Fundamentals of Machine Learning for Computer Vision (IMCV)

Lecture Zero – September 30th, 2021

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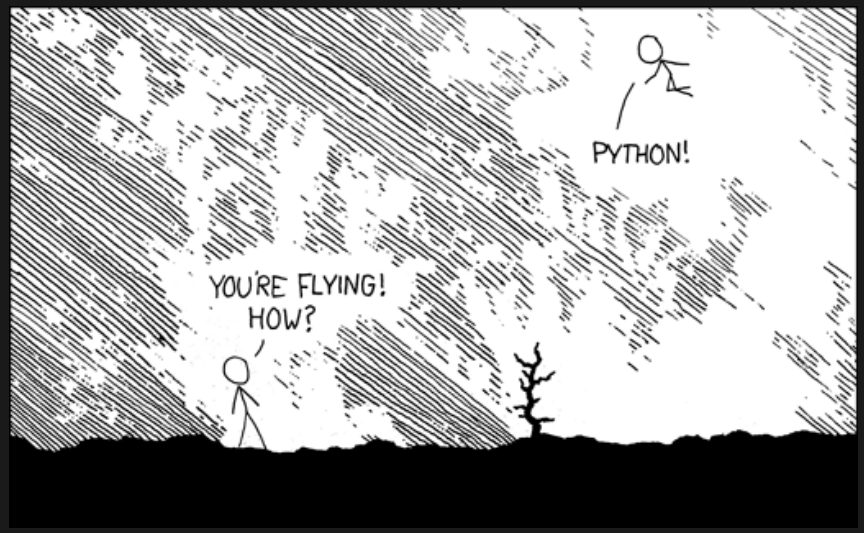
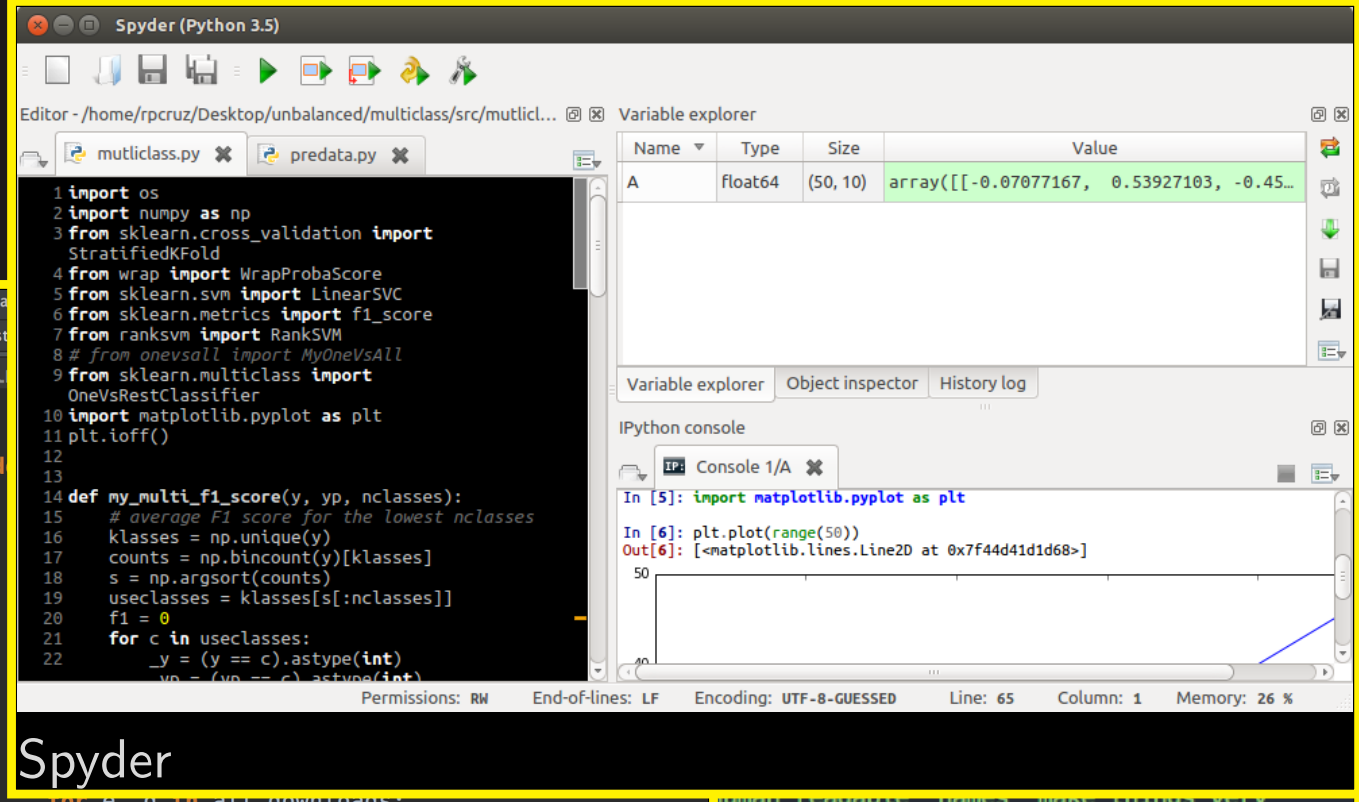
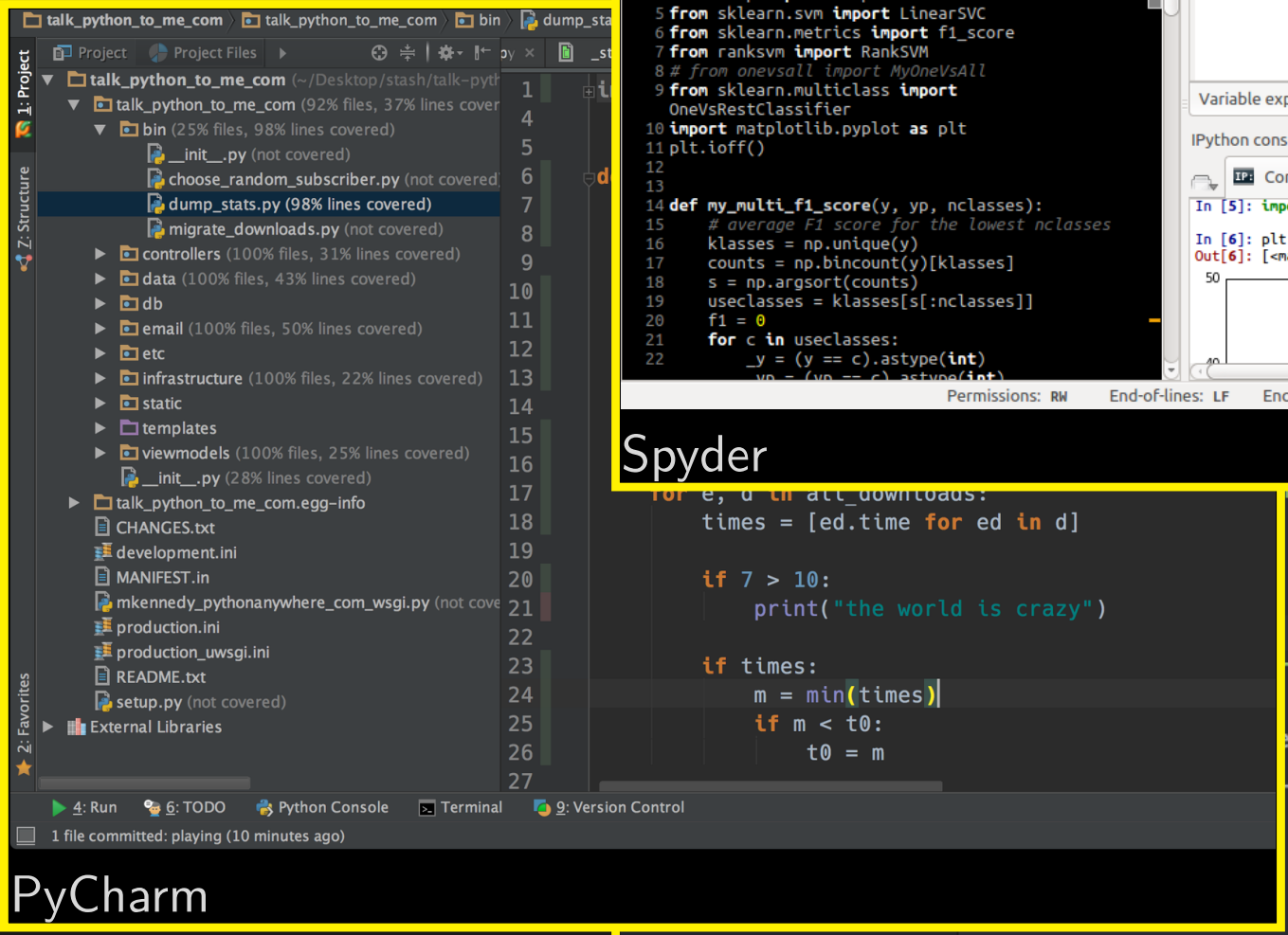


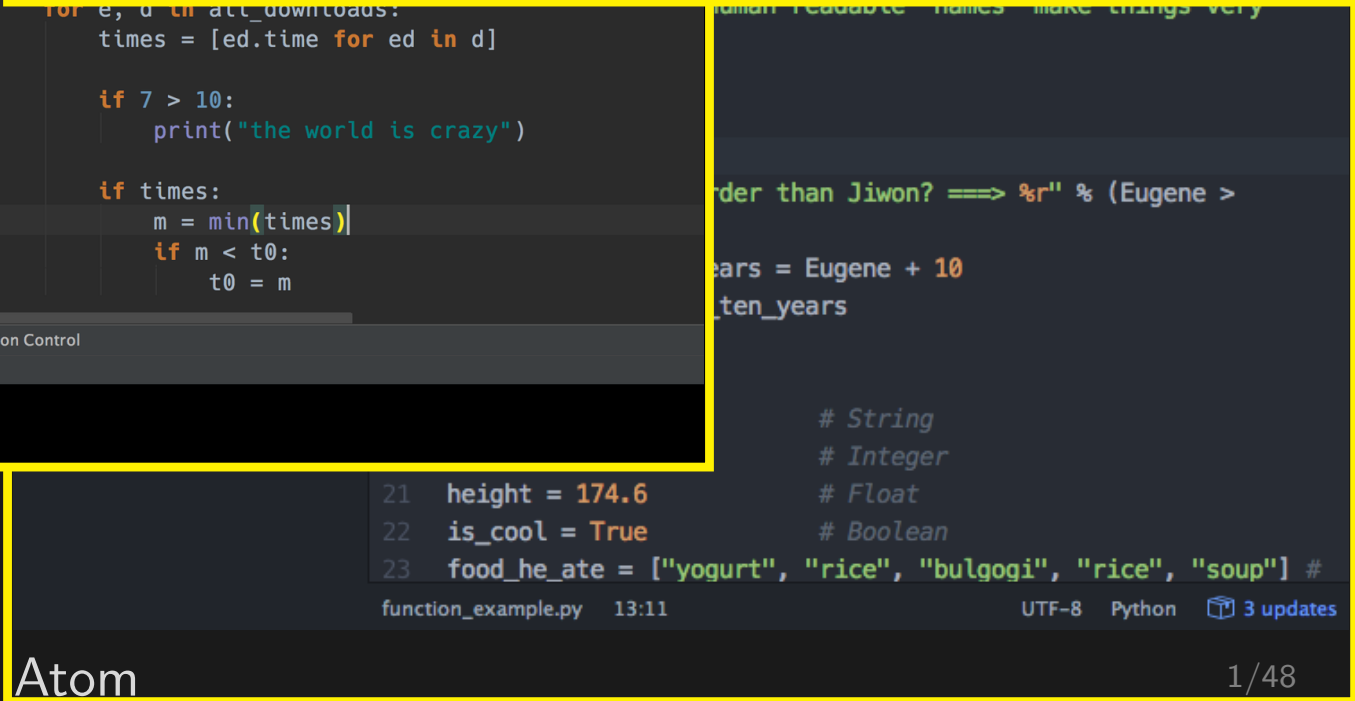
Editors



Spyder



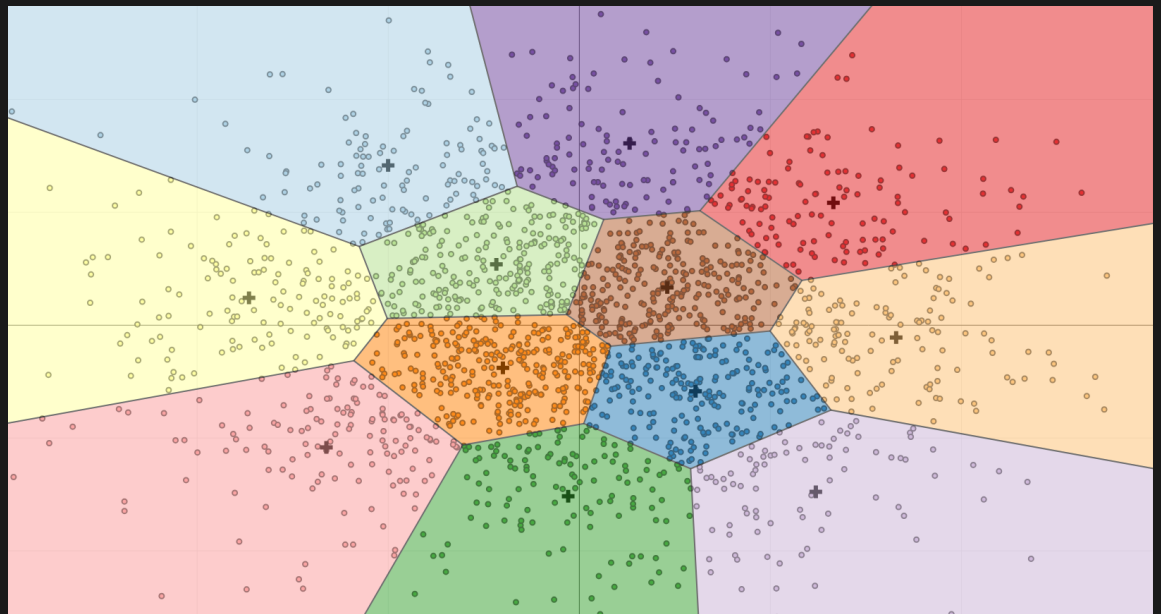
PyCharm



Atom

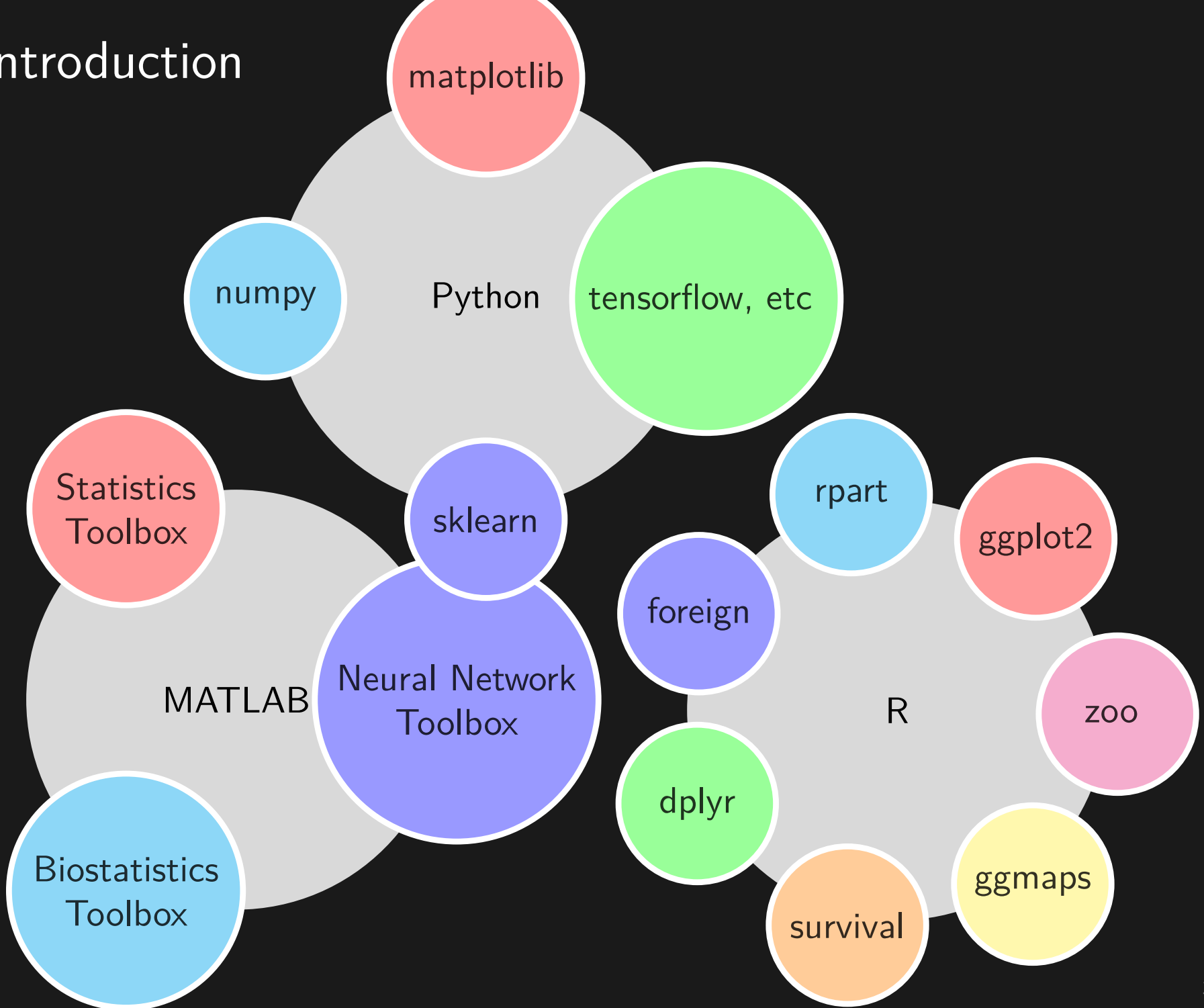
Agenda

Theory	Practice
~Introduction~	
Numpy	Implement Euclidean distance
Cycles/functions	K-means algorithm
File handling	Use a real dataset
Matplotlib	Plots
Classes/modules	—
Scikit-learn	Use its k-means
~Finishing touches~	



Introduction

Introduction



Introduction

- Furthermore, Python is a **general** purpose language
  - It is used in everything from user interfaces to web servers
  - Linear algebra is **not** a primary citizen

Introduction: Syntax

Python

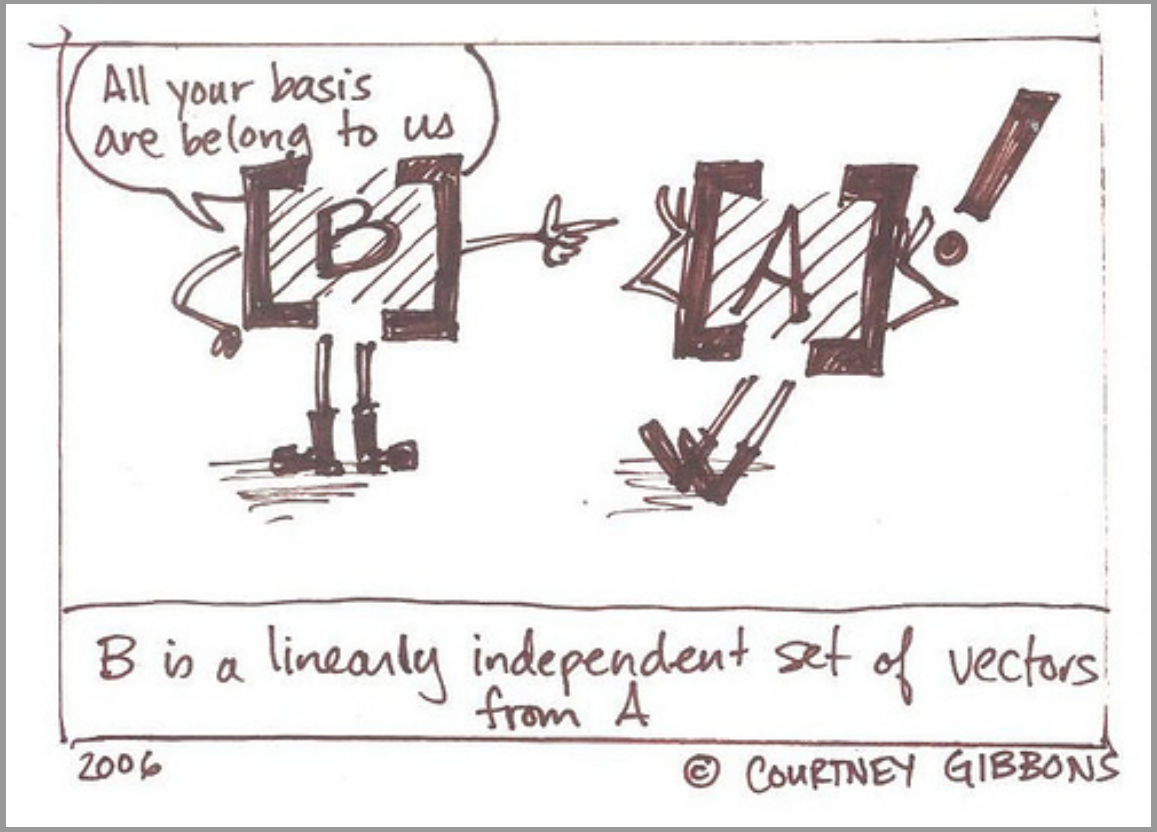
```python
def is_prime(n):
  for m in range(2, n):
    if n % m == 0:
      return False
  return True
```

MATLAB

```matlab
function ret = is_prime(n)
  ret = true;
  for m=1:(n-1)
    if mod(n, m) == 0
      ret = false;
      break
    end
  end
end
```

Warning: In Python you **must** properly indent your code.

NumPy: linear algebra package



NumPy

The *de-facto* package for linear algebra is `numpy`.

Usually, it is shortened to `np`:

```
1 import numpy as np
```

NumPy features two main structures:

- `np.ndarray` — array of multiple dimensions
- `np.matrix` — matrix (two dimensions)

NumPy vs MATLAB

Summary of **NumPy for MATLAB users** [1] [2]

MATLAB	NumPy
`size(a)`	`a.shape`
`a(1:5,:)`	`a[0:5,:]` or `a[0:5]` or `a[:5]`
`a(end-4:end,:)`	`a[-5:]`
`a.'`	`a.transpose()` or `a.T`
`a * b`	`a.dot(b)`
`a .* b`	`a * b`

The main conceptual difference is that Numpy supports **arithmetic broadcasting.** That is, you can do the following element-wise multiplication: (6,3) * (6,1). It automatically assumes you want to multiply by column. In MATLAB, you would have to use `bsxfun(@times,r,A)` or first use `repmat()`.

[1] `https://docs.scipy.org/doc/numpy-dev/user/numpy-for-matlab-users.html`
[2] `http://mathesaurus.sourceforge.net/matlab-numpy.html`

NumPy Example

Create $B_{ij} = \begin{cases} 5, & \text{if } A_{ij} > 1 \\ 0, & \text{otherwise.} \end{cases}$

Suggestions:

```
B = A.copy()
B[A > 1] = 5
B[A <= 1] = 0
```

```
B = np.zeros(A.shape)
B[A > 1] = 5
```

```
B = (A > 1) * 5
```

```
B = np.asarray(
  [[5 if aij > 1 else 0 for aij in ai] for
ai in A])
```

It is probably a good idea to finish this off with:

```
B = B.astype(np.int8)
```

to save memory!

API

Python Lists

1. Create a list – `l = [1, 5, 2]`
2. Access item – `l[1]`
3. Modify item – `l[1] = 7`
4. Add item – `l.append(8)`, `l += [9, 10]`

NumPy

1. Create ndarray from list – `np.array()`
2. Create ndarray of zeros/ones – `np.zeros()`, `np.ones()`
3. Sample Uniform(0,1) – `np.rand`, `np.random.random()`
4. Sample Normal(0,1) – `np.randn`, `np.random.normal()`
5. Horizontal concatenation – `np.vstack()`, `np.c_[]`
6. Vertical concatenation – `np.hstack()`, `np.r_[]`
7. Any concatenation – `np.concatenate(list, axis)`

Project: Implement Euclidean distance

Get the project files from MS Teams.

1. Implement a function called **euclidean_distance(a, b)**
   - Given two vectors **a** and **b**, computes the square-root of the squared difference between the two vectors
   - $d = \|x_1 - x_2\|_2$
   - TIP: you might want to use vectorisation!
2. Use it for the two example vectors given in the script
   v1 = [1.1, 2.5, 4.4, 0.1, 2.3, 3.4]
   v2 = [2.0, 2.2, 1.0, 1.0, 2.5, 3.4]

Possibly useful functions:

`np.random.randn`, `np.mean`, `np.std`, `np.sqrt`, `np.square`, `np.linalg.norm`

Project: Implement Euclidean distance (solution)

```python
# Implement the euclidean_distance function here:
def euclidean_distance(a, b):
    # Computes and returns the Euclidean distance between vectors 'a' and 'b'
    distance = np.sqrt(np.sum(np.square(a - b)))
    return distance

# Check if it is working! Here are two vectors:
v1 = np.array([1.1, 2.5, 4.4, 0.1, 2.3, 3.4])
v2 = np.array([2.0, 2.2, 1.0, 1.0, 2.5, 3.4])

# Call the euclidean_distance function below to compute the distance between them:
dist = euclidean_distance(v1, v2)

print('Distance between v1 and v2: ', dist)  # (For these vectors, it should be something like 3.6482...)
```

Cycles & Functions

Loops

Python has some interesting functions that can help you in loops.

```
for n in range(10, 30, 2):
  print(n)
# 10 12 14 16 18 20 22 24 26 28

for i, n in enumerate(range(10, 20, 2)):
  print((i, n))
# (0, 10) (1, 12) (2, 14) (3, 16) (4, 18)

for a, b in zip(range(10, 20), range(40, 50)):
  print((a, b))
# (10, 40) (11, 41) (12, 42) (13, 43) (14, 44) (15, 45) (16, 46)
    (17, 47) (18, 48) (19, 49)
```

You will probably use these functions a lot in your loops: `range`, `enumerate` and `zip`.

List Comprehension and Functools

List comprehension

```
1 [i**2 for i in range(5)]
```

```
1 [i for i in range(5) if i % 2 ==
      0]
```

Functools

```
1 map(lambda x: x**2, range(5))
```

```
1 filter(lambda x: x % 2 == 0,
      range(5))
```

```
1 functools.reduce(lambda a,b: a+b
      , range(5))  # sum numbers
      (10)
```

- List comprehension is considered the most Pythonic approach.
- But...

Project: Implement the k-means algorithm

Given data X_{ij}, the user first defines K clusters.

The algorithm:

1. Random cluster centroids are selected randomly using the MacQueen method;
2. Each observation is assigned the closest cluster:
   - $c_i(t+1) = \arg\min_k \|x_i - \tilde{c}_k\|_2$
3. Compute the new centroid of each cluster (using the Euclidean distance you implemented before):
   - $\forall k, j : \tilde{c}_{kj} = \frac{1}{\sum_{i=1}^{N} \mathbb{1}_{c_i=k}} \sum_{i=1}^{N} \mathbb{1}_{c_i=k} X_{ij}$
4. Repeat steps 2-3 for a set number of iterations.

Please place this inside a `kmeans`$: \mathbb{Z}, \mathbb{R}^{N\times M} \to \mathbb{Z}^N$ function, which maps K and X to its respective clusters.

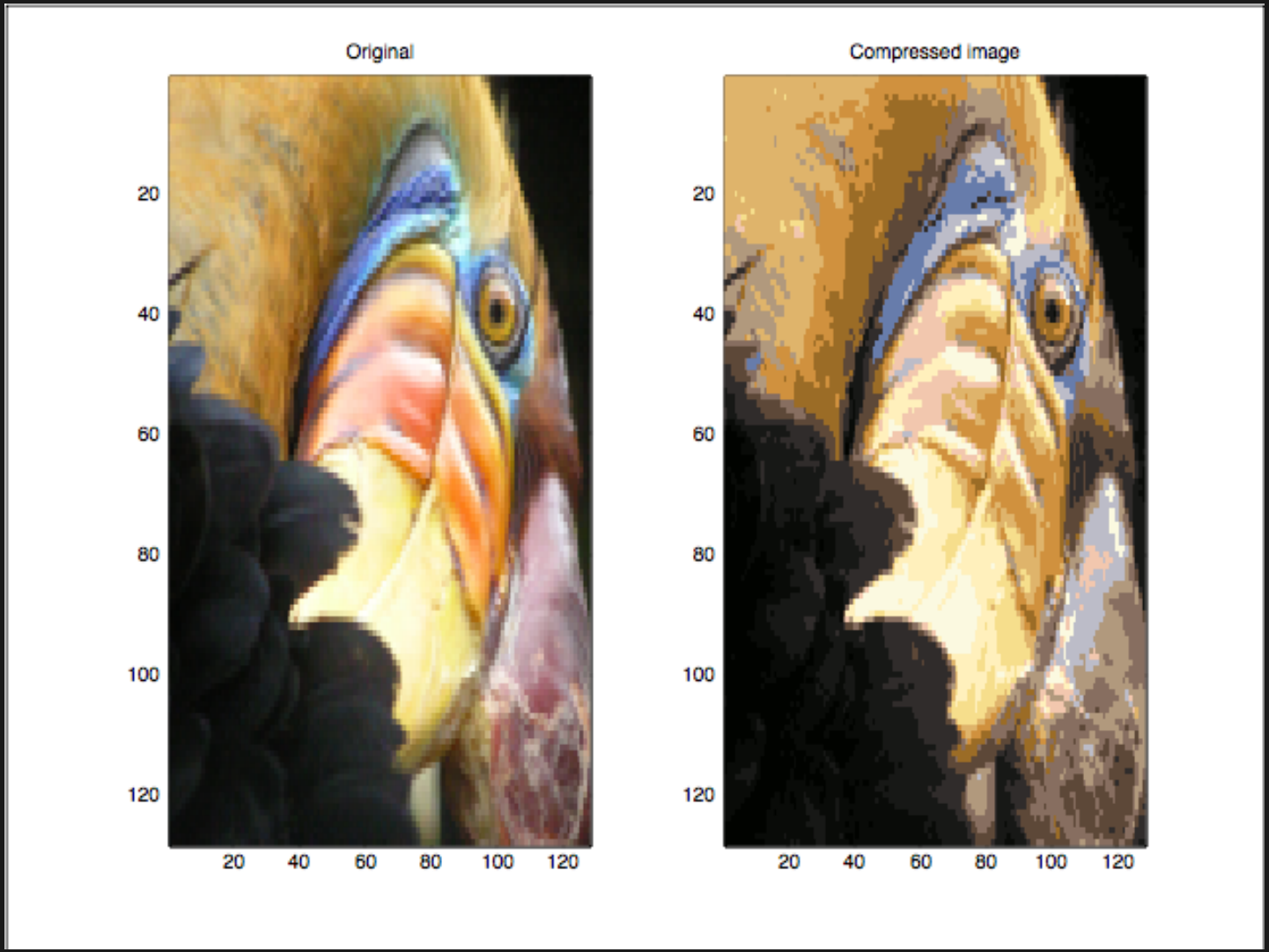
Note: you can also implement a convergence condition that stops the loop as soon as the clusters stabilise.

Project: Implement the k-means algorithm (solution)

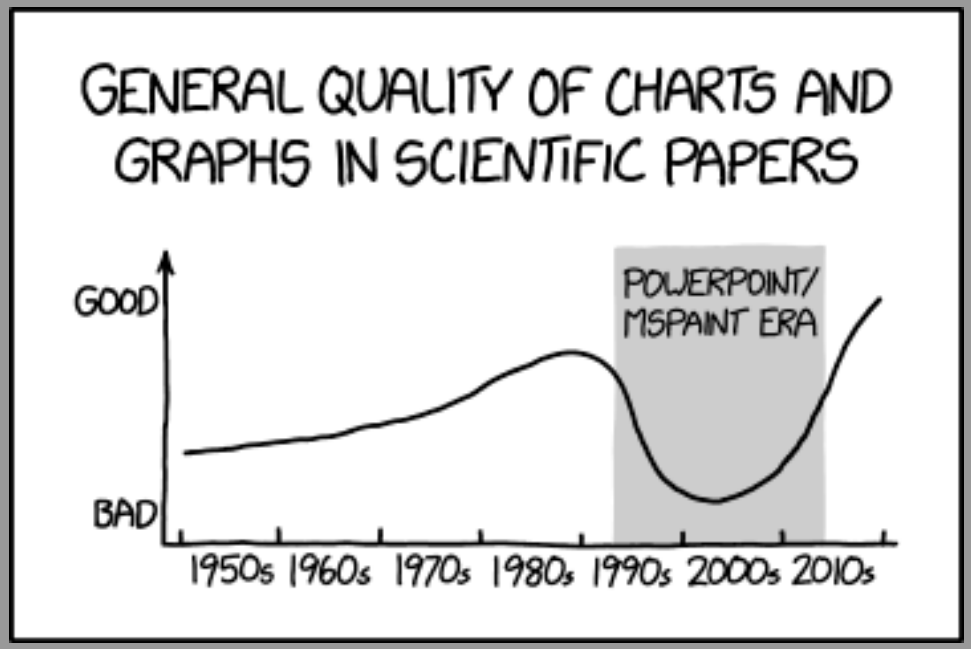
```
def k_means(X, k=3, n_iterations=10):
    # (...)
    # The k_means algorithm is iterative. Start a loop here for 'n_iterations':
    for ii in range(n_iterations):
        # In each loop, for each data point:
        for index in range(X.shape[0]):
            # Compute the Euclidean distance between the data point and each centroid:
            distance = [euclidean_distance(X[index], cc) for cc in centroids]

            # Then, assign each data point to the cluster with the nearest centroid:
            membership[index] = np.argmin(distance)

        # Now, recompute the centroids of each cluster, computing the mean of the cluster data points:
        for cc in range(k):
            centroids[cc] = np.mean(X[membership == cc], axis=0)
    # (...)
```

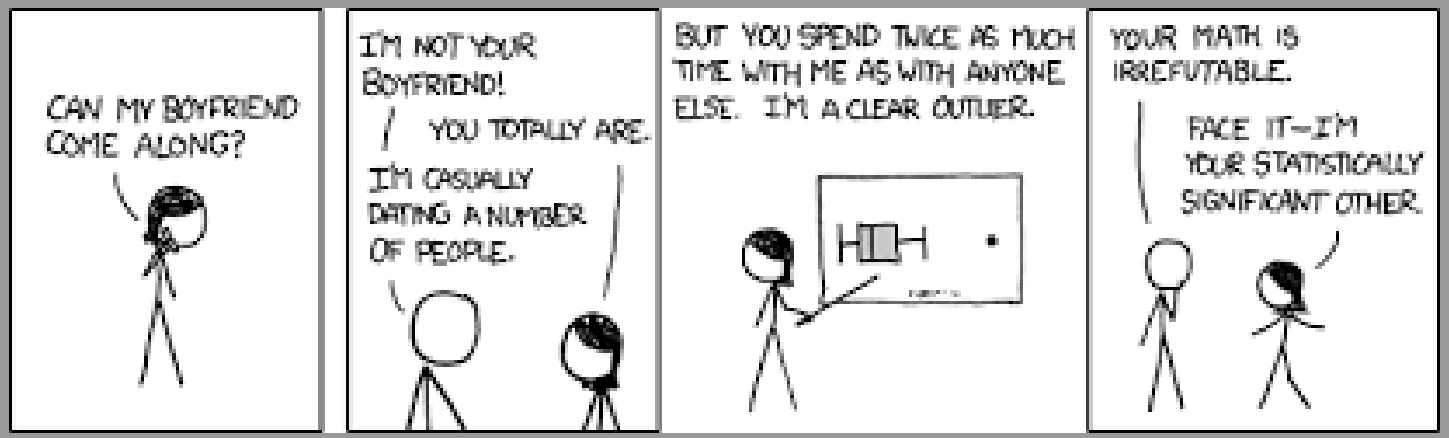
Kmeans: usage example

K-means can be used for e.g. image compression...
24 (8×3) bits $\rightarrow$ k=64 (6 bits)



Matplotlib


GENERAL QUALITY OF CHARTS AND GRAPHS IN SCIENTIFIC PAPERS
GOOD
BAD
POWERPOINT/ MSPAINT ERA
1950s 1960s 1970s 1980s 1990s 2000s 2010s


CAN MY BOYFRIEND COME ALONG?
I'M NOT YOUR BOYFRIEND!
YOU TOTALLY ARE.
I'M CASUALLY DATING A NUMBER OF PEOPLE.
BUT YOU SPEND TWICE AS MUCH TIME WITH ME AS WITH ANYONE ELSE. I'M A CLEAR OUTLIER.
HI
YOUR MATH IS IRREFUTABLE.
FACE IT—I'M YOUR STATISTICALLY SIGNIFICANT OTHER.

Matplotlib

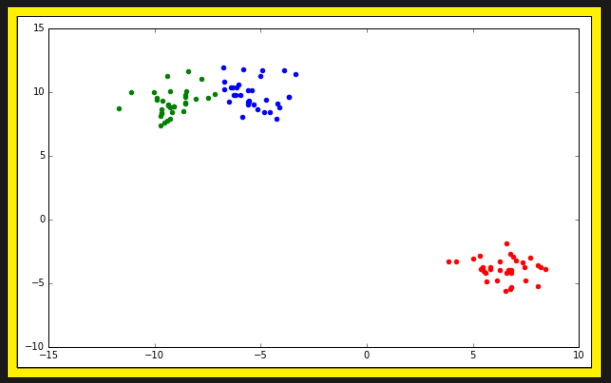
The *de-facto* package for plotting graphics in python is matplotlib.

Matplotlib contains an API[3] called `pyplot` that is inspired in MATLAB.

See: `http://matplotlib.org/1.4.3/api/pyplot_api.html`

[3] API = Application Programmer's Interface

Matplotlib



Example using synthetically created data:

```
from matplotlib.pyplot as plt
from sklearn.datasets import make_blobs
X, y = make_blobs(centers=3)
```

```
plt.scatter(X[y == 0, 0], X[y == 0, 1], color='red')
plt.scatter(X[y == 1, 0], X[y == 1, 1], color='green')
plt.scatter(X[y == 2, 0], X[y == 2, 1], color='blue')
plt.show()
```

OR

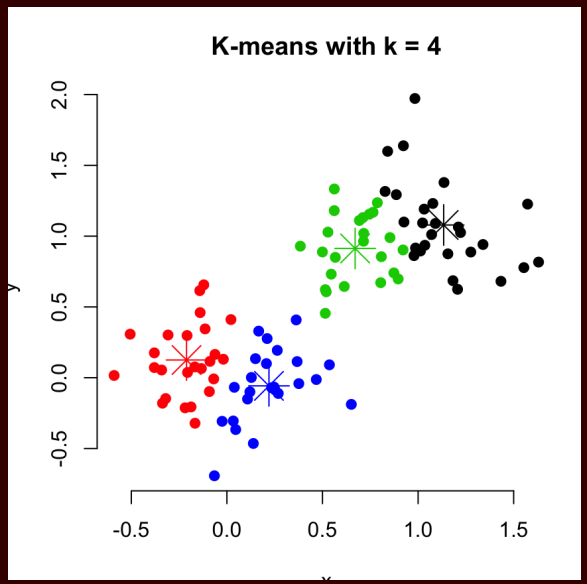
```
colors = ['red', 'green', 'blue']
plt.scatter(X[:, 0], X[:, 1], color=[colors[_y] for _y in y])
plt.show()
```

OR

```
colors = plt.cm.rainbow(np.linspace(0, 1, 3))
plt.scatter(X[:, 0], X[:, 1], color=colors[y])
plt.show()
```

Project: k-Means in a simulated dataset

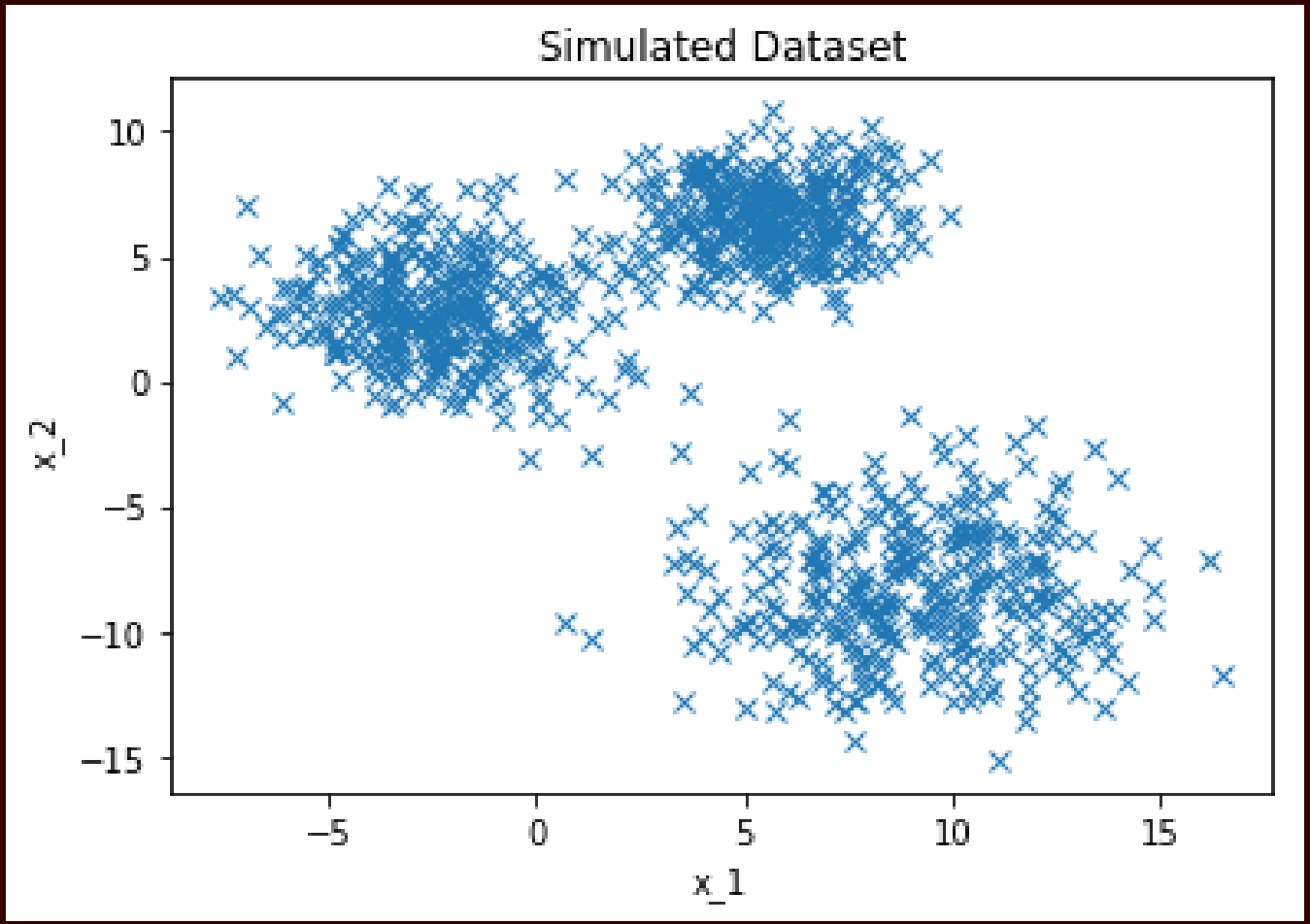
1. Use matplotlib to **plot the simulated dataset**
2. Use the implemented k-Means function to **cluster the dataset** (note: use $k = 3$)
3. Use matplotlib again, to **plot the k-Means clustering result** (use a different color for the points of each cluster)
4. At last, try to **plot the movement of the centroids** over the iterations



Project: k-Means in a simulated dataset (solution)

```
# Now, to test it, we shall use a simulated dataset:
X, _ = additional_stuff.simulated_dataset()

# We can use matplotlib to visualise the simulated data points:
# First, we plot the data points:
pl.plot(X[:,0], X[:,1], 'x')
# Then, some additional stuff:
pl.title('Simulated Dataset')
pl.xlabel('x_1')
pl.ylabel('x_2')
pl.show()

# Now, we can apply our implementation of 'k-means' to this
    dataset:
membership, centroids, centroids_history = k_means(X, k=3)
```

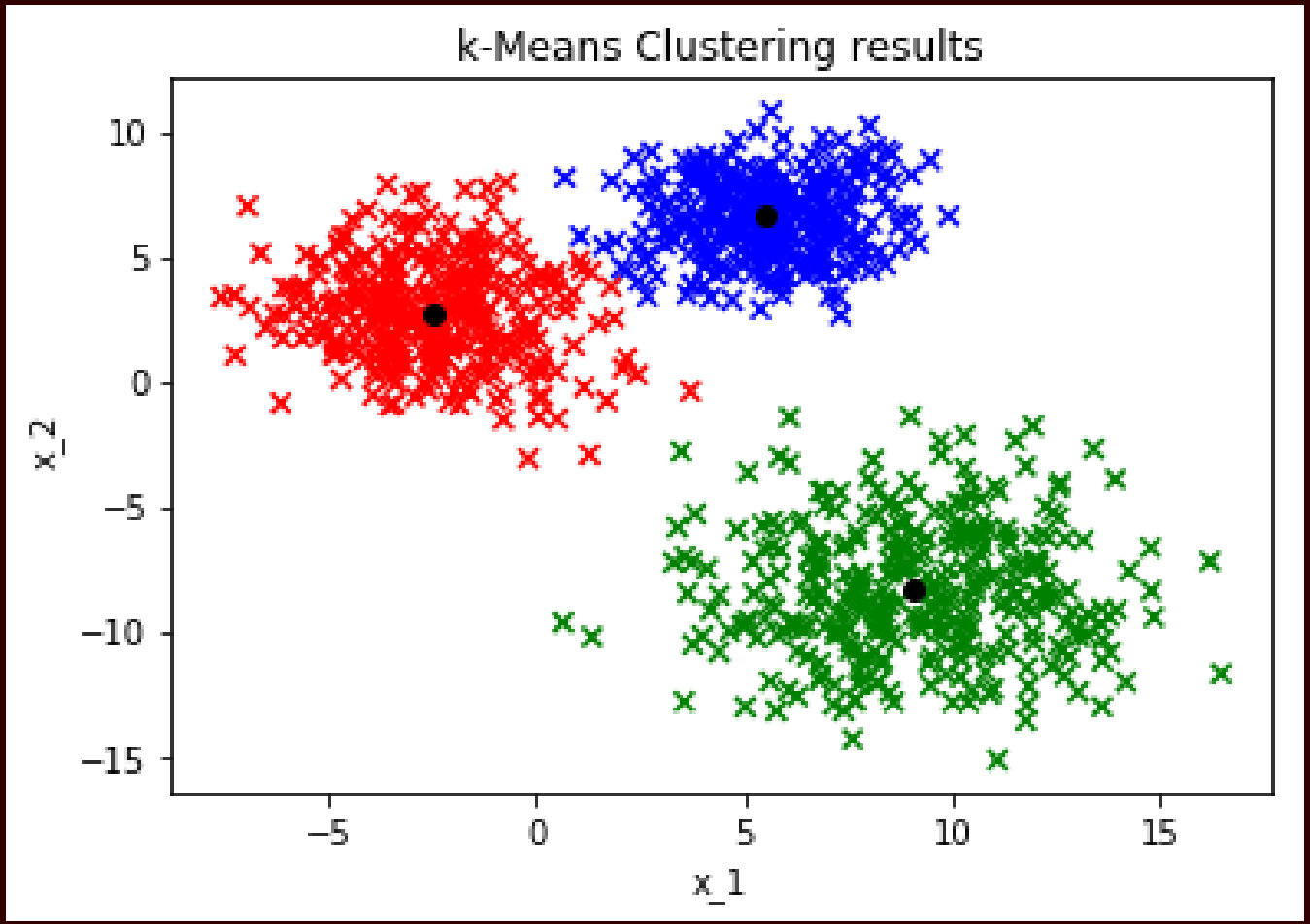
Project: k-Means in a simulated dataset (solution)



Project: k-Means in a simulated dataset (solution)

```
# Using matplotlib, we can plot the result:
# First, plot the data points:
colors = ['red', 'green', 'blue']
pl.scatter(X[:, 0], X[:, 1], marker='x', color=[colors[int(_y)]
    for _y in membership])
# Then, plot the final cluster centroids:
pl.scatter(centroids[:,0], centroids[:,1], 'o', color='black')
# And some additional stuff:
pl.title('k-Means Clustering results')
pl.xlabel('x_1')
pl.ylabel('x_2')
pl.show()
```

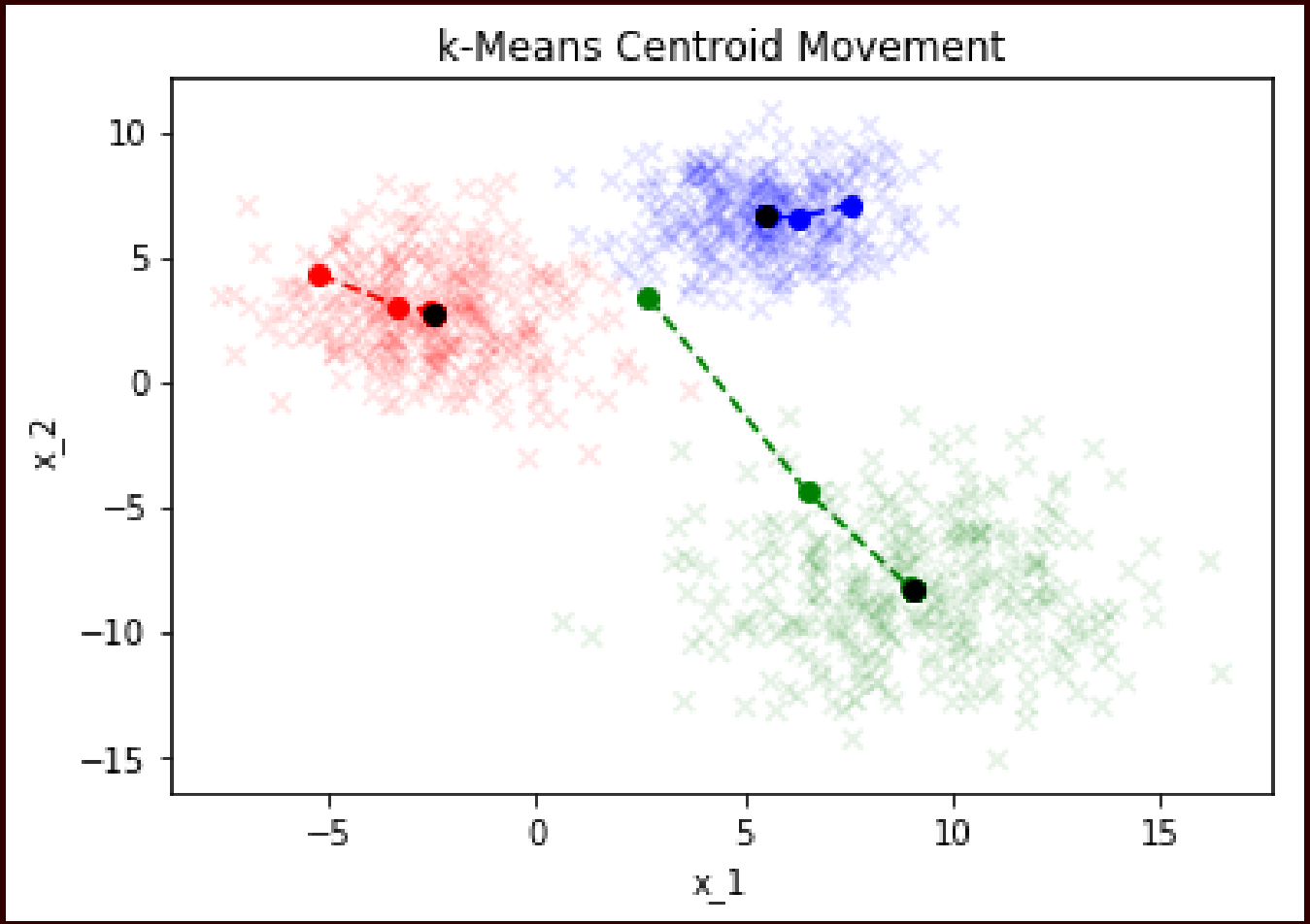
Project: k-Means in a simulated dataset (solution)



Project: k-Means in a simulated dataset (solution)

```
# We can also see the movement of each centroid during the iterations:
# Plot the data points again (use alpha to make them transparent):
pl.scatter(X[:, 0], X[:, 1], marker='x', alpha=0.1, color=[colors[int(_y)] for _y in membership])
# And plot each centroid's movement:
pl.plot(centroids_history[:,0,0], centroids_history[:,0,1], '--', marker='o', color='red')
pl.plot(centroids_history[:,1,0], centroids_history[:,1,1], '--', marker='o', color='green')
pl.plot(centroids_history[:,2,0], centroids_history[:,2,1], '--', marker='o', color='blue')
# Then, plot the final cluster centroids:
pl.plot(centroids[:,0], centroids[:,1], 'o', color='black')
# And some additional stuff:
pl.title('k-Means Centroid Movement')
pl.xlabel('x_1')
pl.ylabel('x_2')
pl.show()
```

Project: k-Means in a simulated dataset (solution)



File Handling

Open files using Numpy

Open a CSV file and add some random noise.

```
1 import numpy as np
2 d = np.loadtxt('file.csv', [np.float64, np.float64, np.int8],
3                delimiter=',', skiprows=1)
4 X = d[:, :-1]
5 y = d[:, -1]
```

Open files using Numpy

Open a CSV file and add some random noise.

```
import numpy as np
d = np.loadtxt('file.csv', [np.float64, np.float64, np.int8],
               delimiter=',', skiprows=1)
X = d[:, :-1]
y = d[:, -1]
```

By default numpy always works with `np.float64`. But you may want to change `dtype` when opening a CSV file or creating a vector in order to use less memory. The following types are available:

`np.int`	8, 16, 32 and 64 bits
`np.uint`	8, 16, 32 and 64 bits
`np.float`	16, 32 and 64 bits
`np.complex`	64 and 128 bits

Complex numbers are represented using two 32-bits or 64-bits floats.

By default numpy always works with `np.float64`. If you work with GPUs, it's a good idea to convert everything to 32-bits.

Open images using Scikit-image

```python
from skimage.io import imread
img = imread('filename.png')

print(img.shape)
# (512, 512, 3)  # if color (RGB)
```

Pandas

If you are used to R `data.frame` then you are going to miss things like accessing columns by column name.

There is a widely used data-frame package for Python called `pandas`.

(This package is particularly useful when dealing with time series because it supports a lot of timeseries functionality we are not going to cover.)

Opening is faster than numpy...

```
import pandas as pd
df = pd.read_csv('titanic.csv')
df = pd.read_excel('a.xlsx')

df.groupby('gender').mean()
#                age      height
# gender
# female   53.870850   158.201459
# male     53.491803   158.971695

df.to_csv('blabla.csv')
df.to_excel('blabla.xlsx')
```

Indexing

```
df['nome-coluna']

df.loc['nome-linha']
df.ix[5]  # nro linha
df.ix[:, 5]  # linha, coluna
```

Save Session

There are two ways to save your session/variables to a file:

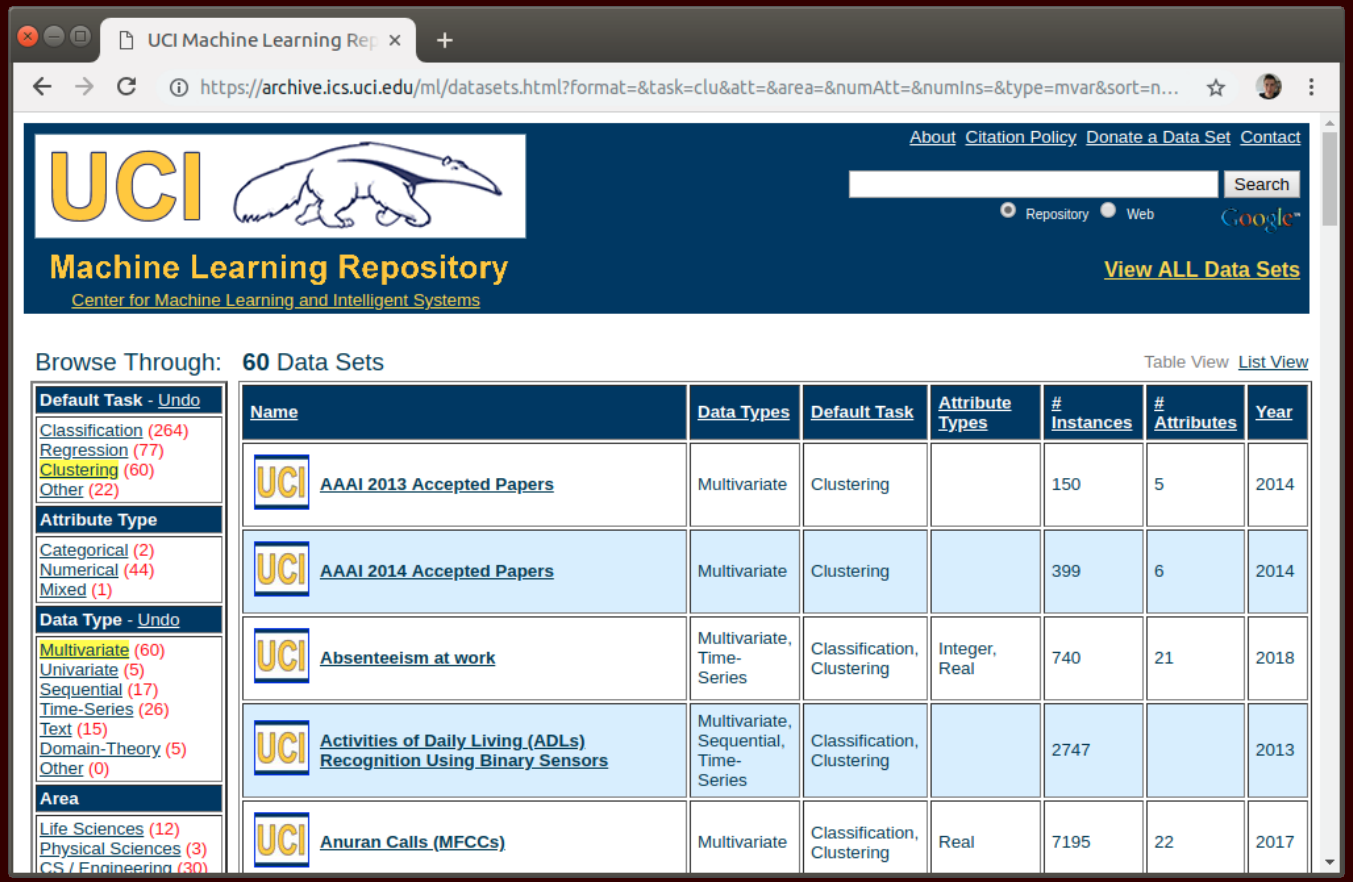
- `np.save`: numpy binary format
- `pickle`: binary file (python version-specific)
- `json`: text file (universal)

Pickle is the native Python approach:

```
1 import pickle
2 pickle.dump(d, open('save.pickle', 'wb'))
3 # and then you can just load it again:
4 d = pickle.load(open('save.pickle', 'rb'))
```

Project: Use a real dataset

We are going to use the Iris dataset from "UCI Machine Learning"



It includes 150 samples of flowers of three classes (iris-setosa, iris-versicolor, iris-virginica) and includes measurements of sepal width and length and petal width and length.

Project: Use a real dataset

Tasks:

1. **Open 'iris.txt'** using pandas read_csv() function;
2. **Check the dataset** using Spyder's Variable Explorer;
3. Make a **numpy array with just two features** of the dataset;
4. Use k-means to **cluster the dataset** (use $k = 3$);
5. Use matplotlib to **plot the results**.

Project: Use a real dataset (solution)

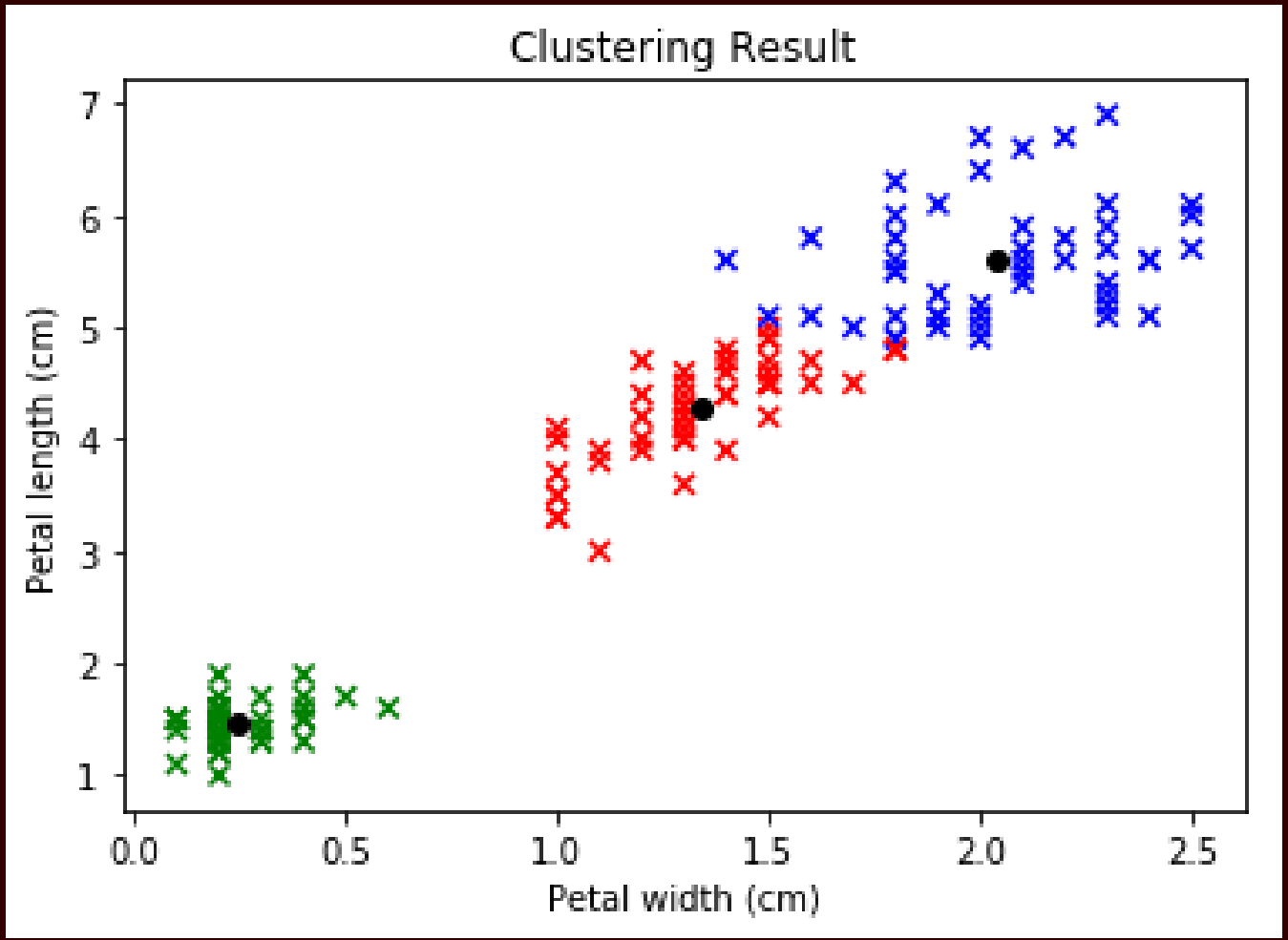
```
# We can also apply our k-means algorithm to a real dataset.
# To do that, we can use pandas to import the dataset:
data = pd.read_csv('iris.txt')

# To use k-means, let's select just two columns of the dataset:
X = np.array(data[['petal width', 'petal length']])

# And perform k-Means clustering with k = 3 (no. of classes)
membership, centroids, _ = k_means(X, k=3)

# And plot the results:
colors = ['red', 'green', 'blue']
pl.scatter(X[:, 0], X[:, 1], marker='x', color=[colors[int(_y)]
    for _y in membership])
pl.plot(centroids[:,0], centroids[:,1], 'o', color='black')
pl.title('Clustering Result')
pl.xlabel('Petal width (cm)')
pl.ylabel('Petal length (cm)')
pl.show()
```

Project: Use a real dataset (solution)



Project: Use an image

Tasks:

1. **Open the image** 'lemons.jpg' using scikit-image `io.imread()` function;
2. **Visualise the image** using matplotlib `imshow()` function;
3. Change the shape from $(w, h, c) \rightarrow (w \times h, c)$ with numpy's `reshape()` function;
4. Use **k-means on the reshaped image**;
5. Reshape the k-means result back: $(w \times h, c) \rightarrow (w, h, c)$;
6. **Visualise the result** using the `imshow()` function;
7. **Save the result** using scikit-image: `io.imsave(filename, image)`.

Project: Use an image (solution)

```
# First, we use scikit-image to import the image:
image = io.imread('lemons.jpg')

# Visualise the image using matplotlib:
pl.imshow(image)
pl.show()

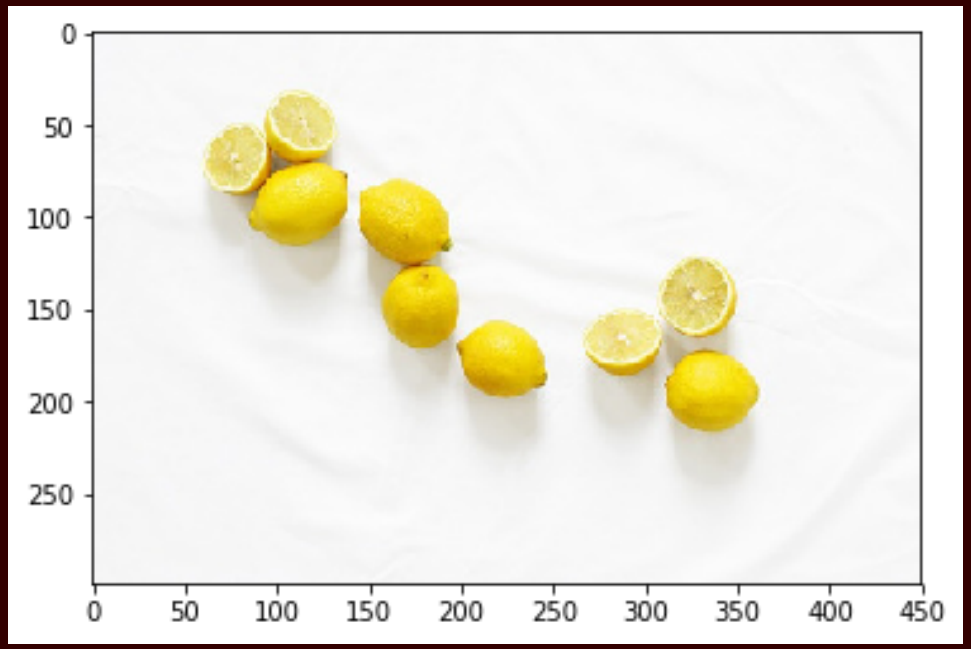
# Each pixel should be considered a single sample (in this case, with three
# features - RGB). We need to restructure the image accordingly:
image_reshaped=image.reshape((image.shape[0]*image.shape[1], 3))

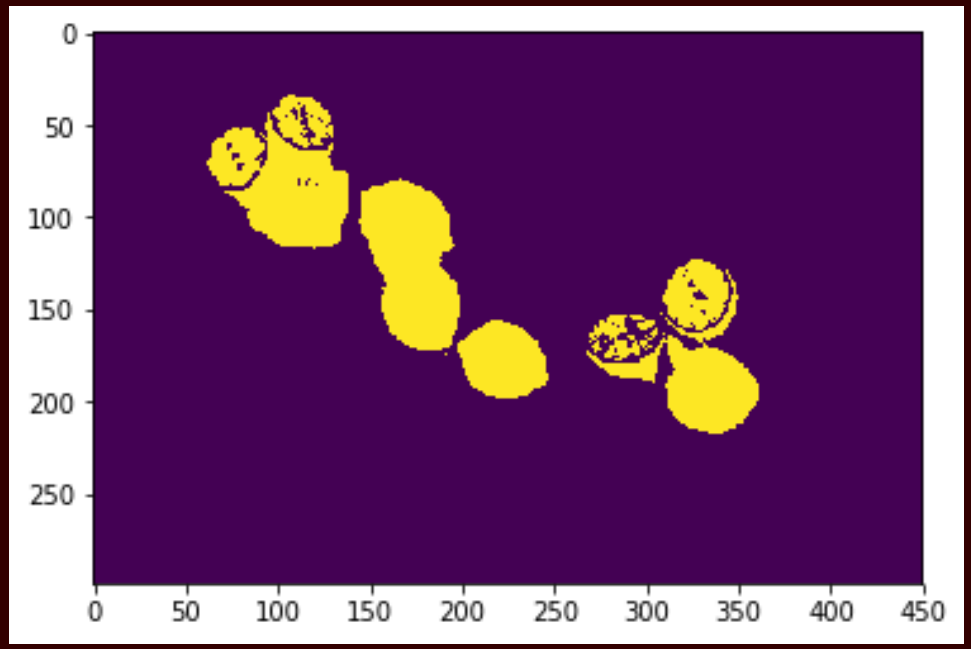
# Now, we finally apply k-means to it:
membership, _ , _ = k_means(image_reshaped, k=2)

# Reshaping and visualising the result:
result = membership.reshape((image.shape[0], image.shape[1]))
pl.imshow(result)
pl.show()

# Save the result as an image:
io.imsave('result.jpg', result)
```

Project: Use an image (solution)





Classes & Modules

Classes

```
1 class Animal:
2   def talk(self):
3     raise NotImplementedError('Implement me')
4
5 class Cat(Animal):
6   def talk(self):
7     print("Miau")
8
9 class Human(Animal):
10  def talk(self):
11    print("Bla bla")
12
13 Cat().talk()  # what is the output?
```

Two notes:

- Python is very dynamic: there are no formal contracts like abstract methods
- in Python, the reference to the object itself is passed explicitly

Modules

Different ways to access a module:

- ```
  1 import fib
  2 fib.whatever()
  ```

- ```
  1 from fib import whatever
  2 whatever()
  ```

- ```
  1 from fib import *
  2 whatever()
  ```

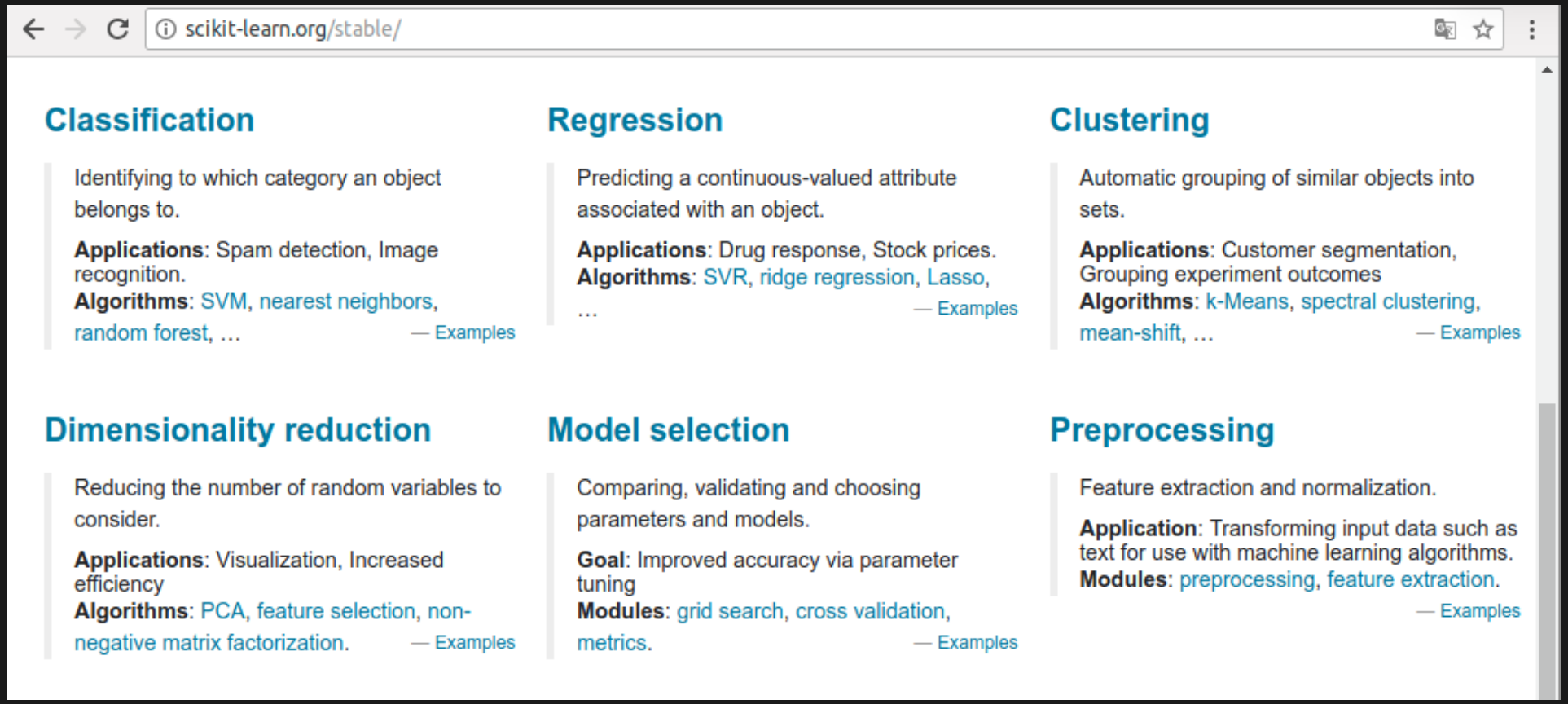
  (import everything into your namespace — usually not recommended)

Inside each directory, you ~~must~~ may have a `__init__.py` file where you can put initialization code.
  ```

Scikit-learn

Scikit-learn

Scikit-learn has literally **everything!**



Scikit-learn interface

Estimator:	Implements the fit method to learn from data.
	For Supervised Learning:
	`estimator = estimatorObj.fit(data, labels)`
	and Unsupervised Learning:
	`estimator = estimatorObj.fit(data)`

Predictor:	`labels = predictorObj.predict(data)` May implement `predict_proba` to return the degree of certainty.
Transformer:	Filters or modifies the data: `new_data = transformerObj.transform(data)`
Model:	Measures goodness of fit: `score = modelObj.score(data, labels)`

Project: Apply K-means with sklearn

Tasks:

1. Find the sklearn documentation for the K-means algorithms;
2. Go to the code you have previously written for the Iris dataset and substitute your k-means function by the KMeans object of sklearn. You should:
   - **2.1** Create the object.
   - **2.2** Estimate the parameters with the data (fit(.)).
   - **2.3** For each sample predict the assigned cluster (predict(.)).
3. Plot and check you have obtained an equivalent result.

Project: Apply K-means with sklearn

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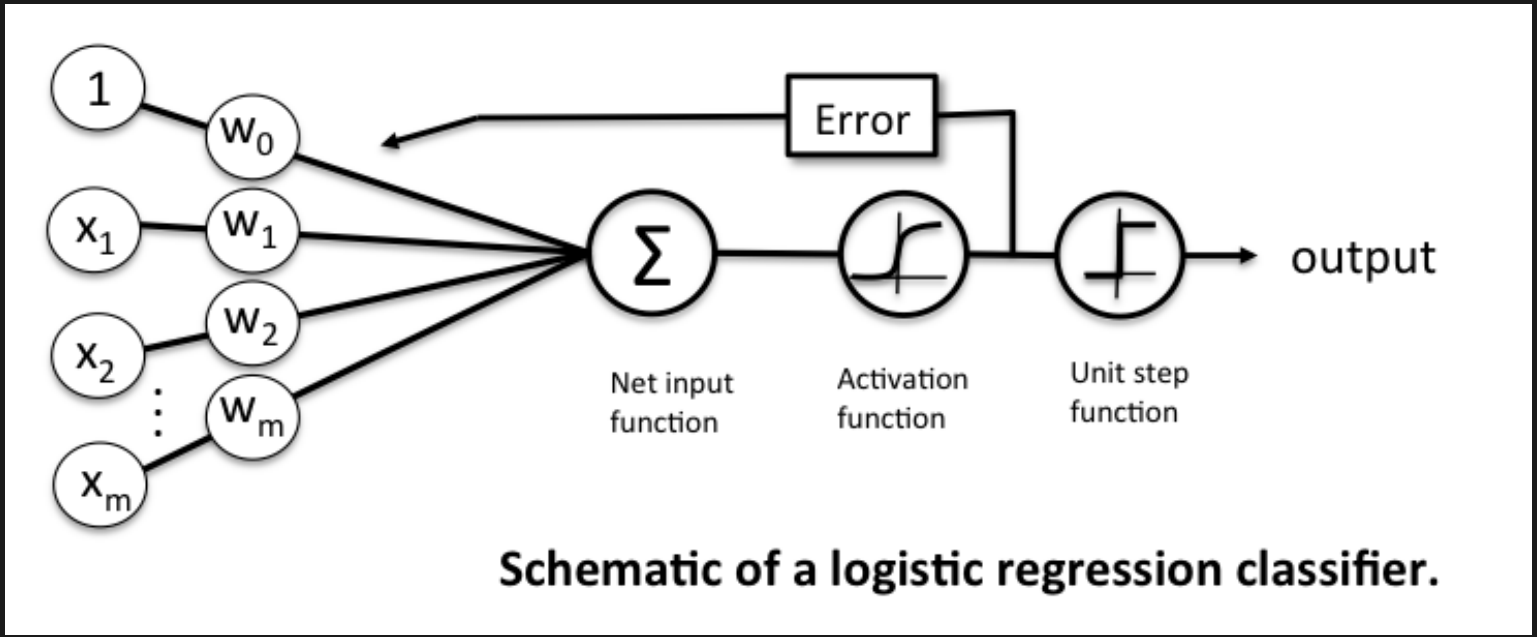
   - **2.1** Create the KMeans object.
   - **2.2** Estimate the parameters with the data (fit(.)).
   - **2.3** For each sample predict the assigned cluster (predict(.)).
3. Plot and check you have obtained an equivalent result.

Solution:

```
from sklearn.cluster import KMeans as kmeans
model = kmeans(n_clusters=3)
model.fit(X)
membership = model.predict(X)
centroids = model.cluster_centers_
```

Classification with Logistic Regression



Schematic of a logistic regression classifier.

Project: Apply Logistic Regression for Classification

We now focus on the problem of categorizing data.

1. Find the sklearn documentation for the Logistic Regression algorithm;
2. Split the data into training and testing.
3. Create the LogisticRegression object and estimate the parameters with the training data.
4. Obtain the accuracy of the model in the training and testing data (score(.)).

Further exercises:

5. Run the same code again. Did you obtain the same result?
6. Try the same exercise with another classifier.

Useful functions: `train_test_split`, `LogisticRegression`, fit, score.

Project: Apply Logistic Regression for Classification (solution)

Solution:

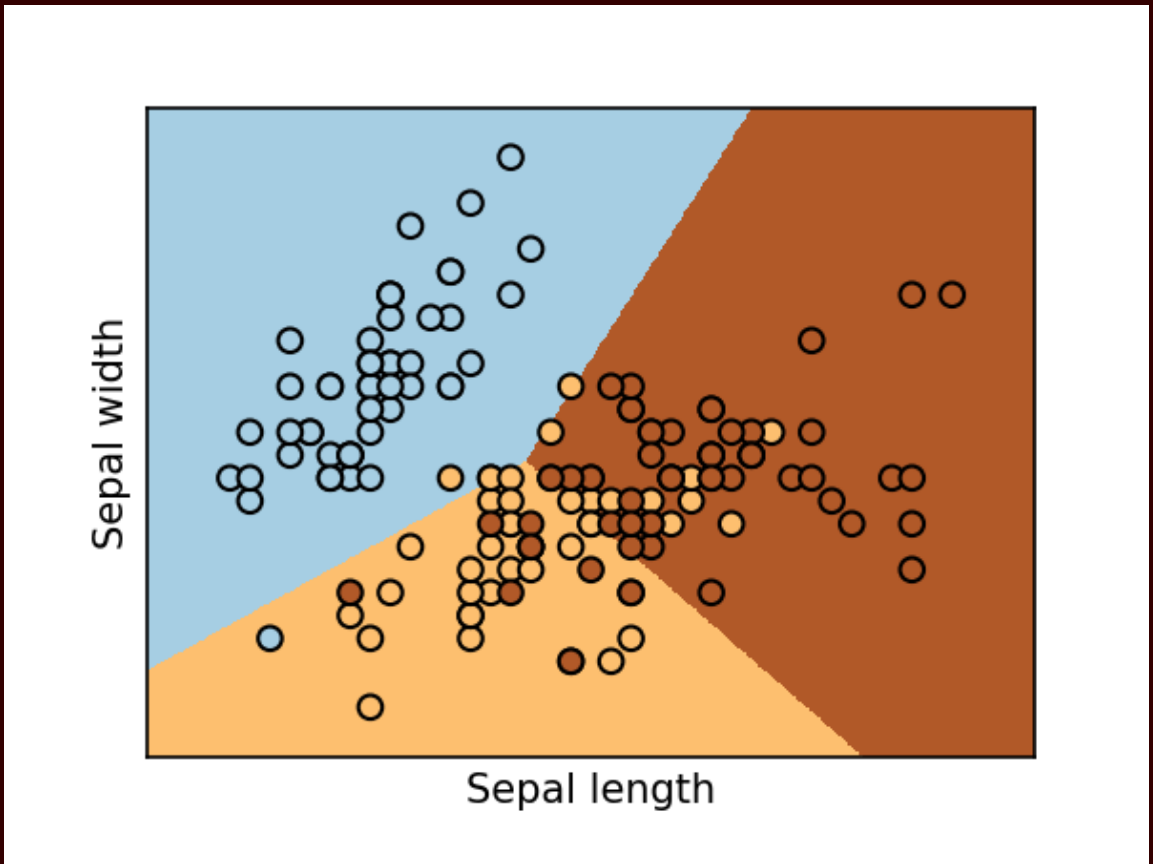
```
1        from sklearn.linear_model import LogisticRegression
2        X_train, X_test, y_train, y_test = train_test_split(X, y)
3        logreg = LogisticRegression()
4        logreg.fit(X_train, y_train)
5
6        print("Train set: ", logreg.score(X_train, y_train))
7        print("Test set: ", logreg.score(X_test, y_test))
```

Note: If you want to obtain the same exact results you need to remove the randomness in the process. Some common sources of variation are the train and test split and the initial parameters of the logistic regression.

Note: Because different classifiers have the same interface, we can simply substitute the 3rd line by another model. In this way we can quickly estimate the performance of multiple models for any machine learning problem we want to solve.

Plotting the Feature Space

Using the provided function (plot_fs()) plot the feature space. This function might be useful for other projects!



Finishing Touches

Pointers

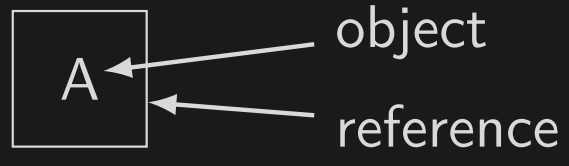
References

In programming languages when calling a function, there are two possible behaviors:

- pass by value (or copy)
- pass by reference

Python uses what some people like to call ‘pass-by-object-reference‘. Everything is an object and the reference to the object is copied (not the object itself).

```
1 def fn(b):
2   print(id(b))
3   print(a is b)
4 a = []
5 print(id(a))
6 fn(a)
```



Output:

```
1 139663236727240
2 139663236727240
3 True
```

References

```
a = [1,2,3]
b = a
b[1] = 7
print(a)
```

What is the value of a?

```
a = [1,2,3]
b = a
b = [1,7,3]
print(a)
```

What is the value of a?

```
a = 2
b += 5
print(a)
```

What is the value of a?

Wilson Silva wilson@fe.up.pt