CS229
Python & Numpy

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How is python related to with others?

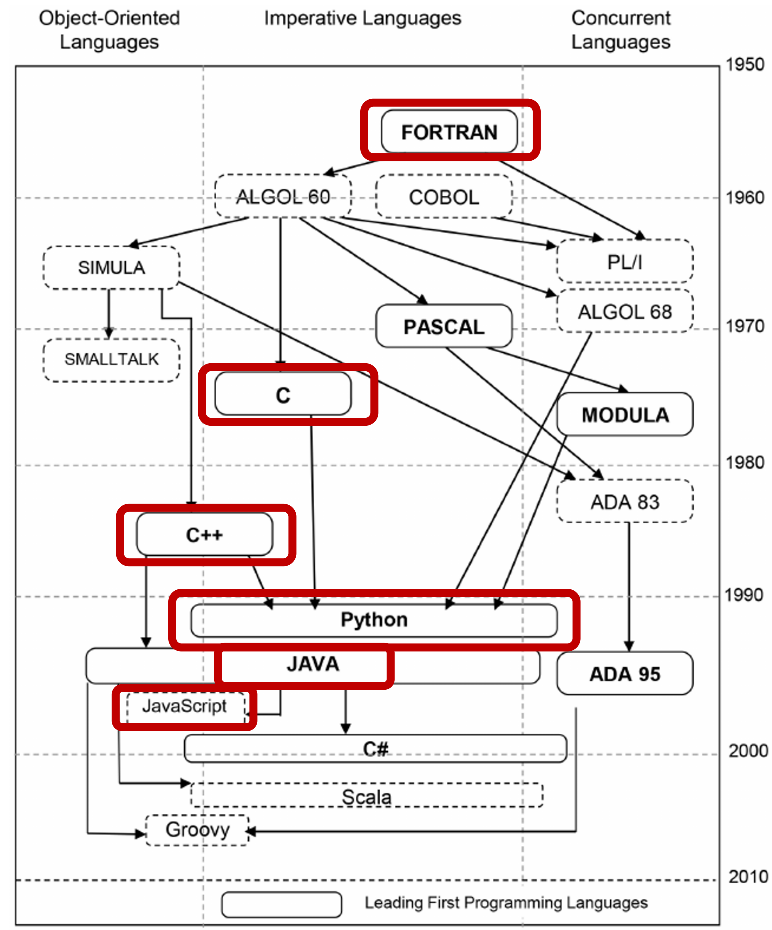
Python 2.0 released in 2000

(Python 2.7 “end-of-life” in 2020)

Python 3.0 released in 2008

(Python 3.6+ for CS 229)

Can run interpreted, like MATLAB



https://www.researchgate.net/figure/Genealogy-of-Programming-Languages-doi101371-journalpone0088941g001_fig1_260447599

Before you start

Use Anaconda

Create a new environment (full Conda)

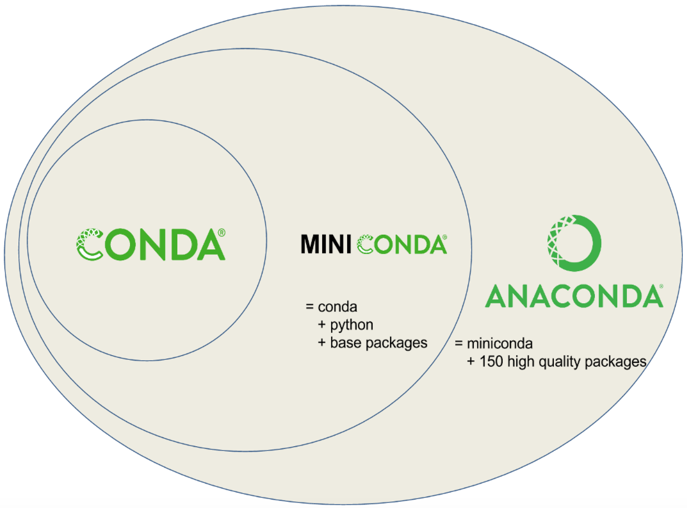
```
conda create -n cs229
```

Create an environment (Miniconda)

```
conda env create -f environment.yml
```

Activate an environment after creation

```
conda activate cs229
```



Notepad is not your friend ...

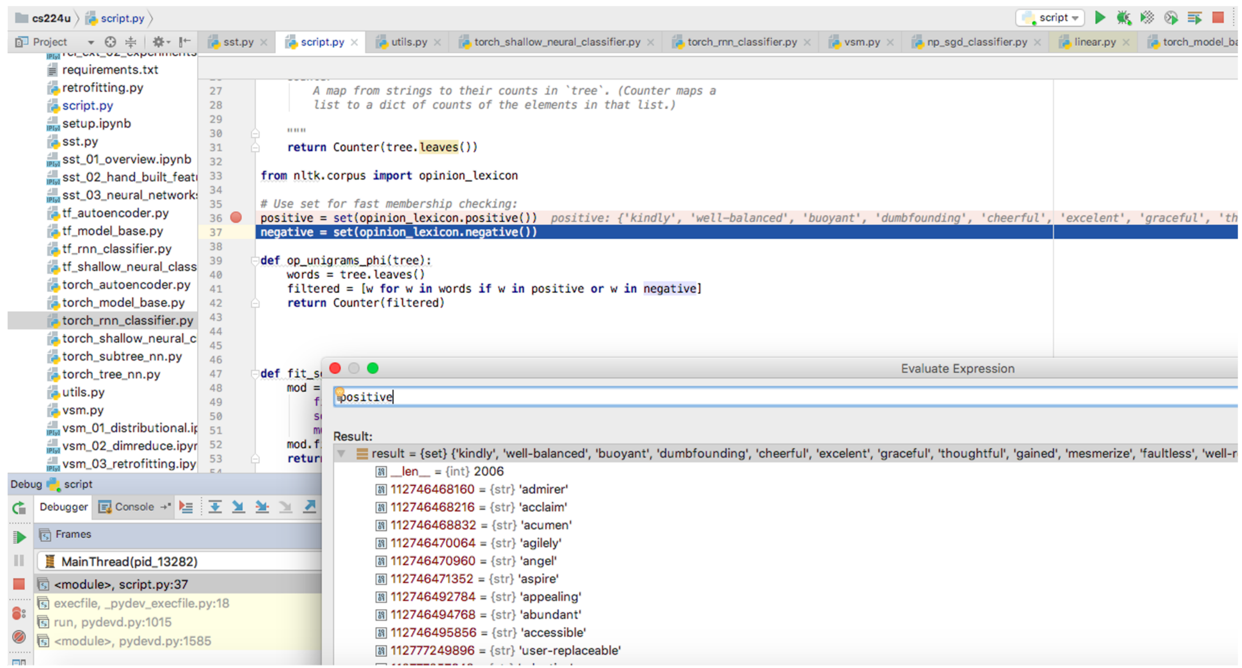
Get a text editor/IDE

- PyCharm (IDE)
- Visual Studio Code (IDE??)
- Sublime Text (IDE??)
- Notepad ++/gedit
- Vim (for Linux)

To make you more prepared

PyCharm

- Great debugger
- Proper project management

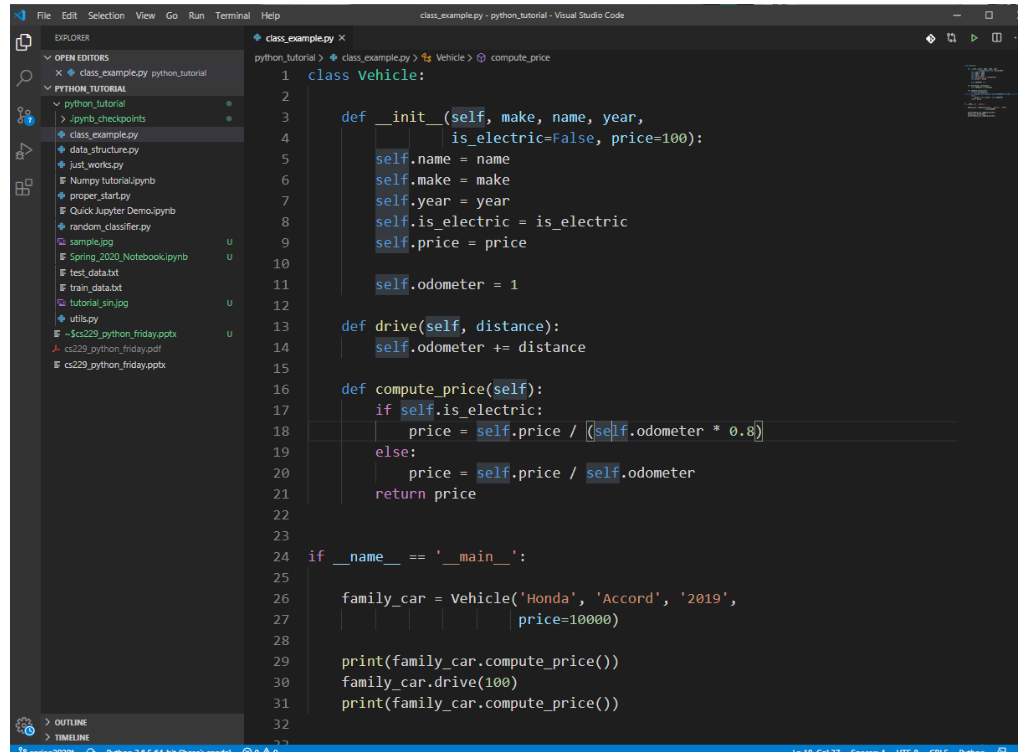


FYI, professional version free for students: https://www.jetbrains.com/student/

To make you more prepared

Visual Studio Code

- Light weight
- Wide variety of plugins to enable support for all languages
- Better UI



Basic Python

String manipulation

Formatting

```
print('I love CS229. (upper)'.upper())
print('I love CS229. (rjust 20)'.rjust(20))
print('we love CS229. (capitalize)'.capitalize())
print('       I love CS229. (strip)        '.strip())
```

Concatenation

```
print('I like ' + str(cs_class_code) + ' a lot!')
print(f'{print} (print a function)')
print(f'{type(229)} (print a type)')
```

Formatting

```
print('Old school formatting: {.2F}'.format(1.358))
```

List

List creation

```
list_1 = ['one', 'two', 'three’]
```

Insertion/extension

```
list_1.append(4)
list_1.insert(0, 'ZERO’)

list_2 = [1, 2, 3]
list_1.extend(list_2)
```

List comprehension

```
long_list = [i for i in range(9)]
long_long_list = [(i, j) for i in range(3)
                                    for j in range(5)]
long_list_list = [[i for i in range(3)]
                                    for _ in range(5)]
```

Sorting

```
sorted(random_list)

random_list_2 = [(3, 'z'), (12, 'r'), (6, 'e’),
                          (8, 'c'), (2, 'g')]
sorted(random_list_2, key=lambda x: x[1])
```

Dictionary and Set

Set
(unordered, unique)

```
my_set = {i ** 2 for i in range(10)}
```

```
{0, 1, 64, 4, 36, 9, 16, 49, 81, 25}
```

Dictionary
(mapping)

```
my_dict = {(5 - i): i ** 2 for i in range(10)}
```

```
{5: 0, 4: 1, 3: 4, 2: 9, 1: 16, 0: 25, -1: 36,
-2: 49, -3: 64, -4: 81}
dict_keys([5, 4, 3, 2, 1, 0, -1, -2, -3, -4])
```

Dictionary update

```
second_dict = {'a': 10, 'b': 11}
my_dict.update(second_dict)
```

Iterate through items

```
for k, it in my_dict.items():
    print(k, it)
```

Numpy

What is Numpy and why?

Numpy – package for vector and matrix manipulation

Broadcasting and vectorization saves time and amount of code

FYI, if you are interested in how/why vectorization is faster, checkout the following topics (completely optional, definitely not within scope)

- AVX instruction set (SIMD) and structure of x86 and RISC
- OpenMP and CUDA for multiprocessing
- Assembly-level optimization, memory stride, caching, etc.
- Or even about memory management, virtualization
- More bare metal → FPGA, TPU

Convenient math functions, read before use!

Python Command	Description
np.linalg.inv	Inverse of matrix (numpy as equivalent)
np.linalg.eig	Get eigen value (Read documentation on eigh and numpy equivalent)
np.matmul	Matrix multiply
np.zeros	Create a matrix filled with zeros (Read on np.ones)
np.arange	Start, stop, step size (Read on np.linspace)
np.identity	Create an identity matrix
np.vstack	Vertically stack 2 arrays (Read on np.hstack)

Your friend for debugging

Python Command	Description
array.shape	Get shape of numpy array
array.dtype	Check data type of array (for precision, for weird behavior)
type(stuff)	Get type of a variable
import pdb; pdb.set_trace()	Set a breakpoint (https://docs.python.org/3/library/pdb.html)
print(f'My name is {name}')	Easy way to construct a message

Basic Numpy usage

Initialization from Python lists

```
array_1d = np.array([1, 2, 3, 4])
array_1by4 = np.array([[1, 2, 3, 4]])

large_array = np.array([i for i in range(400)])
large_array = large_array.reshape((20, 20))
```

Lists with different types (Numpy auto-casts to higher precision, but it should be reasonably consistent)

```
from_list = np.array([1, 2, 3])
from_list_2d = np.array([[1, 2, 3.0], [4, 5, 6]])
from_list_bad_type = np.array([1, 2, 3, 'a'])

print(f'Data type of integer is {from_list.dtype}')
print(f'Data type of float is {from_list_2d.dtype}')
```

Numpy supports many types of algebra on an entire array

```
array_1 + 5
array_1 * 5
np.sqrt(array_1)
np.power(array_1, 2)
np.exp(array_1)
np.log(array_1)
```

Dot product and matrix multiplication

A few ways to write dot product

```
array_1 @ array_2
array_1.dot(array_2)
np.dot(array_1, array_2)
```

Matrix multiplication like Ax

```
weight_matrix = np.array([1, 2, 3, 4]).reshape(2, 2)
sample = np.array([[50, 60]]).T
np.matmul(weight_matrix, sample)
```

2D matrix multiplication

```
mat1 = np.array([[1, 2], [3, 4]])
mat2 = np.array([[5, 6], [7, 8]])
np.matmul(mat1, mat2)
```

Element-wise multiplication

```
a = np.array([i for i in range(10)]).reshape
(2, 5)

a * a
np.multiply(a, a)
np.multiply(a, 10)
```

Broadcasting

Numpy compares dimensions of operands, then infers missing/mismatched dimensions so the operation is still valid. Be careful with *DIMENSIONS*

```
op1 = np.array([i for i in range(9)]).reshape(3, 3)
op2 = np.array([[1, 2, 3]])
op3 = np.array([1, 2, 3])


# Notice that the results here are DIFFERENT!
pp.pprint(op1 + op2)
pp.pprint(op1 + op2.T)
```

```
array([[ 1,  3,  5],
       [ 4,  6,  8],
       [ 7,  9, 11]])

array([[ 1,  2,  3],
       [ 5,  6,  7],
       [ 9, 10, 11]])
```

```
# Notice that the results here are THE SAME!
pp.pprint(op1 + op3)
pp.pprint(op1 + op3.T)
```

```
array([[ 1,  3,  5],
       [ 4,  6,  8],
       [ 7,  9, 11]])

array([[ 1,  3,  5],
       [ 4,  6,  8],
       [ 7,  9, 11]])
```

Broadcasting for pairwise distance

```python
samples = np.random.random((15, 5))

# Without broadcasting
expanded1 = np.expand_dims(samples, axis=1)
tile1 = np.tile(expanded1, (1, samples.shape[0], 1))
expanded2 = np.expand_dims(samples, axis=0)
tile2 = np.tile(expanded2, (samples.shape[0], 1 ,1))
diff = tile2 - tile1
distances = np.linalg.norm(diff, axis=-1)
```

```python
# With broadcasting
diff = samples[: ,np.newaxis, :]
                - samples[np.newaxis, :, :]
distances = np.linalg.norm(diff, axis=-1)
```

```python
# With scipy (another math toolbox)
import scipy
distances = scipy.spatial.distance.cdist(samples, samples)
```

Both achieve the effect of

$$\begin{bmatrix}\vec{a}\\ \vec{b}\end{bmatrix} \Rightarrow \begin{bmatrix}\vec{a}\\ \vec{a}\\ \vec{b}\\ \vec{b}\end{bmatrix} - \begin{bmatrix}\vec{a}\\ \vec{b}\\ \vec{a}\\ \vec{b}\end{bmatrix}$$

Why should I vectorize my code?

Shorter code, faster execution

```
a = np.random.random(500000)
b = np.random.random(500000)
```

With loop

```
dot = 0.0
for i in range(len(a)):
    dot += a[i] * b[i]

print(dot)
```

Wall time: 345ms

Numpy dot product

```
print(np.array(a).dot(np.array(b)))
```

Wall time: **2.9ms**

An example with pairwise distance

Speed up depends on setup and nature of computation

```
samples = np.random.random((100, 5))
```

With loop

```
total_dist = []
for s1 in samples:
    for s2 in samples:
        d = np.linalg.norm(s1 - s2)
        total_dist.append(d)

avg_dist = np.mean(total_dist)
```

Wall time: 162ms

(imagine without Numpy norm)

Numpy with broadcasting

```
diff = samples[: ,np.newaxis, :] -
                    samples[np.newaxis, :, :]
distances = np.linalg.norm(diff, axis=-1)
avg_dist = np.mean(distances)
```

Wall time: **3.5ms**

Plotting

Other Python packages/tools

Jupyter Notebook

- Interactive, re-execution, result storage

Matplotlib

- Visualization (line, scatter, bar, images and even interactive 3D)

Pandas (https://pandas.pydata.org/)

- Dataframe (database/Excel-like)
- Easy filtering, aggregation (also plotting, but few people uses Pandas for plotting)

Example plots

https://matplotlib.org/3.1.1/gallery/index.html

Import

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

Create data

```
# Data for plotting
t = np.arange(0.0, 2.0, 0.01)
s = 1 + np.sin(2 * np.pi * t)
```

Plotting

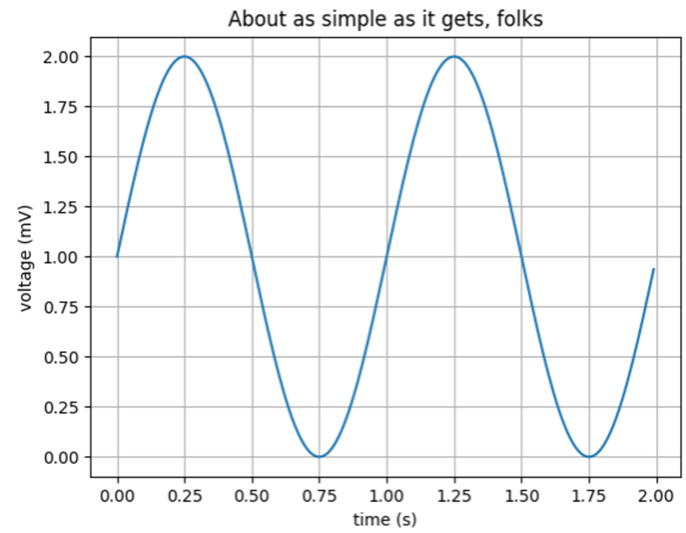
```
fig, ax = plt.subplots()
ax.plot(t, s)
```

Format plot

```
ax.set(xlabel='time (s)', ylabel='voltage (mV)',
       title='About as simple as it gets, folks')
ax.grid()
```

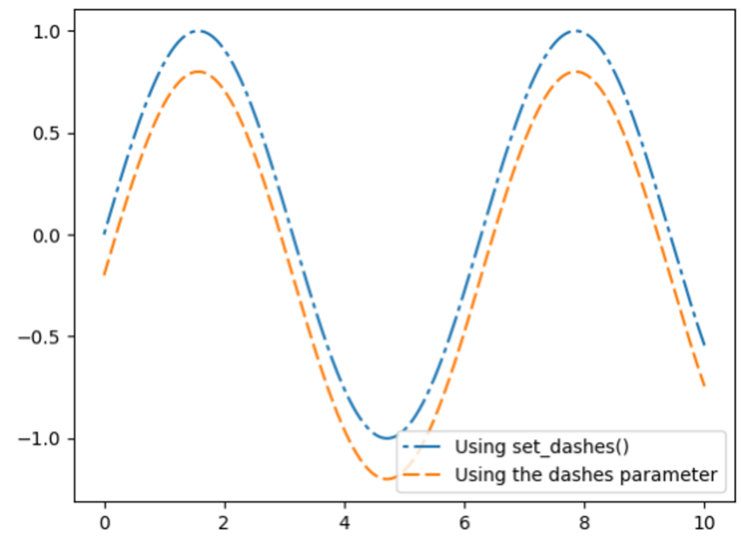
Save/show

```
fig.savefig("test.png")
plt.show()
```



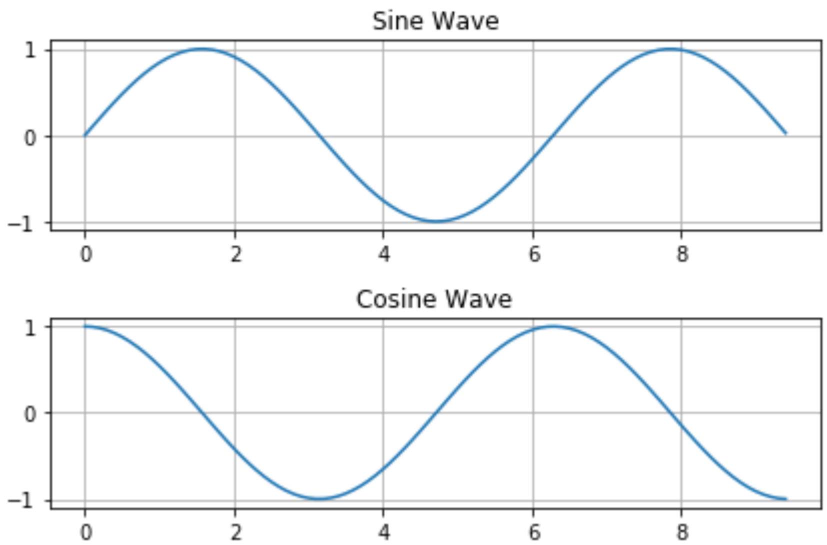
Plot with dash lines and legend

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

x = np.linspace(0, 10, 500)
y = np.sin(x)

fig, ax = plt.subplots()

line1, = ax.plot(x, y, label='Using set_dashes()')
# 2pt line, 2pt break, 10pt line, 2pt break
line1.set_dashes([2, 2, 10, 2])

line2, = ax.plot(x, y - 0.2, dashes=[6, 2],
                 label='Using the dashes parameter')

ax.legend()
plt.show()
```



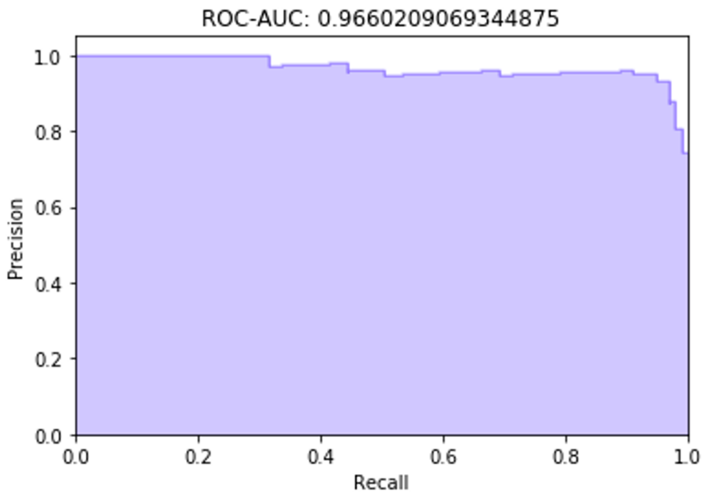
Using subplot

```
x = np.arange(0, 3 * np.pi, 0.1)
y_sin = np.sin(x)
y_cos = np.cos(x)

# Setup grid with height 2 and col 1.
# Plot the 1st subplot
plt.subplot(2, 1, 1)

plt.grid()
plt.plot(x, y_sin)
plt.title('Sine Wave')

# Now plot on the 2nd subplot
plt.subplot(2, 1, 2)
plt.plot(x, y_cos)
plt.title('Cosine Wave')

plt.grid()
plt.tight_layout()
```



Plot area under curve

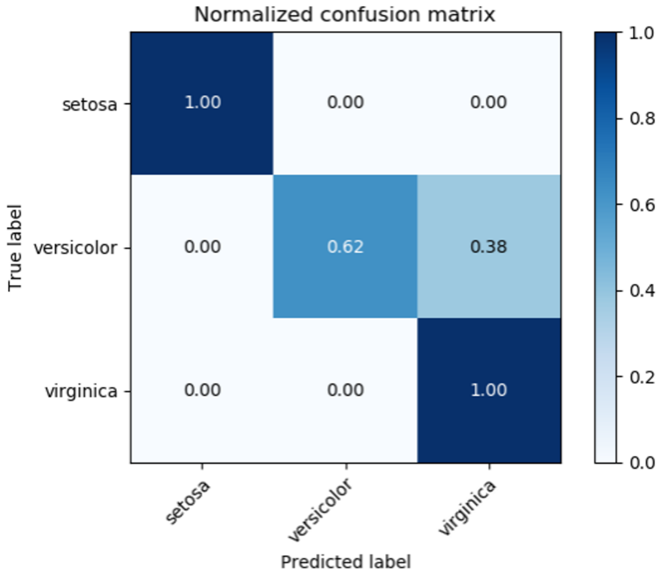
```
def prec_rec_curve(model, X, Y_true, title="", verbose=False):
    probas_pred = model.predict_proba(X)[:, 1]
    pos_label = 1.0
    precision, recall, thresholds = precision_recall_curve(Y_true,
                                                           probas_pred,
                                                           pos_label=pos_label)
    step_kwargs = ({'step': 'post'}
                   if 'step' in signature(plt.fill_between).parameters
                   else {})
    plt.step(recall, precision, color='b', alpha=0.2,
             where='post')
    plt.fill_between(recall, precision, alpha=0.2, color='b', **step_kwargs)

    plt.xlabel('Recall')
    plt.ylabel('Precision')
    plt.ylim([0.0, 1.05])
    plt.xlim([0.0, 1.0])
    plt.title(title+ "ROC-AUC: {}".format(auc(recall, precision)))
    plt.show()
```



Confusion matrix

https://scikit-learn.org/stable/auto_examples/model_selection/plot_confusion_matrix.html

```
fig, ax = plt.subplots()
im = ax.imshow(cm, interpolation='nearest', cmap=cmap)
ax.figure.colorbar(im, ax=ax)
# We want to show all ticks...
ax.set(xticks=np.arange(cm.shape[1]),
        yticks=np.arange(cm.shape[0]),
        xticklabels=classes, yticklabels=classes,
        ylabel='True label', xlabel='Predicted label’,
        title=title)

# Rotate the tick labels and set their alignment.
plt.setp(ax.get_xticklabels(), rotation=45, ha='right',
         rotation_mode='anchor')

# Loop over data dimensions and create text annotations.
fmt = '.2f' if normalize else 'd'
thresh = cm.max() / 2.
for i in range(cm.shape[0]):
    for j in range(cm.shape[1]):
        ax.text(j, i, format(cm[i, j], fmt),
                ha='center', va='center',
                color="white" if cm[i, j] > thresh else "black")
fig.tight_layout()
```



Good luck on your HW/Project!

Questions?

Links

[CS 231N Python Tutorial]

Additional slides in case of Q&A

Where does my program start?

It just works

```python
def do_something(number):
    for i in number:
        print(f'Hello {i}')

do_something(5)
```

A function

Properly

```python
def do_something(number):
    for i in number:
        print(f'Hello {i}')

if __name__ == '__main__':
    do_something(5)
```

What is a class?

Initialize the class to get an **instance** using some parameters

Instance variable

Does something with the **instance**

```python
class Vehicle:

    def __init__(self, make, name, year,
                 is_electric=False, price=100):
        self.name = name
        self.make = make
        self.year = year
        self.is_electric = is_electric
        self.price = price

        self.odometer = 0

    def drive(self, distance):
        self.odometer += distance

    def compute_price(self):
        if self.is_electric:
            price = self.price / (self.odometer * 0.8)
        else:
            price = self.price / self.odometer
        return price
```

To use a class

Instantiate a class,

get an **instance**

Call an instance method

```
if __name__ == '__main__':

    family_car = Vehicle('Honda', 'Accord', '2019',
                         price=10000)

    print(family_car.compute_price())
    family_car.drive(100)
    print(family_car.compute_price())
```

String manipulation

Formatting

```
stripped = '     I love CS229! '.strip()
upper_case = 'i love cs 229! '.upper()
capitalized = 'i love cs 229! '.capitalize()
```

Concatenation

```
joined = ‘string 1’ + ‘ ’ + ‘string 2'
```

Formatting

```
formatted = ‘Formatted number {.2F}’.format(1.2345)
```

Basic data structures

List

```
example_list = [1, 2, '3', 'four’]
```

Set (unordered, unique)

```
example_set = set([1, 2, '3', 'four’])
```

Dictionary (mapping)

```
example_dictionary =
        {
                '1': 'one',
                '2': 'two',
                '3': 'three'
        }
```

More on List

2D list

```
list_of_list = [[1,2,3], [4,5,6], [7,8,9]]
```

List comprehension

```
initialize_a_list = [i for i in range(9)]
initialize_a_list = [i ** 2 for i in range(9)]
initialize_2d_list = [[i + j for i in range(5)] for j in range(9)]
```

Insert/Pop

```
my_list.insert(0, ‘stuff)
print(my_list.pop(0))
```

More on List

Sort a list

```
random_list = [3,12,5,6]
sorted_list = sorted(random_list)

random_list = [(3, ‘A’),(12, ’D’),(5, ‘M’),(6, ‘B’)]
sorted_list = sorted(random_list, key=lambda x: x[1])
```

More on Dict/Set

Comprehension

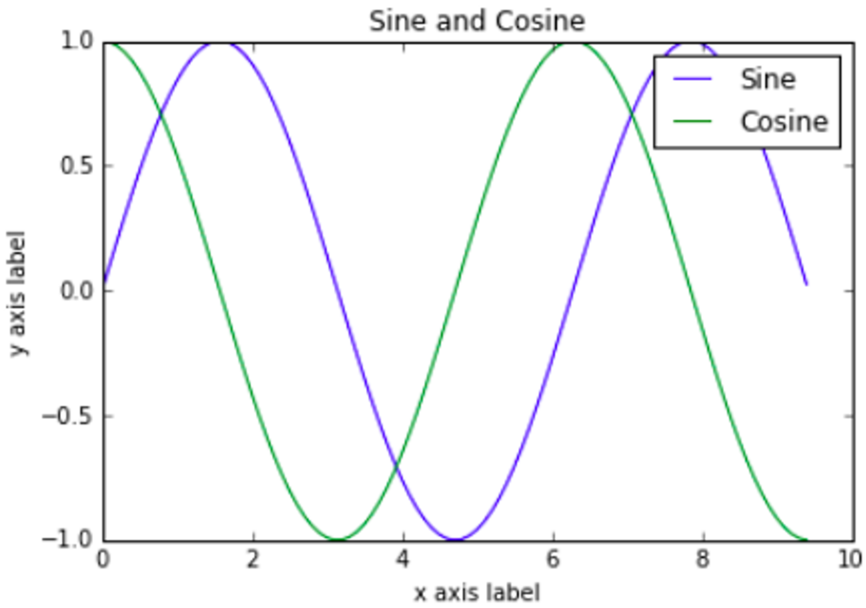
```
my_dict = {i: i ** 2 for i in range(10)}
my_set = {i ** 2 for i in range(10)}
```

Get dictionary keys

```
my_dict.keys()
```

Another way for legend

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

# Compute the x and y coordinates for po
x = np.arange(0, 3 * np.pi, 0.1)
y_sin = np.sin(x)
y_cos = np.cos(x)

# Plot the points using matplotlib
plt.plot(x, y_sin)
plt.plot(x, y_cos)
plt.xlabel('x axis label')
plt.ylabel('y axis label')
plt.title('Sine and Cosine')
plt.legend(['Sine', 'Cosine'])
plt.show()
```



Scatter plot

```
import matplotlib.pyplot as plt
import pandas as pd

girls_grades = [89, 90, 70, 89, 100, 80, 90, 100, 80, 34]
boys_grades = [30, 29, 49, 48, 100, 48, 38, 45, 20, 30]
grades_range = [10, 20, 30, 40, 50, 60, 70, 80, 90, 100]
plt.scatter(grades_range, girls_grades, color='r')
plt.scatter(grades_range, boys_grades, color='g')
plt.xlabel('Grades Range')
plt.ylabel('Grades Scored')
plt.show()
```