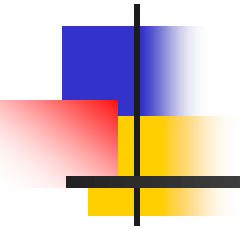
Introduction to Machine Learning

Homework 1
Due: Thursday, 9/12, 5pm



Instructor:
Dr. Tom Arodz

HW1 - Data description

- It involves a simple dataset with 2 classes (car vs. SUV) and 2 features (time 0-60mph, horsepower), 10 samples in total

	A	B	C	D	E
1	SampleName	ZeroToSixty	PowerHP	IsCar	IsSUV
2	c1	8.2	173	1	0
3	c2	8.4	176	1	0
4	c3	8.4	158	1	0
5	c4	9	142	1	0
6	c5	8.8	152	1	0
7	s1	8.7	189	0	1
8	s2	9.1	173	0	1
9	s3	8.6	194	0	1
10	s4	8.7	201	0	1
11	s5	8.7	198	0	1

normalized

	A	B	C	D	E
1	SampleNa	ZeroToSix	PowerHP	IsCar	IsSUV
2	c1	-1.6686	-0.12868	1	0
3	c2	-0.94312	0.019796	1	0
4	c3	-0.94312	-0.87105	1	0
5	c4	1.23331	-1.6629	1	0
6	c5	0.507833	-1.16799	1	0
7	s1	0.145095	0.663182	0	1
8	s2	1.596048	-0.12868	0	1
9	s3	-0.21764	0.910638	0	1
10	s4	0.145095	1.257077	0	1
11	s5	0.145095	1.108603	0	1

- Your task is to analyze the process of training a perceptron (the vector version, next slide)
  - $\mathbf{f(x_i)=sign(w_1x_i^1 + w_2x_i^2)}$
  - $w_{new}=w_{old} + c[y_i - f(x_i)]x_i$
- Python libraries to be used:
  - Pandas (reading in a csv file)
  - Numpy (storing vectors, doing the math with them)
  - Matplotlib (plotting diagrams of training progress)
  - ML libraries (e.g. sklearn, pytorch, tensforflow, others) not allowed

HW1 - model training

- **Data:** Two classes (y_i is -1 or +1),
  two features, i.e., 2D vector: x_i = (x_i^1 and x_i^2)
  Predictive model: $f(x_i) = \text{sign}(w^T x)$
  with two trainable parameters w = (w_1 , w_2)

  - Set initial value of w_1 and w_2 (random, or a guess)
  - Repeat training epochs:
    - Loop over all 10 training samples once (one epoch):
      - Present a sample x_i and predict $f(x_i) = \text{sign}(w^T x)$
      - Compare true class y_i with predicted class $f(x_i)$
      - If prediction is right, go to next sample (i=i+1)
      - If prediction is wrong (incl. f(x)==0), update w
        - $w_{new} = w_{old} + c[y_i - f(x_i)]x_i$
    - Calculate current error rate:
      - Start "error count" at 0
      - Loop over all 10 training samples:
        - Present a sample x_i and predict $f(x_i) = \text{sign}(w^T x)$
        - Compare true class y_i with predicted class $f(x_i)$
        - If wrong (or $f(x_i)==0$), increase "error count"
      - "Error rate" = "error count" / 10 (i.e. /#samples)

HW1 - overall task

- It involves a simple dataset with 2 classes (car vs. SUV) and 2 features (time 0-60mph, horsepower), 10 samples in total
- Your task is to train a perceptron (the vector version)
  - $f(x_i)=sign(w^T x)=sign(w_1 x_i^1 + w_2 x_i^2)$
  - $w_{new}=w_{old} + c[y_i - f(x_i)]x_i$
- Specifically:
  - Use pandas to import **carSUV_normalized.csv** file (file is in Canvas)
  - Extract numpy 2D (10 x 2) array X of features from pandas
  - Extract classes (10 x 1 array Y) from pandas dataframe,
  - Convert them from 0/1 to -1/1
  - Run the perceptron algorithm as described above,
    - One epoch: presenting each of the 10 samples and updating the weights if needed after each sample
    - Perform some number of epochs, until the model no longer improves
    - Use "error rate" as the measure of model quality:
      - At the end of each epoch, do prediction with current weights for each of the 10 samples, count how many are wrong, divide by total number of training samples
- Write functions for *loading data*, *calculating error rate for single w*, *training the model*, and (for 691 only) *calculating error rates for a whole spectrum of w's*

Specific functions to code

- **Upload your submission through Canvas / Gradescope**
- Upload **a single .py python file** (not a .ipynb notebook) with code for:
  1. Function for importing the csv file using pandas:
     - def read_csv_convert_to_numpy(fileName='carSUV_normalized.csv'):
     - #your code
     - return numpy_x, numpy_y
  2. Function for calculating error rate for a given w and dataset:
     - def calc_error_rate_for_single_vector_w(w, numpy_x, numpy_y):
     - #your code
     - return error_rate
  3. Function for training the model:
     - def train_and_evaluate(numpy_x, numpy_y, n_epochs = 20, c = 0.01):
     - #your code
     - return w;
  4. (691 only) Function for evaluating combinations of w1 & w2 in given ranges
     - def function_error_rate_2D(w1_range, w2_range, numpy_x, numpy_y):
     - #your code
     - return error_rates_all_ws

- See H01_Stub.py file in Canvas for stub code and more description

Expected outcome (438 & 691)

- Calling importing data function like this:
  - numpy_x, numpy_y = read_csv_convert_to_numpy(fileName='carSUV_normalized.csv');
- And it should produce the following numpy_x (results from print(numpy_x))
- And numpy_y (results from print(numpy_y))

```
[[-1.66859537 -0.12867714]
[-0.94311912 0.01979648]
[-0.94311912 -0.87104523]
[ 1.23330962 -1.66290453]
[ 0.50783338 -1.16799247]
[ 0.14509525 0.66318216]
[ 1.59604775 -0.12867714]
[-0.21764288 0.91063819]
[ 0.14509525 1.25707664]
[ 0.14509525 1.10860302]]
```

```
[[ 1]
[ 1]
[ 1]
[ 1]
[ 1]
[-1]
[-1]
[-1]
[-1]
[-1]]
```

- Internally, inside your function, if you print the dataframe you import using read_csv, with index_col='SampleName', then print(df) should result in:

SampleName	ZeroToSixty	PowerHP	IsCar	IsSUV
c1	-1.668595	-0.128677	1	0
c2	-0.943119	0.019796	1	0
c3	-0.943119	-0.871045	1	0
c4	1.233310	-1.662905	1	0
c5	0.507833	-1.167992	1	0
s1	0.145095	0.663182	0	1
s2	1.596048	-0.128677	0	1
s3	-0.217643	0.910638	0	1
s4	0.145095	1.257077	0	1
s5	0.145095	1.108603	0	1

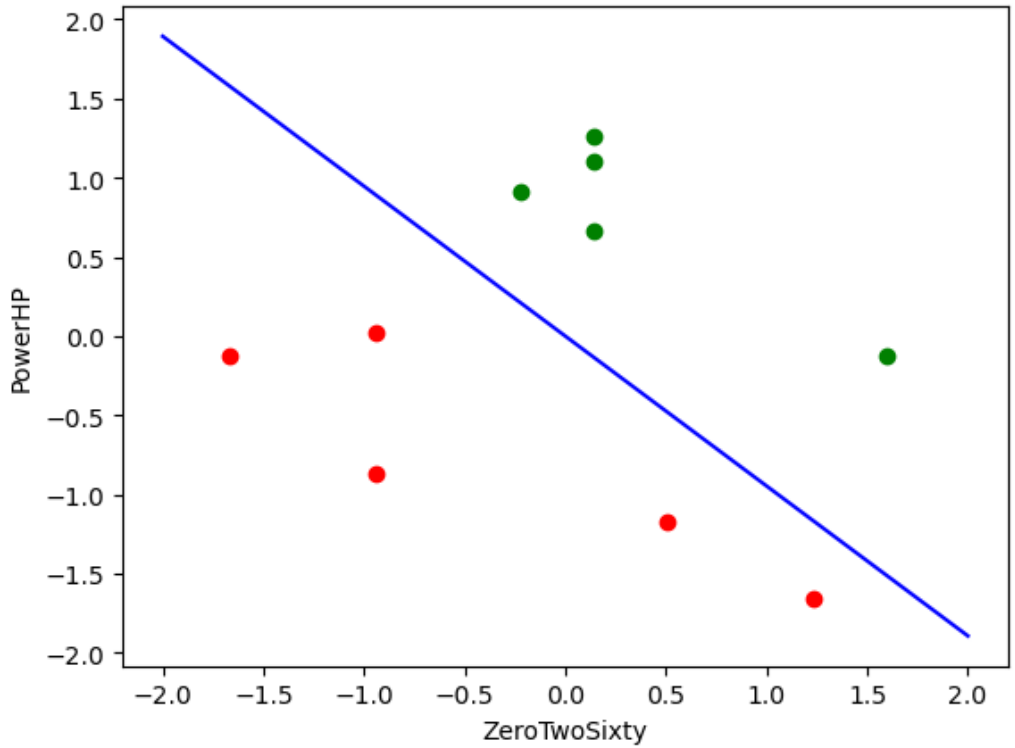
Expected outcome (438 & 691)

- Calling the function to calculate error rate for given weights like this:
  - numpy_x, numpy_y = read_csv_convert_to_numpy(fileName='carSUV_normalized.csv');
  - np.random.seed(3) # to fix randomness
  - random_w = np.random.randn(2,1)
  - print("Random weights array shape",random_w.shape)
  - print("Random weights values\n",random_w)
  - error_rate_random_weights = calc_error_rate_for_single_vector_w(random_w, numpy_x, numpy_y)
  - print("Error rate for random weights",error_rate_random_weights)
- Should produce the following output:

```
Random weights array shape (2, 1)
Random weights values
[[1.78862847]
[0.43650985]]
Error rate for random weights 0.8
```

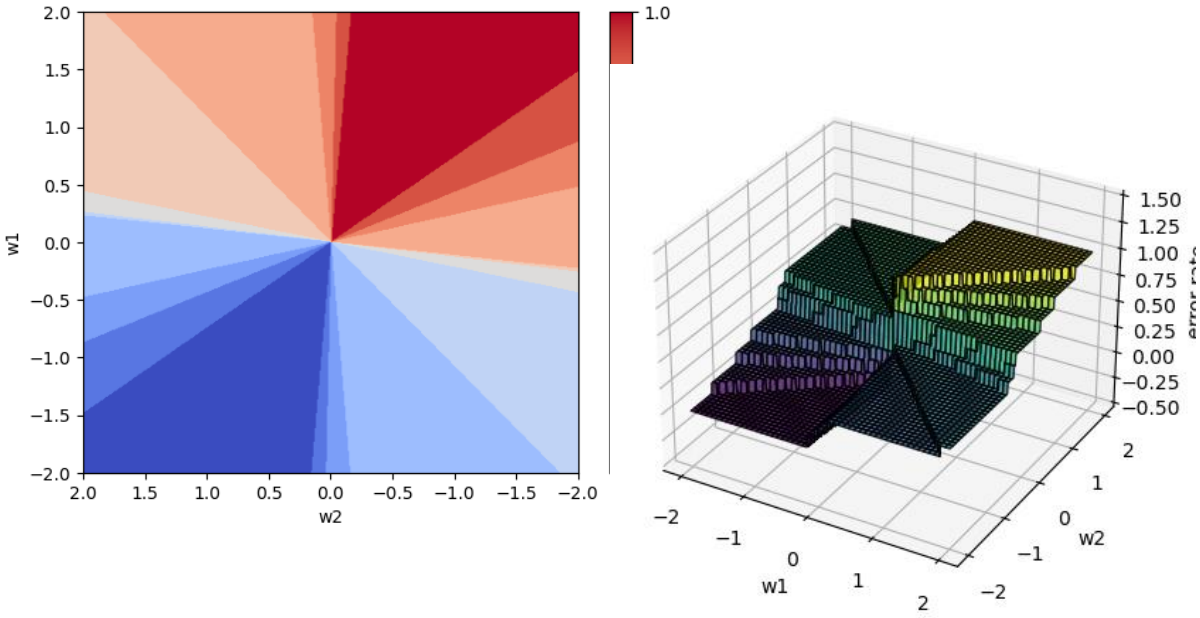
Expected outcome (438 & 691)

- Calling these functions like this:
  - np.random.seed(8) # to fix randomness
  - numpy_x, numpy_y = read_csv_convert_to_numpy(fileName='carSUV_normalized.csv');
  - trained_w = train_and_evaluate(numpy_x, numpy_y, n_epochs = 20, c = 0.01);
  - print(trained_w)
  - plot_trained_w_and_dataset(numpy_x, numpy_y, trained_w);
- Should produce the following *trained_w* values below, and plot:
  - `[[-0.02051863]`
    `[-0.02167551]]`



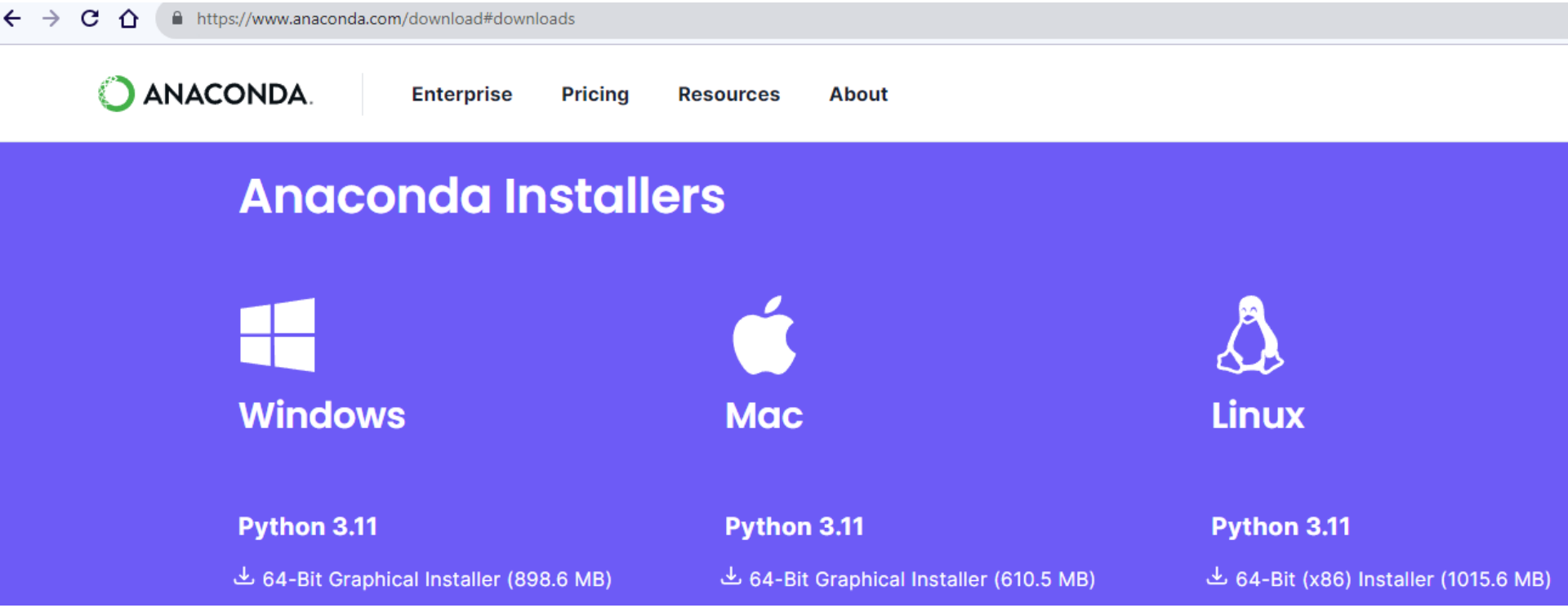
Expected outcome (691 only)

- Another call, like this:
  - w1_range = np.arange(w1min,w1max, 0.01)
  - w2_range = np.arange(w2min,w2max, 0.01)
  - error_rates_all_ws = function_error_rate_2D(w1_range,w2_range,numpy_x, numpy_y)
  - print(error_rates_all_ws)
  - ax = plot_function_on_grid(function_error_rate_2D, numpy_x, numpy_y);
  - plt.show()
  - ax = plot3D_function_on_grid(function_error_rate_2D, numpy_x, numpy_y);
  - plt.show()
- Should produce values and figures like this:
  - [[0. 0. 0. ... 0.4 0.4 0.4]
  - [0. 0. 0. ... 0.4 0.4 0.4]
  - [0. 0. 0. ... 0.4 0.4 0.4]
  - ...
  - [0.6 0.6 0.6 ... 1. 1. 1.]
  - [0.6 0.6 0.6 ... 1. 1. 1.]
  - [0.6 0.6 0.6 ... 1. 1. 1.]]

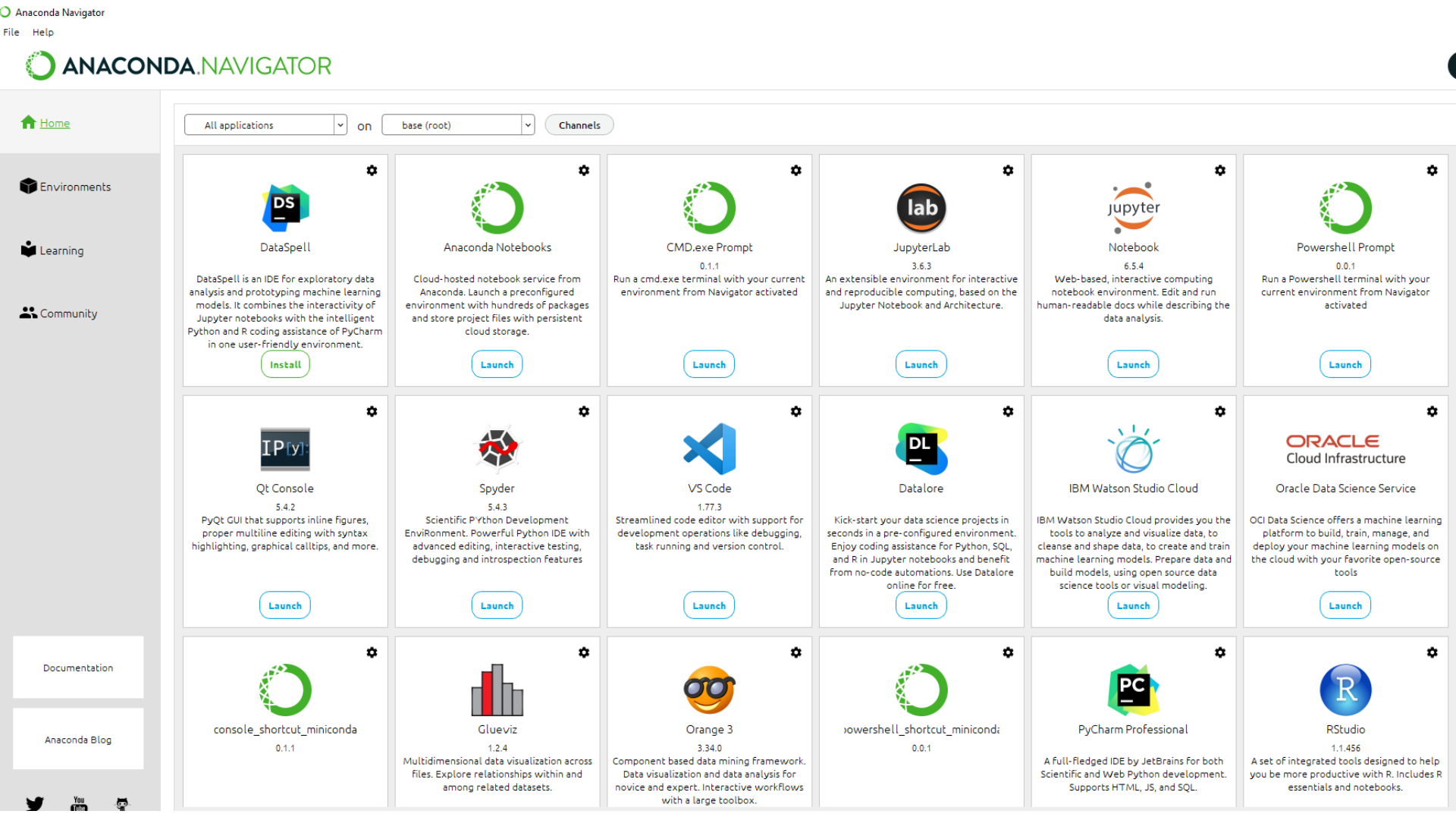


Python – brief into

Anaconda: Python 3 distribution tailored for machine learning and data science programming

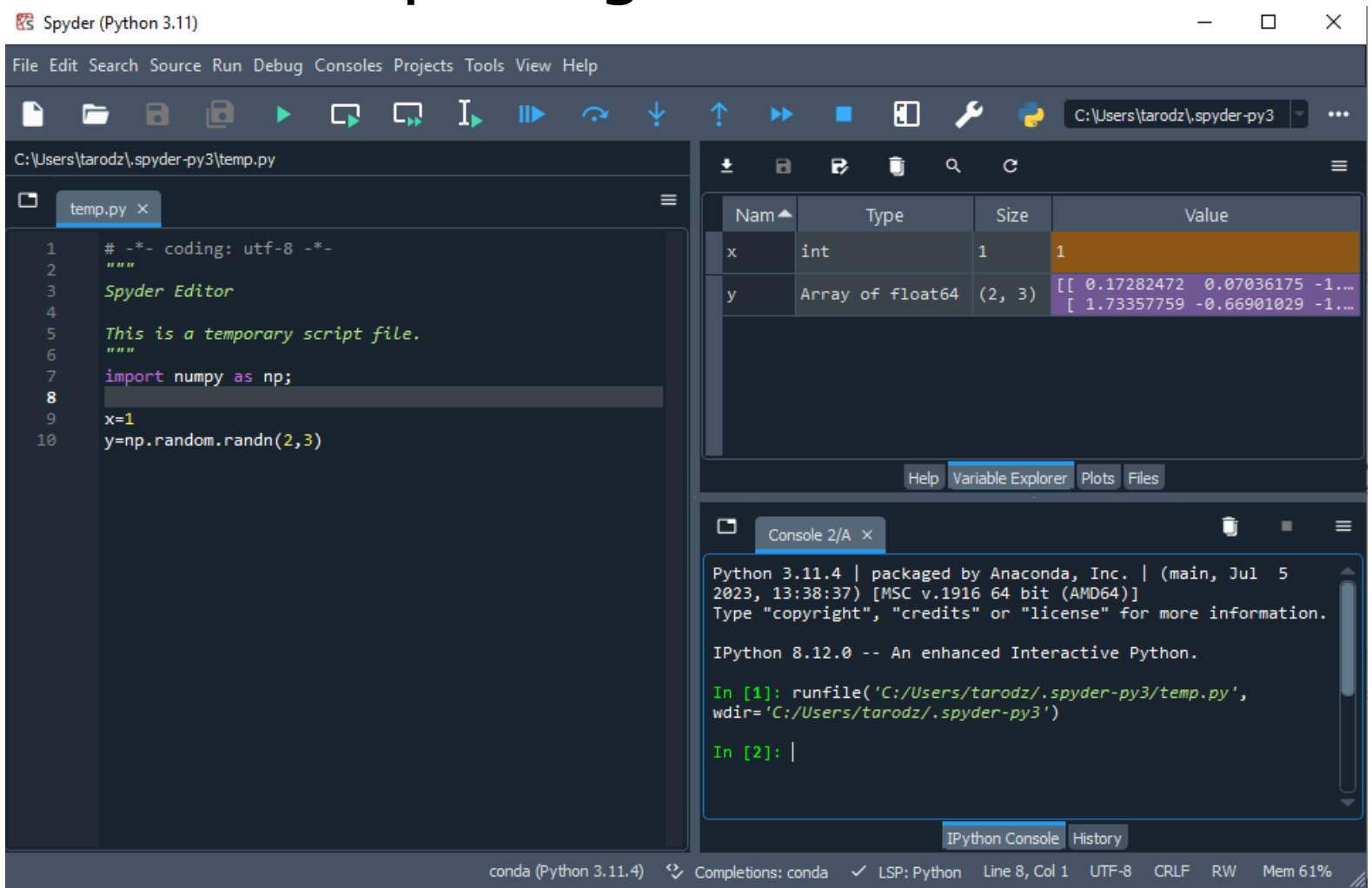


Anaconda Navigator (Windows)



Coding in python, option 1

Spyder: a Matlab-like layout, with panels for plots and inspecting data

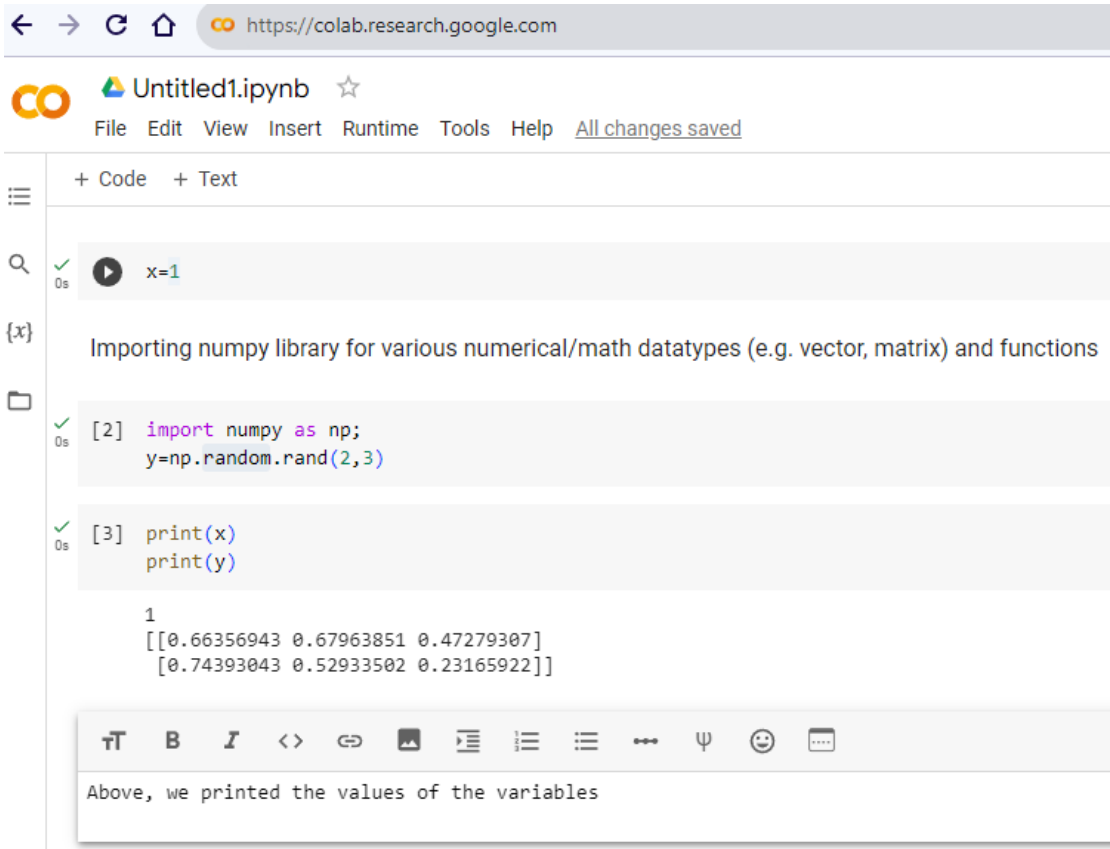


Coding in python, option 2

Jupyter-notebook: combines text and code, runs in the browser

Can run locally
on your machine
(e.g. on Windows:
from Navigator)

Can run online
e.g. google colab:
https://colab.research.google.com/



Python intro

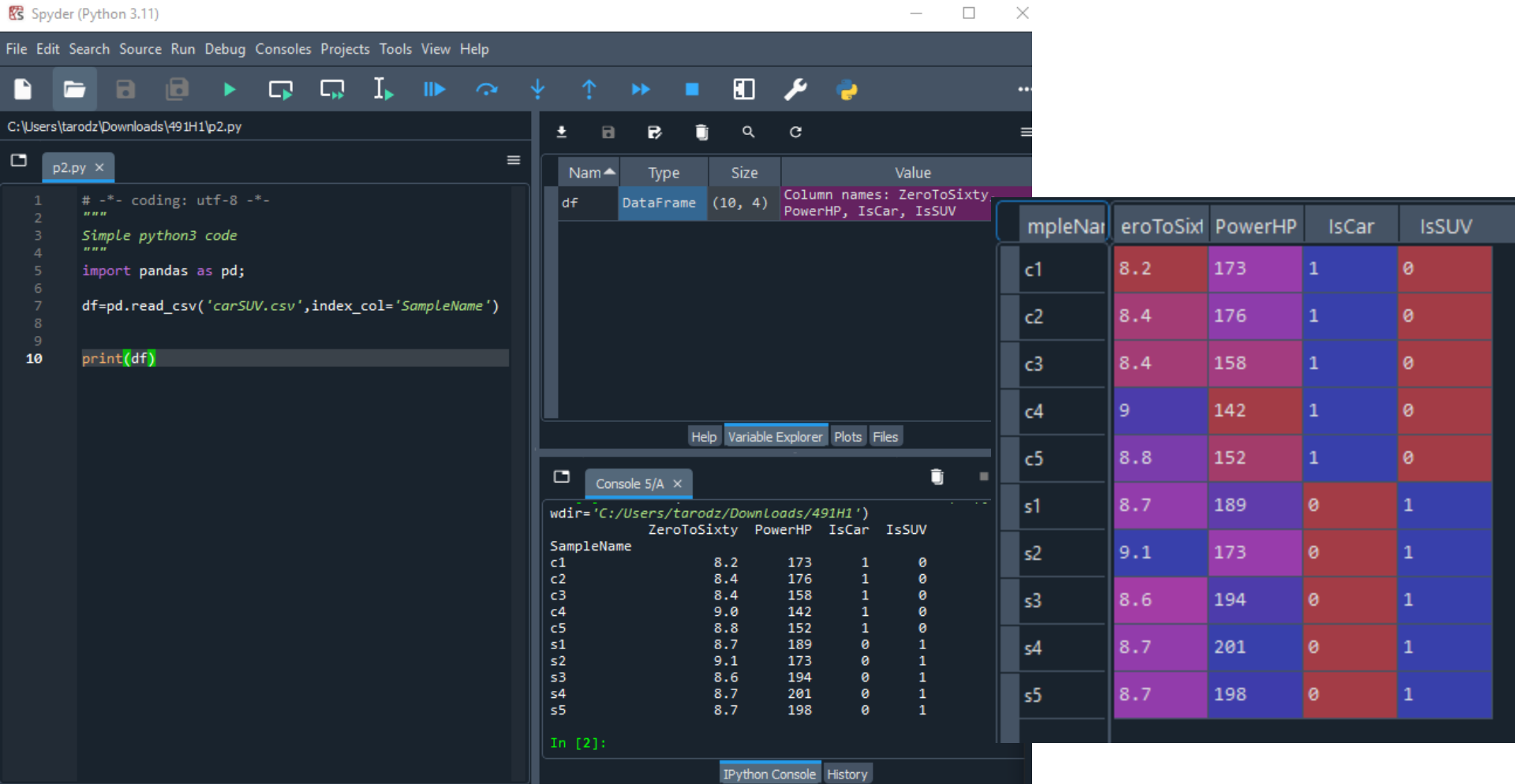
- Interpreted, no sperate compilation step
- Execution starts from line one (like a script)
- Variables do not need declaration and don't need type specification
- [a,b,c] is a list, (a,b,c) is a tuple
- There is automatic garbage collection
- Has standard concepts like functions (can return multiple values), loops, etc.
- Most of useful functionality is provided in libraries (e.g., numpy)
  - Libraries need to be imported, and can be given a shortcut name

```
import numpy as np;

x=1.1

y=0
for index in range(1,5):
    y=y+index

z='one'


def make2Dvector(w1,w2):
    w=np.zeros((2,1));
    w[0]=w1
    w[1]=w2
    return w

w=make2Dvector(0.1,-0.2)

print(x,type(x))
print(y,type(y))
print(z,type(z))
print(w,type(w))
```

```
1.1 <class 'float'>
10 <class 'int'>
one <class 'str'>
[[ 0.1]
 [-0.2]] <class 'numpy.ndarray'>
```

Pandas

- Provides data import and manipulation functionality (a bit like R)
- Main data type is “DataFrame”
  - Basically, a 2D array of data, but with column names, row names, various data types in the same array



Pandas

- Provides data import and manipulation functionality (a bit like R)
- Main data type is “DataFrame”
  - Basically, a 2D array of data, but with column names, row names, various data types in the same array

```
import pandas as pd;

df=pd.read_csv('carSUV.csv',index_col='SampleName’)

#can do all kinds of data analytics
print(df.mean())
```

printed:

```
ZeroToSixty      8.66
PowerHP        175.60
IsCar            0.50
IsSUV            0.50
```

```
# extract raw data as numpy matrix
myDataAsNumpyMatrix = df.to_numpy();
```

Numpy

- Vectors and matrix variables, reshaping (e.g., transposing) them
- Arithmetic and functions on vectors
- Much faster than doing math in raw python

```
import numpy as np;

# a two-by-one matrix (a vector)
w = np.ones((2,1))
print("shape of w",w.shape)

x = np.array( [[0.1,],[0.2,]])

print("x before",x)
x = 2*x-0.1
print("x after",x)

wT = np.transpose(w)

wTx = np.matmul(wT,x)
# compare with
wElementwiseX = np.multiply(w,x)

#squeeze() removes "useless" dimensions
# 1-by-1 matrix becomes just one number
wTxAsNumber = np.squeeze(wTx)
```

x before [[0.1]
 [0.2]]
x after [[0.1]
 [0.3]]

$$\mathbf{w} = \begin{bmatrix} w_1 \\ w_2 \end{bmatrix}$$ ← 2D Vector (2x1)

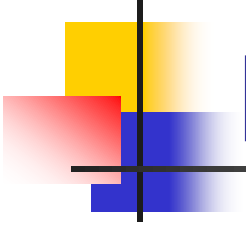
$$\mathbf{x} = \begin{bmatrix} x^1 \\ x^2 \end{bmatrix}$$ ← 2D Vector (2x1)

$$\mathbf{w}^T = [w_1, w_2]$$ ← Transposed vector (1x2)

Matrix multiplication

$$\mathbf{w}^T \mathbf{x} = [w_1, w_2] \begin{bmatrix} x^1 \\ x^2 \end{bmatrix} = w_1 x^1 + w_2 x^2$$

Name	Type	Size	Value
w	Array of float64	(2, 1)	[[1.] [1.]]
wElementwiseX	Array of float64	(2, 1)	[[0.1] [0.3]]
wT	Array of float64	(1, 2)	[[1. 1.]]
wTx	Array of float64	(1, 1)	[[0.4]]
wTxAsNumber	Array of float64	1	0.4
x	Array of float64	(2, 1)	[[0.1] [0.3]]



Matplotlib

Creates plots from data

```
import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
from matplotlib.colors import Normalize

def plot_trained_w_and_dataset(numpy_x, numpy_y, w):

    samples_class1 = numpy_y.flatten()==1
    samples_class0 = numpy_y.flatten()==-1
    plt.scatter(numpy_x[samples_class1,0], numpy_x[samples_class1,1], c='red')
    plt.scatter(numpy_x[samples_class0,0], numpy_x[samples_class0,1], c='green')
    plt.xlabel('ZeroTwoSixty')
    plt.ylabel('PowerHP')

    x1_line = np.linspace(-2, 2, 100)
    x2_line = (-w[0] * x1_line) / w[1]

    # Create a blue line based on the equation
    plt.plot(x1_line, x2_line, c='blue')
    plt.show()
```

Matplotlib

```
import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
from matplotlib.colors import Normalize

def plot3D_function_on_grid(function_to_plot, numpy_x, numpy_y):

    # Create a meshgrid
    w1min,w1max = -2.0, 2.0
    w2min,w2max = -2.0, 2.0
    w1_range = np.arange(w1min,w1max, 0.01)
    w2_range = np.arange(w2min,w2max, 0.01)

    error_rates_values_for_W1W2 = function_to_plot(w1_range, w2_range, numpy_x, numpy_y)
    W1, W2 = np.meshgrid(w1_range, w2_range)

    # Create a figure and a 3D axis
    fig = plt.figure()
    ax = fig.add_subplot(111, projection='3d')

    # Create the surface plot
    surface = ax.plot_surface(W1, W2, error_rates_values_for_W1W2,
                                      cmap='viridis', alpha=0.8, edgecolor='black')

    # Add labels and title
    ax.set_xlabel('w1')
    ax.set_ylabel('w2')
    ax.set_zlabel('error rate')
    ax.set_zlim(-0.5, 1.5)
    return ax;
```

Matplotlib

```
import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
from matplotlib.colors import Normalize

def plot_function_on_grid(function_to_plot, numpy_x, numpy_y):

    # Create a meshgrid
    w1min,w1max = -2.0, 2.0
    w2min,w2max = -2.0, 2.0

    w1_range = np.arange(w1min,w1max, 0.01)
    w2_range = np.arange(w2min,w2max, 0.01)

    error_rates_values_for_W1W2 = function_to_plot(w1_range, w2_range, numpy_x, numpy_y)
    W1, W2 = np.meshgrid(w1_range, w2_range)

    # Create a figure and a 3D axis
    fig = plt.figure()
    ax = fig.add_subplot(111)

    img = ax.imshow(error_rates_values_for_W1W2, origin='lower', cmap='coolwarm',
                        extent=[w1max,w1min,w2min,w2max], aspect='auto')
                             # 'coolwarm' goes from blue (low) to red (high)
    ax.set_xlabel('w2')
    ax.set_ylabel('w1')
    cbar = fig.colorbar(img)  # Add a color bar to show the mapping of values to colors
    cbar.set_label('error rate')
    plt.show()

    return ax;
```