.8
Strasbourg	0.4	5.6	14.0	19.0	15.1	4.9
Toulouse	4.7	9.2	14.9	20.9	18.3	8.6
Vichy	2.4	7.1	13.6	19.3	16.0	6.6

[15 rows x 6 columns]

```
In [20]: print(french_cities.loc["Rennes", mask])
```

```
Janv      4.8
Mars      7.9
Mai      13.1
juil     17.9
Sept     15.7
Nove      7.8
Name: Rennes, dtype: object
```

11.8 New column

```
In [21]: french_cities["std"] = french_cities.iloc[:,12].std(axis=1)
french_cities
```

```
Out[21]:
```

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Bordeaux	5.6	6.6	10.3	12.8	15.8	19.3	20.9	21.0	18.6	13.8	9.1	
Brest	6.1	5.8	7.8	9.2	11.6	14.4	15.6	16.0	14.7	12.0	9.0	
Clermont	2.6	3.7	7.5	10.3	13.8	17.3	19.4	19.1	16.2	11.2	6.6	
Grenoble	1.5	3.2	7.7	10.6	14.5	17.8	20.1	19.5	16.7	11.4	6.5	
...	
Rennes	4.8	5.3	7.9	10.1	13.1	16.2	17.9	17.8	15.7	11.6	7.8	
Strasbourg	0.4	1.5	5.6	9.8	14.0	17.2	19.0	18.3	15.1	9.5	4.9	
Toulouse	4.7	5.6	9.2	11.6	14.9	18.7	20.9	20.9	18.3	13.3	8.6	
Vichy	2.4	3.4	7.1	9.9	13.6	17.1	19.3	18.8	16.0	11.0	6.6	

	Déce	Lati	Long	Mean	Ampl	Région	std
City							
Bordeaux	6.2	44.50	-0.34	13.33	15.4	SO	5.792681
Brest	7.0	48.24	-4.29	10.77	10.2	NO	3.773673
Clermont	3.6	45.47	3.05	10.94	16.8	SE	6.189795
Grenoble	2.3	45.10	5.43	10.98	18.6	SE	6.770771
...
Rennes	5.4	48.05	-1.41	11.13	13.1	NO	4.958800
Strasbourg	1.3	48.35	7.45	9.72	18.6	NE	6.931723
Toulouse	5.5	43.36	1.26	12.68	16.2	SO	6.056977
Vichy	3.4	46.08	3.26	10.72	16.9	SE	6.201148

[15 rows x 18 columns]

```
In [22]: french_cities = french_cities.drop("std", axis=1) # remove this new column
```

In [23]: french_cities

```
Out[23]:
```

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Bordeaux	5.6	6.6	10.3	12.8	15.8	19.3	20.9	21.0	18.6	13.8	9.1	
Brest	6.1	5.8	7.8	9.2	11.6	14.4	15.6	16.0	14.7	12.0	9.0	
Clermont	2.6	3.7	7.5	10.3	13.8	17.3	19.4	19.1	16.2	11.2	6.6	
Grenoble	1.5	3.2	7.7	10.6	14.5	17.8	20.1	19.5	16.7	11.4	6.5	
...	
Rennes	4.8	5.3	7.9	10.1	13.1	16.2	17.9	17.8	15.7	11.6	7.8	
Strasbourg	0.4	1.5	5.6	9.8	14.0	17.2	19.0	18.3	15.1	9.5	4.9	
Toulouse	4.7	5.6	9.2	11.6	14.9	18.7	20.9	20.9	18.3	13.3	8.6	
Vichy	2.4	3.4	7.1	9.9	13.6	17.1	19.3	18.8	16.0	11.0	6.6	

	Déce	Lati	Long	Mean	Ampl	Région
City						
Bordeaux	6.2	44.50	-0.34	13.33	15.4	SO
Brest	7.0	48.24	-4.29	10.77	10.2	NO
Clermont	3.6	45.47	3.05	10.94	16.8	SE
Grenoble	2.3	45.10	5.43	10.98	18.6	SE
...
Rennes	5.4	48.05	-1.41	11.13	13.1	NO
Strasbourg	1.3	48.35	7.45	9.72	18.6	NE
Toulouse	5.5	43.36	1.26	12.68	16.2	SO
Vichy	3.4	46.08	3.26	10.72	16.9	SE

[15 rows x 17 columns]

11.9 Modifying a dataframe with multiple indexing

In [24]: *# french_cities['Rennes']['Sep'] = 25 # It does not works and breaks the DataFrame*
french_cities.loc['Rennes']['Sep'] # = 25 is the right way to do it

```
-----

KeyError                                Traceback (most recent call last)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexes/base.py in
2888         try:
-> 2889             return self._engine.get_loc(casted_key)
2890         except KeyError as err:

pandas/_libs/index.pyx in pandas._libs.index.IndexEngine.get_loc()

pandas/_libs/index.pyx in pandas._libs.index.IndexEngine.get_loc()

pandas/_libs/hashtable_class_helper.pxi in pandas._libs.hashtable.PyObjectHashTable.get_item()

pandas/_libs/hashtable_class_helper.pxi in pandas._libs.hashtable.PyObjectHashTable.get_item()
```

```
KeyError: 'Sep'
```

The above exception was the direct cause of the following exception:

```

KeyError                                Traceback (most recent call last)

<ipython-input-24-c68575f89e60> in <module>
      1 # french_cities['Rennes']['Sep'] = 25 # It does not works and breaks the DataFrame
----> 2 french_cities.loc['Rennes']['Sep'] # = 25 is the right way to do it

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/series.py in __getitem__
    880
    881         elif key_is_scalar:
--> 882             return self._get_value(key)
    883
    884         if (

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/series.py in _get_value
    989
    990         # Similar to Index.get_value, but we do not fall back to positional
--> 991         loc = self.index.get_loc(label)
    992         return self.index._get_values_for_loc(self, loc, label)
    993

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/core/indexes/base.py in get_loc
   2889         return self._engine.get_loc(casted_key)
   2890         except KeyError as err:
-> 2891             raise KeyError(key) from err
   2892
   2893         if tolerance is not None:

KeyError: 'Sep'

```

In [25]: french_cities

```
Out[25]:
```

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Bordeaux	5.6	6.6	10.3	12.8	15.8	19.3	20.9	21.0	18.6	13.8	9.1	
Brest	6.1	5.8	7.8	9.2	11.6	14.4	15.6	16.0	14.7	12.0	9.0	
Clermont	2.6	3.7	7.5	10.3	13.8	17.3	19.4	19.1	16.2	11.2	6.6	
Grenoble	1.5	3.2	7.7	10.6	14.5	17.8	20.1	19.5	16.7	11.4	6.5	
...	
Rennes	4.8	5.3	7.9	10.1	13.1	16.2	17.9	17.8	15.7	11.6	7.8	
Strasbourg	0.4	1.5	5.6	9.8	14.0	17.2	19.0	18.3	15.1	9.5	4.9	
Toulouse	4.7	5.6	9.2	11.6	14.9	18.7	20.9	20.9	18.3	13.3	8.6	
Vichy	2.4	3.4	7.1	9.9	13.6	17.1	19.3	18.8	16.0	11.0	6.6	

	Déce	Lati	Long	Mean	Ampl	Région
City						
Bordeaux	6.2	44.50	-0.34	13.33	15.4	SO
Brest	7.0	48.24	-4.29	10.77	10.2	NO
Clermont	3.6	45.47	3.05	10.94	16.8	SE
Grenoble	2.3	45.10	5.43	10.98	18.6	SE
...
Rennes	5.4	48.05	-1.41	11.13	13.1	NO
Strasbourg	1.3	48.35	7.45	9.72	18.6	NE
Toulouse	5.5	43.36	1.26	12.68	16.2	SO
Vichy	3.4	46.08	3.26	10.72	16.9	SE

[15 rows x 17 columns]

11.10 Transforming datasets

```
In [26]: french_cities['Mean'].min(), french_cities['Ampl'].max()
```

```
Out[26]: (9.72, 18.6)
```

11.11 Apply

Let's convert the temperature mean from Celsius to Fahrenheit degree.

```
In [27]: fahrenheit = lambda T: T*9/5+32
         french_cities['Mean'].apply(fahrenheit)
```

```
Out[27]: City
Bordeaux      55.994
Brest         51.386
Clermont      51.692
Grenoble      51.764
...
Rennes        52.034
Strasbourg    49.496
Toulouse      54.824
Vichy         51.296
Name: Mean, Length: 15, dtype: float64
```

11.12 Sort

```
In [28]: french_cities.sort_values(by='Lati')
```

```
Out[28]:
```

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Marseille	5.5	6.6	10.0	13.0	16.8	20.8	23.3	22.8	19.9	15.0	10.2	
Montpellier	5.6	6.7	9.9	12.8	16.2	20.1	22.7	22.3	19.3	14.6	10.0	
Toulouse	4.7	5.6	9.2	11.6	14.9	18.7	20.9	20.9	18.3	13.3	8.6	
Nice	7.5	8.5	10.8	13.3	16.7	20.1	22.7	22.5	20.3	16.0	11.5	
...
Brest	6.1	5.8	7.8	9.2	11.6	14.4	15.6	16.0	14.7	12.0	9.0	
Strasbourg	0.4	1.5	5.6	9.8	14.0	17.2	19.0	18.3	15.1	9.5	4.9	
Paris	3.4	4.1	7.6	10.7	14.3	17.5	19.1	18.7	16.0	11.4	7.1	

Lille	2.4	2.9	6.0	8.9	12.4	15.3	17.1	17.1	14.7	10.4	6.1
-------	-----	-----	-----	-----	------	------	------	------	------	------	-----

	Déce	Lati	Long	Mean	Ampl	Région
City						
Marseille	6.9	43.18	5.24	14.23	17.8	SE
Montpellier	6.5	43.36	3.53	13.89	17.1	SE
Toulouse	5.5	43.36	1.26	12.68	16.2	SO
Nice	8.2	43.42	7.15	14.84	15.2	SE
...
Brest	7.0	48.24	-4.29	10.77	10.2	NO
Strasbourg	1.3	48.35	7.45	9.72	18.6	NE
Paris	4.3	48.52	2.20	11.18	15.7	NE
Lille	3.5	50.38	3.04	9.73	14.7	NE

[15 rows x 17 columns]

```
In [29]: french_cities = french_cities.sort_values(by='Lati',ascending=False)
french_cities
```

```
Out[29]:
```

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Lille	2.4	2.9	6.0	8.9	12.4	15.3	17.1	17.1	14.7	10.4	6.1	
Paris	3.4	4.1	7.6	10.7	14.3	17.5	19.1	18.7	16.0	11.4	7.1	
Strasbourg	0.4	1.5	5.6	9.8	14.0	17.2	19.0	18.3	15.1	9.5	4.9	
Brest	6.1	5.8	7.8	9.2	11.6	14.4	15.6	16.0	14.7	12.0	9.0	
...
Nice	7.5	8.5	10.8	13.3	16.7	20.1	22.7	22.5	20.3	16.0	11.5	
Montpellier	5.6	6.7	9.9	12.8	16.2	20.1	22.7	22.3	19.3	14.6	10.0	
Toulouse	4.7	5.6	9.2	11.6	14.9	18.7	20.9	20.9	18.3	13.3	8.6	
Marseille	5.5	6.6	10.0	13.0	16.8	20.8	23.3	22.8	19.9	15.0	10.2	

	Déce	Lati	Long	Mean	Ampl	Région
City						
Lille	3.5	50.38	3.04	9.73	14.7	NE
Paris	4.3	48.52	2.20	11.18	15.7	NE
Strasbourg	1.3	48.35	7.45	9.72	18.6	NE
Brest	7.0	48.24	-4.29	10.77	10.2	NO
...
Nice	8.2	43.42	7.15	14.84	15.2	SE
Montpellier	6.5	43.36	3.53	13.89	17.1	SE
Toulouse	5.5	43.36	1.26	12.68	16.2	SO
Marseille	6.9	43.18	5.24	14.23	17.8	SE

[15 rows x 17 columns]

11.13 Stack and unstack

Instead of seeing the months along the axis 1, and the cities along the axis 0, let's try to convert these into an outer and an inner axis along only 1 time dimension.

```
In [30]: pd.set_option("display.max_rows", 20)
unstacked = french_cities.iloc[:,12:].unstack()
unstacked
```

```
Out[30]:
```

	City
Janv	Lille 2.4

```

        Paris      3.4
        Strasbourg 0.4
        Brest      6.1
        Rennes     4.8
        ...
Déce  Bordeaux    6.2
      Nice        8.2
      Montpellier 6.5
      Toulouse    5.5
      Marseille   6.9
Length: 180, dtype: float64

```

```
In [31]: type(unstacked)
```

```
Out[31]: pandas.core.series.Series
```

11.14 Transpose

The result is grouped in the wrong order since it sorts first the axis that was unstacked. We need to transpose the dataframe.

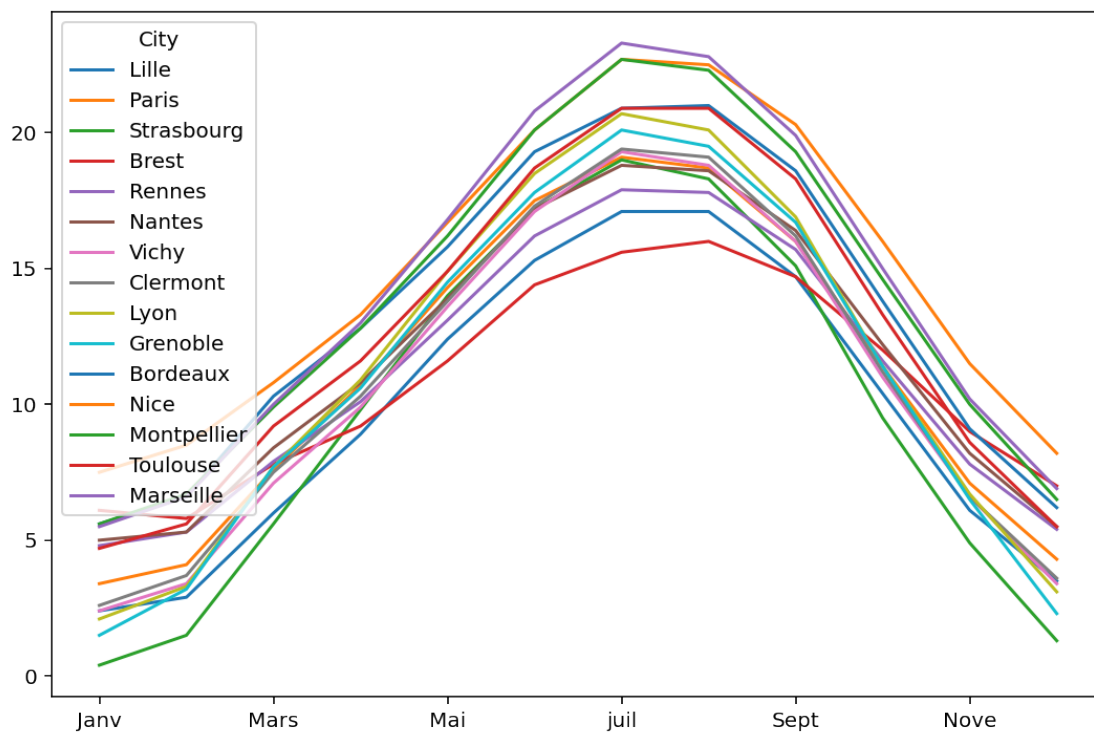
```
In [32]: city_temp = french_cities.iloc[:, :12].transpose()
        city_temp.plot()
```

```

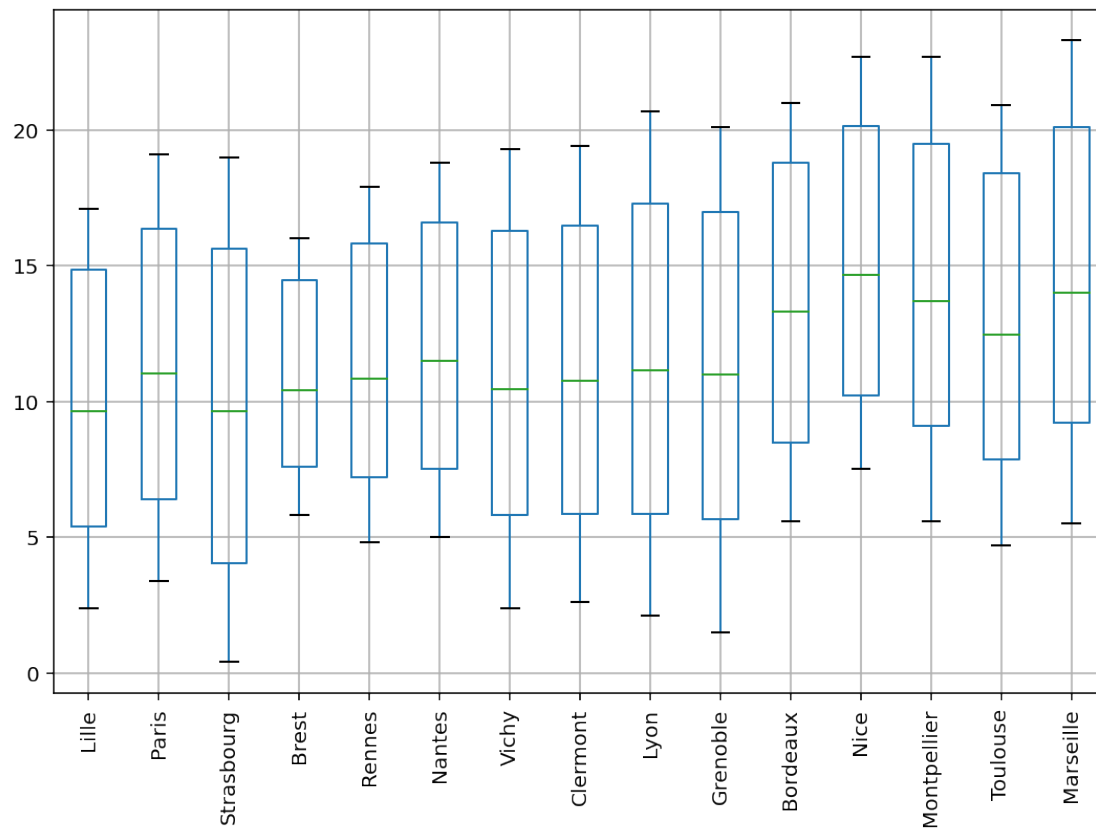
/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pandas/plotting/_matplotlib/core.py:123:
  ax.set_xticklabels(xticklabels)

```

```
Out[32]: <AxesSubplot:>
```



```
In [33]: city_temp.boxplot(rot=90);
```



11.15 Describing

```
In [34]: french_cities['Région'].describe()
```

```
Out[34]: count      15
         unique       4
         top         SE
         freq        7
         Name: Région, dtype: object
```

```
In [35]: french_cities['Région'].unique()
```

```
Out[35]: array(['NE', 'NO', 'SE', 'SO'], dtype=object)
```

```
In [36]: french_cities['Région'].value_counts()
```

```
Out[36]: SE      7
         NO      3
         NE      3
         SO      2
         Name: Région, dtype: int64
```

```
In [37]: # To save memory, we can convert it to a categorical column:
         french_cities["Région"] = french_cities["Région"].astype("category")
```

```
In [38]: french_cities.memory_usage()
```

```
Out[38]: Index      760
         Janv       120
         Févr       120
         Mars       120
         Avri       120
         Mai        120
         Juin       120
         juil       120
         Août       120
         Sept       120
         Octo       120
         Nove       120
         Déce       120
         Lati       120
         Long       120
         Mean       120
         Ampl       120
         Région    207
         dtype: int64
```

11.16 Data Aggregation/summarization

11.17 groupby

```
In [39]: fc_grouped_region = french_cities.groupby("Région")
         type(fc_grouped_region)
```

```
Out[39]: pandas.core.groupby.generic.DataFrameGroupBy
```

```
In [40]: for group_name, subdf in fc_grouped_region:
         print(group_name)
         print(subdf)
         print("")
```

NE

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Lille	2.4	2.9	6.0	8.9	12.4	15.3	17.1	17.1	14.7	10.4	6.1	
Paris	3.4	4.1	7.6	10.7	14.3	17.5	19.1	18.7	16.0	11.4	7.1	
Strasbourg	0.4	1.5	5.6	9.8	14.0	17.2	19.0	18.3	15.1	9.5	4.9	

	Déce	Lati	Long	Mean	Ampl	Région
City						
Lille	3.5	50.38	3.04	9.73	14.7	NE
Paris	4.3	48.52	2.20	11.18	15.7	NE
Strasbourg	1.3	48.35	7.45	9.72	18.6	NE

NO

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Brest	6.1	5.8	7.8	9.2	11.6	14.4	15.6	16.0	14.7	12.0	9.0	
Rennes	4.8	5.3	7.9	10.1	13.1	16.2	17.9	17.8	15.7	11.6	7.8	
Nantes	5.0	5.3	8.4	10.8	13.9	17.2	18.8	18.6	16.4	12.2	8.2	

	Déce	Lati	Long	Mean	Ampl	Région
City						
Brest	7.0	48.24	-4.29	10.77	10.2	NO
Rennes	5.4	48.05	-1.41	11.13	13.1	NO
Nantes	5.5	47.13	-1.33	11.69	13.8	NO

SE

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Vichy	2.4	3.4	7.1	9.9	13.6	17.1	19.3	18.8	16.0	11.0	6.6	
Clermont	2.6	3.7	7.5	10.3	13.8	17.3	19.4	19.1	16.2	11.2	6.6	
Lyon	2.1	3.3	7.7	10.9	14.9	18.5	20.7	20.1	16.9	11.4	6.7	
Grenoble	1.5	3.2	7.7	10.6	14.5	17.8	20.1	19.5	16.7	11.4	6.5	
Nice	7.5	8.5	10.8	13.3	16.7	20.1	22.7	22.5	20.3	16.0	11.5	
Montpellier	5.6	6.7	9.9	12.8	16.2	20.1	22.7	22.3	19.3	14.6	10.0	
Marseille	5.5	6.6	10.0	13.0	16.8	20.8	23.3	22.8	19.9	15.0	10.2	

	Déce	Lati	Long	Mean	Ampl	Région
City						
Vichy	3.4	46.08	3.26	10.72	16.9	SE
Clermont	3.6	45.47	3.05	10.94	16.8	SE
Lyon	3.1	45.45	4.51	11.36	18.6	SE
Grenoble	2.3	45.10	5.43	10.98	18.6	SE
Nice	8.2	43.42	7.15	14.84	15.2	SE
Montpellier	6.5	43.36	3.53	13.89	17.1	SE
Marseille	6.9	43.18	5.24	14.23	17.8	SE

S0

	Janv	Févr	Mars	Avri	Mai	Juin	juil	Août	Sept	Octo	Nove	\
City												
Bordeaux	5.6	6.6	10.3	12.8	15.8	19.3	20.9	21.0	18.6	13.8	9.1	
Toulouse	4.7	5.6	9.2	11.6	14.9	18.7	20.9	20.9	18.3	13.3	8.6	

	Déce	Lati	Long	Mean	Ampl	Région
City						
Bordeaux	6.2	44.50	-0.34	13.33	15.4	S0
Toulouse	5.5	43.36	1.26	12.68	16.2	S0

Chapter 12

PySpark



- [Apache Spark](#) was first released in 2014.
- It was originally developed by [Matei Zaharia](#) as a class project, and later a PhD dissertation, at University of California, Berkeley.
- Spark is written in [Scala](#).
- All images come from [Databricks](#).
- Apache Spark is a fast and general-purpose cluster computing system.
- It provides high-level APIs in Java, Scala, Python and R, and an optimized engine that supports general execution graphs.
- Spark can manage "big data" collections with a small set of high-level primitives like **map**, **filter**, **groupby**, and **join**. With these common patterns we can often handle computations that are more complex than map, but are still structured.
- It also supports a rich set of higher-level tools including [Spark SQL](#) for SQL and structured data processing, [MLlib](#) for machine learning, [GraphX](#) for graph processing, and Spark Streaming.

12.1 Resilient distributed datasets

- The fundamental abstraction of Apache Spark is a read-only, parallel, distributed, fault-tolerant collection called a resilient distributed datasets (RDD).
- RDDs behave a bit like Python collections (e.g. lists).
- When working with Apache Spark we iteratively apply functions to every item of these collections in parallel to produce *new* RDDs.
- The data is distributed across nodes in a cluster of computers.

- Functions implemented in Spark can work in parallel across elements of the collection.
- The Spark framework allocates data and processing to different nodes, without any intervention from the programmer.
- RDDs automatically rebuilt on machine failure.

12.2 Lifecycle of a Spark Program

1. Create some input RDDs from external data or parallelize a collection in your driver program.
2. Lazily transform them to define new RDDs using transformations like `filter()` or `map()`
3. Ask Spark to `cache()` any intermediate RDDs that will need to be reused.
4. Launch actions such as `count()` and `collect()` to kick off a parallel computation, which is then optimized and executed by Spark.

12.3 Operations on Distributed Data

- Two types of operations: **transformations** and **actions**
- Transformations are *lazy* (not computed immediately)
- Transformations are executed when an action is run

12.4 Transformations (lazy)

```
map() flatMap()  
filter()  
mapPartitions() mapPartitionsWithIndex()  
sample()  
union() intersection() distinct()  
groupBy() groupByKey()  
reduceBy() reduceByKey()  
sortBy() sortByKey()  
join()  
cogroup()  
cartesian()  
pipe()  
coalesce()  
repartition()  
partitionBy()  
...
```

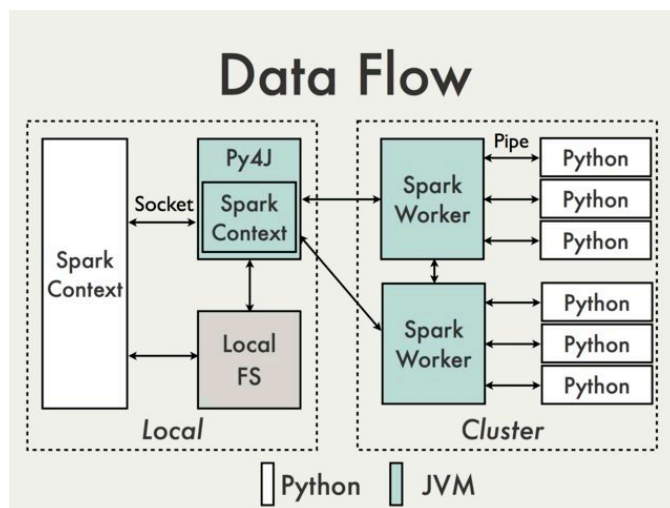
12.5 Actions

```
reduce()  
collect()  
count()  
first()  
take()  
takeSample()  
saveToCassandra()  
takeOrdered()  
saveAsTextFile()  
saveAsSequenceFile()  
saveAsObjectFile()  
countByKey()
```


foreach()

12.6 Python API

PySpark uses Py4J that enables Python programs to dynamically access Java objects.



12.7 The SparkContext class

- When working with Apache Spark we invoke methods on an object which is an instance of the `pyspark.SparkContext` context.
- Typically, an instance of this object will be created automatically for you and assigned to the variable `sc`.
- The `parallelize` method in `SparkContext` can be used to turn any ordinary Python collection into an RDD;
 - normally we would create an RDD from a large file or an HBase table.

12.8 First example

PySpark isn't on `sys.path` by default, but that doesn't mean it can't be used as a regular library. You can address this by either symlinking `pyspark` into your site-packages, or adding `pyspark` to `sys.path` at runtime. [findspark](#) does the latter.

We have a spark context `sc` to use with a tiny local spark cluster with 4 nodes (will work just fine on a multicore machine).

If you use the workstation in room A111 run the code below before:

```
import findspark
import os
os.environ["JAVA_HOME"] = "/usr/lib/jvm/java-8-openjdk-amd64",
os.environ["SPARK_HOME"] = "/export/spark-2.3.1-bin-hadoop2.7"
```

```
findspark.init()
```

```
In [1]: import sys
        sys.executable
```

```

Out[1]: '/usr/share/miniconda3/envs/big-data/bin/python'

In [2]: import sys, os
        os.environ["PYSPARK_PYTHON"] = sys.executable

In [3]: import pyspark

In [4]: sc = pyspark.SparkContext(master="local[*]", appName="FirstExample")
        sc.setLogLevel("ERROR")

In [5]: print(sc) # it is like a Pool Processor executor

<SparkContext master=local[*] appName=FirstExample>

```

12.9 Create your first RDD

```

In [6]: rdd = sc.parallelize(list(range(8))) # create collection

In [7]: rdd

Out[7]: ParallelCollectionRDD[0] at readRDDFromFile at PythonRDD.scala:262

```

12.9.1 Exercise

Create a file `sample.txt` with lorem package. Read and load it into a RDD with the `textFile` spark function.

```

In [8]: import lorem

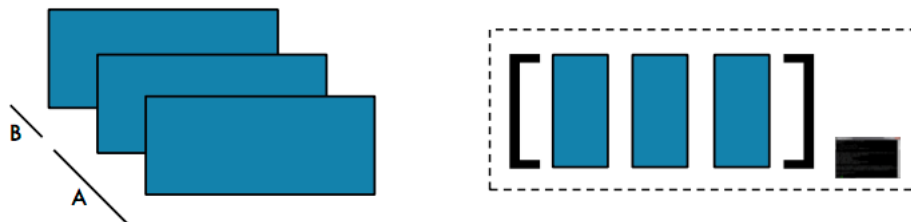
        with open("sample.txt", "w") as f:
            f.write(lorem.text())

        rdd = sc.textFile("sample.txt")

```

12.9.2 Collect

Action / To Driver: Return all items in the RDD to the driver in a single list



Source: <https://i.imgur.com/DUO6ygB.png>

12.9.3 Exercise

Collect the text you read before from the `sample.txt` file.

```

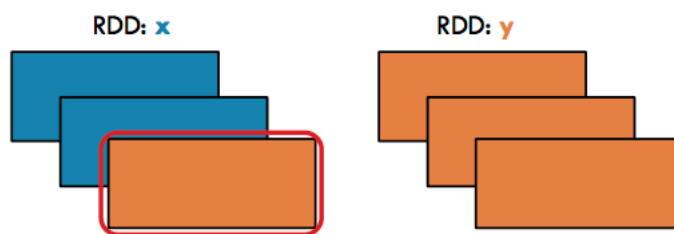
In [9]: rdd.collect()

```

```
Out[9]: ['Est adipisci amet sit aliquam neque consectetur. Ut numquam adipisci consectetur adipisci non
'',
'Porro amet modi dolor. Tempora velit sit tempora. Etincidunt velit etincidunt dolor sed aliqu
'',
'Amet est sit modi dolorem. Tempora aliquam adipisci ut sed eius porro etincidunt. Etincidunt
'',
'Est consectetur magnam adipisci numquam. Porro velit modi modi ipsum. Quaerat consectetur non
'',
'Quiquia tempora sit ipsum porro non. Adipisci quiquia ipsum tempora ut amet aliquam. Tempora a
```

12.9.4 Map

Transformation / Narrow: Return a new RDD by applying a function to each element of this RDD



Source: <http://i.imgur.com/PxNJf0U.png>

```
In [10]: rdd = sc.parallelize(list(range(8)))
         rdd.map(lambda x: x ** 2).collect() # Square each element
```

```
Out[10]: [0, 1, 4, 9, 16, 25, 36, 49]
```

12.9.5 Exercise

Replace the lambda function by a function that contains a pause (`sleep(1)`) and check if the `map` operation is parallelized.

```
In [11]: from time import sleep
         def square(x):
             sleep(1)
             return x**2

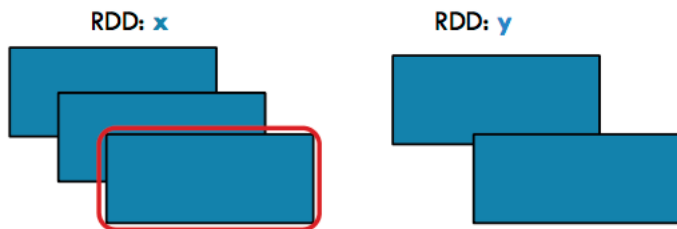
         %time rdd.map(square).collect()
```

```
CPU times: user 6.22 ms, sys: 0 ns, total: 6.22 ms
Wall time: 4.06 s
```

```
Out[11]: [0, 1, 4, 9, 16, 25, 36, 49]
```

12.9.6 Filter

Transformation / Narrow: Return a new RDD containing only the elements that satisfy a predicate



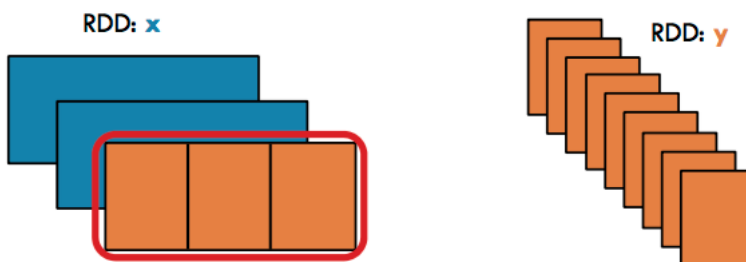
Source: <http://i.imgur.com/GFyji4U.png>

```
In [12]: # Select only the even elements
rdd.filter(lambda x: x % 2 == 0).collect()
```

```
Out[12]: [0, 2, 4, 6]
```

12.9.7 FlatMap

Transformation / Narrow: Return a new RDD by first applying a function to all elements of this RDD, and then flattening the results



```
In [13]: rdd = sc.parallelize([1,2,3])
rdd.flatMap(lambda x: (x, x*100, 42)).collect()
```

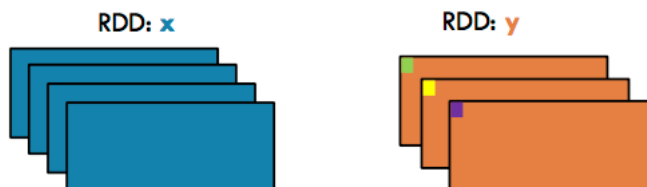
```
Out[13]: [1, 100, 42, 2, 200, 42, 3, 300, 42]
```

12.9.8 Exercise

Use FlatMap to clean the text from `sample.txtfile`. Lower, remove dots and split into words.

12.9.9 GroupBy

Transformation / Wide: Group the data in the original RDD. Create pairs where the key is the output of a user function, and the value is all items for which the function yields this key.

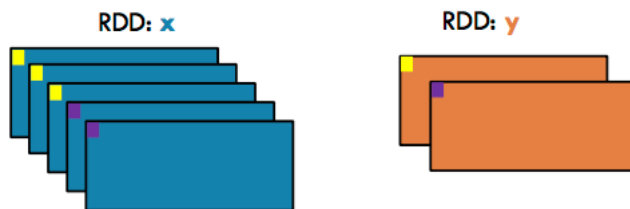


```
In [14]: rdd = sc.parallelize(['John', 'Fred', 'Anna', 'James'])
rdd = rdd.groupBy(lambda w: w[0])
[(k, list(v)) for (k, v) in rdd.collect()]
```

```
Out[14]: [('J', ['John', 'James']), ('F', ['Fred']), ('A', ['Anna'])]
```

12.9.10 GroupByKey

Transformation / Wide: Group the values for each key in the original RDD. Create a new pair where the original key corresponds to this collected group of values.

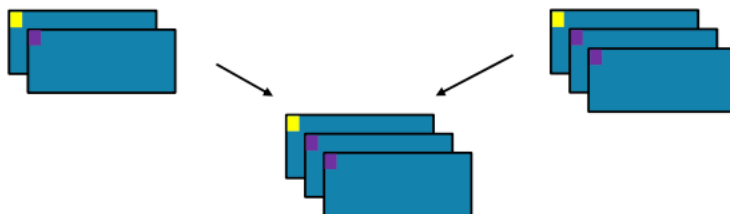


```
In [15]: rdd = sc.parallelize([('B',5),('B',4),('A',3),('A',2),('A',1)])
         rdd = rdd.groupByKey()
         [(j[0], list(j[1])) for j in rdd.collect()]
```

```
Out[15]: [('B', [5, 4]), ('A', [3, 2, 1])]
```

12.9.11 Join

Transformation / Wide: Return a new RDD containing all pairs of elements having the same key in the original RDDs



```
In [16]: x = sc.parallelize([("a", 1), ("b", 2)])
         y = sc.parallelize([("a", 3), ("a", 4), ("b", 5)])
         x.join(y).collect()
```

```
Out[16]: [('b', (2, 5)), ('a', (1, 3)), ('a', (1, 4))]
```

12.9.12 Distinct

Transformation / Wide: Return a new RDD containing distinct items from the original RDD (omitting all duplicates)

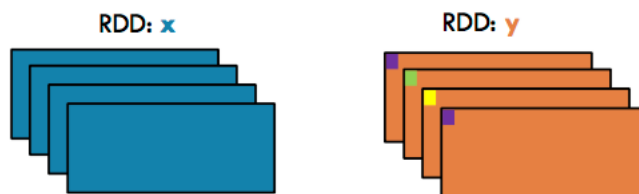


```
In [17]: rdd = sc.parallelize([1,2,3,3,4])
         rdd.distinct().collect()
```

```
Out[17]: [2, 4, 1, 3]
```

12.9.13 KeyBy

Transformation / Narrow: Create a Pair RDD, forming one pair for each item in the original RDD. The pair's key is calculated from the value via a user-supplied function.



```
In [18]: rdd = sc.parallelize(['John', 'Fred', 'Anna', 'James'])
         rdd.keyBy(lambda w: w[0]).collect()
```

```
Out[18]: [('J', 'John'), ('F', 'Fred'), ('A', 'Anna'), ('J', 'James')]
```

12.10 Actions

12.10.1 Map-Reduce operation

Action / To Driver: Aggregate all the elements of the RDD by applying a user function pairwise to elements and partial results, and return a result to the driver

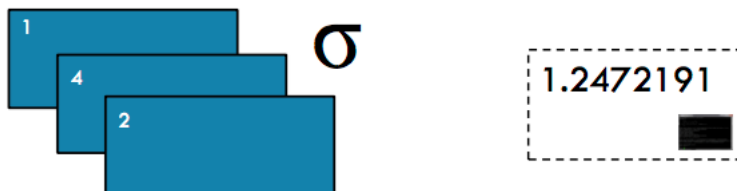


```
In [19]: from operator import add
         rdd = sc.parallelize(list(range(8)))
         rdd.map(lambda x: x ** 2).reduce(add) # reduce is an action!
```

```
Out[19]: 140
```

12.10.2 Max, Min, Sum, Mean, Variance, Stdev

Action / To Driver: Compute the respective function (maximum value, minimum value, sum, mean, variance, or standard deviation) from a numeric RDD



12.10.3 CountByKey

Action / To Driver: Return a map of keys and counts of their occurrences in the RDD



```
In [20]: rdd = sc.parallelize([('J', 'James'), ('F', 'Fred'),
                             ('A', 'Anna'), ('J', 'John')])
```

```
        rdd.countByKey()
```

```
Out[20]: defaultdict(int, {'J': 2, 'F': 1, 'A': 1})
```

```
In [21]: # Stop the local spark cluster
        sc.stop()
```

12.10.4 Exercise 10.1 Word-count in Apache Spark

- Write the sample text file

```
In [22]: from lorem import text
        with open('sample.txt', 'w') as f:
            f.write(text())
```

- Create the rdd with `SparkContext.textFile` method
- lower, remove dots and split using `rdd.flatMap`
- use `rdd.map` to create the list of key/value pair (word, 1)
- `rdd.reduceByKey` to get all occurrences
- `rdd.takeOrdered` to get sorted frequencies of words

All documentation is available [here](#) for `textFile` and [here](#) for RDD.

For a global overview see the Transformations section of the [programming guide](#)

```
In [23]: import pyspark
```

```
        sc = pyspark.SparkContext(master="local[*]", appName="wordcount")
        sc.setLogLevel("ERROR")
```

```
In [24]: rdd = sc.textFile("sample.txt")
```

```
In [25]: (rdd.flatMap(lambda line: line.lower().replace(".", " ").split())
        .map(lambda w : (w,1))
        .reduceByKey(lambda w, c: w + c)
        .sortBy( lambda w : -w[1]).collect())
```

```
Out[25]: [('sed', 13),
          ('ipsum', 13),
          ('magnam', 13),
          ('quiquia', 13),
          ('sit', 13),
          ('porro', 12),
          ('numquam', 11),
          ('aliquam', 11),
          ('quaerat', 10),
          ('quisquam', 10),
          ('labore', 9),
          ('consectetur', 9),
```

```
( 'est', 9),
( 'velit', 9),
( 'modi', 8),
( 'adipisci', 8),
( 'etincidunt', 8),
( 'ut', 8),
( 'voluptatem', 8),
( 'dolor', 8),
( 'eius', 7),
( 'dolore', 7),
( 'dolorem', 7),
( 'neque', 7),
( 'non', 5),
( 'tempora', 4),
( 'amet', 4)]
```

```
In [26]: sc.stop()
```

12.11 SparkSession

Since SPARK 2.0.0, SparkSession provides a single point of entry to interact with Spark functionality and allows programming Spark with DataFrame and Dataset APIs.

12.11.1 π computation example

- We can estimate an approximate value for π using the following Monte-Carlo method:
 1. Inscribe a circle in a square
 2. Randomly generate points in the square
 3. Determine the number of points in the square that are also in the circle
 4. Let r be the number of points in the circle divided by the number of points in the square, then $\pi \approx 4r$.
- Note that the more points generated, the better the approximation

See [this tutorial](#).

```
In [27]: import sys
         from random import random
         from operator import add

         from pyspark.sql import SparkSession

         spark = (SparkSession.builder.master("local[*]")
                  .appName("PythonPi")
                  .getOrCreate())

         partitions = 8
         n = 100000 * partitions

         def f(_):
             x = random() * 2 - 1
             y = random() * 2 - 1
             return 1 if x ** 2 + y ** 2 <= 1 else 0

         count = spark.sparkContext.parallelize(range(1, n+1), partitions).map(f).reduce(add)
         print("Pi is roughly %f" % (4.0 * count / n))

         spark.stop()
```


Pi is roughly 3.139070

12.11.2 Exercise 9.2

Using the same method than the PI computation example, compute the integral

$$I = \int_0^1 \exp(-x^2) dx$$

You can check your result with numpy

```
In [28]: # numpy evaluates solution using numeric computation.
# It uses discrete values of the function
import numpy as np
x = np.linspace(0,1,1000)
np.trapz(np.exp(-x*x),x)
```

Out[28]: 0.7468240713763741

```
In [29]: # numpy and scipy evaluates solution using numeric computation. It uses discrete values
# of the function
import numpy as np
from scipy.integrate import quad
quad(lambda x: np.exp(-x*x), 0, 1)
# note: the solution returned is complex
```

Out[29]: (0.7468241328124271, 8.291413475940725e-15)

12.11.3 Correlation between daily stock

- Data preparation

```
In [30]: import os # library to get directory and file paths
import tarfile # this module makes possible to read and write tar archives

def extract_data(name, where):
    datadir = os.path.join(where,name)
    if not os.path.exists(datadir):
        print("Extracting data...")
        tar_path = os.path.join(where, name+'.tgz')
        with tarfile.open(tar_path, mode='r:gz') as data:
            data.extractall(where)

extract_data('daily-stock','data') # this function call will extract json files
```

```
In [31]: import json
import pandas as pd
import os, glob

here = os.getcwd()
datadir = os.path.join(here, 'data', 'daily-stock')
filenames = sorted(glob.glob(os.path.join(datadir, '*.json')))
filenames
```

Out[31]: ['/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aet.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/afl.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aig.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/al.json',

```

'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/amgn.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/avy.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/b.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/bwa.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ge.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hal.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hp.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hpq.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ibm.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jbl.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jpm.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/luv.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/met.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/pcg.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/tgt.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/usb.json',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/xom.json']

```

```
In [32]: %rm data/daily-stock/*.h5
```

```

In [33]: from glob import glob
import os, json
import pandas as pd

for fn in filenames:
    with open(fn) as f:
        data = [json.loads(line) for line in f]

    df = pd.DataFrame(data)

    out_filename = fn[:-5] + '.h5'
    df.to_hdf(out_filename, '/data')
    print("Finished : %s" % out_filename.split(os.path.sep)[-1])

filenames = sorted(glob(os.path.join('data', 'daily-stock', '*.h5'))) # data/json/*.json

Finished : aet.h5
Finished : afl.h5
Finished : aig.h5
Finished : al.h5
Finished : amgn.h5
Finished : avy.h5
Finished : b.h5
Finished : bwa.h5
Finished : ge.h5
Finished : hal.h5
Finished : hp.h5
Finished : hpq.h5
Finished : ibm.h5
Finished : jbl.h5
Finished : jpm.h5
Finished : luv.h5
Finished : met.h5
Finished : pcg.h5
Finished : tgt.h5
Finished : usb.h5

```

Finished : xom.h5

12.11.4 Sequential code

In [34]: filenames

```
Out[34]: ['data/daily-stock/aet.h5',
          'data/daily-stock/afl.h5',
          'data/daily-stock/aig.h5',
          'data/daily-stock/al.h5',
          'data/daily-stock/amgn.h5',
          'data/daily-stock/avv.h5',
          'data/daily-stock/b.h5',
          'data/daily-stock/bwa.h5',
          'data/daily-stock/ge.h5',
          'data/daily-stock/hal.h5',
          'data/daily-stock/hp.h5',
          'data/daily-stock/hpq.h5',
          'data/daily-stock/ibm.h5',
          'data/daily-stock/jbl.h5',
          'data/daily-stock/jpm.h5',
          'data/daily-stock/luv.h5',
          'data/daily-stock/met.h5',
          'data/daily-stock/pcg.h5',
          'data/daily-stock/tgt.h5',
          'data/daily-stock/usb.h5',
          'data/daily-stock/xom.h5']
```

```
In [35]: with pd.HDFStore('data/daily-stock/aet.h5') as hdf:
          # This prints a list of all group names:
          print(hdf.keys())
```

```
['/data']
```

```
In [36]: df_test = pd.read_hdf('data/daily-stock/aet.h5')
```

```
In [37]: %%time
```

```
series = []
for fn in filenames:    # Simple map over filenames
    series.append(pd.read_hdf(fn)["close"])

results = []

for a in series:        # Doubly nested loop over the same collection
    for b in series:
        if not (a == b).all():    # Filter out comparisons of the same series
            results.append(a.corr(b))    # Apply function

result = max(results)
result
```

CPU times: user 1.12 s, sys: 115 ms, total: 1.23 s

Wall time: 1.23 s

```
Out[37]: 0.9413176064560881
```

12.11.5 Exercise 9.3

Parallelize the code above with Apache Spark.

- Change the filenames because of the Hadoop environment.

In [38]: `import os, glob`

```
here = os.getcwd()
filenames = sorted(glob.glob(os.path.join(here, 'data', 'daily-stock', '*.h5')))
filenames
```

```
Out[38]: ['/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aet.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/afl.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/aig.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/al.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/amgn.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/avy.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/b.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/bwa.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ge.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hal.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hp.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/hpq.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/ibm.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jbl.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/jpm.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/luv.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/met.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/pgc.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/tgt.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/usb.h5',
'/home/runner/work/big-data/big-data/notebooks/data/daily-stock/xom.h5']
```

If it is not started don't forget the PySpark context

In [39]: `### Parallel code`
`import pandas as pd`

```
sc = pyspark.SparkContext(master="local[*]", appName="series")
sc.setLogLevel("ERROR")
```

```
rdd = sc.parallelize(filenames)
series = rdd.map(lambda fn: pd.read_hdf(fn)['close'])
```

```
corr = (series.cartesian(series)
        .filter(lambda ab: not (ab[0] == ab[1]).all())
        .map(lambda ab: ab[0].corr(ab[1]))
        .max())
```

```
print(corr)
sc.stop()
```

0.9413176064560881

Computation time is slower because there is a lot of setup, workers creation, there is a lot of communications the correlation function is too small

12.11.6 Exercise 9.4 Fasta file example

Use a RDD to calculate the GC content of fasta file nucleotide-sample.txt:

$$\frac{G + C}{A + T + G + C} \times 100\%$$

Create a rdd from fasta file genome.txt in data directory and count 'G' and 'C' then divide by the total number of bases.

```
In [40]: import pyspark
sc = pyspark.SparkContext(master="local[*]", appName="series")
sc.setLogLevel("ERROR")

genome = sc.textFile('data/genome.txt')

In [41]: lines = genome.flatMap(lambda line: line.split())
g = lines.map(lambda line: line.count("G")).sum()
c = lines.map(lambda line: line.count("C")).sum()
(g + c) / lines.map(lambda line: len(line)).sum()
```

Out[41]: 0.5048333333333334

12.11.7 Another example

Compute the most frequent sequence with 5 bases.

```
In [42]: def group_characters(line, n=5):
    result = ''
    i = 0
    for ch in line:
        result = result + ch
        i = i + 1
        if (i % n) == 0:
            yield result
            result = ''

    def group_and_split(line):
        return [sequence for sequence in group_characters(line)]

    sequences = genome.flatMap(group_and_split)
    sequences.take(3)

Out[42]: ['GATCA', 'ATGAG', 'GTGGA']

In [43]: counts = sequences.map(lambda w: (w, 1)).reduceByKey(lambda x, y: x + y).sortBy(lambda v: -v[1])
counts.take(10)
```

Out[43]: [('CTGTG', 59),
('CCCAG', 55),
('CCTGG', 52),
('AAAAA', 49),
('TGCTG', 42),
('TGTGT', 41),
('CCACC', 39),
('GGCTG', 38),
('CACCA', 37),
('GTGGG', 37)]

```
In [44]: sc.stop()
```


Chapter 13

Basic Commands in the Unix Shell

For windows 10 users, activate [bash](#).

Or install [Jupyter Lab](#)

```
conda install jupyterlab -c conda-forge
jupyter lab
```

13.1 Unix Shell

The shell is a command programming language that provides an interface to the UNIX operating system. Documentation of unix command is displayed by command `man`. Exemple:

```
man whoami
```

```
In [1]: ###bash
        #man whoami
```

13.2 Directories

The shell should start you in your home directory. This is your individual space on the UNIX system for your files. You can find out the name of your current working directory with the unix command `pwd`.

In the terminal, type the letters 'p', 'w', 'd', and then "enter" - always conclude each command by pressing the "enter" key. The response that follows on the next line will be the name of your home directory, where the name following the last slash should be your username.) The directory structure can be conceptualized as an inverted tree.

In the jupyter notebook, unix shell command can be executed using the escape character "!" or add `%%bash` to the cell first line. You can type command directly in a terminal without the "!".

```
In [2]: ###bash
        #pwd
```

Some unix command (not all) are also jupyter magic command like `%pwd`

```
In [3]: #%pwd
```

13.3 Home directory

No matter where in the directory structure you are, you can always get back to your home directory with `cd`.

13.3.1 Create a new subdirectory named "primer" :

```
mkdir primer
```

```
In [4]: #%%bash
        #rm -rf primer # remove primer directory if it exists
        #mkdir primer # make the new directory
```

Now change to the "primer" subdirectory, making it your current working directory:

```
cd primer
pwd
```

```
In [5]: #%%cd primer
```

```
In [6]: #%%pwd
```

13.4 Files

Create a file using `date` command and `whoami`:

```
date >> first.txt
whoami >> first.txt
```

`date` and `whoami` are not jupyter magic commands

```
In [7]: #%%bash
        #
        #date >> first.txt
        #whoami >> first.txt
```

13.4.1 List files and directories

Files live within directories. You can see a list of the files in your "primer" directory (which should be your current working directory) by typing:

```
ls
```

```
In [8]: #%%bash
        #ls
```

13.4.2 Display file content

You can view a text file with the following command:

```
cat first.txt
```

("cat" is short for concatenate - you can use this to display multiple files together on the screen.) If you have a file that is longer than your 24-line console window, use instead "more" to list one page at a time or "less" to scroll the file down and up with the arrow keys. Don't use these programs to try to display binary (non-text) files on your console - the attempt to print the non-printable control characters might alter your console settings and render the console unusable.

```
In [9]: #%%bash
        #cat first.txt
```

- Copy file "first" using the following command:

```
cp first.txt 2nd.txt
```


By doing this you have created a new file named "2nd.txt" which is a duplicate of file "first.txt". Get the file listing with:

```
ls
```

```
In [10]: ###bash
         #cp first.txt 2nd.txt
         #ls
```

- Now rename the file "2nd" to "second":

```
mv 2nd.txt second.txt
```

Listing the files still shows two files because you haven't created a new file, just changed an existing file's name:

```
ls
```

```
In [11]: ###bash
         #mv 2nd.txt second.txt
         #ls
```

If you "cat" the second file, you'll see the same sentence as in your first file:

```
cat second.txt
```

```
In [12]: ###bash
         #cat second.txt
```

"mv" will allow you to move files, not just rename them. Perform the following commands:

```
mkdir sub
mv second.txt sub
ls sub
ls
```

(where "username" will be your username and "group" will be your group name). Among other things, this lists the creation date and time, file access permissions, and file size in bytes. The letter 'd' (the first character on the line) indicates the directory names.

```
In [13]: ###bash
         #mkdir sub
         #mv second.txt sub
         #ls sub
```

This creates a new subdirectory named "sub", moves "second" into "sub", then lists the contents of both directories. You can list even more information about files by using the "-l" option with "ls":

```
In [14]: ###bash
         #ls -l
```

Next perform the following commands:

```
cd sub
pwd
ls -l
cd ..
pwd
```

```
In [15]: %%%bash
        ## go to sub directory
        #cd sub
        ## current working directory
        #pwd
        ## list files with permissions
        #ls -l
        ## go to parent directory
        #cd ..
        ## current working directory
        #pwd
```

Finally, clean up the duplicate files by removing the "second.txt" file and the "sub" subdirectory:

```
rm sub/second.txt
rmdir sub
ls -l
cd
```

This shows that you can refer to a file in a different directory using the relative path name to the file (you can also use the absolute path name to the file - something like "/Users/username/primer/sub/second.txt", depending on your home directory). You can also include the "." within the path name (for instance, you could have referred to the file as "../primer/sub/second.txt").

```
In [16]: %%%bash
        #rm -f sub/second.txt
        #rmdir sub
        #ls -l
        #cd ..
        #rm -rf primer
```

13.5 Connect to a server

Remote login to another machine can be accomplished using the "ssh" command:

```
ssh -l mylogin host
```

or

```
ssh mylogin@host
```

where "myname" will be your username on the remote system (possibly identical to your username on this system) and "host" is the name (or IP address) of the machine you are logging into.

Transfer files between machines using "scp". - To copy file "myfile" from the remote machine named "host":

```
scp myname@host:myfile .
```

- To copy file "myfile" from the local machine to the remote named "host":

```
scp myfile myname@host:
```

- Use `ssh -r` option to copy a directory (The "." refers to your current working directory, meaning that the destination for "myfile" is your current directory.)

13.5.1 Exercise

- Copy a file to the server `svmass2.mass.uhb.fr`
- Log on to this server and display this file with `cat`

13.6 Secure copy (scp)

Synchronize big-data directory on the cluster:

```
scp -r big-data svmass2:
```

This a secure copy of big-data directory to the server.

or

```
rsync -e ssh -avrz big-data svmass2:
```

It synchronizes the local directory big-data with the remote repository big-data on svmass2 server

13.7 Summary Of Basic Shell Commands

% pico myfile	# text edit file "myfile"
% ls	# list files in current directory
% ls -l	# long format listing
% touch myfile	# create new empty file "myfile"
% cat myfile	# view contents of text file "myfile"
% more myfile	# paged viewing of text file "myfile"
% less myfile	# scroll through text file "myfile"
% head myfile	# view 10 first lines of text file "myfile"
% tail myfile	# view 10 last lines of text file "myfile"
% cp srcfile destfile	# copy file "srcfile" to new file "destfile"
% mv oldname newname	# rename (or move) file "oldname" to "newname"
% rm myfile	# remove file "myfile"
% mkdir subdir	# make new directory "subdir"
% cd subdir	# change current working directory to "subdir"
% rmdir subdir	# remove (empty) directory "subdir"
% pwd	# display current working directory
% date	# display current date and time of day
% ssh -l myname host	# remote shell login of username "myname" to "host"
% scp myname@host:myfile .	# remote copy of file "myfile" to current directory
% scp myfile myname@host:	# copy of file "myfile" to remote server
% firefox &	# start Firefox web browser (in background)
% jobs	# display programs running in background
% kill %n	# kill job number n (use jobs to get this number)
% man -k "topic"	# search manual pages for "topic"
% man command	# display man page for "command"
% exit	# exit a terminal window
% logout	# logout of a console session

13.8 Redirecting

Redirection is usually implemented by placing characters <,>,> between commands.

- Use > to redirect output.

```
ls *.ipynb > file_list.txt
```

executes ls, placing the output in file_list.txt, as opposed to displaying it at the terminal, which is the usual destination for standard output. This will clobber any existing data in file1.

```
In [17]: #%%bash
         #ls *.ipynb > file_list.txt
```

- Use `<` to redirect input.

```
wc < file_list.txt
```

executes `wc`, with `file_list.txt` as the source of input, as opposed to the keyboard, which is the usual source for standard input.

13.8.1 Python example

```
In [18]: %%file test_stdin.py
        #!/usr/bin env python
        import sys

        # input comes from standard input
        k = 0
        for file in sys.stdin:
            k +=1
            print('file {} : {}'.format(k,file))
```

Overwriting `test_stdin.py`

```
In [19]: # %%bash
        # python test_stdin.py < file_list.txt
```

You can combine the two capabilities: read from an input file and write to an output file.

```
In [20]: # %%bash
        # python test_stdin.py < file_list.txt > output.txt
```

```
In [21]: # %%bash
        # cat output.txt
```

To append output to the end of the file, rather than clobbering it, the `>>` operator is used:

`date >> output.txt`

It will append the today date to the end of the file `output.txt`

```
In [22]: # %%bash
        # date >> output.txt
        # cat output.txt
```

13.9 Permissions

Every file on the system has associated with it a set of permissions. Permissions tell UNIX what can be done with that file and by whom. There are three things you can (or can't) do with a given file: - read, - write (modify), - execute.

Unix permissions specify what can 'owner', 'group' and 'all' can do.

If you try `ls -l` on the command prompt you get something like the following:

```
-rw-r--r--  1 navaro  staff   15799  5 oct 15:57 01.MapReduce.ipynb
-rw-r--r--  1 navaro  staff   18209 12 oct 16:04 02.Containers.ipynb
-rw-r--r--  1 navaro  staff   37963 12 oct 21:28 03.ParallelComputation.ipynb
```

Three bits specify access permissions: - **r** read, - **w** access, - **x** execute.

13.9.1 Example

```
rwxr-xr--
```

- the owner can do anything with the file,
- group owners and the can only read or execute it.
- rest of the world can only read

13.10 chmod

To set/modify a file's permissions you need to use the chmod program. Of course, only the owner of a file may use chmod to alter a file's permissions. chmod has the following syntax:

```
chmod [options] mode file(s)
```

- The 'mode' part specifies the new permissions for the file(s) that follow as arguments. A mode specifies which user's permissions should be changed, and afterwards which access types should be changed.
- We use + or - to change the mode for owner, group and the rest of the world.
- The permissions start with a letter specifying what users should be affected by the change.

Original permissions of script.py are `rw-----`

- `chmod u+x script.py` set permissions to `rwx-----`
- `chmod a+x script.py` set permissions to `rwx--x--x`
- `chmod g+r script.py` set permissions to `rwxr-x--x`
- `chmod o-x script.py` set permissions to `rwxr-x---`
- `chmod og+w script.py` set permissions to `rwrxwx-w-`

13.11 Pipelining

```
ls | grep ipynb
```

executes `ls`, using its output as the input for `grep`.

13.11.1 Exercice 11.1

- Pipe `cat *.ipynb` output to `sort` command.
- Pipe `ls` output to `wc` command.
- Pipe `cat 11.UnixCommands.ipynb` to `less` command.

13.12 Chained pipelines

The redirection and piping tokens can be chained together to create complex commands.

13.12.1 Exercice 11.2

Use unix commands chained to display word count of file `sample.txt`.

Hints:

- `fmt -n` takes text as input and reformats it into paragraphs with no line longer than `n`.
- `sort` sort the output alphabetically
- `tr -d str` delete the string `str` from the output
- `uniq -c` writes a copy of each unique input and precede each word with the count of the number of occurrences.

```
In [23]: from lorem import text
         with open('sample.txt', 'w') as f:
             f.write(text())
```

13.12.2 Exercise 11.3

- Create a python script `mapper.py` to count words from `stdin`. The script prints out every word found in `stdin` with the value 1 separate by a tab.

```
Consectetur 1
adipisci    1
quiquia 1
sit 1
```

File `mapper.py` must be executable.

```
In [24]: # %%bash
        # chmod +x mapper.py
```

13.12.3 Exercise 11.4

- Create a python script `reducer.py` to read output from `mapper.py`. The script prints out every word and number of occurrences.

```
cat sample.txt | ./mapper.py | ./reducer.py
```

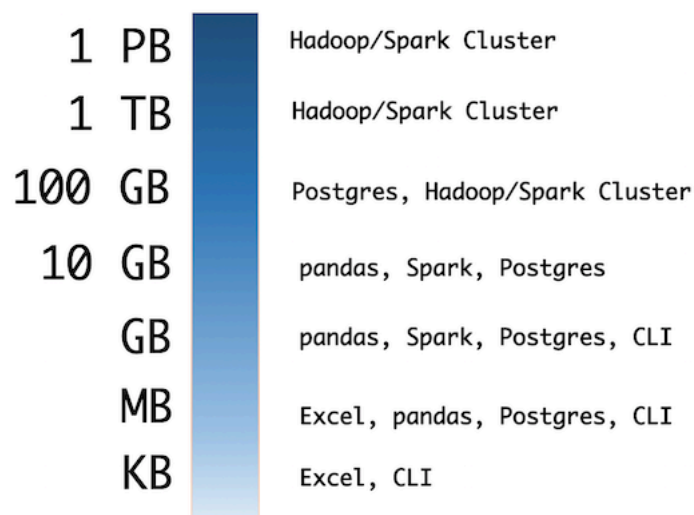
```
7  porro
7  eius
6  non
6  dolore
```

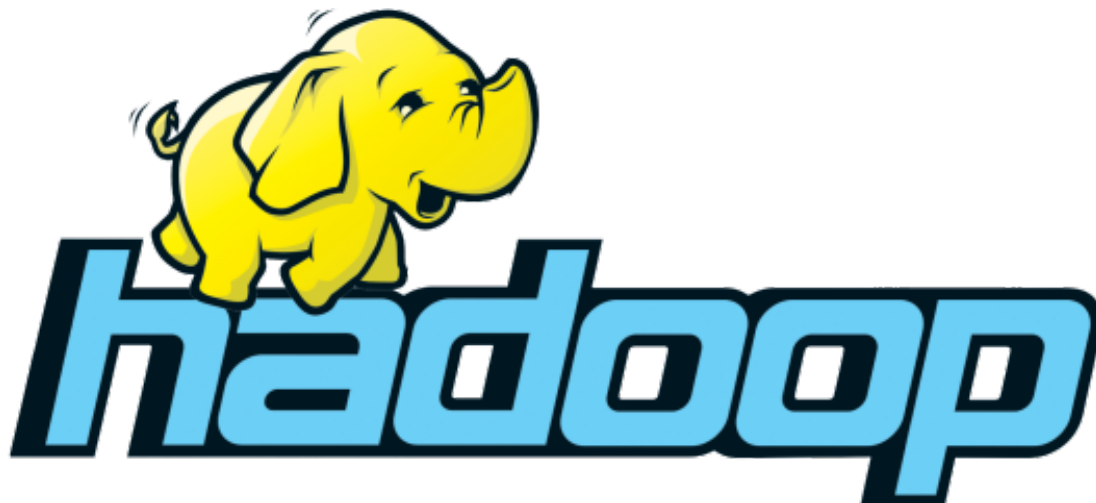
```
In [25]: # %%bash
        # chmod +x ./reducer.py
```

Chapter 14

Hadoop

- Data sets that are so large or complex that traditional data processing application software is inadequate to deal with them.
- Data analysis requires massively parallel software running on several servers.
- **Volume, Variety, Velocity, Variability and Veracity** describe Big Data properties.





- Framework for running applications on large cluster.
- The Hadoop framework transparently provides applications both reliability and data motion.
- Hadoop implements the computational paradigm named **Map/Reduce**, where the application is divided into many small fragments of work, each of which may be executed or re-executed on any node in the cluster.
- It provides a distributed file system (HDFS) that stores data on the compute nodes, providing very high aggregate bandwidth across the cluster.
- Both MapReduce and the **Hadoop Distributed File System** are designed so that node failures are automatically handled by the framework.

14.1 HDFS

- It is a distributed file systems.
- HDFS is highly fault-tolerant and is designed to be deployed on low-cost hardware.
- HDFS is suitable for applications that have large data sets.
- HDFS provides interfaces to move applications closer to where the data is located. The computation is much more efficient when the size of the data set is huge.
- HDFS consists of a single NameNode with a number of DataNodes which manage storage.
- HDFS exposes a file system namespace and allows user data to be stored in files.
 1. A file is split by the NameNode into blocks stored in DataNodes.
 2. The **NameNode** executes operations like opening, closing, and renaming files and directories.
 3. The **Secondary NameNode** stores information from **NameNode**.
 4. The **DataNodes** manage perform block creation, deletion, and replication upon instruction from the NameNode.
 5. The placement of replicas is optimized for data reliability, availability, and network bandwidth utilization.
 6. User data never flows through the NameNode.
- Files in HDFS are write-once and have strictly one writer at any time.
- The DataNode has no knowledge about HDFS files.

14.2 Accessibility

All **HDFS commands** are invoked by the bin/hdfs Java script:

```
hdfs [SHELL_OPTIONS] COMMAND [GENERIC_OPTIONS] [COMMAND_OPTIONS]
```


14.3 Manage files and directories

```
hdfs dfs -ls -h -R # Recursively list subdirectories with human-readable file sizes.
hdfs dfs -cp # Copy files from source to destination
hdfs dfs -mv # Move files from source to destination
hdfs dfs -mkdir /foodir # Create a directory named /foodir
hdfs dfs -rmdir /foodir # Remove a directory named /foodir
hdfs dfs -cat /foodir/myfile.txt #View the contents of a file named /foodir/myfile.txt
```

14.4 Transfer between nodes

14.4.1 put

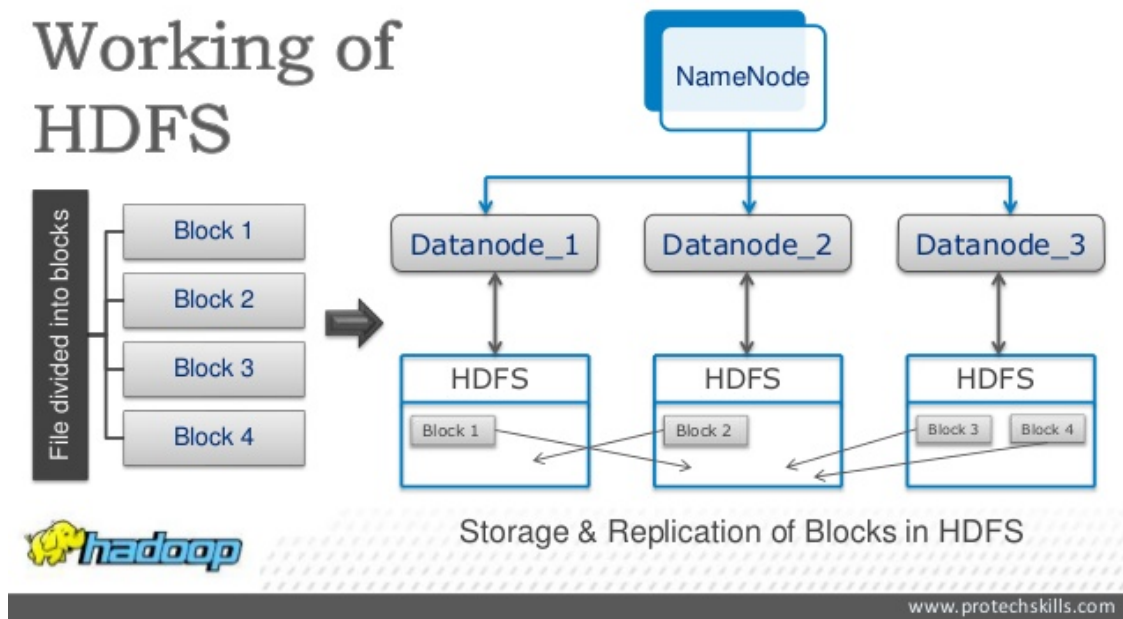
```
hdfs fs -put [-f] [-p] [-l] [-d] [ - | <localsrc> .. ]. <dst>
```

Copy single src, or multiple srcs from local file system to the destination file system.
Options:

-p : Preserves rights and modification times.
-f : Overwrites the destination if it already exists.

```
hdfs fs -put localfile /user/hadoop/hadoopfile
hdfs fs -put -f localfile1 localfile2 /user/hadoop/hadoopdir
```

Similar to the fs -put command - moveFromLocal : to delete the source localsrc after copy. - copyFromLocal : source is restricted to a local file - copyToLocal : destination is restricted to a local file



The Name Node is not in the data path. The Name Node only provides the map of where data is and where data should go in the cluster (file system metadata).

14.5 Hadoop cluster

- 8 computers: sve1 -> sve9

14.5.1 NameNode Web Interface (HDFS layer)

<http://svmass2.mass.uhb.fr:50070>

The name node web UI shows you a cluster summary including information about total/remaining capacity, live and dead nodes. Additionally, it allows you to browse the HDFS namespace and view the contents of its files in the web browser. It also gives access to the local machine's Hadoop log files.

14.5.2 Secondary Namenode Information.

<http://svmass2.mass.uhb.fr:50090/>

14.5.3 Datanode Information.

- <http://svpe1.mass.uhb.fr:50075/>
- <http://svpe2.mass.uhb.fr:50075/>
- ...
- <http://svpe8.mass.uhb.fr:50075/>
- <http://svpe9.mass.uhb.fr:50075/>

To do following hands on you can switch to [JupyterLab](#).

Just go to this following address <http://localhost:9000/lab>

- Check that your HDFS home directory required to execute MapReduce jobs exists:

```
hdfs dfs -ls /user/${USER}
```

- Type the following commands:

```
hdfs dfs -ls
hdfs dfs -ls /
hdfs dfs -mkdir test
```

- Create a local file user.txt containing your name and the date:

```
In [1]: # %%bash
        # echo "FirstName LastName" > user.txt
        # echo `date` >> user.txt
        # cat user.txt
```

Copy it on HDFS :

```
hdfs dfs -put user.txt
```

Check with:

```
hdfs dfs -ls -R
hdfs dfs -cat user.txt
hdfs dfs -tail user.txt
```

```
In [2]: # %%bash
        # hdfs dfs -put user.txt
        # hdfs dfs -ls -R /user/navaro_p/
```

```
In [3]: # %%bash
        # hdfs dfs -cat user.txt
```

Remove the file:

```
hdfs dfs -rm user.txt
```

Put it again on HDFS and move to books directory:

```
hdfs dfs -copyFromLocal user.txt
hdfs dfs -mv user.txt books/user.txt
hdfs dfs -ls -R -h
```

Copy user.txt to hello.txt and remove it.

```
hdfs dfs -cp books/user.txt books/hello.txt
hdfs dfs -count -h /user/$USER
hdfs dfs -rm books/user.txt
```

14.6 Hands-on practice:

1. Create a directory `files` in HDFS.
2. List the contents of a directory `/`.
3. Upload the file `today.txt` in HDFS.

```
date > today.txt
whoami >> today.txt
```

4. Display contents of file `today.txt`
5. Copy `today.txt` file from source to `files` directory.
6. Copy file `jps.txt` from/To Local file system to HDFS


```
jps > jps.txt
```
7. Move file `jps.txt` from source to `files`.
8. Remove file `today.txt` from home directory in HDFS.
9. Display last few lines of `jps.txt`.
10. Display the help of `du` command and show the total amount of space in a human-readable fashion used by your home hdfs directory.
11. Display the help of `df` command and show the total amount of space available in the filesystem in a human-readable fashion.
12. With `chmod` change the rights of `today.txt` file. I has to be readable and writeable only by you.

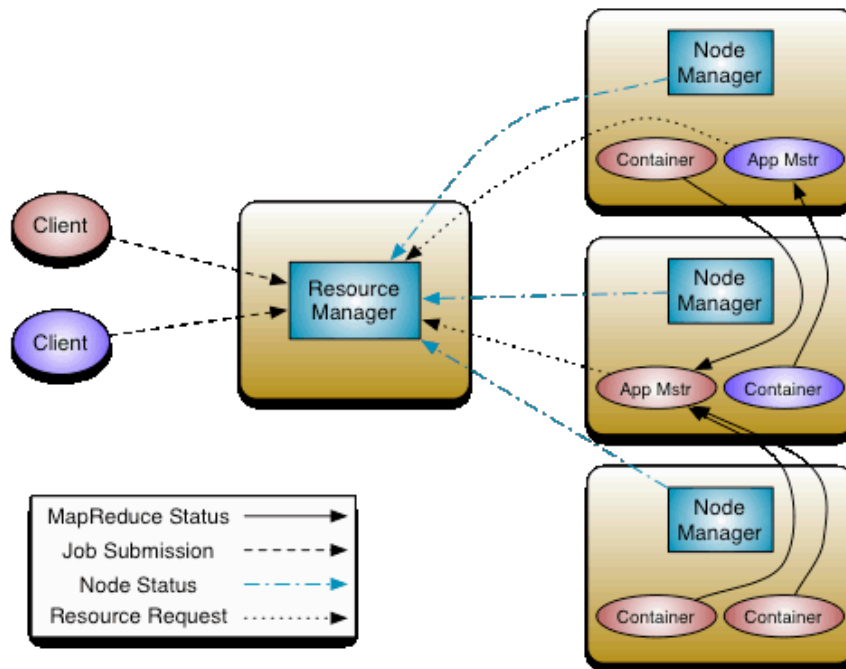
14.7 YARN

YARN takes care of resource management and job scheduling/monitoring.

- The **ResourceManager** is the ultimate authority that arbitrates resources among all the applications in the system. It has two components: **Scheduler** and **ApplicationsManager**.
- The **NodeManager** is the per-machine framework agent who is responsible for **Containers**, monitoring their resource usage (cpu, memory, disk, network) and reporting the same to the **ResourceManager/Scheduler**.

The per-application **ApplicationMaster** negotiates resources from the **ResourceManager** and working with the **NodeManager(s)** to execute and monitor the tasks.

- The **Scheduler** is responsible for allocating resources to the applications.
- The **ApplicationsManager** is responsible for accepting job-submissions, tracking their status and monitoring for progress.



Source: http://hadoop.apache.org/docs/stable/hadoop-yarn/hadoop-yarn-site/yarn_architecture.gif

14.7.1 Yarn Web Interface

The JobTracker web UI provides information about general job statistics of the Hadoop cluster, running/completed/failed jobs and a job history log file. It also gives access to the “local machine’s” Hadoop log files (the machine on which the web UI is running on).

- All Applications <http://svmass2.mass.uhb.fr:8088>

14.8 WordCount Example

The [Wordcount example](#) is implemented in Java and it is the example of [Hadoop MapReduce Tutorial](#)

Let's create some files with lorem python package

```
In [4]: from lorem import text

        for i in range(1,10):
            with open('sample{0:02d}.txt'.format(i), 'w') as f:
                f.write(text())
```

- Make input directory in your HDFS home directory required to execute MapReduce jobs:

```
hdfs dfs -mkdir -p /user/${USER}/input
```

-p flag force the directory creation even if it already exists.

14.8.1 Exercise

- Copy all necessary files in HDFS system.
- Run the Java example using the command

```
hadoop jar /export/hadoop-2.7.6/share/hadoop/mapreduce/hadoop-mapreduce-examples-2.7.6.jar wordcount /u
```

- Remove the output directory and try to use yarn

```
yarn jar /export/hadoop-2.7.6/share/hadoop/mapreduce/hadoop-mapreduce-examples-2.7.6.jar wordcount /use
```

- Connect to the [Yarn web user interface](#) and read the logs carefully.

14.9 Deploying the MapReduce Python code on Hadoop

This Python must use the [Hadoop Streaming API](#) to pass data between our Map and Reduce code via Python's sys.stdin (standard input) and sys.stdout (standard output).

14.10 Map

The following Python code read data from sys.stdin, split it into words and output a list of lines mapping words to their (intermediate) counts to sys.stdout. For every word it outputs 1 tuples immediately.

In [5]: %%file mapper.py

```
from __future__ import print_function # for python2 compatibility
import sys, string
translator = str.maketrans('', '', string.punctuation)
# input comes from standard input
for line in sys.stdin:
    line = line.strip().lower() # remove leading and trailing whitespace
    line = line.translate(translator) # strip punctuation
    for word in line.split(): # split the line into words
        # write the results to 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 (f'{word}\t 1')
```

Overwriting mapper.py

```
In [6]: import sys
        with open("mapper.py", "r+") as f:
            s = f.read()
            f.seek(0)
            f.write("#!" + sys.executable + "\n" + s)
```

The python script must be executable:

```
chmod +x mapper.py
```

Try to run in a terminal with:

```
cat sample01.txt | ./mapper.py | sort
```

or

```
./mapper.py < sample01.txt | sort
```

```
In [7]: # %%bash
        # chmod +x mapper.py
        # cat sample01.txt | ./mapper.py | sort
```

14.11 Reduce

The following code reads the results of mapper.py and sum the occurrences of each word to a final count, and then output its results to sys.stdout. Remember that Hadoop sorts map output so it is easier to count words.

```
In [8]: %%file reducer.py
        from __future__ import print_function
        from operator import itemgetter
        import sys

        current_word = None
        current_count = 0
        word = None

        for line in sys.stdin:

            # 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 sys.stdout
                    print (f'{current_count}\t{current_word}')
                current_count = count
                current_word = word

            # do not forget to output the last word if needed!
            if current_word == word:
                print (f'{current_count}\t{current_word}')
```

Overwriting reducer.py

```
In [9]: import sys
        with open("reducer.py", "r+") as f:
            s = f.read()
            f.seek(0)
            f.write("#!" + sys.executable + "\n" + s)
```

As mapper the python script must be executable:

```
chmod +x reducer.py
```

Try to run in a terminal with:

```
cat sample.txt | ./mapper.py | sort | ./reducer.py | sort
```

or

```
./mapper.py < sample01.txt | sort | ./reducer.py | sort
```

```
In [10]: # %%bash
# chmod +x reducer.py
# ./mapper.py < sample01.txt | sort | ./reducer.py | sort
```

14.12 Execution on Hadoop cluster

- Copy all files to HDFS cluster
- Run the WordCount MapReduce

```
In [11]: %%file Makefile

HADOOP_VERSION=2.7.6
HADOOP_HOME=/export/hadoop-${HADOOP_VERSION}
HADOOP_TOOLS=${HADOOP_HOME}/share/hadoop/tools/lib
HDFS_DIR=/user/${USER}

SAMPLES = sample01.txt sample02.txt sample03.txt sample04.txt

copy_to_hdfs: ${SAMPLES}
    hdfs dfs -mkdir -p ${HDFS_DIR}/input
    hdfs dfs -put $^ ${HDFS_DIR}/input

run_with_hadoop:
    hadoop jar ${HADOOP_TOOLS}/hadoop-streaming-${HADOOP_VERSION}.jar \
    -file ${PWD}/mapper.py -mapper ${PWD}/mapper.py \
    -file ${PWD}/reducer.py -reducer ${PWD}/reducer.py \
    -input ${HDFS_DIR}/input/*.txt -output ${HDFS_DIR}/output-hadoop

run_with_yarn:
    yarn jar ${HADOOP_TOOLS}/hadoop-streaming-${HADOOP_VERSION}.jar \
    -file ${PWD}/mapper.py -mapper ${PWD}/mapper.py \
    -file ${PWD}/reducer.py -reducer ${PWD}/reducer.py \
    -input ${HDFS_DIR}/input/*.txt -output ${HDFS_DIR}/output-yarn
```

Overwriting Makefile

```
In [12]: # %%bash
# hdfs dfs -rm -r input
# make copy_to_hdfs
# hdfs dfs -ls input

In [13]: # %%bash
# hdfs dfs -rm -r -f output-hadoop
# make run_with_hadoop
# hdfs dfs -cat output-hadoop/*
```


Chapter 15

Hadoop File Formats

Format Wars: From VHS and Beta to Avro and Parquet

15.1 Feather

For light data, it is recommended to use [Feather](#). It is a fast, interoperable data frame storage that comes with bindings for python and R.

Feather uses also the Apache Arrow columnar memory specification to represent binary data on disk. This makes read and write operations very fast.

```
In [1]: import feather
import pandas as pd
import numpy as np
arr = np.random.randn(10000) # 10% nulls
arr[:10] = np.nan
df = pd.DataFrame({'column_{0}'.format(i): arr for i in range(10)})
feather.write_dataframe(df, 'test.feather')
```

```
In [2]: df = pd.read_feather("test.feather")
```

```
df.head()
```

```
Out[2]:
```

	column_0	column_1	column_2	column_3	column_4	column_5	column_6	\
0	NaN	NaN	NaN	NaN	NaN	NaN	NaN	
1	-1.686427	-1.686427	-1.686427	-1.686427	-1.686427	-1.686427	-1.686427	
2	-0.206827	-0.206827	-0.206827	-0.206827	-0.206827	-0.206827	-0.206827	
3	-0.335105	-0.335105	-0.335105	-0.335105	-0.335105	-0.335105	-0.335105	
4	-0.522270	-0.522270	-0.522270	-0.522270	-0.522270	-0.522270	-0.522270	

	column_7	column_8	column_9
0	NaN	NaN	NaN
1	-1.686427	-1.686427	-1.686427
2	-0.206827	-0.206827	-0.206827
3	-0.335105	-0.335105	-0.335105
4	-0.522270	-0.522270	-0.522270

15.2 Parquet file format

[Parquet format](#) is a common binary data store, used particularly in the Hadoop/big-data sphere. It provides several advantages relevant to big-data processing:

- columnar storage, only read the data of interest
- efficient binary packing
- choice of compression algorithms and encoding
- split data into files, allowing for parallel processing
- range of logical types
- statistics stored in metadata allow for skipping unneeded chunks
- data partitioning using the directory structure

15.3 Apache Arrow

[Arrow](#) is a columnar in-memory analytics layer designed to accelerate big data. It houses a set of canonical in-memory representations of flat and hierarchical data along with multiple language-bindings for structure manipulation.

<https://arrow.apache.org/docs/python/parquet.html>

The Apache Parquet project provides a standardized open-source columnar storage format for use in data analysis systems. It was created originally for use in Apache Hadoop with systems like Apache Drill, Apache Hive, Apache Impala, and Apache Spark adopting it as a shared standard for high performance data IO.

Apache Arrow is an ideal in-memory transport layer for data that is being read or written with Parquet files. [PyArrow](#) includes Python bindings to read and write Parquet files with pandas.

Example:

```
import pyarrow as pa

hdfs = pa.hdfs.connect('svmass2.mass.uhb.fr', 54311, 'navaro_p')

In [3]: import pyarrow.parquet as pq
import numpy as np
import pandas as pd
import pyarrow as pa

In [4]: df = pd.DataFrame({'one': [-1, np.nan, 2.5],
                           'two': ['foo', 'bar', 'baz'],
                           'three': [True, False, True]},
                           index=list('abc'))
table = pa.Table.from_pandas(df)

In [5]: pq.write_table(table, 'example.parquet')

In [6]: table2 = pq.read_table('example.parquet')

In [7]: table2.to_pandas()

Out[7]:
   one  two  three
a -1.0  foo   True
b  NaN  bar  False
c  2.5  baz   True

In [8]: pq.read_table('example.parquet', columns=['one', 'three'])

Out[8]: pyarrow.Table
  one: double
  three: bool

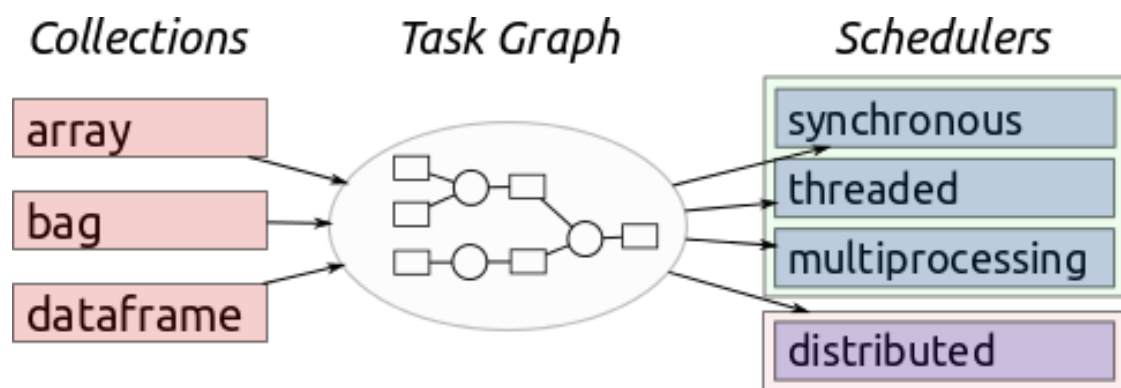
In [9]: pq.read_pandas('example.parquet', columns=['two']).to_pandas()

Out[9]:
   two
a  foo
b  bar
c  baz
```

Chapter 16

Dask Dataframes

Dask is a flexible parallel computing library for analytic computing written in Python. Dask is similar to Spark, by lazily constructing directed acyclic graph (DAG) of tasks and splitting large datasets into small portions called partitions. See the below image from [Dask's web page](#) for illustration.



It has three main interfaces:

- [Array](#), which works like [NumPy](#) arrays;
- [Bag](#), which is similar to RDD interface in Spark;
- [DataFrame](#), which works like [Pandas](#) DataFrame.

While it can work on a [distributed cluster](#), Dask works also very well on a single cpu machine.

16.1 DataFrames

Dask dataframes look and feel (mostly) like Pandas dataframes but they run on the same infrastructure that powers `dask.delayed`.

The `dask.dataframe` module implements a blocked parallel `DataFrame` object that mimics a large subset of the Pandas `DataFrame`. One dask `DataFrame` is comprised of many in-memory pandas `DataFrames` separated along the index. One operation on a dask `DataFrame` triggers many pandas operations on the constituent pandas `DataFrames` in a way that is mindful of potential parallelism and memory constraints.

Related Documentation

- [Dask DataFrame documentation](#)
- [Pandas documentation](#)

In this notebook, we will extract some historical flight data for flights out of NYC between 1990 and 2000. The data is taken from [here](#). This should only take a few seconds to run.

We will use `dask.dataframe` construct our computations for us. The `dask.dataframe.read_csv` function can take a globstring like `"data/nycflights/*.csv"` and build parallel computations on all of our data at once.

16.1.1 Prep the Data

```
In [1]: import os
import pandas as pd
pd.set_option("max.rows", 10)
os.getcwd()

Out[1]: '/home/runner/work/big-data/big-data/notebooks'
```

```
In [2]: import os # library to get directory and file paths
import tarfile # this module makes possible to read and write tar archives

def extract_flight():
    here = os.getcwd()
    flightdir = os.path.join(here, 'data', 'nycflights')
    if not os.path.exists(flightdir):
        print("Extracting flight data")
        tar_path = os.path.join('data', 'nycflights.tar.gz')
        with tarfile.open(tar_path, mode='r:gz') as flights:
            flights.extractall('data/')

extract_flight() # this function call will extract 10 csv files in data/nycflights
```

Extracting flight data

16.1.2 Load Data from CSVs in Dask Dataframes

```
In [3]: import os
here = os.getcwd()
filename = os.path.join(here, 'data', 'nycflights', '*.csv')
filename

Out[3]: '/home/runner/work/big-data/big-data/notebooks/data/nycflights/*.csv'
```

```
In [4]: import dask
import dask.dataframe as dd

df = dd.read_csv(filename,
                  parse_dates={'Date': [0, 1, 2]})
```

Let's take a look to the dataframe

```
In [5]: df
```

Out[5]: Dask DataFrame Structure:

	Date	DayOfWeek	DepTime	CRSDepTime	ArrTime	CRSArrTime	UniqueCarrier	
npartitions=10								
	datetime64[ns]	int64	float64	int64	float64	int64	object	
...
...
...
Dask Name:	read-csv,	10 tasks						

```
In [6]: ### Get the first 5 rows
df.head()
```

```
Out[6]:
```

	Date	DayOfWeek	DepTime	CRSDepTime	ArrTime	CRSArrTime	\
0	1990-01-01	1	1621.0	1540	1747.0	1701	
1	1990-01-02	2	1547.0	1540	1700.0	1701	
2	1990-01-03	3	1546.0	1540	1710.0	1701	
3	1990-01-04	4	1542.0	1540	1710.0	1701	
4	1990-01-05	5	1549.0	1540	1706.0	1701	

	UniqueCarrier	FlightNum	TailNum	ActualElapsedTime	...	AirTime	\
0	US	33	NaN	86.0	...	NaN	
1	US	33	NaN	73.0	...	NaN	
2	US	33	NaN	84.0	...	NaN	
3	US	33	NaN	88.0	...	NaN	
4	US	33	NaN	77.0	...	NaN	

	ArrDelay	DepDelay	Origin	Dest	Distance	TaxiIn	TaxiOut	Cancelled	\
0	46.0	41.0	EWR	PIT	319.0	NaN	NaN	0	
1	-1.0	7.0	EWR	PIT	319.0	NaN	NaN	0	
2	9.0	6.0	EWR	PIT	319.0	NaN	NaN	0	
3	9.0	2.0	EWR	PIT	319.0	NaN	NaN	0	
4	5.0	9.0	EWR	PIT	319.0	NaN	NaN	0	

	Diverted
0	0
1	0
2	0
3	0
4	0

[5 rows x 21 columns]

```
In [7]: import traceback # we use traceback because we except an error.
```

```
try:
    df.tail() # Get the last 5 rows
except Exception:
    traceback.print_exc()
```

Traceback (most recent call last):

```
File "<ipython-input-7-7cb27b738c02>", line 4, in <module>
    df.tail() # Get the last 5 rows
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dataframe/core.py", line 1
    result = result.compute()
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py", line 167, in comp
    (result,) = compute(self, traverse=False, **kwargs)
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py", line 447, in comp
    results = schedule(dsk, keys, **kwargs)
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/threaded.py", line 76, in g
    results = get_async(
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/local.py", line 486, in ge
    raise_exception(exc, tb)
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/local.py", line 316, in re
    raise exc
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/local.py", line 222, in ex
```

```

    result = _execute_task(task, data)
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/core.py", line 121, in _execute_task
    return func(*(_execute_task(a, cache) for a in args))
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/core.py", line 121, in <genexpr>
    return func(*(_execute_task(a, cache) for a in args))
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/core.py", line 121, in _execute_task
    return func(*(_execute_task(a, cache) for a in args))
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dataframe/io/csv.py", line 121, in _read_csv
    coerce_dtypes(df, dtypes)
File "/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dataframe/io/csv.py", line 121, in _read_csv
    raise ValueError(msg)
ValueError: Mismatched dtypes found in `pd.read_csv`/`pd.read_table`.

```

```

+-----+-----+-----+
| Column      | Found   | Expected |
+-----+-----+-----+
| CRSElapsedTime | float64 | int64    |
| TailNum       | object  | float64  |
+-----+-----+-----+

```

The following columns also raised exceptions on conversion:

```

- TailNum
  ValueError("could not convert string to float: 'N54711'")

```

Usually this is due to dask's dtype inference failing, and *may* be fixed by specifying dtypes manually by adding:

```

dtype={'CRSElapsedTime': 'float64',
       'TailNum': 'object'}

```

to the call to `read_csv`/`read_table`.

16.1.3 What just happened?

Unlike `pandas.read_csv` which reads in the entire file before inferring datatypes, `dask.dataframe.read_csv` only reads in a sample from the beginning of the file (or first file if using a glob). These inferred datatypes are then enforced when reading all partitions.

In this case, the datatypes inferred in the sample are incorrect. The first `n` rows have no value for `CRSElapsedTime` (which pandas infers as a `float`), and later on turn out to be strings (`object` dtype). When this happens you have a few options:

- Specify dtypes directly using the `dtype` keyword. This is the recommended solution, as it's the least error prone (better to be explicit than implicit) and also the most performant.
- Increase the size of the `sample` keyword (in bytes)
- Use `assume_missing` to make dask assume that columns inferred to be `int` (which don't allow missing values) are actually floats (which do allow missing values). In our particular case this doesn't apply.

In our case we'll use the first option and directly specify the `dtypes` of the offending columns.

```
In [8]: df.dtypes
```

```
Out[8]: Date          datetime64[ns]
        DayOfWeek      int64
```

```

DepTime          float64
CRSDepTime       int64
ArrTime          float64
...
Distance         float64
TaxiIn           float64
TaxiOut          float64
Cancelled        int64
Diverted         int64
Length: 21, dtype: object

```

```

In [9]: df = dd.read_csv(filename,
                        parse_dates={'Date': [0, 1, 2]},
                        dtype={'TailNum': object,
                              'CRSElapsedTime': float,
                              'Cancelled': bool})

```

```

In [10]: df.tail()

```

```

Out[10]:
      Date DayOfWeek DepTime  CRSDepTime  ArrTime  CRSArrTime  \
269176 1999-12-27         1  1645.0         1645   1830.0       1901
269177 1999-12-28         2  1726.0         1645   1928.0       1901
269178 1999-12-29         3  1646.0         1645   1846.0       1901
269179 1999-12-30         4  1651.0         1645   1908.0       1901
269180 1999-12-31         5  1642.0         1645   1851.0       1901

      UniqueCarrier  FlightNum TailNum  ActualElapsedTime  ...  AirTime  \
269176            UA        1753  N516UA                225.0  ...    205.0
269177            UA        1753  N504UA                242.0  ...    214.0
269178            UA        1753  N592UA                240.0  ...    220.0
269179            UA        1753  N575UA                257.0  ...    233.0
269180            UA        1753  N539UA                249.0  ...    232.0

      ArrDelay  DepDelay  Origin Dest Distance  TaxiIn  TaxiOut  Cancelled  \
269176    -31.0        0.0    LGA  DEN   1619.0     7.0    13.0      False
269177     27.0       41.0    LGA  DEN   1619.0     5.0    23.0      False
269178    -15.0        1.0    LGA  DEN   1619.0     5.0    15.0      False
269179     7.0         6.0    LGA  DEN   1619.0     5.0    19.0      False
269180    -10.0       -3.0    LGA  DEN   1619.0     6.0    11.0      False

      Diverted
269176        0
269177        0
269178        0
269179        0
269180        0

```

```

[5 rows x 21 columns]

```

Let's take a look at one more example to fix ideas.

```

In [11]: len(df)

```

```

Out[11]: 2611892

```

16.1.4 Why df is ten times longer ?

- Dask investigated the input path and found that there are ten matching files.
- A set of jobs was intelligently created for each chunk - one per original CSV file in this case.
- Each file was loaded into a pandas dataframe, had `len()` applied to it.
- The subtotals were combined to give you the final grant total.

16.2 Computations with `dask.dataframe`

We compute the maximum of the `DepDelay` column. With `dask.delayed` we could create this computation as follows:

```
maxes = []
for fn in filenames:
    df = dask.delayed(pd.read_csv)(fn)
    maxes.append(df.DepDelay.max())

final_max = dask.delayed(max)(maxes)
final_max.compute()
```

Now we just use the normal Pandas syntax as follows:

```
In [12]: %time df.DepDelay.max().compute()
```

```
CPU times: user 4.4 s, sys: 411 ms, total: 4.81 s
```

```
Wall time: 3.24 s
```

```
Out[12]: 1435.0
```

This writes the delayed computation for us and then runs it. Recall that the delayed computation is a dask graph made of up of key-value pairs.

Some things to note:

1. As with `dask.delayed`, we need to call `.compute()` when we're done. Up until this point everything is lazy.
2. Dask will delete intermediate results (like the full pandas dataframe for each file) as soon as possible.
 - This lets us handle datasets that are larger than memory
 - This means that repeated computations will have to load all of the data in each time (run the code above again, is it faster or slower than you would expect?)

As with `Delayed` objects, you can view the underlying task graph using the `.visualize` method:

```
In [13]: df.DepDelay.max().visualize()
```

```
-----
FileNotFoundError                                Traceback (most recent call last)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
165     try:
--> 166         proc = subprocess.Popen(cmd, startupinfo=get_startupinfo(), **kwargs)
167     except OSError as e:
```



```

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in __init__(self, args, bufsize
853
--> 854         self._execute_child(args, executable, preexec_fn, close_fds,
855                             pass_fds, cwd, env,

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in _execute_child(self, args, e
1701         err_msg = os.strerror(errno_num)
-> 1702         raise child_exception_type(errno_num, err_msg, err_filename)
1703         raise child_exception_type(err_msg)

```

FileNotFoundError: [Errno 2] No such file or directory: 'dot'

During handling of the above exception, another exception occurred:

```

ExecutableNotFound                                Traceback (most recent call last)

<ipython-input-13-5a7336c66be3> in <module>
----> 1 df.DepDelay.max().visualize()

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(self,
91         https://docs.dask.org/en/latest/optimize.html
92         """
--> 93         return visualize(
94             self,
95             filename=filename,

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(*args
551         raise NotImplementedError("Unknown value color=%s" % color)
552
--> 553         return dot_graph(dsk, filename=filename, **kwargs)
554
555

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in dot_graph(dsk, f
270         """
271         g = to_graphviz(dsk, **kwargs)
--> 272         return graphviz_to_file(g, filename, format)
273
274

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in graphviz_to_file
282         format = "png"
283
--> 284         data = g.pipe(format=format)
285         if not data:
286             raise RuntimeError(

```

```

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/files.py in pipe(self,
134         data = text_type(self.source).encode(self._encoding)
135
--> 136         out = backend.pipe(self._engine, format, data,
137                             renderer=renderer, formatter=formatter,
138                             quiet=quiet)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in pipe(engine,
244     """
245     cmd, _ = command(engine, format, None, renderer, formatter)
--> 246     out, _ = run(cmd, input=data, capture_output=True, check=True, quiet=quiet)
247     return out
248

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
167     except OSError as e:
168         if e.errno == errno.ENOENT:
--> 169             raise ExecutableNotFound(cmd)
170         else:
171             raise

```

ExecutableNotFound: failed to execute ['dot', '-Tpng'], make sure the Graphviz executables are on your system's PATH

If you are already familiar with the Pandas API then know how to use `dask.dataframe`. There are a couple of small changes.

As noted above, computations on `dask.DataFrame` objects don't perform work, instead they build up a dask graph. We can evaluate this dask graph at any time using the `.compute()` method.

```

In [14]: result = df.DepDelay.mean() # create the tasks graph

In [15]: %time result.compute()      # perform actual computation

CPU times: user 4.5 s, sys: 442 ms, total: 4.94 s
Wall time: 3.33 s

```

```
Out[15]: 9.206602541321965
```

16.3 Store Data in Apache Parquet Format

Dask encourage dataframe users to store and load data using Parquet instead. [Apache Parquet](#) is a columnar binary format that is easy to split into multiple files (easier for parallel loading) and is generally much simpler to deal with than HDF5 (from the Dask library's perspective). It is also a common format used by other big data systems like [Apache Spark](#) and [Apache Impala](#) and so is useful to interchange with other systems.

```

In [16]: df.drop("TailNum", axis=1).to_parquet("nycflights/") # save csv files using parquet format

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/pyarrow/compat.py:24: FutureWarning: py
warnings.warn("pyarrow.compat has been deprecated and will be removed in a "

```

It is possible to specify dtypes and compression when converting. This can definitely help give you significantly greater speedups, but just using the default settings will still be a large improvement.

```
In [17]: df.size.compute()
```

```
Out[17]: 54849732
```

```
In [18]: import dask.dataframe as dd
df = dd.read_parquet("nycflights/")
df.head()
```

```
Out[18]:
```

	Date	DayOfWeek	DepTime	CRSDepTime	ArrTime	CRSArrTime	\
0	1990-01-01	1	1621.0	1540	1747.0	1701	
1	1990-01-02	2	1547.0	1540	1700.0	1701	
2	1990-01-03	3	1546.0	1540	1710.0	1701	
3	1990-01-04	4	1542.0	1540	1710.0	1701	
4	1990-01-05	5	1549.0	1540	1706.0	1701	

	UniqueCarrier	FlightNum	ActualElapsedTime	CRSElapsedTime	AirTime	\
0	US	33	86.0	81.0	NaN	
1	US	33	73.0	81.0	NaN	
2	US	33	84.0	81.0	NaN	
3	US	33	88.0	81.0	NaN	
4	US	33	77.0	81.0	NaN	

	ArrDelay	DepDelay	Origin	Dest	Distance	TaxiIn	TaxiOut	Cancelled	\
0	46.0	41.0	EWB	PIT	319.0	NaN	NaN	False	
1	-1.0	7.0	EWB	PIT	319.0	NaN	NaN	False	
2	9.0	6.0	EWB	PIT	319.0	NaN	NaN	False	
3	9.0	2.0	EWB	PIT	319.0	NaN	NaN	False	
4	5.0	9.0	EWB	PIT	319.0	NaN	NaN	False	

	Diverted
0	0
1	0
2	0
3	0
4	0

```
In [19]: result = df.DepDelay.mean()
```

```
In [20]: %time result.compute()
```

```
CPU times: user 142 ms, sys: 17 ms, total: 159 ms
Wall time: 104 ms
```

```
Out[20]: 9.206602541321965
```

The computation is much faster because pulling out the DepDelay column is easy for Parquet.

16.3.1 Parquet advantages:

- Binary representation of data, allowing for speedy conversion of bytes-on-disk to bytes-in-memory
- Columnar storage, meaning that you can load in as few columns as you need without loading the entire dataset
- Row-chunked storage so that you can pull out data from a particular range without touching the others
- Per-chunk statistics so that you can find subsets quickly
- Compression

16.3.2 Exercise 15.1

If you don't remember how to use pandas. Please read [pandas documentation](#).

- Use the `head()` method to get the first ten rows
- How many rows are in our dataset?
- Use selections `df[...]` to find how many positive (late) and negative (early) departure times there are
- In total, how many non-cancelled flights were taken? (To invert a boolean pandas Series `s`, use `~s`).

In [21]: `df.head(10)`

```
Out[21]:
```

	Date	DayOfWeek	DepTime	CRSDepTime	ArrTime	CRSArrTime	\
0	1990-01-01	1	1621.0	1540	1747.0	1701	
1	1990-01-02	2	1547.0	1540	1700.0	1701	
2	1990-01-03	3	1546.0	1540	1710.0	1701	
3	1990-01-04	4	1542.0	1540	1710.0	1701	
4	1990-01-05	5	1549.0	1540	1706.0	1701	
5	1990-01-06	6	1539.0	1540	1653.0	1701	
6	1990-01-07	7	1553.0	1540	1713.0	1701	
7	1990-01-08	1	1543.0	1540	1656.0	1701	
8	1990-01-09	2	1540.0	1540	1704.0	1701	
9	1990-01-10	3	1608.0	1540	1740.0	1701	

	UniqueCarrier	FlightNum	ActualElapsedTime	CRSElapsedTime	AirTime	\
0	US	33	86.0	81.0	NaN	
1	US	33	73.0	81.0	NaN	
2	US	33	84.0	81.0	NaN	
3	US	33	88.0	81.0	NaN	
4	US	33	77.0	81.0	NaN	
5	US	33	74.0	81.0	NaN	
6	US	33	80.0	81.0	NaN	
7	US	33	73.0	81.0	NaN	
8	US	33	84.0	81.0	NaN	
9	US	33	92.0	81.0	NaN	

	ArrDelay	DepDelay	Origin	Dest	Distance	TaxiIn	TaxiOut	Cancelled	\
0	46.0	41.0	EWB	PIT	319.0	NaN	NaN	False	
1	-1.0	7.0	EWB	PIT	319.0	NaN	NaN	False	
2	9.0	6.0	EWB	PIT	319.0	NaN	NaN	False	
3	9.0	2.0	EWB	PIT	319.0	NaN	NaN	False	
4	5.0	9.0	EWB	PIT	319.0	NaN	NaN	False	
5	-8.0	-1.0	EWB	PIT	319.0	NaN	NaN	False	
6	12.0	13.0	EWB	PIT	319.0	NaN	NaN	False	
7	-5.0	3.0	EWB	PIT	319.0	NaN	NaN	False	
8	3.0	0.0	EWB	PIT	319.0	NaN	NaN	False	
9	39.0	28.0	EWB	PIT	319.0	NaN	NaN	False	

	Diverted
0	0
1	0
2	0
3	0
4	0
5	0

6	0
7	0
8	0
9	0

```
In [22]: len(df)
```

```
Out[22]: 2611892
```

```
In [23]: len(df[df.DepDelay > 0])
```

```
Out[23]: 1187146
```

```
In [24]: len(df[df.DepDelay < 0])
```

```
Out[24]: 840942
```

```
In [25]: len(df[~df.Cancelled])
```

```
Out[25]: 2540961
```

16.4 Divisions and the Index

The Pandas index associates a value to each record/row of your data. Operations that align with the index, like `loc` can be a bit faster as a result.

In `dask.dataframe` this index becomes even more important. Recall that one `dask DataFrame` consists of several Pandas `DataFrames`. These dataframes are separated along the index by value. For example, when working with time series we may partition our large dataset by month.

Recall that these many partitions of our data may not all live in memory at the same time, instead they might live on disk; we simply have tasks that can materialize these pandas `DataFrames` on demand.

Partitioning your data can greatly improve efficiency. Operations like `loc`, `groupby`, and `merge/join` along the index are *much more efficient* than operations along other columns. You can see how your dataset is partitioned with the `.divisions` attribute. Note that data that comes out of simple data sources like CSV files aren't intelligently indexed by default. In these cases the values for `.divisions` will be `None`.

```
In [26]: df = dd.read_csv(filename,
                        dtype={'TailNum': str,
                              'CRSElapsedTime': float,
                              'Cancelled': bool})

df.divisions
```

```
Out[26]: (None, None, None, None, None, None, None, None, None, None)
```

However if we set the index to some new column then `dask` will divide our data roughly evenly along that column and create new divisions for us. Warning, `set_index` triggers immediate computation.

```
In [27]: df2 = df.set_index('Year')
df2.divisions
```

```
Out[27]: (1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999)
```

We see here the minimum and maximum values (1990 and 1999) as well as the intermediate values that separate our data well. This dataset has ten partitions, as the final value is assumed to be the inclusive right-side for the last bin.

```
In [28]: df2.npartitions
```

```
Out[28]: 10
```

```
In [29]: df2.head()
```

```
Out[29]:
```

	Month	DayofMonth	DayOfWeek	DepTime	CRSDepTime	ArrTime	CRSArrTime	\
Year								
1990	1	1	1	1621.0	1540	1747.0	1701	
1990	1	2	2	1547.0	1540	1700.0	1701	
1990	1	3	3	1546.0	1540	1710.0	1701	
1990	1	4	4	1542.0	1540	1710.0	1701	
1990	1	5	5	1549.0	1540	1706.0	1701	

	UniqueCarrier	FlightNum	TailNum	...	AirTime	ArrDelay	DepDelay	\
Year				...				
1990	US	33	NaN	...	NaN	46.0	41.0	
1990	US	33	NaN	...	NaN	-1.0	7.0	
1990	US	33	NaN	...	NaN	9.0	6.0	
1990	US	33	NaN	...	NaN	9.0	2.0	
1990	US	33	NaN	...	NaN	5.0	9.0	

	Origin	Dest	Distance	TaxiIn	TaxiOut	Cancelled	Diverted
Year							
1990	EWB	PIT	319.0	NaN	NaN	False	0
1990	EWB	PIT	319.0	NaN	NaN	False	0
1990	EWB	PIT	319.0	NaN	NaN	False	0
1990	EWB	PIT	319.0	NaN	NaN	False	0
1990	EWB	PIT	319.0	NaN	NaN	False	0

```
[5 rows x 22 columns]
```

One of the benefits of this is that operations like `loc` only need to load the relevant partitions

```
In [30]: df2.loc[1991]
```

```
Out[30]: Dask DataFrame Structure:
```

```

      Month DayofMonth DayOfWeek DepTime CRSDepTime ArrTime CRSArrTime UniqueCarrier
npartitions=1
1991      int64      int64      int64 float64      int64 float64      int64      object
1991      ...      ...      ...      ...      ...      ...      ...      ...
Dask Name: loc, 31 tasks
```

```
In [31]: df2.loc[1991].compute()
```

```
Out[31]:
```

	Month	DayofMonth	DayOfWeek	DepTime	CRSDepTime	ArrTime	CRSArrTime	\
Year								
1991	1	8	2	1215.0	1215	1340.0	1336	
1991	1	9	3	1215.0	1215	1353.0	1336	
1991	1	10	4	1216.0	1215	1332.0	1336	
1991	1	11	5	1303.0	1215	1439.0	1336	
1991	1	12	6	1215.0	1215	1352.0	1336	
...	
1991	12	26	4	1600.0	1600	1857.0	1906	
1991	12	27	5	1600.0	1600	1853.0	1906	
1991	12	28	6	1600.0	1600	1856.0	1906	
1991	12	29	7	1601.0	1600	1851.0	1906	
1991	12	31	2	1558.0	1600	1851.0	1906	

	UniqueCarrier	FlightNum	TailNum	...	AirTime	ArrDelay	DepDelay	\
--	---------------	-----------	---------	-----	---------	----------	----------	---

Year								
1991	US	121	NaN	...	NaN	4.0	0.0	
1991	US	121	NaN	...	NaN	17.0	0.0	
1991	US	121	NaN	...	NaN	-4.0	1.0	
1991	US	121	NaN	...	NaN	63.0	48.0	
1991	US	121	NaN	...	NaN	16.0	0.0	
...	
1991	CO	1539	NaN	...	NaN	-9.0	0.0	
1991	CO	1539	NaN	...	NaN	-13.0	0.0	
1991	CO	1539	NaN	...	NaN	-10.0	0.0	
1991	CO	1539	NaN	...	NaN	-15.0	1.0	
1991	CO	1539	NaN	...	NaN	-15.0	-2.0	

	Origin	Dest	Distance	TaxiIn	TaxiOut	Cancelled	Diverted
Year							
1991	EWR	PIT	319.0	NaN	NaN	False	0
1991	EWR	PIT	319.0	NaN	NaN	False	0
1991	EWR	PIT	319.0	NaN	NaN	False	0
1991	EWR	PIT	319.0	NaN	NaN	False	0
1991	EWR	PIT	319.0	NaN	NaN	False	0
...
1991	LGA	FLL	1076.0	NaN	NaN	False	0
1991	LGA	FLL	1076.0	NaN	NaN	False	0
1991	LGA	FLL	1076.0	NaN	NaN	False	0
1991	LGA	FLL	1076.0	NaN	NaN	False	0
1991	LGA	FLL	1076.0	NaN	NaN	False	0

[258274 rows x 22 columns]

16.4.1 Exercises 15.2

In this section we do a few `dask.dataframe` computations. If you are comfortable with Pandas then these should be familiar. You will have to think about when to call `compute`.

- In total, how many non-cancelled flights were taken from each airport?

Hint: use `df.groupby(df.A).B.func()`.

- What was the average departure delay from each airport?

Note, this is the same computation you did in the previous notebook (is this approach faster or slower?)

- What day of the week has the worst average departure delay?

```
In [32]: df = dd.read_parquet("nycflights/")
```

```
In [33]: df[~df.Cancelled].groupby("Origin").Origin.count().compute()
```

```
Out[33]: Origin
EWR      1139451
JFK       427243
LGA       974267
Name: Origin, dtype: int64
```

```
In [34]: df[~df.Cancelled].groupby("Origin").DepDelay.count().compute()
```

```
Out[34]: Origin
        EWR    1139451
        JFK    427243
        LGA    974267
        Name: DepDelay, dtype: int64
```

16.5 Sharing Intermediate Results

When computing all of the above, we sometimes did the same operation more than once. For most operations, `dask.dataframe` hashes the arguments, allowing duplicate computations to be shared, and only computed once.

For example, let's compute the mean and standard deviation for departure delay of all non-cancelled flights:

```
In [35]: non_cancelled = df[~df.Cancelled]
        mean_delay = non_cancelled.DepDelay.mean()
        std_delay = non_cancelled.DepDelay.std()
```

Using two calls to `.compute`:

```
In [36]: %%time
        mean_delay_res = mean_delay.compute()
        std_delay_res = std_delay.compute()
```

```
CPU times: user 2.68 s, sys: 205 ms, total: 2.89 s
Wall time: 1.95 s
```

Using one call to `dask.compute`:

```
In [37]: %%time
        mean_delay_res, std_delay_res = dask.compute(mean_delay, std_delay)
```

```
CPU times: user 1.36 s, sys: 160 ms, total: 1.52 s
Wall time: 1.01 s
```

Using `dask.compute` takes roughly 1/2 the time. This is because the task graphs for both results are merged when calling `dask.compute`, allowing shared operations to only be done once instead of twice. In particular, using `dask.compute` only does the following once:

- the calls to `read_csv`
- the filter (`df[~df.Cancelled]`)
- some of the necessary reductions (`sum`, `count`)

To see what the merged task graphs between multiple results look like (and what's shared), you can use the `dask.visualize` function (we might want to use `filename='graph.pdf'` to zoom in on the graph better):

```
In [38]: dask.visualize(mean_delay, std_delay)
```

```
-----
FileNotFoundError
```

```
Traceback (most recent call last)
```

```
/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
```



```

165     try:
--> 166         proc = subprocess.Popen(cmd, startupinfo=get_startupinfo(), **kwargs)
167     except OSError as e:

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in __init__(self, args, bufsize
853
--> 854         self._execute_child(args, executable, preexec_fn, close_fds,
855                             pass_fds, cwd, env,

/usr/share/miniconda3/envs/big-data/lib/python3.8/subprocess.py in _execute_child(self, args, e
1701         err_msg = os.strerror(errno_num)
-> 1702         raise child_exception_type(errno_num, err_msg, err_filename)
1703         raise child_exception_type(err_msg)

```

FileNotFoundError: [Errno 2] No such file or directory: 'dot'

During handling of the above exception, another exception occurred:

```

ExecutableNotFound                                Traceback (most recent call last)

<ipython-input-38-547954d62040> in <module>
----> 1 dask.visualize(mean_delay, std_delay)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/base.py in visualize(*args
551         raise NotImplementedError("Unknown value color=%s" % color)
552
--> 553     return dot_graph(dsk, filename=filename, **kwargs)
554
555

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in dot_graph(dsk, f
270     """
271     g = to_graphviz(dsk, **kwargs)
--> 272     return graphviz_to_file(g, filename, format)
273
274

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/dask/dot.py in graphviz_to_file
282         format = "png"
283
--> 284     data = g.pipe(format=format)
285     if not data:
286         raise RuntimeError(

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/files.py in pipe(self,

```

```

134         data = text_type(self.source).encode(self._encoding)
135
--> 136         out = backend.pipe(self._engine, format, data,
137                             renderer=renderer, formatter=formatter,
138                             quiet=quiet)

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in pipe(engine,
244     """
245     cmd, _ = command(engine, format, None, renderer, formatter)
--> 246     out, _ = run(cmd, input=data, capture_output=True, check=True, quiet=quiet)
247     return out
248

/usr/share/miniconda3/envs/big-data/lib/python3.8/site-packages/graphviz/backend.py in run(cmd,
167     except OSError as e:
168         if e.errno == errno.ENOENT:
--> 169             raise ExecutableNotFound(cmd)
170         else:
171             raise

```

ExecutableNotFound: failed to execute ['dot', '-Tpng'], make sure the Graphviz executables are on your system's path

Chapter 17

Spark DataFrames

- Enable wider audiences beyond “Big Data” engineers to leverage the power of distributed processing
- Inspired by data frames in R and Python (Pandas)
- Designed from the ground-up to support modern big data and data science applications
- Extension to the existing RDD API

17.1 References

- [Spark SQL, DataFrames and Datasets Guide](#)
- [Introduction to DataFrames - Python](#)
- [PySpark Cheat Sheet: Spark DataFrames in Python](#)

17.1.1 DataFrames are :

- The preferred abstraction in Spark
- Strongly typed collection of distributed elements
- Built on Resilient Distributed Datasets (RDD)
- Immutable once constructed

17.1.2 With Dataframes you can :

- Track lineage information to efficiently recompute lost data
- Enable operations on collection of elements in parallel

17.1.3 You construct DataFrames

- by parallelizing existing collections (e.g., Pandas DataFrames)
- by transforming an existing DataFrames
- from files in HDFS or any other storage system (e.g., Parquet)

17.1.4 Features

- Ability to scale from kilobytes of data on a single laptop to petabytes on a large cluster
- Support for a wide array of data formats and storage systems
- Seamless integration with all big data tooling and infrastructure via Spark
- APIs for Python, Java, Scala, and R

17.1.5 DataFrames versus RDDs

- Nice API for new users familiar with data frames in other programming languages.

17.3.1 Transformation examples

- filter
- select
- drop
- intersect
- join ### Action examples
- count
- collect
- show
- head
- take

17.4 Creating a DataFrame in Python

```
In [1]: import sys, subprocess
import os
```

```
os.environ["PYSPARK_PYTHON"] = sys.executable
```

```
In [2]: from pyspark import SparkContext, SparkConf, SQLContext
# The following three lines are not necessary
# in the pyspark shell
conf = SparkConf().setAppName("people").setMaster("local[*]")
sc = SparkContext(conf=conf)
sc.setLogLevel("ERROR")
sqlContext = SQLContext(sc)
```

```
In [3]: df = sqlContext.read.json("data/people.json") # get a dataframe from json file

df.show(24)
```

```
+-----+-----+-----+
| firstname| lastname|      login|
+-----+-----+-----+
|      Simon|      Uzel|    uzel_s|
|    Perrine|    Moreau|  moreau_p|
|      Elise|     Negri|  negri_e|
|    Camille|    Cochet|  cochet_c|
|    Nolwenn|  Giguelay|  giguelay_n|
|      Youen|     Meyer|  meyer_y|
|     Emilie|    Lacoste|  lacoste_e|
|       Pia|   LeBihan|  lebihan_p|
|      Yann|     Evain|   evain_y|
|    Camille|     Guyon|   guyon_c|
|  Mathilde|   LeMener|  lemener_m|
|     Gildas|  LeGuilly|  liguilly_g|
|    Pierre|  Gardelle|  gardelle_p|
| Christophe| Boulineau|  boulineau_c|
|       Omar|  Aitichou|  aitichou_o|
|     Lijun|       Chi|     chi_l|
|    Jiawei|      Liu|     lin_j|
|     Irvin| Keraudren|  keraudren_i|
|     Bryan|     Jacob|   jacob_b|
|  Raphael|  Guillerme|  guillerm_r|
|     Bruno|  Queguiner|  queguiner_b|
```

```
| Yingshi|      Zeng|      zeng_y|
+-----+-----+-----+
```

17.5 Schema Inference

In this exercise, let's explore schema inference. We're going to be using a file called `irmar.txt`. The data is structured, but it has no self-describing schema. And, it's not JSON, so Spark can't infer the schema automatically. Let's create an RDD and look at the first few rows of the file.

```
In [4]: rdd = sc.textFile("data/irmar.csv")
        for line in rdd.take(10):
            print(line)
```

```
Alphonse Paul;+33223235223;214;R1;DOC;False;EDP;NA
Ammari Zied;+33223235811;209;R1;MC;True;EDP;NA
André Simon;+33223237555;301;R1;DOC;False;THEO-ERG;NA
Angst Jurgen;+33223236519;320;R1;MC;False;PROC-STOC;NA
Bailleul Ismaël;+33223236369;302;R1;MC;True;THEO-ERG;NA
Baker Mark;+33223236028;835;R1;PR;True;GAN;NA
Balac Stephane;+33223236274;110;R1;MC;False;ANANUM;NA
Bauer Max;+33223236675;734;R1;MC;False;GAN;NA
Bavard Juliette;+33223236724;331;CNRS;CR;False;GAN;THEO-ERG
Beauchard Karine;+33223236164;235;R1;PR;True;ANANUM;NA
```

17.6 Hands-on Exercises

You can look at the DataFrames API documentation

Let's take a look to file `"/tmp/irmar.csv"`. Each line consists of the same information about a person:

- name
- phone
- office
- organization
- position
- hdr
- team1
- team2

```
In [5]: from collections import namedtuple
```

```
rdd = sc.textFile("data/irmar.csv")

Person = namedtuple('Person', ['name', 'phone', 'office', 'organization',
                               'position', 'hdr', 'team1', 'team2'])

def str_to_bool(s):
    if s == 'True': return True
    return False

def map_to_person(line):
    cols = line.split(";")
    return Person(name      = cols[0],
                  phone     = cols[1],
```

```

        office      = cols[2],
        organization = cols[3],
        position     = cols[4],
        hdr          = str_to_bool(cols[5]),
        team1        = cols[6],
        team2        = cols[7])

people_rdd = rdd.map(map_to_person)
df = people_rdd.toDF()

```

```
In [6]: df.show()
```

name	phone	office	organization	position	hdr	team1	team2
Alphonse Paul	+33223235223	214	R1	DOC	false	EDP	NA
Ammari Zied	+33223235811	209	R1	MC	true	EDP	NA
André Simon	+33223237555	301	R1	DOC	false	THEO-ERG	NA
Angst Jurgen	+33223236519	320	R1	MC	false	PROC-STOC	NA
Bailleul Ismaël	+33223236369	302	R1	MC	true	THEO-ERG	NA
Baker Mark	+33223236028	835	R1	PR	true	GAN	NA
Balac Stephane	+33223236274	110	R1	MC	false	ANANUM	NA
Bauer Max	+33223236675	734	R1	MC	false	GAN	NA
Bavard Juliette	+33223236724	331	CNRS	CR	false	GAN	THEO-ERG
Beauchard Karine	+33223236164	235	R1	PR	true	ANANUM	NA
Bekka Bachir	+33223235779	307	R1	PR	true	THEO-ERG	NA
Bekka Karim	+33223236180	615	R1	MC	false	G&S	NA
Belgacem Maher	+33223236670	NA	EXT	DOC	false	ANANUM	NA
Bellis Alexandre	+33223236696	634	R1	DOC	false	GAN	NA
Belmiloudi Aziz	+33223238646	NA	INSA	MC	true	ANANUM	NA
Ben Elouefi Rim	+33223236670	NA	EXT	DOC	false	STAT	NA
Benasseni Jacques	+33299141822	NA	R2	PR	true	STAT	NA
Bennani-Dosse Moh...	+33299141796	NA	R2	MC	false	STAT	NA
Bernier Joachim	+33223237558	214	R1	DOC	false	ANANUM	NA
Berthelot Pierre	+33223236043	601	R1	PE	true	GA	NA

only showing top 20 rows

17.6.1 Schema

```
In [7]: df.printSchema()
```

```

root
 |-- name: string (nullable = true)
 |-- phone: string (nullable = true)
 |-- office: string (nullable = true)
 |-- organization: string (nullable = true)
 |-- position: string (nullable = true)
 |-- hdr: boolean (nullable = true)
 |-- team1: string (nullable = true)
 |-- team2: string (nullable = true)

```

17.6.2 display

```
In [8]: display(df)
```

```
DataFrame[name: string, phone: string, office: string, organization: string, position: string, hdr: boo
```

17.6.3 select

```
In [9]: df.select(df["name"], df["position"], df["organization"])
```

```
Out[9]: DataFrame[name: string, position: string, organization: string]
```

```
In [10]: df.select(df["name"], df["position"], df["organization"]).show()
```

name	position	organization
Alphonse Paul	DOC	R1
Ammari Zied	MC	R1
André Simon	DOC	R1
Angst Jurgen	MC	R1
Bailleul Ismaël	MC	R1
Baker Mark	PR	R1
Balac Stephane	MC	R1
Bauer Max	MC	R1
Bavard Juliette	CR	CNRS
Beauchard Karine	PR	R1
Bekka Bachir	PR	R1
Bekka Karim	MC	R1
Belgacem Maher	DOC	EXT
Bellis Alexandre	DOC	R1
Belmiloudi Aziz	MC	INSA
Ben Elouefi Rim	DOC	EXT
Benasseni Jacques	PR	R2
Bennani-Dosse Moh...	MC	R2
Bernier Joachim	DOC	R1
Berthelot Pierre	PE	R1

only showing top 20 rows

17.6.4 filter

```
In [11]: df.filter(df["organization"] == "R2").show()
```

name	phone	office	organization	position	hdr	team1	team2
Benasseni Jacques	+33299141822	NA	R2	PR	true	STAT	NA
Bennani-Dosse Moh...	+33299141796	NA	R2	MC	false	STAT	NA
Cornillon Pierre-...	+33299141819	NA	R2	MC	false	STAT	NA
Fromont Magalie	+33299053264	NA	R2	PR	true	STAT	NA
Giacofci Joyce Ma...	+33299141800	NA	R2	MC	false	STAT	NA
Klutchnikoff Nicolas	+33299141819	NA	R2	MC	false	STAT	NA

	Le Guevel Ronan	+33299141800	NA	R2	MC false	PROC-STOC	STAT
	Mom Alain	+33299141808	NA	R2	MC false	STAT	NA
	Morvan Marie	+33223236670	NA	R2	DOC false	STAT	NA
	Pelletier Bruno	+33299141807	NA	R2	PR true	STAT	NA
	Rouviere Laurent	+33299141804	NA	R2	MC false	STAT	NA

17.6.5 filter + select

```
In [12]: df2 = df.filter(df["organization"] == "R2").select(df['name'],df['team1'])
```

```
In [13]: df2.show()
```

	name	team1
	Benasseni Jacques	STAT
	Bennani-Dosse Moh...	STAT
	Cornillon Pierre-...	STAT
	Fromont Magalie	STAT
	Giacofci Joyce Ma...	STAT
	Klutchnikoff Nicolas	STAT
	Le Guevel Ronan	PROC-STOC
	Mom Alain	STAT
	Morvan Marie	STAT
	Pelletier Bruno	STAT
	Rouviere Laurent	STAT

17.6.6 orderBy

```
In [14]: (df.filter(df["organization"] == "R2")
          .select(df["name"],df["position"])
          .orderBy("position")).show()
```

	name position
	Morvan Marie DOC
	Cornillon Pierre-... MC
	Bennani-Dosse Moh... MC
	Giacofci Joyce Ma... MC
	Mom Alain MC
	Klutchnikoff Nicolas MC
	Rouviere Laurent MC
	Le Guevel Ronan MC
	Benasseni Jacques PR
	Fromont Magalie PR
	Pelletier Bruno PR

17.6.7 groupBy

```
In [15]: df.groupby(df["hdr"])
```

```
Out[15]: <pyspark.sql.group.GroupedData at 0x7f5e90bc3250>
```

```
In [16]: df.groupby(df["hdr"]).count().show()
```

```
+-----+-----+
|  hdr|count|
+-----+-----+
| true|   103|
|false|   141|
+-----+-----+
```

WARNING: Don't confuse `GroupedData.count()` with `DataFrame.count()`. `GroupedData.count()` is not an action. `DataFrame.count()` is an action.

```
In [17]: df.filter(df["hdr"]).count()
```

```
Out[17]: 103
```

```
In [18]: df.filter(df['hdr']).select("name").show()
```

```
+-----+
|          name|
+-----+
|    Ammari Zied|
| Bailleul Ismaël|
|    Baker Mark|
| Beauchard Karine|
|    Bekka Bachir|
| Belmiloudi Aziz|
| Benasseni Jacques|
| Berthelot Pierre|
|    Bourqui David|
|Breton Jean-Chris...|
|    Briane Marc|
|    Cadre Benoît|
|    Caloz Gabriel|
|    Cantat Serge|
|    Caruso Xavier|
| Castella Francois|
|    Causeur David|
| Cerveau Dominique|
| Chartier Philippe|
|    Chauvet Guillaume|
+-----+
```

only showing top 20 rows

```
In [19]: df.groupby(df["organization"]).count().show()
```

```

+-----+-----+
|organization|count|
+-----+-----+
|      ENS|   3|
|      CNRS|  19|
|      INSA|  19|
|       R2|  11|
|     INRIA|   9|
|      AGRO|   5|
|      EXT|   2|
|       R1| 176|
+-----+-----+

```

17.6.8 Exercises

- How many teachers from INSA (PR+MC) ?
- How many MC in STATS team ?
- How many MC+CR with HDR ?
- What is the ratio of student supervision (DOC / HDR) ?
- List number of people for every organization ?
- List number of HDR people for every team ?
- Which team contains most HDR ?
- List number of DOC students for every organization ?
- Which team contains most DOC ?
- List people from CNRS that are neither CR nor DR ?

```
In [20]: df.select("organization").filter(df["organization"]=="INSA").count()
```

```
Out[20]: 19
```

```
In [21]: (df.select(["position", "team1", "team2"])
         .filter((df["team1"]=="STAT") | (df["team2"]=="STAT"))
         .filter(df["position"] == "MC").count())
```

```
Out[21]: 15
```

```
In [22]: (df.select(["position", "hdr"])
         .filter((df["position"]=="MC") | (df["position"]=="CR"))
         .filter(df["hdr"]).count())
```

```
Out[22]: 28
```

```
In [23]: (df.select("position").filter(df["position"]=="DOC").count() /
         df.select(df["hdr"]).filter(df["hdr"]).count())
```

```
Out[23]: 0.6019417475728155
```

```
In [24]: (df.select(["hdr", "team1", "team2"])
         .filter("hdr")
         .rdd.flatMap(lambda row: (row.team1, row.team2))
         .filter(lambda v : v != 'NA')
         .map(lambda row : (row,1))
         .reduceByKey(lambda a, b:a+b)
         .sortBy(lambda v: -v[1])
         .collect()
        )
```

```
Out [24]: [('ANANUM', 21),
          ('THEO-ERG', 14),
          ('STAT', 14),
          ('EDP', 11),
          ('G&S', 9),
          ('GAN', 9),
          ('GA', 8),
          ('GAE', 8),
          ('PROC-STOC', 7),
          ('MECA', 6),
          ('IREM', 2),
          ('ADM', 1)]
```

```
In [25]: (df.select(["position", "team1", "team2"])
         .filter(df.position=="DOC")
         .rdd.flatMap(lambda row: [row.team1, row.team2])
         .filter(lambda v : v != 'NA')
         .map(lambda row : (row,1))
         .reduceByKey(lambda a, b:a+b)
         .sortBy(lambda v: -v[1])
         .collect()
        )
```

```
Out [25]: [('ANANUM', 14),
          ('STAT', 9),
          ('THEO-ERG', 8),
          ('GAN', 8),
          ('PROC-STOC', 8),
          ('EDP', 7),
          ('MECA', 4),
          ('GAE', 4),
          ('GA', 4),
          ('G&S', 2)]
```

```
In [26]: import pyspark.sql.functions as f

df1 = (df.select(["position", "team1", "hdr"])
      .filter(df.hdr)
      .groupBy("team1")
      .agg(f.count("position").alias("count1"))
      )
```

```
In [27]: df2 = (df.select(["position", "team2", "hdr"])
              .filter(df.hdr)
              .filter(df.team2 != "NA")
              .groupBy("team2")
              .agg(f.count("team2").alias("count2"))
              )
```

```
In [28]: df3 = (df1.join(df2, df1.team1 == df2.team2, how="left")
               .na.fill(0)
               .drop("team2"))
```

```
In [29]: df3.withColumn("total", df3.count1+df3.count2).orderBy("total", ascending=False).show()
```

```
+-----+-----+-----+-----+
|   team1|count1|count2|total|
+-----+-----+-----+-----+
```

	ANANUM	21	0	21
	THEO-ERG	11	3	14
	STAT	14	0	14
	EDP	10	1	11
	GAN	9	0	9
	G&S	8	1	9
	GA	7	1	8
	GAE	8	0	8
	PROC-STOC	6	1	7
	MECA	6	0	6
	IREM	2	0	2
	ADM	1	0	1
+-----+-----+-----+-----+				

```
In [30]: (df.filter((df.position=="DOC") & (df.team1 == "ANANUM"))
          .select("name")
          .show()
          )
```

+-----+	
	name
+-----+	
	Belgacem Maher
	Bernier Joachim
	Calvez Adrien
	Corre Samuel
	Dao Manh Khang
	Doli Valentin
	Fontaine Marine
	Horsin Romain
	Joannopoulos Emilie
	Le Balc'h Kevin
	Moitier Zoïs
	Nguyen Thi-Hoai-T...
	Rosello Angelo
	Tusseau Maxime
+-----+	

```
In [31]: (df.select("organization")
          .groupby("organization").count().show())
```

+-----+	
organization	count
+-----+	
	ENS 3
	CNRS 19
	INSA 19
	R2 11
	INRIA 9
	AGRO 5
	EXT 2
	R1 176

```
+-----+-----+
```

```
In [32]: (df.select(["name", "organization", "position"])
         .filter((df.position == "DR") | (df.position == "CR"))
         .show())
```

```
+-----+-----+-----+
|          name|organization|position|
+-----+-----+-----+
|   Bavard Juliette|      CNRS|      CR|
|Bonthonneau Yannick|      CNRS|      CR|
|   Cantat Serge|      CNRS|      DR|
|   Caruso Xavier|      CNRS|      CR|
|   Cérou Frédéric|     INRIA|      CR|
| Chartier Philippe|     INRIA|      DR|
|   Coulon Rémi|      CNRS|      CR|
|Crouseilles Nicolas|     INRIA|      CR|
|   Dauge Monique|      CNRS|      DR|
|   Duchene Vincent|      CNRS|      CR|
|   Erhel Jocelyne|     INRIA|      DR|
|   Faou Erwan|     INRIA|      DR|
|   Gros Michel|      CNRS|      CR|
|   Héas Patrick|      CNRS|      CR|
| Herzet Cedric|      CNRS|      CR|
| Kleptsyn Victor|      CNRS|      CR|
| Le Gland François|     INRIA|      DR|
|   Lemou Mohammed|      CNRS|      DR|
|   Loray Frank|      CNRS|      DR|
|   Memin Etienne|     INRIA|      DR|
+-----+-----+-----+
```

only showing top 20 rows

```
In [33]: (df.select(["name", "organization", "position"])
         .filter(df.organization == "CNRS")
         .filter((df.position != "DR") & (df.position != "CR"))
         .groupBy("position").count().show())
```

```
+-----+-----+
|position|count|
+-----+-----+
|      TC|    2|
|      IR|    2|
|      AI|    1|
|      IE|    1|
+-----+-----+
```

```
In [34]: sc.stop()
```

Chapter 18

Dask dataframes on HDFS

To use Dask dataframes in parallel across an HDFS cluster to read CSV data. We can coordinate these computations with [distributed](#) and `dask.dataframe`.

As Spark, Dask can work in cluster mode. You can use the `dask` module [dask_jobqueue](#) to launch a Dask cluster with the job manager SLURM.

```
In [1]: from dask_jobqueue import SLURMCluster

        cluster = SLURMCluster(cores=16,
                                queue='test',
                                project='myproject',
                                memory="16GB",
                                walltime="01:00:00")
```

The cluster generates a traditional job script and submits that an appropriate number of times to the job queue. You can see the job script that it will generate as follows:

```
In [2]: print(cluster.job_script())
```

```
#!/usr/bin/env bash
```

```
#SBATCH -J dask-worker
```

```
#SBATCH -p test
```

```
#SBATCH -A myproject
```

```
#SBATCH -n 1
```

```
#SBATCH --cpus-per-task=16
```

```
#SBATCH --mem=15G
```

```
#SBATCH -t 01:00:00
```

```
/usr/share/miniconda3/envs/big-data/bin/python -m distributed.cli.dask_worker tcp://10.1.0.4:37681 --nt
```

Access to the cluster using following lines:

```
import dask.dataframe as dd
from dask.distributed import Client
client = Client(cluster)
```

`nyc2014` is a `dask.dataframe` objects which present a subset of the Pandas API to the user, but farm out all of the work to the many Pandas dataframes they control across the network.

```
nyc2014 = dd.read_csv('/opt/datasets/nyc-data/2014/yellow*.csv',
parse_dates=['pickup_datetime', 'dropoff_datetime'],
skipinitialspace=True)
nyc2014 = c.persist(nyc2014)
progress(nyc2014)
```

18.0.1 Exercises

- Display head of the dataframe
- Display number of rows of this dataframe.
- Compute the total number of passengers.
- Count occurrences in the payment_type column both for the full dataset, and filtered by zero tip (tip_amount == 0).
- Create a new column, tip_fraction
- Plot the average of the new column tip_fraction grouped by day of week.
- Plot the average of the new column tip_fraction grouped by hour of day.

[Dask dataframe documentation](#)

```
In [3]: # import dask.dataframe as dd
        # from distributed import Client, progress
        #
        # c = Client('127.0.0.1:8786')
        # nyc2014 = dd.read_csv('hdfs://sumass2.mass.uhb.fr:54310/user/datasets/nyc-tlc/2014/yellow*.csv',
        # parse_dates=['pickup_datetime', 'dropoff_datetime'],
        # skipinitialspace=True)
        #
        # nyc2015 = dd.read_csv('hdfs://sumass2.mass.uhb.fr:54310/user/datasets/nyc-tlc/2015/yellow*.csv',
        # parse_dates=['tpep_pickup_datetime', 'tpep_dropoff_datetime'])
        # nyc2014, nyc2015 = c.persist([nyc2014, nyc2015])
        #
        # progress(nyc2014, nyc2015)
```


Chapter 19

Spark dataframes on HDFS

New York City Taxi Cab Trip

We look at [the New York City Taxi Cab dataset](#). This includes every ride made in the city of New York since 2009.

On [this website](#) you can see the data for one random NYC yellow taxi on a single day.

On [this post](#), you can see an analysis of this dataset. Postgres and R scripts are available on [GitHub](#).

19.1 Loading the data

Normally we would read and load this data into memory as a Pandas dataframe. However in this case that would be unwise because this data is too large to fit in RAM.

The data can stay in the hdfs filesystem but for performance reason we can't use the csv format. The file is large (32Go) and text formatted. Data Access is very slow.

You can convert csv file to parquet with Spark.

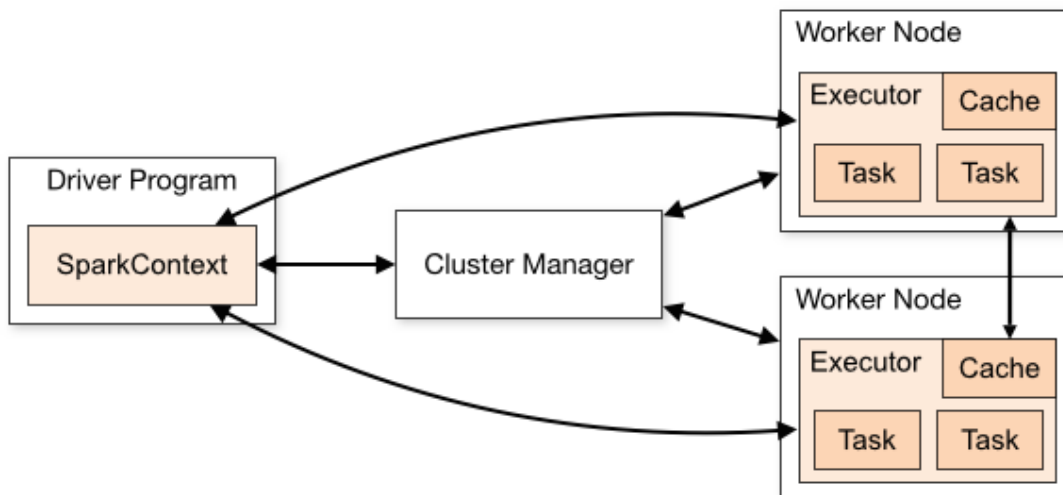
```
from pyspark.sql import SparkSession
spark = SparkSession.builder \
    .master("spark://svmass2.mass.uhb.fr:7077") \
    .config('spark.hadoop.parquet.enable.summary-metadata', 'true') \
    .config("spark.cores.max", "10") \
    .getOrCreate()
df = spark.read.csv(
    "hdfs://svmass2.mass.uhb.fr:54310/user/datasets/nyc-tlc/2009/yellow_tripdata_2009-01.csv",
    header="true",inferSchema="true")
df.write.parquet("hdfs://svmass2.mass.uhb.fr:54310/user/navaro_p/nyc-taxi/2019-01.parquet")
spark.stop()
```

To read multiple files

```
spark.read.format("csv").option("header", "true").load("../Downloads/*.csv")
```

19.2 Spark Cluster

A Spark cluster is available and described on this [web interface](#)



```
from pyspark.sql import SparkSession
spark = SparkSession.builder \
    .master('spark://svmass2.mass.uhb.fr:7077') \
    .getOrCreate()
spark
```

The `SparkSession` is connected to the Spark's own standalone cluster manager (It is also possible to use YARN). The manager allocate resources across applications. Once connected, Spark acquires executors on nodes in the cluster, which are processes that run computations and store data for your application. Next, it sends your application code (Python file) to the executors. Finally, tasks are sent to the executors to run.

Spark can access to files located on hdfs and it is also possible to access to local files. Example:

```
df = spark.read.parquet('file:///home/navaro_p/nyc-taxi/2016.parquet')
```

19.2.1 Exercise

- Pick a year and read and convert csv files to parquet in your hdfs homedirectory.
- **Don't run the python code inside a notebook cell.** Save a python script and launch it from a terminal instead. In Jupyter notebook you won't see any progress or information if error occurs.
- Use the `spark-submit` command shell to run your script on the cluster.
- You can control the log with

```
spark.sparkContext.setLogLevel('ERROR')
```

Valid log levels include: ALL, DEBUG, ERROR, FATAL, INFO, OFF, TRACE, WARN

Try your script with a single file before to do it for a whole year.

Read carefully the script given above, don't submit it as is. You have to change some part of this code

19.3 Some examples that can be run on the cluster

- Here we read the NYC taxi data files of year 2016 and select some variables.

```
columns = ['tpep_pickup_datetime', 'passenger_count', 'pickup_longitude', 'pickup_latitude', 'dropoff_latitude', 'dropoff_longitude']
```

```
df = (spark.read.parquet('hdfs://svmass2.mass.uhb.fr:54310/user/navaro/nyc-taxi/2016.parquet')).select(*columns)
```

- Sum the total number of passengers

```
df.agg({'passenger_count': 'sum'}).collect()
```
- Average number of passenger per trip

```
df.agg({'passenger_count': 'avg'}).collect()
```
- How many trip with 0,1,2,3,...,9 passenger

```
df.groupby('passenger_count').agg({'*': 'count'}).collect()
```

19.4 Exercise

How well people tip based on the number of passengers in a cab. To do this you have to:

1. Remove rides with zero fare
2. Add a new column `tip_fraction` that is equal to the ratio of the tip to the fare
3. Group by the `passenger_count` column and take the mean of the `tip_fraction` column.

19.4.1 Cheat Sheets and documentation

- [Spark DataFrames in Python](#)
- [Spark in Python](#)
- <https://spark.apache.org/docs/latest/api/python/pyspark.sql.html>

Use the [PySpark API](#).

- **Write a python program and use `spark-submit`**
- **Read the parquet files instead of csv files**
- **Don't forget `spark.stop()` at the end of the script**

19.5 Hints

- How to remove rows

```
df = df.filter(df.name == 'expression')
```
- How to make new columns

```
df = df.withColumn('var2', df.var0 + df.var1)
```
- How to do groupby-aggregations

```
df.groupBy(df.name).agg({'column-name': 'avg'})
```

When you want to collect the result of your computation, finish with the `.collect()` method.

19.5.1 Exercices

1. Plot the tip as a function of the hour of day and the day of the week?
2. Investigate the `payment_type` column. See how well each of the payment types correlate with the `tip_fraction`. Did you find anything interesting? Any guesses on what the different payment types might be? If you're interested you may be able to find more information on the [NYC TLC's website](#)
3. How quickly can you get a taxi cab for a particular day of the year? How about for a particular hour of that day?