Big Data Applications

Contents

Introduction

Pre-requisites

- Be comfortable with basic Python. Familiarity with Numpy and Pandas is beneficial but not required.
- Have an environment ready for the several hands-on exercises (e.g., own laptop or cloud resource)

Syllabus

Something broken?

If you encounter any problem or bug in these materials, please remember to add an issue to the course repo, explaining the problem and, potentially, its solution. By doing this, you will improve the instructions for future users. 🎉

Installation Instructions

Introduction

This document contains instructions for installation of the software we'll be using during the course. If you want to follow the training on your own machines, then please complete these instructions.

If you encounter any problem during installation and you manage to solve them, please remember to add an issue, explaining the problem and solution. By doing this you will be helping to improve the instructions for future users! :tada:

What we're installing

- the `Python` programming language (version `3.7` or greater)
- `git` for version control
- your favourite text editor
- `Apache Spark`
- `Jupyter notebooks`

Please ensure that you have a computer or a cloud-based workbench with all of these installed.

Linux

Package Manager

`Linux` users should be able to use their package manager to install all of the software from this page.

However note that if you are running an older `Linux` distribution you may get older versions with different look and features. We target Ubuntu 21.10 for the sake of homogeneity.

> **Tip**
>
> We recommend to upgrade the system and get the latest security packages: `sudo apt-get upgrade`
>
> Please do not forget to restart after the upgrade finishes.

You can test the `Python` version by issuing:

```
python3 --version
```

You should get an output similar to the following:

```
Python 3.9.7
```

Python via package manager

Recents versions of `Ubuntu` come with mostly up to date versions of all needed packages.

The version of `IPython` might be slightly out of date. Thus, you may wish to upgrade this using `pip`.

You should ensure that the following packages are installed using `apt-get`:

- `python3-pip`
- `jupyter`
- `ipython3`

```
sudo apt-update
sudo apt-get install -y gcc make perl python3-pip jupyter ipython3
```

You can test the installation by issuing:

```
pip --version
```

You should get an output similar to the following:

```
pip 20.3.4 from /usr/lib/python3/dist-packages/pip (python 3.9)
```

Editor

You have many different text editors suitable for programming at your fingertips. Here is an opinionated list of editors in case you do not already have a favourite:

- Visual Studio Code
- Atom
- Neovim
- Vim

Apache Spark

TL;DR

You can skip the whole Step-by-step Setup section by issuing the following commands in a terminal.

```
cd ~
wget https://dlcdn.apache.org/spark/spark-3.2.1/spark-3.2.1-bin-hadoop3.2.tgz
sudo tar -xzvf spark-3.2.1-bin-hadoop3.2.tgz
sudo apt-get install openjdk-8-jre -y
echo 'export SPARK_HOME=~/spark-3.2.1-bin-hadoop3.2' >> ~/.bashrc
echo 'export PATH=$SPARK_HOME/bin:$PATH' >> ~/.bashrc
echo 'export PYTHONPATH=$SPARK_HOME/python:$PYTHONPATH' >> ~/.bashrc
echo 'export PYSPARK_DRIVER_PYTHON=jupyter' >> ~/.bashrc
echo 'export PYSPARK_DRIVER_PYTHON_OPTS=notebook' >> ~/.bashrc
echo 'export PYSPARK_PYTHON=python3.9' >> ~/.bashrc
echo 'export JAVA_HOME=/usr/lib/jvm/java-8-openjdk-amd64' >> ~/.bashrc
exec bash
jupyter notebook --generate-config
sed -i '/# c.NotebookApp.use_redirect_file/s/$*True/False/g' ~/.jupyter/jupyter_notebook_config.py
sed -i '/c.NotebookApp.use_redirect_file/s/^#*\s*//g' ~/.jupyter/jupyter_notebook_config.py
```

Step-by-step Setup

We will setup Apache Spark now. You need to open the `downloads` page, and download a spark distribution.

Download Apache Spark

We suggest to choose the same options as on the screenshot below. If you see a newer version is available, please feel free to choose it.

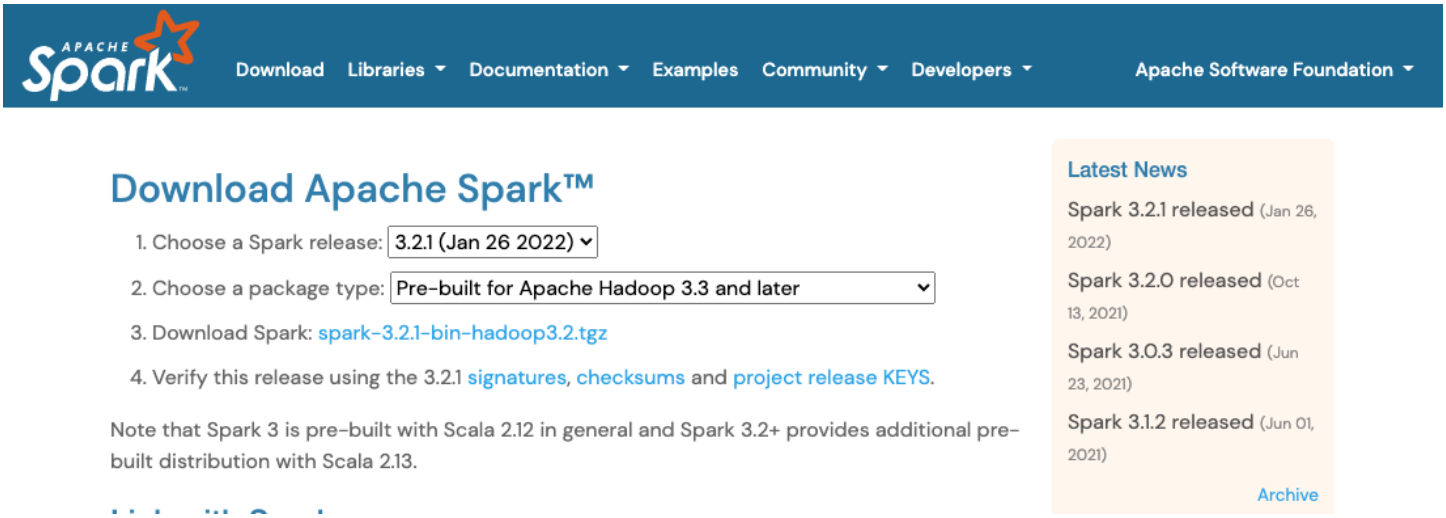
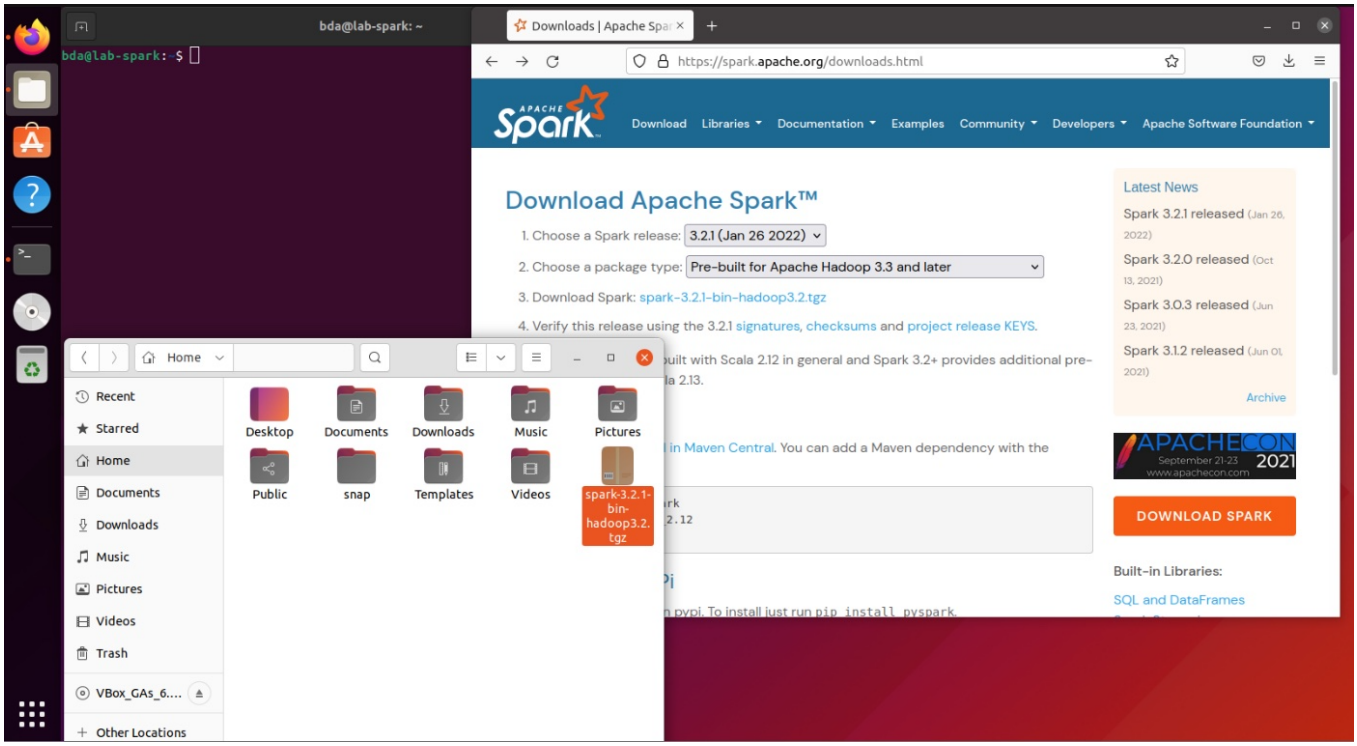


Image Link

Tip

We want the package in the right location, so open the file explorer and place it into your home folder.



Then go to your command line and issue the following to unzip the downloaded file:

```
sudo tar -xzvf spark-3.2.1-bin-hadoop3.2.tgz
```

Important

The above command assumes you downloaded version 3.2.1 with hadoop 3.2 binaries. Please ammend it as needed.

Setup JRE

Next step is installing a JRE (Java Runtime Engine), so that we can use the PySpark shell (or submit a job to a cluster):

```
sudo apt-get install openjdk-8-jre -y
export JAVA_HOME=/usr/lib/jvm/java-8-openjdk-amd64/
```

Configure PySpark

We need to define several environment variables to let Spark find `Python` and use Jupyter notebooks when initiating the PySpark shell:

```
echo 'export SPARK_HOME=~/spark-3.2.1-bin-hadoop3.2' >> ~/.bashrc
echo 'export PATH=$SPARK_HOME/bin:$PATH' >> ~/.bashrc
echo 'export PYTHONPATH=$SPARK_HOME/python:$PYTHONPATH' >> ~/.bashrc
echo 'export PYSPARK_DRIVER_PYTHON=jupyter' >> ~/.bashrc
echo 'export PYSPARK_DRIVER_PYTHON_OPTS=notebook' >> ~/.bashrc
echo 'export PYSPARK_PYTHON=python3.9' >> ~/.bashrc
```

Note

PySpark requires the same minor version of Python in both driver and workers. This is why we specify what exact version to use in the `PYSPARK_PYTHON` variable.

> **Important**
>
> Please do not forget to reload your interactive shell session. [1]

Workaround for Jupyter Notebooks in Linux

If you start a PySpark shell (i.e., `pyspark`) and get a "Access to the file was denied after starting…", then you could try the following workround. [2]

```
jupyter notebook --generate-config
sed -i '/# c.NotebookApp.use_redirect_file/s/$*True/False/g' ~/.jupyter/jupyter_notebook_config.py
sed -i '/c.NotebookApp.use_redirect_file/s/^#*\s*//g' ~/.jupyter/jupyter_notebook_config.py
```

---

[1] https://www.delftstack.com/howto/linux/reload-bashrc/

[2] https://github.com/jupyter/notebook/issues/4353#issuecomment-570564277

Introduction to RDD

In this first session, we will introduce what is a Resilient Distributed Dataset (RDD). Please refer to the original paper for in-depth details [1].

To understand how Spark works, we need to understand the essence of RDD. Long story short, an RDD **represents a fault-tolerant collection of elements partitioned across the nodes of a cluster that can be operated in parallel**. We will chop the last sentence into pieces now.

Processing Logic Expressed as RDD Operations

We use RDDs to express a certain processic logic we want to apply to a dataset. For example, finding the average number of days required to recover from a certain disease.

Then, Spark makes its magic to **schedule** and **execute** our data processing logic on a distributed fashion.

If we look behind the scenes, the Spark runtime requires to determine the order of execution of RDDs, and make sure the execution is fault-tolerant. It uses the following pieces of information for the aforementioned purposes:

- Lineage
  - Dependencies on parent RDDs
- Fault-tolerance
  - The partitions that makes the whole dataset: used to execute in **parallel** to speed up the computation with **executors**.
  - The function for computing all the rows in the dataset: provided by users (i.e., "you"). Each **executor** in the cluster execute this function against each row in each partition.

With the above information, Spark can reproduce the RDD in case of failure scenarios.

Quick Demo

Prepare a Jupyter Kernel

You will need to prepare a Jupyter kernel in order to run this notebook on your local environment.

> **Note**
>
> This course relies on Poetry as package manager. Commands below can might slightly differ if you are using a different strategy (e.g., Pipenv or Conda, just to mention a few).

```
poetry shell
ipython kernel install --name "bda-labs" --user
```

▶ Details

Initialize Spark

We need to do some preparation first. In the next snippet, we will import the SparkContext and SparkConf classes.

Now we we proceed to create the **configuration** for our application and a **context** which tells Spark how to access the execution environment (local or a cluster).

```
from pyspark import SparkContext, SparkConf

# we use "local" to indicate we're running in local mode
conf = SparkConf().setAppName("intro-to-rdd").setMaster("local")
sc = SparkContext(conf=conf)
```

```
WARNING: An illegal reflective access operation has occurred
WARNING: Illegal reflective access by org.apache.spark.unsafe.Platform
(file:/opt/hostedtoolcache/Python/3.9.10/x64/lib/python3.9/site-
packages/pyspark/jars/spark-unsafe_2.12-3.2.1.jar) to constructor
java.nio.DirectByteBuffer(long,int)
WARNING: Please consider reporting this to the maintainers of
org.apache.spark.unsafe.Platform
WARNING: Use --illegal-access=warn to enable warnings of further illegal reflective
access operations
WARNING: All illegal access operations will be denied in a future release
```

```
Using Spark's default log4j profile: org/apache/spark/log4j-defaults.properties
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use
setLogLevel(newLevel).
```

```
22/03/07 12:29:51 WARN NativeCodeLoader: Unable to load native-hadoop library for
your platform... using builtin-java classes where applicable
```

SparkConf

We triggered a couple of actions with the above code. To start with, we created a `SparkConfig` object and chained two important configurations: - The Spark application name. - The URL where the `master node` can be located. **Setting it to `"local"` is a special configuration to indicate we are running on the same host where this code is being executed.**

Note: it is important to notice that Spark runs on a JVM. When a `SparkConf` is created, it will load values from `spark.*` Java system properties. If we make such properties available to the process running Spark, then they would be picked up.

Let's inspect a couple of common Spark configuration properties:

```
print(f"spark.app.name: {conf.get('spark.app.name')}")
print(f"spark.master: {conf.get('spark.master')}")
print(f"spark.home: {conf.get('spark.home')}")
```

```
spark.app.name: intro-to-rdd
spark.master: local
spark.home: None
```

So far so good. We get the same value we chained to the `SparkConf` object before.

Homework/self-research:

- Why don't we have a value for `spark.home`?
- Should we care?

Should we want to know all the properties available, then the following snippet might help.

```
for p in sorted(conf.getAll(), key=lambda p: p[0]):
    print(p)
```

```
('spark.app.name', 'intro-to-rdd')
('spark.master', 'local')
```

SparkContext

`SparkContext` is at the hearth of Spark. It is the main entry point for Spark that representes the connection of the "driver program" to a Spark cluster. **You must get familiarized with it**.

We can pass several parameters to it, from which two of them are mandatory: `master` and `appName`. In our case, we passed such information wrapped into a `SparkConf` object.

> **Attention**
>
> - `SparkContext` is **always** created on the driver and **it is not serialized**. Thus, it cannot be shipped to workers.
> - We can have one `SparkContext` per application at most. Try to run the cell where we created the `SparkContext` and see what happens!

> **Note**
>
> Actually, only one `SparkContext` can be active per JVM. If we want to create a new one, we must call the `stop()` method to our existing `SparkContext` object first.

Another consequence of passing a `SparkConf` object to the `SparkContext` constructor is **immutable configuration**. The `SparkConf` object is cloned and can no longer be modified. Let's see it in action:

```
# Is our SparkConf object the same we get from SparkContext?
print(f"conf == sc.getConf() --> {conf == sc.getConf()}")
```

```
conf == sc.getConf() --> False
```

Define an RDD

Let's start by defining a very simple RDD. We can think of it as data points indicating the recovery days for a certain disease.

```
recovery_days_per_disease = [("disease_1", [3, 6, 9, 10]), ("disease_2", [11, 11,
10, 9])]
rdd = sc.parallelize(recovery_days_per_disease)
```

Now we can operate on it. For example, we can compute the average.

```
rdd.mapValues(lambda x: sum(x) / len(x)).collect()
```

```
[Stage 0:>                                                          (0 + 1) / 1]
```

```
[('disease_1', 7.0), ('disease_2', 10.25)]
```

References

[1] Matei Zaharia, Mosharaf Chowdhury, Tathagata Das, Ankur Dave, Justin Ma, Murphy McCauly, Michael J Franklin, Scott Shenker, and Ion Stoica. Resilient distributed datasets: a fault-tolerant abstraction for in-memory cluster computing. In *9th USENIX Symposium on Networked Systems Design and Implementation (NSDI 12)*, 15–28. 2012.

Introduction to the DataFrame API

In this section, we will introduce the DataFrame and Dataset APIs.

We will use a small subset from the Record Linkage Comparison Data Set, borrowed from UC Irvine Machine Learning Repository. It consists of several CSV files with match scores for patients in a Germany hospital, but we will use only one of them for the sake of simplicity. Please consult [1] and [2] for more details regarding the data sets and research.

Setup

- Setup a `SparkSession` to work with the Dataset and DataFrame API
- Unzip the `scores.zip` file located under `data` folder.

```
from pyspark import SparkContext, SparkConf

conf = SparkConf().setAppName("intro-to-df").setMaster("local")
sc = SparkContext(conf=conf)
# Avoid polluting the console with warning messages
sc.setLogLevel("ERROR")
```

```
WARNING: An illegal reflective access operation has occurred
WARNING: Illegal reflective access by org.apache.spark.unsafe.Platform
(file:/opt/hostedtoolcache/Python/3.9.10/x64/lib/python3.9/site-
packages/pyspark/jars/spark-unsafe_2.12-3.2.1.jar) to constructor
java.nio.DirectByteBuffer(long,int)
WARNING: Please consider reporting this to the maintainers of
org.apache.spark.unsafe.Platform
WARNING: Use --illegal-access=warn to enable warnings of further illegal reflective
access operations
WARNING: All illegal access operations will be denied in a future release
```

```
Using Spark's default log4j profile: org/apache/spark/log4j-defaults.properties
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use
setLogLevel(newLevel).
```

```
22/03/07 12:29:59 WARN NativeCodeLoader: Unable to load native-hadoop library for
your platform... using builtin-java classes where applicable
```

Create a SparkSession to work with the DataFrame API

```
from pyspark.sql import SparkSession

spark = SparkSession(sc)
```

Unzip the scores file, if it was not done already

```
from os import path
scores_zip = path.join("data", "scores.zip")
scores_csv = path.join("data", "scores.csv")

%set_env SCORES_ZIP=$scores_zip
%set_env SCORES_CSV=$scores_csv
```

```
env: SCORES_ZIP=data/scores.zip
env: SCORES_CSV=data/scores.csv
```

```
%%bash
command -v unzip >/dev/null 2>&1 || { echo >&2 "unzip command is not installed.
Aborting."; exit 1; }
[[ -f "$SCORES_CSV" ]] && { echo "file data/$SCORES_CSV already exist. Skipping.";
exit 0; }

[[ -f "$SCORES_ZIP" ]] || { echo "file data/$SCORES_ZIP does not exist.
Aborting."; exit 1; }

echo "Unzip file $SCORES_ZIP"
unzip "$SCORES_ZIP" -d data
```

```
Unzip file data/scores.zip
```

```
Archive:  data/scores.zip
```

```
  inflating: data/scores.csv
```

```
  inflating: data/__MACOSX/._scores.csv
```

```
! head "$SCORES_CSV"
```

```
"id_1","id_2","cmp_fname_c1","cmp_fname_c2","cmp_lname_c1","cmp_lname_c2","cmp_sex"
,"cmp_bd","cmp_bm","cmp_by","cmp_plz","is_match"
37291,53113,0.833333333333333,?,1,?,1,1,1,1,0,TRUE
39086,47614,1,?,1,?,1,1,1,1,1,TRUE
70031,70237,1,?,1,?,1,1,1,1,1,TRUE
84795,97439,1,?,1,?,1,1,1,1,1,TRUE
36950,42116,1,?,1,1,1,1,1,1,1,TRUE
42413,48491,1,?,1,?,1,1,1,1,1,TRUE
25965,64753,1,?,1,?,1,1,1,1,1,TRUE
49451,90407,1,?,1,?,1,1,1,1,0,TRUE
39932,40902,1,?,1,?,1,1,1,1,1,TRUE
```

Loading the Scores CSV file into a DataFrame

References

[1] Irene Schmidtmann, Gaël Hammer, Murat Sariyar, Aslihan Gerhold-Ay, and Körperschaft des öffentlichen Rechts. Evaluation des krebsregisters nrw schwerpunkt record linkage. *Abschlußbericht vom*, 2009.

[2] Murat Sariyar, Andreas Borg, and Klaus Pommerening. Controlling false match rates in record linkage using extreme value theory. *Journal of biomedical informatics*, 44(4):648–654, 2011.

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