



Learning Apache Spark with Python

Release v1.0

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March 09, 2019

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Welcome to my **Learning Apache Spark with Python** note! In this note, you will learn a wide array of concepts about **PySpark** in Data Mining, Text Mining, Machine Learning and Deep Learning. The PDF version can be downloaded from [HERE](#).

**CHAPTER
ONE**

PREFACE

1.1 About

1.1.1 About this note

This is a shared repository for [Learning Apache Spark Notes](#). The PDF version can be downloaded from [HERE](#). The first version was posted on Github in [ChenFeng \(\[Feng2017\]\)](#). This shared repository mainly contains the self-learning and self-teaching notes from Wenqiang during his [IMA Data Science Fellowship](#). The reader is referred to the repository <https://github.com/runawayhorse001/LearningApacheSpark> for more details about the dataset and the .ipynb files.

In this repository, I try to use the detailed demo code and examples to show how to use each main functions. If you find your work wasn't cited in this note, please feel free to let me know.

Although I am by no means an data mining programming and Big Data expert, I decided that it would be useful for me to share what I learned about PySpark programming in the form of easy tutorials with detailed example. I hope those tutorials will be a valuable tool for your studies.

The tutorials assume that the reader has a preliminary knowledge of programing and Linux. And this document is generated automatically by using [sphinx](#).

1.1.2 About the authors

- **Wenqiang Feng**

- Data Scientist and PhD in Mathematics
- University of Tennessee at Knoxville
- Email: von198@gmail.com

- **Biography**

Wenqiang Feng is Data Scientist within DST's Applied Analytics Group. Dr. Feng's responsibilities include providing DST clients with access to cutting-edge skills and technologies, including Big Data analytic solutions, advanced analytic and data enhancement techniques and modeling.

Dr. Feng has deep analytic expertise in data mining, analytic systems, machine learning algorithms, business intelligence, and applying Big Data tools to strategically solve industry problems in a cross-functional business. Before joining DST, Dr. Feng was an IMA Data Science Fellow at The Institute for Mathematics and its Applications (IMA) at the University of Minnesota. While there, he helped startup companies make marketing decisions based on deep predictive analytics.

Dr. Feng graduated from University of Tennessee, Knoxville, with Ph.D. in Computational Mathematics and Master's degree in Statistics. He also holds Master's degree in Computational Mathematics from Missouri University of Science and Technology (MST) and Master's degree in Applied Mathematics from the University of Science and Technology of China (USTC).

- **Declaration**

The work of Wenqiang Feng was supported by the IMA, while working at IMA. However, any opinion, finding, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the IMA, UTK and DST.

1.2 Motivation for this tutorial

I was motivated by the [IMA Data Science Fellowship](#) project to learn PySpark. After that I was impressed and attracted by the PySpark. And I foud that:

1. It is no exaggeration to say that Spark is the most powerful Bigdata tool.
2. However, I still found that learning Spark was a difficult process. I have to Google it and identify which one is true. And it was hard to find detailed examples which I can easily learned the full process in one file.
3. Good sources are expensive for a graduate student.

1.3 Copyright notice and license info

This Learning Apache Spark with Python PDF file is supposed to be a free and living document, which is why its source is available online at <https://runawayhorse001.github.io/LearningApacheSpark/pyspark.pdf>. But this document is licensed according to both [MIT License](#) and [Creative Commons Attribution-NonCommercial 2.0 Generic \(CC BY-NC 2.0\) License](#).

When you plan to use, copy, modify, merge, publish, distribute or sublicense, Please see the terms of those licenses for more details and give the corresponding credits to the author.

1.4 Acknowledgement

At here, I would like to thank Ming Chen, Jian Sun and Zhongbo Li at the University of Tennessee at Knoxville for the valuable dissussion and thank the generous anonymous authors for providing the detailed solutions and source code on the internet. Without those help, this repository would not have been possible to be made. Wenqiang also would like to thank the [Institute for Mathematics and Its Applications \(IMA\)](#) at [University of Minnesota, Twin Cities](#) for support during his IMA Data Scientist Fellow visit.

A special thank you goes to [Dr. Haiping Lu](#), Lecturer in Machine Learning at Department of Computer Science, University of Sheffield, for recommending and heavily using my tutorial in his teaching class and for the valuable suggestions.

1.5 Feedback and suggestions

Your comments and suggestions are highly appreciated. I am more than happy to receive corrections, suggestions or feedbacks through email (von198@gmail.com) for improvements.

WHY SPARK WITH PYTHON ?

Chinese proverb

Sharpening the knife longer can make it easier to hack the firewood – old Chinese proverb

I want to answer this question from the following two parts:

2.1 Why Spark?

I think the following four main reasons from [Apache Spark™](#) official website are good enough to convince you to use Spark.

1. Speed

Run programs up to 100x faster than Hadoop MapReduce in memory, or 10x faster on disk.

Apache Spark has an advanced DAG execution engine that supports acyclic data flow and in-memory computing.

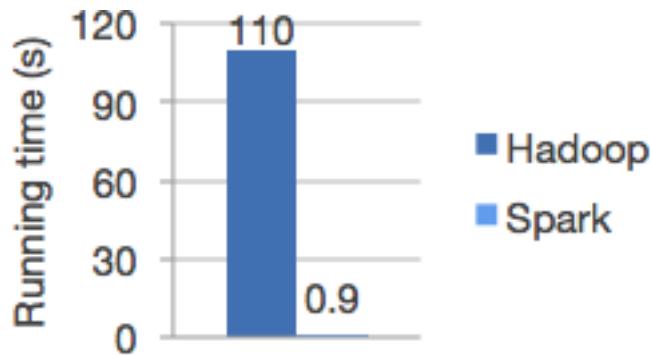


Figure 2.1: Logistic regression in Hadoop and Spark

2. Ease of Use

Write applications quickly in Java, Scala, Python, R.

Spark offers over 80 high-level operators that make it easy to build parallel apps. And you can use it interactively from the Scala, Python and R shells.

3. Generality

Combine SQL, streaming, and complex analytics.

Spark powers a stack of libraries including SQL and DataFrames, MLlib for machine learning, GraphX, and Spark Streaming. You can combine these libraries seamlessly in the same application.

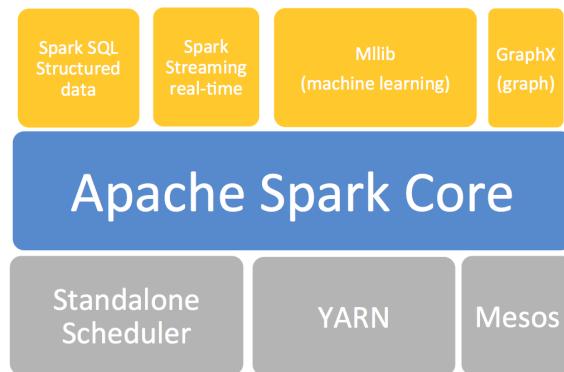


Figure 2.2: The Spark stack

4. Runs Everywhere

Spark runs on Hadoop, Mesos, standalone, or in the cloud. It can access diverse data sources including HDFS, Cassandra, HBase, and S3.



Figure 2.3: The Spark platform

2.2 Why Spark with Python (PySpark)?

No matter you like it or not, Python has been one of the most popular programming languages.

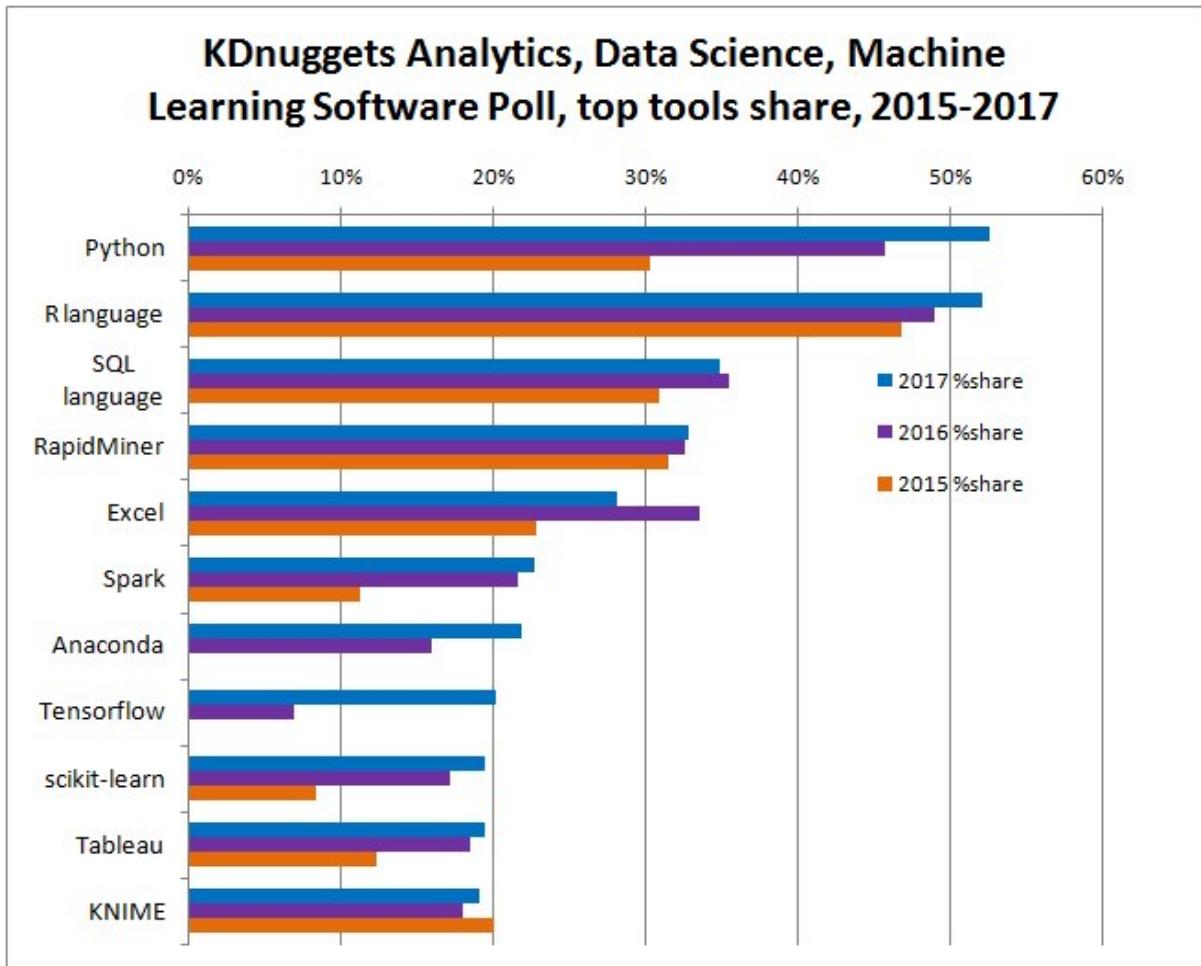


Figure 2.4: KDnuggets Analytics/Data Science 2017 Software Poll from [kdnnuggets](#).

CHAPTER
THREE

CONFIGURE RUNNING PLATFORM

Chinese proverb

Good tools are prerequisite to the successful execution of a job. – old Chinese proverb

A good programming platform can save you lots of troubles and time. Herein I will only present how to install my favorite programming platform and only show the easiest way which I know to set it up on Linux system. If you want to install on the other operator system, you can Google it. In this section, you may learn how to set up Pyspark on the corresponding programming platform and package.

3.1 Run on Databricks Community Cloud

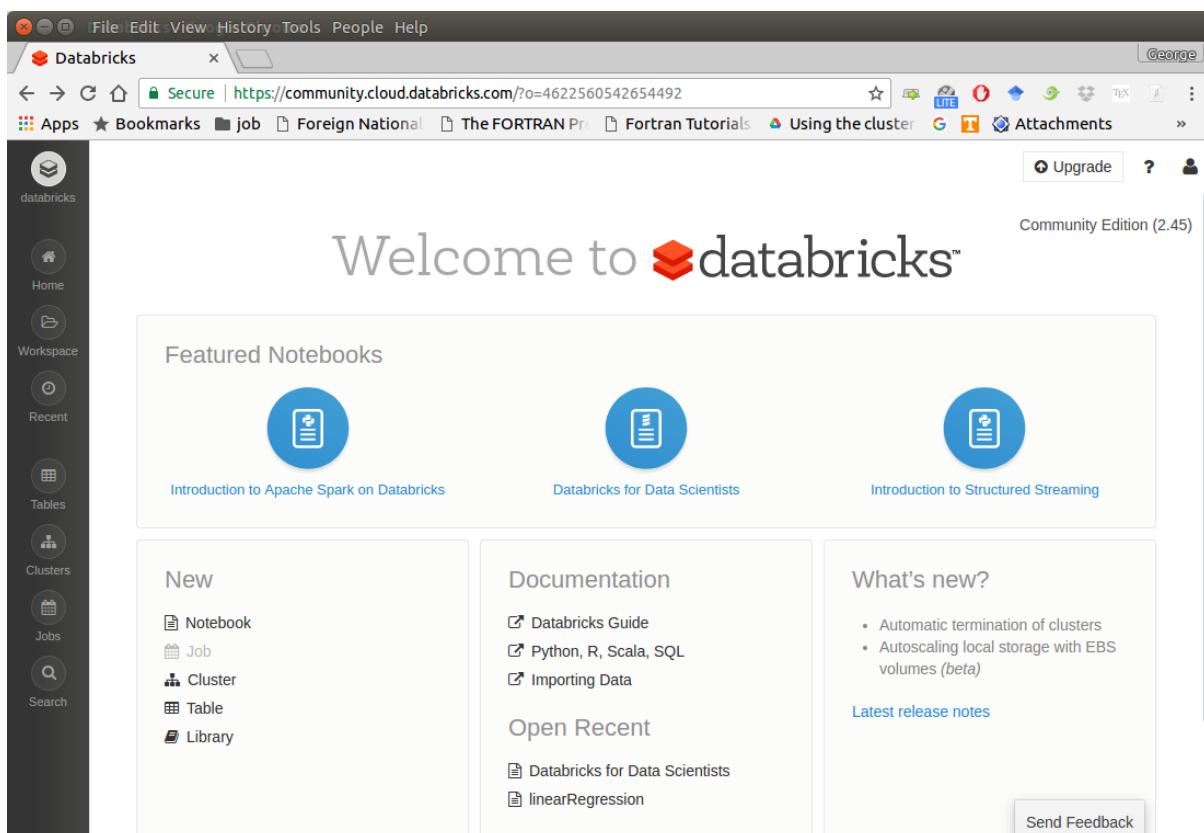
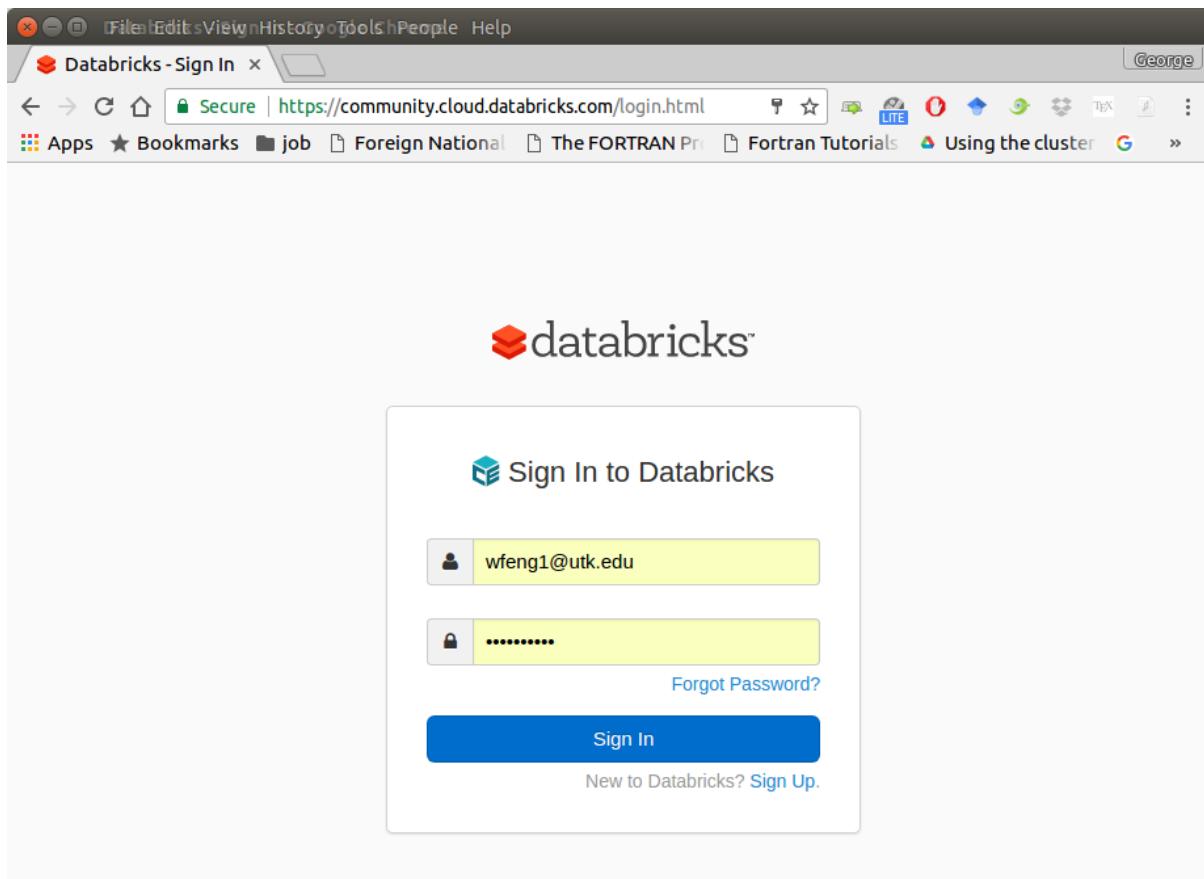
If you don't have any experience with Linux or Unix operator system, I would love to recommend you to use Spark on Databricks Community Cloud. Since you do not need to setup the Spark and it's totally free for Community Edition. Please follow the steps listed below.

1. Sign up a account at: <https://community.cloud.databricks.com/login.html>
2. Sign in with your account, then you can creat your cluster(machine), table(dataset) and notebook(code).
3. Create your cluster where your code will run
4. Import your dataset

Note: You need to save the path which appears at Uploaded to DBFS: /File-Store/tables/05rmhuqv1489687378010/. Since we will use this path to load the dataset.

5. Creat your notebook

After finishing the above 5 steps, you are ready to run your Spark code on Databricks Community Cloud. I will run all the following demos on Databricks Community Cloud. Hopefully, when you run the demo code, you will get the following results:



The screenshot shows the 'Create Cluster' interface in the Databricks web interface. The left sidebar has 'Clusters' selected. The main area shows a 'New Cluster' form with the following details:

- Cluster Name:** MLmachine
- Databricks Runtime Version:** Spark 2.1 (Auto-updating, Scala 2.10)
- Instance:** Free 6GB Memory. A note states: "As a Community Edition user, your cluster will automatically terminate after an idle period of two hours." A link to "upgrade your Databricks subscription" is provided.
- AWS:** Spark
- Availability Zone:** us-west-2c

At the bottom right is a "Send Feedback" button.

The screenshot shows the 'Create Table' interface in the Databricks web interface. The left sidebar has 'Tables' selected. The main area shows a 'Data Import' form with the following details:

- Data Source:** File
- File(s):** A large input field with the placeholder "Drop file or click here to upload".

On the left sidebar, under 'Tables', there is a list of existing tables: advertising_csv, crab, praedict, and raw_classified_txt. At the bottom right is a "Send Feedback" button.

Create Table

File(s)

Heart (1).csv
19.9 KB Remove file

Uploaded to DBFS /FileStore/tables/nlqogm7b1495157186117/Heart__1_~466d4.csv

Preview Table

Table Details

Table name: heart

	_c0	Age	Sex	ChestPain	RestBP
1	63	1	typical	145	
2	67	1	asymptomatic	160	

File type: CSV

Column Delimiter: ,

First row is header

Create Table

Create Notebook

Name: test

Language: Python

Cluster: MLMachine (6 GB, Failed to atta

Create

Community Edition (2.45)

Featured Notebooks

New

- Notebook
- Job
- Cluster
- Table
- Library

Documentation

- Databricks Guide
- Python, R, Scala, SQL
- Importing Data

Open Recent

- DataFrames for Data Scientists
- linearRegression

What's new?

- Automatic termination of clusters
- Autoscaling local storage with EBS volumes (*beta*)

Latest release notes

Send Feedback

The screenshot shows a Databricks notebook interface. On the left is a sidebar with icons for Home, Workspace, Recent, Tables, Clusters, Jobs, and Search. The main area has a title bar 'linearRegression (Python)'. Below it are several command cells:

- Cmd 1:** **1.Linear Regression with PySpark on Databricks**
Author: Wenqiang Feng
- Cmd 2:** Set up SparkSession
- Cmd 3:** PySpark session configuration code:

```
1 from pyspark.sql import SparkSession
2
3 spark = SparkSession \
4     .builder \
5     .appName("Python Spark Linear Regression Example") \
6     .config("spark.some.config.option", "some-value") \
7     .getOrCreate()
```

Command took 0.16 seconds -- by wfeng1@utk.edu at 4/2/2017, 11:12:21 PM on MLmachine
- Cmd 4:** Load dataset
- Cmd 5:** Data loading code:

```
1 df = spark.read.format('com.databricks.spark.csv')\
2     .options(header='true', \
3             inferSchema='true')\
4     .load("/FileStore/tables/05rmhuvq1489687378010/", header= True)
```

Send Feedback

```
+---+---+---+---+---+
| _c0 | TV | Radio | Newspaper | Sales |
+---+---+---+---+---+
| 1 | 230.1 | 37.8 | 69.2 | 22.1 |
| 2 | 44.5 | 39.3 | 45.1 | 10.4 |
| 3 | 17.2 | 45.9 | 69.3 | 9.3 |
| 4 | 151.5 | 41.3 | 58.5 | 18.5 |
| 5 | 180.8 | 10.8 | 58.4 | 12.9 |
+---+---+---+---+---+
only showing top 5 rows
```

```
root
| -- _c0: integer (nullable = true)
| -- TV: double (nullable = true)
| -- Radio: double (nullable = true)
| -- Newspaper: double (nullable = true)
| -- Sales: double (nullable = true)
```

3.2 Configure Spark on Mac and Ubuntu

3.2.1 Installing Prerequisites

I will strongly recommend you to install [Anaconda](#), since it contains most of the prerequisites and support multiple Operator Systems.

1. Install Python

Go to Ubuntu Software Center and follow the following steps:

1. Open Ubuntu Software Center

2. Search for python

3. And click Install

Or Open your terminal and using the following command:

```
sudo apt-get install build-essential checkinstall  
sudo apt-get install libreadline-gplv2-dev libncursesw5-dev libssl-dev  
      libsqlite3-dev tk-dev libgdbm-dev libc6-dev libbz2-dev  
sudo apt-get install python  
sudo easy_install pip  
sudo pip install ipython
```

3.2.2 Install Java

Java is used by many other softwares. So it is quite possible that you have already installed it. You can by using the following command in Command Prompt:

```
java -version
```

Otherwise, you can follow the steps in [How do I install Java for my Mac?](#) to install java on Mac and use the following command in Command Prompt to install on Ubuntu:

```
sudo apt-add-repository ppa:webupd8team/java  
sudo apt-get update  
sudo apt-get install oracle-java8-installer
```

3.2.3 Install Java SE Runtime Environment

I installed ORACLE Java JDK.

Warning: Installing Java and Java SE Runtime Environment steps are very important, since Spark is a domain-specific language written in Java.

You can check if your Java is available and find it's version by using the following command in Command Prompt:

```
java -version
```

If your Java is installed successfully, you will get the similar results as follows:

```
java version "1.8.0_131"  
Java(TM) SE Runtime Environment (build 1.8.0_131-b11)  
Java HotSpot(TM) 64-Bit Server VM (build 25.131-b11, mixed mode)
```

3.2.4 Install Apache Spark

Actually, the Pre-build version doesn't need installation. You can use it when you unpack it.

1. Download: You can get the Pre-built Apache Spark™ from [Download Apache Spark™](#).
2. Unpack: Unpack the Apache Spark™ to the path where you want to install the Spark.

3. Test: Test the Prerequisites: change the direction
spark-#.#.#-bin-hadoop#.#/bin and run

```
./pyspark
```

```
Python 2.7.13 |Anaconda 4.4.0 (x86_64)| (default, Dec 20 2016, 23:05:08)
[GCC 4.2.1 Compatible Apple LLVM 6.0 (clang-600.0.57)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
Anaconda is brought to you by Continuum Analytics.
Please check out: http://continuum.io/thanks and https://anaconda.org
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).
17/08/30 13:30:12 WARN NativeCodeLoader: Unable to load native-hadoop
library for your platform... using builtin-java classes where applicable
17/08/30 13:30:17 WARN ObjectStore: Failed to get database global_temp,
returning NoSuchObjectException
Welcome to
```

```
    /__/_/____/____/____/____/____/
   _\ \ \_\_ \_\_ \_\_ \_\_ \_\_ \_\_
  /__ / .__/\_\_,_/_/ /_/\_\_\_ \
  /__/                                version 2.1.1
```

```
Using Python version 2.7.13 (default, Dec 20 2016 23:05:08)
SparkSession available as 'spark'.
```

3.2.5 Configure the Spark

1. **Mac Operator System:** open your `bash_profile` in Terminal

```
vim ~/.bash_profile
```

And add the following lines to your `bash_profile` (remember to change the path)

```
# add for spark
export SPARK_HOME=your_spark_installation_path
export PATH=$PATH:$SPARK_HOME/bin:$SPARK_HOME/sbin
export PATH=$PATH:$SPARK_HOME/bin
export PYSPARK_DRIVER_PYTHON="jupyter"
export PYSPARK_DRIVER_PYTHON_OPTS="notebook"
```

At last, remember to source your `bash_profile`

```
source ~/.bash_profile
```

2. **Ubuntu Operator System:** open your `bashrc` in Terminal

```
vim ~/.bashrc
```

And add the following lines to your `bashrc` (remember to change the path)

```
# add for spark
export SPARK_HOME=your_spark_installation_path
export PATH=$PATH:$SPARK_HOME/bin:$SPARK_HOME/sbin
export PATH=$PATH:$SPARK_HOME/bin
```

```
export PYSPARK_DRIVER_PYTHON=jupyter
export PYSPARK_DRIVER_PYTHON_OPTS="notebook"
```

At last, remember to source your bashrc

```
source ~/.bashrc
```

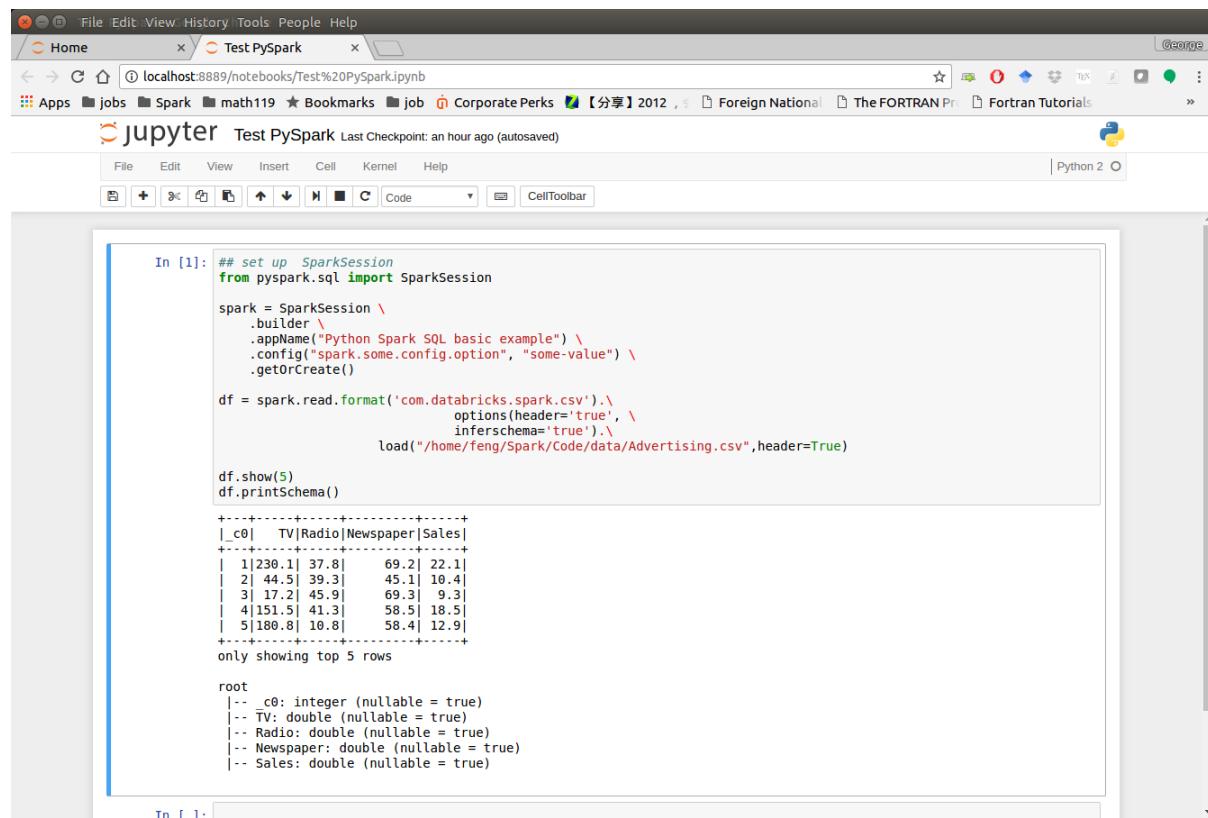
3.3 Configure Spark on Windows

Installing open source software on Windows is always a nightmare for me. Thanks for Deelesh Mandloi. You can follow the detailed procedures in the blog [Getting Started with PySpark on Windows](#) to install the Apache Spark™ on your Windows Operator System.

3.4 PySpark With Text Editor or IDE

3.4.1 PySpark With Jupyter Notebook

After you finishing the above setup steps in [Configure Spark on Mac and Ubuntu](#), then you should be good to write and run your PySpark Code in Jupyter notebook.



The screenshot shows a Jupyter Notebook interface running on a Mac OS X desktop. The title bar says "George" and the window title is "Test PySpark". The URL in the address bar is "localhost:8889/notebooks/Test%20PySpark.ipynb". The notebook has one cell, "In [1]", containing Python code to set up a SparkSession and read a CSV file. The output shows the first five rows of the DataFrame and its schema.

```
In [1]: ## set up SparkSession
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark SQL basic example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()

df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', \
            inferschema='true') \
    .load("/home/feng/Spark/Code/data/Advertising.csv",header=True)

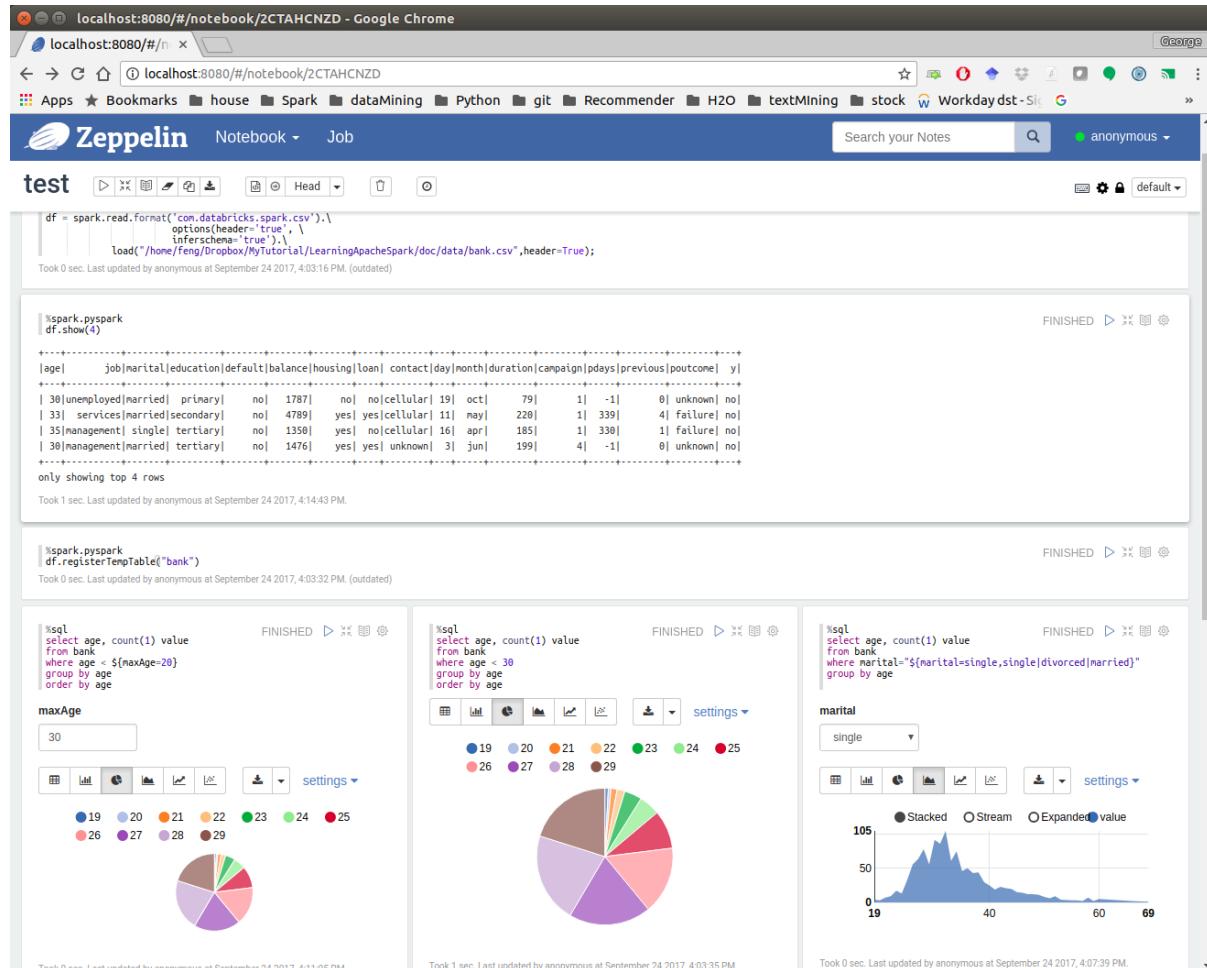
df.show(5)
df.printSchema()

+---+---+---+---+
|_c0| TV|Radio|Newspaper|Sales|
+---+---+---+---+
| 1|230.1| 37.8|   69.2| 22.1|
| 2| 44.5| 39.3|   45.1| 10.4|
| 3| 17.2| 45.9|   69.3|  9.3|
| 4|151.5| 41.3|   58.5| 18.5|
| 5|180.8| 10.8|   58.4| 12.9|
+---+---+---+---+
only showing top 5 rows

root
|-- _c0: integer (nullable = true)
|-- TV: double (nullable = true)
|-- Radio: double (nullable = true)
|-- Newspaper: double (nullable = true)
|-- Sales: double (nullable = true)
```

3.4.2 PySpark With Apache Zeppelin

After you finishing the above setup steps in [Configure Spark on Mac and Ubuntu](#), then you should be good to write and run your PySpark Code in Apache Zeppelin.



The screenshot shows a Apache Zeppelin notebook interface with several cells of PySpark code and their corresponding visualizations:

- Cell 1:** PySpark code to read a CSV file and show the first 4 rows.
- Cell 2:** PySpark code to register a temporary table named "bank" and show its schema.
- Cell 3:** SQL query to select age and count from bank where age is less than 30, grouped by age.
- Cell 4:** SQL query to select age and count from bank where marital status is single, divorced, or married, grouped by age.
- Data Visualizations:**
 - A pie chart showing the distribution of age groups (19-29) for the maxAge query.
 - A pie chart showing the distribution of age groups (19-29) for the marital query.
 - A histogram showing the count of ages (19-69) for the marital query.

3.4.3 PySpark With Sublime Text

After you finishing the above setup steps in [Configure Spark on Mac and Ubuntu](#), then you should be good to use Sublime Text to write your PySpark Code and run your code as a normal python code in Terminal.

```
python test_pyspark.py
```

Then you should get the output results in your terminal.

3.4.4 PySpark With Eclipse

If you want to run PySpark code on Eclipse, you need to add the paths for the **External Libraries** for your **Current Project** as follows:

```

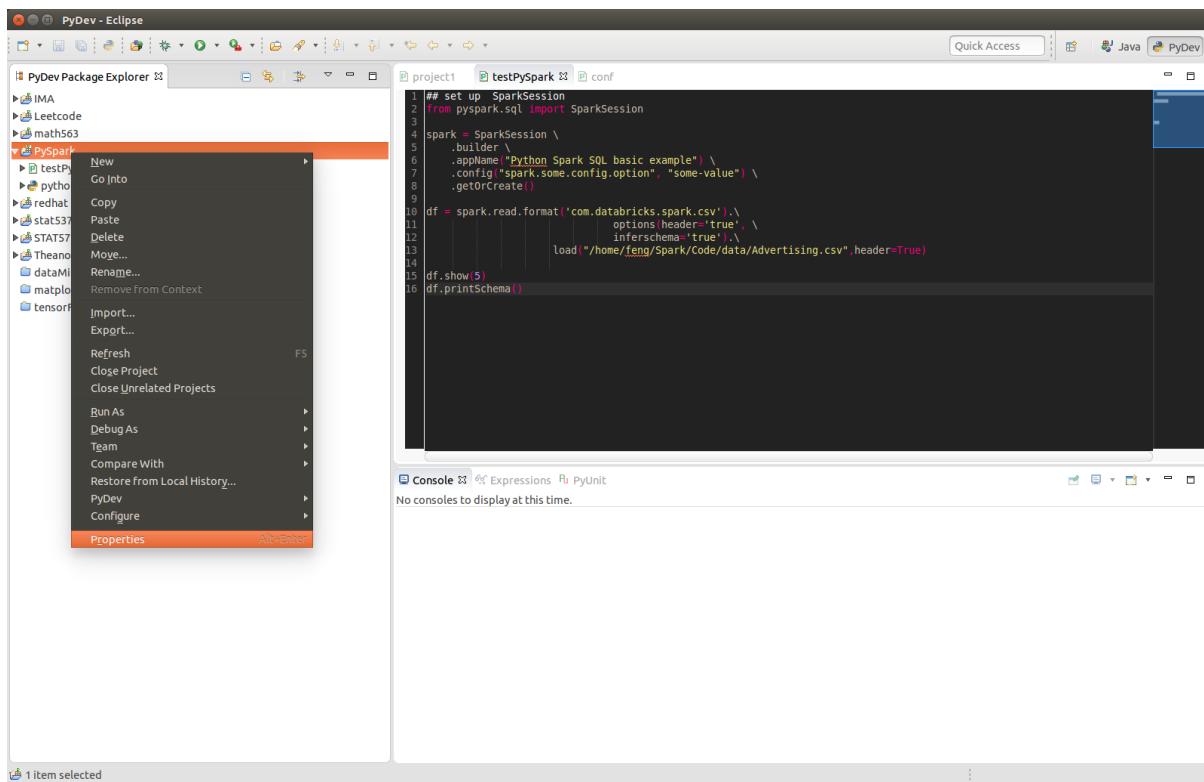
feng@feng-ThinkPad:~/Spark/Code$ python test_pyspark.py
## set up SparkSession
from pyspark.sql import SparkSession
spark = SparkSession \
    .builder \
    .appName("Python Spark SQL basic example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
df = spark.read.format('com.databricks.spark.csv')\
    .options(header='true', \
            inferSchema='true')\
    .load("/home/feng/Spark/Code/data/Advertising.csv")
df.show(5)
df.printSchema()

+---+---+---+---+
|_c0| TV|Radio|Newspaper|Sales|
+---+---+---+---+
| 1|230.1| 37.8| 69.2| 22.1|
| 2| 44.5| 39.3| 45.1| 10.4|
| 3| 17.2| 45.9| 69.3| 9.3|
| 4|151.5| 41.3| 58.5| 18.5|
| 5|180.8| 10.8| 58.4| 12.9|
+---+---+---+---+
only showing top 5 rows

root
|-- _c0: integer (nullable = true)
|-- TV: double (nullable = true)
|-- Radio: double (nullable = true)
|-- Newspaper: double (nullable = true)
|-- Sales: double (nullable = true)

feng@feng-ThinkPad:~/Spark/Code$ 
    
```

1. Open the properties of your project

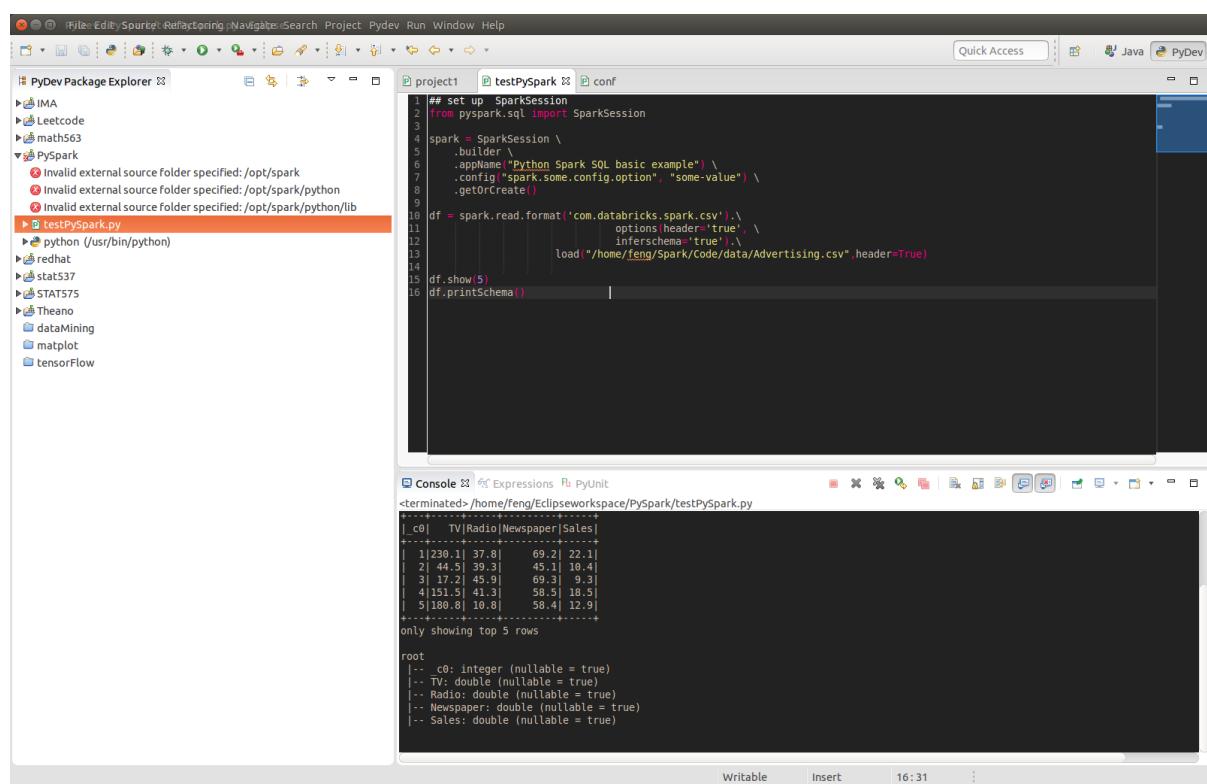
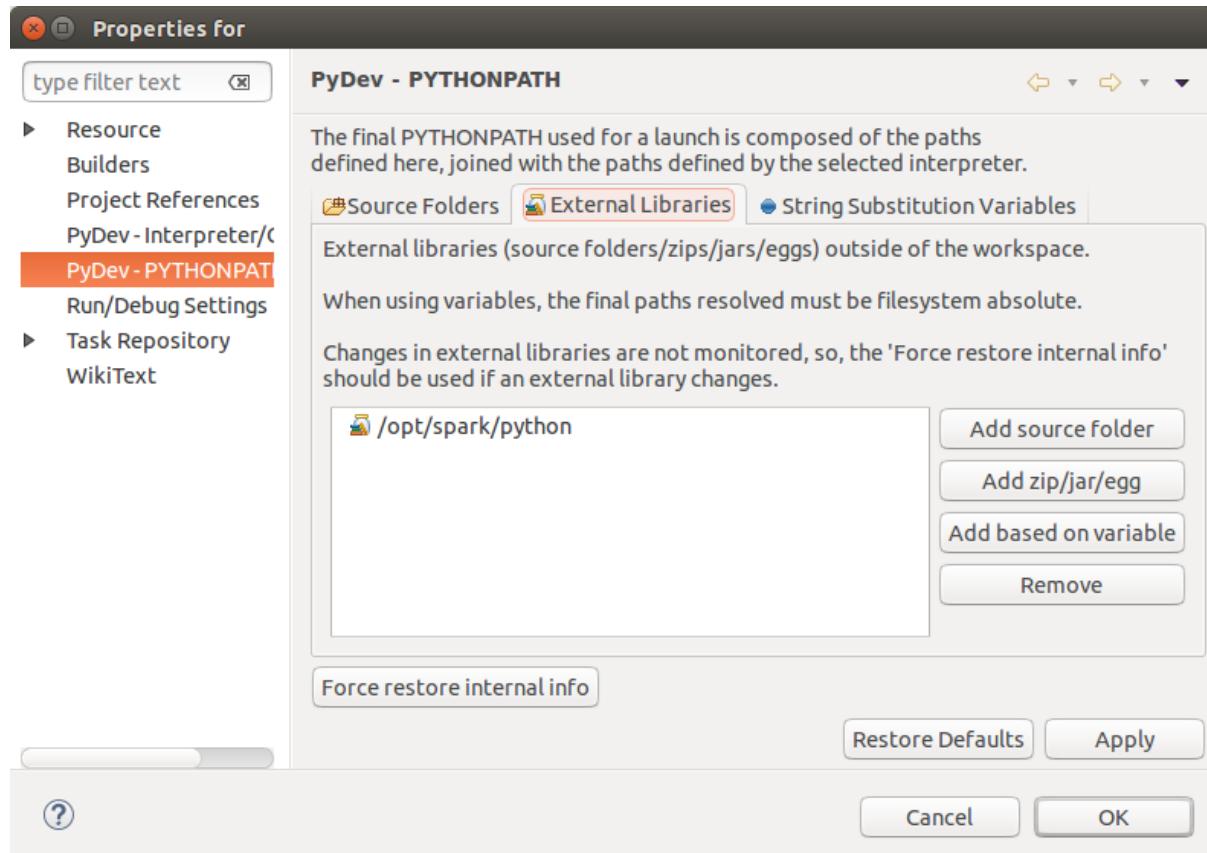


2. Add the paths for the External Libraries

And then you should be good to run your code on Eclipse with PyDev.

3.5 PySparkling Water: Spark + H2O

1. Download Sparkling Water from: <https://s3.amazonaws.com/h2o-release/sparkling-water/rel-2.4/5/index.html>



2. Test PySparkling

```
unzip sparkling-water-2.4.5.zip  
cd ~/sparkling-water-2.4.5/bin  
./pysparkling
```

If you have a correct setup for PySpark, then you will get the following results:

```
Using Spark defined in the SPARK_HOME=/Users/dt216661/spark environmental property
```

```
Python 3.7.1 (default, Dec 14 2018, 13:28:58)  
[GCC 4.2.1 Compatible Apple LLVM 6.0 (clang-600.0.57)] on darwin  
Type "help", "copyright", "credits" or "license" for more information.  
2019-02-15 14:08:30 WARN NativeCodeLoader:62 - Unable to load native-hadoop library for  
Setting default log level to "WARN".  
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)  
2019-02-15 14:08:31 WARN Utils:66 - Service 'SparkUI' could not bind on port 4040. Atte  
2019-02-15 14:08:31 WARN Utils:66 - Service 'SparkUI' could not bind on port 4041. Atte  
17/08/30 13:30:12 WARN NativeCodeLoader: Unable to load native-hadoop  
library for your platform... using builtin-java classes where applicable  
17/08/30 13:30:17 WARN ObjectStore: Failed to get database global_temp,  
returning NoSuchObjectException  
Welcome to
```

```
    /__/  
   / \ / \ / \ / \ / \ /  
  / \ \ / \ / \ / \ / \ /  
 / \ / . \ / \ / \ / \ / \ /  
 / \ / \ / \ / \ / \ / \ /  
version 2.4.0
```

```
Using Python version 3.7.1 (default, Dec 14 2018 13:28:58)  
SparkSession available as 'spark'.
```

3. Setup pysparkling with Jupyter notebook

Add the following alias to your bashrc (Linux systems) or bash_profile (Mac system)

```
alias sparkling="PYSPARK_DRIVER_PYTHON='ipython' PYSPARK_DRIVER_PYTHON_OPTS='--notebook'
```

4. Open pysparkling in terminal

```
sparkling
```

3.6 Set up Spark on Cloud

Following the setup steps in [Configure Spark on Mac and Ubuntu](#), you can set up your own cluster on the cloud, for example AWS, Google Cloud. Actually, for those clouds, they have their own Big Data tool. You can run them directly without any setting just like Databricks Community Cloud. If you want more details, please feel free to contact with me.

3.7 Demo Code in this Section

The code for this section is available for download test_pyspark, and the Jupyter notebook can be download from test_pyspark_ipynb.

- Python Source code

```
## set up SparkSession
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark SQL basic example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()

df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', \
            inferSchema='true') \
    .load("/home/feng/Spark/Code/data/Advertising.csv", header=True)

df.show(5)
df.printSchema()
```

CHAPTER
FOUR

AN INTRODUCTION TO APACHE SPARK

Chinese proverb

Know yourself and know your enemy, and you will never be defeated – idiom, from Sunzi's Art of War

4.1 Core Concepts

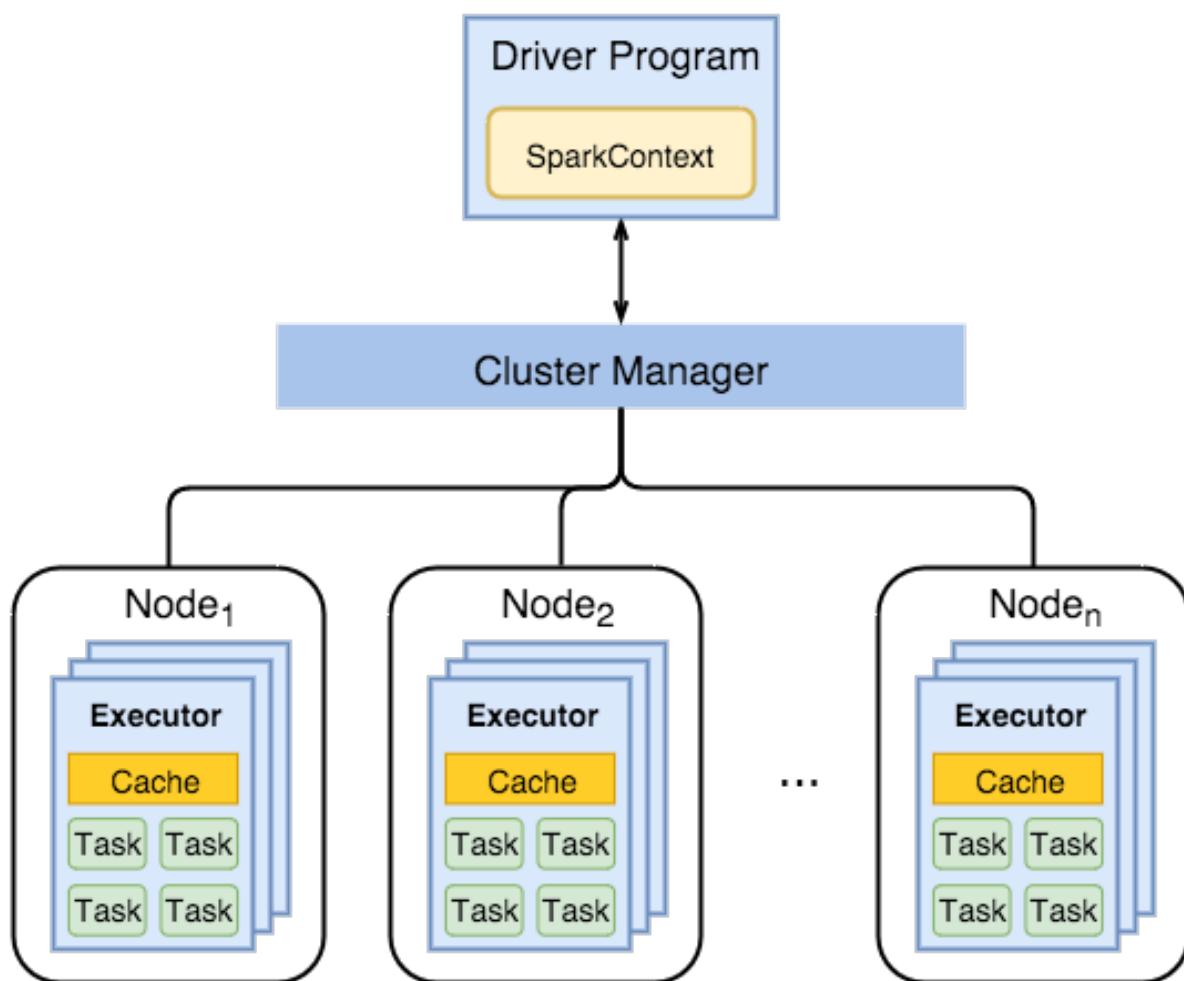
Most of the following content comes from [\[Kirillov2016\]](#). So the copyright belongs to **Anton Kirillov**. I will refer you to get more details from [Apache Spark core concepts, architecture and internals](#).

Before diving deep into how Apache Spark works, lets understand the jargon of Apache Spark

- Job: A piece of code which reads some input from HDFS or local, performs some computation on the data and writes some output data.
- Stages: Jobs are divided into stages. Stages are classified as a Map or reduce stages (Its easier to understand if you have worked on Hadoop and want to correlate). Stages are divided based on computational boundaries, all computations (operators) cannot be Updated in a single Stage. It happens over many stages.
- Tasks: Each stage has some tasks, one task per partition. One task is executed on one partition of data on one executor (machine).
- DAG: DAG stands for Directed Acyclic Graph, in the present context its a DAG of operators.
- Executor: The process responsible for executing a task.
- Master: The machine on which the Driver program runs
- Slave: The machine on which the Executor program runs

4.2 Spark Components

1. Spark Driver
 - separate process to execute user applications
 - creates SparkContext to schedule jobs execution and negotiate with cluster manager
2. Executors

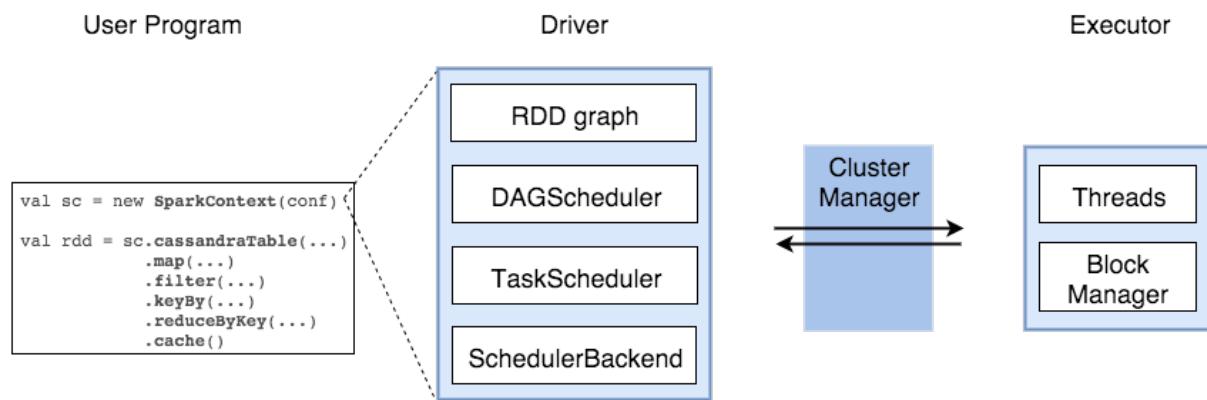


- run tasks scheduled by driver
- store computation results in memory, on disk or off-heap
- interact with storage systems

3. Cluster Manager

- Mesos
- YARN
- Spark Standalone

Spark Driver contains more components responsible for translation of user code into actual jobs executed on cluster:



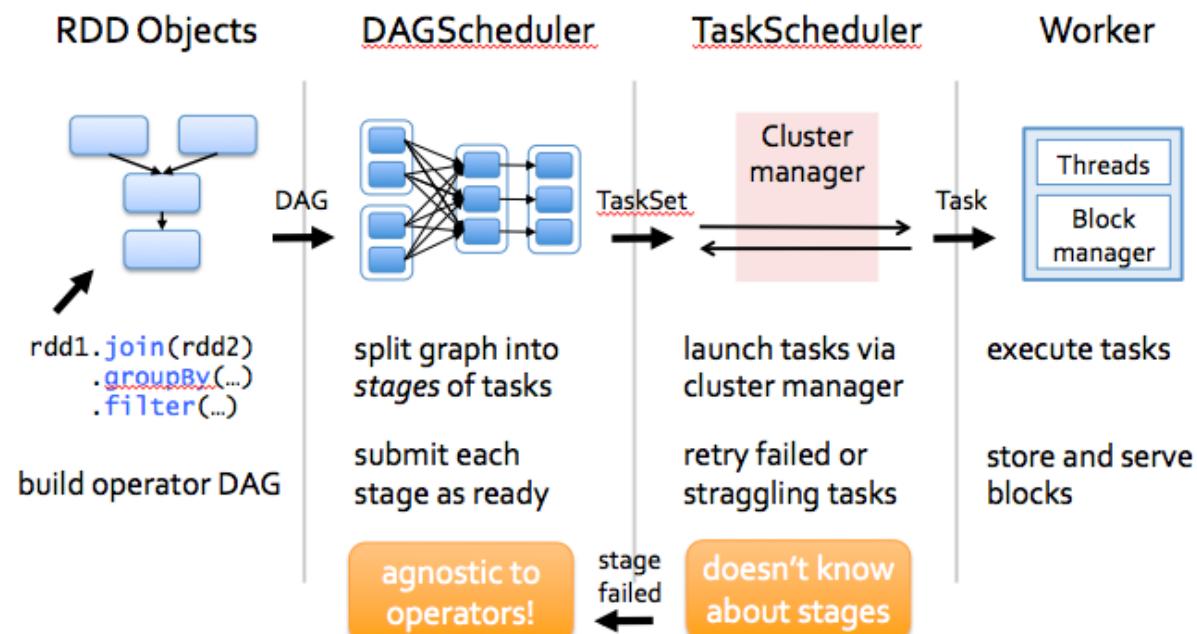
- **SparkContext**
 - represents the connection to a Spark cluster, and can be used to create RDDs, accumulators and broadcast variables on that cluster
- **DAGScheduler**
 - computes a DAG of stages for each job and submits them to TaskScheduler determines preferred locations for tasks (based on cache status or shuffle files locations) and finds minimum schedule to run the jobs
- **TaskScheduler**
 - responsible for sending tasks to the cluster, running them, retrying if there are failures, and mitigating stragglers
- **SchedulerBackend**
 - backend interface for scheduling systems that allows plugging in different implementations(Mesos, YARN, Standalone, local)
- **BlockManager**
 - provides interfaces for putting and retrieving blocks both locally and remotely into various stores (memory, disk, and off-heap)

4.3 Architecture

4.4 How Spark Works?

Spark has a small code base and the system is divided in various layers. Each layer has some responsibilities. The layers are independent of each other.

The first layer is the interpreter, Spark uses a Scala interpreter, with some modifications. As you enter your code in spark console (creating RDD's and applying operators), Spark creates a operator graph. When the user runs an action (like collect), the Graph is submitted to a DAG Scheduler. The DAG scheduler divides operator graph into (map and reduce) stages. A stage is comprised of tasks based on partitions of the input data. The DAG scheduler pipelines operators together to optimize the graph. For e.g. Many map operators can be scheduled in a single stage. This optimization is key to Sparks performance. The final result of a DAG scheduler is a set of stages. The stages are passed on to the Task Scheduler. The task scheduler launches tasks via cluster manager. (Spark Standalone/Yarn/Mesos). The task scheduler doesn't know about dependencies among stages.



CHAPTER
FIVE

PROGRAMMING WITH RDDS

Chinese proverb

If you only know yourself, but not your opponent, you may win or may lose. If you know neither yourself nor your enemy, you will always endanger yourself – idiom, from Sunzi's Art of War

RDD represents **Resilient Distributed Dataset**. An RDD in Spark is simply an immutable distributed collection of objects sets. Each RDD is split into multiple partitions (similar pattern with smaller sets), which may be computed on different nodes of the cluster.

5.1 Create RDD

Usually, there are two popular way to create the RDDs: loading an external dataset, or distributing a set of collection of objects. The following examples show some simplest ways to create RDDs by using `parallelize()` function which takes an already existing collection in your program and pass the same to the Spark Context.

1. By using `parallelize()` function

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark create RDD example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()

df = spark.sparkContext.parallelize([(1, 2, 3, 'a b c'),
                                    (4, 5, 6, 'd e f'),
                                    (7, 8, 9, 'g h i')]).toDF(['col1', 'col2', 'col3', 'col4'])
```

Then you will get the RDD data:

```
df.show()

+---+---+---+---+
| col1 | col2 | col3 | col4 |
+---+---+---+---+
|    1 |    2 |    3 | a b c |
|    4 |    5 |    6 | d e f |
|    7 |    8 |    9 | g h i |
+---+---+---+---+
```

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark create RDD example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()

myData = spark.sparkContext.parallelize([(1,2), (3,4), (5,6), (7,8), (9,10)])
```

Then you will get the RDD data:

```
myData.collect()

[(1, 2), (3, 4), (5, 6), (7, 8), (9, 10)]
```

2. By using `createDataFrame()` function

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark create RDD example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()

Employee = spark.createDataFrame([
    ('1', 'Joe', '70000', '1'),
    ('2', 'Henry', '80000', '2'),
    ('3', 'Sam', '60000', '2'),
    ('4', 'Max', '90000', '1')],
    ['Id', 'Name', 'Salary', 'DepartmentId']
)
```

Then you will get the RDD data:

```
+---+---+---+---+
| Id | Name | Salary | DepartmentId |
+---+---+---+---+
| 1 | Joe | 70000 | 1 |
| 2 | Henry | 80000 | 2 |
| 3 | Sam | 60000 | 2 |
| 4 | Max | 90000 | 1 |
+---+---+---+---+
```

3. By using `read` and `load` functions

1. Read dataset from .csv file

```
## set up SparkSession
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark create RDD example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()

df = spark.read.format('com.databricks.spark.csv').\
```

```

        options(header='true', \
        inferSchema='true') .\
load("/home/feng/Spark/Code/data/Advertising.csv",header=True)

df.show(5)
df.printSchema()

```

Then you will get the RDD data:

```

+---+---+---+---+
| _c0 | TV | Radio | Newspaper | Sales |
+---+---+---+---+
| 1 | 230.1 | 37.8 | 69.2 | 22.1 |
| 2 | 44.5 | 39.3 | 45.1 | 10.4 |
| 3 | 17.2 | 45.9 | 69.3 | 9.3 |
| 4 | 151.5 | 41.3 | 58.5 | 18.5 |
| 5 | 180.8 | 10.8 | 58.4 | 12.9 |
+---+---+---+---+
only showing top 5 rows

```

```

root
|-- _c0: integer (nullable = true)
|-- TV: double (nullable = true)
|-- Radio: double (nullable = true)
|-- Newspaper: double (nullable = true)
|-- Sales: double (nullable = true)

```

Once created, RDDs offer two types of operations: transformations and actions.

2. Read dataset from DataBase

```

## set up SparkSession
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark create RDD example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()

## User information
user = 'your_username'
pw = 'your_password'

## Database information
table_name = 'table_name'
url = 'jdbc:postgresql://##.##.##.##:5432/dataset?user=' + user + '&password=' + pw
properties = {'driver': 'org.postgresql.Driver', 'password': pw, 'user': user}

df = spark.read.jdbc(url=url, table=table_name, properties=properties)

df.show(5)
df.printSchema()

```

Then you will get the RDD data:

```

+---+---+---+---+
| _c0 | TV | Radio | Newspaper | Sales |
+---+---+---+---+

```

```
| 1|230.1| 37.8|      69.2| 22.1|
| 2| 44.5| 39.3|      45.1| 10.4|
| 3| 17.2| 45.9|      69.3|  9.3|
| 4|151.5| 41.3|      58.5| 18.5|
| 5|180.8| 10.8|      58.4| 12.9|
+----+----+----+----+
only showing top 5 rows

root
|-- _c0: integer (nullable = true)
|-- TV: double (nullable = true)
|-- Radio: double (nullable = true)
|-- Newspaper: double (nullable = true)
|-- Sales: double (nullable = true)
```

Note: Reading tables from Database needs the proper drive for the corresponding Database. For example, the above demo needs `org.postgresql.Driver` and you need to download it and put it in `jars` folder of your spark installation path. I download `postgresql-42.1.1.jar` from the official website and put it in `jars` folder.

3. Read dataset from HDFS

```
from pyspark.conf import SparkConf
from pyspark.context import SparkContext
from pyspark.sql import HiveContext

sc= SparkContext('local','example')
hc = HiveContext(sc)
tf1 = sc.textFile("hdfs://cdhstltest/user/data/demo.CSV")
print(tf1.first())

hc.sql("use intg_cme_w")
spf = hc.sql("SELECT * FROM spf LIMIT 100")
print(spf.show(5))
```

5.2 Spark Operations

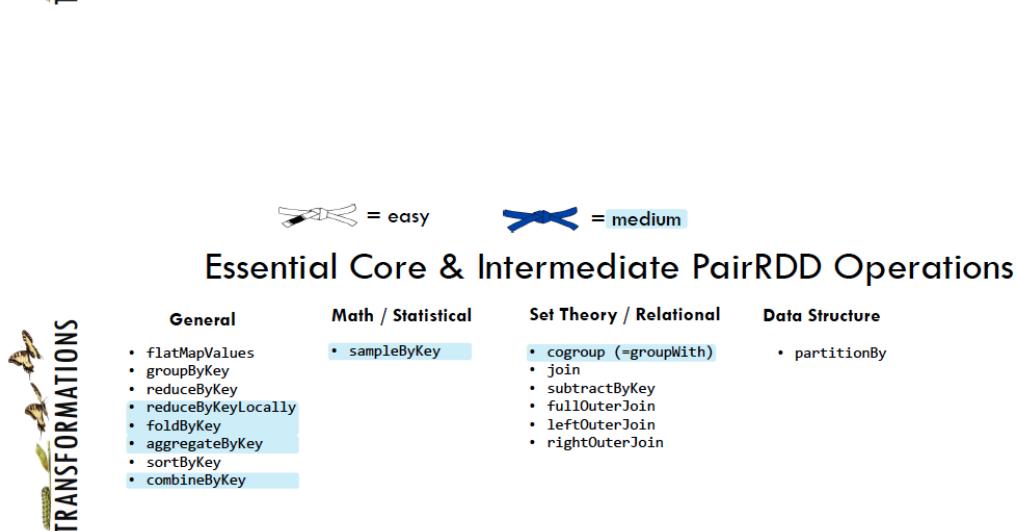
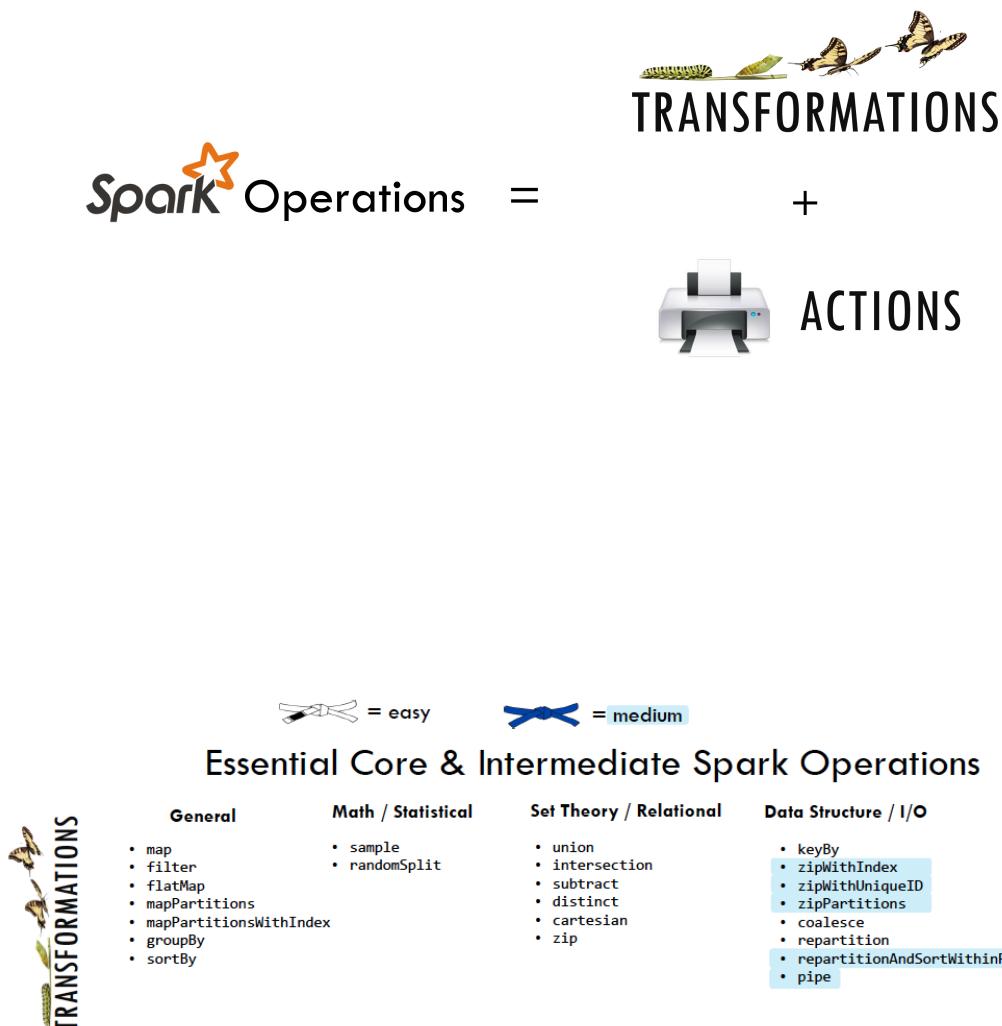
Warning: All the figures below are from Jeffrey Thompson. The interested reader is referred to [pyspark pictures](#)

There are two main types of Spark operations: Transformations and Actions.

Note: Some people defined three types of operations: Transformations, Actions and Shuffles.

5.2.1 Spark Transformations

Transformations construct a new RDD from a previous one. For example, one common transformation is filtering data that matches a predicate.



5.2.2 Spark Actions

Actions, on the other hand, compute a result based on an RDD, and either return it to the driver program or save it to an external storage system (e.g., HDFS).



5.3 rdd.DataFrame vs pd.DataFrame

5.3.1 Create DataFrame

1. From List

```
my_list = [['a', 1, 2], ['b', 2, 3], ['c', 3, 4]]
col_name = ['A', 'B', 'C']
```

:: Python Code:

```
# caution for the columns=
pd.DataFrame(my_list,columns= col_name)
#
spark.createDataFrame(my_list, col_name).show()
```

:: Comparison:

	A	B	C
0	a	1	2
1	b	2	3
2	c	3	4

Attention: Pay attention to the parameter `columns=` in `pd.DataFrame`. Since the default value will make the list as rows.

:: Python Code:

```
# caution for the columns=
pd.DataFrame(my_list, columns= col_name)
#
pd.DataFrame(my_list, col_name)
```

:: Comparison:

	A	B	C	0	1	2
0	a	1	2	A	a	1
1	b	2	3	B	b	2
2	c	3	4	C	c	3

2. From Dict

```
d = {'A': [0, 1, 0],
      'B': [1, 0, 1],
      'C': [1, 0, 0]}
```

:: Python Code:

```
pd.DataFrame(d) for
# Tedious for PySpark
spark.createDataFrame(np.array(list(d.values()))).T.tolist(), list(d.keys())).show()
```

:: Comparison:

	A	B	C	0	1	1
0	0	1	1	0	1	1
1	1	0	0	1	0	0
2	0	1	0	0	1	0

5.3.2 Load DataFrame

1. From DataBase

Most of time, you need to share your code with your colleagues or release your code for Code Review or Quality assurance(QA). You will definitely do not want to have your User Information in the code. So you can save them in login.txt:

```
runawayhorse001
PythonTips
```

and use the following code to import your User Information:

```
#User Information
try:
    login = pd.read_csv(r'login.txt', header=None)
    user = login[0][0]
    pw = login[0][1]
    print('User information is ready!')
```

```
except:  
    print('Login information is not available!!!!')  
  
#Database information  
host = '##.##.##.##'  
db_name = 'db_name'  
table_name = 'table_name'  
  
:: Comparison:  
  
conn = psycopg2.connect(host=host, database=db_name, user=user, password=pw)  
cur = conn.cursor()  
  
sql = """  
    select *  
    from {table_name}  
""".format(table_name=table_name)  
dp = pd.read_sql(sql, conn)  
  
# connect to database  
url = 'jdbc:postgresql://'+host+':5432/' +db_name+'?user=' +user+'&password=' +pw  
properties ={'driver': 'org.postgresql.Driver', 'password': pw,'user': user}  
ds = spark.read.jdbc(url=url, table=table_name, properties=properties)
```

Attention: Reading tables from Database with PySpark needs the proper drive for the corresponding Database. For example, the above demo needs org.postgresql.Driver and you need to download it and put it in jars folder of your spark installation path. I download postgresql-42.1.1.jar from the official website and put it in jars folder.

2. From .csv

```
:: Comparison:  
  
# pd.DataFrame dp: DataFrame pandas  
dp = pd.read_csv('Advertising.csv')  
#rdd.DataFrame. dp: DataFrame spark  
ds = spark.read.csv(path='Advertising.csv',  
#                     sep=',',  
#                     encoding='UTF-8',  
#                     comment=None,  
#                     header=True,  
#                     inferSchema=True)
```

3. From .json

Data from: <http://api.luftdaten.info/static/v1/data.json>

```
dp = pd.read_json("data/data.json")  
ds = spark.read.json('data/data.json')  
  
:: Python Code:  
  
dp[['id','timestamp']].head(4)  
#  
ds[['id','timestamp']].show(4)  
  
:: Comparison:
```

```

        id  timestamp
0  2994551481  2019-02-28 17:23:52
1  2994551482  2019-02-28 17:23:52
2  2994551483  2019-02-28 17:23:52
3  2994551484  2019-02-28 17:23:52
+-----+-----+
|      id |      timestamp |
+-----+-----+
| 2994551481 | 2019-02-28 17:23:52 |
| 2994551482 | 2019-02-28 17:23:52 |
| 2994551483 | 2019-02-28 17:23:52 |
| 2994551484 | 2019-02-28 17:23:52 |
+-----+-----+
only showing top 4 rows

```

5.3.3 First n Rows

:: Python Code:

```
dp.head(4)
#
ds.show(4)
```

:: Comparison:

	TV	Radio	Newspaper	Sales
0	230.1	37.8	69.2	22.1
1	44.5	39.3	45.1	10.4
2	17.2	45.9	69.3	9.3
3	151.5	41.3	58.5	18.5

	TV	Radio	Newspaper	Sales
0	230.1	37.8	69.2	22.1
1	44.5	39.3	45.1	10.4
2	17.2	45.9	69.3	9.3
3	151.5	41.3	58.5	18.5

5.3.4 Column Names

:: Python Code:

```
dp.columns
#
ds.columns
```

:: Comparison:

```
Index(['TV', 'Radio', 'Newspaper', 'Sales'], dtype='object')
['TV', 'Radio', 'Newspaper', 'Sales']
```

5.3.5 Data types

:: Python Code:

```
dp.dtypes
#
ds.dtypes
```

:: Comparison:

```
TV          float64      [ ('TV', 'double'),  
Radio       float64      ('Radio', 'double'),  
Newspaper    float64      ('Newspaper', 'double'),  
Sales        float64      ('Sales', 'double')]  
dtype: object
```

5.3.6 Fill Null

```
my_list = [['a', 1, None], ['b', 2, 3], ['c', 3, 4]]  
dp = pd.DataFrame(my_list, columns=['A', 'B', 'C'])  
ds = spark.createDataFrame(my_list, ['A', 'B', 'C'])  
#  
dp.head()  
ds.show()
```

:: Comparison:

	A	B	C
0	male	1	Nan
1	female	2	3.0
2	male	3	4.0

	A	B	C
0	male	1	null
1	female	2	3
2	male	3	4

:: Python Code:

```
dp.fillna(-99)  
#  
ds.fillna(-99).show()
```

:: Comparison:

	A	B	C
0	male	1	-99
1	female	2	3.0
2	male	3	4.0

	A	B	C
0	male	1	-99
1	female	2	3
2	male	3	4

5.3.7 Replace Values

:: Python Code:

```
# caution: you need to chose specific col  
dp.A.replace(['male', 'female'], [1, 0], inplace=True)  
dp  
#caution: Mixed type replacements are not supported  
ds.na.replace(['male', 'female'], ['1', '0']).show()
```

:: Comparison:

A	B	C

```

0  1  1  NaN |  1|  1|null|
1  0  2  3.0 |  0|  2|   3|
2  1  3  4.0 |  1|  3|   4|
+---+---+---+

```

5.3.8 Rename Columns

1. Rename all columns

:: Python Code:

```

dp.columns = ['a','b','c','d']
dp.head(4)
#
ds.toDF('a','b','c','d').show(4)

```

:: Comparison:

	a	b	c	d
0	230.1	37.8	69.2	22.1
1	44.5	39.3	45.1	10.4
2	17.2	45.9	69.3	9.3
3	151.5	41.3	58.5	18.5

	a	b	c	d
1	230.1	37.8	69.2	22.1
2	44.5	39.3	45.1	10.4
3	17.2	45.9	69.3	9.3
4	151.5	41.3	58.5	18.5

only showing top 4 rows

2. Rename one or more columns

```
mapping = {'Newspaper':'C','Sales':'D'}
```

:: Python Code:

```

dp.rename(columns=mapping).head(4)
#
new_names = [mapping.get(col,col) for col in ds.columns]
ds.toDF(*new_names).show(4)

```

:: Comparison:

	TV	Radio	C	D
0	230.1	37.8	69.2	22.1
1	44.5	39.3	45.1	10.4
2	17.2	45.9	69.3	9.3
3	151.5	41.3	58.5	18.5

	TV	Radio	C	D
1	230.1	37.8	69.2	22.1
2	44.5	39.3	45.1	10.4
3	17.2	45.9	69.3	9.3
4	151.5	41.3	58.5	18.5

only showing top 4 rows

Note: You can also use `withColumnRenamed` to rename one column in PySpark.

:: Python Code:

```
ds.withColumnRenamed('Newspaper','Paper').show(4)
```

:: Comparison:

```
+----+----+----+----+
|   TV|Radio|Paper|Sales|
+----+----+----+----+
| 230.1| 37.8| 69.2| 22.1|
| 44.5| 39.3| 45.1| 10.4|
| 17.2| 45.9| 69.3|  9.3|
|151.5| 41.3| 58.5| 18.5|
+----+----+----+----+
only showing top 4 rows
```

5.3.9 Drop Columns

```
drop_name = ['Newspaper', 'Sales']
```

```
:: Python Code:
```

```
dp.drop(drop_name, axis=1).head(4)
#
ds.drop(*drop_name).show(4)
```

```
:: Comparison:
```

```
+----+----+
|   TV|Radio|
+----+----+
  TV  Radio
0  230.1  37.8
1   44.5  39.3
2   17.2  45.9
3  151.5  41.3
+----+----+
only showing top 4 rows
```

5.3.10 Filter

```
dp = pd.read_csv('Advertising.csv')
#
ds = spark.read.csv(path='Advertising.csv',
                     header=True,
                     inferSchema=True)
```

```
:: Python Code:
```

```
dp[dp.Newspaper<20].head(4)
#
ds[ds.Newspaper<20].show(4)
```

```
:: Comparison:
```

```
+----+----+----+----+
|   TV|Radio|Newspaper|Sales|
+----+----+----+----+
  TV  Radio  Newspaper  Sales
7  120.2  19.6      11.6  13.2
8    8.6   2.1       1.0   4.8
11 214.7  24.0      4.0  17.4
+----+----+----+----+
```

```

13   97.5     7.6      7.2     9.7
      | 97.5| 7.6| 7.2| 9.7|
      +----+----+----+----+
only showing top 4 rows

```

:: Python Code:

```

dp[(dp.Newspaper<20) & (dp.TV>100)].head(4)
#
ds[(ds.Newspaper<20) & (ds.TV>100)].show(4)

```

:: Comparison:

	TV	Radio	Newspaper	Sales
7	120.2	19.6	11.6	13.2
11	214.7	24.0	4.0	17.4
19	147.3	23.9	19.1	14.6
25	262.9	3.5	19.5	12.0

```

+-----+-----+-----+-----+
|     TV|Radio|Newspaper|Sales|
+-----+-----+-----+-----+
| 120.2| 19.6| 11.6| 13.2|
| 214.7| 24.0| 4.0| 17.4|
| 147.3| 23.9| 19.1| 14.6|
| 262.9| 3.5| 19.5| 12.0|
+-----+-----+-----+-----+
only showing top 4 rows

```

5.3.11 With New Column

:: Python Code:

```

dp['tv_norm'] = dp.TV/sum(dp.TV)
dp.head(4)
#
ds.withColumn('tv_norm', ds.TV/ds.groupBy().agg(F.sum("TV")).collect()[0][0]).show(4)

```

:: Comparison:

	TV	Radio	Newspaper	Sales	tv_norm
0	230.1	37.8	69.2	22.1	0.007824
1	44.5	39.3	45.1	10.4	0.001513
2	17.2	45.9	69.3	9.3	0.000585
3	151.5	41.3	58.5	18.5	0.005152

```

+-----+-----+-----+-----+
|     TV|Radio|Newspaper|Sales|
+-----+-----+-----+-----+
| 230.1| 37.8| 69.2| 22.1| 0.007824268
| 44.5| 39.3| 45.1| 10.4| 0.001513167
| 17.2| 45.9| 69.3| 9.3| 5.848649200
| 151.5| 41.3| 58.5| 18.5| 0.005151571
+-----+-----+-----+-----+
only showing top 4 rows

```

:: Python Code:

```

dp['cond'] = dp.apply(lambda c: 1 if ((c.TV>100)&(c.Radio<40)) else 2 if c.Sales> 10 else 3)
#
ds.withColumn('cond', F.when((ds.TV>100)&(ds.Radio<40), 1) \
               .when(ds.Sales>10, 2) \
               .otherwise(3)).show(4)

```

:: Comparison:

	TV	Radio	Newspaper	Sales	cond
0	230.1	37.8	69.2	22.1	1

```

+-----+-----+-----+-----+
|     TV|Radio|Newspaper|Sales|cond|
+-----+-----+-----+-----+
| 230.1| 37.8| 69.2| 22.1| 1|
+-----+-----+-----+-----+

```

```

1    44.5    39.3      45.1    10.4      2      | 44.5| 39.3| 45.1| 10.4| 2|
2    17.2    45.9      69.3     9.3      3      | 17.2| 45.9| 69.3| 9.3| 3|
3   151.5    41.3      58.5    18.5      2      | 151.5| 41.3| 58.5| 18.5| 2|
+----+----+----+----+----+
only showing top 4 rows

```

:: Python Code:

```

dp['log_tv'] = np.log(dp.TV)
dp.head(4)
#
ds.withColumn('log_tv', F.log(ds.TV)).show(4)

```

:: Comparison:

	TV	Radio	Newspaper	Sales	log_tv
0	230.1	37.8	69.2	22.1	5.438514
1	44.5	39.3	45.1	10.4	3.795489
2	17.2	45.9	69.3	9.3	2.844909
3	151.5	41.3	58.5	18.5	5.020586

	TV	Radio	Newspaper	Sales
0	230.1	37.8	69.2	22.1 5.4385139
1	44.5	39.3	45.1	10.4 3.795489189
2	17.2	45.9	69.3	9.3 2.844909383
3	151.5	41.3	58.5	18.5 5.02058562

:: Python Code:

```

dp['tv+10'] = dp.TV.apply(lambda x: x+10)
dp.head(4)
#
ds.withColumn('tv+10', ds.TV+10).show(4)

```

:: Comparison:

	TV	Radio	Newspaper	Sales	tv+10
0	230.1	37.8	69.2	22.1	240.1
1	44.5	39.3	45.1	10.4	54.5
2	17.2	45.9	69.3	9.3	27.2
3	151.5	41.3	58.5	18.5	161.5

	TV	Radio	Newspaper	Sales	tv+10
0	230.1	37.8	69.2	22.1 240.1	
1	44.5	39.3	45.1	10.4 54.5	
2	17.2	45.9	69.3	9.3 27.2	
3	151.5	41.3	58.5	18.5 161.5	

5.3.12 Join

```

leftp = pd.DataFrame({'A': ['A0', 'A1', 'A2', 'A3'],
                      'B': ['B0', 'B1', 'B2', 'B3'],
                      'C': ['C0', 'C1', 'C2', 'C3'],
                      'D': ['D0', 'D1', 'D2', 'D3']},
                     index=[0, 1, 2, 3])

rightp = pd.DataFrame({'A': ['A0', 'A1', 'A6', 'A7'],
                       'F': ['B4', 'B5', 'B6', 'B7'],
                       'G': ['C4', 'C5', 'C6', 'C7'],
                       'H': ['D4', 'D5', 'D6', 'D7']},
                      index=[4, 5, 6, 7])

```

```
lefts = spark.createDataFrame(leftp)
rights = spark.createDataFrame(rightp)
```

	A	B	C	D		A	F	G	H	
0	A0	B0	C0	D0		4	A0	B4	C4	D4
1	A1	B1	C1	D1		5	A1	B5	C5	D5
2	A2	B2	C2	D2		6	A6	B6	C6	D6
3	A3	B3	C3	D3		7	A7	B7	C7	D7

1. Left Join

:: Python Code:

```
leftp.merge(rightp, on='A', how='left')
#
lefts.join(rights, on='A', how='left')
    .orderBy('A', ascending=True).show()
```

:: Comparison:

	A	B	C	D	F	G	H		A	B	C	D	F	G	H
0	A0	B0	C0	D0	B4	C4	D4		A0	B0	C0	D0	B4	C4	D4
1	A1	B1	C1	D1	B5	C5	D5		A1	B1	C1	D1	B5	C5	D5
2	A2	B2	C2	D2	NaN	NaN	NaN		A2	B2	C2	D2	null	null	null
3	A3	B3	C3	D3	NaN	NaN	NaN		A3	B3	C3	D3	null	null	null

2. Right Join

:: Python Code:

```
leftp.merge(rightp, on='A', how='right')
#
lefts.join(rights, on='A', how='right')
    .orderBy('A', ascending=True).show()
```

:: Comparison:

	A	B	C	D	F	G	H		A	B	C	D	F	G	H
0	A0	B0	C0	D0	B4	C4	D4		A0	B0	C0	D0	B4	C4	D4
1	A1	B1	C1	D1	B5	C5	D5		A1	B1	C1	D1	B5	C5	D5
2	A6	NaN	NaN	NaN	B6	C6	D6		A6	null	null	null	B6	C6	D6
3	A7	NaN	NaN	NaN	B7	C7	D7		A7	null	null	null	B7	C7	D7

3. Inner Join

:: Python Code:

```
leftp.merge(rightp, on='A', how='inner')
#
lefts.join(rights, on='A', how='inner')
    .orderBy('A', ascending=True).show()
```

:: Comparison:

	A	B	C	D	F	G	H	A	B	C	D	F	G	H
0	A0	B0	C0	D0	B4	C4	D4	A0	B0	C0	D0	B4	C4	D4
1	A1	B1	C1	D1	B5	C5	D5	A1	B1	C1	D1	B5	C5	D5
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+														

4. Full Join

:: Python Code:

```
leftp.merge(rightp, on='A', how='full')
#
lefts.join(rights, on='A', how='full')
    .orderBy('A', ascending=True).show()
```

:: Comparison:

	A	B	C	D	F	G	H	A	B	C	D	F	G	H
0	A0	B0	C0	D0	B4	C4	D4	A0	B0	C0	D0	B4	C4	D4
1	A1	B1	C1	D1	B5	C5	D5	A1	B1	C1	D1	B5	C5	D5
2	A2	B2	C2	D2	NaN	NaN	NaN	A2	B2	C2	D2	null	null	null
3	A3	B3	C3	D3	NaN	NaN	NaN	A3	B3	C3	D3	null	null	null
4	A6	NaN	NaN	NaN	B6	C6	D6	A6	null	null	null	B6	C6	D6
5	A7	NaN	NaN	NaN	B7	C7	D7	A7	null	null	null	B7	C7	D7
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+														

5.3.13 Concat Columns

```
my_list = [('a', 2, 3),
           ('b', 5, 6),
           ('c', 8, 9),
           ('a', 2, 3),
           ('b', 5, 6),
           ('c', 8, 9)]
col_name = ['col1', 'col2', 'col3']
#
dp = pd.DataFrame(my_list, columns=col_name)
ds = spark.createDataFrame(my_list, schema=col_name)
```

	col1	col2	col3
0	a	2	3
1	b	5	6
2	c	8	9
3	a	2	3
4	b	5	6
5	c	8	9

:: Python Code:

```
dp['concat'] = dp.apply(lambda x:'%s%s' % (x['col1'],x['col2']),axis=1)
dp
#
ds.withColumn('concat',F.concat('col1','col2')).show()
```

:: Comparison:

	col1	col2	col3	concat		col1	col2	col3	concat
0	a	2	3	a2		a	2	3	a2
1	b	5	6	b5		b	5	6	b5
2	c	8	9	c8		c	8	9	c8
3	a	2	3	a2		a	2	3	a2
4	b	5	6	b5		b	5	6	b5
5	c	8	9	c8		c	8	9	c8

5.3.14 GroupBy

:: Python Code:

```
dp.groupby(['col1']).agg({'col2': 'min', 'col3': 'mean'})
#
ds.groupBy(['col1']).agg({'col2': 'min', 'col3': 'avg'}).show()
```

:: Comparison:

	col2	col3		col1	min(col2)	avg(col3)
col1	a	2	3	c	8	9.0
a	5	6		b	5	6.0
b	8	9		a	2	3.0

5.3.15 Pivot

:: Python Code:

```
pd.pivot_table(dp, values='col3', index='col1', columns='col2', aggfunc=np.sum)
#
ds.groupBy(['col1']).pivot('col2').sum('col3').show()
```

:: Comparison:

	col2	2	5	8		col1	2	5	8
col1	a	6.0	NaN	NaN		c	null	null	18
a	b	NaN	12.0	NaN		b	null	12	null
b	c	NaN	NaN	18.0		a	6	null	null

CHAPTER
SIX

STATISTICS PRELIMINARY

Chinese proverb

If you only know yourself, but not your opponent, you may win or may lose. If you know neither yourself nor your enemy, you will always endanger yourself – idiom, from Sunzi's Art of War

6.1 Notations

- m : the number of the samples
- n : the number of the features
- y_i : i-th label
- $\bar{y} = \frac{1}{m} \sum_{i=1}^n y_i$: the mean of y .

6.2 Measurement Formula

- Mean squared error

In statistics, the **MSE** (Mean Squared Error) of an estimator (of a procedure for estimating an unobserved quantity) measures the average of the squares of the errors or deviations—that is, the difference between the estimator and what is estimated.

$$\text{MSE} = \frac{1}{m} \sum_{i=1}^m (\hat{y}_i - y_i)^2$$

- Root Mean squared error

$$\text{RMSE} = \sqrt{\text{MSE}} = \sqrt{\frac{1}{m} \sum_{i=1}^m (\hat{y}_i - y_i)^2}$$

- Total sum of squares

In statistical data analysis the **TSS** (Total Sum of Squares) is a quantity that appears as part of a standard way of presenting results of such analyses. It is defined as being the sum, over all observations, of the squared differences of each observation from the overall mean.

$$\text{TSS} = \sum_{i=1}^m (y_i - \bar{y})^2$$

- Residual Sum of Squares

$$\text{RSS} = \frac{1}{m} \sum_{i=1}^m (\hat{y}_i - y_i)^2$$

- Coefficient of determination R^2

$$R^2 := 1 - \frac{\text{RSS}}{\text{TSS}}.$$

6.3 Statistical Tests

6.3.1 Correlational Test

- Pearson correlation: Tests for the strength of the association between two continuous variables.
- Spearman correlation: Tests for the strength of the association between two ordinal variables (does not rely on the assumption of normal distributed data).
- Chi-square: Tests for the strength of the association between two categorical variables.

6.3.2 Comparison of Means test

- Paired T-test: Tests for difference between two related variables.
- Independent T-test: Tests for difference between two independent variables.
- ANOVA: Tests the difference between group means after any other variance in the outcome variable is accounted for.

6.3.3 Non-parametric Test

- Wilcoxon rank-sum test: Tests for difference between two independent variables - takes into account magnitude and direction of difference.
- Wilcoxon sign-rank test: Tests for difference between two related variables - takes into account magnitude and direction of difference.
- Sign test: Tests if two related variables are different – ignores magnitude of change, only takes into account direction.

CHAPTER SEVEN

DATA EXPLORATION

Chinese proverb

A journey of a thousand miles begins with a single step – idiom, from Laozi.

I wouldn't say that understanding your dataset is the most difficult thing in data science, but it is really important and time-consuming. Data Exploration is about describing the data by means of statistical and visualization techniques. We explore data in order to understand the features and bring important features to our models.

7.1 Univariate Analysis

In mathematics, univariate refers to an expression, equation, function or polynomial of only one variable. "Uni" means "one", so in other words your data has only one variable. So you do not need to deal with the causes or relationships in this step. Univariate analysis takes data, summarizes that variables (attributes) one by one and finds patterns in the data.

There are many ways that can describe patterns found in univariate data include central tendency (mean, mode and median) and dispersion: range, variance, maximum, minimum, quartiles (including the interquartile range), coefficient of variation and standard deviation. You also have several options for visualizing and describing data with univariate data. Such as frequency Distribution Tables, bar Charts, histograms, frequency Polygons, pie Charts.

The variable could be either categorical or numerical, I will demonstrate the different statistical and visualization techniques to investigate each type of the variable.

- The Jupyter notebook can be download from Data Exploration.
- The data can be downloaf from German Credit.

7.1.1 Numerical Variables

- Describe

The desctibe function in pandas and spark will give us most of the statistical results, such as min, median, max, quartiles and standard deviation. With the help of the user defined function, you can get even more statistical results.

```
# selected varables for the demonstration
num_cols = ['Account Balance', 'No of dependents']
df.select(num_cols).describe().show()
```

```
+-----+-----+-----+
| summary| Account Balance| No of dependents|
+-----+-----+-----+
| count| 1000| 1000|
| mean| 2.577| 1.155|
| stddev| 1.2576377271108936| 0.36208577175319395|
| min| 1| 1|
| max| 4| 2|
+-----+-----+-----+
```

You may find out that the default function in PySpark does not include the quartiles. The following function will help you to get the same results in Pandas

```
def describe_pd(df_in, columns, style):
    """
    Function to union the basic stats results and deciles
    :param df_in: the input dataframe
    :param columns: the column name list of the numerical variable
    :param style: the display style

    :return : the numerical describe info. of the input dataframe

    :author: MIng Chen and Wenqiang Feng
    :email: von198@gmail.com
    """

    if style == 1:
        percentiles = [25, 50, 75]
    else:
        percentiles = np.array(range(0, 110, 10))

    percs = np.transpose([np.percentile(df_in.select(x).collect(), percentiles) for x in
    percs = pd.DataFrame(percs, columns=columns)
    percs['summary'] = [str(p) + '%' for p in percentiles]

    spark_describe = df_in.describe().toPandas()
    new_df = pd.concat([spark_describe, percs], ignore_index=True)
    new_df = new_df.round(2)
    return new_df[['summary']] + columns

describe_pd(df, num_cols, 1)

+-----+-----+-----+
| summary| Account Balance| No of dependents|
+-----+-----+-----+
| count| 1000.0| 1000.0|
| mean| 2.577| 1.155|
| stddev| 1.2576377271108936| 0.362085771753194|
| min| 1.0| 1.0|
| max| 4.0| 2.0|
| 25%| 1.0| 1.0|
| 50%| 2.0| 1.0|
| 75%| 4.0| 1.0|
+-----+-----+-----+
```

Sometimes, because of the confidential data issues, you can not deliver the real data and your clients may ask more statistical results, such as deciles. You can apply the following function to achieve it.

```
describe_pd(df, num_cols, 2)

+-----+-----+
| summary | Account Balance | No of dependents |
+-----+-----+
| count | 1000.0 | 1000.0 |
| mean | 2.577 | 1.155 |
| stddev | 1.2576377271108936 | 0.362085771753194 |
| min | 1.0 | 1.0 |
| max | 4.0 | 2.0 |
| 0% | 1.0 | 1.0 |
| 10% | 1.0 | 1.0 |
| 20% | 1.0 | 1.0 |
| 30% | 2.0 | 1.0 |
| 40% | 2.0 | 1.0 |
| 50% | 2.0 | 1.0 |
| 60% | 3.0 | 1.0 |
| 70% | 4.0 | 1.0 |
| 80% | 4.0 | 1.0 |
| 90% | 4.0 | 2.0 |
| 100% | 4.0 | 2.0 |
+-----+-----+
```

- Skewness and Kurtosis

This subsection comes from Wikipedia [Skewness](#).

In probability theory and statistics, skewness is a measure of the asymmetry of the probability distribution of a real-valued random variable about its mean. The skewness value can be positive or negative, or undefined. For a unimodal distribution, negative skew commonly indicates that the tail is on the left side of the distribution, and positive skew indicates that the tail is on the right.

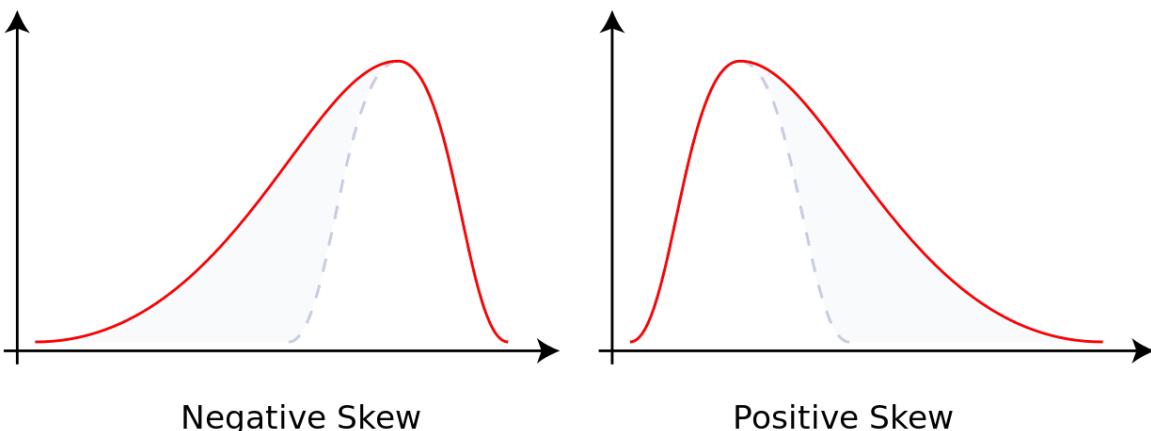
Consider the two distributions in the figure just below. Within each graph, the values on the right side of the distribution taper differently from the values on the left side. These tapering sides are called tails, and they provide a visual means to determine which of the two kinds of skewness a distribution has:

1. negative skew: The left tail is longer; the mass of the distribution is concentrated on the right of the figure. The distribution is said to be left-skewed, left-tailed, or skewed to the left, despite the fact that the curve itself appears to be skewed or leaning to the right; left instead refers to the left tail being drawn out and, often, the mean being skewed to the left of a typical center of the data. A left-skewed distribution usually appears as a right-leaning curve.
2. positive skew: The right tail is longer; the mass of the distribution is concentrated on the left of the figure. The distribution is said to be right-skewed, right-tailed, or skewed to the right, despite the fact that the curve itself appears to be skewed or leaning to the left; right instead refers to the right tail being drawn out and, often, the mean being skewed to the right of a typical center of the data. A right-skewed distribution usually appears as a left-leaning curve.

This subsection comes from Wikipedia [Kurtosis](#).

In probability theory and statistics, kurtosis (kyrtos or kurtos, meaning “curved, arching”) is a measure of the “tailedness” of the probability distribution of a real-valued random variable. In a similar way to the concept of skewness, kurtosis is a descriptor of the shape of a probability distribution and, just as for skewness, there are different ways of quantifying it for a theoretical

distribution and corresponding ways of estimating it from a sample from a population.



```
from pyspark.sql.functions import col, skewness, kurtosis
df.select(skewness(var), kurtosis(var)).show()

+-----+-----+
| skewness(Age (years)) | kurtosis(Age (years)) |
+-----+-----+
|    1.0231743160548064 |    0.6114371688367672 |
+-----+-----+
```

Warning: Sometimes the statistics can be misleading!

F. J. Anscombe once said that make both calculations and graphs. Both sorts of output should be studied; each will contribute to understanding. These 13 datasets in Figure *Same Stats, Different Graphs* (the Datasaurus, plus 12 others) each have the same summary statistics (x/y mean, x/y standard deviation, and Pearson's correlation) to two decimal places, while being drastically different in appearance. This work describes the technique we developed to create this dataset, and others like it. More details and interesting results can be found in [Same Stats Different Graphs](#).

- Histogram

Warning: Histograms are often confused with Bar graphs!

The fundamental difference between histogram and bar graph will help you to identify the two easily is that there are gaps between bars in a bar graph but in the histogram, the bars are adjacent to each other. The interested reader is referred to [Difference Between Histogram and Bar Graph](#).

```
var = 'Age (years)'
x = data1[var]
bins = np.arange(0, 100, 5.0)

plt.figure(figsize=(10,8))
# the histogram of the data
plt.hist(x, bins, alpha=0.8, histtype='bar', color='gold',
         ec='black', weights=np.zeros_like(x) + 100. / x.size)

plt.xlabel(var)
plt.ylabel('percentage')
plt.xticks(bins)
plt.show()
```

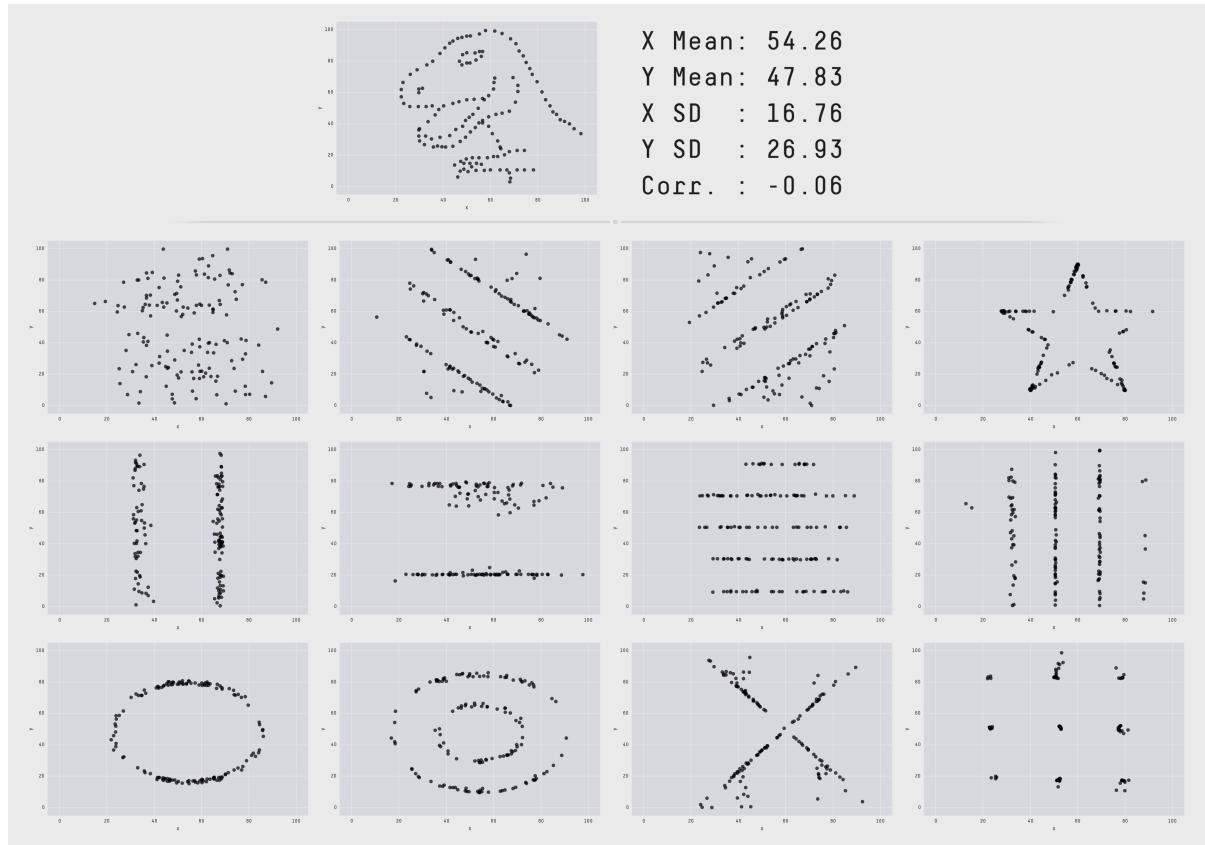


Figure 7.1: Same Stats, Different Graphs

```

fig.savefig(var+".pdf", bbox_inches='tight')

var = 'Age (years)'
x = data1[var]
bins = np.arange(0, 100, 5.0)

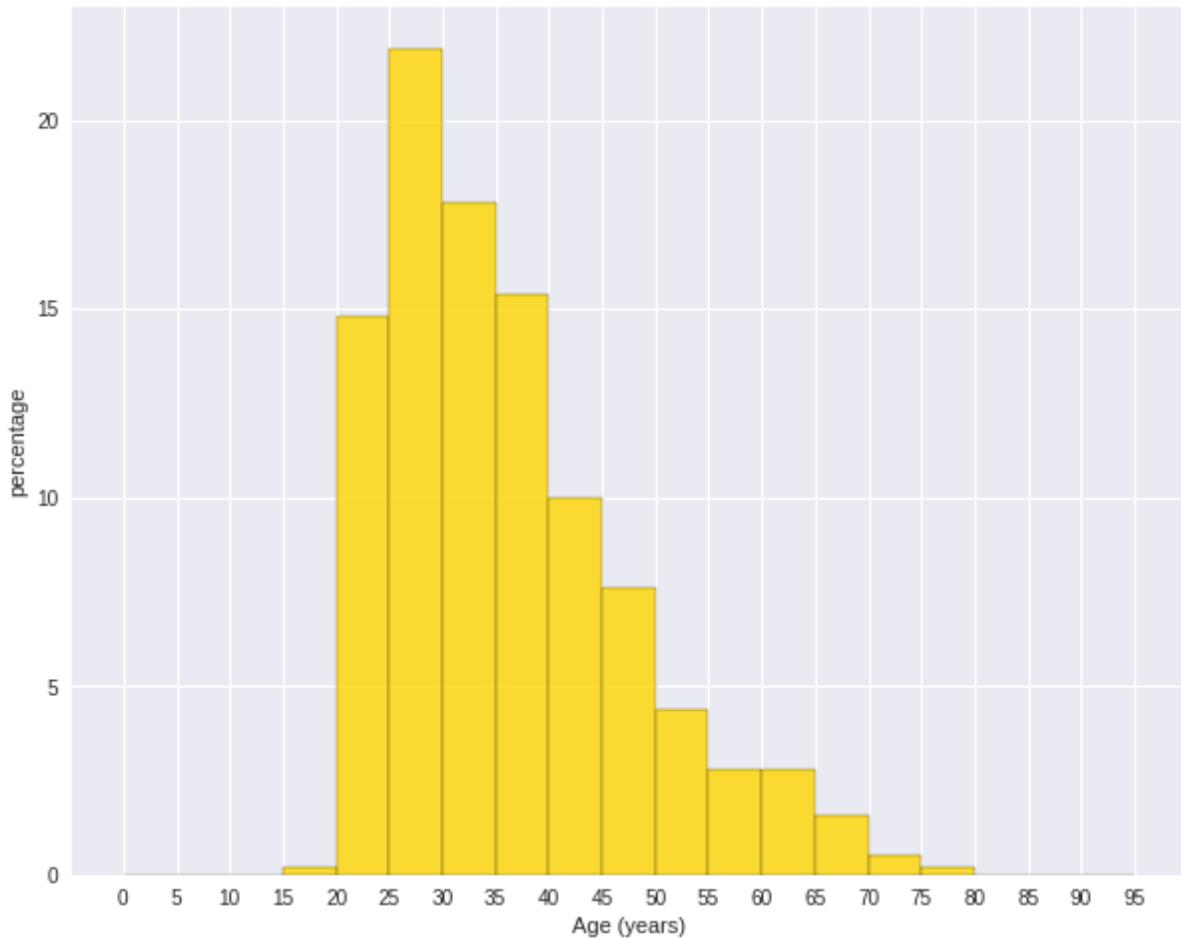
#####
hist, bin_edges = np.histogram(x,bins,
                               weights=np.zeros_like(x) + 100. / x.size)
# make the histogram

fig = plt.figure(figsize=(20, 8))
ax = fig.add_subplot(1, 2, 1)

# Plot the histogram heights against integers on the x axis
ax.bar(range(len(hist)),hist,width=1,alpha=0.8,ec ='black', color='gold')
# # Set the ticks to the middle of the bars
ax.set_xticks([0.5+i for i,j in enumerate(hist)])
# Set the xticklabels to a string that tells us what the bin edges were
labels =[ '{}'.format(int(bins[i+1])) for i,j in enumerate(hist)]
labels.insert(0,'0')
ax.set_xticklabels(labels)
plt.xlabel(var)
plt.ylabel('percentage')

#####

```



```

hist, bin_edges = np.histogram(x,bins) # make the histogram

ax = fig.add_subplot(1, 2, 2)
# Plot the histogram heights against integers on the x axis
ax.bar(range(len(hist)),hist,width=1,alpha=0.8,ec ='black', color='gold')

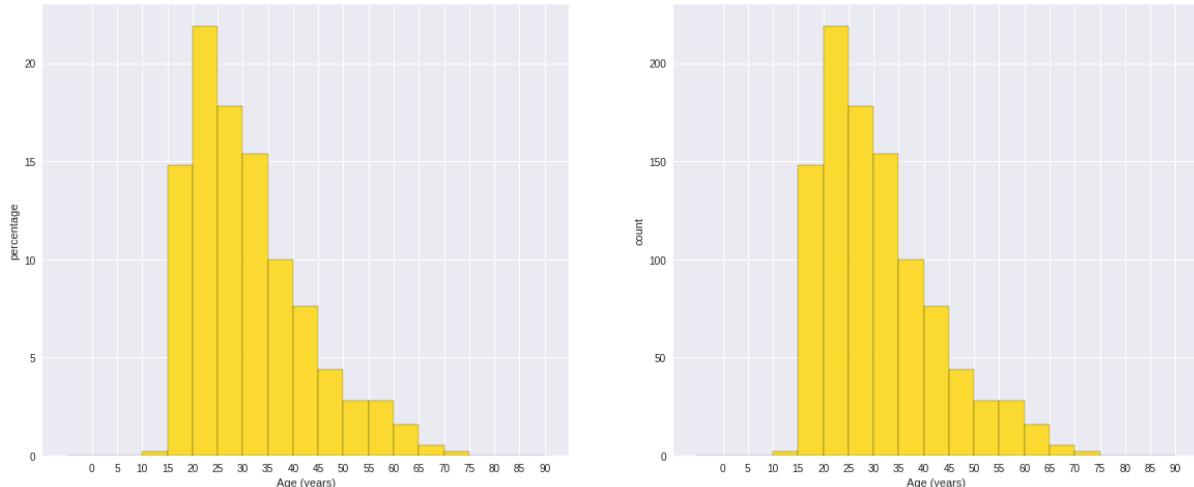
# # Set the ticks to the middle of the bars
ax.set_xticks([0.5+i for i,j in enumerate(hist)])

# Set the xticklabels to a string that tells us what the bin edges were
labels =[ '{}'.format(int(bins[i+1])) for i,j in enumerate(hist)]
labels.insert(0,'0')
ax.set_xticklabels(labels)
plt.xlabel(var)
plt.ylabel('count')
plt.suptitle('Histogram of {}: Left with percentage output;Right with count output'
            .format(var), size=16)
plt.show()

fig.savefig(var+".pdf", bbox_inches='tight')

```

Histogram of Age (years): Left with percentage output;Right with count output



Sometimes, some people will ask you to plot the unequal width (invalid argument for histogram) of the bars. You can still achieve it by the following trick.

```

var = 'Credit Amount'
plot_data = df.select(var).toPandas()
x= plot_data[var]

bins =[0,200,400,600,700,800,900,1000,2000,3000,4000,5000,6000,10000,25000]

hist, bin_edges = np.histogram(x,bins,weights=np.zeros_like(x) + 100. / x.size) # make t

fig = plt.figure(figsize=(10, 8))
ax = fig.add_subplot(1, 1, 1)
# Plot the histogram heights against integers on the x axis
ax.bar(range(len(hist)),hist,width=1,alpha=0.8,ec ='black',color = 'gold')

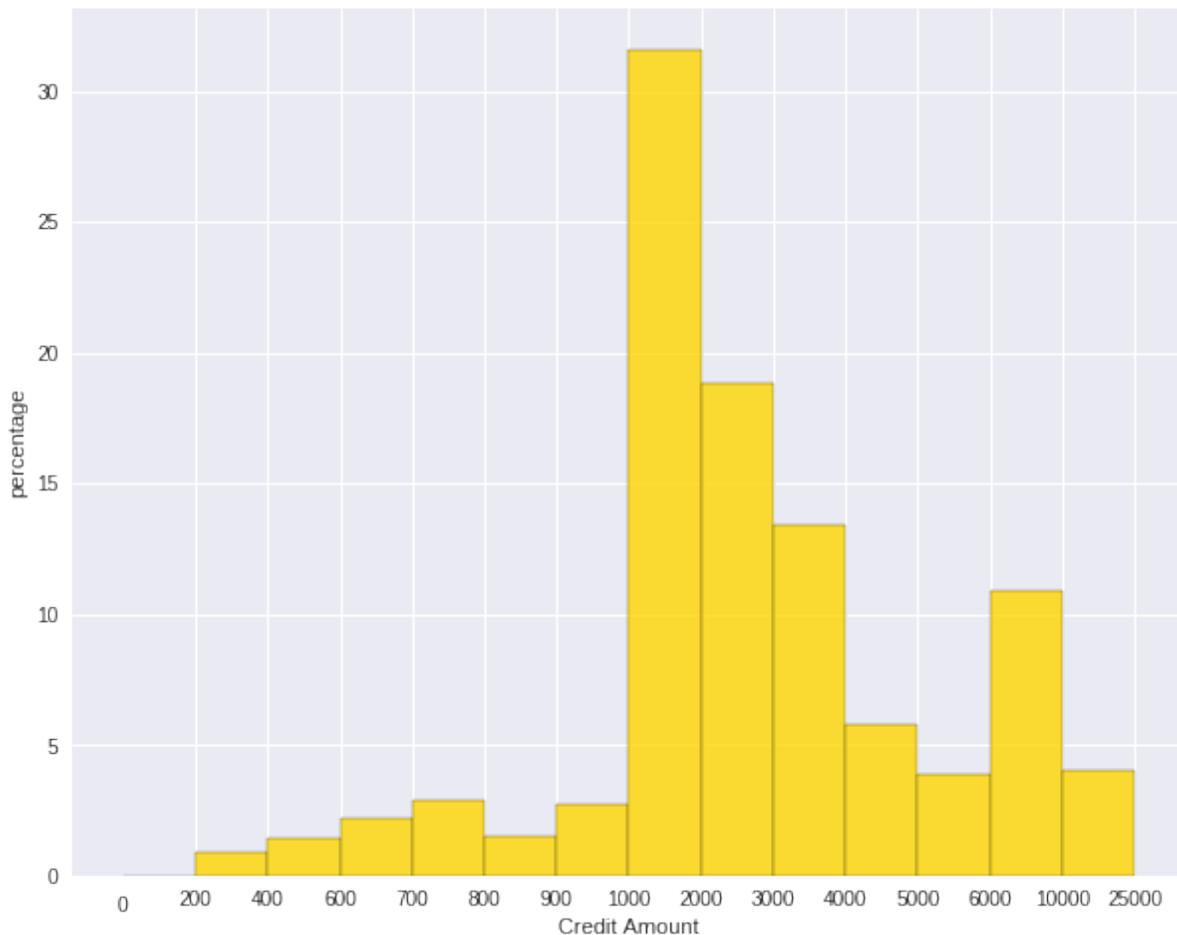
# # Set the ticks to the middle of the bars

```

```

ax.set_xticks([0.5+i for i,j in enumerate(hist)])
# Set the xticklabels to a string that tells us what the bin edges were
#labels =['{}k'.format(int(bins[i+1]/1000)) for i,j in enumerate(hist)]
labels =['{}'.format(bins[i+1]) for i,j in enumerate(hist)]
labels.insert(0,'0')
ax.set_xticklabels(labels)
#plt.text(-0.6, -1.4,'0')
plt.xlabel(var)
plt.ylabel('percentage')
plt.show()

```



- Box plot and violin plot

Note that although violin plots are closely related to Tukey's (1977) box plots, the violin plot can show more information than box plot. When we perform an exploratory analysis, nothing about the samples could be known. So the distribution of the samples can not be assumed to a normal distribution and usually when you get a big data, the normal distribution will show some outliers in box plot.

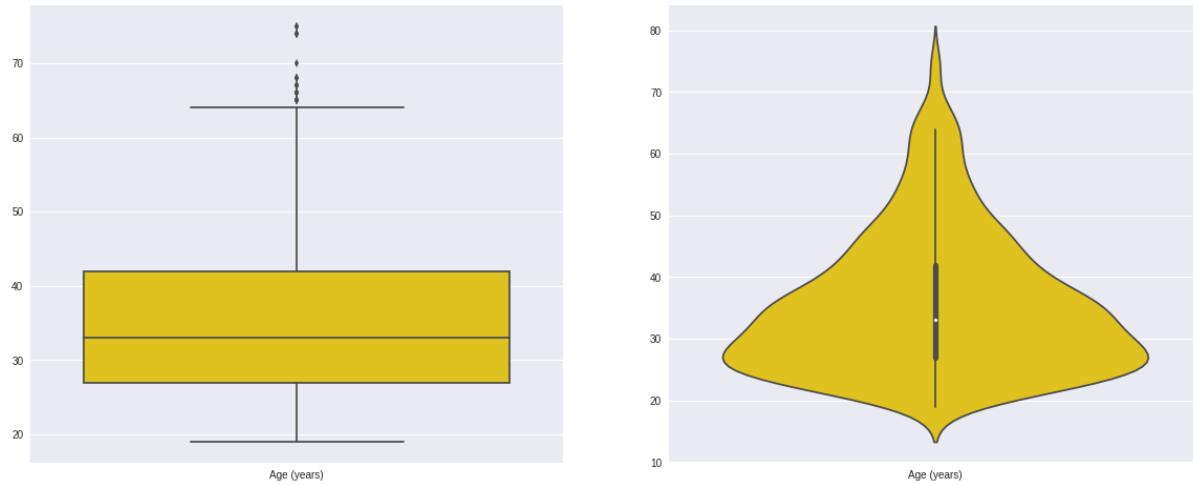
However, the violin plots are potentially misleading for smaller sample sizes, where the density plots can appear to show interesting features (and group-differences therein) even when produced for standard normal data. Some poster suggested the sample size should larger than 250. The sample sizes (e.g. n>250 or ideally even larger), where the kernel density plots provide a reasonably accurate representation of the distributions, potentially showing nuances such as bimodality or other forms of non-normality that would be invisible or less clear in box plots. More details can be found in [A simple comparison of box plots and violin plots](#).

```

x = df.select(var).toPandas()

fig = plt.figure(figsize=(20, 8))
ax = fig.add_subplot(1, 2, 1)
ax = sns.boxplot(data=x)

ax = fig.add_subplot(1, 2, 2)
ax = sns.violinplot(data=x)
    
```



7.1.2 Categorical Variables

Compared with the numerical variables, the categorical variables are much more easier to do the exploration.

- Frequency table

```

from pyspark.sql import functions as F
from pyspark.sql.functions import rank,sum,col
from pyspark.sql import Window

window = Window.rowsBetween(Window.unboundedPreceding,Window.unboundedFollowing)
# withColumn('Percent %',F.format_string("%5.0f%%\n",col('Credit_num')*100/col('total')))
tab = df.select(['age_class','Credit Amount']).\
    groupBy('age_class').\
    agg(F.count('Credit Amount').alias('Credit_num'),\
        F.mean('Credit Amount').alias('Credit_avg'),\
        F.min('Credit Amount').alias('Credit_min'),\
        F.max('Credit Amount').alias('Credit_max')).\
    withColumn('total',sum(col('Credit_num')).over(window)).\
    withColumn('Percent',col('Credit_num')*100/col('total')).\
    drop(col('total'))

+-----+-----+-----+-----+-----+
| age_class | Credit_num | Credit_avg | Credit_min | Credit_max | Percent |
+-----+-----+-----+-----+-----+
| 45-54 | 120 | 3183.066666666666 | 338 | 12612 | 12.0 |
| <25 | 150 | 2970.733333333333 | 276 | 15672 | 15.0 |
| 55-64 | 56 | 3493.660714285714 | 385 | 15945 | 5.6 |
| 35-44 | 254 | 3403.771653543307 | 250 | 15857 | 25.4 |
| 25-34 | 397 | 3298.823677581864 | 343 | 18424 | 39.7 |
    
```

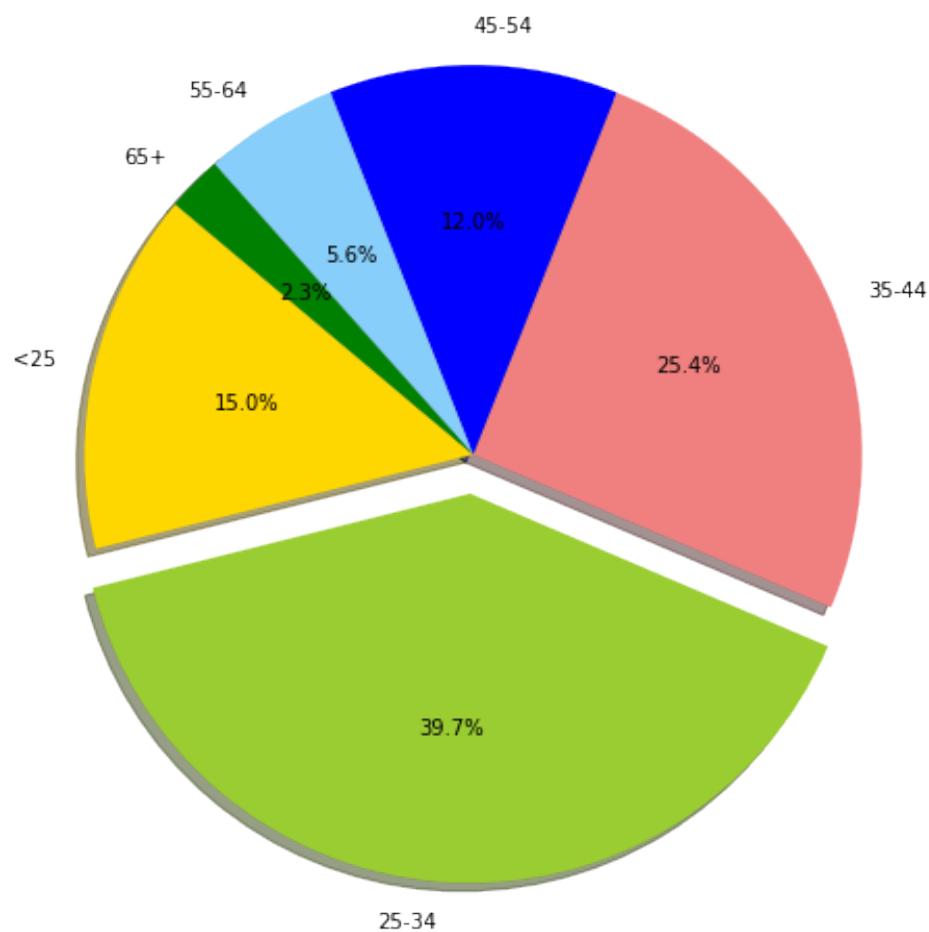
	65+	23 3210.1739130434785	571	14896	2.3
--	-----	-------------------------	-----	-------	-----

- Pie plot

```
# Data to plot
labels = plot_data.age_class
sizes = plot_data.Percent
colors = ['gold', 'yellowgreen', 'lightcoral','blue', 'lightskyblue','green','red']
explode = (0, 0.1, 0, 0,0,0) # explode 1st slice

# Plot
plt.figure(figsize=(10,8))
plt.pie(sizes, explode=explode, labels=labels, colors=colors,
        autopct='%.1f%%', shadow=True, startangle=140)

plt.axis('equal')
plt.show()
```



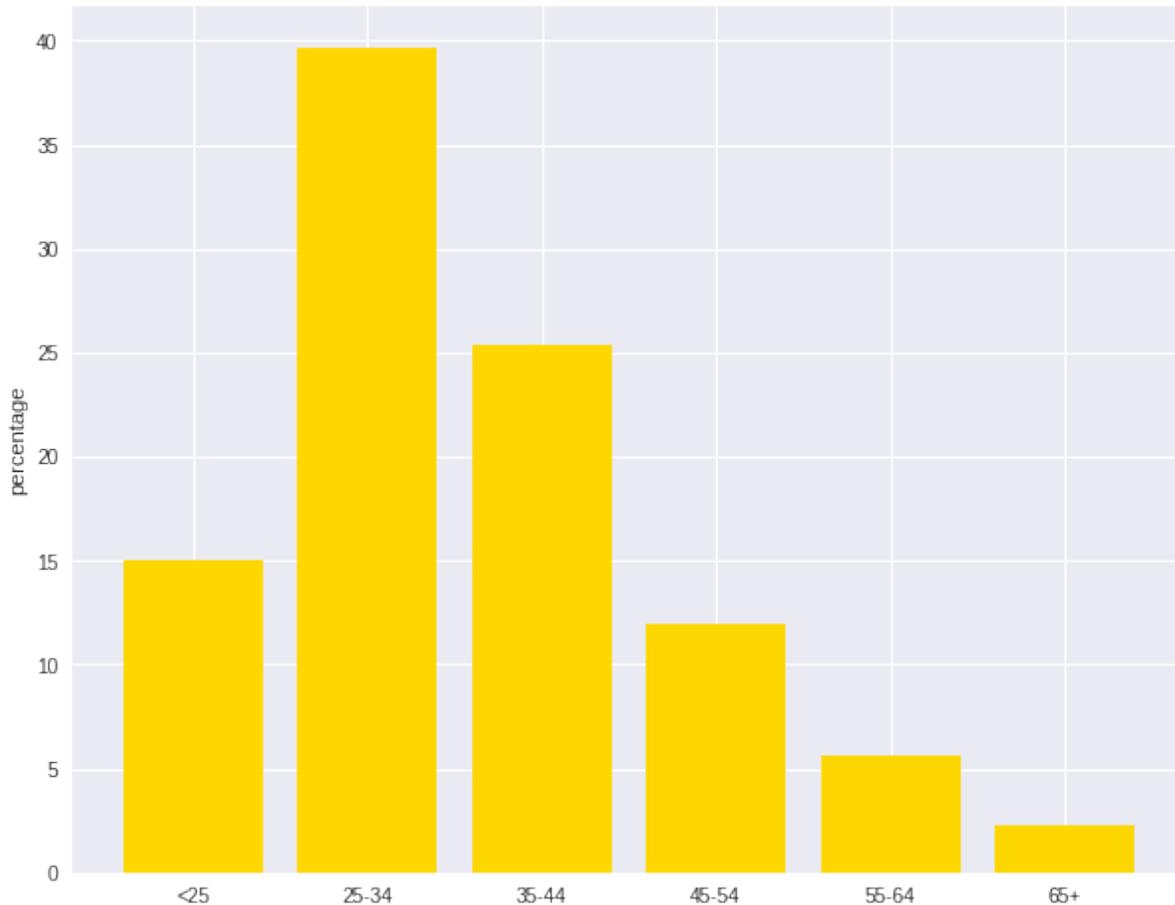
- Bar plot

```
labels = plot_data.age_class
missing = plot_data.Percent
ind = [x for x, _ in enumerate(labels)]

plt.figure(figsize=(10,8))
plt.bar(ind, missing, width=0.8, label='missing', color='gold')
```

```
plt.xticks(ind, labels)
plt.ylabel("percentage")

plt.show()
```

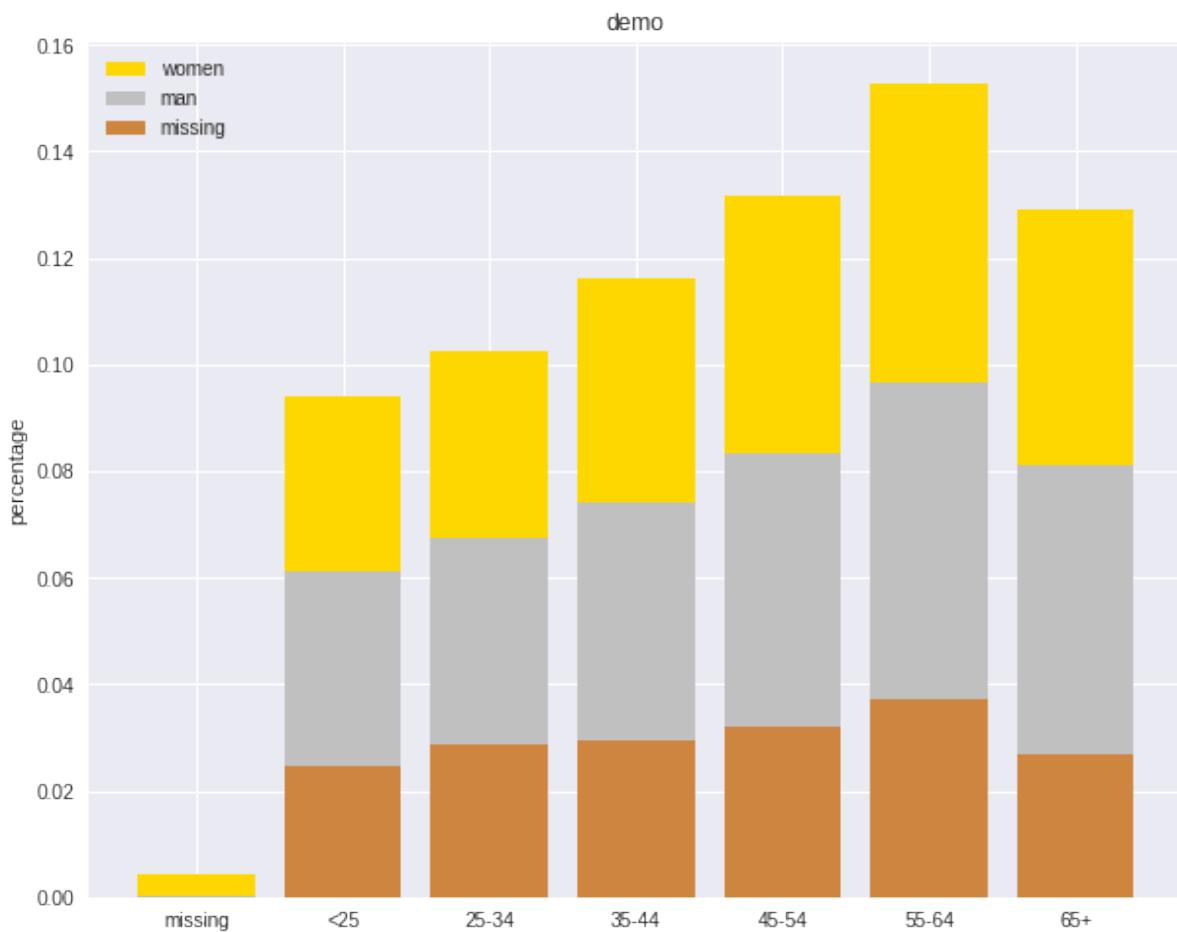


```
labels = ['missing', '<25', '25-34', '35-44', '45-54', '55-64', '65+']
missing = np.array([0.000095, 0.024830, 0.028665, 0.029477, 0.031918, 0.037073, 0.026699])
man = np.array([0.000147, 0.036311, 0.038684, 0.044761, 0.051269, 0.059542, 0.054259])
women = np.array([0.004035, 0.032935, 0.035351, 0.041778, 0.048437, 0.056236, 0.048091])
ind = [x for x, _ in enumerate(labels)]

plt.figure(figsize=(10,8))
plt.bar(ind, women, width=0.8, label='women', color='gold', bottom=man+missing)
plt.bar(ind, man, width=0.8, label='man', color='silver', bottom=missing)
plt.bar(ind, missing, width=0.8, label='missing', color='#CD853F')

plt.xticks(ind, labels)
plt.ylabel("percentage")
plt.legend(loc="upper left")
plt.title("demo")

plt.show()
```



7.2 Multivariate Analysis

In this section, I will only demonstrate the bivariate analysis. Since the multivariate analysis is the generation of the bivariate.

7.2.1 Numerical V.S. Numerical

- Correlation matrix

```
from pyspark.mllib.stat import Statistics
import pandas as pd

corr_data = df.select(num_cols)

col_names = corr_data.columns
features = corr_data.rdd.map(lambda row: row[0:])
corr_mat=Statistics.corr(features, method="pearson")
corr_df = pd.DataFrame(corr_mat)
corr_df.index, corr_df.columns = col_names, col_names

print(corr_df.to_string())

+-----+-----+
| Account Balance| No of dependents|
+-----+-----+
| 1.0 |-0.01414542650320914 |
|-0.01414542650320914 | 1.0 |
+-----+-----+
```

- Scatter Plot

```
import seaborn as sns
sns.set(style="ticks")

df = sns.load_dataset("iris")
sns.pairplot(df, hue="species")
plt.show()
```

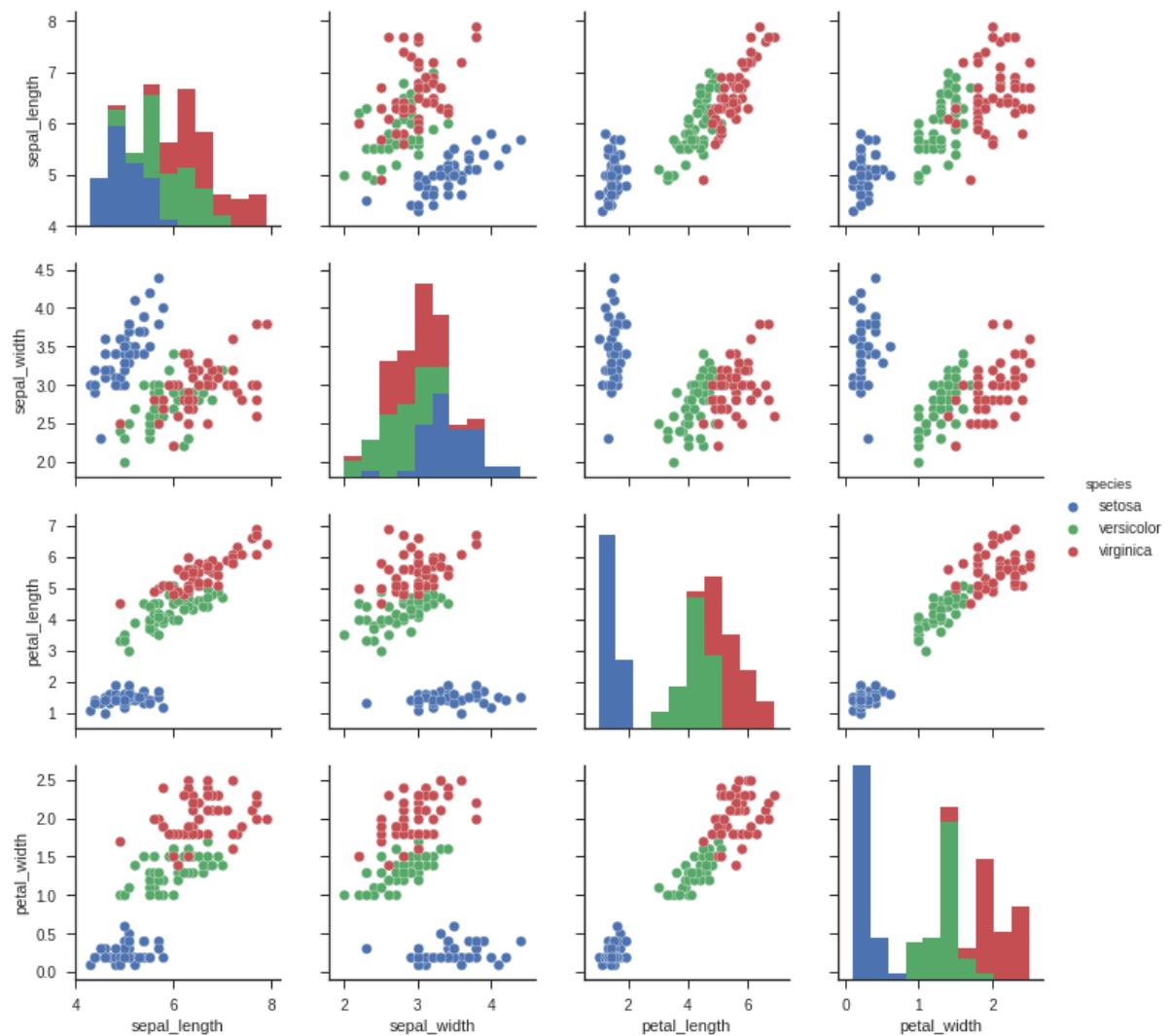
7.2.2 Categorical V.S. Categorical

- Pearson's Chi-squared test

Warning: `pyspark.ml.stat` is only available in Spark 2.4.0.

```
from pyspark.ml.linalg import Vectors
from pyspark.ml.stat import ChiSquareTest

data = [(0.0, Vectors.dense(0.5, 10.0)),
        (0.0, Vectors.dense(1.5, 20.0)),
        (1.0, Vectors.dense(1.5, 30.0)),
        (0.0, Vectors.dense(3.5, 30.0)),
        (0.0, Vectors.dense(3.5, 40.0)),
        (1.0, Vectors.dense(3.5, 40.0))]
df = spark.createDataFrame(data, ["label", "features"])
```



```
r = ChiSquareTest.test(df, "features", "label").head()
print("pValues: " + str(r.pValues))
print("degreesOfFreedom: " + str(r.degreesOfFreedom))
print("statistics: " + str(r.statistics))

pValues: [0.687289278791, 0.682270330336]
degreesOfFreedom: [2, 3]
statistics: [0.75, 1.5]
```

- Cross table

```
df.stat.crosstab("age_class", "Occupation").show()
```

age_class_Occupation	1	2	3	4
<25	4	34	108	4
55-64	1	15	31	9
25-34	7	61	269	60
35-44	4	58	143	49
65+	5	3	6	9
45-54	1	29	73	17

- Stacked plot

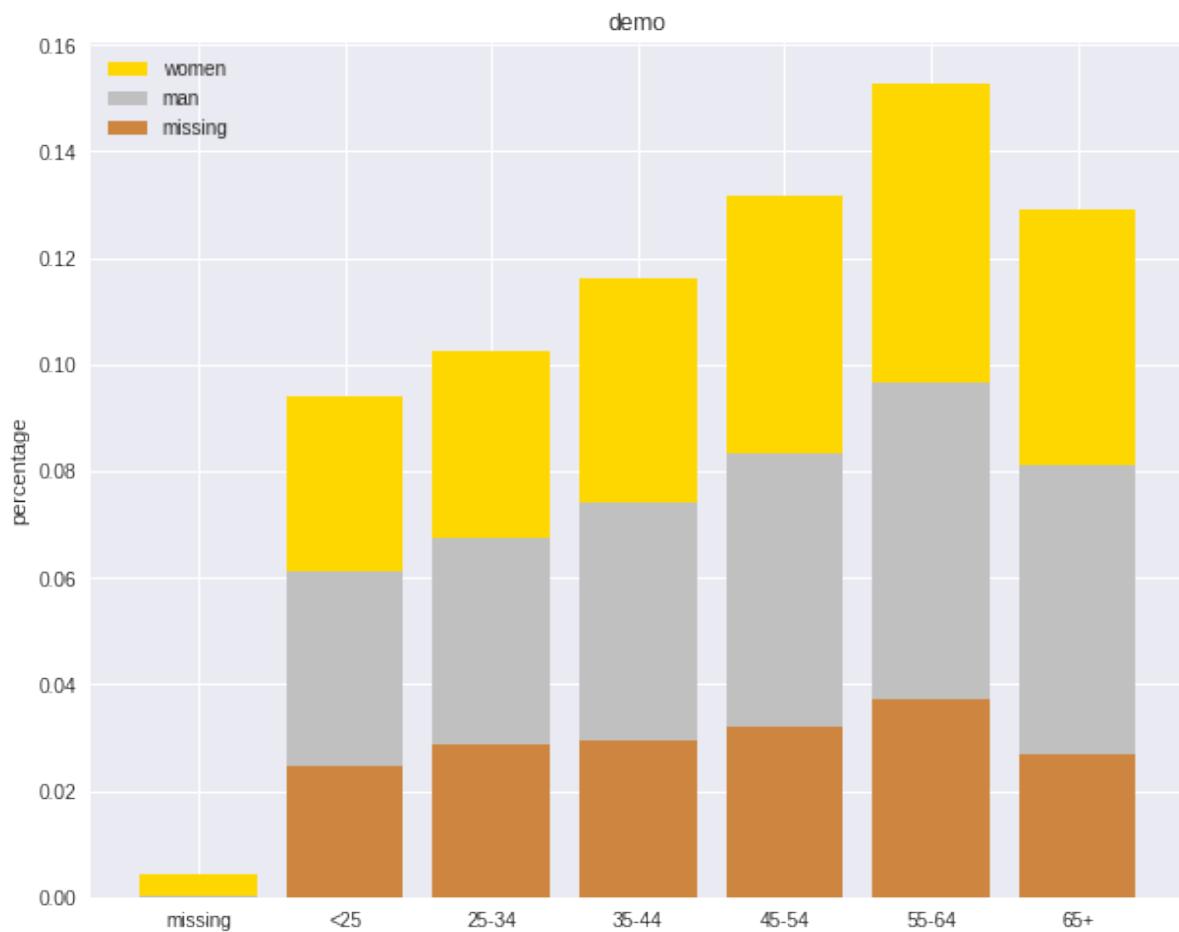
```
labels = ['missing', '<25', '25-34', '35-44', '45-54', '55-64', '65+']
missing = np.array([0.000095, 0.024830, 0.028665, 0.029477, 0.031918, 0.037073, 0.026699])
man = np.array([0.000147, 0.036311, 0.038684, 0.044761, 0.051269, 0.059542, 0.054259])
women = np.array([0.004035, 0.032935, 0.035351, 0.041778, 0.048437, 0.056236, 0.048091])
ind = [x for x, _ in enumerate(labels)]

plt.figure(figsize=(10,8))
plt.bar(ind, women, width=0.8, label='women', color='gold', bottom=man+missing)
plt.bar(ind, man, width=0.8, label='man', color='silver', bottom=missing)
plt.bar(ind, missing, width=0.8, label='missing', color='#CD853F')

plt.xticks(ind, labels)
plt.ylabel("percentage")
plt.legend(loc="upper left")
plt.title("demo")

plt.show()
```

7.2.3 Numerical V.S. Categorical



**CHAPTER
EIGHT**

REGRESSION

Chinese proverb

A journey of a thousand miles begins with a single step. – old Chinese proverb

In statistical modeling, regression analysis focuses on investigating the relationship between a dependent variable and one or more independent variables. [Wikipedia Regression analysis](#)

In data mining, Regression is a model to represent the relationship between the value of lable (or target, it is numerical variable) and on one or more features (or predictors they can be numerical and categorical variables).

8.1 Linear Regression

8.1.1 Introduction

Given that a data set $\{x_{i1}, \dots, x_{in}, y_i\}_{i=1}^m$ which contains n features (variables) and m samples (data points), in simple linear regression model for modeling m data points with one independent variable: x_{i1} , the formula is given by:

$$y_i = \beta_0 + \beta_1 x_{i1}, \text{ where, } i = 1, \dots, m.$$

In matrix notation, the data set is written as $\mathbf{X} = [\mathbf{X}_1, \dots, \mathbf{X}_n]$ with $\mathbf{X}_i = \{x_{i.}\}_{i=1}^n$, $\mathbf{y} = \{y_i\}_{i=1}^m$ and $\boldsymbol{\beta}^\top = \{\beta_i\}_{i=1}^m$. Then the normal equations are written as

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta}.$$

8.1.2 How to solve it?

1. Direct Methods (For more information please refer to my [Prelim Notes for Numerical Analysis](#))
 - For squared or rectangular matrices
 - Singular Value Decomposition
 - Gram-Schmidt orthogonalization
 - QR Decomposition

- For squared matrices
 - LU Decomposition
 - Cholesky Decomposition
 - Regular Splittings
- 2. Iterative Methods
 - Stationary cases iterative method
 - Jacobi Method
 - Gauss-Seidel Method
 - Richardson Method
 - Successive Over Relaxation (SOR) Method
 - Dynamic cases iterative method
 - Chebyshev iterative Method
 - Minimal residuals Method
 - Minimal correction iterative method
 - Steepest Descent Method
 - Conjugate Gradients Method

8.1.3 Demo

- The Jupyter notebook can be download from Linear Regression which was implemented without using Pipeline.
- The Jupyter notebook can be download from Linear Regression with Pipeline which was implemented with using Pipeline.
- I will only present the code with pipeline style in the following.
- For more details about the parameters, please visit [Linear Regression API](#).

1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark regression example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
```

2. Load dataset

```
df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', \
            inferschema='true') \
    .load("../data/Advertising.csv", header=True);
```

check the data set

```
df.show(5, True)
df.printSchema()
```

Then you will get

```
+----+----+----+----+
|   TV| Radio|Newspaper|Sales|
+----+----+----+----+
| 230.1| 37.8|    69.2| 22.1|
|  44.5| 39.3|    45.1| 10.4|
| 17.2| 45.9|    69.3|  9.3|
|151.5| 41.3|    58.5| 18.5|
|180.8| 10.8|    58.4| 12.9|
+----+----+----+----+
only showing top 5 rows
```

```
root
 |-- TV: double (nullable = true)
 |-- Radio: double (nullable = true)
 |-- Newspaper: double (nullable = true)
 |-- Sales: double (nullable = true)
```

You can also get the Statistical results from the data frame (Unfortunately, it only works for numerical).

```
df.describe().show()
```

Then you will get

```
+-----+-----+-----+-----+-----+
| summary |          TV |        Radio |      Newspaper |       Sales |
+-----+-----+-----+-----+-----+
|  count |        200 |        200 |        200 |        200 |
|  mean | 147.0425 | 23.26400000000024 | 30.55399999999995 | 14.02250000000003 |
| stddev | 85.85423631490805 | 14.846809176168728 | 21.77862083852283 | 5.217456565710477 |
|  min |        0.7 |        0.0 |        0.3 |        1.6 |
|  max |      296.4 |       49.6 |      114.0 |       27.0 |
+-----+-----+-----+-----+-----+
```

3. Convert the data to dense vector (**features** and **label**)

```
from pyspark.sql import Row
from pyspark.ml.linalg import Vectors

# I provide two ways to build the features and labels

# method 1 (good for small feature):
#def transData(row):
#    return Row(label=row["Sales"],
#               features=Vectors.dense([row["TV"],
#                                      row["Radio"],
#                                      row["Newspaper"]]))

# Method 2 (good for large features):
def transData(data):
    return data.rdd.map(lambda r: [Vectors.dense(r[:-1]), r[-1]]).toDF(['features', 'label'])
```

Note: You are strongly encouraged to try my `get_dummy` function for dealing with the categorical data in complex dataset.

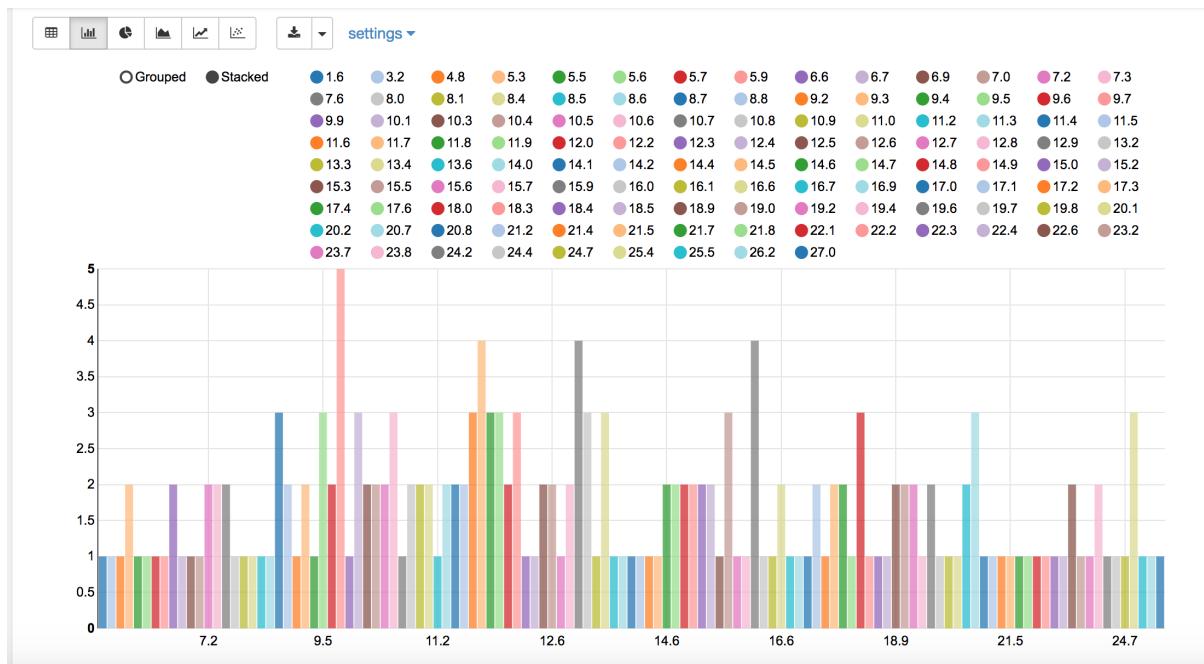


Figure 8.1: Sales distribution

Supervised learning version:

```
def get_dummy(df, indexCol, categoricalCols, continuousCols, labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                  for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                            + continuousCols, outputCol="features"])

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    data = data.withColumn('label', col(labelCol))

    return data.select(indexCol,'features','label')
```

Unsupervised learning version:

```
def get_dummy(df, indexCol, categoricalCols, continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learning
    :param df: the dataframe
```

```

:param categoricalCols: the name list of the categorical data
:param continuousCols: the name list of the numerical data
:return k: feature matrix

:author: Wenqiang Feng
:email: von198@gmail.com
'''

indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
             for c in categoricalCols ]

# default setting: dropLast=True
encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                            outputCol="{0}_encoded".format(indexer.getOutputCol()))
              for indexer in indexers ]

assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders]
                             + continuousCols, outputCol="features")

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

return data.select(indexCol,'features')

```

4. Transform the dataset to DataFrame

```
transformed= transData(df)
transformed.show(5)
```

```
+-----+-----+
|      features|label|
+-----+-----+
| [230.1,37.8,69.2]| 22.1|
| [44.5,39.3,45.1]| 10.4|
| [17.2,45.9,69.3]|  9.3|
| [151.5,41.3,58.5]| 18.5|
| [180.8,10.8,58.4]| 12.9|
+-----+-----+
only showing top 5 rows
```

Note: You will find out that all of the supervised machine learning algorithms in Spark are based on the **features** and **label** (unsupervised machine learning algorithms in Spark are based on the **features**). That is to say, you can play with all of the machine learning algorithms in Spark when you get ready the **features** and **label** in pipeline architecture.

5. Deal With Categorical Variables

```
from pyspark.ml import Pipeline
from pyspark.ml.regression import LinearRegression
from pyspark.ml.feature import VectorIndexer
from pyspark.ml.evaluation import RegressionEvaluator

# Automatically identify categorical features, and index them.
# We specify maxCategories so features with > 4 distinct values are treated as continuou
```

```

featureIndexer = VectorIndexer(inputCol="features", \
                               outputCol="indexedFeatures", \
                               maxCategories=4).fit(transformed)

data = featureIndexer.transform(transformed)
    
```

Now you check your dataset with

```
data.show(5, True)
```

you will get

```
+-----+-----+-----+
|       features|label| indexedFeatures|
+-----+-----+-----+
| [230.1,37.8,69.2]| 22.1|[230.1,37.8,69.2]|
| [44.5,39.3,45.1]| 10.4|[44.5,39.3,45.1]|
| [17.2,45.9,69.3]|  9.3|[17.2,45.9,69.3]|
| [151.5,41.3,58.5]| 18.5|[151.5,41.3,58.5]|
| [180.8,10.8,58.4]| 12.9|[180.8,10.8,58.4]|
+-----+-----+-----+
only showing top 5 rows
```

6. Split the data into training and test sets (40% held out for testing)

```
# Split the data into training and test sets (40% held out for testing)
(trainingData, testData) = transformed.randomSplit([0.6, 0.4])
```

You can check your train and test data as follows (In my opinion, it is always good to keep tracking your data during prototype phase):

```
trainingData.show(5)
testData.show(5)
```

Then you will get

```
+-----+-----+-----+
|       features|label| indexedFeatures|
+-----+-----+-----+
| [4.1,11.6,5.7]|  3.2|[4.1,11.6,5.7]|
| [5.4,29.9,9.4]|  5.3|[5.4,29.9,9.4]|
| [7.3,28.1,41.4]|  5.5|[7.3,28.1,41.4]|
| [7.8,38.9,50.6]|  6.6|[7.8,38.9,50.6]|
| [8.6,2.1,1.0]|  4.8|[8.6,2.1,1.0]|
+-----+-----+-----+
only showing top 5 rows

+-----+-----+-----+
|       features|label| indexedFeatures|
+-----+-----+-----+
| [0.7,39.6,8.7]|  1.6|[0.7,39.6,8.7]|
| [8.4,27.2,2.1]|  5.7|[8.4,27.2,2.1]|
| [11.7,36.9,45.2]|  7.3|[11.7,36.9,45.2]|
| [13.2,15.9,49.6]|  5.6|[13.2,15.9,49.6]|
| [16.9,43.7,89.4]|  8.7|[16.9,43.7,89.4]|
+-----+-----+-----+
only showing top 5 rows
```

7. Fit Ordinary Least Square Regression Model

For more details about the parameters, please visit [Linear Regression API](#).

```
# Import LinearRegression class
from pyspark.ml.regression import LinearRegression

# Define LinearRegression algorithm
lr = LinearRegression()

# Chain indexer and tree in a Pipeline
pipeline = Pipeline(stages=[featureIndexer, lr])

model = pipeline.fit(trainingData)
```

8. Pipeline Architecture

9. Summary of the Model

Spark has a poor summary function for data and model. I wrote a summary function which has similar format as **R** output for the linear regression in PySpark.

```
def modelsummary(model):
    import numpy as np
    print ("Note: the last rows are the information for Intercept")
    print ("##", "-----")
    print ("##", " Estimate | Std.Error | t Values | P-value")
    coef = np.append(list(model.coefficients),model.intercept)
    Summary=model.summary

    for i in range(len(Summary.pValues)):
        print ("##", '{:10.6f}'.format(coef[i]), \
              '{:10.6f}'.format(Summary.coefficientStandardErrors[i]), \
              '{:8.3f}'.format(Summary.tValues[i]), \
              '{:10.6f}'.format(Summary.pValues[i]))

    print ("##", "---")
    print ("##", "Mean squared error: % .6f" \
          % Summary.meanSquaredError, ", RMSE: % .6f" \
          % Summary.rootMeanSquaredError )
    print ("##", "Multiple R-squared: %f" % Summary.r2, ", " \
          Total iterations: %i" % Summary.totalIterations)

modelsummary(model.stages[-1])
```

You will get the following summary results:

```
Note: the last rows are the information for Intercept
('##', '-----')
('##', ' Estimate | Std.Error | t Values | P-value')
('##', ' 0.044186', ' 0.001663', ' 26.573', ' 0.000000')
('##', ' 0.206311', ' 0.010846', ' 19.022', ' 0.000000')
('##', ' 0.001963', ' 0.007467', ' 0.263', ' 0.793113')
('##', ' 2.596154', ' 0.379550', ' 6.840', ' 0.000000')
('##', '---')
('##', 'Mean squared error: 2.588230', ', RMSE: 1.608798')
('##', 'Multiple R-squared: 0.911869', ', Total iterations: 1')
```

10. Make predictions

```
# Make predictions.
predictions = model.transform(testData)

# Select example rows to display.
predictions.select("features", "label", "predictedLabel").show(5)

+-----+-----+-----+
|      features|label|      prediction|
+-----+-----+-----+
| [0.7, 39.6, 8.7] | 1.6 | 10.81405928637388 |
| [8.4, 27.2, 2.1] | 5.7 | 8.583086404079918 |
| [11.7, 36.9, 45.2] | 7.3 | 10.814712818232422 |
| [13.2, 15.9, 49.6] | 5.6 | 6.557106943899219 |
| [16.9, 43.7, 89.4] | 8.7 | 12.534151375058645 |
+-----+-----+-----+
only showing top 5 rows
```

9. Evaluation

```
from pyspark.ml.evaluation import RegressionEvaluator
# Select (prediction, true label) and compute test error
evaluator = RegressionEvaluator(labelCol="label",
                                 predictionCol="prediction",
                                 metricName="rmse")

rmse = evaluator.evaluate(predictions)
print("Root Mean Squared Error (RMSE) on test data = %g" % rmse)
```

The final Root Mean Squared Error (RMSE) is as follows:

```
Root Mean Squared Error (RMSE) on test data = 1.63114
```

You can also check the R^2 value for the test data:

```
y_true = predictions.select("label").toPandas()
y_pred = predictions.select("prediction").toPandas()

import sklearn.metrics
r2_score = sklearn.metrics.r2_score(y_true, y_pred)
print('r2_score: {}'.format(r2_score))
```

Then you will get

```
r2_score: 0.854486655585
```

Warning: You should know most softwares are using different formula to calculate the R^2 value when no intercept is included in the model. You can get more information from the discussion at [StackExchange](#).

8.2 Generalized linear regression

8.2.1 Introduction

8.2.2 How to solve it?

8.2.3 Demo

- The Jupyter notebook can be download from Generalized Linear Regression.
 - For more details about the parameters, please visit [Generalized Linear Regression API](#).
1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark regression example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
```

2. Load dataset

```
df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', \
            inferschema='true') \
    .load("../data/Advertising.csv", header=True);
```

check the data set

```
df.show(5, True)
df.printSchema()
```

Then you will get

```
+----+-----+-----+
|    TV|Radio|Newspaper|Sales|
+----+-----+-----+
| 230.1| 37.8|   69.2|  22.1|
|  44.5| 39.3|   45.1| 10.4|
| 17.2| 45.9|   69.3|   9.3|
|151.5| 41.3|   58.5| 18.5|
|180.8| 10.8|   58.4| 12.9|
+----+-----+-----+
only showing top 5 rows

root
 |-- TV: double (nullable = true)
 |-- Radio: double (nullable = true)
 |-- Newspaper: double (nullable = true)
 |-- Sales: double (nullable = true)
```

You can also get the Statistical results from the data frame (Unfortunately, it only works for numerical).

```
df.describe().show()
```

Then you will get

summary	TV	Radio	Newspaper	Sales
count	200	200	200	200
mean	147.042523.26400000000024	30.553999999999995	14.022500000000003	
stddev	85.85423631490805	14.846809176168728	21.77862083852283	5.217456565710477
min	0.7	0.0	0.3	1.6
max	296.4	49.6	114.0	27.0

3. Convert the data to dense vector (**features** and **label**)

Note: You are strongly encouraged to try my `get_dummy` function for dealing with the categorical data in comple dataset.

Supervised learning version:

```
def get_dummy(df, indexCol, categoricalCols, continuousCols, labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                 for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                            + continuousCols, outputCol="features"])

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    data = data.withColumn('label', col(labelCol))

    return data.select(indexCol, 'features', 'label')
```

Unsupervised learning version:

```
def get_dummy(df, indexCol, categoricalCols, continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learn
    :param df: the dataframe
    :param categoricalCols: the name list of the categorical data
    :param continuousCols: the name list of the numerical data
    :return k: feature matrix

    :author: Wenqiang Feng
    :email: von198@gmail.com
    """

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
```

```

        for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                 for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in
                                            + continuousCols, outputCol="features")]

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    return data.select(indexCol,'features')

```

```

from pyspark.sql import Row
from pyspark.ml.linalg import Vectors

# I provide two ways to build the features and labels

# method 1 (good for small feature):
#def transData(row):
#    return Row(label=row["Sales"],
#               features=Vectors.dense([row["TV"],
#                                      row["Radio"],
#                                      row["Newspaper"]]))

# Method 2 (good for large features):
def transData(data):
    return data.rdd.map(lambda r: [Vectors.dense(r[:-1]),r[-1]]).toDF(['features','label'])

transformed= transData(df)
transformed.show(5)

+-----+-----+
|      features|label|
+-----+-----+
| [230.1,37.8,69.2]| 22.1|
| [44.5,39.3,45.1]| 10.4|
| [17.2,45.9,69.3]|  9.3|
| [151.5,41.3,58.5]| 18.5|
| [180.8,10.8,58.4]| 12.9|
+-----+-----+
only showing top 5 rows

```

Note: You will find out that all of the machine learning algorithms in Spark are based on the **features** and **label**. That is to say, you can play with all of the machine learning algorithms in Spark when you get ready the **features** and **label**.

4. Convert the data to dense vector

```
# convert the data to dense vector
def transData(data):
```

```

    return data.rdd.map(lambda r: [r[-1], Vectors.dense(r[:-1])]).\
        toDF(['label','features'])

from pyspark.sql import Row
from pyspark.ml.linalg import Vectors

data= transData(df)
data.show()

```

5. Deal with the Categorical variables

```

from pyspark.ml import Pipeline
from pyspark.ml.regression import LinearRegression
from pyspark.ml.feature import VectorIndexer
from pyspark.ml.evaluation import RegressionEvaluator

# Automatically identify categorical features, and index them.
# We specify maxCategories so features with > 4
# distinct values are treated as continuous.

featureIndexer = VectorIndexer(inputCol="features", \
                                outputCol="indexedFeatures", \
                                maxCategories=4).fit(transformed)

data = featureIndexer.transform(transformed)

```

When you check your data at this point, you will get

```

+-----+-----+
|     features|label| indexedFeatures|
+-----+-----+
| [230.1,37.8,69.2]| 22.1|[230.1,37.8,69.2]|
| [44.5,39.3,45.1]| 10.4|[44.5,39.3,45.1]|
| [17.2,45.9,69.3]|  9.3|[17.2,45.9,69.3]|
| [151.5,41.3,58.5]| 18.5|[151.5,41.3,58.5]|
| [180.8,10.8,58.4]| 12.9|[180.8,10.8,58.4]|
+-----+
only showing top 5 rows

```

6. Split the data into training and test sets (40% held out for testing)

```

# Split the data into training and test sets (40% held out for testing)
(trainingData, testData) = transformed.randomSplit([0.6, 0.4])

```

You can check your train and test data as follows (In my opinion, it is always good to keep tracking your data during prototype phase):

```

trainingData.show(5)
testData.show(5)

```

Then you will get

```

+-----+-----+
|     features|label| indexedFeatures|
+-----+-----+
| [5.4,29.9,9.4]|  5.3|[5.4,29.9,9.4]|
| [7.8,38.9,50.6]|  6.6|[7.8,38.9,50.6]|
| [8.4,27.2,2.1]|  5.7|[8.4,27.2,2.1]|
| [8.7,48.9,75.0]|  7.2|[8.7,48.9,75.0]|

```

```
| [11.7,36.9,45.2] | 7.3| [11.7,36.9,45.2] |
+-----+-----+-----+
only showing top 5 rows

+-----+-----+
| features|label|indexedFeatures|
+-----+-----+
| [0.7,39.6,8.7]| 1.6| [0.7,39.6,8.7]|
| [4.1,11.6,5.7]| 3.2| [4.1,11.6,5.7]|
| [7.3,28.1,41.4]| 5.5|[7.3,28.1,41.4]|
| [8.6,2.1,1.0]| 4.8| [8.6,2.1,1.0]|
| [17.2,4.1,31.6]| 5.9|[17.2,4.1,31.6]|
+-----+-----+
only showing top 5 rows
```

7. Fit Generalized Linear Regression Model

```
# Import LinearRegression class
from pyspark.ml.regression import GeneralizedLinearRegression

# Define LinearRegression algorithm
glr = GeneralizedLinearRegression(family="gaussian", link="identity", \
                                    maxIter=10, regParam=0.3)
```

8. Pipeline Architecture

```
# Chain indexer and tree in a Pipeline
pipeline = Pipeline(stages=[featureIndexer, glr])

model = pipeline.fit(trainingData)
```

9. Summary of the Model

Spark has a poor summary function for data and model. I wrote a summary function which has similar format as **R** output for the linear regression in PySpark.

```
def modelsummary(model):
    import numpy as np
    print ("Note: the last rows are the information for Intercept")
    print ("##,"-----")
    print ("##," Estimate | Std.Error | t Values | P-value")
    coef = np.append(list(model.coefficients),model.intercept)
    Summary=model.summary

    for i in range(len(Summary.pValues)):
        print ("##",'{:10.6f}'.format(coef[i]),\
              '{:10.6f}'.format(Summary.coefficientStandardErrors[i]),\
              '{:8.3f}'.format(Summary.tValues[i]),\
              '{:10.6f}'.format(Summary.pValues[i]))

    print ("##,'---')
    #    print ("##,"Mean squared error: % .6f" \
    #          "% Summary.meanSquaredError, ", RMSE: % .6f" \
    #          "% Summary.rootMeanSquaredError ")
    #    print ("##,"Multiple R-squared: %f" % Summary.r2, ", \
    #          Total iterations: %i"% Summary.totalIterations)
```

```
modelsummary(model.stages[-1])
```

You will get the following summary results:

```
Note: the last rows are the information for Intercept
('##', '-----')
('##', ' Estimate | Std.Error | t Values | P-value')
('##', ' 0.042857', ' 0.001668', ' 25.692', ' 0.000000')
('##', ' 0.199922', ' 0.009881', ' 20.232', ' 0.000000')
('##', ' -0.001957', ' 0.006917', ' -0.283', ' 0.777757')
('##', ' 3.007515', ' 0.406389', ' 7.401', ' 0.000000')
('##', '---')
```

10. Make predictions

```
# Make predictions.
predictions = model.transform(testData)

# Select example rows to display.
predictions.select("features", "label", "predictedLabel").show(5)

+-----+-----+-----+
|     features|label|      prediction|
+-----+-----+-----+
| [0.7,39.6,8.7]| 1.6|10.937383732327625|
| [4.1,11.6,5.7]| 3.2| 5.491166258750164|
| [7.3,28.1,41.4]| 5.5|  8.8571603947873|
| [8.6,2.1,1.0]| 4.8| 3.793966281660073|
| [17.2,4.1,31.6]| 5.9| 4.502507124763654|
+-----+-----+-----+
only showing top 5 rows
```

11. Evaluation

```
from pyspark.ml.evaluation import RegressionEvaluator
from pyspark.ml.evaluation import RegressionEvaluator
# Select (prediction, true label) and compute test error
evaluator = RegressionEvaluator(labelCol="label",
                                 predictionCol="prediction",
                                 metricName="rmse")

rmse = evaluator.evaluate(predictions)
print("Root Mean Squared Error (RMSE) on test data = %g" % rmse)
```

The final Root Mean Squared Error (RMSE) is as follows:

```
Root Mean Squared Error (RMSE) on test data = 1.89857

y_true = predictions.select("label").toPandas()
y_pred = predictions.select("prediction").toPandas()

import sklearn.metrics
r2_score = sklearn.metrics.r2_score(y_true, y_pred)
print('r2_score: {0}'.format(r2_score))
```

Then you will get the R^2 value:

```
r2_score: 0.87707391843
```

8.3 Decision tree Regression

8.3.1 Introduction

8.3.2 How to solve it?

8.3.3 Demo

- The Jupyter notebook can be download from Decision Tree Regression.
 - For more details about the parameters, please visit [Decision Tree Regressor API](#).
1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark regression example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
```

2. Load dataset

```
df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', \
    inferSchema='true') \
    .load("../data/Advertising.csv", header=True);
```

check the data set

```
df.show(5, True)
df.printSchema()
```

Then you will get

```
+---+---+---+---+
| TV | Radio | Newspaper | Sales |
+---+---+---+---+
| 230.1 | 37.8 | 69.2 | 22.1 |
| 44.5 | 39.3 | 45.1 | 10.4 |
| 17.2 | 45.9 | 69.3 | 9.3 |
| 151.5 | 41.3 | 58.5 | 18.5 |
| 180.8 | 10.8 | 58.4 | 12.9 |
+---+---+---+---+
only showing top 5 rows

root
 |-- TV: double (nullable = true)
 |-- Radio: double (nullable = true)
 |-- Newspaper: double (nullable = true)
 |-- Sales: double (nullable = true)
```

You can also get the Statistical results from the data frame (Unfortunately, it only works for numerical).

```
df.describe().show()
```

Then you will get

summary	TV	Radio	Newspaper	Sales
count	200	200	200	200
mean	147.0425	23.26400000000024	30.553999999999995	14.022500000000003
stddev	85.85423631490805	14.846809176168728	21.77862083852283	5.217456565710477
min	0.7	0.0	0.3	1.6
max	296.4	49.6	114.0	27.0

3. Convert the data to dense vector (**features** and **label**)

Note: You are strongly encouraged to try my `get_dummy` function for dealing with the categorical data in complex dataset.

Supervised learning version:

```
def get_dummy(df, indexCol, categoricalCols, continuousCols, labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                 for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                            + continuousCols, outputCol="features")

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    data = data.withColumn('label', col(labelCol))

    return data.select(indexCol, 'features', 'label')
```

Unsupervised learning version:

```
def get_dummy(df, indexCol, categoricalCols, continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learning
    :param df: the dataframe
    :param categoricalCols: the name list of the categorical data
    :param continuousCols: the name list of the numerical data
    :return k: feature matrix
    """
```

```
:author: Wengiang Feng
:email: von198@gmail.com
'''

indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
             for c in categoricalCols ]

# default setting: dropLast=True
encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                            outputCol="{0}_encoded".format(indexer.getOutputCol()))
              for indexer in indexers ]

assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders] + continuousCols, outputCol="features")

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

return data.select(indexCol,'features')
```

```
from pyspark.sql import Row
from pyspark.ml.linalg import Vectors

# I provide two ways to build the features and labels

# method 1 (good for small feature):
#def transData(row):
#    return Row(label=row["Sales"],
#               features=Vectors.dense([row["TV"],
#                                      row["Radio"],
#                                      row["Newspaper"]]))

# Method 2 (good for large features):
def transData(data):
    return data.rdd.map(lambda r: [Vectors.dense(r[:-1]), r[-1]]).toDF(['features','label'])

transformed= transData(df)
transformed.show(5)

+-----+---+
|      features|label|
+-----+---+
|[230.1,37.8,69.2]| 22.1|
|[44.5,39.3,45.1]| 10.4|
|[17.2,45.9,69.3]|  9.3|
|[151.5,41.3,58.5]| 18.5|
|[180.8,10.8,58.4]| 12.9|
+-----+---+
only showing top 5 rows
```

Note: You will find out that all of the machine learning algorithms in Spark are based on the **features** and **label**. That is to say, you can play with all of the machine learning algorithms in Spark when you get ready the **features** and **label**.

4. Convert the data to dense vector

```
# convert the data to dense vector
def transData(data):
    return data.rdd.map(lambda r: [r[-1], Vectors.dense(r[:-1])]).\
        toDF(['label','features'])

transformed = transData(df)
transformed.show(5)
```

5. Deal with the Categorical variables

```
from pyspark.ml import Pipeline
from pyspark.ml.regression import LinearRegression
from pyspark.ml.feature import VectorIndexer
from pyspark.ml.evaluation import RegressionEvaluator

# Automatically identify categorical features, and index them.
# We specify maxCategories so features with > 4
# distinct values are treated as continuous.

featureIndexer = VectorIndexer(inputCol="features", \
                                outputCol="indexedFeatures", \
                                maxCategories=4).fit(transformed)

data = featureIndexer.transform(transformed)
```

When you check your data at this point, you will get

```
+-----+-----+-----+
|      features|label| indexedFeatures|
+-----+-----+-----+
| [230.1,37.8,69.2]| 22.1|[230.1,37.8,69.2]|
| [44.5,39.3,45.1]| 10.4|[44.5,39.3,45.1]|
| [17.2,45.9,69.3]|  9.3|[17.2,45.9,69.3]|
| [151.5,41.3,58.5]| 18.5|[151.5,41.3,58.5]|
| [180.8,10.8,58.4]| 12.9|[180.8,10.8,58.4]|
+-----+-----+-----+
only showing top 5 rows
```

6. Split the data into training and test sets (40% held out for testing)

```
# Split the data into training and test sets (40% held out for testing)
(trainingData, testData) = transformed.randomSplit([0.6, 0.4])
```

You can check your train and test data as follows (In my opinion, it is always good to keep tracking your data during prototype phase):

```
trainingData.show(5)
testData.show(5)
```

Then you will get

```
+-----+-----+-----+
|      features|label| indexedFeatures|
+-----+-----+-----+
| [4.1,11.6,5.7]|  3.2|[4.1,11.6,5.7]|
| [7.3,28.1,41.4]|  5.5|[7.3,28.1,41.4]|
| [8.4,27.2,2.1]|  5.7|[8.4,27.2,2.1]|
+-----+-----+-----+
```

```
| [8.6,2.1,1.0]| 4.8| [8.6,2.1,1.0]|
| [8.7,48.9,75.0]| 7.2|[8.7,48.9,75.0]|
+-----+-----+
only showing top 5 rows

+-----+-----+-----+
| features|label| indexedFeatures|
+-----+-----+-----+
| [0.7,39.6,8.7]| 1.6| [0.7,39.6,8.7]|
| [5.4,29.9,9.4]| 5.3| [5.4,29.9,9.4]|
| [7.8,38.9,50.6]| 6.6| [7.8,38.9,50.6]|
| [17.2,45.9,69.3]| 9.3|[17.2,45.9,69.3]|
| [18.7,12.1,23.4]| 6.7|[18.7,12.1,23.4]|
+-----+-----+-----+
only showing top 5 rows
```

7. Fit Decision Tree Regression Model

```
from pyspark.ml.regression import DecisionTreeRegressor

# Train a DecisionTree model.
dt = DecisionTreeRegressor(featuresCol="indexedFeatures")
```

8. Pipeline Architecture

```
# Chain indexer and tree in a Pipeline
pipeline = Pipeline(stages=[featureIndexer, dt])

model = pipeline.fit(trainingData)
```

9. Make predictions

```
# Make predictions.
predictions = model.transform(testData)

# Select example rows to display.
predictions.select("features", "label", "predictedLabel").show(5)

+-----+-----+-----+
|prediction|label|      features|
+-----+-----+-----+
|       7.2|  1.6| [0.7,39.6,8.7]|
|       7.3|  5.3| [5.4,29.9,9.4]|
|       7.2|  6.6| [7.8,38.9,50.6]|
|      8.64|  9.3|[17.2,45.9,69.3]|
|      6.45|  6.7|[18.7,12.1,23.4]|
+-----+-----+-----+
only showing top 5 rows
```

10. Evaluation

```
from pyspark.ml.evaluation import RegressionEvaluator
from pyspark.ml.evaluation import RegressionEvaluator
# Select (prediction, true label) and compute test error
evaluator = RegressionEvaluator(labelCol="label",
                                 predictionCol="prediction",
                                 metricName="rmse")
```

```
rmse = evaluator.evaluate(predictions)
print("Root Mean Squared Error (RMSE) on test data = %g" % rmse)
```

The final Root Mean Squared Error (RMSE) is as follows:

```
Root Mean Squared Error (RMSE) on test data = 1.50999
```

```
y_true = predictions.select("label").toPandas()
y_pred = predictions.select("prediction").toPandas()

import sklearn.metrics
r2_score = sklearn.metrics.r2_score(y_true, y_pred)
print('r2_score: {0}'.format(r2_score))
```

Then you will get the R^2 value:

```
r2_score: 0.911024318967
```

You may also check the importance of the features:

```
model.stages[1].featureImportances
```

The you will get the weight for each features

```
SparseVector(3, {0: 0.6811, 1: 0.3187, 2: 0.0002})
```

8.4 Random Forest Regression

8.4.1 Introduction

8.4.2 How to solve it?

8.4.3 Demo

- The Jupyter notebook can be download from [Random Forest Regression](#).
 - For more details about the parameters, please visit [Random Forest Regressor API](#).
1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark RandomForest Regression example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
```

2. Load dataset

```
df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', \
    inferschema='true') \
    .load("../data/Advertising.csv", header=True);
```

```

df.show(5, True)
df.printSchema()

+---+---+---+---+
| TV | Radio | Newspaper | Sales |
+---+---+---+---+
| 230.1 | 37.8 | 69.2 | 22.1 |
| 44.5 | 39.3 | 45.1 | 10.4 |
| 17.2 | 45.9 | 69.3 | 9.3 |
| 151.5 | 41.3 | 58.5 | 18.5 |
| 180.8 | 10.8 | 58.4 | 12.9 |
+---+---+---+---+
only showing top 5 rows

root
 |-- TV: double (nullable = true)
 |-- Radio: double (nullable = true)
 |-- Newspaper: double (nullable = true)
 |-- Sales: double (nullable = true)

df.describe().show()

+-----+-----+-----+-----+-----+
| summary | TV | Radio | Newspaper | Sales |
+-----+-----+-----+-----+-----+
| count | 200 | 200 | 200 | 200 |
| mean | 147.0425 | 23.26400000000024 | 30.553999999999995 | 14.022500000000003 |
| stddev | 85.85423631490805 | 14.846809176168728 | 21.77862083852283 | 5.217456565710477 |
| min | 0.7 | 0.0 | 0.3 | 1.6 |
| max | 296.4 | 49.6 | 114.0 | 27.0 |
+-----+-----+-----+-----+

```

3. Convert the data to dense vector (**features** and **label**)

Note: You are strongly encouraged to try my `get_dummy` function for dealing with the categorical data in complex dataset.

Supervised learning version:

```

def get_dummy(df, indexCol, categoricalCols, continuousCols, labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                  for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                            + continuousCols, outputCol="features"])

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

```

```

model=pipeline.fit(df)
data = model.transform(df)

data = data.withColumn('label', col(labelCol))

return data.select(indexCol,'features','label')

```

Unsupervised learning version:

```

def get_dummy (df,indexCol,categoricalCols,continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learn
    :param df: the dataframe
    :param categoricalCols: the name list of the categorical data
    :param continuousCols: the name list of the numerical data
    :return k: feature matrix

    :author: Wenqiang Feng
    :email: von198@gmail.com
    """

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
        for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
        for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                           + continuousCols, outputCol="features")

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    return data.select(indexCol,'features')

```

```

from pyspark.sql import Row
from pyspark.ml.linalg import Vectors

# convert the data to dense vector
#def transData(row):
#    return Row(label=row["Sales"],
#              features=Vectors.dense([row["TV"],
#                                     row["Radio"],
#                                     row["Newspaper"]]))
def transData(data):
    return data.rdd.map(lambda r: [Vectors.dense(r[:-1]),r[-1]]).toDF(['features','label'])

```

4. Convert the data to dense vector

```

transformed= transData(df)
transformed.show(5)

```

```
+-----+-----+
|      features|label|
+-----+-----+
|[230.1,37.8,69.2]| 22.1|
|[44.5,39.3,45.1]| 10.4|
|[17.2,45.9,69.3]|  9.3|
|[151.5,41.3,58.5]| 18.5|
|[180.8,10.8,58.4]| 12.9|
+-----+-----+
only showing top 5 rows
```

5. Deal with the Categorical variables

```
from pyspark.ml import Pipeline
from pyspark.ml.regression import LinearRegression
from pyspark.ml.feature import VectorIndexer
from pyspark.ml.evaluation import RegressionEvaluator

featureIndexer = VectorIndexer(inputCol="features", \
                                outputCol="indexedFeatures", \
                                maxCategories=4).fit(transformed)

data = featureIndexer.transform(transformed)
data.show(5, True)

+-----+-----+-----+
|      features|label| indexedFeatures|
+-----+-----+-----+
|[230.1,37.8,69.2]| 22.1|[230.1,37.8,69.2]|
|[44.5,39.3,45.1]| 10.4|[44.5,39.3,45.1]|
|[17.2,45.9,69.3]|  9.3|[17.2,45.9,69.3]|
|[151.5,41.3,58.5]| 18.5|[151.5,41.3,58.5]|
|[180.8,10.8,58.4]| 12.9|[180.8,10.8,58.4]|
+-----+-----+-----+
only showing top 5 rows
```

6. Split the data into training and test sets (40% held out for testing)

```
# Split the data into training and test sets (40% held out for testing)
(trainingData, testData) = data.randomSplit([0.6, 0.4])

trainingData.show(5)
testData.show(5)

+-----+-----+-----+
|      features|label| indexedFeatures|
+-----+-----+-----+
|[0.7,39.6,8.7]| 1.6|[0.7,39.6,8.7]|
|[8.6,2.1,1.0]| 4.8|[8.6,2.1,1.0]|
|[8.7,48.9,75.0]| 7.2|[8.7,48.9,75.0]|
|[11.7,36.9,45.2]| 7.3|[11.7,36.9,45.2]|
|[13.2,15.9,49.6]| 5.6|[13.2,15.9,49.6]|
+-----+-----+-----+
only showing top 5 rows

+-----+-----+-----+
|      features|label| indexedFeatures|
+-----+-----+-----+
```

```

| [4.1,11.6,5.7]| 3.2| [4.1,11.6,5.7]|
| [5.4,29.9,9.4]| 5.3| [5.4,29.9,9.4]|
| [7.3,28.1,41.4]| 5.5|[7.3,28.1,41.4]|
| [7.8,38.9,50.6]| 6.6|[7.8,38.9,50.6]|
| [8.4,27.2,2.1]| 5.7| [8.4,27.2,2.1]|
+-----+
only showing top 5 rows

```

7. Fit RandomForest Regression Model

```

# Import LinearRegression class
from pyspark.ml.regression import RandomForestRegressor

# Define LinearRegression algorithm
rf = RandomForestRegressor() # featuresCol="indexedFeatures", numTrees=2, maxDepth=2, ...

```

Note: If you decide to use the indexedFeatures features, you need to add the parameter featuresCol="indexedFeatures".

8. Pipeline Architecture

```

# Chain indexer and tree in a Pipeline
pipeline = Pipeline(stages=[featureIndexer, rf])
model = pipeline.fit(trainingData)

```

9. Make predictions

```

predictions = model.transform(testData)

# Select example rows to display.
predictions.select("features", "label", "prediction").show(5)

+-----+-----+-----+
|     features|label|      prediction|
+-----+-----+-----+
| [4.1,11.6,5.7]| 3.2| 8.155439814814816|
| [5.4,29.9,9.4]| 5.3|10.412769901394899|
| [7.3,28.1,41.4]| 5.5| 12.13735648148148|
| [7.8,38.9,50.6]| 6.6|11.321796703296704|
| [8.4,27.2,2.1]| 5.7|12.071421957671957|
+-----+-----+-----+
only showing top 5 rows

```

10. Evaluation

```

# Select (prediction, true label) and compute test error
evaluator = RegressionEvaluator(
    labelCol="label", predictionCol="prediction", metricName="rmse")
rmse = evaluator.evaluate(predictions)
print("Root Mean Squared Error (RMSE) on test data = %g" % rmse)

Root Mean Squared Error (RMSE) on test data = 2.35912

import sklearn.metrics
r2_score = sklearn.metrics.r2_score(y_true, y_pred)
print('r2_score: {:.4f}'.format(r2_score))

```

```
r2_score: 0.831
```

11. Feature importances

```
model.stages[-1].featureImportances  
  
SparseVector(3, {0: 0.4994, 1: 0.3196, 2: 0.181})  
  
model.stages[-1].trees  
  
[DecisionTreeRegressionModel (uid=dtr_c75f1c75442c) of depth 5 with 43 nodes,  
 DecisionTreeRegressionModel (uid=dtr_70fc2d441581) of depth 5 with 45 nodes,  
 DecisionTreeRegressionModel (uid=dtr_bc8464f545a7) of depth 5 with 31 nodes,  
 DecisionTreeRegressionModel (uid=dtr_a8a7e5367154) of depth 5 with 59 nodes,  
 DecisionTreeRegressionModel (uid=dtr_3ea01314fcbe) of depth 5 with 47 nodes,  
 DecisionTreeRegressionModel (uid=dtr_be9a04ac22a6) of depth 5 with 45 nodes,  
 DecisionTreeRegressionModel (uid=dtr_38610d47328a) of depth 5 with 51 nodes,  
 DecisionTreeRegressionModel (uid=dtr_bf14aea0ad3b) of depth 5 with 49 nodes,  
 DecisionTreeRegressionModel (uid=dtr_cde24ebd6bb6) of depth 5 with 39 nodes,  
 DecisionTreeRegressionModel (uid=dtr_a1fc9bd4fbef) of depth 5 with 57 nodes,  
 DecisionTreeRegressionModel (uid=dtr_37798d6db1ba) of depth 5 with 41 nodes,  
 DecisionTreeRegressionModel (uid=dtr_c078b73ada63) of depth 5 with 41 nodes,  
 DecisionTreeRegressionModel (uid=dtr_fd00e3a070ad) of depth 5 with 55 nodes,  
 DecisionTreeRegressionModel (uid=dtr_9d01d5fb8604) of depth 5 with 45 nodes,  
 DecisionTreeRegressionModel (uid=dtr_8bd8bdddf642) of depth 5 with 41 nodes,  
 DecisionTreeRegressionModel (uid=dtr_e53b7bae30f8) of depth 5 with 49 nodes,  
 DecisionTreeRegressionModel (uid=dtr_808a869db21c) of depth 5 with 47 nodes,  
 DecisionTreeRegressionModel (uid=dtr_64d0916bceb0) of depth 5 with 33 nodes,  
 DecisionTreeRegressionModel (uid=dtr_0891055fff94) of depth 5 with 55 nodes,  
 DecisionTreeRegressionModel (uid=dtr_19c8bbad26c2) of depth 5 with 51 nodes]
```

8.5 Gradient-boosted tree regression

8.5.1 Introduction

8.5.2 How to solve it?

8.5.3 Demo

- The Jupyter notebook can be download from Gradient-boosted tree regression.
 - For more details about the parameters, please visit [Gradient boosted tree API](#).
1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession  
  
spark = SparkSession \  
    .builder \  
    .appName("Python Spark GBTRegressor example") \  
    .config("spark.some.config.option", "some-value") \  
    .getOrCreate()
```

2. Load dataset

```

df = spark.read.format('com.databricks.spark.csv').\
    options(header='true', \
    inferSchema='true').\
    load("../data/Advertising.csv",header=True);

df.show(5, True)
df.printSchema()

+---+---+---+
| TV | Radio | Newspaper | Sales |
+---+---+---+
| 230.1 | 37.8 | 69.2 | 22.1 |
| 44.5 | 39.3 | 45.1 | 10.4 |
| 17.2 | 45.9 | 69.3 | 9.3 |
| 151.5 | 41.3 | 58.5 | 18.5 |
| 180.8 | 10.8 | 58.4 | 12.9 |
+---+---+---+
only showing top 5 rows

root
|-- TV: double (nullable = true)
|-- Radio: double (nullable = true)
|-- Newspaper: double (nullable = true)
|-- Sales: double (nullable = true)

df.describe().show()

+-----+-----+-----+-----+-----+
| summary | TV | Radio | Newspaper | Sales |
+-----+-----+-----+-----+-----+
| count | 200 | 200 | 200 | 200 |
| mean | 147.0425 | 23.26400000000024 | 30.553999999999995 | 14.022500000000003 |
| stddev | 85.85423631490805 | 14.846809176168728 | 21.77862083852283 | 5.217456565710477 |
| min | 0.7 | 0.0 | 0.3 | 1.6 |
| max | 296.4 | 49.6 | 114.0 | 27.0 |
+-----+-----+-----+-----+
    
```

3. Convert the data to dense vector (**features** and **label**)

Note: You are strongly encouraged to try my `get_dummy` function for dealing with the categorical data in comple dataset.

Supervised learning version:

```

def get_dummy(df, indexCol, categoricalCols, continuousCols, labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
        for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
        outputCol="{0}_encoded".format(indexer.getOutputCol()))
        for indexer in indexers ]
    
```

```

assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                             + continuousCols, outputCol="features")

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

data = data.withColumn('label', col(labelCol))

return data.select(indexCol,'features','label')

```

Unsupervised learning version:

```

def get_dummy(df,indexCol,categoricalCols,continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learning
    :param df: the dataframe
    :param categoricalCols: the name list of the categorical data
    :param continuousCols: the name list of the numerical data
    :return k: feature matrix

    :author: Wengiang Feng
    :email: von198@gmail.com
    """

indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
             for c in categoricalCols ]

# default setting: dropLast=True
encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                           outputCol="{0}_encoded".format(indexer.getOutputCol()))
            for indexer in indexers ]

assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                      + continuousCols, outputCol="features")

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

return data.select(indexCol,'features')

```

```

from pyspark.sql import Row
from pyspark.ml.linalg import Vectors

# convert the data to dense vector
#def transData(row):
#    return Row(label=row["Sales"],
#               features=Vectors.dense([row["TV"],
#                                      row["Radio"],
#                                      row["Newspaper"]]))
def transData(data):
    return data.rdd.map(lambda r: [Vectors.dense(r[:-1]),r[-1]]).toDF(['features','label'])

```

4. Convert the data to dense vector

```

transformed= transData(df)
transformed.show(5)

+-----+-----+
|      features|label|
+-----+-----+
|[230.1,37.8,69.2]| 22.1|
|[44.5,39.3,45.1]| 10.4|
|[17.2,45.9,69.3]| 9.3|
|[151.5,41.3,58.5]| 18.5|
|[180.8,10.8,58.4]| 12.9|
+-----+-----+
only showing top 5 rows

```

5. Deal with the Categorical variables

```

from pyspark.ml import Pipeline
from pyspark.ml.regression import GBTRegressor
from pyspark.ml.feature import VectorIndexer
from pyspark.ml.evaluation import RegressionEvaluator

featureIndexer = VectorIndexer(inputCol="features", \
                                outputCol="indexedFeatures", \
                                maxCategories=4).fit(transformed)

data = featureIndexer.transform(transformed)
data.show(5, True)

+-----+-----+-----+
|      features|label| indexedFeatures|
+-----+-----+-----+
|[230.1,37.8,69.2]| 22.1|[230.1,37.8,69.2]|
|[44.5,39.3,45.1]| 10.4|[44.5,39.3,45.1]|
|[17.2,45.9,69.3]| 9.3|[17.2,45.9,69.3]|
|[151.5,41.3,58.5]| 18.5|[151.5,41.3,58.5]|
|[180.8,10.8,58.4]| 12.9|[180.8,10.8,58.4]|
+-----+-----+-----+
only showing top 5 rows

```

6. Split the data into training and test sets (40% held out for testing)

```

# Split the data into training and test sets (40% held out for testing)
(trainingData, testData) = data.randomSplit([0.6, 0.4])

trainingData.show(5)
testData.show(5)

+-----+-----+-----+
|      features|label| indexedFeatures|
+-----+-----+-----+
|[0.7,39.6,8.7]| 1.6|[0.7,39.6,8.7]|
|[8.6,2.1,1.0]| 4.8|[8.6,2.1,1.0]|
|[8.7,48.9,75.0]| 7.2|[8.7,48.9,75.0]|
|[11.7,36.9,45.2]| 7.3|[11.7,36.9,45.2]|
|[13.2,15.9,49.6]| 5.6|[13.2,15.9,49.6]|
+-----+-----+-----+
only showing top 5 rows

```

```
+-----+-----+-----+
| features|label|indexedFeatures|
+-----+-----+-----+
| [4.1,11.6,5.7]| 3.2| [4.1,11.6,5.7]|
| [5.4,29.9,9.4]| 5.3| [5.4,29.9,9.4]|
| [7.3,28.1,41.4]| 5.5|[7.3,28.1,41.4]|
| [7.8,38.9,50.6]| 6.6|[7.8,38.9,50.6]|
| [8.4,27.2,2.1]| 5.7| [8.4,27.2,2.1]|
+-----+-----+-----+
only showing top 5 rows
```

7. Fit RandomForest Regression Model

```
# Import LinearRegression class
from pyspark.ml.regression import GBTRegressor

# Define LinearRegression algorithm
rf = GBTRegressor() #numTrees=2, maxDepth=2, seed=42
```

Note: If you decide to use the indexedFeatures features, you need to add the parameter featuresCol="indexedFeatures".

8. Pipeline Architecture

```
# Chain indexer and tree in a Pipeline
pipeline = Pipeline(stages=[featureIndexer, rf])
model = pipeline.fit(trainingData)
```

9. Make predictions

```
predictions = model.transform(testData)

# Select example rows to display.
predictions.select("features", "label", "prediction").show(5)

+-----+-----+-----+
| features|label|      prediction|
+-----+-----+-----+
| [7.8,38.9,50.6]| 6.6| 6.836040343319862|
| [8.6,2.1,1.0]| 4.8| 5.652202764688849|
| [8.7,48.9,75.0]| 7.2| 6.908750296855572|
| [13.1,0.4,25.6]| 5.3| 5.784020210692574|
| [19.6,20.1,17.0]| 7.6| 6.8678921062629295|
+-----+-----+-----+
only showing top 5 rows
```

10. Evaluation

```
# Select (prediction, true label) and compute test error
evaluator = RegressionEvaluator(
    labelCol="label", predictionCol="prediction", metricName="rmse")
rmse = evaluator.evaluate(predictions)
print("Root Mean Squared Error (RMSE) on test data = %g" % rmse)
```

```
Root Mean Squared Error (RMSE) on test data = 1.36939
```

```
import sklearn.metrics
r2_score = sklearn.metrics.r2_score(y_true, y_pred)
print('r2_score: {:.4.3f}'.format(r2_score))

r2_score: 0.932
```

11. Feature importances

```
model.stages[-1].featureImportances

SparseVector(3, {0: 0.3716, 1: 0.3525, 2: 0.2759})

model.stages[-1].trees

[DecisionTreeRegressionModel (uid=dtr_7f5cd2ef7cb6) of depth 5 with 61 nodes,
 DecisionTreeRegressionModel (uid=dtr_ef3ab6baeac9) of depth 5 with 39 nodes,
 DecisionTreeRegressionModel (uid=dtr_07c6e3cf3819) of depth 5 with 45 nodes,
 DecisionTreeRegressionModel (uid=dtr_ce724af79a2b) of depth 5 with 47 nodes,
 DecisionTreeRegressionModel (uid=dtr_d149ecc71658) of depth 5 with 55 nodes,
 DecisionTreeRegressionModel (uid=dtr_d3a79bdea516) of depth 5 with 43 nodes,
 DecisionTreeRegressionModel (uid=dtr_7abc1a337844) of depth 5 with 51 nodes,
 DecisionTreeRegressionModel (uid=dtr_480834b46d8f) of depth 5 with 33 nodes,
 DecisionTreeRegressionModel (uid=dtr_0cbd1eaa3874) of depth 5 with 39 nodes,
 DecisionTreeRegressionModel (uid=dtr_8088acf71a204) of depth 5 with 57 nodes,
 DecisionTreeRegressionModel (uid=dtr_2ceb9e8deb45) of depth 5 with 47 nodes,
 DecisionTreeRegressionModel (uid=dtr_cc334e84e9a2) of depth 5 with 57 nodes,
 DecisionTreeRegressionModel (uid=dtr_a665c562929e) of depth 5 with 41 nodes,
 DecisionTreeRegressionModel (uid=dtr_2999b1ffd2dc) of depth 5 with 45 nodes,
 DecisionTreeRegressionModel (uid=dtr_29965cbe8cfc) of depth 5 with 55 nodes,
 DecisionTreeRegressionModel (uid=dtr_731df51bf0ad) of depth 5 with 41 nodes,
 DecisionTreeRegressionModel (uid=dtr_354cf33424da) of depth 5 with 51 nodes,
 DecisionTreeRegressionModel (uid=dtr_4230f200b1c0) of depth 5 with 41 nodes,
 DecisionTreeRegressionModel (uid=dtr_3279cd1c1celd) of depth 5 with 45 nodes,
 DecisionTreeRegressionModel (uid=dtr_f474a99ff06e) of depth 5 with 55 nodes]
```

CHAPTER
NINE

REGULARIZATION

In mathematics, statistics, and computer science, particularly in the fields of machine learning and inverse problems, regularization is a process of introducing additional information in order to solve an ill-posed problem or to prevent overfitting ([Wikipedia Regularization](#)).

Due to the sparsity within our data, our training sets will often be ill-posed (singular). Applying regularization to the regression has many advantages, including:

1. Converting ill-posed problems to well-posed by adding additional information via the penalty parameter λ
2. Preventing overfitting
3. Variable selection and the removal of correlated variables ([Glmnet Vignette](#)). The Ridge method shrinks the coefficients of correlated variables while the LASSO method picks one variable and discards the others. The elastic net penalty is a mixture of these two; if variables are correlated in groups then $\alpha = 0.5$ tends to select the groups as in or out. If α is close to 1, the elastic net performs much like the LASSO method and removes any degeneracies and wild behavior caused by extreme correlations.

9.1 Ordinary least squares regression

$$\min_{\beta \in \mathbb{R}^p} \frac{1}{n} \|\hat{X}\beta - \hat{Y}\|^2$$

When $\lambda = 0$ (i.e. `regParam = 0`), then there is no penalty.

```
LinearRegression(featuresCol="features", labelCol="label", predictionCol="prediction",  
regParam=0.0, elasticNetParam=0.0, tol=1e-6, fitIntercept=True, standardization=True,  
weightCol=None, aggregationDepth=2)
```

9.2 Ridge regression

$$\min_{\beta \in \mathbb{R}^p} \frac{1}{n} \|\hat{X}\beta - \hat{Y}\|^2 + \lambda \|\beta\|_2^2$$

When $\lambda > 0$ (i.e. `regParam > 0`) and $\alpha = 0$ (i.e. `elasticNetParam = 0`), then the penalty is an L2 penalty.

```
LinearRegression(featuresCol="features", labelCol="label", predictionCol="prediction",
regParam=0.1, elasticNetParam=0.0, tol=1e-6, fitIntercept=True, standardization=True,
weightCol=None, aggregationDepth=2)
```

9.3 Least Absolute Shrinkage and Selection Operator (LASSO)

$$\min_{\beta \in \mathbb{R}^p} \frac{1}{n} \|\hat{X}\beta - \hat{Y}\|^2 + \lambda \|\beta\|_1$$

When $\lambda > 0$ (i.e. `regParam > 0`) and $\alpha = 1$ (i.e. `elasticNetParam = 1`), then the penalty is an L1 penalty.

```
LinearRegression(featuresCol="features", labelCol="label", predictionCol="prediction",
regParam=0.0, elasticNetParam=0.0, tol=1e-6, fitIntercept=True, standardization=True,
weightCol=None, aggregationDepth=2)
```

9.4 Elastic net

$$\min_{\beta \in \mathbb{R}^p} \frac{1}{n} \|\hat{X}\beta - \hat{Y}\|^2 + \lambda(\alpha \|\beta\|_1 + (1 - \alpha) \|\beta\|_2^2), \alpha \in (0, 1)$$

When $\lambda > 0$ (i.e. `regParam > 0`) and `elasticNetParam ∈ (0, 1)` (i.e. $\alpha ∈ (0, 1)$) , then the penalty is an L1 + L2 penalty.

```
LinearRegression(featuresCol="features", labelCol="label", predictionCol="prediction",
regParam=0.0, elasticNetParam=0.0, tol=1e-6, fitIntercept=True, standardization=True,
weightCol=None, aggregationDepth=2)
```

CLASSIFICATION

Chinese proverb

Birds of a feather flock together. – old Chinese proverb

10.1 Binomial logistic regression

10.1.1 Introduction

10.1.2 Demo

- The Jupyter notebook can be download from Logistic Regression.
- For more details, please visit [Logistic Regression API](#).

Note: In this demo, I introduced a new function `get_dummy` to deal with the categorical data. I highly recommend you to use my `get_dummy` function in the other cases. This function will save a lot of time for you.

1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark Logistic Regression example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
```

2. Load dataset

```
df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', inferSchema='true') \
    .load("./data/bank.csv", header=True);
df.drop('day', 'month', 'poutcome').show(5)

+---+-----+-----+-----+-----+-----+-----+-----+
| age | job|marital|education|default|balance|housing|loan|contact|duration|campai
+---+-----+-----+-----+-----+-----+-----+-----+
| 58 | management|married| tertiary| no| 2143| yes| no|unknown| 261 |
| 44 | technician| single|secondary| no| 29| yes| no|unknown| 151 |
```

```

| 33|entrepreneur|married|secondary|      no|      2|     yes| yes|unknown|      76|
| 47| blue-collar|married| unknown|      no|  1506|     yes| no|unknown|      92|
| 33|      unknown| single| unknown|      no|      1|     no| no|unknown|  198|
+---+-----+-----+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

df.printSchema()

root
 |-- age: integer (nullable = true)
 |-- job: string (nullable = true)
 |-- marital: string (nullable = true)
 |-- education: string (nullable = true)
 |-- default: string (nullable = true)
 |-- balance: integer (nullable = true)
 |-- housing: string (nullable = true)
 |-- loan: string (nullable = true)
 |-- contact: string (nullable = true)
 |-- day: integer (nullable = true)
 |-- month: string (nullable = true)
 |-- duration: integer (nullable = true)
 |-- campaign: integer (nullable = true)
 |-- pdays: integer (nullable = true)
 |-- previous: integer (nullable = true)
 |-- poutcome: string (nullable = true)
 |-- y: string (nullable = true)

```

Note: You are strongly encouraged to try my get_dummy function for dealing with the categorical data in complex dataset.

Supervised learning version:

```

def get_dummy(df,indexCol,categoricalCols,continuousCols,labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                 for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                           + continuousCols, outputCol="features")

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    data = data.withColumn('label',col(labelCol))

    return data.select(indexCol,'features','label')

```

Unsupervised learning version:

```
def get_dummy(df, indexCol, categoricalCols, continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learning
    :param df: the dataframe
    :param categoricalCols: the name list of the categorical data
    :param continuousCols: the name list of the numerical data
    :return k: feature matrix

    :author: Wengiang Feng
    :email: von198@gmail.com
    """

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                  for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                           + continuousCols, outputCol="features"])

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    return data.select(indexCol,'features')
```

```
def get_dummy(df,categoricalCols,continuousCols,labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                  for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                           + continuousCols, outputCol="features"])

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    data = data.withColumn('label',col(labelCol))

    return data.select('features','label')
```

3. Deal with categorical data and Convert the data to dense vector

```
catcols = ['job','marital','education','default',
           'housing','loan','contact','poutcome']

num_cols = ['balance', 'duration','campaign','pdays','previous',]
labelCol = 'y'

data = get_dummy(df,catcols,num_cols,labelCol)
data.show(5)

+-----+-----+
|      features|label|
+-----+-----+
| (29,[1,11,14,16,1...| no |
| (29,[2,12,13,16,1...| no |
| (29,[7,11,13,16,1...| no |
| (29,[0,11,16,17,1...| no |
| (29,[12,16,18,20,...| no |
+-----+-----+
only showing top 5 rows
```

4. Deal with Categorical Label and Variables

```
from pyspark.ml.feature import StringIndexer
# Index labels, adding metadata to the label column
labelIndexer = StringIndexer(inputCol='label',
                             outputCol='indexedLabel').fit(data)
labelIndexer.transform(data).show(5, True)

+-----+-----+-----+
|      features|label|indexedLabel|
+-----+-----+-----+
| (29,[1,11,14,16,1...| no | 0.0 |
| (29,[2,12,13,16,1...| no | 0.0 |
| (29,[7,11,13,16,1...| no | 0.0 |
| (29,[0,11,16,17,1...| no | 0.0 |
| (29,[12,16,18,20,...| no | 0.0 |
+-----+-----+-----+
only showing top 5 rows

from pyspark.ml.feature import VectorIndexer
# Automatically identify categorical features, and index them.
# Set maxCategories so features with > 4 distinct values are treated as continuous.
featureIndexer =VectorIndexer(inputCol="features", \
                               outputCol="indexedFeatures", \
                               maxCategories=4).fit(data)
featureIndexer.transform(data).show(5, True)

+-----+-----+-----+
|      features|label| indexedFeatures|
+-----+-----+-----+
| (29,[1,11,14,16,1...| no | (29,[1,11,14,16,1... |
| (29,[2,12,13,16,1...| no | (29,[2,12,13,16,1... |
| (29,[7,11,13,16,1...| no | (29,[7,11,13,16,1... |
| (29,[0,11,16,17,1...| no | (29,[0,11,16,17,1... |
| (29,[12,16,18,20,...| no | (29,[12,16,18,20,... |
+-----+-----+-----+
only showing top 5 rows
```

5. Split the data to training and test data sets

```
# Split the data into training and test sets (40% held out for testing)
(trainingData, testData) = data.randomSplit([0.6, 0.4])

trainingData.show(5, False)
testData.show(5, False)

+-----+
| features
+-----+
| (29, [0,11,13,16,17,18,19,21,24,25,26,27], [1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,-731.0,401.0,
| (29, [0,11,13,16,17,18,19,21,24,25,26,27], [1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,-723.0,112.0,
| (29, [0,11,13,16,17,18,19,21,24,25,26,27], [1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,-626.0,205.0,
| (29, [0,11,13,16,17,18,19,21,24,25,26,27], [1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,-498.0,357.0,
| (29, [0,11,13,16,17,18,19,21,24,25,26,27], [1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,-477.0,473.0,
+-----+
only showing top 5 rows

+-----+
| features
+-----+
| (29, [0,11,13,16,17,18,19,21,24,25,26,27], [1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,-648.0,280.0,
| (29, [0,11,13,16,17,18,19,21,24,25,26,27], [1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,-596.0,147.0,
| (29, [0,11,13,16,17,18,19,21,24,25,26,27], [1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,-529.0,416.0,
| (29, [0,11,13,16,17,18,19,21,24,25,26,27], [1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,-518.0,46.0,
| (29, [0,11,13,16,17,18,19,21,24,25,26,27], [1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,-470.0,275.0,
+-----+
only showing top 5 rows
```

6. Fit Logistic Regression Model

```
from pyspark.ml.classification import LogisticRegression
logr = LogisticRegression(featuresCol='indexedFeatures', labelCol='indexedLabel')
```

7. Pipeline Architecture

```
# Convert indexed labels back to original labels.
labelConverter = IndexToString(inputCol="prediction", outputCol="predictedLabel",
                                labels=labelIndexer.labels)

# Chain indexers and tree in a Pipeline
pipeline = Pipeline(stages=[labelIndexer, featureIndexer, logr,labelConverter])

# Train model. This also runs the indexers.
model = pipeline.fit(trainingData)
```

8. Make predictions

```
# Make predictions.
predictions = model.transform(testData)
# Select example rows to display.
predictions.select("features", "label", "predictedLabel").show(5)

+-----+-----+-----+
| features|label|predictedLabel|
+-----+-----+-----+
```

```
| (29, [0,11,13,16,1... |    no |      no |
+-----+-----+-----+
only showing top 5 rows
```

9. Evaluation

```
from pyspark.ml.evaluation import MulticlassClassificationEvaluator

# Select (prediction, true label) and compute test error
evaluator = MulticlassClassificationEvaluator(
    labelCol="indexedLabel", predictionCol="prediction", metricName="accuracy")
accuracy = evaluator.evaluate(predictions)
print("Test Error = %g" % (1.0 - accuracy))

Test Error = 0.0987688

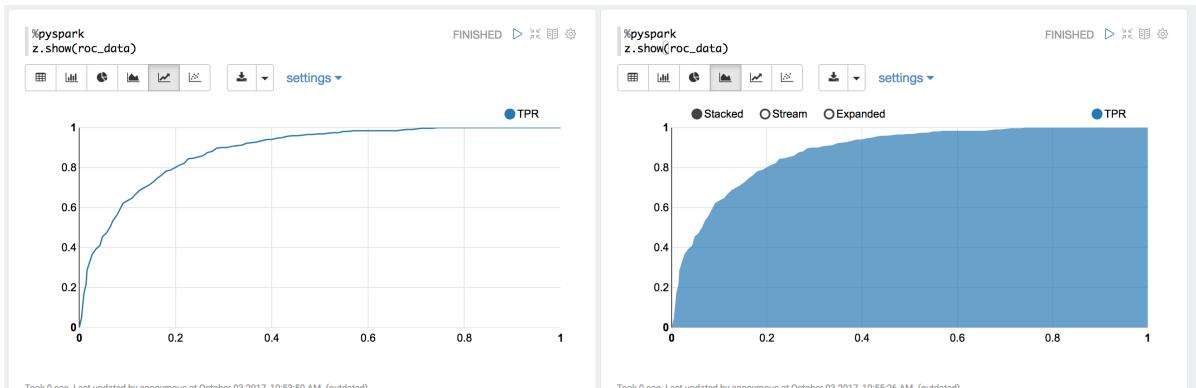
lrModel = model.stages[2]
trainingSummary = lrModel.summary

# Obtain the objective per iteration
# objectiveHistory = trainingSummary.objectiveHistory
# print("objectiveHistory:")
# for objective in objectiveHistory:
#     print(objective)

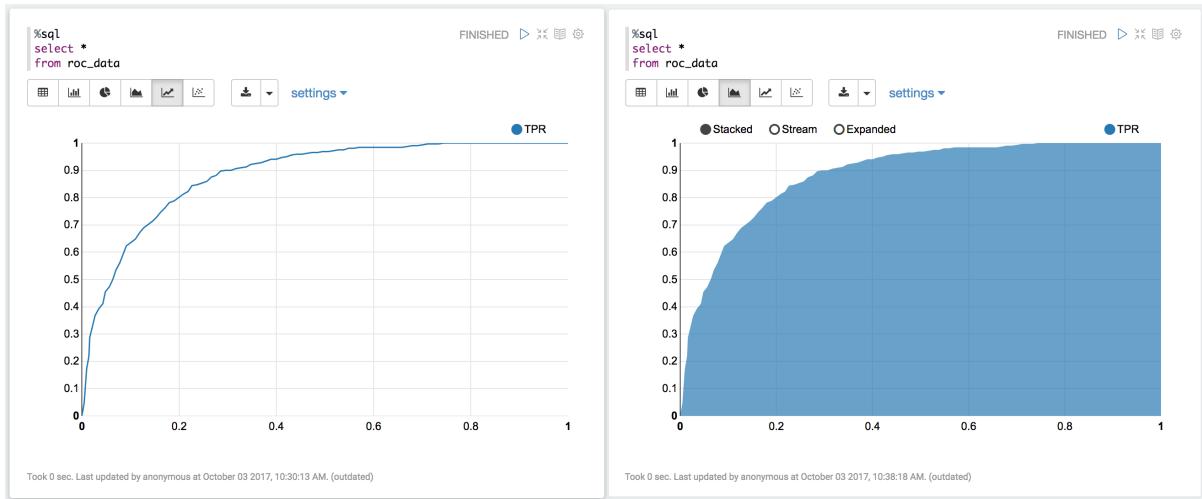
# Obtain the receiver-operating characteristic as a dataframe and areaUnderROC.
trainingSummary.roc.show(5)
print("areaUnderROC: " + str(trainingSummary.areaUnderROC))

# Set the model threshold to maximize F-Measure
fMeasure = trainingSummary.fMeasureByThreshold
maxFMeasure = fMeasure.groupBy().max('F-Measure').select('max(F-Measure)').head(5)
# bestThreshold = fMeasure.where(fMeasure['F-Measure'] == maxFMeasure['max(F-Measure)'])
# .select('threshold').head()['threshold']
# lr.setThreshold(bestThreshold)
```

You can use `z.show()` to get the data and plot the ROC curves:



You can also register a TempTable `data.registerTempTable('roc_data')` and then use `sql` to plot the ROC curve:



10. visualization

```
import matplotlib.pyplot as plt
import numpy as np
import itertools

def plot_confusion_matrix(cm, classes,
                         normalize=False,
                         title='Confusion matrix',
                         cmap=plt.cm.Blues):
    """
    This function prints and plots the confusion matrix.
    Normalization can be applied by setting 'normalize=True'.
    """
    if normalize:
        cm = cm.astype('float') / cm.sum(axis=1)[:, np.newaxis]
        print("Normalized confusion matrix")
    else:
        print('Confusion matrix, without normalization')

    print(cm)

    plt.imshow(cm, interpolation='nearest', cmap=cmap)
    plt.title(title)
    plt.colorbar()
    tick_marks = np.arange(len(classes))
    plt.xticks(tick_marks, classes, rotation=45)
    plt.yticks(tick_marks, classes)

    fmt = '.2f' if normalize else 'd'
    thresh = cm.max() / 2.
    for i, j in itertools.product(range(cm.shape[0]), range(cm.shape[1])):
        plt.text(j, i, format(cm[i, j], fmt),
                 horizontalalignment="center",
                 color="white" if cm[i, j] > thresh else "black")

    plt.tight_layout()
    plt.ylabel('True label')
    plt.xlabel('Predicted label')
```

```

class_temp = predictions.select("label").groupBy("label") \
    .count().sort('count', ascending=False).toPandas()
class_temp = class_temp["label"].values.tolist()
class_names = map(str, class_temp)
# # # print(class_name)
class_names

['no', 'yes']

from sklearn.metrics import confusion_matrix
y_true = predictions.select("label")
y_true = y_true.toPandas()

y_pred = predictions.select("predictedLabel")
y_pred = y_pred.toPandas()

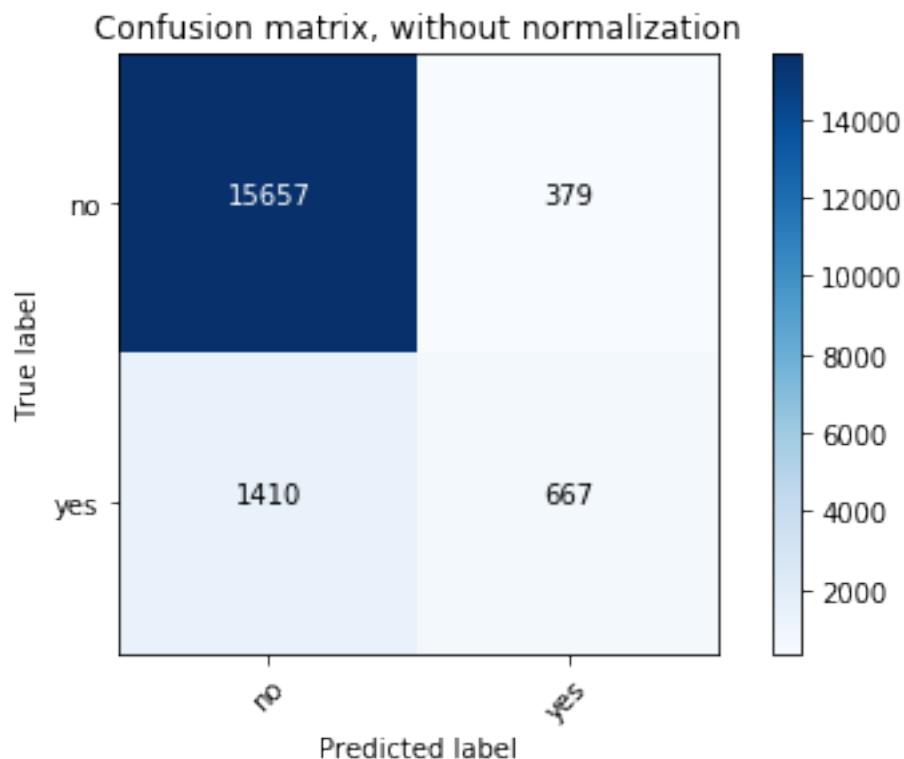
cnf_matrix = confusion_matrix(y_true, y_pred, labels=class_names)
cnf_matrix

array([[15657,    379],
       [ 1410,   667]])

# Plot non-normalized confusion matrix
plt.figure()
plot_confusion_matrix(cnf_matrix, classes=class_names,
                      title='Confusion matrix, without normalization')
plt.show()

Confusion matrix, without normalization
[[15657  379]
 [ 1410  667]]

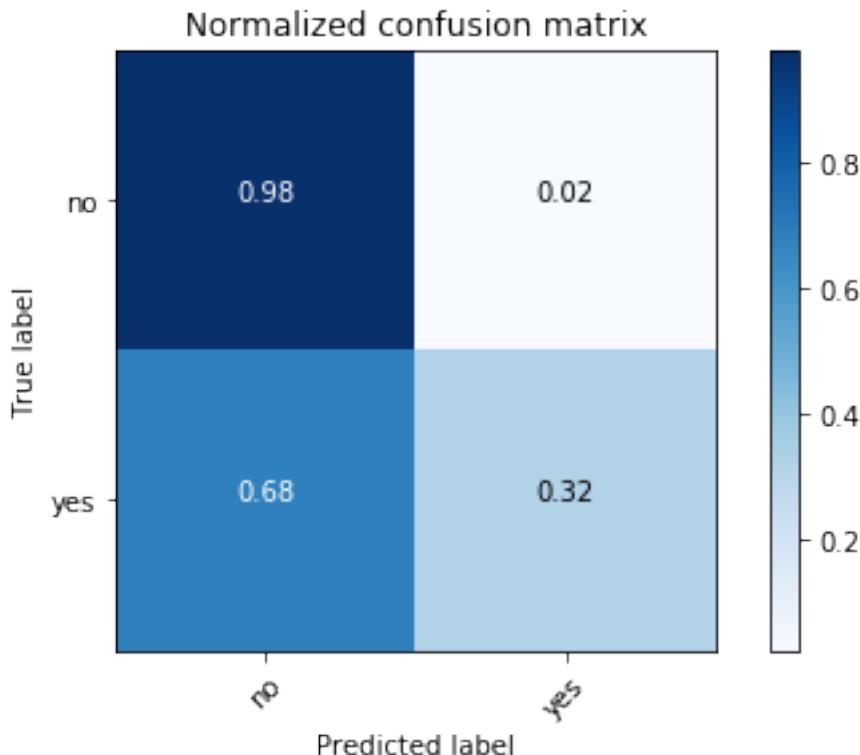
```



```
# Plot normalized confusion matrix
plt.figure()
plot_confusion_matrix(cnf_matrix, classes=class_names, normalize=True,
                      title='Normalized confusion matrix')

plt.show()

Normalized confusion matrix
[[ 0.97636568  0.02363432]
 [ 0.67886375  0.32113625]]
```



10.2 Multinomial logistic regression

10.2.1 Introduction

10.2.2 Demo

- The Jupyter notebook can be download from [Logistic Regression](#).
- For more details, please visit [Logistic Regression API](#).

Note: In this demo, I introduced a new function `get_dummy` to deal with the categorical data. I highly recommend you to use my `get_dummy` function in the other cases. This function will save a lot of time for you.

1. Set up spark context and SparkSession

```

from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark MultinomialLogisticRegression classification") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()

2. Load dataset

df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', inferSchema='true') \
    .load("./data/WineData2.csv", header=True);
df.show(5)

+---+---+---+---+---+---+---+---+---+---+---+---+
|fixed|volatile|citric|sugar|chlorides|free|total|density| pH|sulphates|alcohol|quality|
+---+---+---+---+---+---+---+---+---+---+---+---+
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| 5
| 7.8| 0.88| 0.0| 2.6| 0.098|25.0| 67.0| 0.9968|3.2| 0.68| 9.8| 5
| 7.8| 0.76| 0.04| 2.3| 0.092|15.0| 54.0| 0.997|3.26| 0.65| 9.8| 5
| 11.2| 0.28| 0.56| 1.9| 0.075|17.0| 60.0| 0.998|3.16| 0.58| 9.8| 6
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| 5
+---+---+---+---+---+---+---+---+---+---+---+---+
only showing top 5 rows

df.printSchema()

root
 |-- fixed: double (nullable = true)
 |-- volatile: double (nullable = true)
 |-- citric: double (nullable = true)
 |-- sugar: double (nullable = true)
 |-- chlorides: double (nullable = true)
 |-- free: double (nullable = true)
 |-- total: double (nullable = true)
 |-- density: double (nullable = true)
 |-- pH: double (nullable = true)
 |-- sulphates: double (nullable = true)
 |-- alcohol: double (nullable = true)
 |-- quality: string (nullable = true)

# Convert to float format
def string_to_float(x):
    return float(x)

#
def condition(r):
    if (0 <= r <= 4):
        label = "low"
    elif (4 < r <= 6):
        label = "medium"
    else:
        label = "high"
    return label

from pyspark.sql.functions import udf
from pyspark.sql.types import StringType, DoubleType

```

```

string_to_float_udf = udf(string_to_float, DoubleType())
quality_udf = udf(lambda x: condition(x), StringType())

df = df.withColumn("quality", quality_udf("quality"))

df.show(5, True)

+---+-----+-----+-----+-----+-----+-----+-----+-----+
|fixed|volatile|citric|sugar|chlorides|free|total|density| pH|sulphates|alcohol|quality|
+---+-----+-----+-----+-----+-----+-----+-----+-----+
| 7.4|    0.7|   0.0|   1.9|   0.076|11.0| 34.0| 0.9978|3.51|   0.56|   9.4| medium
| 7.8|    0.88|   0.0|   2.6|   0.098|25.0| 67.0| 0.9968|3.2|   0.68|   9.8| medium
| 7.8|    0.76|   0.04|   2.3|   0.092|15.0| 54.0| 0.997|3.26|   0.65|   9.8| medium
| 11.2|   0.28|   0.56|   1.9|   0.075|17.0| 60.0| 0.998|3.16|   0.58|   9.8| medium
| 7.4|    0.7|   0.0|   1.9|   0.076|11.0| 34.0| 0.9978|3.51|   0.56|   9.4| medium
+---+-----+-----+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

df.printSchema()

root
|-- fixed: double (nullable = true)
|-- volatile: double (nullable = true)
|-- citric: double (nullable = true)
|-- sugar: double (nullable = true)
|-- chlorides: double (nullable = true)
|-- free: double (nullable = true)
|-- total: double (nullable = true)
|-- density: double (nullable = true)
|-- pH: double (nullable = true)
|-- sulphates: double (nullable = true)
|-- alcohol: double (nullable = true)
|-- quality: string (nullable = true)

```

3. Deal with categorical data and Convert the data to dense vector

Note: You are strongly encouraged to try my `get_dummy` function for dealing with the categorical data in complex dataset.

Supervised learning version:

```

def get_dummy(df, indexCol, categoricalCols, continuousCols, labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                  for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                           + continuousCols, outputCol="features")]

```

```

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

data = data.withColumn('label', col(labelCol))

return data.select(indexCol,'features','label')

```

Unsupervised learning version:

```

def get_dummy(df,indexCol,categoricalCols,continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learn
    :param df: the dataframe
    :param categoricalCols: the name list of the categorical data
    :param continuousCols: the name list of the numerical data
    :return k: feature matrix

    :author: Wenqiang Feng
    :email: von198@gmail.com
    """

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
        for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
        for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                            + continuousCols, outputCol="features")

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    return data.select(indexCol,'features')

```

```

def get_dummy(df,categoricalCols,continuousCols,labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
        for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
        for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                            + continuousCols, outputCol="features")

```

```

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

data = data.withColumn('label', col(labelCol))

return data.select('features','label')

```

4. Transform the dataset to DataFrame

```

from pyspark.ml.linalg import Vectors # !!!!caution: not from pyspark.mllib.linalg import
from pyspark.ml import Pipeline
from pyspark.ml.feature import IndexToString, StringIndexer, VectorIndexer
from pyspark.ml.tuning import CrossValidator, ParamGridBuilder
from pyspark.ml.evaluation import MulticlassClassificationEvaluator

def transData(data):
return data.rdd.map(lambda r: [Vectors.dense(r[:-1]),r[-1]]).toDF(['features','label'])

transformed = transData(df)
transformed.show(5)

+-----+-----+
| features| label |
+-----+-----+
|[7.4,0.7,0.0,1.9,...|medium|
|[7.8,0.88,0.0,2.6...|medium|
|[7.8,0.76,0.04,2....|medium|
|[11.2,0.28,0.56,1...|medium|
|[7.4,0.7,0.0,1.9,...|medium|
+-----+-----+
only showing top 5 rows

```

4. Deal with Categorical Label and Variables

```

# Index labels, adding metadata to the label column
labelIndexer = StringIndexer(inputCol='label',
                             outputCol='indexedLabel').fit(transformed)
labelIndexer.transform(transformed).show(5, True)

+-----+-----+-----+
| features| label|indexedLabel|
+-----+-----+-----+
|[7.4,0.7,0.0,1.9,...|medium| 0.0|
|[7.8,0.88,0.0,2.6...|medium| 0.0|
|[7.8,0.76,0.04,2....|medium| 0.0|
|[11.2,0.28,0.56,1...|medium| 0.0|
|[7.4,0.7,0.0,1.9,...|medium| 0.0|
+-----+-----+-----+
only showing top 5 rows

# Automatically identify categorical features, and index them.
# Set maxCategories so features with > 4 distinct values are treated as continuous.
featureIndexer =VectorIndexer(inputCol="features", \
                               outputCol="indexedFeatures", \
                               maxCategories=4).fit(transformed)
featureIndexer.transform(transformed).show(5, True)

```

```
+-----+-----+-----+
|      features | label | indexedFeatures |
+-----+-----+-----+
|[7.4,0.7,0.0,1.9,...|medium|[7.4,0.7,0.0,1.9,...|
|[7.8,0.88,0.0,2.6...|medium|[7.8,0.88,0.0,2.6...|
|[7.8,0.76,0.04,2....|medium|[7.8,0.76,0.04,2....|
|[11.2,0.28,0.56,1...|medium|[11.2,0.28,0.56,1...|
|[7.4,0.7,0.0,1.9,...|medium|[7.4,0.7,0.0,1.9,...|
+-----+-----+-----+
only showing top 5 rows
```

5. Split the data to training and test data sets

```
# Split the data into training and test sets (40% held out for testing)
```

```
(trainingData, testData) = data.randomSplit([0.6, 0.4])
```

```
trainingData.show(5, False)
testData.show(5, False)
```

```
+-----+-----+
| features | label |
+-----+-----+
|[4.7,0.6,0.17,2.3,0.058,17.0,106.0,0.9932,3.85,0.6,12.9] |medium|
|[5.0,0.38,0.01,1.6,0.048,26.0,60.0,0.99084,3.7,0.75,14.0] |medium|
|[5.0,0.4,0.5,4.3,0.046,29.0,80.0,0.9902,3.49,0.66,13.6] |medium|
|[5.0,0.74,0.0,1.2,0.041,16.0,46.0,0.99258,4.01,0.59,12.5] |medium|
|[5.1,0.42,0.0,1.8,0.044,18.0,88.0,0.99157,3.68,0.73,13.6] |high |
+-----+-----+
only showing top 5 rows
```

```
+-----+-----+
| features | label |
+-----+-----+
|[4.6,0.52,0.15,2.1,0.054,8.0,65.0,0.9934,3.9,0.56,13.1] |low |
|[4.9,0.42,0.0,2.1,0.048,16.0,42.0,0.99154,3.71,0.74,14.0] |high |
|[5.0,0.42,0.24,2.0,0.06,19.0,50.0,0.9917,3.72,0.74,14.0] |high |
|[5.0,1.02,0.04,1.4,0.045,41.0,85.0,0.9938,3.75,0.48,10.5] |low |
|[5.0,1.04,0.24,1.6,0.05,32.0,96.0,0.9934,3.74,0.62,11.5] |medium|
+-----+-----+
only showing top 5 rows
```

6. Fit Multinomial logisticRegression Classification Model

```
from pyspark.ml.classification import LogisticRegression
logr = LogisticRegression(featuresCol='indexedFeatures', labelCol='indexedLabel')
```

7. Pipeline Architecture

```
# Convert indexed labels back to original labels.
labelConverter = IndexToString(inputCol="prediction", outputCol="predictedLabel",
                                labels=labelIndexer.labels)

# Chain indexers and tree in a Pipeline
pipeline = Pipeline(stages=[labelIndexer, featureIndexer, logr, labelConverter])
```

```
# Train model. This also runs the indexers.  
model = pipeline.fit(trainingData)
```

8. Make predictions

```
# Make predictions.  
predictions = model.transform(testData)  
# Select example rows to display.  
predictions.select("features", "label", "predictedLabel").show(5)  
  
+-----+-----+-----+  
| features | label | predictedLabel |  
+-----+-----+-----+  
| [4.6, 0.52, 0.15, 2.... | low | medium |  
| [4.9, 0.42, 0.0, 2.1.... | high | high |  
| [5.0, 0.42, 0.24, 2.... | high | high |  
| [5.0, 1.02, 0.04, 1.... | low | medium |  
| [5.0, 1.04, 0.24, 1.... | medium | medium |  
+-----+-----+-----+  
only showing top 5 rows
```

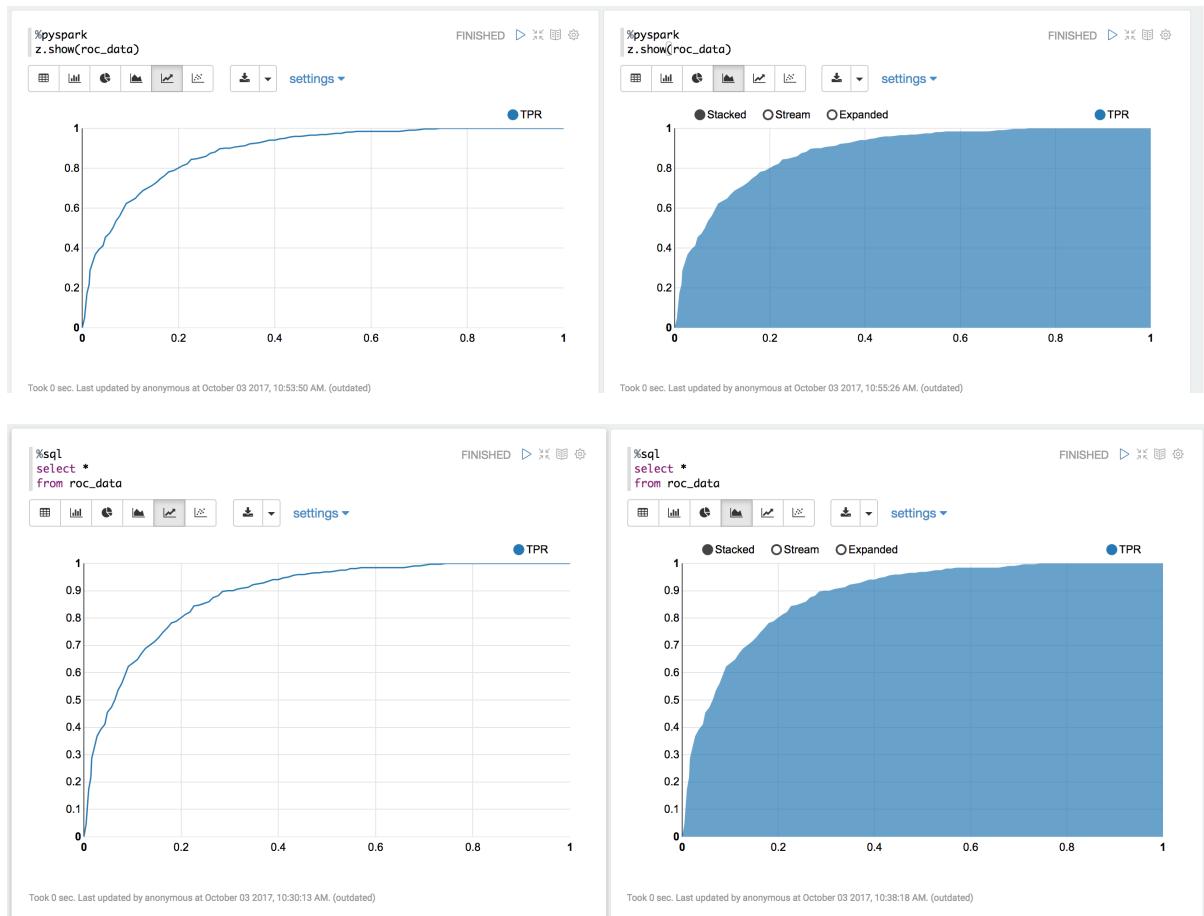
9. Evaluation

```
from pyspark.ml.evaluation import MulticlassClassificationEvaluator  
  
# Select (prediction, true label) and compute test error  
evaluator = MulticlassClassificationEvaluator(  
    labelCol="indexedLabel", predictionCol="prediction", metricName="accuracy")  
accuracy = evaluator.evaluate(predictions)  
print("Test Error = %g" % (1.0 - accuracy))  
  
Test Error = 0.181287  
  
lrModel = model.stages[2]  
trainingSummary = lrModel.summary  
  
# Obtain the objective per iteration  
# objectiveHistory = trainingSummary.objectiveHistory  
# print("objectiveHistory:")  
# for objective in objectiveHistory:  
#     print(objective)  
  
# Obtain the receiver-operating characteristic as a dataframe and areaUnderROC.  
trainingSummary.roc.show(5)  
print("areaUnderROC: " + str(trainingSummary.areaUnderROC))  
  
# Set the model threshold to maximize F-Measure  
fMeasure = trainingSummary.fMeasureByThreshold  
maxFMeasure = fMeasure.groupBy().max('F-Measure').select('max(F-Measure)').head(5)  
# bestThreshold = fMeasure.where(fMeasure['F-Measure'] == maxFMeasure['max(F-Measure)'])  
# .select('threshold').head()['threshold']  
# lr.setThreshold(bestThreshold)
```

You can use `z.show()` to get the data and plot the ROC curves:

You can also register a TempTable `data.registerTempTable('roc_data')` and then use `sql` to plot the ROC curve:

10. visualization



```

import matplotlib.pyplot as plt
import numpy as np
import itertools

def plot_confusion_matrix(cm, classes,
                        normalize=False,
                        title='Confusion matrix',
                        cmap=plt.cm.Blues):

    """
    This function prints and plots the confusion matrix.
    Normalization can be applied by setting 'normalize=True'.
    """

    if normalize:
        cm = cm.astype('float') / cm.sum(axis=1)[:, np.newaxis]
        print("Normalized confusion matrix")
    else:
        print('Confusion matrix, without normalization')

    print(cm)

    plt.imshow(cm, interpolation='nearest', cmap=cmap)
    plt.title(title)
    plt.colorbar()
    tick_marks = np.arange(len(classes))
    plt.xticks(tick_marks, classes, rotation=45)
    plt.yticks(tick_marks, classes)

```

```

fmt = '.2f' if normalize else 'd'
thresh = cm.max() / 2.
for i, j in itertools.product(range(cm.shape[0]), range(cm.shape[1])):
    plt.text(j, i, format(cm[i, j], fmt),
              horizontalalignment="center",
              color="white" if cm[i, j] > thresh else "black")

plt.tight_layout()
plt.ylabel('True label')
plt.xlabel('Predicted label')

class_temp = predictions.select("label").groupBy("label") \
    .count().sort('count', ascending=False).toPandas()
class_temp = class_temp["label"].values.tolist()
class_names = map(str, class_temp)
# # print(class_name)
class_names

['medium', 'high', 'low']

from sklearn.metrics import confusion_matrix
y_true = predictions.select("label")
y_true = y_true.toPandas()

y_pred = predictions.select("predictedLabel")
y_pred = y_pred.toPandas()

cnf_matrix = confusion_matrix(y_true, y_pred, labels=class_names)
cnf_matrix

array([[526,   11,    2],
       [ 73,   33,    0],
       [ 38,    0,    1]])

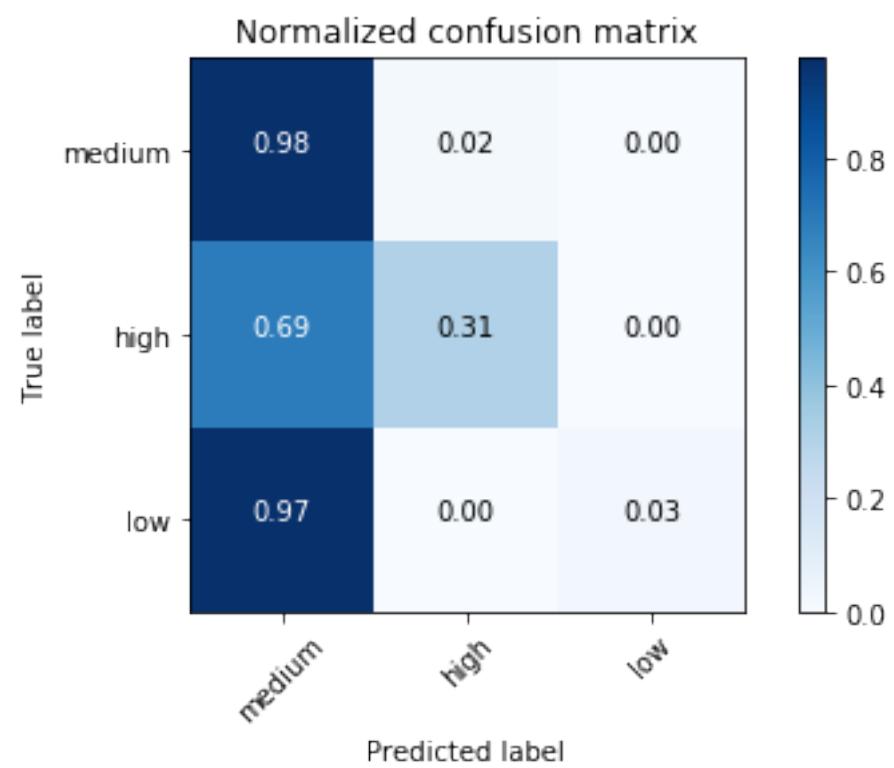
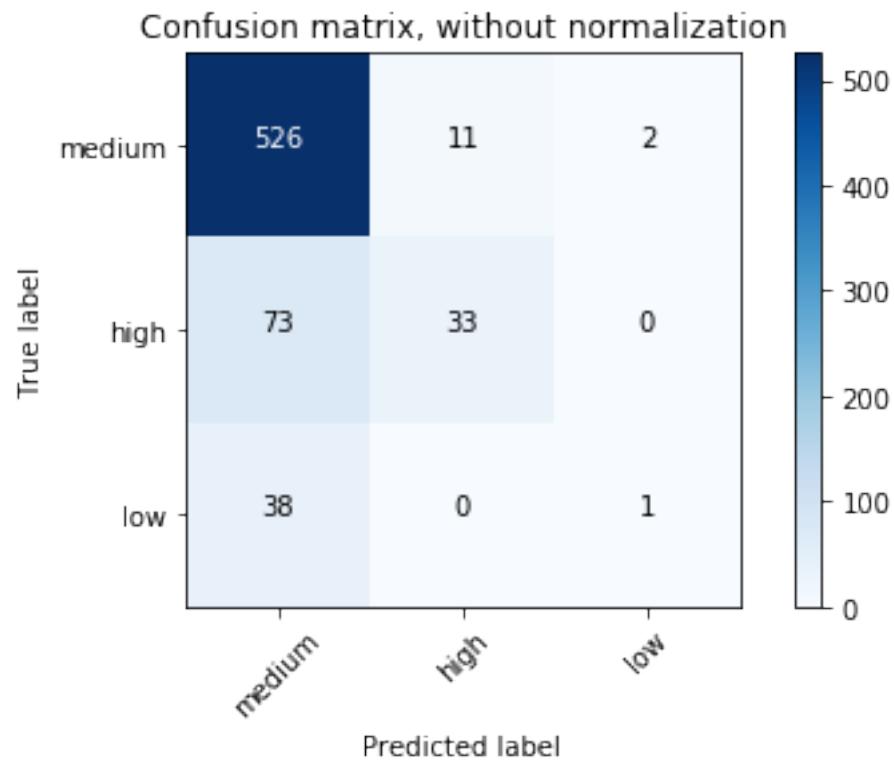
# Plot non-normalized confusion matrix
plt.figure()
plot_confusion_matrix(cnf_matrix, classes=class_names,
                      title='Confusion matrix, without normalization')
plt.show()

Confusion matrix, without normalization
[[526  11   2]
 [ 73  33   0]
 [ 38   0   1]]

# Plot normalized confusion matrix
plt.figure()
plot_confusion_matrix(cnf_matrix, classes=class_names, normalize=True,
                      title='Normalized confusion matrix')

plt.show()

Normalized confusion matrix
[[0.97588126  0.02040816  0.00371058]
 [0.68867925  0.31132075  0.        ]
 [0.97435897  0.        0.02564103]]
```



10.3 Decision tree Classification

10.3.1 Introduction

10.3.2 Demo

- The Jupyter notebook can be download from [Decision Tree Classification](#).
 - For more details, please visit [DecisionTreeClassifier API](#).
1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark Decision Tree classification") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
```

2. Load dataset

```
df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', \
    inferSchema='true') \
    .load("../data/WineData2.csv", header=True);
df.show(5, True)

+---+---+---+---+---+---+---+---+---+---+---+---+---+
|fixed|volatile|citric|sugar|chlorides|free|total|density| pH|sulphates|alcohol|quality|
+---+---+---+---+---+---+---+---+---+---+---+---+---+
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| 5
| 7.8| 0.88| 0.0| 2.6| 0.098|25.0| 67.0| 0.9968| 3.2| 0.68| 9.8| 5
| 7.8| 0.76| 0.04| 2.3| 0.092|15.0| 54.0| 0.997|3.26| 0.65| 9.8| 5
| 11.2| 0.28| 0.56| 1.9| 0.075|17.0| 60.0| 0.998|3.16| 0.58| 9.8| 6
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| 5
+---+---+---+---+---+---+---+---+---+---+---+---+---+
only showing top 5 rows
```

```
# Convert to float format
def string_to_float(x):
    return float(x)

#
def condition(r):
    if (0 <= r <= 4):
        label = "low"
    elif(4 < r <= 6):
        label = "medium"
    else:
        label = "high"
    return label

from pyspark.sql.functions import udf
from pyspark.sql.types import StringType, DoubleType
string_to_float_udf = udf(string_to_float, DoubleType())
quality_udf = udf(lambda x: condition(x), StringType())
```

```

df = df.withColumn("quality", quality_udf("quality"))
df.show(5, True)
df.printSchema()

+---+---+---+---+---+---+---+---+---+---+
|fixed|volatile|citric|sugar|chlorides|free|total|density| pH|sulphates|alcohol|quality|
+---+---+---+---+---+---+---+---+---+---+
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| medium
| 7.8| 0.88| 0.0| 2.6| 0.098|25.0| 67.0| 0.9968| 3.2| 0.68| 9.8| medium
| 7.8| 0.76| 0.04| 2.3| 0.092|15.0| 54.0| 0.997|3.26| 0.65| 9.8| medium
| 11.2| 0.28| 0.56| 1.9| 0.075|17.0| 60.0| 0.998|3.16| 0.58| 9.8| medium
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| medium
+---+---+---+---+---+---+---+---+---+---+
only showing top 5 rows

root
|-- fixed: double (nullable = true)
|-- volatile: double (nullable = true)
|-- citric: double (nullable = true)
|-- sugar: double (nullable = true)
|-- chlorides: double (nullable = true)
|-- free: double (nullable = true)
|-- total: double (nullable = true)
|-- density: double (nullable = true)
|-- pH: double (nullable = true)
|-- sulphates: double (nullable = true)
|-- alcohol: double (nullable = true)
|-- quality: string (nullable = true)

```

3. Convert the data to dense vector

Note: You are strongly encouraged to try my get_dummy function for dealing with the categorical data in complex dataset.

Supervised learning version:

```

def get_dummy(df, indexCol, categoricalCols, continuousCols, labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                  for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                            + continuousCols, outputCol="features"])

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

```

```

    data = data.withColumn('label', col(labelCol))

    return data.select(indexCol,'features','label')

```

Unsupervised learning version:

```

def get_dummy (df, indexCol, categoricalCols, continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learning
    :param df: the dataframe
    :param categoricalCols: the name list of the categorical data
    :param continuousCols: the name list of the numerical data
    :return k: feature matrix

    :author: Wengiang Feng
    :email: von198@gmail.com
    """

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                  for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                           + continuousCols, outputCol="features")

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    return data.select(indexCol,'features')

```

```

# !!!!caution: not from pyspark.mllib.linalg import Vectors
from pyspark.ml.linalg import Vectors
from pyspark.ml import Pipeline
from pyspark.ml.feature import IndexToString, StringIndexer, VectorIndexer
from pyspark.ml.tuning import CrossValidator, ParamGridBuilder
from pyspark.ml.evaluation import MulticlassClassificationEvaluator

def transData(data):
    return data.rdd.map(lambda r: [Vectors.dense(r[:-1]),r[-1]]).toDF(['features','label'])

```

4. Transform the dataset to DataFrame

```

transformed = transData(df)
transformed.show(5)

```

```

+-----+-----+
|      features| label |
+-----+-----+
|[7.4,0.7,0.0,1.9,...|medium|
|[7.8,0.88,0.0,2.6...|medium|
|[7.8,0.76,0.04,2....|medium|

```

```
| [11.2,0.28,0.56,1...|medium|
| [7.4,0.7,0.0,1.9,...|medium|
+-----+-----+
only showing top 5 rows
```

5. Deal with Categorical Label and Variables

```
# Index labels, adding metadata to the label column
labelIndexer = StringIndexer(inputCol='label',
                             outputCol='indexedLabel').fit(transformed)
labelIndexer.transform(transformed).show(5, True)

+-----+-----+-----+
|       features| label|indexedLabel|
+-----+-----+-----+
| [7.4,0.7,0.0,1.9,...|medium|      0.0|
| [7.8,0.88,0.0,2.6...|medium|      0.0|
| [7.8,0.76,0.04,2....|medium|      0.0|
| [11.2,0.28,0.56,1...|medium|      0.0|
| [7.4,0.7,0.0,1.9,...|medium|      0.0|
+-----+-----+-----+
only showing top 5 rows

# Automatically identify categorical features, and index them.
# Set maxCategories so features with > 4 distinct values are treated as continuous.
featureIndexer = VectorIndexer(inputCol="features", \
                                 outputCol="indexedFeatures", \
                                 maxCategories=4).fit(transformed)
featureIndexer.transform(transformed).show(5, True)

+-----+-----+-----+
|       features| label|     indexedFeatures|
+-----+-----+-----+
| [7.4,0.7,0.0,1.9,...|medium|[7.4,0.7,0.0,1.9,...|
| [7.8,0.88,0.0,2.6...|medium|[7.8,0.88,0.0,2.6...|
| [7.8,0.76,0.04,2....|medium|[7.8,0.76,0.04,2....|
| [11.2,0.28,0.56,1...|medium|[11.2,0.28,0.56,1...|
| [7.4,0.7,0.0,1.9,...|medium|[7.4,0.7,0.0,1.9,...|
+-----+-----+-----+
only showing top 5 rows
```

6. Split the data to training and test data sets

```
# Split the data into training and test sets (40% held out for testing)
(trainingData, testData) = transformed.randomSplit([0.6, 0.4])

trainingData.show(5)
testData.show(5)

+-----+-----+
|       features| label|
+-----+-----+
| [4.6,0.52,0.15,2....|   low|
| [4.7,0.6,0.17,2.3...|medium|
| [5.0,1.02,0.04,1....|   low|
| [5.0,1.04,0.24,1....|medium|
| [5.1,0.585,0.0,1....|  high|
+-----+-----+
```

```
only showing top 5 rows

+-----+-----+
|      features| label|
+-----+-----+
|[4.9,0.42,0.0,2.1...| high|
|[5.0,0.38,0.01,1....|medium|
|[5.0,0.4,0.5,4.3,...|medium|
|[5.0,0.42,0.24,2....| high|
|[5.0,0.74,0.0,1.2...|medium|
+-----+-----+
only showing top 5 rows
```

7. Fit Decision Tree Classification Model

```
from pyspark.ml.classification import DecisionTreeClassifier

# Train a DecisionTree model
dTree = DecisionTreeClassifier(labelCol='indexedLabel', featuresCol='indexedFeatures')
```

8. Pipeline Architecture

```
# Convert indexed labels back to original labels.
labelConverter = IndexToString(inputCol="prediction", outputCol="predictedLabel",
                                labels=labelIndexer.labels)

# Chain indexers and tree in a Pipeline
pipeline = Pipeline(stages=[labelIndexer, featureIndexer, dTree,labelConverter])

# Train model. This also runs the indexers.
model = pipeline.fit(trainingData)
```

9. Make predictions

```
# Make predictions.
predictions = model.transform(testData)
# Select example rows to display.
predictions.select("features","label","predictedLabel").show(5)

+-----+-----+-----+
|      features| label|predictedLabel|
+-----+-----+-----+
|[4.9,0.42,0.0,2.1...| high|      high|
|[5.0,0.38,0.01,1....|medium|      medium|
|[5.0,0.4,0.5,4.3,...|medium|      medium|
|[5.0,0.42,0.24,2....| high|      medium|
|[5.0,0.74,0.0,1.2...|medium|      medium|
+-----+-----+-----+
only showing top 5 rows
```

10. Evaluation

```
from pyspark.ml.evaluation import MulticlassClassificationEvaluator

# Select (prediction, true label) and compute test error
evaluator = MulticlassClassificationEvaluator(
    labelCol="indexedLabel", predictionCol="prediction", metricName="accuracy")
accuracy = evaluator.evaluate(predictions)
```

```

print("Test Error = %g" % (1.0 - accuracy))

rfModel = model.stages[-2]
print(rfModel) # summary only

Test Error = 0.45509
DecisionTreeClassificationModel (uid=DecisionTreeClassifier_4545ac8dca9c8438ef2a)
of depth 5 with 59 nodes

```

11. visualization

```

import matplotlib.pyplot as plt
import numpy as np
import itertools

def plot_confusion_matrix(cm, classes,
                         normalize=False,
                         title='Confusion matrix',
                         cmap=plt.cm.Blues):
    """
    This function prints and plots the confusion matrix.
    Normalization can be applied by setting 'normalize=True'.
    """
    if normalize:
        cm = cm.astype('float') / cm.sum(axis=1)[:, np.newaxis]
        print("Normalized confusion matrix")
    else:
        print('Confusion matrix, without normalization')

    print(cm)

    plt.imshow(cm, interpolation='nearest', cmap=cmap)
    plt.title(title)
    plt.colorbar()
    tick_marks = np.arange(len(classes))
    plt.xticks(tick_marks, classes, rotation=45)
    plt.yticks(tick_marks, classes)

    fmt = '.2f' if normalize else 'd'
    thresh = cm.max() / 2.
    for i, j in itertools.product(range(cm.shape[0]), range(cm.shape[1])):
        plt.text(j, i, format(cm[i, j], fmt),
                 horizontalalignment="center",
                 color="white" if cm[i, j] > thresh else "black")

    plt.tight_layout()
    plt.ylabel('True label')
    plt.xlabel('Predicted label')

class_temp = predictions.select("label").groupBy("label") \
    .count().sort('count', ascending=False).toPandas()
class_temp = class_temp["label"].values.tolist()
class_names = map(str, class_temp)
# # # print(class_name)
class_names

```

```

['medium', 'high', 'low']

from sklearn.metrics import confusion_matrix
y_true = predictions.select("label")
y_true = y_true.toPandas()

y_pred = predictions.select("predictedLabel")
y_pred = y_pred.toPandas()

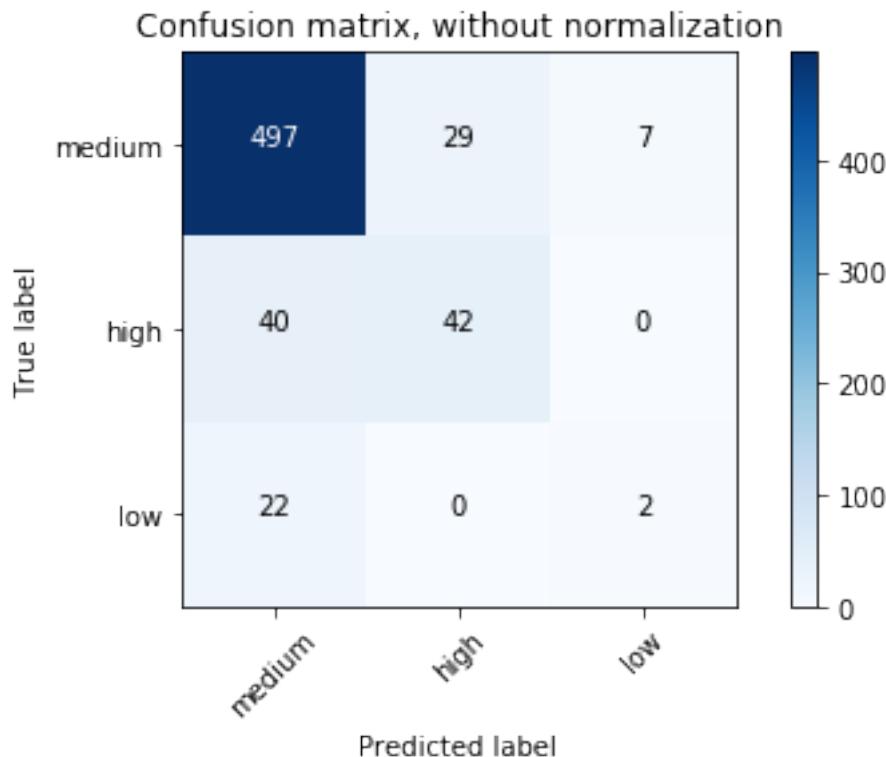
cnf_matrix = confusion_matrix(y_true, y_pred, labels=class_names)
cnf_matrix

array([[497,   29,    7],
       [ 40,   42,    0],
       [ 22,    0,    2]])

# Plot non-normalized confusion matrix
plt.figure()
plot_confusion_matrix(cnf_matrix, classes=class_names,
                      title='Confusion matrix, without normalization')
plt.show()

Confusion matrix, without normalization
[[497  29  7]
 [ 40  42  0]
 [ 22   0  2]]

```



```

# Plot normalized confusion matrix
plt.figure()
plot_confusion_matrix(cnf_matrix, classes=class_names, normalize=True,
                      title='Normalized confusion matrix')

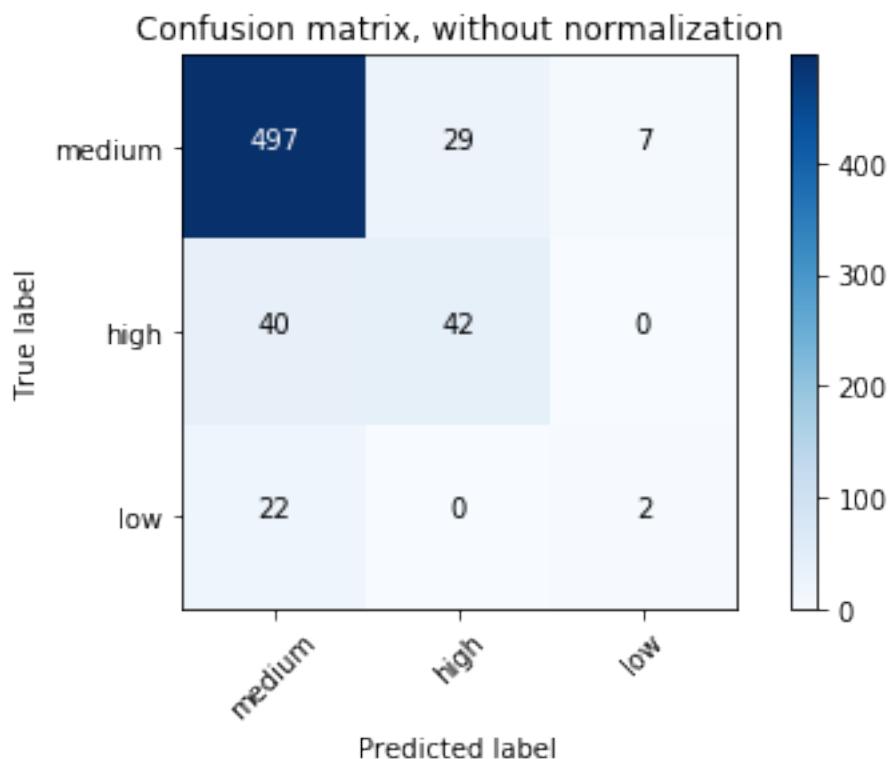
```

```

plt.show()

Normalized confusion matrix
[[ 0.93245779  0.05440901  0.01313321]
 [ 0.48780488  0.51219512  0.          ]
 [ 0.91666667  0.          0.08333333]]

```



10.4 Random forest Classification

10.4.1 Introduction

10.4.2 Demo

- The Jupyter notebook can be download from Random forest Classification.
 - For more details, please visit [RandomForestClassifier API](#).
1. Set up spark context and SparkSession

```

from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark Decision Tree classification") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()

```

2. Load dataset

```

df = spark.read.format('com.databricks.spark.csv').\
    options(header='true', \
    inferSchema='true') \
    .load("../data/WineData2.csv",header=True);
df.show(5, True)

+---+---+---+---+---+---+---+---+---+---+---+---+
|fixed|volatile|citric|sugar|chlorides|free|total|density| pH|sulphates|alcohol|quality|
+---+---+---+---+---+---+---+---+---+---+---+---+
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| 5
| 7.8| 0.88| 0.0| 2.6| 0.098|25.0| 67.0| 0.9968| 3.2| 0.68| 9.8| 5
| 7.8| 0.76| 0.04| 2.3| 0.092|15.0| 54.0| 0.997|3.26| 0.65| 9.8| 5
| 11.2| 0.28| 0.56| 1.9| 0.075|17.0| 60.0| 0.998|3.16| 0.58| 9.8| 6
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| 5
+---+---+---+---+---+---+---+---+---+---+---+---+
only showing top 5 rows

# Convert to float format
def string_to_float(x):
    return float(x)

#
def condition(r):
    if (0 <= r <= 4):
        label = "low"
    elif(4 < r <= 6):
        label = "medium"
    else:
        label = "high"
    return label

from pyspark.sql.functions import udf
from pyspark.sql.types import StringType, DoubleType
string_to_float_udf = udf(string_to_float, DoubleType())
quality_udf = udf(lambda x: condition(x), StringType())

df = df.withColumn("quality", quality_udf("quality"))
df.show(5, True)
df.printSchema()

+---+---+---+---+---+---+---+---+---+---+---+---+
|fixed|volatile|citric|sugar|chlorides|free|total|density| pH|sulphates|alcohol|quality|
+---+---+---+---+---+---+---+---+---+---+---+---+
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| medium
| 7.8| 0.88| 0.0| 2.6| 0.098|25.0| 67.0| 0.9968| 3.2| 0.68| 9.8| medium
| 7.8| 0.76| 0.04| 2.3| 0.092|15.0| 54.0| 0.997|3.26| 0.65| 9.8| medium
| 11.2| 0.28| 0.56| 1.9| 0.075|17.0| 60.0| 0.998|3.16| 0.58| 9.8| medium
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| medium
+---+---+---+---+---+---+---+---+---+---+---+---+
only showing top 5 rows

root
|-- fixed: double (nullable = true)
|-- volatile: double (nullable = true)
|-- citric: double (nullable = true)
|-- sugar: double (nullable = true)
|-- chlorides: double (nullable = true)
|-- free: double (nullable = true)

```

```
|-- total: double (nullable = true)
|-- density: double (nullable = true)
|-- pH: double (nullable = true)
|-- sulphates: double (nullable = true)
|-- alcohol: double (nullable = true)
|-- quality: string (nullable = true)
```

3. Convert the data to dense vector

Note: You are strongly encouraged to try my get_dummy function for dealing with the categorical data in complex dataset.

Supervised learning version:

```
def get_dummy(df, indexCol, categoricalCols, continuousCols, labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                 for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                           + continuousCols, outputCol="features")

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    data = data.withColumn('label', col(labelCol))

    return data.select(indexCol, 'features', 'label')
```

Unsupervised learning version:

```
def get_dummy(df, indexCol, categoricalCols, continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learning
    :param df: the dataframe
    :param categoricalCols: the name list of the categorical data
    :param continuousCols: the name list of the numerical data
    :return k: feature matrix

    :author: Wenqiang Feng
    :email: von198@gmail.com
    """

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
```

```

encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                           outputCol="{0}_encoded".format(indexer.getOutputCol()))
             for indexer in indexers ]

assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                      + continuousCols, outputCol="features")

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

return data.select(indexCol,'features')

```

```

# !!!!caution: not from pyspark.mllib.linalg import Vectors
from pyspark.ml.linalg import Vectors
from pyspark.ml import Pipeline
from pyspark.ml.feature import IndexToString, StringIndexer, VectorIndexer
from pyspark.ml.tuning import CrossValidator, ParamGridBuilder
from pyspark.ml.evaluation import MulticlassClassificationEvaluator

def transData(data):
    return data.rdd.map(lambda r: [Vectors.dense(r[:-1]),r[-1]]).toDF(['features','label'])

```

4. Transform the dataset to DataFrame

```

transformed = transData(df)
transformed.show(5)

+-----+-----+
|      features| label|
+-----+-----+
| [7.4,0.7,0.0,1.9,...|medium|
| [7.8,0.88,0.0,2.6...|medium|
| [7.8,0.76,0.04,2....|medium|
| [11.2,0.28,0.56,1...|medium|
| [7.4,0.7,0.0,1.9,...|medium|
+-----+-----+
only showing top 5 rows

```

5. Deal with Categorical Label and Variables

```

# Index labels, adding metadata to the label column
labelIndexer = StringIndexer(inputCol='label',
                             outputCol='indexedLabel').fit(transformed)
labelIndexer.transform(transformed).show(5, True)

+-----+-----+-----+
|      features| label|indexedLabel|
+-----+-----+-----+
| [7.4,0.7,0.0,1.9,...|medium|      0.0|
| [7.8,0.88,0.0,2.6...|medium|      0.0|
| [7.8,0.76,0.04,2....|medium|      0.0|
| [11.2,0.28,0.56,1...|medium|      0.0|
| [7.4,0.7,0.0,1.9,...|medium|      0.0|
+-----+-----+-----+
only showing top 5 rows

```

```
# Automatically identify categorical features, and index them.
# Set maxCategories so features with > 4 distinct values are treated as continuous.
featureIndexer = VectorIndexer(inputCol="features", \
                                outputCol="indexedFeatures", \
                                maxCategories=4).fit(transformed)
featureIndexer.transform(transformed).show(5, True)

+-----+-----+
|      features| label|      indexedFeatures|
+-----+-----+
|[7.4,0.7,0.0,1.9,...|medium|[7.4,0.7,0.0,1.9,...|
|[7.8,0.88,0.0,2.6...|medium|[7.8,0.88,0.0,2.6...|
|[7.8,0.76,0.04,2....|medium|[7.8,0.76,0.04,2....|
|[11.2,0.28,0.56,1...|medium|[11.2,0.28,0.56,1...|
|[7.4,0.7,0.0,1.9,...|medium|[7.4,0.7,0.0,1.9,...|
+-----+-----+
only showing top 5 rows
```

6. Split the data to training and test data sets

```
# Split the data into training and test sets (40% held out for testing)
(trainingData, testData) = transformed.randomSplit([0.6, 0.4])

trainingData.show(5)
testData.show(5)

+-----+-----+
|      features| label|
+-----+-----+
|[4.6,0.52,0.15,2....| low|
|[4.7,0.6,0.17,2.3...|medium|
|[5.0,1.02,0.04,1....| low|
|[5.0,1.04,0.24,1....|medium|
|[5.1,0.585,0.0,1....| high|
+-----+-----+
only showing top 5 rows

+-----+-----+
|      features| label|
+-----+-----+
|[4.9,0.42,0.0,2.1...| high|
|[5.0,0.38,0.01,1....|medium|
|[5.0,0.4,0.5,4.3,...|medium|
|[5.0,0.42,0.24,2....| high|
|[5.0,0.74,0.0,1.2...|medium|
+-----+-----+
only showing top 5 rows
```

7. Fit Random Forest Classification Model

```
from pyspark.ml.classification import RandomForestClassifier

# Train a RandomForest model.
rf = RandomForestClassifier(labelCol="indexedLabel", featuresCol="indexedFeatures", numT
```

8. Pipeline Architecture

```
# Convert indexed labels back to original labels.
labelConverter = IndexToString(inputCol="prediction", outputCol="predictedLabel",
                                labels=labelIndexer.labels)

# Chain indexers and tree in a Pipeline
pipeline = Pipeline(stages=[labelIndexer, featureIndexer, rf,labelConverter])

# Train model. This also runs the indexers.
model = pipeline.fit(trainingData)

9. Make predictions

# Make predictions.
predictions = model.transform(testData)
# Select example rows to display.
predictions.select("features","label","predictedLabel").show(5)

+-----+-----+-----+
|       features| label|predictedLabel|
+-----+-----+-----+
|[4.9,0.42,0.0,2.1...| high|      high|
|[5.0,0.38,0.01,1....|medium|    medium|
|[5.0,0.4,0.5,4.3,...|medium|    medium|
|[5.0,0.42,0.24,2....| high|    medium|
|[5.0,0.74,0.0,1.2...|medium|    medium|
+-----+-----+-----+
only showing top 5 rows
```

10. Evaluation

```
from pyspark.ml.evaluation import MulticlassClassificationEvaluator

# Select (prediction, true label) and compute test error
evaluator = MulticlassClassificationEvaluator(
    labelCol="indexedLabel", predictionCol="prediction", metricName="accuracy")
accuracy = evaluator.evaluate(predictions)
print("Test Error = %g" % (1.0 - accuracy))

rfModel = model.stages[-2]
print(rfModel) # summary only

Test Error = 0.173502
RandomForestClassificationModel (uid=rfc_a3395531f1d2) with 10 trees
```

11. visualization

```
import matplotlib.pyplot as plt
import numpy as np
import itertools

def plot_confusion_matrix(cm, classes,
                        normalize=False,
                        title='Confusion matrix',
                        cmap=plt.cm.Blues):
    """
    This function prints and plots the confusion matrix.
    Normalization can be applied by setting 'normalize=True'.
    """
    """
```

```

if normalize:
    cm = cm.astype('float') / cm.sum(axis=1)[:, np.newaxis]
    print("Normalized confusion matrix")
else:
    print('Confusion matrix, without normalization')

print(cm)

plt.imshow(cm, interpolation='nearest', cmap=cmap)
plt.title(title)
plt.colorbar()
tick_marks = np.arange(len(classes))
plt.xticks(tick_marks, classes, rotation=45)
plt.yticks(tick_marks, classes)

fmt = '.2f' if normalize else 'd'
thresh = cm.max() / 2.
for i, j in itertools.product(range(cm.shape[0]), range(cm.shape[1])):
    plt.text(j, i, format(cm[i, j], fmt),
              horizontalalignment="center",
              color="white" if cm[i, j] > thresh else "black")

plt.tight_layout()
plt.ylabel('True label')
plt.xlabel('Predicted label')

class_temp = predictions.select("label").groupBy("label") \
    .count().sort('count', ascending=False).toPandas()
class_temp = class_temp["label"].values.tolist()
class_names = map(str, class_temp)
# # # print(class_name)
class_names

['medium', 'high', 'low']

from sklearn.metrics import confusion_matrix
y_true = predictions.select("label")
y_true = y_true.toPandas()

y_pred = predictions.select("predictedLabel")
y_pred = y_pred.toPandas()

cnf_matrix = confusion_matrix(y_true, y_pred, labels=class_names)
cnf_matrix

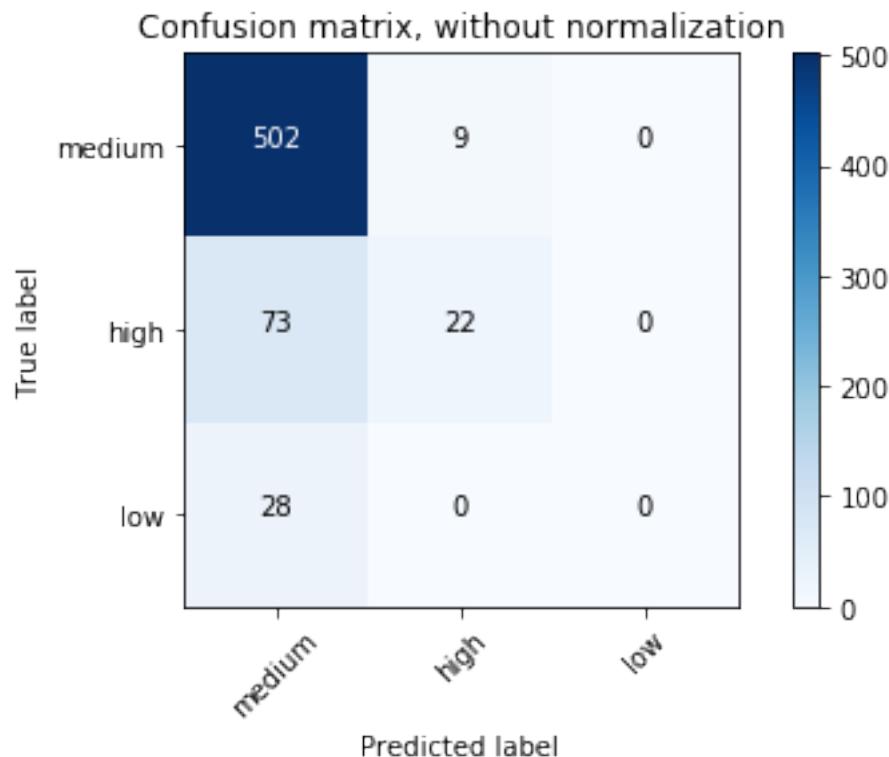
array([[502,    9,    0],
       [ 73,   22,    0],
       [ 28,    0,    0]])

# Plot non-normalized confusion matrix
plt.figure()
plot_confusion_matrix(cnf_matrix, classes=class_names,
                      title='Confusion matrix, without normalization')
plt.show()

Confusion matrix, without normalization
[[502  9  0]]

```

```
[ 73  22   0]
[ 28   0   0]]
```



```
# Plot normalized confusion matrix
plt.figure()
plot_confusion_matrix(cnf_matrix, classes=class_names, normalize=True,
                      title='Normalized confusion matrix')

plt.show()

Normalized confusion matrix
[[ 0.98238748  0.01761252  0.        ]
 [ 0.76842105  0.23157895  0.        ]
 [ 1.          0.          0.        ]]
```

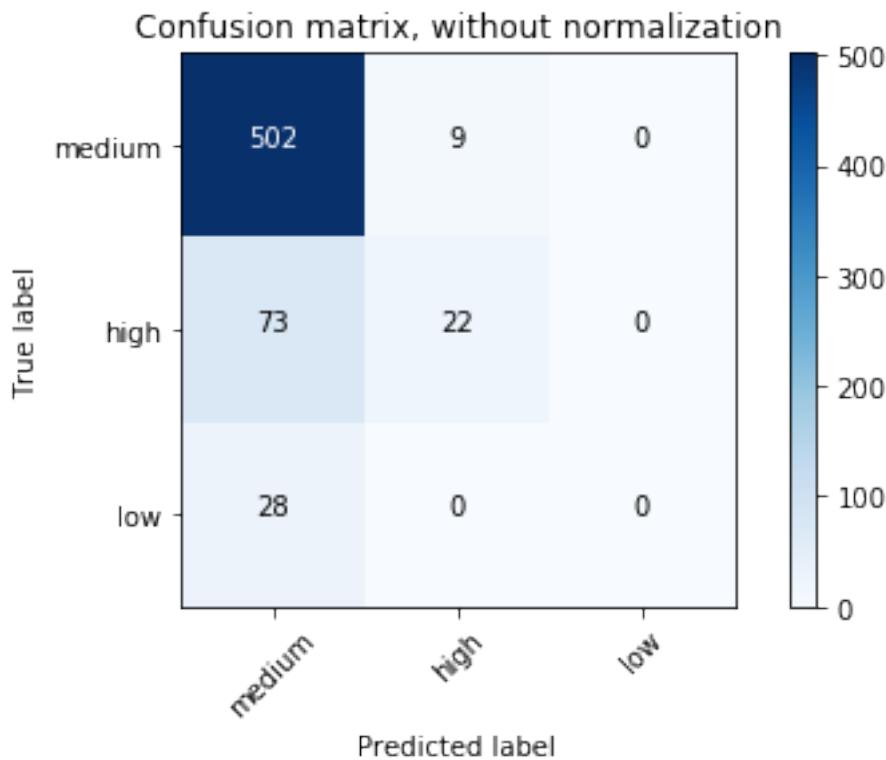
10.5 Gradient-boosted tree Classification

10.5.1 Introduction

10.5.2 Demo

- The Jupyter notebook can be download from Gradient boosted tree Classification.
- For more details, please visit [GBTClassifier API](#).

Warning: Unfortunately, the GBTClassifier currently only supports binary labels.



10.6 XGBoost: Gradient-boosted tree Classification

10.6.1 Introduction

10.6.2 Demo

- The Jupyter notebook can be download from Gradient boosted tree Classification.
- For more details, please visit [GBTClassifier API](#).

Warning: Unfortunately, I didn't find a good way to setup the XGBoost directly in Spark. But I do get the XGBoost work with pysparkling on my machine.

1. Start H2O cluster inside the Spark environment

```
from pysparkling import *
hc = H2OContext.getOrCreate(spark)

Connecting to H2O server at http://192.168.0.102:54323... successful.
H2O cluster uptime:      07 secs
H2O cluster timezone:    America/Chicago
H2O data parsing timezone:    UTC
H2O cluster version:     3.22.1.3
H2O cluster version age:   20 days
H2O cluster name:        sparkling-water-dt216661_local-1550259209801
H2O cluster total nodes:  1
H2O cluster free memory:  848 Mb
H2O cluster total cores:  8
H2O cluster allowed cores: 8
H2O cluster status:       accepting new members, healthy
```

```
H2O connection url:      http://192.168.0.102:54323
H2O connection proxy:    None
H2O internal security:  False
H2O API Extensions:    XGBoost, Algos, AutoML, Core V3, Core V4
Python version: 3.7.1 final
```

Sparkling Water Context:

```
* H2O name: sparkling-water-dt216661_local-1550259209801
* cluster size: 1
* list of used nodes:
  (executorId, host, port)
  -----
  (driver, 192.168.0.102, 54323)
  -----
```

Open H2O Flow **in** browser: http://192.168.0.102:54323 (CMD + click **in** Mac OSX)

2. Parse the data using H2O and convert them to Spark Frame

```
import h2o
frame = h2o.import_file("https://raw.githubusercontent.com/h2oai/sparkling-water/master/data/breast-cancer.csv")
spark_frame = hc.as_spark_frame(frame)
```

Parse progress: |███████████| 100%

```
spark_frame.show(4)
```

```
+---+-----+-----+-----+-----+-----+
| ID|CAPSULE|AGE|RACE|DPROS|DCAPS| PSA| VOL|GLEASON|
+---+-----+-----+-----+-----+-----+-----+
|  1|     0|  65|   1|    2|    1| 1.4| 0.0|       6|
|  2|     0|  72|   1|    3|    2| 6.7| 0.0|       7|
|  3|     0|  70|   1|    1|    2| 4.9| 0.0|       6|
|  4|     0|  76|   2|    2|    1|51.2|20.0|       7|
+---+-----+-----+-----+-----+-----+
only showing top 4 rows
```

3. Train the model

```
from pysparkling.ml import H2OXGBoost
estimator = H2OXGBoost(predictionCol="AGE")
model = estimator.fit(spark_frame)
```

4. Run Predictions

```
predictions = model.transform(spark_frame)
predictions.show(4)
```

```
+---+-----+-----+-----+-----+-----+-----+-----+
| ID|CAPSULE|AGE|RACE|DPROS|DCAPS| PSA| VOL|GLEASON| prediction_output|
+---+-----+-----+-----+-----+-----+-----+-----+
|  1|     0|  65|   1|    2|    1| 1.4| 0.0|       6|[64.85852813720703]|
|  2|     0|  72|   1|    3|    2| 6.7| 0.0|       7|[72.0611801147461]|
|  3|     0|  70|   1|    1|    2| 4.9| 0.0|       6|[70.26496887207031]|
|  4|     0|  76|   2|    2|    1|51.2|20.0|       7|[75.26521301269531]|
+---+-----+-----+-----+-----+-----+-----+-----+
only showing top 4 rows
```

10.7 Naive Bayes Classification

10.7.1 Introduction

10.7.2 Demo

- The Jupyter notebook can be download from Naive Bayes Classification.
 - For more details, please visit [NaiveBayes API](#).
1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark Naive Bayes classification") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()

2. Load dataset

df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', inferSchema='true') \
    .load("./data/WineData2.csv", header=True);
df.show(5)

+---+---+---+---+---+---+---+---+---+---+---+---+---+
|fixed|volatile|citric|sugar|chlorides|free|total|density| pH|sulphates|alcohol|quality|
+---+---+---+---+---+---+---+---+---+---+---+---+---+
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| 5
| 7.8| 0.88| 0.0| 2.6| 0.098|25.0| 67.0| 0.9968| 3.2| 0.68| 9.8| 5
| 7.8| 0.76| 0.04| 2.3| 0.092|15.0| 54.0| 0.997|3.26| 0.65| 9.8| 5
| 11.2| 0.28| 0.56| 1.9| 0.075|17.0| 60.0| 0.998|3.16| 0.58| 9.8| 6
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| 5
+---+---+---+---+---+---+---+---+---+---+---+---+---+
only showing top 5 rows

df.printSchema()

root
 |-- fixed: double (nullable = true)
 |-- volatile: double (nullable = true)
 |-- citric: double (nullable = true)
 |-- sugar: double (nullable = true)
 |-- chlorides: double (nullable = true)
 |-- free: double (nullable = true)
 |-- total: double (nullable = true)
 |-- density: double (nullable = true)
 |-- pH: double (nullable = true)
 |-- sulphates: double (nullable = true)
 |-- alcohol: double (nullable = true)
 |-- quality: string (nullable = true)

# Convert to float format
def string_to_float(x):
    return float(x)
```

```

#
def condition(r):
    if (0 <= r <= 6):
        label = "low"
    else:
        label = "high"
    return label

from pyspark.sql.functions import udf
from pyspark.sql.types import StringType, DoubleType
string_to_float_udf = udf(string_to_float, DoubleType())
quality_udf = udf(lambda x: condition(x), StringType())

df = df.withColumn("quality", quality_udf("quality"))

df.show(5, True)

+-----+-----+-----+-----+-----+-----+-----+-----+
|fixed|volatile|citric|sugar|chlorides|free|total|density| pH|sulphates|alcohol|quality
+-----+-----+-----+-----+-----+-----+-----+-----+
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| medium
| 7.8| 0.88| 0.0| 2.6| 0.098|25.0| 67.0| 0.9968|3.2| 0.68| 9.8| medium
| 7.8| 0.76| 0.04| 2.3| 0.092|15.0| 54.0| 0.997|3.26| 0.65| 9.8| medium
| 11.2| 0.28| 0.56| 1.9| 0.075|17.0| 60.0| 0.998|3.16| 0.58| 9.8| medium
| 7.4| 0.7| 0.0| 1.9| 0.076|11.0| 34.0| 0.9978|3.51| 0.56| 9.4| medium
+-----+-----+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

df.printSchema()

root
 |-- fixed: double (nullable = true)
 |-- volatile: double (nullable = true)
 |-- citric: double (nullable = true)
 |-- sugar: double (nullable = true)
 |-- chlorides: double (nullable = true)
 |-- free: double (nullable = true)
 |-- total: double (nullable = true)
 |-- density: double (nullable = true)
 |-- pH: double (nullable = true)
 |-- sulphates: double (nullable = true)
 |-- alcohol: double (nullable = true)
 |-- quality: string (nullable = true)

```

3. Deal with categorical data and Convert the data to dense vector

Note: You are strongly encouraged to try my `get_dummy` function for dealing with the categorical data in complex dataset.

Supervised learning version:

```

def get_dummy(df, indexCol, categoricalCols, continuousCols, labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

```

```

indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
             for c in categoricalCols ]

# default setting: dropLast=True
encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                            outputCol="{0}_encoded".format(indexer.getOutputCol()))
              for indexer in indexers ]

assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                         + continuousCols, outputCol="features"])

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

data = data.withColumn('label', col(labelCol))

return data.select(indexCol,'features','label')

```

Unsupervised learning version:

```

def get_dummy(df,indexCol,categoricalCols,continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learning
    :param df: the dataframe
    :param categoricalCols: the name list of the categorical data
    :param continuousCols: the name list of the numerical data
    :return k: feature matrix

    :author: Wenqiang Feng
    :email: von198@gmail.com
    """

indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
             for c in categoricalCols ]

# default setting: dropLast=True
encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                            outputCol="{0}_encoded".format(indexer.getOutputCol()))
              for indexer in indexers ]

assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                         + continuousCols, outputCol="features"])

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

return data.select(indexCol,'features')

```

```
def get_dummy(df,categoricalCols,continuousCols,labelCol):
```

```

from pyspark.ml import Pipeline
from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
from pyspark.sql.functions import col

```

```

indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
             for c in categoricalCols ]

# default setting: dropLast=True
encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                            outputCol="{0}_encoded".format(indexer.getOutputCol()))
              for indexer in indexers ]

assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders]
                            + continuousCols, outputCol="features")

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

data = data.withColumn('label', col(labelCol))

return data.select('features','label')

```

4. Transform the dataset to DataFrame

```

from pyspark.ml.linalg import Vectors # !!!!caution: not from pyspark.mllib.linalg import Vectors
from pyspark.ml import Pipeline
from pyspark.ml.feature import IndexToString, StringIndexer, VectorIndexer
from pyspark.ml.tuning import CrossValidator, ParamGridBuilder
from pyspark.ml.evaluation import MulticlassClassificationEvaluator

def transData(data):
    return data.rdd.map(lambda r: [Vectors.dense(r[:-1]),r[-1]]).toDF(['features','label'])

transformed = transData(df)
transformed.show(5)

+-----+-----+
|      features|label |
+-----+-----+
|[7.4,0.7,0.0,1.9,...| low |
|[7.8,0.88,0.0,2.6...| low |
|[7.8,0.76,0.04,2....| low |
|[11.2,0.28,0.56,1...| low |
|[7.4,0.7,0.0,1.9,...| low |
+-----+-----+
only showing top 5 rows

```

4. Deal with Categorical Label and Variables

```

# Index labels, adding metadata to the label column
labelIndexer = StringIndexer(inputCol='label',
                             outputCol='indexedLabel').fit(transformed)
labelIndexer.transform(transformed).show(5, True)

+-----+-----+-----+
|      features|label|indexedLabel |
+-----+-----+-----+
|[7.4,0.7,0.0,1.9,...| low | 0.0 |
|[7.8,0.88,0.0,2.6...| low | 0.0 |
|[7.8,0.76,0.04,2....| low | 0.0 |

```

```

| [11.2,0.28,0.56,1...| low| 0.0|
| [7.4,0.7,0.0,1.9,...| low| 0.0|
+-----+-----+-----+
only showing top 5 rows

# Automatically identify categorical features, and index them.
# Set maxCategories so features with > 4 distinct values are treated as continuous.
featureIndexer =VectorIndexer(inputCol="features", \
                               outputCol="indexedFeatures", \
                               maxCategories=4).fit(transformed)
featureIndexer.transform(transformed).show(5, True)

+-----+-----+-----+
| features|label| indexedFeatures|
+-----+-----+-----+
| [7.4,0.7,0.0,1.9,...| low| [7.4,0.7,0.0,1.9,...|
| [7.8,0.88,0.0,2.6...| low| [7.8,0.88,0.0,2.6...|
| [7.8,0.76,0.04,2....| low| [7.8,0.76,0.04,2....|
| [11.2,0.28,0.56,1...| low| [11.2,0.28,0.56,1...|
| [7.4,0.7,0.0,1.9,...| low| [7.4,0.7,0.0,1.9,...|
+-----+-----+-----+
only showing top 5 rows

```

5. Split the data to training and test data sets

```

# Split the data into training and test sets (40% held out for testing)
(trainingData, testData) = data.randomSplit([0.6, 0.4])

trainingData.show(5, False)
testData.show(5, False)

+-----+-----+
| features | label |
+-----+-----+
| [5.0,0.38,0.01,1.6,0.048,26.0,60.0,0.99084,3.7,0.75,14.0]|low  |
| [5.0,0.42,0.24,2.0,0.06,19.0,50.0,0.9917,3.72,0.74,14.0] |high |
| [5.0,0.74,0.0,1.2,0.041,16.0,46.0,0.99258,4.01,0.59,12.5] |low  |
| [5.0,1.02,0.04,1.4,0.045,41.0,85.0,0.9938,3.75,0.48,10.5] |low  |
| [5.0,1.04,0.24,1.6,0.05,32.0,96.0,0.9934,3.74,0.62,11.5] |low  |
+-----+-----+
only showing top 5 rows

+-----+-----+
| features | label |
+-----+-----+
| [4.6,0.52,0.15,2.1,0.054,8.0,65.0,0.9934,3.9,0.56,13.1] |low  |
| [4.7,0.6,0.17,2.3,0.058,17.0,106.0,0.9932,3.85,0.6,12.9] |low  |
| [4.9,0.42,0.0,2.1,0.048,16.0,42.0,0.99154,3.71,0.74,14.0] |high |
| [5.0,0.4,0.5,4.3,0.046,29.0,80.0,0.9902,3.49,0.66,13.6] |low  |
| [5.2,0.49,0.26,2.3,0.09,23.0,74.0,0.9953,3.71,0.62,12.2] |low  |
+-----+-----+
only showing top 5 rows

```

6. Fit Naive Bayes Classification Model

```

from pyspark.ml.classification import NaiveBayes
nb = NaiveBayes(featuresCol='indexedFeatures', labelCol='indexedLabel')

```

7. Pipeline Architecture

```
# Convert indexed labels back to original labels.
labelConverter = IndexToString(inputCol="prediction", outputCol="predictedLabel",
                                labels=labelIndexer.labels)

# Chain indexers and tree in a Pipeline
pipeline = Pipeline(stages=[labelIndexer, featureIndexer, nb, labelConverter])

# Train model. This also runs the indexers.
model = pipeline.fit(trainingData)
```

8. Make predictions

```
# Make predictions.
predictions = model.transform(testData)
# Select example rows to display.
predictions.select("features", "label", "predictedLabel").show(5)

+-----+-----+-----+
|       features|label|predictedLabel|
+-----+-----+-----+
|[4.6,0.52,0.15,2....| low| low|
|[4.7,0.6,0.17,2.3...| low| low|
|[4.9,0.42,0.0,2.1...| high| low|
|[5.0,0.4,0.5,4.3,...| low| low|
|[5.2,0.49,0.26,2....| low| low|
+-----+-----+-----+
only showing top 5 rows
```

9. Evaluation

```
from pyspark.ml.evaluation import MulticlassClassificationEvaluator

# Select (prediction, true label) and compute test error
evaluator = MulticlassClassificationEvaluator(
    labelCol="indexedLabel", predictionCol="prediction", metricName="accuracy")
accuracy = evaluator.evaluate(predictions)
print("Test Error = %g" % (1.0 - accuracy))

Test Error = 0.307339

lrModel = model.stages[2]
trainingSummary = lrModel.summary

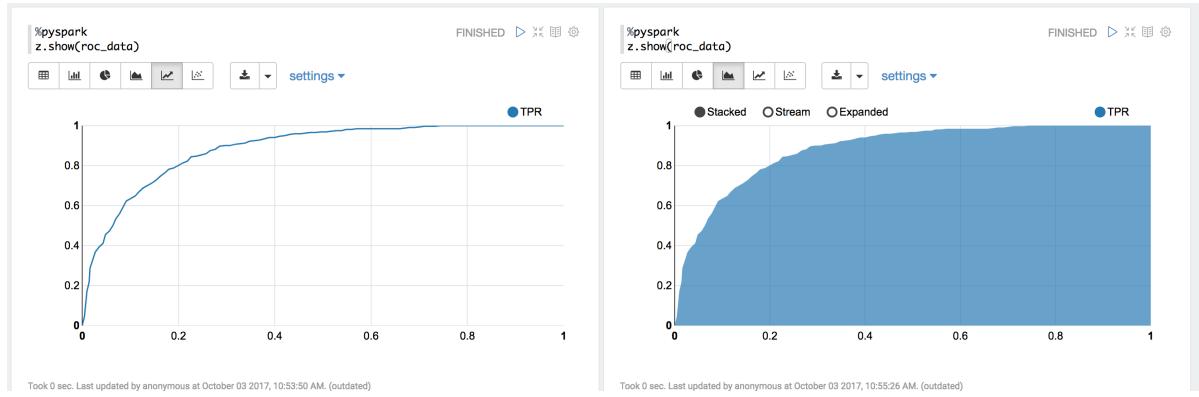
# Obtain the objective per iteration
# objectiveHistory = trainingSummary.objectiveHistory
# print("objectiveHistory:")
# for objective in objectiveHistory:
#     print(objective)

# Obtain the receiver-operating characteristic as a dataframe and areaUnderROC.
trainingSummary.roc.show(5)
print("areaUnderROC: " + str(trainingSummary.areaUnderROC))

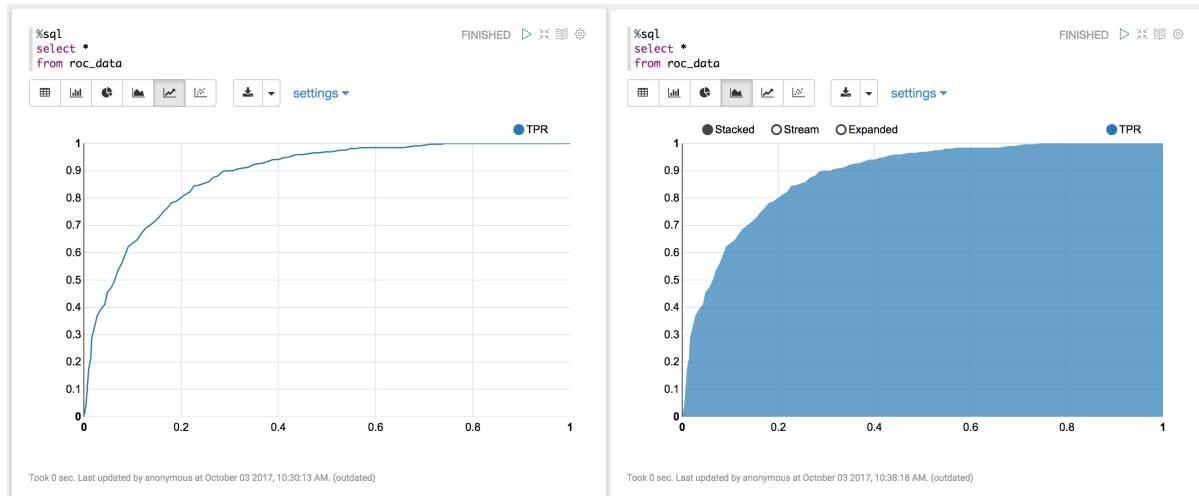
# Set the model threshold to maximize F-Measure
fMeasure = trainingSummary.fMeasureByThreshold
maxFMeasure = fMeasure.groupBy().max('F-Measure').select('max(F-Measure)').head(5)
```

```
# bestThreshold = fMeasure.where(fMeasure['F-Measure'] == maxFMeasure['max(F-Measure)'])
#     .select('threshold').head()['threshold']
# lr.setThreshold(bestThreshold)
```

You can use `z.show()` to get the data and plot the ROC curves:



You can also register a TempTable `data.registerTempTable('roc_data')` and then use `sql` to plot the ROC curve:



10. visualization

```
import matplotlib.pyplot as plt
import numpy as np
import itertools

def plot_confusion_matrix(cm, classes,
                        normalize=False,
                        title='Confusion matrix',
                        cmap=plt.cm.Blues):
    """
    This function prints and plots the confusion matrix.
    Normalization can be applied by setting 'normalize=True'.
    """
    if normalize:
        cm = cm.astype('float') / cm.sum(axis=1)[:, np.newaxis]
        print("Normalized confusion matrix")
    else:
        print('Confusion matrix, without normalization')

    plt.imshow(cm, interpolation='nearest', cmap=cmap)
    plt.title(title)
    plt.colorbar()
    tick_marks = np.arange(len(classes))
    plt.xticks(tick_marks, classes, rotation=45)
    plt.yticks(tick_marks, classes)

    plt.tight_layout()
    plt.ylabel('True label')
    plt.xlabel('Predicted label')
```

```

print('Confusion matrix, without normalization')

print(cm)

plt.imshow(cm, interpolation='nearest', cmap=cmap)
plt.title(title)
plt.colorbar()
tick_marks = np.arange(len(classes))
plt.xticks(tick_marks, classes, rotation=45)
plt.yticks(tick_marks, classes)

fmt = '.2f' if normalize else 'd'
thresh = cm.max() / 2.
for i, j in itertools.product(range(cm.shape[0]), range(cm.shape[1])):
    plt.text(j, i, format(cm[i, j], fmt),
              horizontalalignment="center",
              color="white" if cm[i, j] > thresh else "black")

plt.tight_layout()
plt.ylabel('True label')
plt.xlabel('Predicted label')

class_temp = predictions.select("label").groupBy("label") \
    .count().sort('count', ascending=False).toPandas()
class_temp = class_temp["label"].values.tolist()
class_names = map(str, class_temp)
# # print(class_name)
class_names

['low', 'high']

from sklearn.metrics import confusion_matrix
y_true = predictions.select("label")
y_true = y_true.toPandas()

y_pred = predictions.select("predictedLabel")
y_pred = y_pred.toPandas()

cnf_matrix = confusion_matrix(y_true, y_pred, labels=class_names)
cnf_matrix

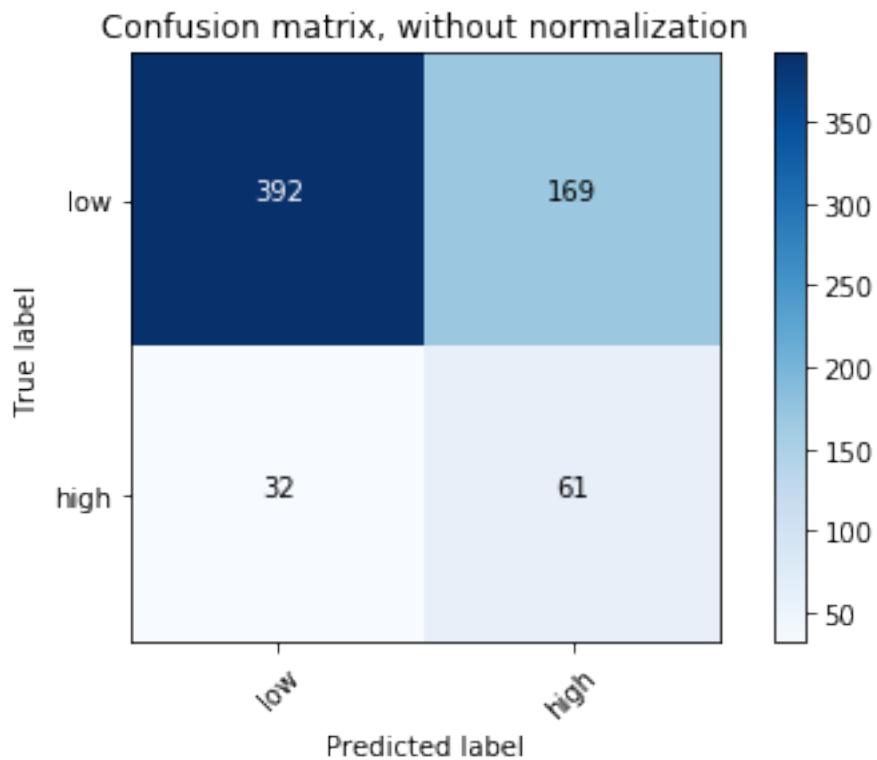
array([[392, 169],
       [ 32,  61]])

# Plot non-normalized confusion matrix
plt.figure()
plot_confusion_matrix(cnf_matrix, classes=class_names,
                      title='Confusion matrix, without normalization')
plt.show()

Confusion matrix, without normalization
[[392 169]
 [ 32  61]]

# Plot normalized confusion matrix
plt.figure()
plot_confusion_matrix(cnf_matrix, classes=class_names, normalize=True,

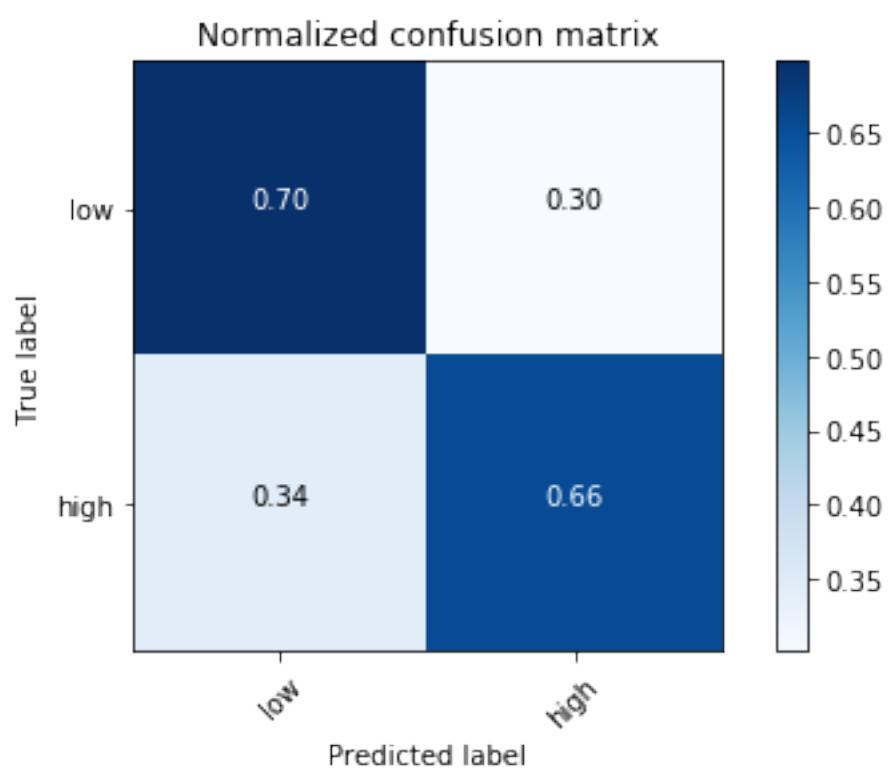
```



```
title='Normalized confusion matrix')

plt.show()

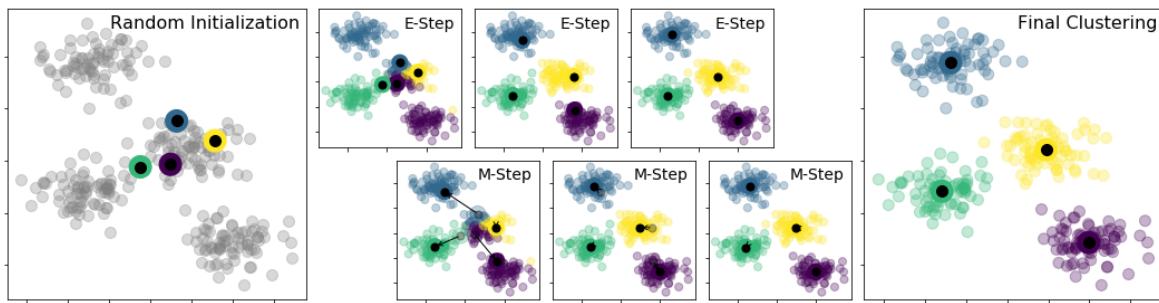
Normalized confusion matrix
[[0.69875223  0.30124777]
 [0.34408602  0.65591398]]
```



CLUSTERING

Chinese proverb

Sharpening the knife longer can make it easier to hack the firewood – old Chinese proverb



The above figure was generated by the code from: Python Data Science Handbook.

11.1 K-Means Model

11.1.1 Introduction

11.1.2 Demo

1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark K-means example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
```

2. Load dataset

```
df = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', \
            inferschema='true') \
    .load("../data/iris.csv", header=True);
```

check the data set

```
df.show(5, True)
df.printSchema()
```

Then you will get

```
+-----+-----+-----+-----+
| sepal_length | sepal_width | petal_length | petal_width | species |
+-----+-----+-----+-----+
|      5.1 |      3.5 |      1.4 |      0.2 | setosa |
|      4.9 |      3.0 |      1.4 |      0.2 | setosa |
|      4.7 |      3.2 |      1.3 |      0.2 | setosa |
|      4.6 |      3.1 |      1.5 |      0.2 | setosa |
|      5.0 |      3.6 |      1.4 |      0.2 | setosa |
+-----+-----+-----+-----+
only showing top 5 rows
```

```
root
|-- sepal_length: double (nullable = true)
|-- sepal_width: double (nullable = true)
|-- petal_length: double (nullable = true)
|-- petal_width: double (nullable = true)
|-- species: string (nullable = true)
```

You can also get the Statistical results from the data frame (Unfortunately, it only works for numerical).

```
df.describe().show()
```

Then you will get

```
+-----+-----+-----+-----+
| summary | sepal_length | sepal_width | petal_length | petal_width |
+-----+-----+-----+-----+
| count | 150 | 150 | 150 | 150 |
| mean | 5.843333333333335 | 3.054000000000007 | 3.7586666666666693 | 1.198666666666672 |
| stddev | 0.8280661279778637 | 0.43359431136217375 | 1.764420419952262 | 0.7631607417008414 |
| min | 4.3 | 2.0 | 1.0 | 0.1 |
| max | 7.9 | 4.4 | 6.9 | 2.5 |
+-----+-----+-----+-----+
```

3. Convert the data to dense vector (**features**)

```
# convert the data to dense vector
def transData(data):
    return data.rdd.map(lambda r: [Vectors.dense(r[:-1])]).toDF(['features'])
```

Note: You are strongly encouraged to try my `get_dummy` function for dealing with the categorical data in complex dataset.

Supervised learning version:

```
def get_dummy(df, indexCol, categoricalCols, continuousCols, labelCol):

    from pyspark.ml import Pipeline
    from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
    from pyspark.sql.functions import col

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]
```

```

# default setting: dropLast=True
encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                            outputCol="{0}_encoded".format(indexer.getOutputCol()))
             for indexer in indexers ]

assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                       + continuousCols, outputCol="features"])

pipeline = Pipeline(stages=indexers + encoders + [assembler])

model=pipeline.fit(df)
data = model.transform(df)

data = data.withColumn('label', col(labelCol))

return data.select(indexCol,'features','label')

```

Unsupervised learning version:

```

def get_dummy(df,indexCol,categoricalCols,continuousCols):
    """
    Get dummy variables and concat with continuous variables for unsupervised learning
    :param df: the dataframe
    :param categoricalCols: the name list of the categorical data
    :param continuousCols: the name list of the numerical data
    :return k: feature matrix

    :author: Wenqiang Feng
    :email: von198@gmail.com
    """

    indexers = [ StringIndexer(inputCol=c, outputCol="{0}_indexed".format(c))
                 for c in categoricalCols ]

    # default setting: dropLast=True
    encoders = [ OneHotEncoder(inputCol=indexer.getOutputCol(),
                                outputCol="{0}_encoded".format(indexer.getOutputCol()))
                 for indexer in indexers ]

    assembler = VectorAssembler(inputCols=[encoder.getOutputCol() for encoder in encoders
                                           + continuousCols, outputCol="features"])

    pipeline = Pipeline(stages=indexers + encoders + [assembler])

    model=pipeline.fit(df)
    data = model.transform(df)

    return data.select(indexCol,'features')

```

4. Transform the dataset to DataFrame

```

transformed= transData(df)
transformed.show(5, False)

+-----+
| features |
+-----+

```

```
| [5.1,3.5,1.4,0.2] |
| [4.9,3.0,1.4,0.2] |
| [4.7,3.2,1.3,0.2] |
| [4.6,3.1,1.5,0.2] |
| [5.0,3.6,1.4,0.2] |
+-----+
only showing top 5 rows
```

5. Deal With Categorical Variables

```
from pyspark.ml import Pipeline
from pyspark.ml.regression import LinearRegression
from pyspark.ml.feature import VectorIndexer
from pyspark.ml.evaluation import RegressionEvaluator

# Automatically identify categorical features, and index them.
# We specify maxCategories so features with > 4 distinct values are treated as continuous

featureIndexer = VectorIndexer(inputCol="features", \
                                outputCol="indexedFeatures", \
                                maxCategories=4).fit(transformed)

data = featureIndexer.transform(transformed)
```

Now you check your dataset with

```
data.show(5, True)
```

you will get

```
+-----+-----+
|       features| indexedFeatures|
+-----+-----+
| [5.1,3.5,1.4,0.2] | [5.1,3.5,1.4,0.2] |
| [4.9,3.0,1.4,0.2] | [4.9,3.0,1.4,0.2] |
| [4.7,3.2,1.3,0.2] | [4.7,3.2,1.3,0.2] |
| [4.6,3.1,1.5,0.2] | [4.6,3.1,1.5,0.2] |
| [5.0,3.6,1.4,0.2] | [5.0,3.6,1.4,0.2] |
+-----+
only showing top 5 rows
```

6. Elbow method to determine the optimal number of clusters for k-means clustering

```
import numpy as np
cost = np.zeros(20)
for k in range(2,20):
    kmeans = KMeans() \
        .setK(k) \
        .setSeed(1) \
        .setFeaturesCol("indexedFeatures") \
        .setPredictionCol("cluster")

    model = kmeans.fit(data)
    cost[k] = model.computeCost(data) # requires Spark 2.0 or later

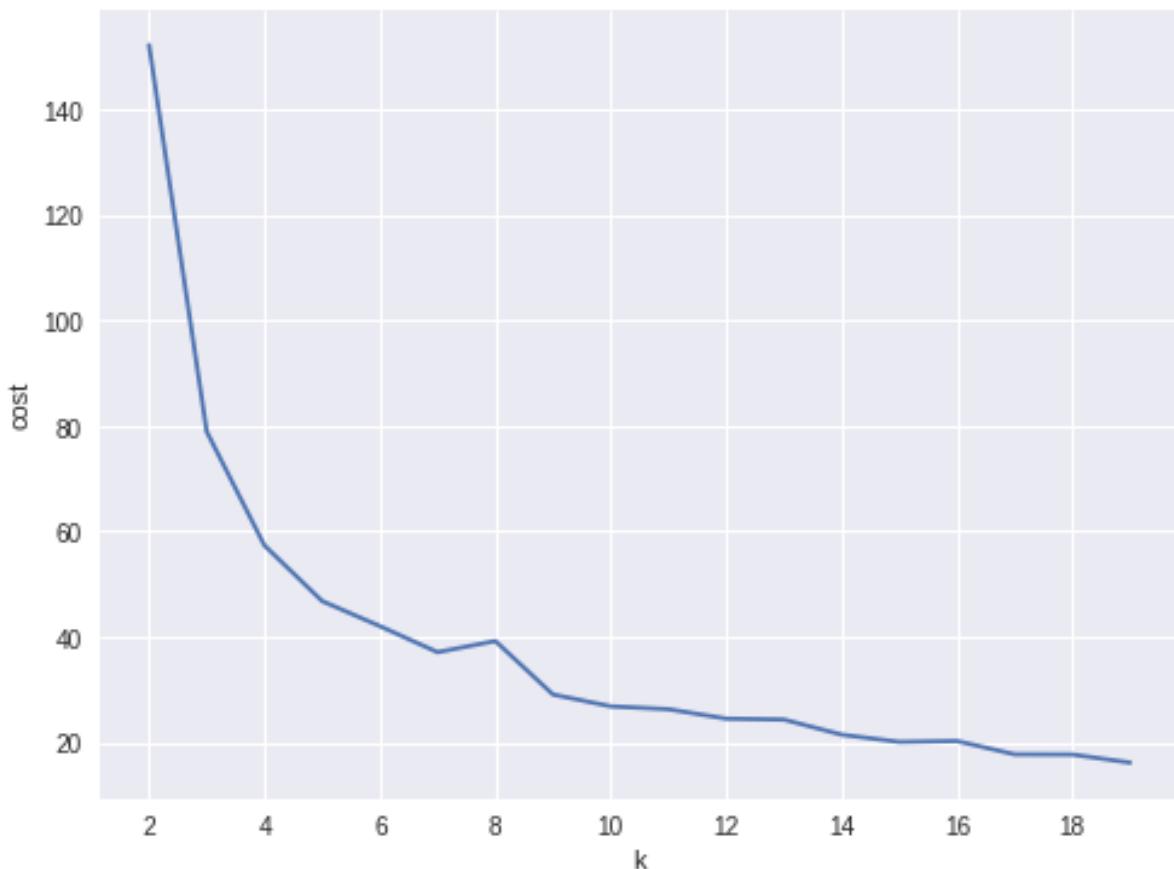
import numpy as np
import matplotlib.mlab as mlab
import matplotlib.pyplot as plt
```

```

import seaborn as sns
from matplotlib.ticker import MaxNLocator

fig, ax = plt.subplots(1,1, figsize=(8,6))
ax.plot(range(2,20),cost[2:20])
ax.set_xlabel('k')
ax.set_ylabel('cost')
ax.xaxis.set_major_locator(MaxNLocator(integer=True))
plt.show()

```



In my opinion, sometimes it's hard to choose the optimal number of the clusters by using the elbow method. As shown in the following Figure, you can choose 3, 5 or even 8. I will choose 3 in this demo.

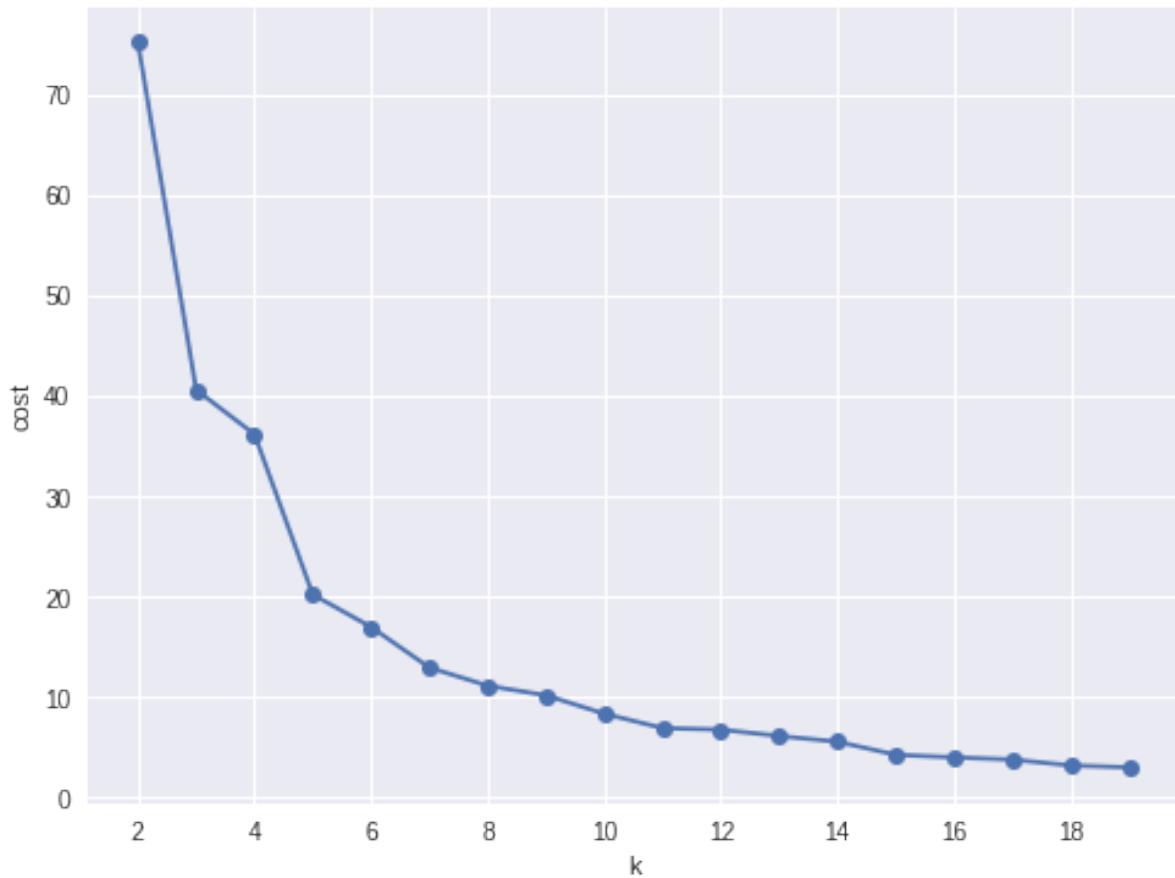
- Silhouette analysis

```

#PySpark libraries
from pyspark.ml import Pipeline
from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
from pyspark.sql.functions import col, percent_rank, lit
from pyspark.sql.window import Window
from pyspark.sql import DataFrame, Row
from pyspark.sql.types import StructType
from functools import reduce # For Python 3.x

from pyspark.ml.clustering import KMeans
from pyspark.ml.evaluation import ClusteringEvaluator

```



```
def optimal_k(df_in, index_col, k_min, k_max, num_runs):
    """
    Determine optimal number of clusters by using Silhouette Score Analysis.
    :param df_in: the input dataframe
    :param index_col: the name of the index column
    :param k_min: the train dataset
    :param k_min: the minimum number of the clusters
    :param k_max: the maximum number of the clusters
    :param num_runs: the number of runs for each fixed clusters

    :return k: optimal number of the clusters
    :return silh_lst: Silhouette score
    :return r_table: the running results table

    :author: Wenqiang Feng
    :email: WFeng@dstsystems.com
    """

    start = time.time()
    silh_lst = []
    k_lst = np.arange(k_min, k_max+1)

    r_table = df_in.select(index_col).toPandas()
    r_table = r_table.set_index(index_col)
    centers = pd.DataFrame()

    for k in k_lst:
```

```

silh_val = []
for run in np.arange(1, num_runs+1):

    # Trains a k-means model.
    kmeans = KMeans() \
        .setK(k) \
        .setSeed(int(np.random.randint(100, size=1)))
    model = kmeans.fit(df_in)

    # Make predictions
    predictions = model.transform(df_in)
    r_table['cluster_{k}_{run}'.format(k=k, run=run)] = predictions.select('predi

    # Evaluate clustering by computing Silhouette score
    evaluator = ClusteringEvaluator()
    silhouette = evaluator.evaluate(predictions)
    silh_val.append(silhouette)

    silh_array=np.asarray(silh_val)
    silh_lst.append(silh_array.mean())

elapsed = time.time() - start

silhouette = pd.DataFrame(list(zip(k_lst,silh_lst)),columns = ['k', 'silhouette'])

print('+'-----+')
print("|       The finding optimal k phase took %8.0f s.      |" %(elapsed))
print('+'-----+')

return k_lst[np.argmax(silh_lst, axis=0)], silhouette , r_table

```

k, silh_lst, r_table = optimal_k(scaledData,index_col,k_min, k_max,num_runs)

```

+-----+
|       The finding optimal k phase took      1783 s.      |
+-----+

```

```

spark.createDataFrame(silh_lst).show()

+---+-----+
|   k|      silhouette|
+---+-----+
| 3|0.8045154385557953|
| 4|0.6993528775512052|
| 5|0.6689286654221447|
| 6|0.6356184024841809|
| 7|0.7174102265711756|
| 8|0.6720861758298997|
| 9| 0.601771359881241|
| 10|0.6292447334578428|
+---+-----+

```

From the silhouette list, we can choose 3 as the optimal number of the clusters.

Warning: ClusteringEvaluator in pyspark.ml.evaluation requires Spark 2.4 or later!!

7. Pipeline Architecture

```
from pyspark.ml.clustering import KMeans, KMeansModel

kmeans = KMeans() \
    .setK(3) \
    .setFeaturesCol("indexedFeatures") \
    .setPredictionCol("cluster")

# Chain indexer and tree in a Pipeline
pipeline = Pipeline(stages=[featureIndexer, kmeans])

model = pipeline.fit(transformed)

cluster = model.transform(transformed)
```

8. k-means clusters

```
cluster = model.transform(transformed)

+-----+-----+-----+
|      features| indexedFeatures|cluster|
+-----+-----+-----+
| [5.1,3.5,1.4,0.2]| [5.1,3.5,1.4,0.2] | 1 |
| [4.9,3.0,1.4,0.2]| [4.9,3.0,1.4,0.2] | 1 |
| [4.7,3.2,1.3,0.2]| [4.7,3.2,1.3,0.2] | 1 |
| [4.6,3.1,1.5,0.2]| [4.6,3.1,1.5,0.2] | 1 |
| [5.0,3.6,1.4,0.2]| [5.0,3.6,1.4,0.2] | 1 |
| [5.4,3.9,1.7,0.4]| [5.4,3.9,1.7,0.4] | 1 |
| [4.6,3.4,1.4,0.3]| [4.6,3.4,1.4,0.3] | 1 |
| [5.0,3.4,1.5,0.2]| [5.0,3.4,1.5,0.2] | 1 |
| [4.4,2.9,1.4,0.2]| [4.4,2.9,1.4,0.2] | 1 |
| [4.9,3.1,1.5,0.1]| [4.9,3.1,1.5,0.1] | 1 |
| [5.4,3.7,1.5,0.2]| [5.4,3.7,1.5,0.2] | 1 |
| [4.8,3.4,1.6,0.2]| [4.8,3.4,1.6,0.2] | 1 |
| [4.8,3.0,1.4,0.1]| [4.8,3.0,1.4,0.1] | 1 |
| [4.3,3.0,1.1,0.1]| [4.3,3.0,1.1,0.1] | 1 |
| [5.8,4.0,1.2,0.2]| [5.8,4.0,1.2,0.2] | 1 |
| [5.7,4.4,1.5,0.4]| [5.7,4.4,1.5,0.4] | 1 |
| [5.4,3.9,1.3,0.4]| [5.4,3.9,1.3,0.4] | 1 |
| [5.1,3.5,1.4,0.3]| [5.1,3.5,1.4,0.3] | 1 |
| [5.7,3.8,1.7,0.3]| [5.7,3.8,1.7,0.3] | 1 |
| [5.1,3.8,1.5,0.3]| [5.1,3.8,1.5,0.3] | 1 |
+-----+-----+-----+
only showing top 20 rows
```

**CHAPTER
TWELVE**

RFM ANALYSIS

Segment	RFM	Description	Marketing
Best Customers	111	Bought most recently and most often, and spend the most	No price incentives, new products, and loyalty programs
Loyal Customers	X1X	Buy most frequently	Use R and M to further segment
Big Spenders	XX1	Spend the most	Market your most expensive products
Almost Lost	311	Haven't purchased for some time, but purchased frequently and spend the most	Aggressive price incentives
Lost Customers	411	Haven't purchased for some time, but purchased frequently and spend the most	Aggressive price incentives
Lost Cheap Customers	444	Last purchased long ago, purchased few, and spent little	Don't spend too much trying to re-acquire

The above figure source: Blast Analytics Marketing

RFM is a method used for analyzing customer value. It is commonly used in database marketing and direct marketing and has received particular attention in retail and professional services industries. More details can be found at Wikipedia [RFM_wikipedia](#).

RFM stands for the three dimensions:

- Recency – How recently did the customer purchase? i.e. Duration since last purchase
- Frequency – How often do they purchase? i.e. Total number of purchases

- Monetary Value – How much do they spend? i.e. Total money this customer spent

12.1 RFM Analysis Methodology

RFM Analysis contains three main steps:

12.1.1 1. Build the RFM features matrix for each customer

```
+-----+-----+-----+-----+
|CustomerID|Recency|Frequency| Monetary |
+-----+-----+-----+-----+
| 14911 |     1 |      248 | 132572.62 |
| 12748 |     0 |      224 |  29072.1 |
| 17841 |     1 |      169 | 40340.78 |
| 14606 |     1 |      128 | 11713.85 |
| 15311 |     0 |      118 | 59419.34 |
+-----+-----+-----+-----+
only showing top 5 rows
```

12.1.2 2. Determine cutting points for each feature

```
+-----+-----+-----+-----+-----+-----+
|CustomerID|Recency|Frequency|Monetary|r_seg|f_seg|m_seg|
+-----+-----+-----+-----+-----+-----+
| 17420 |    50 |      3 |  598.83 |    2 |    3 |    2 |
| 16861 |    59 |      3 |  151.65 |    3 |    3 |    1 |
| 16503 |   106 |      5 | 1421.43 |    3 |    2 |    3 |
| 15727 |    16 |      7 | 5178.96 |    1 |    1 |    4 |
| 17389 |     0 |     43 | 31300.08 |    1 |    1 |    4 |
+-----+-----+-----+-----+-----+-----+
only showing top 5 rows
```

12.1.3 3. Determine the RFM scores and summarize the corresponding business value

```
+-----+-----+-----+-----+-----+-----+-----+
|CustomerID|Recency|Frequency|Monetary|r_seg|f_seg|m_seg|RFMScore|
+-----+-----+-----+-----+-----+-----+-----+
| 17988 |    11 |      8 | 191.17 |    1 |    1 |    1 |    111 |
| 16892 |     1 |      7 | 496.84 |    1 |    1 |    2 |    112 |
| 16668 |    15 |      6 | 306.72 |    1 |    1 |    2 |    112 |
| 16554 |     3 |      7 | 641.55 |    1 |    1 |    2 |    112 |
| 16500 |     4 |      6 | 400.86 |    1 |    1 |    2 |    112 |
+-----+-----+-----+-----+-----+-----+-----+
only showing top 5 rows
```

The corresponding business description and marketing value:

Segment	RFM	Description	Marketing
Best Customers	111	Bought most recently and most often, and spend the most	No price incentives, new products, and loyalty programs
Loyal Customers	X1X	Buy most frequently	Use R and M to further segment
Big Spenders	XX1	Spend the most	Market your most expensive products
Almost Lost	311	Haven't purchased for some time, but purchased frequently and spend the most	Aggressive price incentives
Lost Customers	411	Haven't purchased for some time, but purchased frequently and spend the most	Aggressive price incentives
Lost Cheap Customers	444	Last purchased long ago, purchased few, and spent little	Don't spend too much trying to re-acquire

Figure 12.1: Source: Blast Analytics Marketing

12.2 Demo

- The Jupyter notebook can be download from Data Exploration.
- The data can be downloaf from German Credit.

12.2.1 Load and clean data

1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark RFM example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
```

2. Load dataset

```
df_raw = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', \
             inferschema='true') \
    .load("Online Retail.csv", header=True);
```

check the data set

```
df_raw.show(5)
df_raw.printSchema()
```

Then you will get

InvoiceNo	StockCode	Description	Quantity	InvoiceDate	UnitPrice	CustomerID	Country
536365	85123A	WHITE HANGING HEA...	6	12/1/10 8:26	2.55	17850	United Kingdom
536365	71053	WHITE METAL LANTERN	6	12/1/10 8:26	3.39	17850	United Kingdom
536365	84406B	CREAM CUPID HEART...	8	12/1/10 8:26	2.75	17850	United Kingdom
536365	84029G	KNITTED UNION FLA...	6	12/1/10 8:26	3.39	17850	United Kingdom
536365	84029E	RED WOOLLY HOTTIE...	6	12/1/10 8:26	3.39	17850	United Kingdom

only showing top 5 rows

```
root
|-- InvoiceNo: string (nullable = true)
|-- StockCode: string (nullable = true)
|-- Description: string (nullable = true)
|-- Quantity: integer (nullable = true)
|-- InvoiceDate: string (nullable = true)
|-- UnitPrice: double (nullable = true)
|-- CustomerID: integer (nullable = true)
|-- Country: string (nullable = true)
```

3. Data clean and data manipulation

- check and remove the null values

```

from pyspark.sql.functions import count

def my_count(df_in):
    df_in.agg( *[ count(c).alias(c) for c in df_in.columns ] ).show()

my_count(df_raw)

+-----+-----+-----+-----+-----+-----+-----+
| InvoiceNo| StockCode| Description| Quantity| InvoiceDate| UnitPrice| CustomerID| Country|
+-----+-----+-----+-----+-----+-----+-----+
| 541909| 541909| 540455| 541909| 541909| 541909| 406829| 541909|
+-----+-----+-----+-----+-----+-----+-----+

```

Since the count results are not the same, we have some null value in the CustomerID column. We can drop these records from the dataset.

```

df = df_raw.dropna(how='any')
my_count(df)

+-----+-----+-----+-----+-----+-----+
| InvoiceNo| StockCode| Description| Quantity| InvoiceDate| UnitPrice| CustomerID| Country|
+-----+-----+-----+-----+-----+-----+
| 406829| 406829| 406829| 406829| 406829| 406829| 406829| 406829|
+-----+-----+-----+-----+-----+-----+

```

- Dealwith the InvoiceDate

```

from pyspark.sql.functions import to_utc_timestamp, unix_timestamp, lit, datediff, col
timeFmt = "MM/dd/yy HH:mm"

df = df.withColumn('NewInvoiceDate',
                   to_utc_timestamp(unix_timestamp(col('InvoiceDate'), timeFmt).cast('timestamp'),
                                    'UTC'))

df.show(5)

+-----+-----+-----+-----+-----+-----+
| InvoiceNo| StockCode| Description| Quantity| InvoiceDate| UnitPrice| CustomerID| Country|
+-----+-----+-----+-----+-----+-----+
| 536365| 85123A| WHITE HANGING HEA...| 6| 12/1/10 8:26| 2.55| 17850| Uni...
| 536365| 71053| WHITE METAL LANTERN| 6| 12/1/10 8:26| 3.39| 17850| Uni...
| 536365| 84406B| CREAM CUPID HEART...| 8| 12/1/10 8:26| 2.75| 17850| Uni...
| 536365| 84029G| KNITTED UNION FLA...| 6| 12/1/10 8:26| 3.39| 17850| Uni...
| 536365| 84029E| RED WOOLLY HOTTIE...| 6| 12/1/10 8:26| 3.39| 17850| Uni...
+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

```

Warning: The spark is pretty sensitive to the date format!

- calculate total price

```

from pyspark.sql.functions import round

df = df.withColumn('TotalPrice', round(df.Quantity * df.UnitPrice, 2))

• calculate the time difference

```

```

from pyspark.sql.functions import mean, min, max, sum, datediff, to_date

date_max = df.select(max('NewInvoiceDate')).toPandas()
current = to_utc_timestamp(unix_timestamp(lit(str(date_max.iloc[0][0]))), \
                           'yy-MM-dd HH:mm').cast('timestamp'), 'UTC')

# Calculate Duration
df = df.withColumn('Duration', datediff(lit(current), 'NewInvoiceDate'))

• build the Recency, Frequency and Monetary

recency = df.groupBy('CustomerID').agg(min('Duration').alias('Recency'))
frequency = df.groupBy('CustomerID', 'InvoiceNo').count() \
    .groupBy('CustomerID') \
    .agg(count('*').alias("Frequency"))
monetary = df.groupBy('CustomerID').agg(round(sum('TotalPrice'), 2).alias('Monetary'))
rfm = recency.join(frequency, 'CustomerID', how = 'inner') \
    .join(monetary, 'CustomerID', how = 'inner')

rfm.show(5)

+-----+-----+-----+-----+
| CustomerID | Recency | Frequency | Monetary |
+-----+-----+-----+-----+
| 17420 | 50 | 3 | 598.83 |
| 16861 | 59 | 3 | 151.65 |
| 16503 | 106 | 5 | 1421.43 |
| 15727 | 16 | 7 | 5178.96 |
| 17389 | 0 | 43 | 31300.08 |
+-----+-----+-----+-----+
only showing top 5 rows

```

12.2.2 RFM Segmentation

4. Determine cutting points

In this section, you can use the techniques (statistical results and visualizations) in *Data Exploration* section to help you determine the cutting points for each attribute. In my opinion, the cutting points are mainly depend on the business sense. You's better talk to your makrtng people and get feedback and suggestion from them. I will use the quantile as the cutting points in this demo.

```

cols = ['Recency', 'Frequency', 'Monetary']
describe_pd(rfm, cols, 1)

+-----+-----+-----+-----+
| summary | Recency | Frequency | Monetary |
+-----+-----+-----+-----+
| count | 4372.0 | 4372.0 | 4372.0 |
| mean | 91.58119853613907 | 5.07548032936871 | 1898.4597003659655 |
| stddev | 100.7721393138483 | 9.338754163574727 | 8219.345141139722 |
| min | 0.0 | 1.0 | -4287.63 |
| max | 373.0 | 248.0 | 279489.02 |
| 25% | 16.0 | 1.0 | 293.36249999999995 |
| 50% | 50.0 | 3.0 | 648.075 |
| 75% | 143.0 | 5.0 | 1611.725 |
+-----+-----+-----+-----+

```

The user defined function by using the cutting points:

```

def RScore(x):
    if x <= 16:
        return 1
    elif x<= 50:
        return 2
    elif x<= 143:
        return 3
    else:
        return 4

def FScore(x):
    if x <= 1:
        return 4
    elif x <= 3:
        return 3
    elif x <= 5:
        return 2
    else:
        return 1

def MScore(x):
    if x <= 293:
        return 4
    elif x <= 648:
        return 3
    elif x <= 1611:
        return 2
    else:
        return 1

from pyspark.sql.functions import udf
from pyspark.sql.types import StringType, DoubleType

R_udf = udf(lambda x: RScore(x), StringType())
F_udf = udf(lambda x: FScore(x), StringType())
M_udf = udf(lambda x: MScore(x), StringType())

```

5. RFM Segmentation

```

rfm_seg = rfm.withColumn("r_seg", R_udf("Recency"))
rfm_seg = rfm_seg.withColumn("f_seg", F_udf("Frequency"))
rfm_seg = rfm_seg.withColumn("m_seg", M_udf("Monetary"))
rfm_seg = rfm_seg.withColumn('RFMScore',
                             F.concat(F.col('r_seg'), F.col('f_seg'), F.col('m_seg')))
rfm_seg.sort(F.col('RFMScore')).show(5)

```

12.2.3 Statistical Summary

6. Statistical Summary

- simple summary

```

rfm_seg.groupBy('RFMScore')\
    .agg({'Recency':'mean',
          'Frequency': 'mean',

```

```

        'Monetary': 'mean' } ) \\
    .sort(F.col('RFMScore')) .show(5)

+-----+-----+-----+-----+
| RFMScore | avg(Recency) | avg(Monetary) | avg(Frequency) |
+-----+-----+-----+-----+
| 111 | 11.0 | 191.17 | 8.0 |
| 112 | 8.0 | 505.9775 | 7.5 |
| 113 | 7.237113402061856 | 1223.3604123711339 | 7.752577319587629 |
| 114 | 6.035123966942149 | 8828.888595041324 | 18.882231404958677 |
| 121 | 9.6 | 207.24 | 4.4 |
+-----+-----+-----+-----+
only showing top 5 rows
    
```

- complex summary

```

grp = 'RFMScore'
num_cols = ['Recency', 'Frequency', 'Monetary']
df_input = rfm_seg

quantile_grouped = quantile_agg(df_input, grp, num_cols)
quantile_grouped.toPandas().to_csv(output_dir+'quantile_grouped.csv')

deciles_grouped = deciles_agg(df_input, grp, num_cols)
deciles_grouped.toPandas().to_csv(output_dir+'deciles_grouped.csv')
    
```

12.3 Extension

You can also apply the K-means clustering in *Clustering* section to do the segmentation.

12.3.1 Build feature matrix

1. build dense feature matrix

```

from pyspark.sql import Row
from pyspark.ml.linalg import Vectors

# method 1 (good for small feature):
#def transData(row):
#    return Row(label=row["Sales"],
#               features=Vectors.dense([row["TV"],
#                                      row["Radio"],
#                                      row["Newspaper"]]))

# Method 2 (good for large features):
def transData(data):
    return data.rdd.map(lambda r: [r[0], Vectors.dense(r[1:])]).toDF(['CustomerID', 'rfm'])

transformed= transData(rfm)
transformed.show(5)
    
```

```

+-----+-----+
| CustomerID | rfm |
+-----+-----+
    
```

```

| 17420 | [50.0,3.0,598.83] |
| 16861 | [59.0,3.0,151.65] |
| 16503 | [106.0,5.0,1421.43] |
| 15727 | [16.0,7.0,5178.96] |
| 17389 | [0.0,43.0,31300.08] |
+-----+
only showing top 5 rows

```

2. Scaler the feature matrix

```

from pyspark.ml.feature import MinMaxScaler

scaler = MinMaxScaler(inputCol="rfm", \
                      outputCol="features")
scalerModel = scaler.fit(transformed)
scaledData = scalerModel.transform(transformed)
scaledData.show(5, False)

+-----+-----+
| CustomerID | rfm | features
+-----+-----+
| 17420 | [50.0,3.0,598.83] | [0.13404825737265416, 0.008097165991902834, 0.017219387148 |
| 16861 | [59.0,3.0,151.65] | [0.1581769436997319, 0.008097165991902834, 0.0156435703924 |
| 16503 | [106.0,5.0,1421.43] | [0.28418230563002683, 0.016194331983805668, 0.020118145731 |
| 15727 | [16.0,7.0,5178.96] | [0.04289544235924933, 0.024291497975708502, 0.033359298589 |
| 17389 | [0.0,43.0,31300.08] | [0.0, 0.1700404858299595, 0.12540746393334334 |
+-----+-----+
only showing top 5 rows

```

12.3.2 K-means clustering

3. Find optimal number of cluster

I will present two popular ways to determine the optimal number of the cluster.

- elbow analysis

```

#PySpark libraries
from pyspark.ml import Pipeline
from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
from pyspark.sql.functions import col, percent_rank, lit
from pyspark.sql.window import Window
from pyspark.sql import DataFrame, Row
from pyspark.sql.types import StructType
from functools import reduce # For Python 3.x

from pyspark.ml.clustering import KMeans
#from pyspark.ml.evaluation import ClusteringEvaluator # requires Spark 2.4 or later

import numpy as np
cost = np.zeros(20)
for k in range(2,20):
    kmeans = KMeans() \
        .setK(k) \
        .setSeed(1) \
        .setFeaturesCol("features") \
        .setPredictionCol("cluster")

```

```

model = kmeans.fit(scaledData)
cost[k] = model.computeCost(scaledData) # requires Spark 2.0 or later

import numpy as np
import matplotlib.mlab as mlab
import matplotlib.pyplot as plt
import seaborn as sns
from matplotlib.ticker import MaxNLocator

fig, ax = plt.subplots(1,1, figsize=(8,6))
ax.plot(range(2,20),cost[2:20], marker = "o")
ax.set_xlabel('k')
ax.set_ylabel('cost')
ax.xaxis.set_major_locator(MaxNLocator(integer=True))
plt.show()
    
```

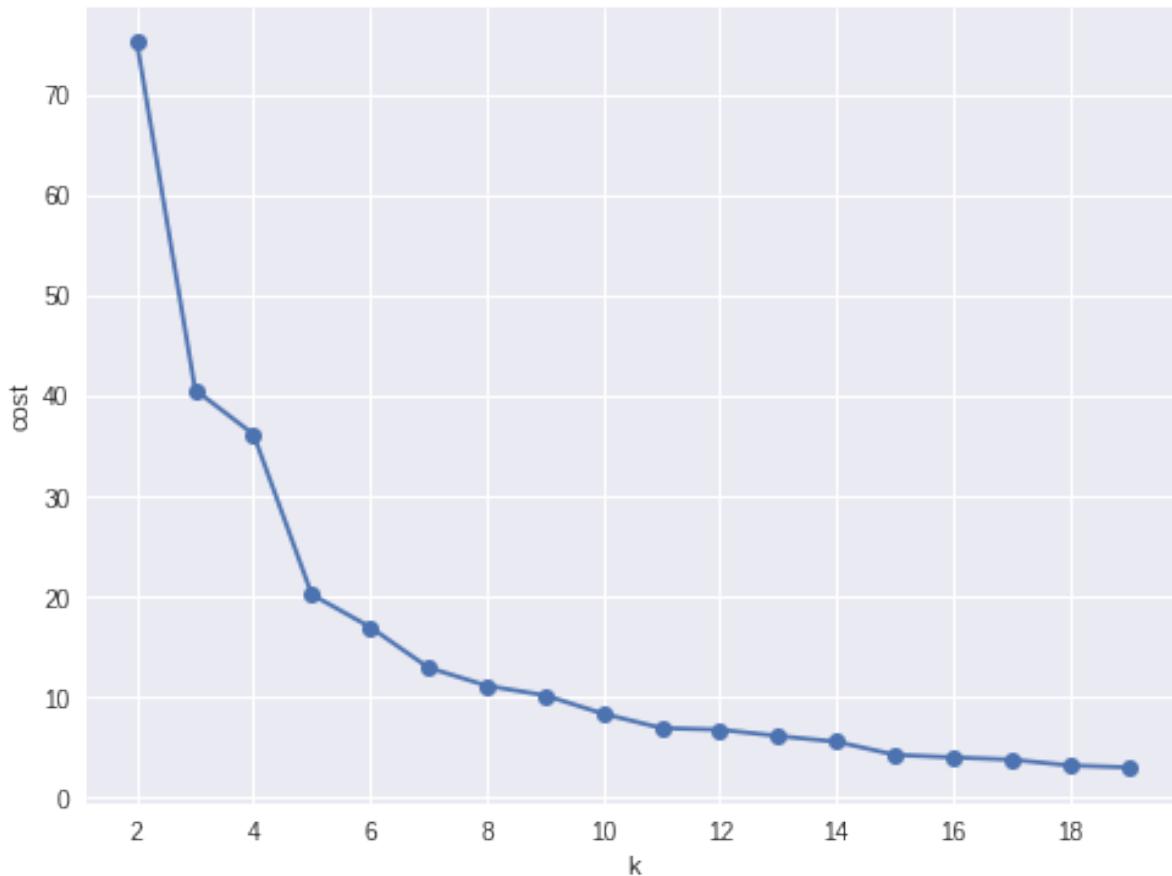


Figure 12.2: Cost v.s. the number of the clusters

In my opinion, sometimes it's hard to choose the number of the clusters. As shown in Figure *Cost v.s. the number of the clusters*, you can choose 3, 5 or even 8. I will choose 3 in this demo.

- Silhouette analysis

```

#PySpark libraries
from pyspark.ml import Pipeline
from pyspark.ml.feature import StringIndexer, OneHotEncoder, VectorAssembler
from pyspark.sql.functions import col, percent_rank, lit
    
```

```

from pyspark.sql.window import Window
from pyspark.sql import DataFrame, Row
from pyspark.sql.types import StructType
from functools import reduce # For Python 3.x

from pyspark.ml.clustering import KMeans
from pyspark.ml.evaluation import ClusteringEvaluator

def optimal_k(df_in,index_col,k_min, k_max,num_runs):
    """
    Determine optimal number of clusters by using Silhouette Score Analysis.
    :param df_in: the input datafram
    :param index_col: the name of the index column
    :param k_min: the train dataset
    :param k_min: the minimum number of the clusters
    :param k_max: the maxmum number of the clusters
    :param num_runs: the number of runs for each fixed clusters

    :return k: optimal number of the clusters
    :return silh_lst: Silhouette score
    :return r_table: the running results table

    :author: Wenqiang Feng
    :email: WFeng@dstsystems.com
    """

    start = time.time()
    silh_lst = []
    k_lst = np.arange(k_min, k_max+1)

    r_table = df_in.select(index_col).toPandas()
    r_table = r_table.set_index(index_col)
    centers = pd.DataFrame()

    for k in k_lst:
        silh_val = []
        for run in np.arange(1, num_runs+1):

            # Trains a k-means model.
            kmeans = KMeans() \
                .setK(k) \
                .setSeed(int(np.random.randint(100, size=1)))
            model = kmeans.fit(df_in)

            # Make predictions
            predictions = model.transform(df_in)
            r_table['cluster_{k}_{run}'.format(k=k, run=run)] = predictions.select('predi')

            # Evaluate clustering by computing Silhouette score
            evaluator = ClusteringEvaluator()
            silhouette = evaluator.evaluate(predictions)
            silh_val.append(silhouette)

        silh_array=np.asarray(silh_val)
        silh_lst.append(silh_array.mean())

    elapsed = time.time() - start

```

```

silhouette = pd.DataFrame(list(zip(k_lst,silh_lst)),columns = ['k', 'silhouette'])

print('-----+')
print("|      The finding optimal k phase took %8.0f s.      |" %(elapsed))
print('-----+')

return k_lst[np.argmax(silh_lst, axis=0)], silhouette , r_table

```

k, silh_lst, r_table = optimal_k(scaledData,index_col,k_min, k_max,num_runs)

```

+-----+
|      The finding optimal k phase took      1783 s.      |
+-----+

```

```

spark.createDataFrame(silh_lst).show()

```

k	silhouette
3	0.8045154385557953
4	0.6993528775512052
5	0.6689286654221447
6	0.6356184024841809
7	0.7174102265711756
8	0.6720861758298997
9	0.601771359881241
10	0.6292447334578428

From the silhouette list, we can choose 3 as the optimal number of the clusters.

Warning: ClusteringEvaluator in pyspark.ml.evaluation requires Spark 2.4 or later!!

4. K-means clustering

```

k = 3
kmeans = KMeans().setK(k).setSeed(1)
model = kmeans.fit(scaledData)
# Make predictions
predictions = model.transform(scaledData)
predictions.show(5,False)

+-----+-----+-----+-----+
|CustomerID|          rfm|        features|prediction|
+-----+-----+-----+-----+
|    17420| [50.0,3.0,598.83]| [0.13404825737265...|     0|
|    16861| [59.0,3.0,151.65]| [0.15817694369973...|     0|
|    16503|[106.0,5.0,1421.43]| [0.28418230563002...|     2|
|    15727|[16.0,7.0,5178.96]| [0.04289544235924...|     0|
|    17389|[0.0,43.0,31300.08]| [0.0,0.01700404858...|     0|
+-----+-----+-----+-----+
only showing top 5 rows

```

12.3.3 Statistical summary

5. statistical summary

```
results = rfm.join(predictions.select('CustomerID','prediction'),'CustomerID',how='left')
results.show(5)

+-----+-----+-----+-----+
|CustomerID|Recency|Frequency|Monetary|prediction|
+-----+-----+-----+-----+
| 13098 |     1 |      41 | 28658.88 |      0 |
| 13248 |    124 |      2 |   465.68 |      2 |
| 13452 |    259 |      2 |   590.0 |      1 |
| 13460 |     29 |      2 |  183.44 |      0 |
| 13518 |     85 |      1 |  659.44 |      0 |
+-----+-----+-----+-----+
only showing top 5 rows
```

- simple summary

```
results.groupBy('prediction')\
    .agg({'Recency':'mean',
          'Frequency': 'mean',
          'Monetary': 'mean'})\
    .sort(F.col('prediction')).show(5)

+-----+-----+-----+
|prediction| avg(Recency) | avg(Monetary) | avg(Frequency) |
+-----+-----+-----+
| 0 | 30.966337980278816 | 2543.0355321319284 | 6.514450867052023 |
| 1 | 296.02403846153845 | 407.16831730769206 | 1.5592948717948718 |
| 2 | 154.40148698884758 | 702.5096406443623 | 2.550185873605948 |
+-----+-----+-----+
```

- complex summary

```
grp = 'RFMScore'
num_cols = ['Recency', 'Frequency', 'Monetary']
df_input = results

quantile_grouped = quantile_agg(df_input, grp, num_cols)
quantile_grouped.toPandas().to_csv(output_dir+'quantile_grouped.csv')

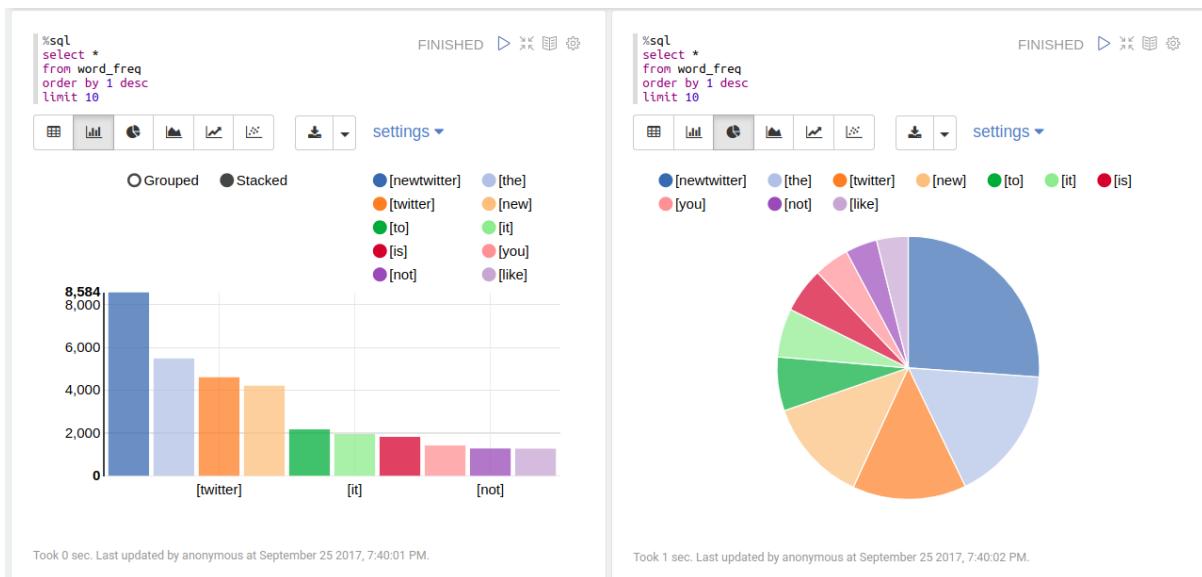
deciles_grouped = deciles_agg(df_input, grp, num_cols)
deciles_grouped.toPandas().to_csv(output_dir+'deciles_grouped.csv')
```

CHAPTER THIRTEEN

TEXT MINING

Chinese proverb

Articles showed more than intended. – Xianglong Shen



13.1 Text Collection

13.1.1 Image to text

- My img2txt function

```
def img2txt(img_dir):
    """
    convert images to text
    """
    import os, PythonMagick
    from datetime import datetime
    import PyPDF2

    from PIL import Image
    import pytesseract

    f = open('doc4img.txt', 'wa')
```

```

for img in [img_file for img_file in os.listdir(img_dir)
            if (img_file.endswith(".png") or
                img_file.endswith(".jpg") or
                img_file.endswith(".jpeg"))]:
    start_time = datetime.now()

    input_img = img_dir + "/" + img

    print('-----')
    print(img)
    print('Converting ' + img + '.....')
    print('-----')

    # extract the text information from images
    text = pytesseract.image_to_string(Image.open(input_img))
    print(text)

    # output text file
    f.write(img + "\n")
    f.write(text.encode('utf-8'))

    print "CPU Time for converting" + img + ":" + str(datetime.now() - start_time) + "\n"
    f.write("-----\n")

f.close()

```

- Demo

I applied my img2txt function to the image in Image folder.

```

image_dir = r"Image"

img2txt(image_dir)

```

Then I got the following results:

```

-----
feng.pdf_0.png
Converting feng.pdf_0.png.....
-----
l I l w

Wenqiang Feng
Data Scientist
DST APPLIED ANALYTICS GROUP

```

Wenqiang Feng is Data Scientist **for** DST's Applied Analytics Group. Dr. Feng's responsibilities include providing DST clients with access to cutting-edge skills and technologies, including Data analytic solutions, advanced analytic and data enhancement techniques and modeling.

Dr. Feng has deep analytic expertise in data mining, analytic systems, machine learning algorithms, business intelligence, and applying Big Data tools to strategically solve important problems in a cross-functional business. Before joining the DST Applied Analytics Group, Feng holds a MA Data Science Fellow at The Institute **for** Mathematics and Its Applications.

{IMA) at the University of Minnesota. While there, he helped startup companies make marketing decisions based on deep predictive analytics.

Dr. Feng graduated from University of Tennessee, Knoxville with PhD in Computational mathematics and Master's degree in Statistics. He also holds Master's degree in Computational Mathematics at Missouri University of Science and Technology (MST) and Master's degree in Applied Mathematics at University of science and technology of China (USTC).
CPU Time **for** convertingfeng.pdf_0.png:0:00:02.061208

13.1.2 Image Enhanced to text

- My img2txt_enhance function

```
def img2txt_enhance(img_dir,scaler):  
    """  
    convert images files to text  
    """  
  
    import numpy as np  
    import os, PythonMagick  
    from datetime import datetime  
    import PyPDF2  
  
    from PIL import Image, ImageEnhance, ImageFilter  
    import pytesseract  
  
    f = open('doc4img.txt','w')  
    for img in [img_file for img_file in os.listdir(img_dir)  
                if (img_file.endswith(".png") or  
                    img_file.endswith(".jpg") or  
                    img_file.endswith(".jpeg"))]:  
  
        start_time = datetime.now()  
  
        input_img = img_dir + "/" + img  
        enhanced_img = img_dir + "/" +"Enhanced" + "/" + img  
  
        im = Image.open(input_img) # the second one  
        im = im.filter(ImageFilter.MedianFilter())  
        enhancer = ImageEnhance.Contrast(im)  
        im = enhancer.enhance(1)  
        im = im.convert('1')  
        im.save(enhanced_img)  
  
        for scale in np.ones(scaler):  
            im = Image.open(enhanced_img) # the second one  
            im = im.filter(ImageFilter.MedianFilter())  
            enhancer = ImageEnhance.Contrast(im)  
            im = enhancer.enhance(scale)  
            im = im.convert('1')  
            im.save(enhanced_img)  
  
    print('-----')  
    print(img)
```

```

print('Converting ' + img + '.....')
print('-----')

# extract the text information from images
text = pytesseract.image_to_string(Image.open(enhanced_img))
print(text)

# output text file
f.write(img + "\n")
f.write(text.encode('utf-8'))

print "CPU Time for converting" + img + ":" + str(datetime.now() - start_time) + "\n"
f.write("\n-----\n")

f.close()

```

- Demo

I applied my img2txt_enhance function to the following noised image in Enhance folder.



```

image_dir = r"Enhance"

pdf2txt_enhance(image_dir)

```

Then I got the following results:

```

-----
noised.jpg
Converting noised.jpg.....
-----
zHHH
CPU Time for convertingnoised.jpg:0:00:00.135465

```

while the result from img2txt function is

```

-----
noised.jpg
Converting noised.jpg.....
-----
,2 WW
CPU Time for convertingnoised.jpg:0:00:00.133508

```

which is not correct.

13.1.3 PDF to text

- My pdf2txt function

```

def pdf2txt(pdf_dir,image_dir):
    """

```

```

convert PDF to text
"""

import os, PythonMagick
from datetime import datetime
import PyPDF2

from PIL import Image
import pytesseract

f = open('doc.txt', 'wa')
for pdf in [pdf_file for pdf_file in os.listdir(pdf_dir) if pdf_file.endswith(".pdf")]

    start_time = datetime.now()

    input_pdf = pdf_dir + "/" + pdf

    pdf_im = PyPDF2.PdfFileReader(file(input_pdf, "rb"))
    npage = pdf_im.getNumPages()

    print('-----')
    print(pdf)
    print('Converting %d pages.' % npage)
    print('-----')

f.write( "\n-----"

for p in range(npage):

    pdf_file = input_pdf + '[' + str(p) + ']'
    image_file = image_dir + "/" + pdf+ '_' + str(p)+ '.png'

    # convert PDF files to Images
    im = PythonMagick.Image()
    im.density('300')
    im.read(pdf_file)
    im.write(image_file)

    # extract the text information from images
    text = pytesseract.image_to_string(Image.open(image_file))

    #print(text)

    # ouput text file
    f.write( pdf + "\n")
    f.write(text.encode('utf-8'))

    print "CPU Time for converting" + pdf + ":" + str(datetime.now() - start_time) + "\n"

f.close()

```

- Demo

I applied my pdf2txt function to my scanned bio pdf file in pdf folder.

```

pdf_dir = r"pdf"
image_dir = r"Image"

```

```
pdf2txt(pdf_dir,image_dir)
```

Then I got the following results:

```
-----
feng.pdf
Converting 1 pages.
-----
l l l w

Wenqiang Feng
Data Scientist
DST APPLIED ANALYTICS GROUP
```

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Dr. Feng graduated from University of Tennessee, Knoxville with PhD in Computational mathematics and Master's degree in Statistics. He also holds Master's degree in Computational Mathematics at Missouri University of Science and Technology (MST) and Master's degree in Applied Mathematics at University of science and technology of China (USTC).
CPU Time **for** convertingfeng.pdf:0:00:03.143800

13.1.4 Audio to text

- My audio2txt function

```
def audio2txt(audio_dir):
    ''' convert audio to text'''

    import speech_recognition as sr
    r = sr.Recognizer()

    f = open('doc.txt','w')
    for audio_n in [audio_file for audio_file in os.listdir(audio_dir) \
                    if audio_file.endswith(".wav")]:
        filename = audio_dir + "/" + audio_n

        # Read audio data
        with sr.AudioFile(filename) as source:
            audio = r.record(source) # read the entire audio file

        # Google Speech Recognition
        text = r.recognize_google(audio)
```

```
# output text file
f.write( audio_n + ": ")
f.write(text.encode('utf-8'))
f.write("\n")

print('You said: ' + text)

f.close()
```

- Demo

I applied my audio2txt function to my audio records in audio folder.

```
audio_dir = r"audio"

audio2txt(audio_dir)
```

Then I got the following results:

```
You said: hello this is George welcome to my tutorial
You said: mathematics is important in daily life
You said: call me tomorrow
You said: do you want something to eat
You said: I want to speak with him
You said: nice to see you
You said: can you speak slowly
You said: have a good day
```

By the way, you can use my following python code to record your own audio and play with audio2txt function in Command-line python record.py "demo2.wav":

```
import sys, getopt

import speech_recognition as sr

audio_filename = sys.argv[1]

r = sr.Recognizer()
with sr.Microphone() as source:
    r.adjust_for_ambient_noise(source)
    print("Hey there, say something, I am recording!")
    audio = r.listen(source)
    print("Done listening!")

with open(audio_filename, "wb") as f:
    f.write(audio.get_wav_data())
```

13.2 Text Preprocessing

- check to see if a row only contains whitespace

```
def check_blanks(data_str):
    is_blank = str(data_str.isspace())
    return is_blank
```

- Determine whether the language of the text content is english or not: Use langid module to classify the language to make sure we are applying the correct cleanup actions for English langid

```
def check_lang(data_str):
    predict_lang = langid.classify(data_str)
    if predict_lang[1] >= .9:
        language = predict_lang[0]
    else:
        language = 'NA'
    return language
```

- Remove features

```
def remove_features(data_str):
    # compile regex
    url_re = re.compile('https?://(www.)?\w+\.\w+(/(\w+)*)/?')
    punc_re = re.compile('[%s]' % re.escape(string.punctuation))
    num_re = re.compile('(\d+)')
    mention_re = re.compile('@(\w+)')
    alpha_num_re = re.compile("^[a-z0-9_.]+$")
    # convert to lowercase
    data_str = data_str.lower()
    # remove hyperlinks
    data_str = url_re.sub(' ', data_str)
    # remove @mentions
    data_str = mention_re.sub(' ', data_str)
    # remove punctuation
    data_str = punc_re.sub(' ', data_str)
    # remove numeric 'words'
    data_str = num_re.sub(' ', data_str)
    # remove non a-z 0-9 characters and words shorter than 3 characters
    list_pos = 0
    cleaned_str = ''
    for word in data_str.split():
        if list_pos == 0:
            if alpha_num_re.match(word) and len(word) > 2:
                cleaned_str = word
            else:
                cleaned_str = ' '
        else:
            if alpha_num_re.match(word) and len(word) > 2:
                cleaned_str = cleaned_str + ' ' + word
            else:
                cleaned_str += ' '
        list_pos += 1
    return cleaned_str
```

- removes stop words

```
def remove_stops(data_str):
    # expects a string
    stops = set(stopwords.words("english"))
    list_pos = 0
    cleaned_str = ''
    text = data_str.split()
    for word in text:
        if word not in stops:
            # rebuild cleaned_str
```

```

if list_pos == 0:
    cleaned_str = word
else:
    cleaned_str = cleaned_str + ' ' + word
list_pos += 1
return cleaned_str

```

- tagging text

```

def tag_and_remove(data_str):
    cleaned_str = ''
    # noun tags
    nn_tags = ['NN', 'NNP', 'NNP', 'NNPS', 'NNS']
    # adjectives
    jj_tags = ['JJ', 'JJR', 'JJS']
    # verbs
    vb_tags = ['VB', 'VBD', 'VBG', 'VBN', 'VBP', 'VBZ']
    nltk_tags = nn_tags + jj_tags + vb_tags

    # break string into 'words'
    text = data_str.split()

    # tag the text and keep only those with the right tags
    tagged_text = pos_tag(text)
    for tagged_word in tagged_text:
        if tagged_word[1] in nltk_tags:
            cleaned_str += tagged_word[0] + ' '

    return cleaned_str

```

- lemmatization

```

def lemmatize(data_str):
    # expects a string
    list_pos = 0
    cleaned_str = ''
    lmtzr = WordNetLemmatizer()
    text = data_str.split()
    tagged_words = pos_tag(text)
    for word in tagged_words:
        if 'v' in word[1].lower():
            lemma = lmtzr.lemmatize(word[0], pos='v')
        else:
            lemma = lmtzr.lemmatize(word[0], pos='n')
        if list_pos == 0:
            cleaned_str = lemma
        else:
            cleaned_str = cleaned_str + ' ' + lemma
        list_pos += 1
    return cleaned_str

```

define the preprocessing function in PySpark

```

from pyspark.sql.functions import udf
from pyspark.sql.types import StringType
import preproc as pp

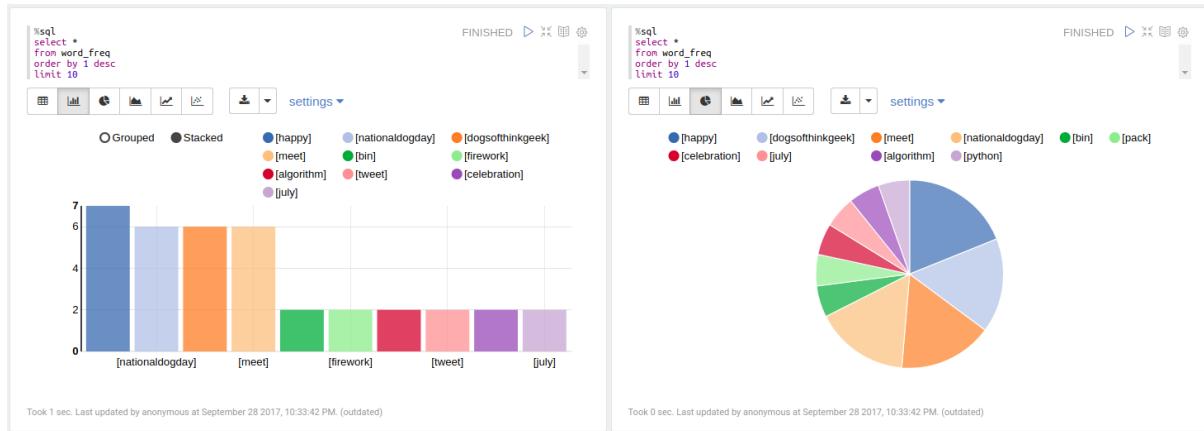
check_lang_udf = udf(pp.check_lang, StringType())

```

```
remove_stops_udf = udf(pp.remove_stops, StringType())
remove_features_udf = udf(pp.remove_features, StringType())
tag_and_remove_udf = udf(pp.tag_and_remove, StringType())
lemmatize_udf = udf(pp.lemmatize, StringType())
check_blanks_udf = udf(pp.check_blanks, StringType())
```

13.3 Text Classification

Theoretically speaking, you may apply any classification algorithms to do classification. I will only present Naive Bayes method is the following.



13.3.1 Introduction

13.3.2 Demo

1. create spark contexts

```
import pyspark
from pyspark.sql import SQLContext

# create spark contexts
sc = pyspark.SparkContext()
sqlContext = SQLContext(sc)
```

2. load dataset

```
# Load a text file and convert each line to a Row.
data_rdd = sc.textFile("../data/raw_data.txt")
parts_rdd = data_rdd.map(lambda l: l.split("\t"))

# Filter bad rows out
garantee_col_rdd = parts_rdd.filter(lambda l: len(l) == 3)
typed_rdd = guarantee_col_rdd.map(lambda p: (p[0], p[1], float(p[2])))

# Create DataFrame
data_df = sqlContext.createDataFrame(typed_rdd, ["text", "id", "label"])

# get the raw columns
```

```
raw_cols = data_df.columns

#data_df.show()
data_df.printSchema()

root
 |-- text: string (nullable = true)
 |-- id: string (nullable = true)
 |-- label: double (nullable = true)

+-----+-----+-----+
|       text |           id | label |
+-----+-----+-----+
|Fresh install of ...| 1018769417 | 1.0 |
|Well. Now I know ...| 10284216536 | 1.0 |
|"Literally six we...| 10298589026 | 1.0 |
|Mitsubishi i MiEV...| 109017669432377344 | 1.0 |
+-----+-----+-----+
only showing top 4 rows
```

3. setup pyspark udf function

```
from pyspark.sql.functions import udf
from pyspark.sql.types import StringType
import preproc as pp

# Register all the functions in Preproc with Spark Context
check_lang_udf = udf(pp.check_lang, StringType())
remove_stops_udf = udf(pp.remove_stops, StringType())
remove_features_udf = udf(pp.remove_features, StringType())
tag_and_remove_udf = udf(pp.tag_and_remove, StringType())
lemmatize_udf = udf(pp.lemmatize, StringType())
check_blanks_udf = udf(pp.check_blanks, StringType())
```

4. language identification

```
lang_df = data_df.withColumn("lang", check_lang_udf(data_df["text"]))
en_df = lang_df.filter(lang_df["lang"] == "en")
en_df.show(4)

+-----+-----+-----+
|       text |           id | label | lang |
+-----+-----+-----+
| RT @goeentertain:...| 665305154954989568 | 1.0 | en |
| Teforia Uses Mach...| 660668007975268352 | 1.0 | en |
| Apple TV or Roku?| 25842461136 | 1.0 | en |
| Finished http://t...| 9412369614 | 1.0 | en |
+-----+-----+-----+
only showing top 4 rows
```

5. remove stop words

```
rm_stops_df = en_df.select(raw_cols) \
    .withColumn("stop_text", remove_stops_udf(en_df["text"]))
rm_stops_df.show(4)

+-----+-----+-----+
|       text |           id | label | stop_text |
+-----+-----+-----+
```

```
+-----+-----+-----+
| RT @goeentertain:...|665305154954989568| 1.0|RT @goeentertain:...|
| Teforia Uses Mach...|660668007975268352| 1.0|Teforia Uses Mach...|
| Apple TV or Roku?| 25842461136| 1.0| Apple TV Roku?|
| Finished http://t...| 9412369614| 1.0|Finished http://t...|
+-----+-----+-----+
only showing top 4 rows
```

6. remove irrelevant features

```
rm_features_df = rm_stops_df.select(raw_cols+["stop_text"])\n    .withColumn("feat_text", \n        remove_features_udf(rm_stops_df["stop_text"]))\nrm_features_df.show(4)
```

```
+-----+-----+-----+-----+\n| text | id | label | stop_text | feat_text |\n+-----+-----+-----+-----+\n| RT @goeentertain:...|665305154954989568| 1.0|RT @goeentertain:...| future blase ...|\n| Teforia Uses Mach...|660668007975268352| 1.0|Teforia Uses Mach...|teforia uses mach...|\n| Apple TV or Roku?| 25842461136| 1.0| Apple TV Roku?| apple roku |\n| Finished http://t...| 9412369614| 1.0|Finished http://t...| finished |\n+-----+-----+-----+-----+\nonly showing top 4 rows
```

7. tag the words

```
tagged_df = rm_features_df.select(raw_cols+["feat_text"])\n    .withColumn("tagged_text", \n        tag_and_remove_udf(rm_features_df.feat_text))
```

```
tagged_df.show(4)
```

```
+-----+-----+-----+-----+\n| text | id | label | feat_text | tagged_text |\n+-----+-----+-----+-----+\n| RT @goeentertain:...|665305154954989568| 1.0| future blase ...| future blase vic...|\n| Teforia Uses Mach...|660668007975268352| 1.0|teforia uses mach...| teforia uses mac...|\n| Apple TV or Roku?| 25842461136| 1.0| apple roku | apple roku |\n| Finished http://t...| 9412369614| 1.0| finished | finished |\n+-----+-----+-----+-----+\nonly showing top 4 rows
```

8. lemmatization of words

```
lemm_df = tagged_df.select(raw_cols+["tagged_text"])\n    .withColumn("lemm_text", lemmatize_udf(tagged_df["tagged_text"]))\nlemm_df.show(4)
```

```
+-----+-----+-----+-----+\n| text | id | label | tagged_text | lemm_text |\n+-----+-----+-----+-----+\n| RT @goeentertain:...|665305154954989568| 1.0| future blase vic...|future blase vice...|\n| Teforia Uses Mach...|660668007975268352| 1.0|teforia uses mac...|teforia use machi...|\n| Apple TV or Roku?| 25842461136| 1.0| apple roku | apple roku |\n| Finished http://t...| 9412369614| 1.0| finished | finished |\n+-----+-----+-----+-----+\nonly showing top 4 rows
```

9. remove blank rows and drop duplicates

```

check_blanks_df = lemm_df.select(raw_cols+["lemm_text"]) \
    .withColumn("is_blank", check_blanks_udf(lemm_df["lemm_text"]))
# remove blanks
no_blanks_df = check_blanks_df.filter(check_blanks_df["is_blank"] == "False")

# drop duplicates
dedup_df = no_blanks_df.dropDuplicates(['text', 'label'])

dedup_df.show(4)

+-----+-----+-----+-----+
|      text|      id|label|      lemm_text|is_blank|
+-----+-----+-----+-----+
| RT @goeentertain:...|665305154954989568| 1.0|future blase vice...| False|
| Teforia Uses Mach...|660668007975268352| 1.0|teforia use machi...| False|
| Apple TV or Roku?| 25842461136| 1.0|apple roku| False|
| Finished http://t...| 9412369614| 1.0|finish| False|
+-----+-----+-----+-----+
only showing top 4 rows

```

10. add unique ID

```

from pyspark.sql.functions import monotonically_increasing_id
# Create Unique ID
dedup_df = dedup_df.withColumn("uid", monotonically_increasing_id())
dedup_df.show(4)

+-----+-----+-----+-----+-----+
|      text|      id|label|      lemm_text|is_blank|      uid|
+-----+-----+-----+-----+-----+
| dragon| 1546813742| 1.0|dragon| False| 8589934592|
| hurt much| 1558492525| 1.0|hurt much| False| 11166914969|
| seth blog word se...|383221484023709697| 1.0|seth blog word se...| False| 12884901888|
| teforia use machi...|660668007975268352| 1.0|teforia use machi...| False| 13743895347|
+-----+-----+-----+-----+-----+
only showing top 4 rows

```

11. create final dataset

```

data = dedup_df.select('uid','id', 'text', 'label')
data.show(4)

+-----+-----+-----+
|      uid|      id|      text|label|
+-----+-----+-----+
| 85899345920| 1546813742| dragon| 1.0|
| 111669149696| 1558492525| hurt much| 1.0|
| 128849018880|383221484023709697|seth blog word se...| 1.0|
| 137438953472|660668007975268352|teforia use machi...| 1.0|
+-----+-----+-----+
only showing top 4 rows

```

12. Create training and test sets

```

# Split the data into training and test sets (40% held out for testing)
(trainingData, testData) = data.randomSplit([0.6, 0.4])

```

13. NaiveBayes Pipeline

```

from pyspark.ml.feature import HashingTF, IDF, Tokenizer
from pyspark.ml import Pipeline
from pyspark.ml.classification import NaiveBayes, RandomForestClassifier
from pyspark.ml.classification import DecisionTreeClassifier
from pyspark.ml.evaluation import MulticlassClassificationEvaluator
from pyspark.ml.tuning import ParamGridBuilder
from pyspark.ml.tuning import CrossValidator
from pyspark.ml.feature import IndexToString, StringIndexer, VectorIndexer
from pyspark.ml.feature import CountVectorizer

# Configure an ML pipeline, which consists of tree stages: tokenizer, hashingTF, and nb.
tokenizer = Tokenizer(inputCol="text", outputCol="words")
hashingTF = HashingTF(inputCol=tokenizer.getOutputCol(), outputCol="rawFeatures")
# vectorizer = CountVectorizer(inputCol= "words", outputCol="rawFeatures")
idf = IDF(minDocFreq=3, inputCol="rawFeatures", outputCol="features")

# Naive Bayes model
nb = NaiveBayes()

# Pipeline Architecture
pipeline = Pipeline(stages=[tokenizer, hashingTF, idf, nb])

# Train model. This also runs the indexers.
model = pipeline.fit(trainingData)

```

14. Make predictions

```

predictions = model.transform(testData)

# Select example rows to display.
predictions.select("text", "label", "prediction").show(5, False)

+-----+-----+-----+
|text |label|prediction|
+-----+-----+-----+
| finish | 1.0 | 1.0 |
| meet rolo dogsofthinkgeek happy nationaldogday | 1.0 | 1.0 |
| pumpkin family | 1.0 | 1.0 |
| meet jet dogsofthinkgeek happy nationaldogday | 1.0 | 1.0 |
| meet vixie dogsofthinkgeek happy nationaldogday | 1.0 | 1.0 |
+-----+-----+-----+
only showing top 5 rows

```

15. evaluation

```

from pyspark.ml.evaluation import MulticlassClassificationEvaluator
evaluator = MulticlassClassificationEvaluator(predictionCol="prediction")
evaluator.evaluate(predictions)

0.912655971479501

```



13.4 Sentiment analysis

13.4.1 Introduction

Sentiment analysis (sometimes known as opinion mining or emotion AI) refers to the use of natural language processing, text analysis, computational linguistics, and biometrics to systematically identify, extract, quantify, and study affective states and subjective information. Sentiment analysis is widely applied to voice of the customer materials such as reviews and survey responses, online and social media, and healthcare materials for applications that range from marketing to customer service to clinical medicine.

Generally speaking, sentiment analysis aims to **determine the attitude** of a speaker, writer, or other subject with respect to some topic or the overall contextual polarity or emotional reaction to a document, interaction, or event. The attitude may be a judgment or evaluation (see appraisal theory), affective state (that is to say, the emotional state of the author or speaker), or the intended emotional communication (that is to say, the emotional effect intended by the author or interlocutor).

Sentiment analysis in business, also known as opinion mining is a process of identifying and cataloging a piece of text according to the tone conveyed by it. It has broad application:

- Sentiment Analysis in Business Intelligence Build up
- Sentiment Analysis in Business for Competitive Advantage
- Enhancing the Customer Experience through Sentiment Analysis in Business

13.4.2 Pipeline

13.4.3 Demo

1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
```

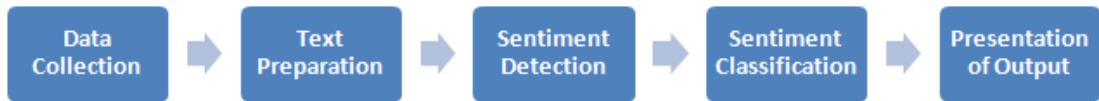


Figure 13.1: Sentiment Analysis Pipeline

```
.appName("Python Spark Sentiment Analysis example") \
.config("spark.some.config.option", "some-value") \
.getOrCreate()
```

2. Load dataset

```
df = spark.read.format('com.databricks.spark.csv').\
    options(header='true', \
    inferSchema='true').\
    load("../data/newtwitter.csv", header=True);

+-----+-----+-----+
|      text |      id|pubdate|
+-----+-----+-----+
| 10 Things Missing...|2602860537| 18536|
| RT @_NATURALBWINN...|2602850443| 18536|
| RT @HBO24 yo the ...|2602761852| 18535|
| Aaaaaaaaand I have...|2602738438| 18535|
| can I please have...|2602684185| 18535|
+-----+-----+-----+
only showing top 5 rows
```

3. Text Preprocessing

- remove non ASCII characters

```
from pyspark.sql.functions import udf
from pyspark.sql.types import StringType

from nltk.stem.wordnet import WordNetLemmatizer
from nltk.corpus import stopwords
from nltk import pos_tag
import string
import re

# remove non ASCII characters
def strip_non_ascii(data_str):
    ''' Returns the string without non ASCII characters'''
    stripped = (c for c in data_str if 0 < ord(c) < 127)
    return ''.join(stripped)
# setup pyspark udf function
strip_non_ascii_udf = udf(strip_non_ascii, StringType())
```

check:

```
df = df.withColumn('text_non_ascii', strip_non_ascii_udf(df['text']))
df.show(5, True)
```

output:

```
+-----+-----+-----+-----+
|       text |      id |pubdate |    text_non_ascii |
+-----+-----+-----+-----+
| 10 Things Missing...|2602860537| 18536|10 Things Missing...|
| RT @_NATURALBWINN...|2602850443| 18536|RT @_NATURALBWINN...|
| RT @HBO24 yo the ...|2602761852| 18535|RT @HBO24 yo the ...|
| Aaaaaaaaand I have...|2602738438| 18535|Aaaaaaaaand I have...|
| can I please have...|2602684185| 18535|can I please have...|
+-----+-----+-----+-----+
only showing top 5 rows
```

- fixed abbreviation

```
# fixed abbreviation
def fix_abbreviation(data_str):
    data_str = data_str.lower()
    data_str = re.sub(r'\bthats\b', 'that is', data_str)
    data_str = re.sub(r'\bive\b', 'i have', data_str)
    data_str = re.sub(r'\bim\b', 'i am', data_str)
    data_str = re.sub(r'\bya\b', 'yeah', data_str)
    data_str = re.sub(r'\bcant\b', 'can not', data_str)
    data_str = re.sub(r'\bdont\b', 'do not', data_str)
    data_str = re.sub(r'\bwont\b', 'will not', data_str)
    data_str = re.sub(r'\bid\b', 'i would', data_str)
    data_str = re.sub(r'\wtf', 'what the fuck', data_str)
    data_str = re.sub(r'\bwth\b', 'what the hell', data_str)
    data_str = re.sub(r'\br\b', 'are', data_str)
    data_str = re.sub(r'\bu\b', 'you', data_str)
    data_str = re.sub(r'\bk\b', 'OK', data_str)
    data_str = re.sub(r'\bsux\b', 'sucks', data_str)
    data_str = re.sub(r'\bno+\b', 'no', data_str)
    data_str = re.sub(r'\bcoo+\b', 'cool', data_str)
    data_str = re.sub(r'\rt\b', '', data_str)
    data_str = data_str.strip()
    return data_str
```

```
fix_abbreviation_udf = udf(fix_abbreviation, StringType())
```

check:

```
df = df.withColumn('fixed_abbrev', fix_abbreviation_udf(df['text_non_ascii']))
df.show(5, True)
```

output:

```
+-----+-----+-----+-----+-----+
|       text |      id |pubdate |    text_non_ascii |    fixed_abbrev |
+-----+-----+-----+-----+
| 10 Things Missing...|2602860537| 18536|10 Things Missing...|10 things missing...|
| RT @_NATURALBWINN...|2602850443| 18536|RT @_NATURALBWINN...|@_naturalbwinner ...|
| RT @HBO24 yo the ...|2602761852| 18535|RT @HBO24 yo the ...|@hbo24 yo the #ne...|
| Aaaaaaaaand I have...|2602738438| 18535|Aaaaaaaaand I have...|aaaaaaaaand i have...|
| can I please have...|2602684185| 18535|can I please have...|can i please have...|
+-----+-----+-----+-----+
only showing top 5 rows
```

- remove irrelevant features

```

def remove_features(data_str):
    # compile regex
    url_re = re.compile('https?://(www.)?\w+\.\w+(/[\w+]*)/?')
    punc_re = re.compile('[%s]' % re.escape(string.punctuation))
    num_re = re.compile('(\d+)')
    mention_re = re.compile('@(\w+)')
    alpha_num_re = re.compile("^[a-z0-9_.]+$")
    # convert to lowercase
    data_str = data_str.lower()
    # remove hyperlinks
    data_str = url_re.sub(' ', data_str)
    # remove @mentions
    data_str = mention_re.sub(' ', data_str)
    # remove punctuation
    data_str = punc_re.sub(' ', data_str)
    # remove numeric 'words'
    data_str = num_re.sub(' ', data_str)
    # remove non a-z 0-9 characters and words shorter than 1 characters
    list_pos = 0
    cleaned_str = ''
    for word in data_str.split():
        if list_pos == 0:
            if alpha_num_re.match(word) and len(word) > 1:
                cleaned_str = word
            else:
                cleaned_str = ' '
        else:
            if alpha_num_re.match(word) and len(word) > 1:
                cleaned_str = cleaned_str + ' ' + word
            else:
                cleaned_str += ' '
        list_pos += 1
    # remove unwanted space, *.split() will automatically split on
    # whitespace and discard duplicates, the ".join() joins the
    # resulting list into one string.
    return " ".join(cleaned_str.split())
# setup pyspark udf function
remove_features_udf = udf(remove_features, StringType())

```

check:

```

df = df.withColumn('removed', remove_features_udf(df['fixed_abbrev']))
df.show(5, True)

```

output:

	text	id	pubdate	text_non_ascii	fixed_abbrev
10	Things Missing...	2602860537	18536	10 Things Missing...	10 things missing...
RT	@_NATURALBWINN...	2602850443	18536	RT @_NATURALBWINN...	@_naturalbwinner ...
RT	@HBO24 yo the ...	2602761852	18535	RT @HBO24 yo the ...	@hbo24 yo the #ne.../yo th
Aaaaaaaaand I have...	2602738438	18535	Aaaaaaaaand I have...	aaaaaaaand i have...	
can I please have...	2602684185	18535	can I please have...	can i please have...	

only showing top 5 rows

4. Sentiment Analysis main function

```

from pyspark.sql.types import FloatType

from textblob import TextBlob

def sentiment_analysis(text):
    return TextBlob(text).sentiment.polarity

sentiment_analysis_udf = udf(sentiment_analysis, FloatType())

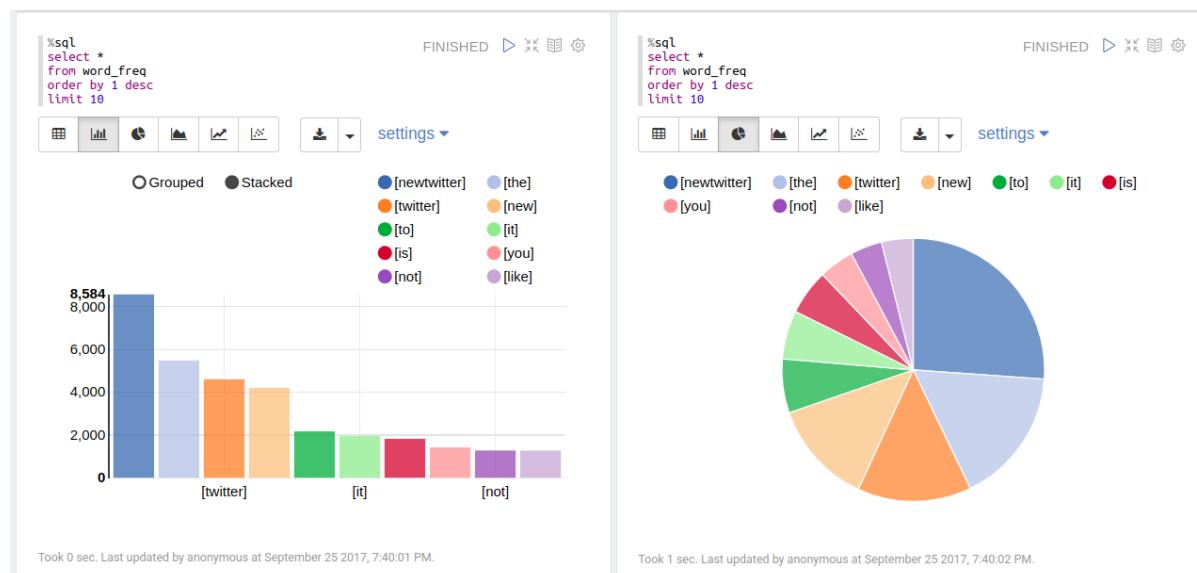
df = df.withColumn("sentiment_score", sentiment_analysis_udf(df['removed']))
df.show(5, True)

```

- Sentiment score

```
+-----+-----+
|       removed|sentiment_score|
+-----+-----+
|things missing in...| -0.03181818 |
|oh and do not lik...| -0.03181818 |
|yo the newtwitter...| 0.3181818 |
|aaaaaaaaand have t...| 0.11818182 |
|can please have t...| 0.13636364 |
+-----+-----+
only showing top 5 rows
```

- Words frequency



- Sentiment Classification

```

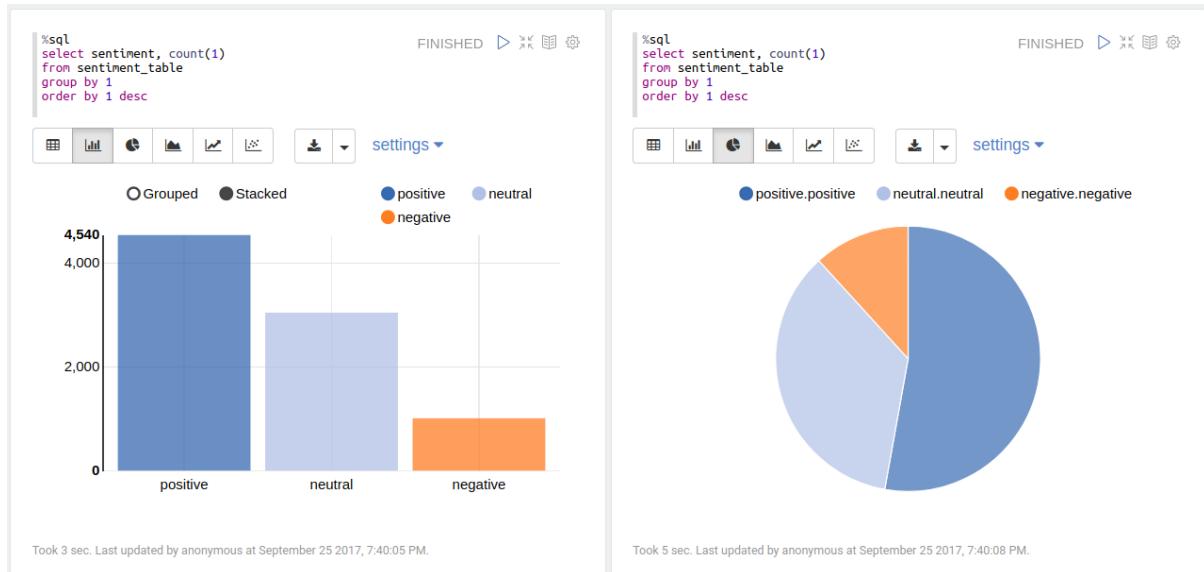
def condition(r):
    if (r >= 0.1):
        label = "positive"
    elif(r <= -0.1):
        label = "negative"
    else:
        label = "neutral"
    return label

sentiment_udf = udf(lambda x: condition(x), StringType())

```

5. Output

- Sentiment Class



- Top tweets from each sentiment class

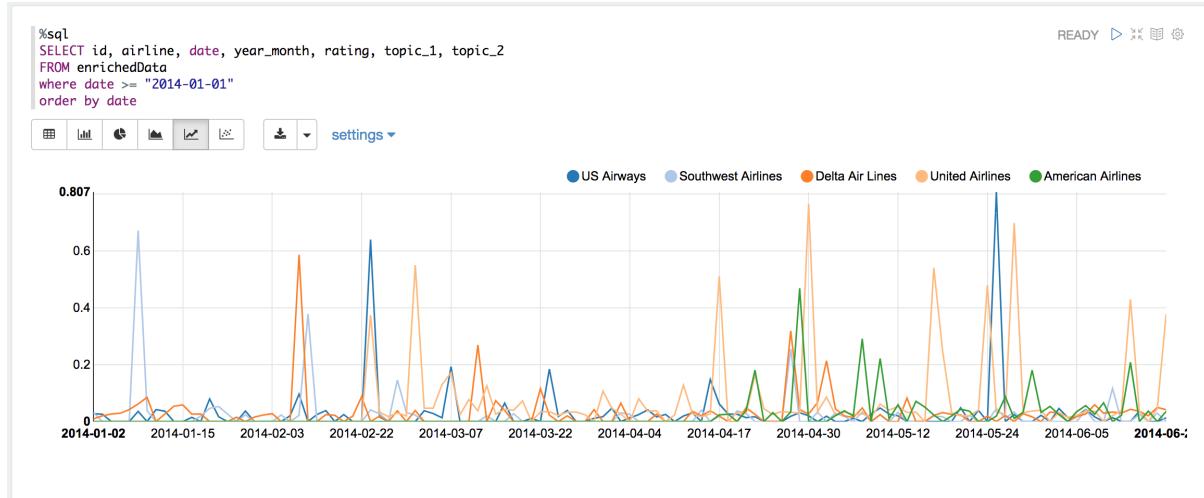
```
+-----+-----+-----+
|           text|sentiment_score|sentiment|
+-----+-----+-----+
| and this #newtwit... /      1.0| positive| |
| "RT @SarahsJokes:... |      1.0| positive|
| #newtwitter using... /      1.0| positive|
| The #NewTwitter h... /      1.0| positive|
| You can now undo ... |      1.0| positive|
+-----+-----+-----+
only showing top 5 rows

+-----+-----+-----+
|           text|sentiment_score|sentiment|
+-----+-----+-----+
| Lists on #NewTwit... /     -0.1| neutral| |
| Too bad most of m.... |     -0.1| neutral|
| the #newtwitter i... /     -0.1| neutral|
| Looks like our re... |     -0.1| neutral|
| i switched to the... |     -0.1| neutral|
+-----+-----+-----+
only showing top 5 rows

+-----+-----+-----+
|           text|sentiment_score|sentiment|
+-----+-----+-----+
| oh. #newtwitter i... /    -1.0| negative| |
| RT @chqwn: #NewTw... /    -1.0| negative|
| Copy that - its W... |    -1.0| negative|
| RT @chqwn: #NewTw... /    -1.0| negative|
| #NewTwitter has t... /    -1.0| negative|
+-----+-----+-----+
only showing top 5 rows
```

13.5 N-grams and Correlations

13.6 Topic Model: Latent Dirichlet Allocation



13.6.1 Introduction

In text mining, a topic model is a unsupervised model for discovering the abstract “topics” that occur in a collection of documents.

Latent Dirichlet Allocation (LDA) is a mathematical method for estimating both of these at the same time: finding the mixture of words that is associated with each topic, while also determining the mixture of topics that describes each document.

13.6.2 Demo

1. Load data

```
rawdata = spark.read.load("../data/airlines.csv", format="csv", header=True)
rawdata.show(5)
```

id	airline	date	location	rating	cabin	value	recommended	
10001	Delta Air Lines	21-Jun-14	Thailand	7	Economy	4	YES Flew Ma	
10002	Delta Air Lines	19-Jun-14	USA	0	Economy	2	NO Flight	
10003	Delta Air Lines	18-Jun-14	USA	0	Economy	1	NO Delta W	
10004	Delta Air Lines	17-Jun-14	USA	9	Business	4	YES "I just	
10005	Delta Air Lines	17-Jun-14	Ecuador	7	Economy	3	YES "Round-	

only showing top 5 rows

1. Text preprocessing

I will use the following raw column names to keep my table concise:

```

raw_cols = rawdata.columns
raw_cols

['id', 'airline', 'date', 'location', 'rating', 'cabin', 'value', 'recommended', 'r

rawdata = rawdata.dropDuplicates(['review'])

from pyspark.sql.functions import udf, col
from pyspark.sql.types import StringType, DoubleType, DateType

from nltk.stem.wordnet import WordNetLemmatizer
from nltk.corpus import stopwords
from nltk import pos_tag
import langid
import string
import re

```

- remove non ASCII characters

```

# remove non ASCII characters
def strip_non_ascii(data_str):
    ''' Returns the string without non ASCII characters'''
    stripped = (c for c in data_str if 0 < ord(c) < 127)
    return ''.join(stripped)

```

- check it blank line or not

```

# check to see if a row only contains whitespace
def check_blanks(data_str):
    is_blank = str(data_str.isspace())
    return is_blank

```

- check the language (a little bit slow, I skited this step)

```

# check the language (only apply to english)
def check_lang(data_str):
    from langid.langid import LanguageIdentifier, model
    identifier = LanguageIdentifier.from_modelstring(model, norm_probs=True)
    predict_lang = identifier.classify(data_str)

    if predict_lang[1] >= .9:
        language = predict_lang[0]
    else:
        language = predict_lang[1]
    return language

```

- fixed abbreviation

```

# fixed abbreviation
def fix_abbreviation(data_str):
    data_str = data_str.lower()
    data_str = re.sub(r'\bthat\b', 'that is', data_str)
    data_str = re.sub(r'\bive\b', 'i have', data_str)
    data_str = re.sub(r'\bim\b', 'i am', data_str)
    data_str = re.sub(r'\bya\b', 'yeah', data_str)
    data_str = re.sub(r'\bcant\b', 'can not', data_str)
    data_str = re.sub(r'\bdont\b', 'do not', data_str)
    data_str = re.sub(r'\bwont\b', 'will not', data_str)

```

```

data_str = re.sub(r'\bid\b', 'i would', data_str)
data_str = re.sub(r'wtf', 'what the fuck', data_str)
data_str = re.sub(r'\bwth\b', 'what the hell', data_str)
data_str = re.sub(r'\br\b', 'are', data_str)
data_str = re.sub(r'\bu\b', 'you', data_str)
data_str = re.sub(r'\bk\b', 'OK', data_str)
data_str = re.sub(r'\bsux\b', 'sucks', data_str)
data_str = re.sub(r'\bno+\b', 'no', data_str)
data_str = re.sub(r'\bcoo+\b', 'cool', data_str)
data_str = re.sub(r'\rt\b', '', data_str)
data_str = data_str.strip()
return data_str

```

- remove irrelevant features

```

# remove irrelevant features
def remove_features(data_str):
    # compile regex
    url_re = re.compile('https?://(www.)?\w+.\w+(/(\w+)*/?)')
    punc_re = re.compile('[%s]' % re.escape(string.punctuation))
    num_re = re.compile('(\d+)')
    mention_re = re.compile('@(\w+)')
    alpha_num_re = re.compile("^[a-z0-9_.]+$")
    # convert to lowercase
    data_str = data_str.lower()
    # remove hyperlinks
    data_str = url_re.sub(' ', data_str)
    # remove @mentions
    data_str = mention_re.sub(' ', data_str)
    # remove punctuation
    data_str = punc_re.sub(' ', data_str)
    # remove numeric words
    data_str = num_re.sub(' ', data_str)
    # remove non a-z 0-9 characters and words shorter than 1 characters
    list_pos = 0
    cleaned_str = ''
    for word in data_str.split():
        if list_pos == 0:
            if alpha_num_re.match(word) and len(word) > 1:
                cleaned_str = word
            else:
                cleaned_str = ' '
        else:
            if alpha_num_re.match(word) and len(word) > 1:
                cleaned_str = cleaned_str + ' ' + word
            else:
                cleaned_str += ' '
        list_pos += 1
    # remove unwanted space, *.split() will automatically split on
    # whitespace and discard duplicates, the ".join() joins the
    # resulting list into one string.
return " ".join(cleaned_str.split())

```

- removes stop words

```

# removes stop words
def remove_stops(data_str):
    # expects a string

```

```

stops = set(stopwords.words("english"))
list_pos = 0
cleaned_str = ''
text = data_str.split()
for word in text:
    if word not in stops:
        # rebuild cleaned_str
        if list_pos == 0:
            cleaned_str = word
        else:
            cleaned_str = cleaned_str + ' ' + word
        list_pos += 1
return cleaned_str

```

- Part-of-Speech Tagging

```

# Part-of-Speech Tagging
def tag_and_remove(data_str):
    cleaned_str = ''
    # noun tags
    nn_tags = ['NN', 'NNP', 'NNP', 'NNPS', 'NNS']
    # adjectives
    jj_tags = ['JJ', 'JJR', 'JJS']
    # verbs
    vb_tags = ['VB', 'VBD', 'VBG', 'VBN', 'VBP', 'VBZ']
    nltk_tags = nn_tags + jj_tags + vb_tags

    # break string into 'words'
    text = data_str.split()

    # tag the text and keep only those with the right tags
    tagged_text = pos_tag(text)
    for tagged_word in tagged_text:
        if tagged_word[1] in nltk_tags:
            cleaned_str += tagged_word[0] + ' '

    return cleaned_str

```

- lemmatization

```

# lemmatization
def lemmatize(data_str):
    # expects a string
    list_pos = 0
    cleaned_str = ''
    lmtzr = WordNetLemmatizer()
    text = data_str.split()
    tagged_words = pos_tag(text)
    for word in tagged_words:
        if 'v' in word[1].lower():
            lemma = lmtzr.lemmatize(word[0], pos='v')
        else:
            lemma = lmtzr.lemmatize(word[0], pos='n')
        if list_pos == 0:
            cleaned_str = lemma
        else:
            cleaned_str = cleaned_str + ' ' + lemma
        list_pos += 1

```

```
    return cleaned_str

• setup pyspark udf function

# setup pyspark udf function
strip_non_ascii_udf = udf(strip_non_ascii, StringType())
check_blanks_udf = udf(check_blanks, StringType())
check_lang_udf = udf(check_lang, StringType())
fix_abbreviation_udf = udf(fix_abbreviation, StringType())
remove_stops_udf = udf(remove_stops, StringType())
remove_features_udf = udf(remove_features, StringType())
tag_and_remove_udf = udf(tag_and_remove, StringType())
lemmatize_udf = udf(lemmatize, StringType())
```

1. Text processing

- correct the data schema

```
rawdata = rawdata.withColumn('rating', rawdata.rating.cast('float'))

rawdata.printSchema()

root
|-- id: string (nullable = true)
|-- airline: string (nullable = true)
|-- date: string (nullable = true)
|-- location: string (nullable = true)
|-- rating: float (nullable = true)
|-- cabin: string (nullable = true)
|-- value: string (nullable = true)
|-- recommended: string (nullable = true)
|-- review: string (nullable = true)

from datetime import datetime
from pyspark.sql.functions import col

# https://docs.python.org/2/library/datetime.html#strftime-and-strptime-behavior
# 21-Jun-14 <----> %d-%b-%y
to_date = udf (lambda x: datetime.strptime(x, '%d-%b-%y'), DateType())

rawdata = rawdata.withColumn('date', to_date(col('date')))

rawdata.printSchema()

root
|-- id: string (nullable = true)
|-- airline: string (nullable = true)
|-- date: date (nullable = true)
|-- location: string (nullable = true)
|-- rating: float (nullable = true)
|-- cabin: string (nullable = true)
|-- value: string (nullable = true)
|-- recommended: string (nullable = true)
|-- review: string (nullable = true)

rawdata.show(5)
```

```
+-----+-----+-----+-----+-----+-----+
|   id|      airline|      date|location|rating|    cabin|value|recommended|
+-----+-----+-----+-----+-----+-----+
|10551|Southwest Airlines|2013-11-06|     USA|    1.0|Business|    2|    NO|Flight|
|10298|        US Airways|2014-03-31|     UK|    1.0|Business|    0|    NO|Flight|
|10564|Southwest Airlines|2013-09-06|     USA|   10.0| Economy|    5| YES|I'm|
|10134|    Delta Air Lines|2013-12-10|     USA|    8.0| Economy|    4| YES|MSP|
|10912|    United Airlines|2014-04-07|     USA|    3.0| Economy|    1|    NO|Work|
+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

rawdata = rawdata.withColumn('non_ascii', strip_non_ascii_udf(rawdata['review']))

+-----+-----+-----+-----+-----+-----+
|   id|      airline|      date|location|rating|    cabin|value|recommended|
+-----+-----+-----+-----+-----+-----+
|10551|Southwest Airlines|2013-11-06|     USA|    1.0|Business|    2|    NO|Flight|
|10298|        US Airways|2014-03-31|     UK|    1.0|Business|    0|    NO|Flight|
|10564|Southwest Airlines|2013-09-06|     USA|   10.0| Economy|    5| YES|I'm|
|10134|    Delta Air Lines|2013-12-10|     USA|    8.0| Economy|    4| YES|MSP|
|10912|    United Airlines|2014-04-07|     USA|    3.0| Economy|    1|    NO|Work|
+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

rawdata = rawdata.select(raw_cols+['non_ascii']) \
    .withColumn('fixed_abbrev', fix_abbreviation_udf(rawdata['non_ascii']))

+-----+-----+-----+-----+-----+-----+
|   id|      airline|      date|location|rating|    cabin|value|recommended|
+-----+-----+-----+-----+-----+-----+
|10551|Southwest Airlines|2013-11-06|     USA|    1.0|Business|    2|    NO|Flight|
|10298|        US Airways|2014-03-31|     UK|    1.0|Business|    0|    NO|Flight|
|10564|Southwest Airlines|2013-09-06|     USA|   10.0| Economy|    5| YES|I'm|
|10134|    Delta Air Lines|2013-12-10|     USA|    8.0| Economy|    4| YES|MSP|
|10912|    United Airlines|2014-04-07|     USA|    3.0| Economy|    1|    NO|Work|
+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

rawdata = rawdata.select(raw_cols+['fixed_abbrev']) \
    .withColumn('stop_text', remove_stops_udf(rawdata['fixed_abbrev']))

+-----+-----+-----+-----+-----+-----+
|   id|      airline|      date|location|rating|    cabin|value|recommended|
+-----+-----+-----+-----+-----+-----+
|10551|Southwest Airlines|2013-11-06|     USA|    1.0|Business|    2|    NO|Flight|
|10298|        US Airways|2014-03-31|     UK|    1.0|Business|    0|    NO|Flight|
|10564|Southwest Airlines|2013-09-06|     USA|   10.0| Economy|    5| YES|I'm|
|10134|    Delta Air Lines|2013-12-10|     USA|    8.0| Economy|    4| YES|MSP|
|10912|    United Airlines|2014-04-07|     USA|    3.0| Economy|    1|    NO|Work|
+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

rawdata = rawdata.select(raw_cols+['stop_text']) \
    .withColumn('feat_text', remove_features_udf(rawdata['stop_text']))
```

```

|   id|      airline|      date|location|rating|    cabin|value|recommended|
+----+-----+-----+-----+-----+-----+-----+-----+
|10551|Southwest Airlines|2013-11-06|     USA|    1.0|Business|    2|    NO|Fli
|10298|        US Airways|2014-03-31|     UK|    1.0|Business|    0|    NO|Fli
|10564|Southwest Airlines|2013-09-06|     USA|   10.0| Economy|    5| YES|I'm
|10134|    Delta Air Lines|2013-12-10|     USA|    8.0| Economy|    4| YES|MSP
|10912|    United Airlines|2014-04-07|     USA|    3.0| Economy|    1|    NO|Wor
+----+-----+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

rawdata = rawdata.select(raw_cols+['feat_text']) \
    .withColumn('tagged_text',tag_and_remove_udf(rawdata['feat_text']))

+----+-----+-----+-----+-----+-----+-----+-----+
|   id|      airline|      date|location|rating|    cabin|value|recommended|
+----+-----+-----+-----+-----+-----+-----+-----+
|10551|Southwest Airlines|2013-11-06|     USA|    1.0|Business|    2|    NO|Fli
|10298|        US Airways|2014-03-31|     UK|    1.0|Business|    0|    NO|Fli
|10564|Southwest Airlines|2013-09-06|     USA|   10.0| Economy|    5| YES|I'm
|10134|    Delta Air Lines|2013-12-10|     USA|    8.0| Economy|    4| YES|MSP
|10912|    United Airlines|2014-04-07|     USA|    3.0| Economy|    1|    NO|Wor
+----+-----+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

rawdata = rawdata.select(raw_cols+['tagged_text']) \
    .withColumn('lemm_text',lemmatize_udf(rawdata['tagged_text']))


+----+-----+-----+-----+-----+-----+-----+-----+
|   id|      airline|      date|location|rating|    cabin|value|recommended|
+----+-----+-----+-----+-----+-----+-----+-----+
|10551|Southwest Airlines|2013-11-06|     USA|    1.0|Business|    2|    NO|Fli
|10298|        US Airways|2014-03-31|     UK|    1.0|Business|    0|    NO|Fli
|10564|Southwest Airlines|2013-09-06|     USA|   10.0| Economy|    5| YES|I'm
|10134|    Delta Air Lines|2013-12-10|     USA|    8.0| Economy|    4| YES|MSP
|10912|    United Airlines|2014-04-07|     USA|    3.0| Economy|    1|    NO|Wor
+----+-----+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

rawdata = rawdata.select(raw_cols+['lemm_text']) \
    .withColumn("is_blank", check_blanks_udf(rawdata["lemm_text"]))

+----+-----+-----+-----+-----+-----+-----+-----+
|   id|      airline|      date|location|rating|    cabin|value|recommended|
+----+-----+-----+-----+-----+-----+-----+-----+
|10551|Southwest Airlines|2013-11-06|     USA|    1.0|Business|    2|    NO|Fli
|10298|        US Airways|2014-03-31|     UK|    1.0|Business|    0|    NO|Fli
|10564|Southwest Airlines|2013-09-06|     USA|   10.0| Economy|    5| YES|I'm
|10134|    Delta Air Lines|2013-12-10|     USA|    8.0| Economy|    4| YES|MSP
|10912|    United Airlines|2014-04-07|     USA|    3.0| Economy|    1|    NO|Wor
+----+-----+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

from pyspark.sql.functions import monotonically_increasing_id
# Create Unique ID
rawdata = rawdata.withColumn("uid", monotonically_increasing_id())

```

```

data = rawdata.filter(rawdata["is_blank"] == "False")

+-----+-----+-----+-----+-----+-----+
| id | airline | date | location | rating | cabin | value | recommended |
+-----+-----+-----+-----+-----+-----+
| 10551 | Southwest Airlines | 2013-11-06 | USA | 1.0 | Business | 2 | NO | Fli
| 10298 | US Airways | 2014-03-31 | UK | 1.0 | Business | 0 | NO | Fli
| 10564 | Southwest Airlines | 2013-09-06 | USA | 10.0 | Economy | 5 | YES | I'm
| 10134 | Delta Air Lines | 2013-12-10 | USA | 8.0 | Economy | 4 | YES | MSP
| 10912 | United Airlines | 2014-04-07 | USA | 3.0 | Economy | 1 | NO | Wor
+-----+-----+-----+-----+-----+-----+
only showing top 5 rows

```

Pipeline for LDA model

```

from pyspark.ml.feature import HashingTF, IDF, Tokenizer
from pyspark.ml import Pipeline
from pyspark.ml.classification import NaiveBayes, RandomForestClassifier
from pyspark.ml.clustering import LDA
from pyspark.ml.classification import DecisionTreeClassifier
from pyspark.ml.evaluation import MulticlassClassificationEvaluator
from pyspark.ml.tuning import ParamGridBuilder
from pyspark.ml.tuning import CrossValidator
from pyspark.ml.feature import IndexToString, StringIndexer, VectorIndexer
from pyspark.ml.feature import CountVectorizer

# Configure an ML pipeline, which consists of tree stages: tokenizer, hashingTF, an
tokenizer = Tokenizer(inputCol="lemm_text", outputCol="words")
#data = tokenizer.transform(data)
vectorizer = CountVectorizer(inputCol= "words", outputCol="rawFeatures")
idf = IDF(inputCol="rawFeatures", outputCol="features")
#idfModel = idf.fit(data)

lda = LDA(k=20, seed=1, optimizer="em")

pipeline = Pipeline(stages=[tokenizer, vectorizer,idf, lda])

model = pipeline.fit(data)

```

1. Results presentation

- Topics

```

+-----+-----+-----+
| topic | termIndices | termWeights |
+-----+-----+-----+
| 0|[60, 7, 12, 483, ...|[0.01349507958269...|
| 1|[363, 29, 187, 55....|[0.01247250144447...|
| 2|[46, 107, 672, 27....|[0.01188684264641...|
| 3|[76, 43, 285, 152....|[0.01132638300115...|
| 4|[201, 13, 372, 69....|[0.01337529863256...|
| 5|[122, 103, 181, 4....|[0.00930415977117...|
| 6|[14, 270, 18, 74,...|[0.01253817708163...|
| 7|[111, 36, 341, 10....|[0.01269584954257...|
| 8|[477, 266, 297, 1....|[0.01017486869509...|
| 9|[10, 73, 46, 1, 2....|[0.01050875237546...|
| 10|[57, 29, 411, 10,...|[0.01777350667863...|

```

```

| 11|[293, 119, 385, 4...|[0.01280305149305...
| 12|[116, 218, 256, 1...|[0.01570714218509...
| 13|[433, 171, 176, 3...|[0.00819684813575...
| 14|[74, 84, 45, 108,...|[0.01700630002172...
| 15|[669, 215, 14, 58...|[0.00779310974971...
| 16|[198, 21, 98, 164...|[0.01030577084202...
| 17|[96, 29, 569, 444...|[0.01297142577633...
| 18|[18, 60, 140, 64,...|[0.01306356985169...
| 19|[33, 178, 95, 2, ...|[0.00907425683229...
+-----+-----+

```

- Topic terms

```

from pyspark.sql.types import ArrayType, StringType

def termsIdx2Term(vocabulary):
    def termsIdx2Term(termIndices):
        return [vocabulary[int(index)] for index in termIndices]
    return udf(termsIdx2Term, ArrayType(StringType()))

```

vectorizerModel = model.stages[1]
vocabList = vectorizerModel.vocabulary
final = ldatopics.withColumn("Terms", termsIdx2Term(vocabList) ("termIndices"))

topic	termIndices	Terms
0	[60, 7, 12, 483, 292, 326, 88, 4, 808, 32]	pm, plane, board, kid, onl
1	[363, 29, 187, 55, 48, 647, 30, 9, 204, 457]	dublin, class, th, sit, en
2	[46, 107, 672, 274, 92, 539, 23, 27, 279, 8]	economy, sfo, milwaukee, d
3	[76, 43, 285, 152, 102, 34, 300, 113, 24, 31]	didn, pay, lose, different
4	[201, 13, 372, 692, 248, 62, 211, 187, 105, 110]	houstan, crew, heathrow, l
5	[122, 103, 181, 48, 434, 10, 121, 147, 934, 169]	1hr, serve, screen, entert
6	[14, 270, 18, 74, 70, 37, 16, 450, 3, 20]	check, employee, gate, lin
7	[111, 36, 341, 10, 320, 528, 844, 19, 195, 524]	atlanta, first, toilet, de
8	[477, 266, 297, 185, 1, 33, 22, 783, 17, 908]	fuel, group, pas, boarding
9	[10, 73, 46, 1, 248, 302, 213, 659, 48, 228]	delta, lax, economy, seat,
10	[57, 29, 411, 10, 221, 121, 661, 19, 805, 733]	business, class, fra, delt
11	[293, 119, 385, 481, 503, 69, 13, 87, 176, 545]	march, ua, manchester, phx
12	[116, 218, 256, 156, 639, 20, 365, 18, 22, 136]	san, clt, francisco, secon
13	[433, 171, 176, 339, 429, 575, 10, 26, 474, 796]	daughter, small, aa, ba, s
14	[74, 84, 45, 108, 342, 111, 315, 87, 52, 4]	line, agent, next, hotel,
15	[669, 215, 14, 58, 561, 59, 125, 179, 93, 5]	fit, carry, check, people,
16	[198, 21, 98, 164, 57, 141, 345, 62, 121, 174]	ife, good, nice, much, bus
17	[96, 29, 569, 444, 15, 568, 21, 103, 657, 505]	phl, class, diego, lady, f
18	[18, 60, 140, 64, 47, 40, 31, 35, 2, 123]	gate, pm, phoenix, connect
19	[33, 178, 95, 2, 9, 284, 42, 4, 89, 31]	trip, counter, philadelphi

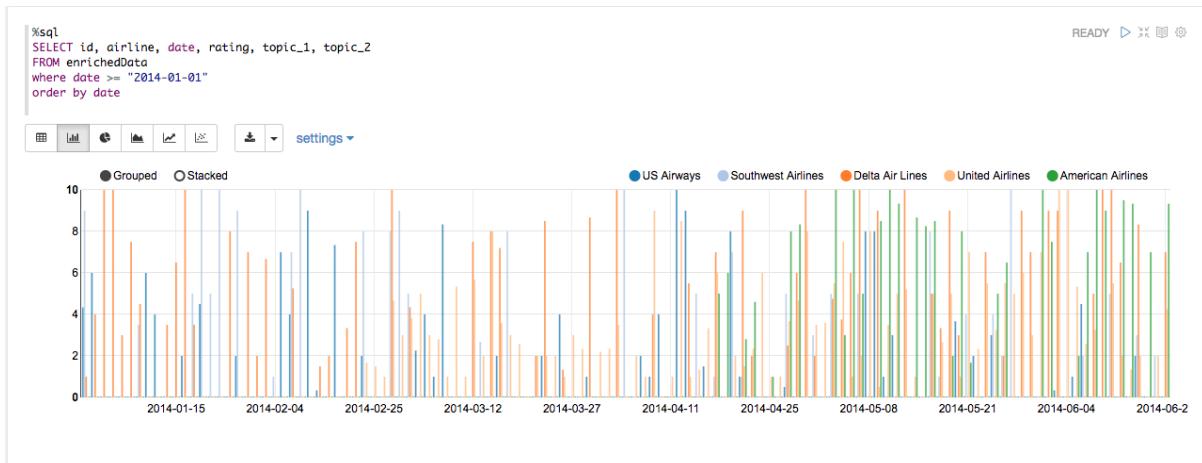
- LDA results

id	airline	date	cabin	rating	words
10551	Southwest Airlines	2013-11-06	Business	1.0	[flight, chicago,...](4695,
10298	US Airways	2014-03-31	Business	1.0	[flight, manchest...](4695,
10564	Southwest Airlines	2013-09-06	Economy	10.0	[executive, plati...](4695,
10134	Delta Air Lines	2013-12-10	Economy	8.0	[msp, jfk, mxp, r...](4695,

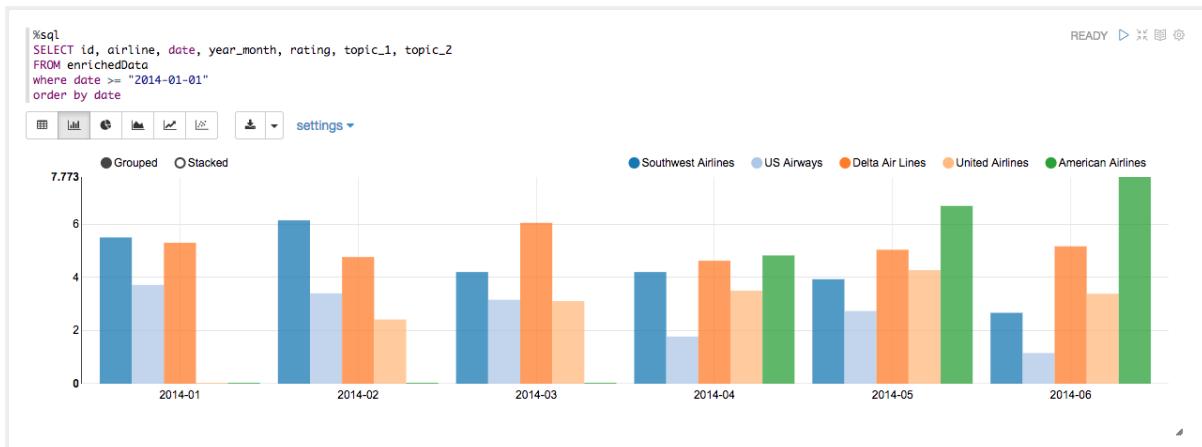
```

| 10912 | United Airlines | 2014-04-07 | Economy | 3.0 | [worst, airline, ...] | (4695,
| 10089 | Delta Air Lines | 2014-02-18 | Economy | 2.0 | [dl, mia, lax, im...] | (4695,
| 10385 | US Airways | 2013-10-21 | Economy | 10.0 | [flew, gla, phl, ...] | (4695,
| 10249 | US Airways | 2014-06-17 | Economy | 1.0 | [friend, book, fl...] | (4695,
| 10289 | US Airways | 2014-04-12 | Economy | 10.0 | [flew, air, rome,...] | (4695,
| 10654 | Southwest Airlines | 2012-07-10 | Economy | 8.0 | [lhr, jfk, think,...] | (4695,
| 10754 | American Airlines | 2014-05-04 | Economy | 10.0 | [san, diego, moli...] | (4695,
| 10646 | Southwest Airlines | 2012-08-17 | Economy | 7.0 | [toledo, co, stop...] | (4695,
| 10097 | Delta Air Lines | 2014-02-03 | First Class | 10.0 | [honolulu, la, fi...] | (4695,
| 10132 | Delta Air Lines | 2013-12-16 | Economy | 7.0 | [manchester, uk, ...] | (4695,
| 10560 | Southwest Airlines | 2013-09-20 | Economy | 9.0 | [first, time, sou...] | (4695,
| 10579 | Southwest Airlines | 2013-07-25 | Economy | 0.0 | [plane, land, pm,...] | (4695,
| 10425 | US Airways | 2013-08-06 | Economy | 3.0 | [airway, bad, pro...] | (4695,
| 10650 | Southwest Airlines | 2012-07-27 | Economy | 9.0 | [flew, jfk, lhr, ...] | (4695,
| 10260 | US Airways | 2014-06-03 | Economy | 1.0 | [february, air, u...] | (4695,
| 10202 | Delta Air Lines | 2013-09-14 | Economy | 10.0 | [aug, lhr, jfk, b...] | (4695,
+-----+-----+-----+-----+-----+-----+
only showing top 20 rows
    
```

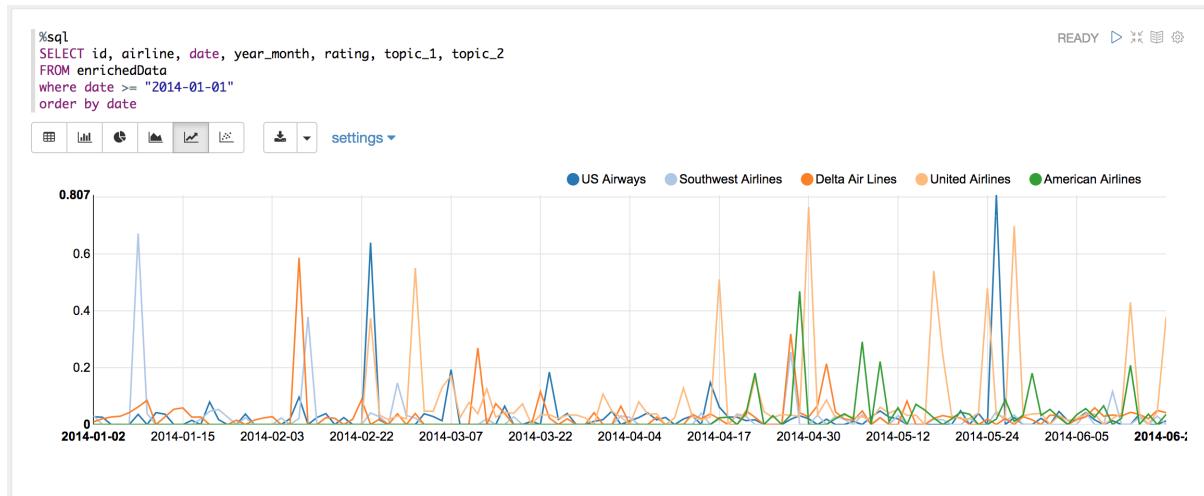
- Average rating and airlines for each day



- Average rating and airlines for each month



- Topic 1 corresponding to time line
- reviews (documents) relate to topic 1

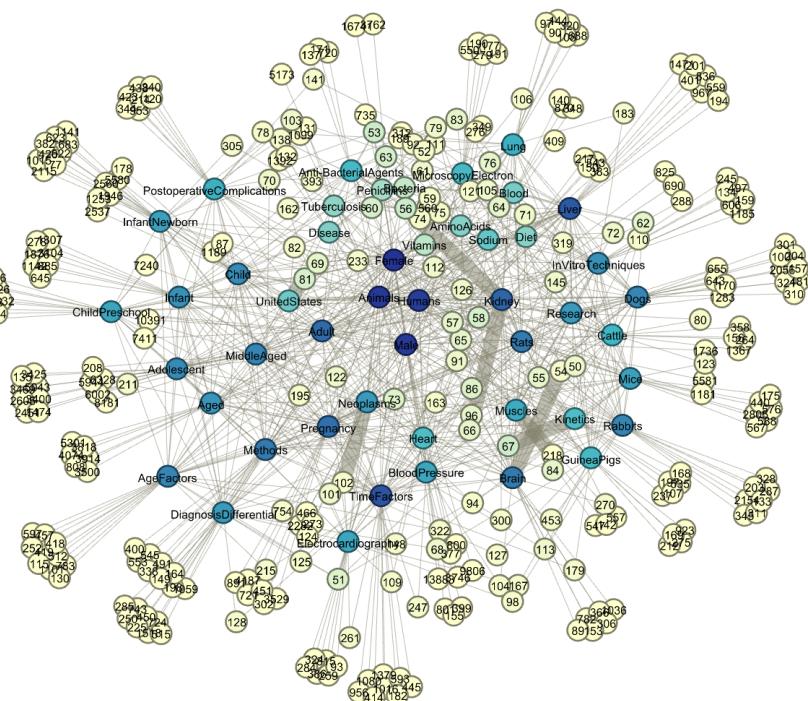


	id	airline	date	review
10263	US Airways	2014-05-25	"Delays on all booked flights. Outward bound - Dublin to Philadelphia Philadelphia to Vegas. Vegas to LA. Baggage did not arrive some hours later. Cabin staff were unfriendly and quite rude. From Dublin We were sitting at the back of the plane and we were told "thats what you get when you travel at the back" . I opened my little tub of butter which had been heated in hot liquid and went all over my hand. I said to the stewardess who was passing by who could have brought me a napkin to speed by saying "oh I know that happens". Only that I had a tray of food on my lap she would have had more to deal with! All baggage was to be stored in the overhead lockers or underneath the seat in front. This obviously does not apply to cabin staff back centre aisle seats of the plane it was not secured in any way. Their baggage was a danger to all the passengers in that is what they preach and put staff baggage in the hold. Cabin crew were ungracious in appearance. Homeward bound to Dublin delayed resulting in us overnighting in Orlando very grateful for the overnight accommodation provided at the Hyatt. Flew to Orlando Boarding for Dublin at Charlotte was very confused and inefficiently exercised by Gate staff - resulting in delay in take-off. Enjoyed quality on those flights that had the facility. General impression overall. Very Disappointing."	

SOCIAL NETWORK ANALYSIS

Chinese proverb

A Touch of Cloth, linked in countless ways. – old Chinese proverb



14.2.1 Methodology

- Build Corpus C
- Build Document-Term matrix D based on Corpus C
- Compute Term-Document matrix D^T
- Adjacency Matrix $A = D^T \cdot D$

There are four main components in this algorithm in the algorithm: Corpus C, Document-Term matrix D, Term-Document matrix D^T and Adjacency Matrix A. In this demo part, I will show how to build those four main components.

Given that we have three groups of friends, they are

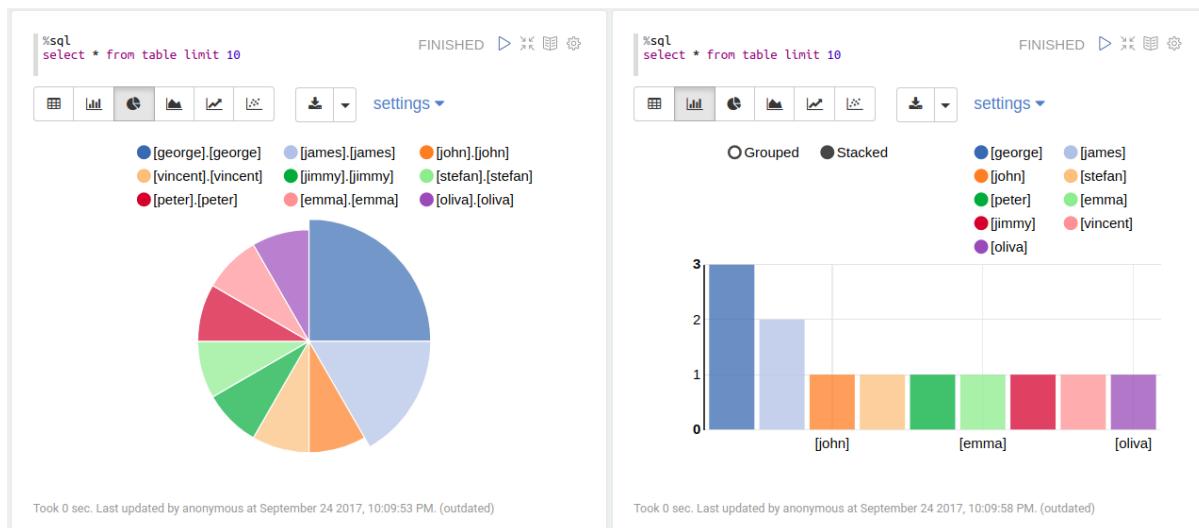
```
+-----+
| words
+-----+
|[ [george] [jimmy] [john] [peter] ] |
|[ [vincent] [george] [stefan] [james] ] |
|[ [emma] [james] [olivia] [george] ] |
+-----+
```

1. Corpus C

Then we can build the following corpus based on the unique elements in the given group data:

```
[u'george', u'james', u'jimmy', u'peter', u'stefan', u'vencent', u'olivia', u'john'
```

The corresponding elements frequency:



2. Document-Term matrix D based on Corpus C (CountVectorizer)

```
from pyspark.ml.feature import CountVectorizer
count_vectorizer_wo = CountVectorizer(inputCol='term', outputCol='features')
# with total unique vocabulary
countVectorizer_mod_wo = count_vectorizer_wo.fit(df)
countVectorizer_twitter_wo = countVectorizer_mod_wo.transform(df)
# with truncated unique vocabulary (99%)
count_vectorizer = CountVectorizer(vocabSize=48, inputCol='term', outputCol='features')
```

```

countVectorizer_mod = count_vectorizer.fit(df)
countVectorizer_twitter = countVectorizer_mod.transform(df)

+-----+
| features
+-----+
|(9,[0,2,3,7],[1.0,1.0,1.0,1.0])|
|(9,[0,1,4,5],[1.0,1.0,1.0,1.0])|
|(9,[0,1,6,8],[1.0,1.0,1.0,1.0])|
+-----+
    
```

- Term-Document matrix D^T

RDD:

```
[array([[ 1.,  1.,  1.], [ 0.,  1.,  1.], [ 1.,  0.,  0.], [ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 1.,  0.,  0.], [ 0.,  0.,  1.]]), array([[ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 0.,  0.,  0.], [ 1.,  0.,  0.], [ 0.,  0.,  1.]]), array([[ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 0.,  0.,  0.], [ 0.,  1.,  0.], [ 1.,  0.,  0.]])]
```

Matrix:

```
array([[ 1.,  1.,  1.], [ 0.,  1.,  1.], [ 1.,  0.,  0.], [ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 1.,  0.,  0.], [ 0.,  0.,  1.]])
```

3. Adjacency Matrix $A = D^T \cdot D$

RDD:

```
[array([[ 1.,  1.,  1.], [ 0.,  1.,  1.], [ 1.,  0.,  0.], [ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 1.,  0.,  0.], [ 0.,  0.,  1.]]), array([[ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 0.,  0.,  0.], [ 0.,  1.,  0.], [ 1.,  0.,  0.]]), array([[ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 1.,  0.,  0.], [ 0.,  1.,  0.], [ 0.,  0.,  1.], [ 0.,  0.,  0.], [ 0.,  1.,  0.], [ 1.,  0.,  0.]])]
```

Matrix:

```
array([[ 3.,  2.,  1.,  1.,  1.,  1.,  1.,  1.,  1.], [ 2.,  2.,  0.,  0.,  1.,  1.,  1.,  0.,  1.], [ 1.,  0.,  1.,  1.,  0.,  0.,  0.,  1.,  0.], [ 1.,  0.,  1.,  1.,  0.,  0.,  0.,  1.,  0.], [ 1.,  1.,  0.,  0.,  1.,  1.,  0.,  0.,  0.], [ 1.,  1.,  0.,  0.,  1.,  1.,  0.,  0.,  0.], [ 1.,  1.,  0.,  0.,  0.,  0.,  1.,  0.,  1.], [ 1.,  0.,  1.,  1.,  0.,  0.,  0.,  1.,  0.], [ 1.,  1.,  0.,  0.,  0.,  0.,  1.,  0.,  1.]])
```

14.2.2 Coding Puzzle from my interview

- Problem

The attached utf-8 encoded text file contains the tags associated with an online biomedical scientific article formatted as follows (size: 100000). Each Scientific article is represented by a line in the file delimited by carriage return.

```
+-----+
|          words |
+-----+
| [ACTH Syndrome, E... |
| [Antibody Formati... |
| [Adaptation, Phys... |
| [Aerosol Propella... |
+-----+
only showing top 4 rows
```

Write a program that, using this file as input, produces a list of pairs of tags which appear TOGETHER in any order and position in at least fifty different Scientific articles. For example, in the above sample, [Female] and [Humans] appear together twice, but every other pair appears only once. Your program should output the pair list to stdout in the same form as the input (eg tag 1, tag 2n).

- My solution

The corresponding words frequency:

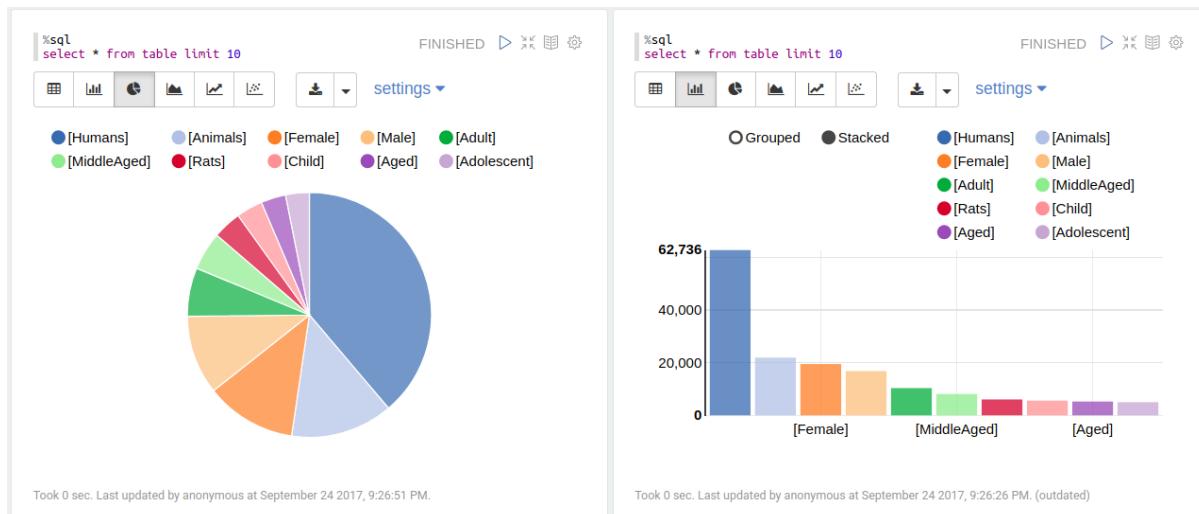


Figure 14.1: Word frequency

Output:

```
+-----+-----+-----+
|      term.x|term.y|    freq|
+-----+-----+-----+
|   Female| Humans| 16741.0 |
|     Male| Humans| 13883.0 |
|   Adult| Humans| 10391.0 |
|     Male| Female|  9806.0 |
|MiddleAged| Humans|  8181.0 |
|   Adult| Female|  7411.0 |
|     Adult|  Male|  7240.0 |
|MiddleAged|  Male|  6328.0 |
|MiddleAged| Female|  6002.0 |
|MiddleAged| Adult|  5944.0 |
+-----+-----+-----+
only showing top 10 rows
```

The corresponding Co-occurrence network:

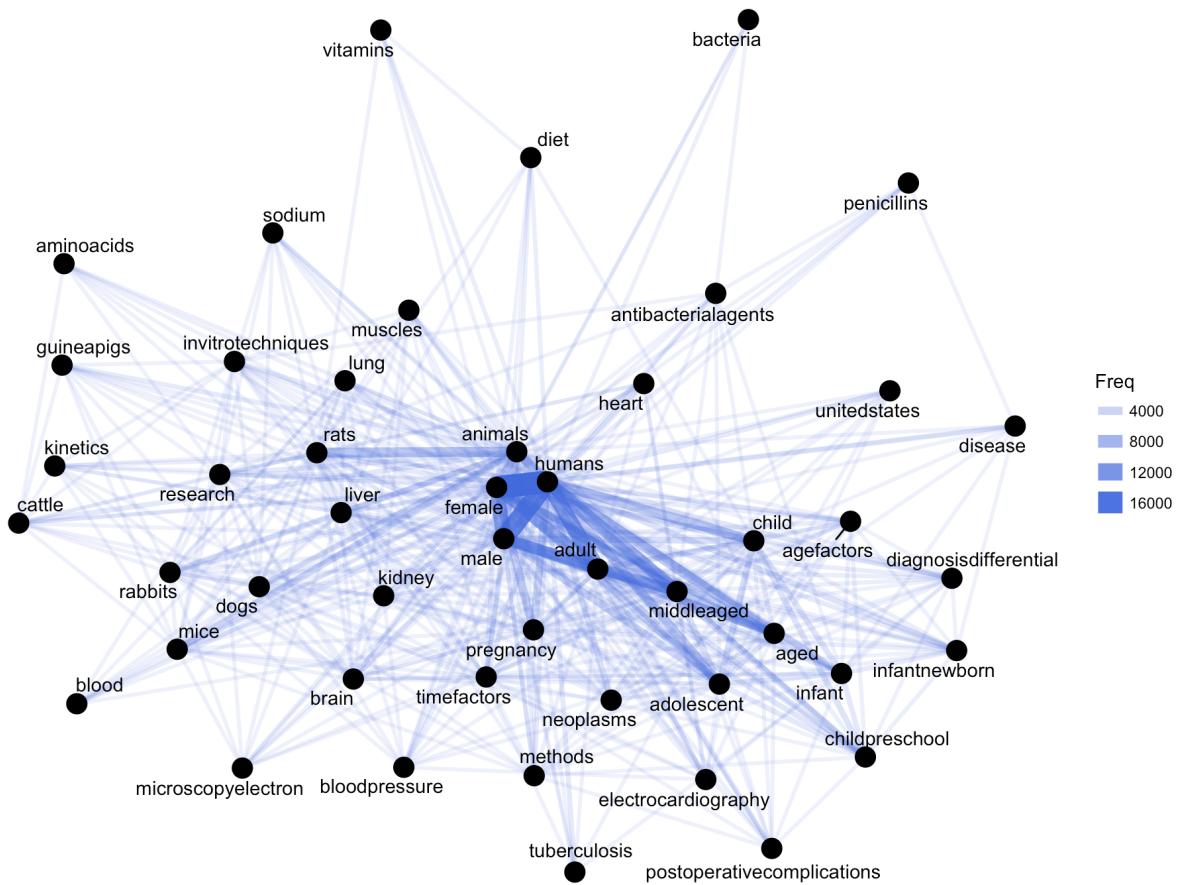


Figure 14.2: Co-occurrence network

Then you will get Figure *Co-occurrence network*

14.3 Appendix: matrix multiplication in PySpark

1. load test matrix

```
df = spark.read.csv("matrix1.txt", sep=",", inferSchema=True)
df.show()
```

```
+---+---+---+---+
| _c0 | _c1 | _c2 | _c3 |
+---+---+---+---+
| 1.2 | 3.4 | 2.3 | 1.1 |
| 2.3 | 1.1 | 1.5 | 2.2 |
| 3.3 | 1.8 | 4.5 | 3.3 |
| 5.3 | 2.2 | 4.5 | 4.4 |
| 9.3 | 8.1 | 0.3 | 5.5 |
| 4.5 | 4.3 | 2.1 | 6.6 |
+---+---+---+---+
```

2. main function for matrix multiplication in PySpark

```

from pyspark.sql import functions as F
from functools import reduce
# reference: https://stackoverflow.com/questions/44348527/matrix-multiplication-at-a-time
# do the sum of the multiplication that we want, and get
# one data frame for each column
colDFs = []
for c2 in df.columns:
    colDFs.append( df.select( [ F.sum(df[c1]*df[c2]).alias("op_{0}".format(i)) for i,c1
    # now union those separate data frames to build the "matrix"
    mtxDF = reduce(lambda a,b: a.select(a.columns).union(b.select(a.columns)), colDFs )
    mtxDF.show()

+-----+-----+-----+-----+
|      op_0 |      op_1 |      op_2 |      op_3 |
+-----+-----+-----+-----+
| 152.45 | 118.8899999999999 | 57.15 | 121.44000000000001 |
| 118.8899999999999 | 104.9499999999999 | 38.93 | 94.71 |
| 57.15 | 38.93 | 52.54000000000006 | 55.99 |
| 121.4400000000001 | 94.71 | 55.99 | 110.1099999999999 |
+-----+-----+-----+-----+

```

3. Validation with python version

```

import numpy as np
a = np.genfromtxt("matrix1.txt", delimiter=",")
np.dot(a.T, a)

array([[152.45, 118.89, 57.15, 121.44],
       [118.89, 104.95, 38.93, 94.71],
       [57.15, 38.93, 52.54, 55.99],
       [121.44, 94.71, 55.99, 110.11]])

```

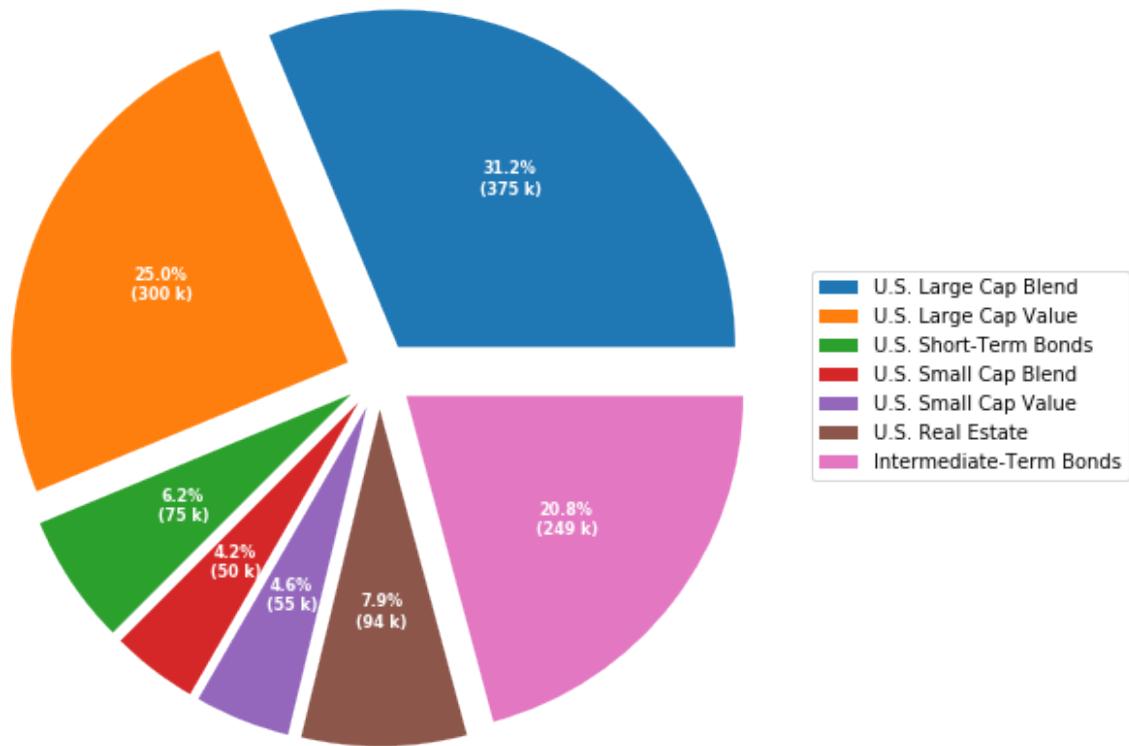
14.4 Correlation Network

TODO ..

ALS: STOCK PORTFOLIO RECOMMENDATIONS

Chinese proverb

Don't put all your eggs in one basket.



Code for the above figure:

```
import numpy as np
import matplotlib.pyplot as plt

fig, ax = plt.subplots(figsize=(10, 8), subplot_kw=dict(aspect="equal"))

recipe = ["375 k U.S. Large Cap Blend",
          "300 k U.S. Large Cap Value",
          "75 k U.S. Short-Term Bonds",
          "50 k U.S. Small Cap Blend",
          "55 k U.S. Small Cap Value",
          "94 k U.S. Real Estate",
          "249 k Intermediate-Term Bonds"]
```

```

    "55 k U.S. Small Cap Value",
    "95 k U.S. Real Estate",
    "250 k Intermediate-Term Bonds"]

data = [float(x.split()[0]) for x in recipe]
ingredients = [' '.join(x.split()[2:]) for x in recipe]

print(data)
print(ingredients)
def func(pct, allvals):
    absolute = int(pct/100.*np.sum(allvals))
    return "{:.1f}{}\n{:d} k".format(pct, absolute)

explode = np.empty(len(data)) #(0.1, 0.1, 0.1, 0.1, 0.1, 0.1) # explode 1st slice
explode.fill(0.1)

wedges, texts, autotexts = ax.pie(data, explode=explode, autopct=lambda pct: func(pct,
    textprops=dict(color="w")))
ax.legend(wedges, ingredients,
    title="Stock portfolio",
    loc="center left",
    bbox_to_anchor=(1, 0, 0.5, 1))

plt.setp(autotexts, size=8, weight="bold")

#ax.set_title("Stock portfolio")

plt.show()

```

15.1 Recommender systems

Recommender systems or recommendation systems (sometimes replacing “system” with a synonym such as platform or engine) are a subclass of information filtering system that seek to predict the “rating” or “preference” that a user would give to an item.”

The main idea is to build a matrix users R items rating values and try to factorize it, to recommend main products rated by other users. A popular approach for this is matrix factorization is Alternating Least Squares (ALS)

15.2 Alternating Least Squares

Apache Spark ML implements ALS for collaborative filtering, a very popular algorithm for making recommendations.

ALS recommender is a matrix factorization algorithm that uses Alternating Least Squares with Weighted-Lambda-Regularization (ALS-WR). It factors the user to item matrix A into the user-to-feature matrix U and the item-to-feature matrix M: It runs the ALS algorithm in a parallel fashion. The ALS algorithm should uncover the latent factors that explain the observed user to item ratings and tries to find optimal factor weights to minimize the least squares between predicted and actual ratings.

<https://www.elenacuoco.com/2016/12/22/alternating-least-squares-als-spark-ml/>

15.3 Demo

- The Jupyter notebook can be download from ALS Recommender systems.
- The data can be downloaf from German Credit.

15.3.1 Load and clean data

1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark RFM example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
```

2. Load dataset

```
df_raw = spark.read.format('com.databricks.spark.csv') \
    .options(header='true', \
             inferschema='true') \
    .load("Online Retail.csv", header=True);
```

check the data set

```
df_raw.show(5)
df_raw.printSchema()
```

Then you will get

InvoiceNo	StockCode	Description	Quantity	InvoiceDate	UnitPrice	CustomerID	Country
536365	85123A	WHITE HANGING HEA...	6	12/1/10 8:26	2.55	17850	United Kingdom
536365	71053	WHITE METAL LANTERN	6	12/1/10 8:26	3.39	17850	United Kingdom
536365	84406B	CREAM CUPID HEART...	8	12/1/10 8:26	2.75	17850	United Kingdom
536365	84029G	KNITTED UNION FLA...	6	12/1/10 8:26	3.39	17850	United Kingdom
536365	84029E	RED WOOLLY HOTTIE...	6	12/1/10 8:26	3.39	17850	United Kingdom

only showing top 5 rows

```
root
|-- InvoiceNo: string (nullable = true)
|-- StockCode: string (nullable = true)
|-- Description: string (nullable = true)
|-- Quantity: integer (nullable = true)
|-- InvoiceDate: string (nullable = true)
|-- UnitPrice: double (nullable = true)
|-- CustomerID: integer (nullable = true)
|-- Country: string (nullable = true)
```

3. Data clean and data manipulation

- check and remove the null values

```

from pyspark.sql.functions import count

def my_count(df_in):
    df_in.agg( *[ count(c).alias(c) for c in df_in.columns ] ).show()

import pyspark.sql.functions as F
from pyspark.sql.functions import round
df_raw = df_raw.withColumn('Asset',round( F.col('Quantity') * F.col('UnitPrice'), 2 ))
df = df_raw.withColumnRenamed('StockCode', 'Cusip')\
    .select('CustomerID','Cusip','Quantity','UnitPrice','Asset')

my_count(df)

+-----+-----+-----+-----+
|CustomerID| Cusip|Quantity|UnitPrice| Asset |
+-----+-----+-----+-----+
|      406829| 541909|   541909|     541909| 541909|
+-----+-----+-----+-----+

```

Since the count results are not the same, we have some null value in the CustomerID column. We can drop these records from the dataset.

```

df = df.filter(F.col('Asset')>=0)
df = df.dropna(how='any')
my_count(df)

+-----+-----+-----+-----+
|CustomerID| Cusip|Quantity|UnitPrice| Asset |
+-----+-----+-----+-----+
|      397924| 397924|   397924|     397924| 397924|
+-----+-----+-----+-----+

```

```

df.show(3)

+-----+-----+-----+-----+
|CustomerID| Cusip|Quantity|UnitPrice|Asset |
+-----+-----+-----+-----+
|      17850| 85123A|       6|     2.55| 15.3|
|      17850|  71053|       6|     3.39| 20.34|
|      17850| 84406B|       8|     2.75| 22.0|
+-----+-----+-----+-----+
only showing top 3 rows

```

- Convert the Cusip to consistent format

```

from pyspark.sql.functions import udf
from pyspark.sql.types import StringType, DoubleType

def toUpper(s):
    return s.upper()

upper_udf = udf(lambda x: toUpper(x), StringType())

```

- Find the most top n stocks

```

pop = df.groupBy('Cusip')\
    .agg(F.count('CustomerID').alias('Customers'),F.round(F.sum('Asset'),2).alias('TotalAssets'))\
    .sort([F.col('Customers'),F.col('TotalAssets')],ascending=[0,0])

```

```
pop.show(5)

+-----+-----+
| Cusip|Customers|TotalAsset|
+-----+-----+
| 85123A|    2035| 100603.5|
| 22423|    1724| 142592.95|
| 85099B|    1618| 85220.78|
| 84879|    1408| 56580.34|
| 47566|    1397| 68844.33|
+-----+-----+
only showing top 5 rows
```

Build feature matrix -----+

- Fetch the top n cusip list

```
top = 10
cusip_lst = pd.DataFrame(pop.select('Cusip').head(top)).astype('str').iloc[:, 0].tolist()
cusip_lst.insert(0, 'CustomerID')
```

- Create the portfolio table for each customer

```
pivot_tab = df.groupby('CustomerID').pivot('Cusip').sum('Asset')
pivot_tab = pivot_tab.fillna(0)
```

- Fetch the most n stock's portfolio table for each customer

```
selected_tab = pivot_tab.select(cusip_lst)
selected_tab.show(4)
```

```
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|CustomerID|85123A|22423|85099B|84879|47566|20725|22720|20727|POST|23203|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|      16503|  0.0|  0.0|  0.0|  0.0|  0.0|  0.0|  0.0|  33.0|  0.0|  0.0|
|     15727| 123.9| 25.5|  0.0|  0.0|  0.0| 33.0| 99.0|  0.0|  0.0|  0.0|
|     14570|  0.0|  0.0|  0.0|  0.0|  0.0|  0.0|  0.0|  0.0|  0.0|  0.0|
|     14450|  0.0|  0.0|  8.32|  0.0|  0.0|  0.0|  49.5|  0.0|  0.0|  0.0|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
only showing top 4 rows
```

- Build the rating matrix

```
def elemwiseDiv(df_in):
    num = len(df_in.columns)
    temp = df_in.rdd.map(lambda x: list(flatten([x[0], [x[i]/float(sum(x[1:])) if sum(x[1:])>0 else x[i] for i in range(1,num)]])))
    return spark.createDataFrame(temp,df_in.columns)

ratings = elemwiseDiv(selected_tab)

ratings.show(4)

+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|CustomerID|85123A|22423|85099B|84879|47566|20725|22720|20727|POST|23203|
```

```
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| 16503| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 1.0| 0.0| 0.0|
| 15727| 0.44| 0.09| 0.0| 0.0| 0.0| 0.12| 0.35| 0.0| 0.0| 0.0|
| 14570| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|
| 14450| 0.0| 0.0| 0.14| 0.0| 0.0| 0.0| 0.86| 0.0| 0.0| 0.0|
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

- Convert rating matrix to long table

```
from pyspark.sql.functions import array, col, explode, struct, lit

def to_long(df, by):
    """
    reference: https://stackoverflow.com/questions/37864222transpose-column-to-row
    """

    # Filter dtypes and split into column names and type description
    cols, dtypes = zip(*((c, t) for (c, t) in df.dtypes if c not in by))
    # Spark SQL supports only homogeneous columns
    assert len(set(dtypes)) == 1, "All columns have to be of the same type"

    # Create and explode an array of (column_name, column_value) structs
    kvs = explode(array([
        struct(lit(c).alias("Cusip"), col(c).alias("rating")) for c in cols
    ]).alias("kvs"))

df_all = to_long(ratings, ['CustomerID'])
df_all.show(5)

+-----+-----+
|CustomerID| Cusip|rating|
+-----+-----+
| 16503|85123A| 0.0|
| 16503| 22423| 0.0|
| 16503|85099B| 0.0|
| 16503| 84879| 0.0|
| 16503| 47566| 0.0|
+-----+
only showing top 5 rows
```

- Convert the string Cusip to numerical index

```
from pyspark.ml.feature import StringIndexer
# Index labels, adding metadata to the label column
labelIndexer = StringIndexer(inputCol='Cusip',
                             outputCol='indexedCusip').fit(df_all)
df_all = labelIndexer.transform(df_all)

df_all.show(5, True)
df_all.printSchema()

+-----+-----+-----+
|CustomerID| Cusip|rating|indexedCusip|
+-----+-----+-----+
| 16503|85123A| 0.0|       6.0|
| 16503| 22423| 0.0|       9.0|
| 16503|85099B| 0.0|       5.0|
| 16503| 84879| 0.0|       1.0|
+-----+
```

```
| 16503| 47566| 0.0| 0.0|
+-----+-----+-----+
only showing top 5 rows

root
|-- CustomerID: long (nullable = true)
|-- Cusip: string (nullable = false)
|-- rating: double (nullable = true)
|-- indexedCusip: double (nullable = true)
```

15.3.2 Train model

- build train and test dataset

```
train, test = df_all.randomSplit([0.8, 0.2])

train.show(5)
test.show(5)

+-----+-----+-----+-----+
|CustomerID|Cusip|indexedCusip|rating|
+-----+-----+-----+-----+
| 12940|20725| 2.0| 0.0|
| 12940|20727| 4.0| 0.0|
| 12940|22423| 9.0| 0.49990198000392083|
| 12940|22720| 3.0| 0.0|
| 12940|23203| 7.0| 0.0|
+-----+-----+-----+-----+
only showing top 5 rows

+-----+-----+-----+-----+
|CustomerID|Cusip|indexedCusip|rating|
+-----+-----+-----+-----+
| 12940|84879| 1.0| 0.1325230346990786|
| 13285|20725| 2.0| 0.2054154995331466|
| 13285|20727| 4.0| 0.2054154995331466|
| 13285|47566| 0.0| 0.0|
| 13623|23203| 7.0| 0.0|
+-----+-----+-----+-----+
only showing top 5 rows
```

- train model

```
import itertools
from math import sqrt
from operator import add
import sys
from pyspark.ml.recommendation import ALS

from pyspark.ml.evaluation import RegressionEvaluator

evaluator = RegressionEvaluator(metricName="rmse", labelCol="rating",
                                 predictionCol="prediction")
def computeRmse(model, data):
    """
    Compute RMSE (Root mean Squared Error).
    """
```

```

"""
predictions = model.transform(data)
rmse = evaluator.evaluate(predictions)
print("Root-mean-square error = " + str(rmse))
return rmse

#train models and evaluate them on the validation set

ranks = [4,5]
lambdas = [0.05]
numIters = [30]
bestModel = None
bestValidationRmse = float("inf")
bestRank = 0
bestLambda = -1.0
bestNumIter = -1

val = test.na.drop()
for rank, lmbda, numIter in itertools.product(ranks, lambdas, numIters):
    als = ALS(rank=rank, maxIter=numIter, regParam=lmbda, numUserBlocks=10, numItemBlocks=10,
              alpha=1.0,
              userCol="CustomerID", itemCol="indexedCusip", seed=1, ratingCol="rating",
              model=als.fit(train)

    validationRmse = computeRmse(model, val)
    print("RMSE (validation) = %f for the model trained with " % validationRmse + \
          "rank = %d, lambda = %.1f, and numIter = %d." % (rank, lmbda, numIter))
    if (validationRmse, bestValidationRmse):
        bestModel = model
        bestValidationRmse = validationRmse
        bestRank = rank
        bestLambda = lmbda
        bestNumIter = numIter

model = bestModel

```

15.3.3 Make prediction

- make prediction

```

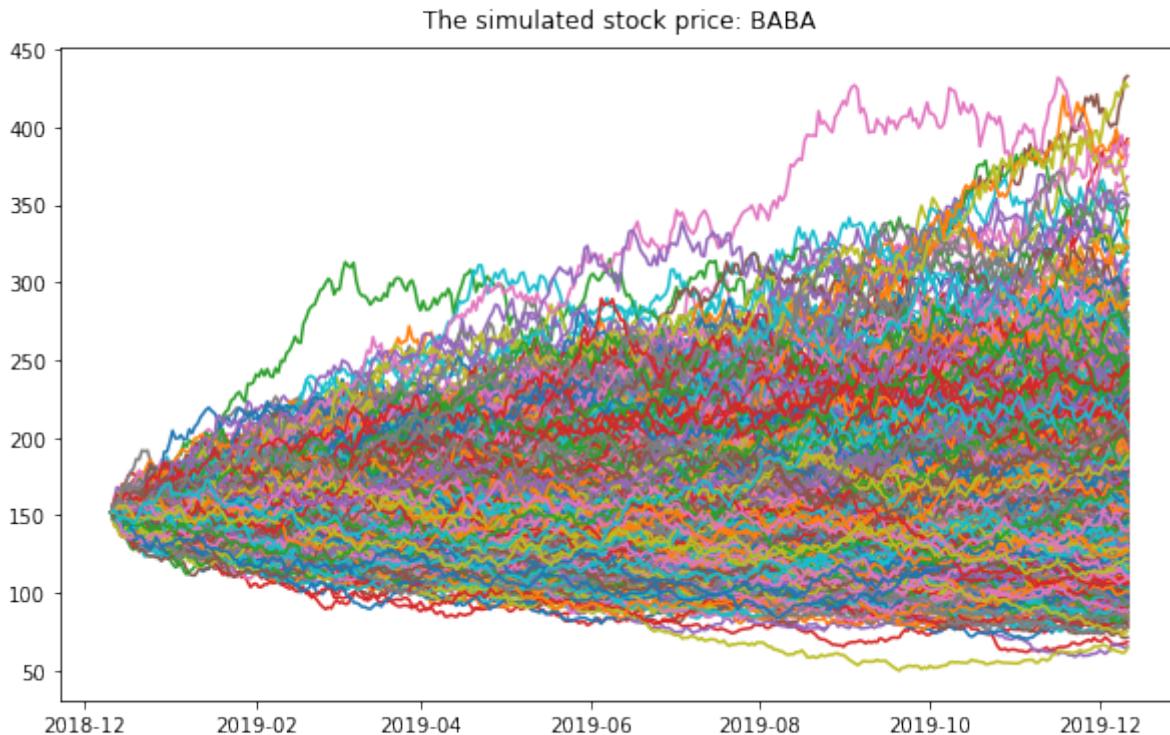
topredict=test[test['rating']==0]

predictions=model.transform(topredict)
predictions.filter(predictions.prediction>0)\n    .sort([F.col('CustomerID'),F.col('Cusip')],ascending=[0,0]).show(5)

+-----+-----+-----+-----+
|CustomerID| Cusip|indexedCusip|rating| prediction|
+-----+-----+-----+-----+
|     18283| 47566|      0.0|   0.0|  0.01625076|
|     18282| 85123A|      6.0|   0.0|  0.057172246|
|     18282|  84879|      1.0|   0.0|  0.059531752|
|     18282| 23203|      7.0|   0.0|  0.010502596|
|     18282| 22720|      3.0|   0.0|  0.053893942|
+-----+-----+-----+-----+
only showing top 5 rows

```

MONTE CARLO SIMULATION



Monte Carlo simulations are just a way of estimating a fixed parameter by repeatedly generating random numbers. More details can be found at [A Zero Math Introduction to Markov Chain Monte Carlo Methods](#).

Monte Carlo simulation is a technique used to understand the impact of risk and uncertainty in financial, project management, cost, and other forecasting models. A Monte Carlo simulator helps one visualize most or all of the potential outcomes to have a better idea regarding the risk of a decision. More details can be found at [The house always wins](#).

16.1 Simulating Casino Win

We assume that the player John has the 49% chance to win the game and the wager will be \$5 per game.

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
```

```

start_m = 100
wager = 5
bets = 100
trials = 1000

trans = np.vectorize(lambda t: -wager if t <=0.51 else wager)

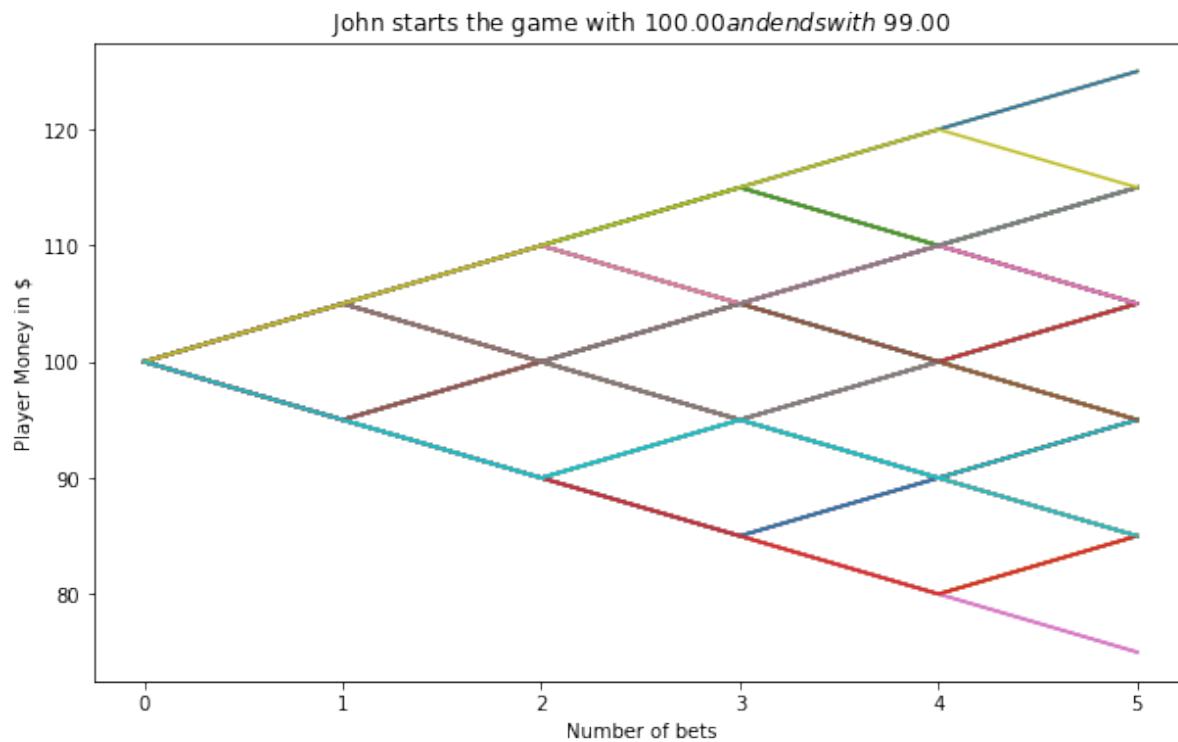
fig = plt.figure(figsize=(10, 6))
ax = fig.add_subplot(1,1,1)

end_m = []

for i in range(trials):
    money = reduce(lambda c, x: c + [c[-1] + x], trans(np.random.random(bets)), [start_m])
    end_m.append(money[-1])
    plt.plot(money)

plt.ylabel('Player Money in $')
plt.xlabel('Number of bets')
plt.title(("John starts the game with $ %.2f and ends with $ %.2f")%(start_m,sum(end_m)))
plt.show()

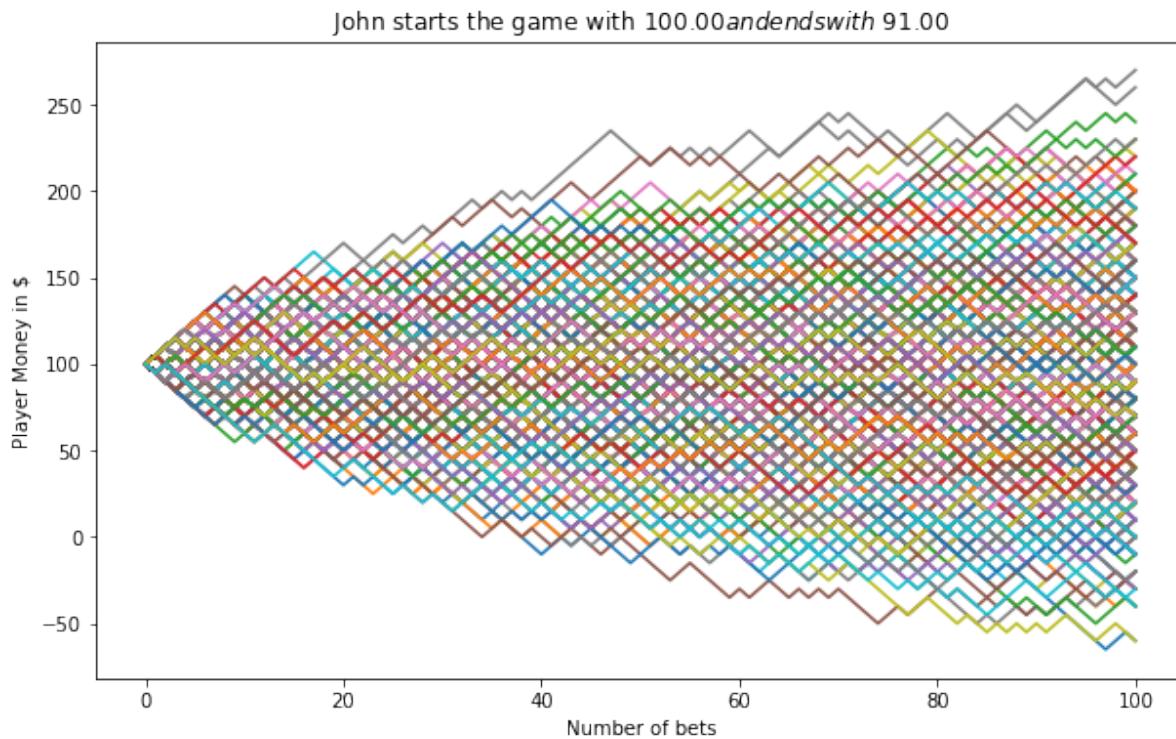
```



16.2 Simulating a Random Walk

16.2.1 Fetch the historical stock price

1. Fetch the data. If you need the code for this piece, you can contact with me.



```
stock.tail(4)
```

	Date	Open	High	Low	Close	Adj Close	Volume
2018-12-07	155.399994	158.050003	151.729996	153.059998	153.059998	17447900	
2018-12-10	150.389999	152.809998	147.479996	151.429993	151.429993	15525500	
2018-12-11	155.259995	156.240005	150.899994	151.830002	151.830002	13651900	
2018-12-12	155.240005	156.169998	151.429993	151.5	151.5	16597900	

2. Convert the str type date to date type

```
stock['Date'] = pd.to_datetime(stock['Date'])
```

3. Data visualization

```
# Plot everything by leveraging the very powerful matplotlib package
width = 10
height = 6
data = stock
fig = plt.figure(figsize=(width, height))
ax = fig.add_subplot(1,1,1)
ax.plot(data.Date, data.Close, label='Close')
ax.plot(data.Date, data.High, label='High')
# ax.plot(data.Date, data.Low, label='Low')
ax.set_xlabel('Date')
ax.set_ylabel('price ($)')
ax.legend()
ax.set_title('Stock price: ' + ticker, y=1.01)
# plt.xticks(rotation=70)
plt.show()
# Plot everything by leveraging the very powerful matplotlib package
```

```

fig = plt.figure(figsize=(width, height))
ax = fig.add_subplot(1,1,1)
ax.plot(data.Date, data.Volume, label='Volume')
#ax.plot(data.Date, data.High, label='High')
# ax.plot(data.Date, data.Low, label='Low')
ax.set_xlabel('Date')
ax.set_ylabel('Volume')
ax.legend()
ax.set_title('Stock volume: ' + ticker, y=1.01)
#plt.xticks(rotation=70)
plt.show()
    
```

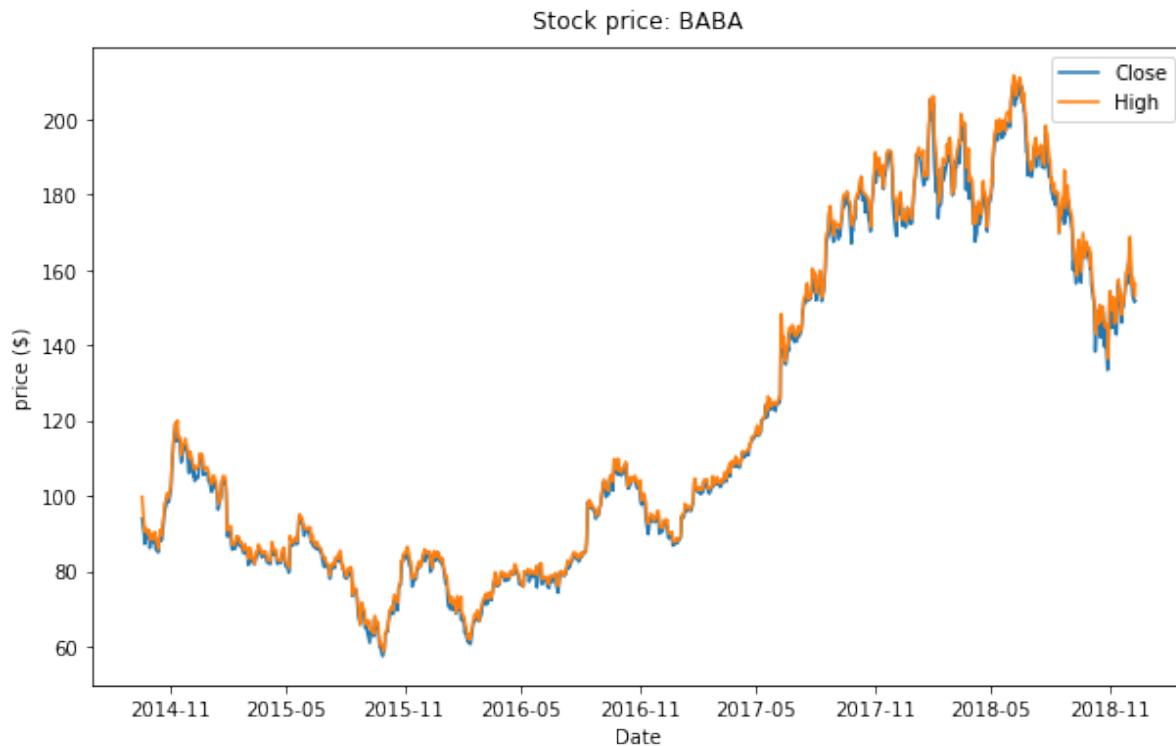


Figure 16.1: Historical Stock Price

16.2.2 Calculate the Compound Annual Growth Rate

The formula for Compound Annual Growth Rate (CAGR) is very useful for investment analysis. It may also be referred to as the annualized rate of return or annual percent yield or effective annual rate, depending on the algebraic form of the equation. Many investments such as stocks have returns that can vary wildly. The CAGR formula allows you to calculate a “smoothed” rate of return that you can use to compare to other investments. The formula is defined as (more details can be found at [CAGR Calculator and Formula](#))

$$\text{CAGR} = \left(\frac{\text{End Value}}{\text{Start Value}} \right)^{\frac{365}{\text{Days}}} - 1$$

```

days = (stock.Date.iloc[-1] - stock.Date.iloc[0]).days
cagr = (((stock['Adj Close'].iloc[-1]) / stock['Adj Close'].iloc[0])) ** (365.0/days)
    
```

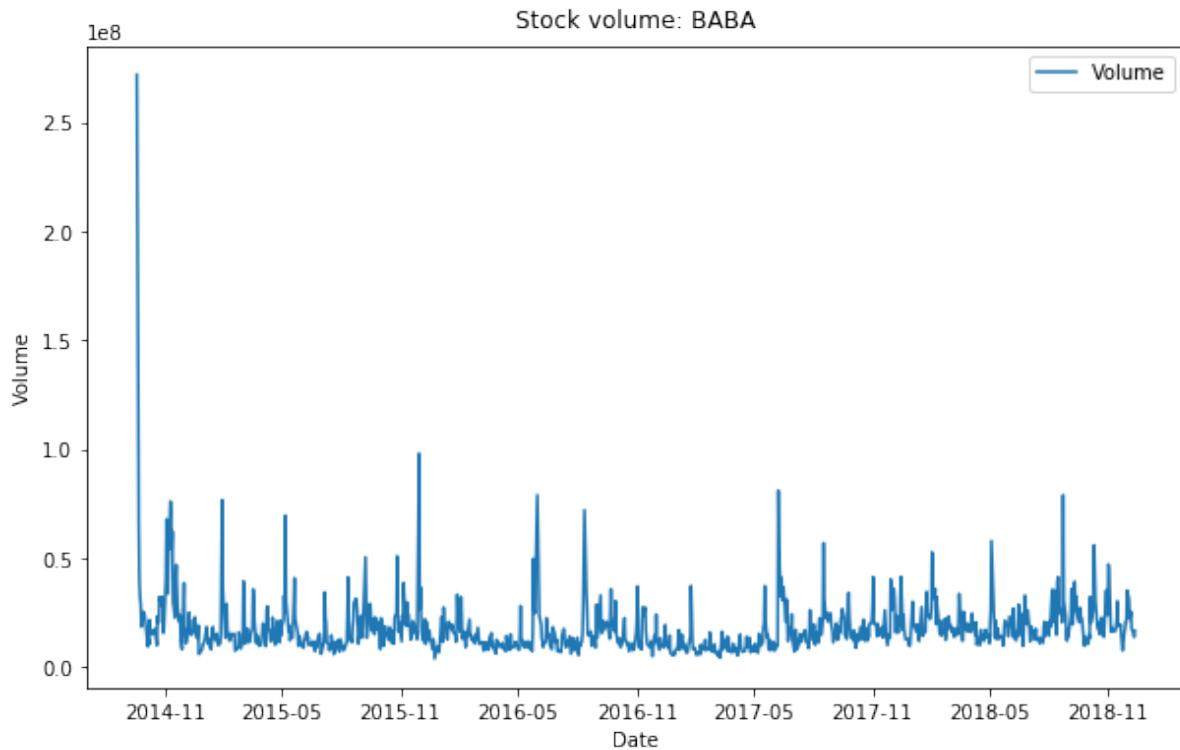


Figure 16.2: Historical Stock Volume

```
print ('CAGR =', str(round(cagr, 4)*100)+"%")
mu = cagr
```

16.2.3 Calculate the annual volatility

A stock's volatility is the variation in its price over a period of time. For example, one stock may have a tendency to swing wildly higher and lower, while another stock may move in much steadier, less turbulent way. Both stocks may end up at the same price at the end of day, but their path to that point can vary wildly. First, we create a series of percentage returns and calculate the annual volatility of returns Annualizing volatility. To present this volatility in annualized terms, we simply need to multiply our daily standard deviation by the square root of 252. This assumes there are 252 trading days in a given year. More details can be found at [How to Calculate Annualized Volatility](#).

```
stock['Returns'] = stock['Adj Close'].pct_change()
vol = stock['Returns'].std()*np.sqrt(252)
```

16.2.4 Create matrix of daily returns

1. Create matrix of daily returns using random normal distribution Generates an RDD matrix comprised of i.i.d. samples from the uniform distribution $U(0.0, 1.0)$.

```
S = stock['Adj Close'].iloc[-1] #starting stock price (i.e. last available real stock price)
T = 5 #Number of trading days
mu = cagr #Return
vol = vol #Volatility
trials = 10000
```

```
mat = RandomRDDs.normalVectorRDD(sc, trials, T, seed=1)
```

2. Transform the distribution in the generated RDD from U(0.0, 1.0) to U(a, b), use RandomRDDs.uniformRDD(sc, n, p, seed) .map(lambda v: a + (b - a) * v)

```
a = mu/T
b = vol/math.sqrt(T)
v = mat.map(lambda x: a + (b - a) * x)
```

3. Convert Rdd mstrix to dataframe

```
df = v.map(lambda x: [round(i, 6)+1 for i in x]).toDF()
df.show(5)
```

```
+-----+-----+-----+-----+-----+
|      _1|      _2|      _3|      _4|      _5|
+-----+-----+-----+-----+-----+
| 0.935234|1.162894| 1.07972|1.238257|1.066136|
| 0.878456|1.045922|0.990071|1.045552|0.854516|
| 1.186472|0.944777|0.742247|0.940023|1.220934|
| 0.872928|1.030882|1.248644|1.114262|1.063762|
| 1.09742|1.188537|1.137283|1.162548|1.024612|
+-----+-----+-----+-----+-----+
only showing top 5 rows
```

```
from pyspark.sql.functions import lit
S = stock['Adj Close'].iloc[-1]
price = df.withColumn('init_price', lit(S))

price.show(5)
```

```
+-----+-----+-----+-----+-----+
|      _1|      _2|      _3|      _4|      _5|init_price|
+-----+-----+-----+-----+-----+
| 0.935234|1.162894| 1.07972|1.238257|1.066136|     151.5|
| 0.878456|1.045922|0.990071|1.045552|0.854516|     151.5|
| 1.186472|0.944777|0.742247|0.940023|1.220934|     151.5|
| 0.872928|1.030882|1.248644|1.114262|1.063762|     151.5|
| 1.09742|1.188537|1.137283|1.162548|1.024612|     151.5|
+-----+-----+-----+-----+-----+
only showing top 5 rows
```

```
price = price.withColumn('day_0', col('init_price'))
price.show(5)
```

```
+-----+-----+-----+-----+-----+
|      _1|      _2|      _3|      _4|      _5|init_price|day_0|
+-----+-----+-----+-----+-----+
| 0.935234|1.162894| 1.07972|1.238257|1.066136|     151.5|151.5|
| 0.878456|1.045922|0.990071|1.045552|0.854516|     151.5|151.5|
| 1.186472|0.944777|0.742247|0.940023|1.220934|     151.5|151.5|
| 0.872928|1.030882|1.248644|1.114262|1.063762|     151.5|151.5|
| 1.09742|1.188537|1.137283|1.162548|1.024612|     151.5|151.5|
+-----+-----+-----+-----+-----+
only showing top 5 rows
```

16.2.5 Monte Carlo Simulation

```
from pyspark.sql.functions import round
for name in price.columns[:-2]:
    price = price.withColumn('day'+name, round(col(name)*col('init_price'),2))
    price = price.withColumn('init_price', col('day'+name))

price.show(5)

+-----+-----+-----+-----+-----+-----+-----+-----+
|      _1|      _2|      _3|      _4|      _5|init_price|day_0| day_1| day_2| day_3| day
+-----+-----+-----+-----+-----+-----+-----+-----+
| 0.935234| 1.162894| 1.07972| 1.238257| 1.066136|   234.87| 151.5| 141.69| 164.77| 177.91| 220
| 0.878456| 1.045922| 0.990071| 1.045552| 0.854516|   123.14| 151.5| 133.09| 139.2| 137.82| 144
| 1.186472| 0.944777| 0.742247| 0.940023| 1.220934|   144.67| 151.5| 179.75| 169.82| 126.05| 118
| 0.872928| 1.030882| 1.248644| 1.114262| 1.063762|   201.77| 151.5| 132.25| 136.33| 170.23| 189
| 1.09742| 1.188537| 1.137283| 1.162548| 1.024612|   267.7| 151.5| 166.26| 197.61| 224.74| 261
+-----+-----+-----+-----+-----+-----+-----+-----+
only showing top 5 rows
```

16.2.6 Summary

```
selected_col = [name for name in price.columns if 'day' in name]

simulated = price.select(selected_col)
simulated.describe().show()

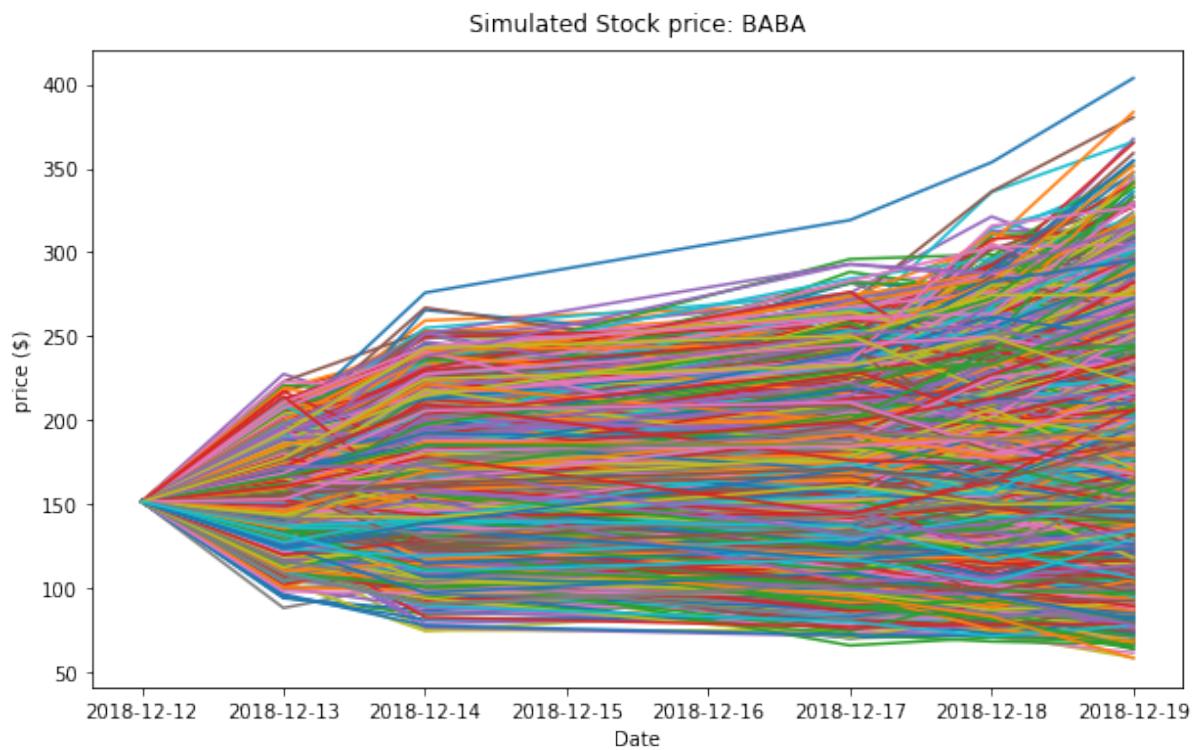
+-----+-----+-----+-----+-----+-----+
|summary|2018-12-12| 2018-12-13| 2018-12-14| 2018-12-17| 201
+-----+-----+-----+-----+-----+-----+
| count| 10000.0| 10000.0| 10000.0| 10000.0| 10000.0|
| mean| 151.5| 155.11643700000002| 158.489058| 162.23713200000003| 166
| std| 0.0| 18.313783237787845| 26.460919262517276| 33.37780495150803| 39.36910107
| min| 151.5| 88.2| 74.54| 65.87|
| 25%| 151.5| 142.485| 140.15| 138.72|
| 50%| 151.5| 154.97| 157.175| 159.82|
| 75%| 151.5| 167.445| 175.4849999999999| 182.8625|
| max| 151.5| 227.48| 275.94| 319.17|
+-----+-----+-----+-----+-----+-----+

data_plt = simulated.toPandas()
days = pd.date_range(stock['Date'].iloc[-1], periods= T+1, freq='B').date

width = 10
height = 6
fig = plt.figure(figsize=(width, height))
ax = fig.add_subplot(1,1,1)

days = pd.date_range(stock['Date'].iloc[-1], periods= T+1, freq='B').date

for i in range(trials):
    plt.plot(days, data_plt.iloc[i])
    ax.set_xlabel('Date')
    ax.set_ylabel('price ($)')
    ax.set_title('Simulated Stock price: ' + ticker, y=1.01)
    plt.show()
```



16.2.7 One-year Stock price simulation

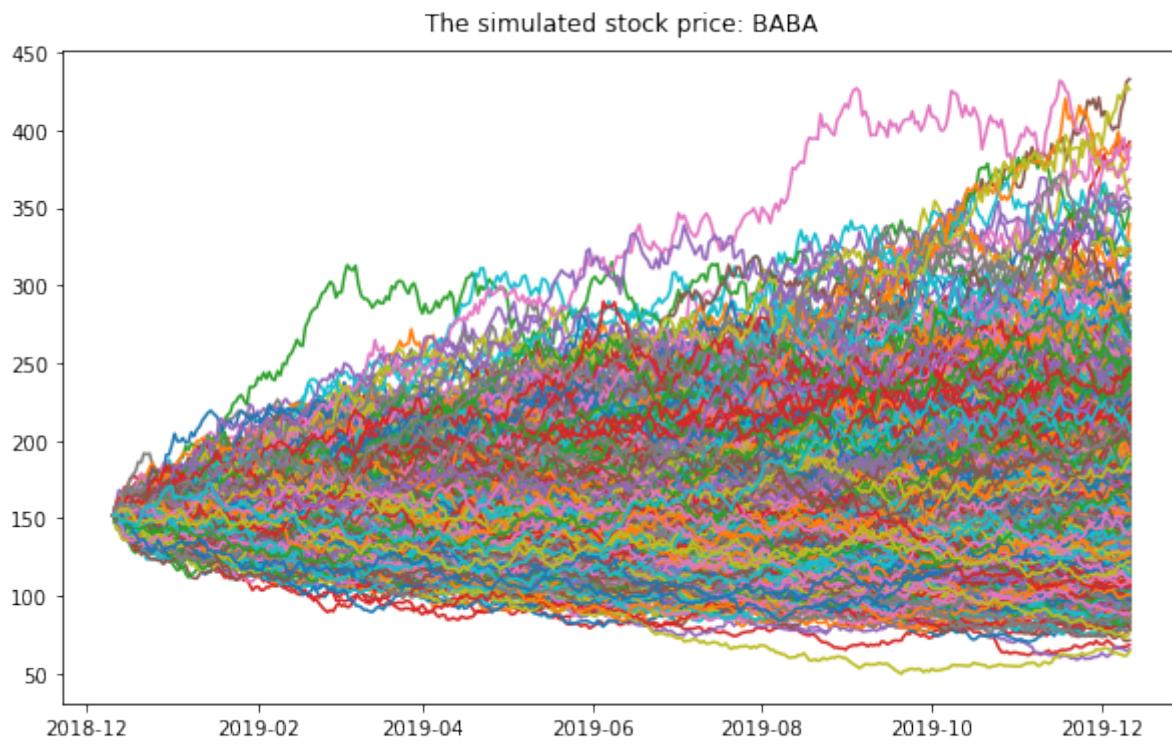


Figure 16.3: Simulated Stock Price

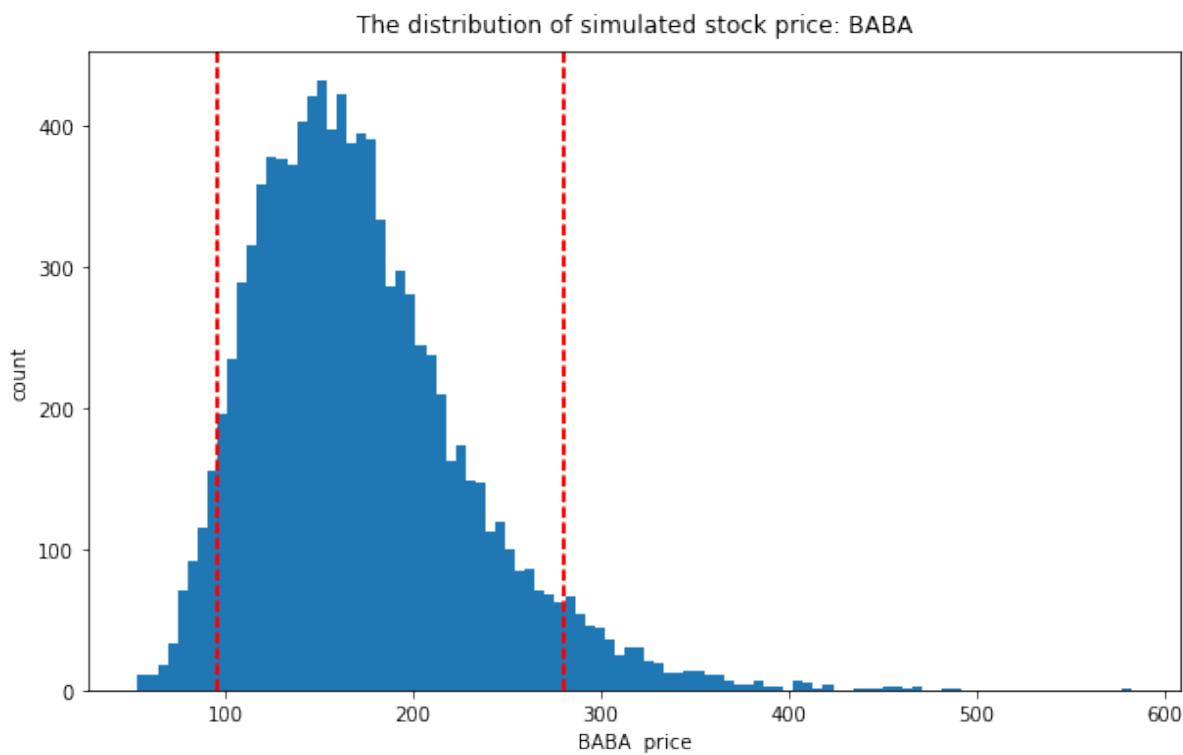


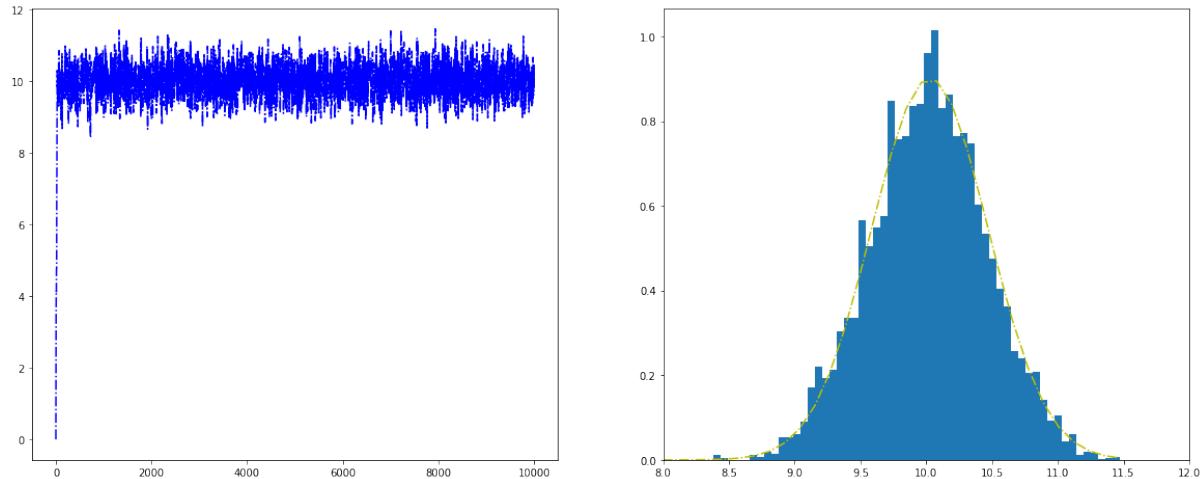
Figure 16.4: Simulated Stock Price distribution

CHAPTER SEVENTEEN

MARKOV CHAIN MONTE CARLO

Chinese proverb

A book is known in time of need.



Monte Carlo simulations are just a way of estimating a fixed parameter by repeatedly generating random numbers. More details can be found at [A Zero Math Introduction to Markov Chain Monte Carlo Methods](#).

Markov Chain Monte Carlo (MCMC) methods are used to approximate the posterior distribution of a parameter of interest by random sampling in a probabilistic space. More details can be found at [A Zero Math Introduction to Markov Chain Monte Carlo Methods](#).

The following theory and demo are from Dr. Rebecca C. Steorts's [Intro to Markov Chain Monte Carlo](#). More details can be found at Dr. Rebecca C. Steorts's STA 360/601: [Bayesian Methods and Modern Statistics](#) class at Duke.

17.1 Metropolis algorithm

The Metropolis algorithm takes three main steps:

1. Sample $\theta^* \sim J(\theta|\theta^{(s)})$
2. Compute the acceptance ratio (r)

$$r = \frac{p(\theta^*|y)}{p(\theta^{(s)}|y)} = \frac{p(y|\theta^*)p(\theta^*)}{p(y|\theta^{(s)})p(\theta^{(s)})}$$

3. Let

$$\theta^{(s+1)} = \begin{cases} \theta^* & \text{with prob } \min(r, 1) \\ \theta^{(s)} & \text{otherwise} \end{cases} \quad (17.1)$$

Caution: Actually, the Step 3 in (17.1) can be replaced by sampling $u \sim \text{Uniform}(0, 1)$ and setting $\theta^{(s+1)} = \theta^*$ if $u < r$ and setting $\theta^{(s+1)} = \theta^{(s)}$ otherwise.

17.2 A Toy Example of Metropolis

The following example is going to test out the Metropolis algorithm for the conjugate Normal-Normal model with a known variance situation.

17.2.1 Conjugate Normal-Normal model

$$\begin{aligned} X_1, \dots, X_n &\stackrel{iid}{\sim} \text{Normal}(\theta, \sigma^2) \\ \theta &\sim \text{Normal}(\mu, \tau^2) \end{aligned}$$

Recall that the posterior of θ is $\text{Normal}(\mu_n, \tau_n^2)$, where

$$\mu_n = \bar{x} \frac{n/\sigma^2}{n/\sigma^2 + 1/\tau^2} + \mu \frac{1/\tau^2}{n/\sigma^2 + 1/\tau^2}$$

and

$$\tau_n^2 = \frac{1}{n/\sigma^2 + 1/\tau^2}$$

17.2.2 Example setup

The rest of the parameters are $\sigma^2 = 1$, $\tau^2 = 10$, $\mu = 5$, $n = 5$ and

$$y = [9.37, 10.18, 9.16, 11.60, 10.33]$$

For this setup, we get that $\mu_n = 10.02745$ and $\tau_n^2 = 0.1960784$.

17.2.3 Essential mathematical derivation

In the *Metropolis algorithm*, we need to compute the acceptance ratio r , i.e.

$$\begin{aligned} r &= \frac{p(\theta^*|x)}{p(\theta^{(s)}|x)} \\ &= \frac{p(x|\theta^*)p(\theta^*)}{p(x|\theta^{(s)})p(\theta^{(s)})} \\ &= \left(\frac{\prod_i \text{dnorm}(x_i, \theta^*, \sigma)}{\prod_i \text{dnorm}(x_i, \theta^{(s)}, \sigma)} \right) \left(\frac{\text{dnorm}(\theta^*, \mu, \tau)}{\text{dnorm}(\theta^{(s)}, \mu, \tau)} \right) \end{aligned}$$

In many cases, computing the ratio r directly can be numerically unstable, however, this can be modified by taking $\log r$. i.e.

$$\begin{aligned} \log r &= \sum_i \left(\log[\text{dnorm}(x_i, \theta^*, \sigma)] - \log[\text{dnorm}(x_i, \theta^{(s)}, \sigma)] \right) \\ &\quad + \sum_i \left(\log[\text{dnorm}(\theta^*, \mu, \tau)] - \log[\text{dnorm}(\theta^{(s)}, \mu, \tau)] \right) \end{aligned}$$

Then the criteria of the acceptance becomes: if $\log u < \log r$, where u is sample from the Uniform(0, 1).

17.3 Demos

Now, We generate S iterations of the Metropolis algorithm starting at $\theta^{(0)} = 0$ and using a normal proposal distribution, where

$$\theta^{(s+1)} \sim \text{Normal}(\theta^{(s)}, 2).$$

17.3.1 R results

```
# setting values
set.seed(1)
s2<-1
t2<-10
mu<-5; n<-5

# rounding the rnorm to 2 decimal places
y<-round(rnorm(n,10,1),2)
# mean of the normal posterior
mu.n<- ( mean(y)*n/s2 + mu/t2 )/( n/s2+1/t2 )
# variance of the normal posterior
t2.n<-1/(n/s2+1/t2)
# defining the data
y<-c(9.37, 10.18, 9.16, 11.60, 10.33)
```

```

#####metropolis part#####
##S = total num of simulations
theta<-0 ; delta<-2 ; S<-10000 ; THETA<-NULL ; set.seed(1)
for(s in 1:S){
  ## simulating our proposal
  #the new value of theta
  #print(theta)
  theta.star<-rnorm(1,theta,sqrt(delta))
  ##taking the log of the ratio r
  log.r<-( sum(dnorm(y,theta.star,sqrt(s2),log=TRUE))+
             dnorm(theta.star,mu,sqrt(t2),log=TRUE))-(
    sum(dnorm(y,theta,sqrt(s2),log=TRUE))+dnorm(theta,mu,sqrt(t2),log=TRUE))
  #print(log.r)
  if(log(runif(1))<log.r) { theta<-theta.star }
  ##updating THETA
  #print(log(runif(1)))
  THETA<-c(THETA,theta)
}

##two plots: trace of theta and comparing the empirical distribution
##of simulated values to the true posterior
par(mar=c(3,3,1,1),mgp=c(1.75,.75,0))
par(mfrow=c(1,2))
# creating a sequence
skeep<-seq(10,S,by=10)
# making a trace place
plot(skeep,THETA[skeep],type="l",
      xlab="iteration",ylab=expression(theta))
# making a histogram
hist(THETA[-(1:50)],prob=TRUE,main="",
      xlab=expression(theta),ylab="density")
th<-seq(min(THETA),max(THETA),length=100)
lines(th,dnorm(th,mu.n,sqrt(t2.n)) )

```

Figure. *Histogram for the Metropolis algorithm with r* shows a trace plot for this run as well as a histogram for the Metropolis algorithm compared with a draw from the true normal density.

17.3.2 Python results

```

# coding: utf-8

# In[1]:


import numpy as np


# In[2]:


from scipy.stats import norm


def rnorm(n,mean,sd):
    """
    same functions as rnorm in r
    r: rnorm(n, mean=0, sd=1)
    py: rvs(loc=0, scale=1, size=1, random_state=None)

```

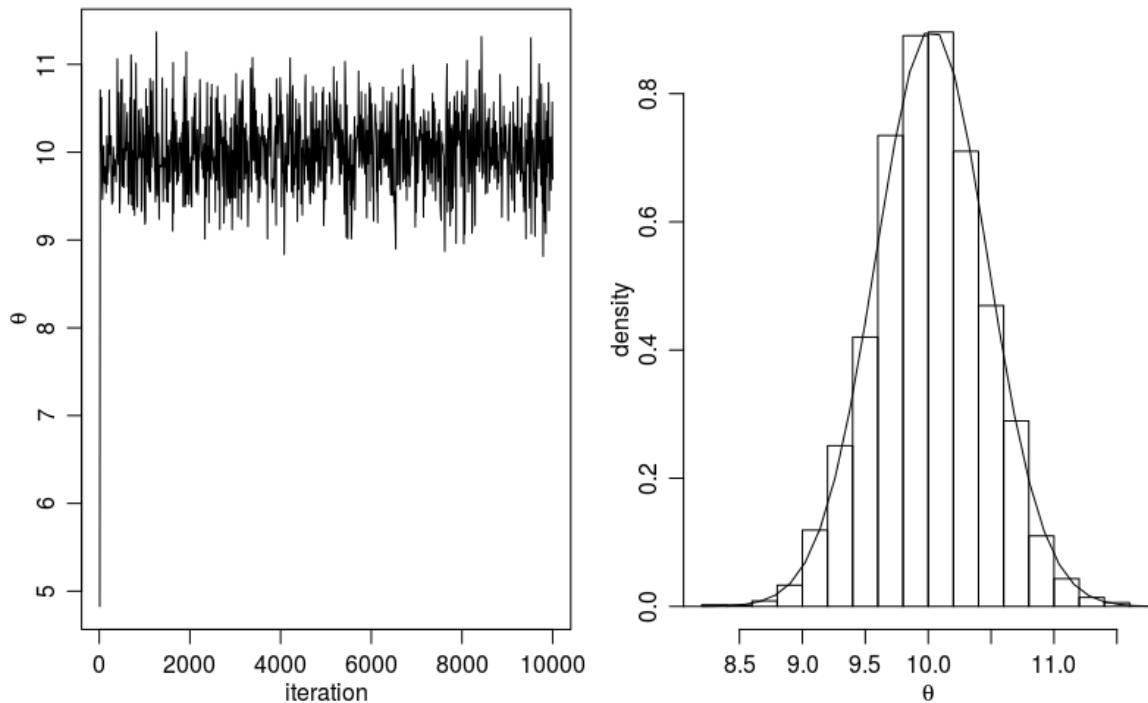


Figure 17.1: Histogram for the Metropolis algorithm with r

```

"""
    return norm.rvs(loc=mean, scale=sd, size=n)

def dnorm(x, mean, sd, log=False):
    """
    same functions as dnorm in r
    dnorm(x, mean=0, sd=1, log=FALSE)
    pdf(x, loc=0, scale=1)
    """
    if log:
        return np.log(norm.pdf(x=x, loc=mean, scale=sd))
    else:
        return norm.pdf(x=x, loc=mean, scale=sd)

def runif(n, min=0, max=1):
    """
    r: runif(n, min = 0, max = 1)
    py: random.uniform(low=0.0, high=1.0, size=None)
    """
    return np.random.uniform(min, max, size=n)

# In[3]:
```

```

s2 = 1
t2 = 10
mu = 5
n = 5

```

```
# In[4]:
```

```
y = rnorm(n,10,1)
y
```

```
# In[5]:
```

```
# mean of the normal posterior
mu_n = (np.mean(y)*n/s2 + mu/float(t2)) / (n/float(s2)+1/float(t2))
mu_n
```

```
# In[6]:
```

```
# variance of the normal posterior
# t2.n<-1/(n/s2+1/t2)
```

```
t2_n = 1.0/(n/float(s2)+1.0/t2)
t2_n
```

```
# In[7]:
```

```
# defining the data
# y<-c(9.37, 10.18, 9.16, 11.60, 10.33)
```

```
y = [9.37, 10.18, 9.16, 11.60, 10.33]
```

```
# In[8]:
```

```
mu_n = (np.mean(y)*n/s2 + mu/float(t2)) / (n/float(s2)+1/float(t2))
mu_n
```

```
# In[9]:
```

```
####metropolis part#####
##S = total num of simulations
# theta<-0 ; delta<-2 ; S<-10000 ; THETA<-NULL ; set.seed(1)
```

```
theta = 0
delta = 2
```

```
S = 10000
```

```
theta_v = []
```

```
# In[ ]:
```

```
for s in range(S):
    theta_star = norm.rvs(theta,np.sqrt(delta),1)
    logr = (sum(dnorm(y,theta_star,np.sqrt(s2),log=True)) +
            sum(dnorm(theta_star,mu,np.sqrt(t2),log=True)))-
            (sum(dnorm(y,theta,np.sqrt(s2),log=True)) +
```

```

        sum(dnorm([theta], mu, np.sqrt(t2), log=True)))
#print(logr)
if np.log(runif(1))<logr:
    theta = theta_star
#print(theta)
theta_v.append(theta)

# In[ ]:

import matplotlib.mlab as mlab
import matplotlib.pyplot as plt

plt.figure(figsize=(20, 8))

plt.subplot(1, 2, 1)
plt.plot(theta_v,'b-.')

plt.subplot(1, 2, 2)
#bins = np.arange(0, S, 10)
plt.hist(theta_v, density=True,bins='auto')
x = np.linspace(min(theta_v),max(theta_v),100)
y = norm.pdf(x,mu_n,np.sqrt(t2_n))
plt.plot(x,y,'y-')
plt.xlim(right=12) # adjust the right leaving left unchanged
plt.xlim(left=8) # adjust the left leaving right unchanged
plt.show()
    
```

```
# In[ ]:
```

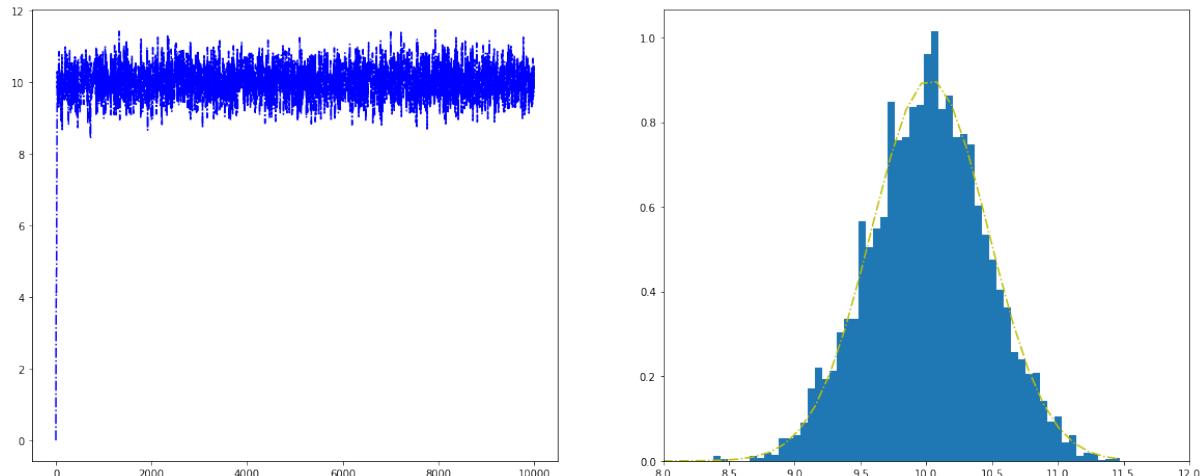


Figure 17.2: Histogram for the Metropolis algorithm with python

Figure. *Histogram for the Metropolis algorithm with python* shows a trace plot for this run as well as a histogram for the Metropolis algorithm compared with a draw from the true normal density.

17.3.3 PySpark results

TODO...

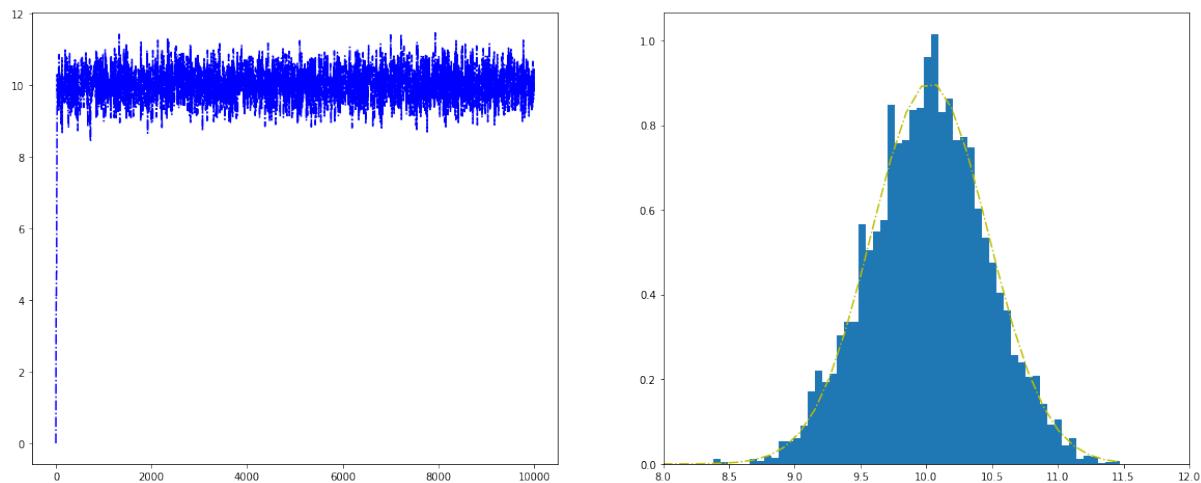


Figure 17.3: Histogram for the Metropolis algorithm with PySpark

Figure. *Histogram for the Metropolis algorithm with PySpark* shows a trace plot for this run as well as a histogram for the Metropolis algorithm compared with a draw from the true normal density.

NEURAL NETWORK

Chinese proverb

Sharpening the knife longer can make it easier to hack the firewood – old Chinese proverb

18.1 Feedforward Neural Network

18.1.1 Introduction

A feedforward neural network is an artificial neural network wherein connections between the units do not form a cycle. As such, it is different from recurrent neural networks.

The feedforward neural network was the first and simplest type of artificial neural network devised. In this network, the information moves in only one direction, forward (see Fig. *MultiLayer Neural Network*), from the input nodes, through the hidden nodes (if any) and to the output nodes. There are no cycles or loops in the network.

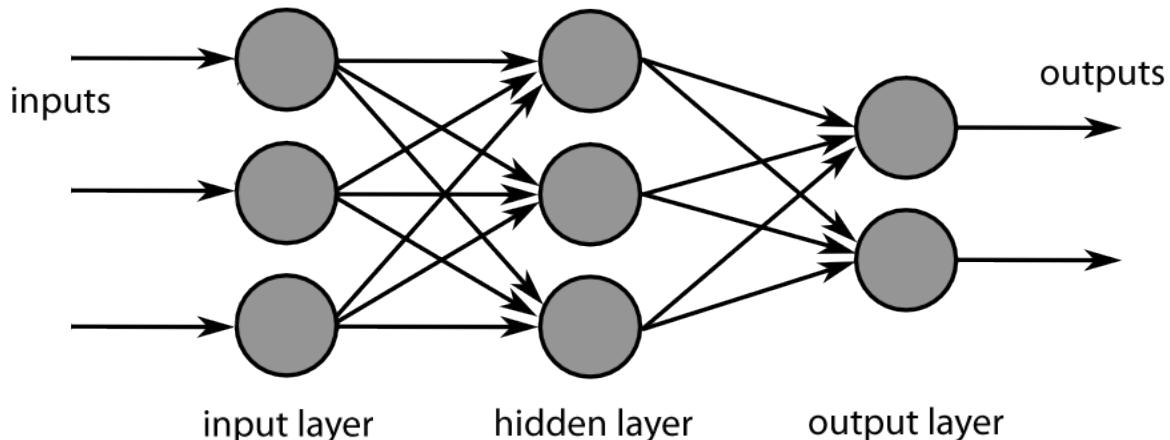


Figure 18.1: MultiLayer Neural Network

18.1.2 Demo

1. Set up spark context and SparkSession

```
from pyspark.sql import SparkSession

spark = SparkSession \
    .builder \
    .appName("Python Spark Feedforward neural network example") \
    .config("spark.some.config.option", "some-value") \
    .getOrCreate()
```

2. Load dataset

```
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|fixed|volatile|citric|sugar|chlorides|free|total|density| pH|sulphates|alcohol|quality
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| 7.4|    0.7|   0.0|   1.9|   0.076|11.0| 34.0| 0.9978|3.51|   0.56|   9.4| 5
| 7.8|    0.88|   0.0|   2.6|   0.098|25.0| 67.0| 0.9968|3.2|   0.68|   9.8| 5
| 7.8|    0.76|   0.04|   2.3|   0.092|15.0| 54.0| 0.997|3.26|   0.65|   9.8| 5
| 11.2|   0.28|   0.56|   1.9|   0.075|17.0| 60.0| 0.998|3.16|   0.58|   9.8| 6
| 7.4|    0.7|   0.0|   1.9|   0.076|11.0| 34.0| 0.9978|3.51|   0.56|   9.4| 5
+-----+-----+-----+-----+-----+-----+-----+-----+-----+
only showing top 5 rows
```

3. change categorical variable size

```
# Convert to float format
def string_to_float(x):
    return float(x)

#
def condition(r):
    if (0 <= r <= 4):
        label = "low"
    elif(4 < r <= 6):
        label = "medium"
    else:
        label = "high"
    return label

from pyspark.sql.functions import udf
from pyspark.sql.types import StringType, DoubleType
string_to_float_udf = udf(string_to_float, DoubleType())
quality_udf = udf(lambda x: condition(x), StringType())
df= df.withColumn("quality", quality_udf("quality"))
```

4. Convert the data to dense vector

```
# convert the data to dense vector
def transData(data):
    return data.rdd.map(lambda r: [r[-1], Vectors.dense(r[:-1])]).\
        toDF(['label','features'])

from pyspark.sql import Row
from pyspark.ml.linalg import Vectors

data= transData(df)
data.show()
```

5. Split the data into training and test sets (40% held out for testing)

```
# Split the data into train and test
(trainingData, testData) = data.randomSplit([0.6, 0.4])
```

6. Train neural network

```
# specify layers for the neural network:
# input layer of size 11 (features), two intermediate of size 5 and 4
# and output of size 7 (classes)
layers = [11, 5, 4, 3, 7]

# create the trainer and set its parameters
FNN = MultilayerPerceptronClassifier(labelCol="indexedLabel", \
                                       featuresCol="indexedFeatures", \
                                       maxIter=100, layers=layers, \
                                       blockSize=128, seed=1234)
# Convert indexed labels back to original labels.
labelConverter = IndexToString(inputCol="prediction", outputCol="predictedLabel",
                                labels=labelIndexer.labels)
# Chain indexers and forest in a Pipeline
from pyspark.ml import Pipeline
pipeline = Pipeline(stages=[labelIndexer, featureIndexer, FNN, labelConverter])
# train the model
# Train model. This also runs the indexers.
model = pipeline.fit(trainingData)
```

7. Make predictions

```
# Make predictions.
predictions = model.transform(testData)
# Select example rows to display.
predictions.select("features", "label", "predictedLabel").show(5)
```

8. Evaluation

```
# Select (prediction, true label) and compute test error
evaluator = MulticlassClassificationEvaluator(
    labelCol="indexedLabel", predictionCol="prediction", metricName="accuracy")
accuracy = evaluator.evaluate(predictions)
print("Predictions accuracy = %g, Test Error = %g" % (accuracy, (1.0 - accuracy)))
```

MY PYSPARK PACKAGE

It's super easy to wrap your own package in Python. I packed some functions which I frequently used in my daily work. You can download and install it from [My PySpark Package](#). The hierarchical structure and the directory structure of this package are as follows.

19.1 Hierarchical Structure

```
|-- build
|   |-- bdist.linux-x86_64
|   |-- lib.linux-x86_64-2.7
|       |-- PySparkTools
|           |-- __init__.py
|           |-- Manipulation
|               |-- DataManipulation.py
|               |-- __init__.py
|           |-- Visualization
|               |-- __init__.py
|               |-- PyPlots.py
|-- dist
|   |-- PySparkTools-1.0-py2.7.egg
|-- __init__.py
|-- PySparkTools
|   |-- __init__.py
|   |-- Manipulation
|       |-- DataManipulation.py
|       |-- __init__.py
|   |-- Visualization
|       |-- __init__.py
|       |-- PyPlots.py
|       |-- PyPlots.pyc
|-- PySparkTools.egg-info
|   |-- dependency_links.txt
|   |-- PKG-INFO
|   |-- requires.txt
|   |-- SOURCES.txt
|   |-- top_level.txt
|-- README.md
|-- requirements.txt
|-- setup.py
|-- test
    |-- spark-warehouse
    |-- test1.py
    |-- test2.py
```

From the above hierarchical structure, you will find that you have to have `__init__.py` in each directory. I will explain the `__init__.py` file with the example below:

19.2 Set Up

```
from setuptools import setup, find_packages

try:
    with open("README.md") as f:
        long_description = f.read()
except IOError:
    long_description = ""

try:
    with open("requirements.txt") as f:
        requirements = [x.strip() for x in f.read().splitlines() if x.strip()]
except IOError:
    requirements = []

setup(name='PySparkTools',
      install_requires=requirements,
      version='1.0',
      description='Python Spark Tools',
      author='Wenqiang Feng',
      author_email='von198@gmail.com',
      url='https://github.com/runawayhorse001/PySparkTools',
      packages=find_packages(),
      long_description=long_description
)
```

19.3 ReadMe

```
# PySparkTools
```

This is my PySpark Tools. If you want to clone and install it, you can use

- clone

```
```{bash}
git clone git@github.com:runawayhorse001/PySparkTools.git
```

```

- install

```
```{bash}
cd PySparkTools
pip install -r requirements.txt
python setup.py install
```

```

- test

```
```{bash}
cd PySparkTools/test

```

```
python test1.py
^ ^ ^
```

# CHAPTER TWENTY

## MY CHEAT SHEET

You can download the PDF version: PySpark Cheat Sheet and pdDataFrame vs rddDataFrame.

### Cheat Sheet for PySpark

Wenqiang Feng  
E-mail: von198@gmail.com, Web: <http://web.ukt.edu/~wqfeng1>; <https://runawayhorse001.github.io/LearningApacheSpark>

**Spark Configuration**

```
from pyspark.sql import SparkSession
spark = SparkSession.builder
 .appName("Python Spark regression example")
 .config("config.option", "value").getOrCreate()
```

**Auditing Data**

**Checking schema**

```
df.printSchema()
root
|- id: integer (nullable = true)
|- TV: double (nullable = true)
|- Radio: double (nullable = true)
|- Newspaper: double (nullable = true)
|- Sales: double (nullable = true)
```

**Checking missing value**

```
from pyspark.sql.functions import count
def my_count(df):
 df = df.agg({count(c).alias(c) for c in df_in.columns}).show()
my_count(df_raw)
+-----+
| (InvoiceId,StockCode,Quantity,InvoiceDate,CustomerID,Country)|count|
+-----+
| 5419091 | 5419091 | 5419091 | 5419091 | 406829 | 5419091 |
+-----+
```

**Checking statistical results**

```
Function from pyspark
df_raw.describe().show()
+-----+
|summary| TV | Radio | Newspaper |
+-----+
| count | 200 | 200 | 200 |
| mean | 147.0425133.26400000000024130.5539999999999995 |
| std | 85.854283140414.468691616021.778203898303 |
| min | 0.0 | 0.0 | 0.0 |
| max | 296.41 | 49.61 | 114.0 |
+-----+
```

**Modeling Pipeline**

**Deal with categorical feature and label data**

```
Deal with categorical feature data
from pyspark.ml.feature import VectorIndexer
featureIndexer = VectorIndexer(inputCol="features",
 outputCol="indexedFeatures",
 maxCategories=4).fit(data)
featureIndexer.transform(data).show(2, True)
+-----+
| features|label| indexedFeatures |
+-----+
| (29,1,1,1,1,1,1,...)| no | (29,1,1,1,1,1,1,...) |
+-----+
```

**Deal with categorical label data**

```
labelIndexer = StringIndexer(inputCol="label",
 outputCol="indexedLabel").fit(data)
labelIndexer.transform(data).show(2, True)
+-----+
| features|label| indexedLabel |
+-----+
| (29,1,1,1,1,1,1,...)| no | 0.0 |
+-----+
```

**Splitting the data to training and test data sets**

```
(trainingData, testData) = data.randomSplit([0.6, 0.4])
```

**Importing the model**

```
from pyspark.ml.classification import LogisticRegression
lr = LogisticRegression(featuresCol="indexedFeatures",
 labelCol="indexedLabel")
```

**Converting indexed labels back to original labels**

```
from pyspark.ml.feature import IndexToString
labelConverter = IndexToString(inputCol="prediction",
 outputCol="predictedLabel",
 labels=labelIndexer.labels)
```

**Wrapping Pipeline**

```
pipeline = Pipeline(stages=[labelIndexer, featureIndexer,
 lr, labelConverter])
```

**Training model and making predictions**

```
model = pipeline.fit(trainingData)
predictions = model.transform(testData)
predictions.select("features", "label", "predictedLabel").show(2)
+-----+
| features|label|predictedLabel |
+-----+
| (29,1,1,1,1,1,1,...)| no | no |
+-----+
```

**Evaluating**

```
from pyspark.ml.evaluation import *
evaluator = MulticlassClassificationEvaluator(
 labelCol="indexedLabel",
 predictionCol="predictedLabel",
 metricName="accuracy")
accu = evaluator.evaluate(predictions)
print("Test Error: %g, AUC: %g" % (1 - accu, accu))
Test Error: 0.0986395, AUC: 0.866664269877
```

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**Data Wrangling: Combining DataFrame**

**Mutating Joins**

A	B
x   x1   x2	x   x1   x3
a   1	a   1
b   2	b   2
c   3	c   3
d   4	d   4

```

Result Function
x1 x2 x3
x | 1 | 2
a | 1 |
b | 2 |
c | 3 |
d | 4 |

#Join matching rows from B to A
#using method join(A, B, by = "x")
#join(B, 'x1', how='left')
A.join(B,'x1',how='left').show()
.orderBy('x1', ascending=True).show()

x1 x2 x3
x | 1 | 2
A.join(B,'x1',how='right')
.orderBy('x1', ascending=True).show()

x1 x2 x3
#Retain only rows in both sets
#using inner join(A, B, by = "x")
A.join(B,'x1',how='inner')
.orderBy('x1', ascending=True).show()

x1 x2 x3
#Retain all values,all rows
#using full join(A, B, by = "x")
A.join(B,'x1',how='full')
.orderBy('x1', ascending=True).show()

```

**Filtering Joins**

X1 X2
a   1
b   2
c   3
d   4

```

Result Function
X1 X2
#All rows in A that have a match in B
#Applies: semi_join(A, B, by = "x1")
a.join(b,'x1',how='left_semi')
.orderBy('x1', ascending=True).show()

X1 X2
#Rows that appear in either or both Y and Z
#Applies: intersect(Y, Z)
Y.intersect(Z).show()

X1 X2
#Shows that appear in Y but not Z
#Applies: left_anti_join(Y, Z)
Y.subtract(Z).show()

```

**DataFrame Operations**

Y	Z
x   x1   x2	x   x1   x2
a   1	a   1
b   2	b   2
c   3	c   3
d   4	d   4

```

Result Function
X1 X2
#Rows that appear in both Y and Z
#Applies: intersect(Y, Z)
Y.intersect(Z).show()

X1 X2
#Shows that appear in either or both Y and Z
#Applies: union(Y, Z).dropDuplicates()
Y.union(Z).dropDuplicates()
.orderBy('x1', ascending=True).show()

X1 X2
#Shows that appear in Y but not Z
#Applies: left_anti_join(Y, Z)
Y.subtract(Z).show()

```

**Binding**

X1 X2
a   1
b   2
c   3
d   4

```

Result Function
X1 X2 X1 X2
#Append Z to Y as new rows
#Applies: zipDataFrames(Y, Z)
Y.union(Z)
.orderBy('x1', ascending=True).show()

X1 X2 X1 X2
#Append Z to Y as new columns
#Caution: zipDataFrames form my package
zipDataFrames(Y,Z).show()

```

**Data Wrangling: Reshaping Data**

**Splitting**

df	df.select("key").split("value")	df.value[0], df.value[1], df.value[2].show()
df	df.select("key")	df.show()
df	df.select("key").split("value", ",")	df.select("key", "value,*").show()
df	df.select("key")	#Splitting one column into several
df	df.select("key", "value")	df.select("key", "value", "value")
df	df.select("key")	#Splitting one column into rows
df	df.toLong(df, by)	def toLong(df, by):
df	df.select("key", "value")	col, dtype = df[0].dtypes for (c, t) in df.dtypes if c not in by:
df	df.select("key", "value")	if t == 'array': F.decode(F.split("values", ",").alias("values"),
df	df.select("key", "value")	1).cast("array<string>").alias("values"))
df	df.select("key", "value")	else: df.select("key", "value")
df	df.select("key", "value")	assert len(set(dtypes)) == 1, "All columns have to be of the same type"
df	df.select("key", "value")	kvs = explode(array(
df	df.select("key", "value")	struct(lit(c).alias("key"), col(c).alias("value")) for c in cols
df	df.select("key", "value")	)), alias("key"), alias("value"))
df	df.select("key", "value")	return df.select(*kvs).selectBy(*kvs).alias("val").show()

**Pivot**

df	df.groupBy("key").pivot("col1").sum("col1").show()
df	df
df	grouped = df.groupby("key")
df	grouped.pivot("col1").sum("col1").show()

**Subset Observations (Rows)**

df	df.na.drop()
df	#Omitting rows with null values

**Subset Variables (Columns)**

df	df.select()
df	#Applies expressions and returns a new DataFrame

**Make New Variables**

df	df.withColumn("new", 1/df.col)
df	df.withColumn("new", F.log(df.col))
df	df.withColumn("id", F.monotonically_increasing_id())
df	df.withColumn("new", F.n("col")) #Fn: F.udf()
df	df.withColumn("new", F.when((df.c1>1)&(df.c2>2),1)
df	.when((df.c3>3),2).otherwise(0)).show()

**Data Wrangling: Reshaping Data**

**Summarise Data**

df	df.describe()
df	#Computes simple statistics

**Correlation**

df	df.corr()
df	#Computes the correlation matrix

**Count**

df	df.count()
df	#Count the number of rows

**Description Demo**

#Sum	df.agg(F.max(df.C).head(10)).similarFor: F.min,max,avg,ctddev
------	---------------------------------------------------------------

**Group Data**

df	df.groupby("A").agg(F.min("B").alias("min_b"), F.max("B").alias("max_b"), F.avg("C").alias("avg_c")).show()
df	df.groupby("A").agg(F.min("B").alias("min_b"), F.max("B").alias("max_b"), F.avg("C").alias("avg_c")).show()
df	def quant_pd(val_list):
df	quant = np.round(np.percentile(val_list, [20,50,75]))[2]
df	return list(np.float(quant))
df	Fs = F.udf(quant_pd, ArrayType(FloatType()))
df	df.groupby("A").agg(Fs(min("B").alias("min_b"), F.max("B").alias("max_b"), F.collect_list(col("C"))).alias("list_c")))

**Windows**

df	from pyspark.sql import Window
df	#Define windows for difference
df	w = Window.partitionBy(df.B)
df	D = df.C - F.max(df.C).over(w)
df	df.withColumn("D", D).show()
df	df = df.withColumn("D", F.monotonically_increasing_id())
df	#Define windows for row_num
df	w = Window.orderBy("D")
df	df.withColumn("D", F.row_number().over(w))
df	df = df.withColumn("D", F.partitionBy("B").rank().over(w))
df	.order_by(df.C.desc())
df	df.withColumn("D", rank().over(w)).show()

**Rename Variables**

df	df.withColumnRenamed()
df	#Renaming an existing column

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**pd.DataFrame vs rdd.DataFrame**

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**Loading DataFrame**

**Creating DataFrame**

- From List

```
pd.DataFrame(my_list,columns= col_name)
spark.createDataFrame(my_list, col_name).show()
```

From Dictionary

```
pd.DataFrame(d)
spark.createDataFrame(np.array(list(d.values())).T.tolist(),
list(d.keys())).show()
```

**From Data Sources**

- From Database

```
conn = psycopg2.connect(host=host, database=db_name,
user=user, password=pw)
cur = conn.cursor()
sql = """select * from table_name
""",format(table_name_to_table_name)
dp = pd.read_sql(sql, conn)

url='jdbc:postgresql://'+host+'5432/'+db_name+'?user='+user
+'&password='+pw
ps.driver='org.postgresql.Driver',password='pw',user=user
dsspark.read.jdbc(url=url, table=table_name, properties=p)
```

From CSV

```
dp = pd.read_csv('Advertising.csv')
ds = spark.read.csv(path='Advertising.csv',
header=True,inferSchema=True)
```

From json

```
dp = pd.read_json("data/data.json")
ds = spark.read.json('data/data.json')
```

**Basic Manipulation**

**Rename one or more columns**

```
map = {key: "val1", key2: "val2"} # mapping
df = df.rename(columns=map).head(4)
new_names = [mapping.get(col,col) for col in ds.columns]
ds.toDF(*new_names).show()
```

**Replace one or more data types**

```
d = "col1": "int", "col2": "str" # string for pyspark
dp = dp.astype(d)
ds = ds.select(*list(set(ds.columns)-set(d.keys())))
for c in d.items():
 col=c[0].astype(c[1]).alias(c[0]) for c in d.items()
```

**Random Split**

```
from sklearn.model_selection import train_test_split
a, b = train_test_split(dp, test_size=0.8)
a, b = ds.randomSplit([0.2,0.8])
```

**Unixtime to Date**

```
dp['date']=dp['date'].dt.datetime(dp['ts'],unit='s').dt.tz_localize('UTC')
spark.conf.set("spark.sql.session.timeZone", "UTC")
ds.withColumn("date", F.from_unixtime('ts'))
```

**Make New Variables**

```
dp['tv_norm'] = dp.TV.sum(dp.TV)
ds.withColumn('tv_norm', dp.TV/ds.groupBy()
 .agg(F.sum("TV").collect())[0][0]).show(4)
dp['cond'] = dp.apply(lambda c: 1 if ((c.TV>100)&(c.Radio<40))
 else 2 if c.Sales> 10
 else 3,axis=1)
ds.withColumn('cond',F.when((ds.TV>100)&(ds.Radio<40),1)
 .when(ds.Sales>10, 2)
 .otherwise(3)).show(4)

dp['log_tv'] = np.log(dp.TV)
ds.withColumn('log_tv',F.log(ds.TV)).show(4)
dp['tv*10'] = dp.TV.apply(lambda x: x*10)
ds.withColumn('tv*10', ds.TV*10).show(4)
```

**Mutating Joins**

**Result Function**

```
x1| x2| x3
---+---+---
a | 1 |
b | 2 |
c | 3 |
-----+
x1| x3
---+---
b | f |
c | g |
d | h |
-----+
```

#Join matching rows from B to A  
A.merge(B,on='X1',how='left')  
A.join(B,'X1',how='left')  
.orderby('X1', ascending=True).show()

**Result Function**

```
x1| x2| x3
---+---+---
a | 1 |
b | 2 |
c | 3 |
-----+
x1| x3
---+---
a | e |
b | f |
c | g |
-----+
```

#Join matching rows from A to B  
A.merge(B,on='X1',how='right')  
A.join(B,'X1',how='right')  
.orderby('X1', ascending=True).show()

**Result Function**

```
x1| x2| x3
---+---+---
a | 1 |
b | 2 |
c | 3 |
-----+
x1| x3
---+---
a | e |
b | f |
c | g |
-----+
```

#Retain only rows in both sets  
A.merge(B,on='X1',how='inner')  
A.join(B,'X1',how='inner')  
.orderby('X1', ascending=True).show()

**Result Function**

```
x1| x2| x3
---+---+---
a | 1 |
b | 2 |
c | 3 |
-----+
x1| x3
---+---
a | e |
b | f |
c | g |
-----+
```

#Retain all values,all rows  
A.merge(B,on='X1',how='full')  
A.join(B,'X1',how='full')  
.orderby('X1', ascending=True).show()

**Group Data**

**Pivot**

```
dp.pivot_table(dp, values='col1', index='key',
columns='col2', aggfunc=np.sum)
df.groupby(['key']).pivot('col1').sum('col2').show()
```

**Windows**

**SQL**

```
sql = """
SELECT * FROM table_name
""",format(table_name_to_table_name)
dp = pd.read_sql(sql, conn)
...
ds.registerTempTable("ds")
spark.sql("SELECT * FROM ds").show()
```

---

**CHAPTER  
TWENTYONE**

---

**MAIN REFERENCE**



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