# CS229 Section: Python & Numpy

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Content adapted from past CS229 iterations

# How is Python related to with others?

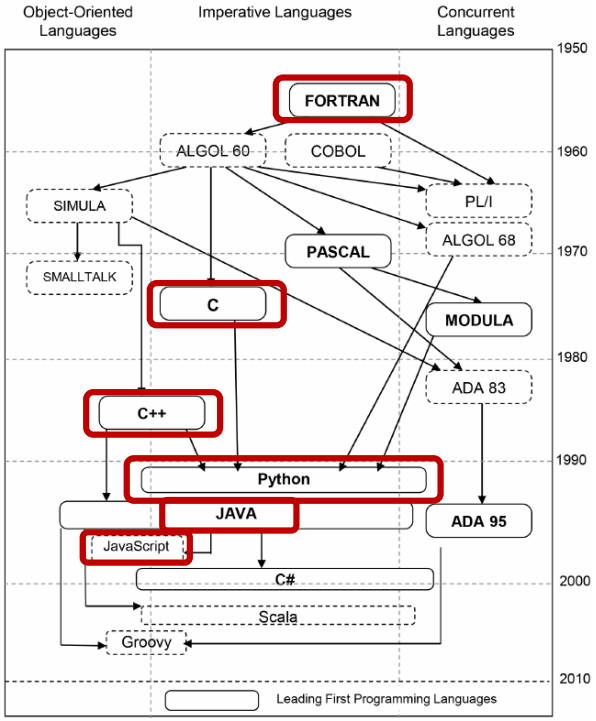
Python 2.0 released in 2000

(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)

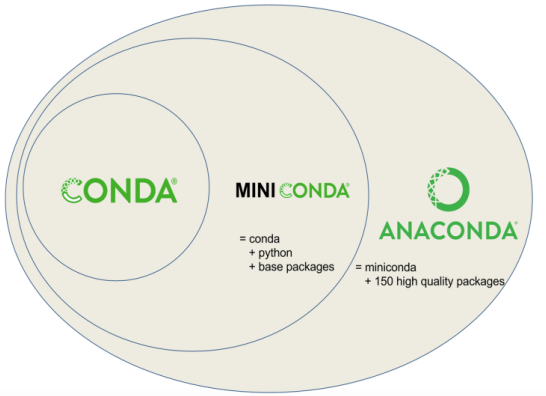
```
conda create -n cs229
```

Create an environment (Miniconda)

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

Activate an environment after creation

```
conda activate cs229
```



# Notepad is not your friend ...

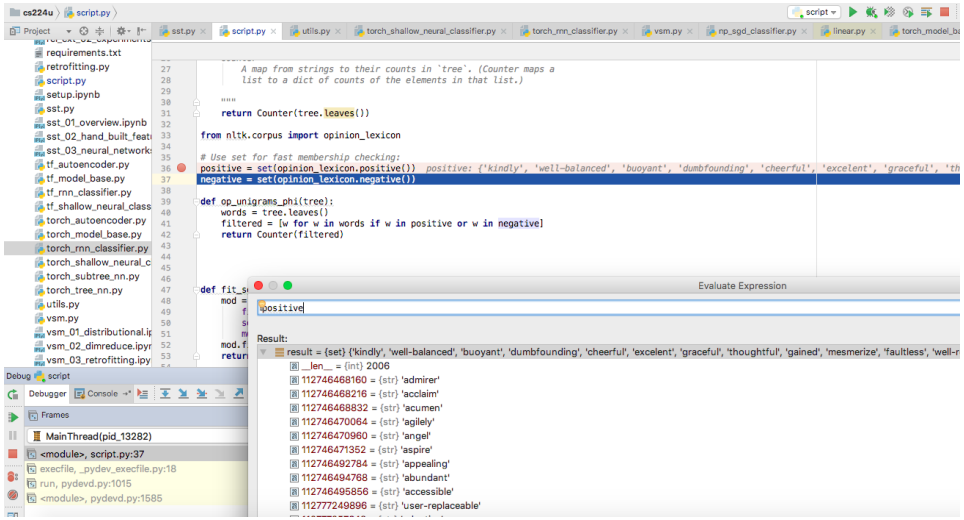
Get a text editor/IDE

- 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

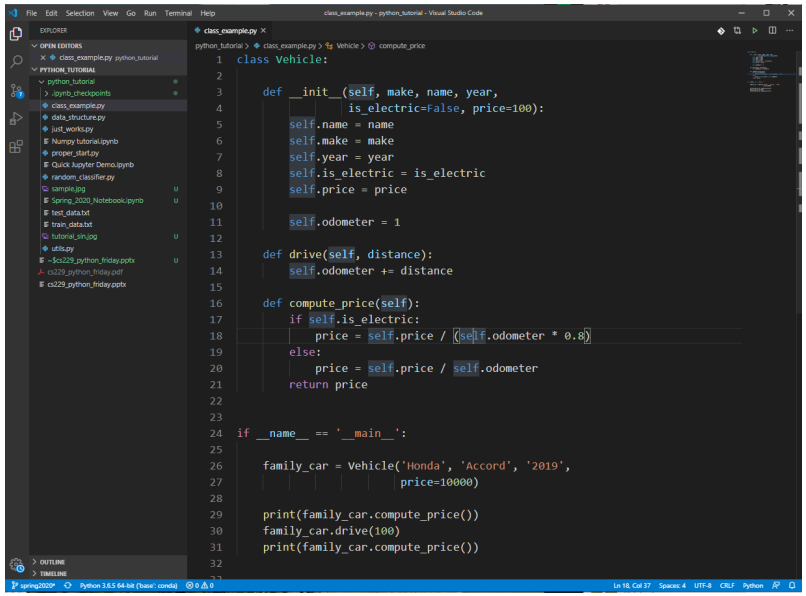



FYI, professional version free for students: https://www.jetbrains.com/student/

# To make you more prepared

## Visual Studio Code

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



# Basic Python

Strings, Lists, Dictionaries

# 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]])
```

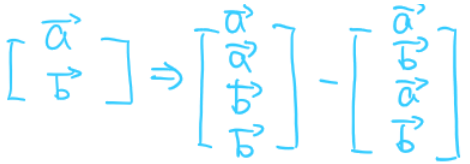
# Broadcasting for pairwise distance

```
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)
```

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

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

Both achieve the effect of



# 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

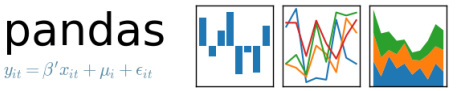
## Jupyter Notebook


- 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**

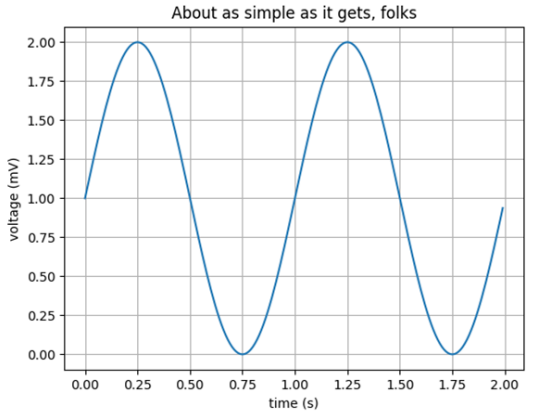
```
fig, ax = plt.subplots()
ax.plot(t, s)
```

**Format plot**

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

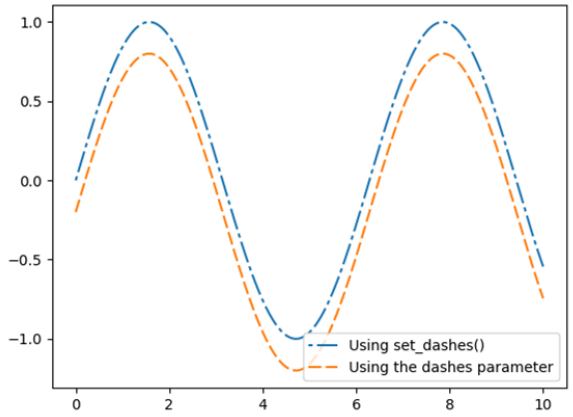
**Save/show**

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



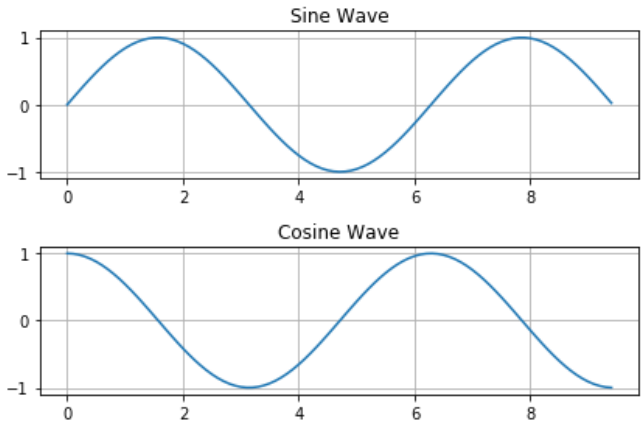
# Plot with dash lines and legend

```
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()
```



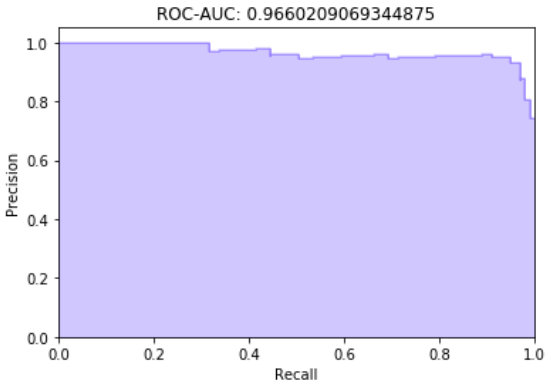
# Using subplot

```
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

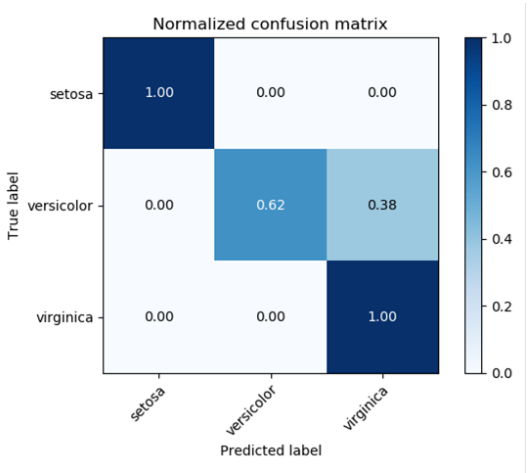
```
def prec_rec_curve(model, X, Y_true, title="", verbose=False):
    probas_pred = model.predict_proba(X)[:, 1]
    pos_label = 1.0
    precision, recall, thresholds = precision_recall_curve(Y_true,
                                                           probas_pred,
                                                           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?

# Additional slides in case of Q&A

# Where does my program start?

It just works

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

do_something(5)
```

A function

Properly

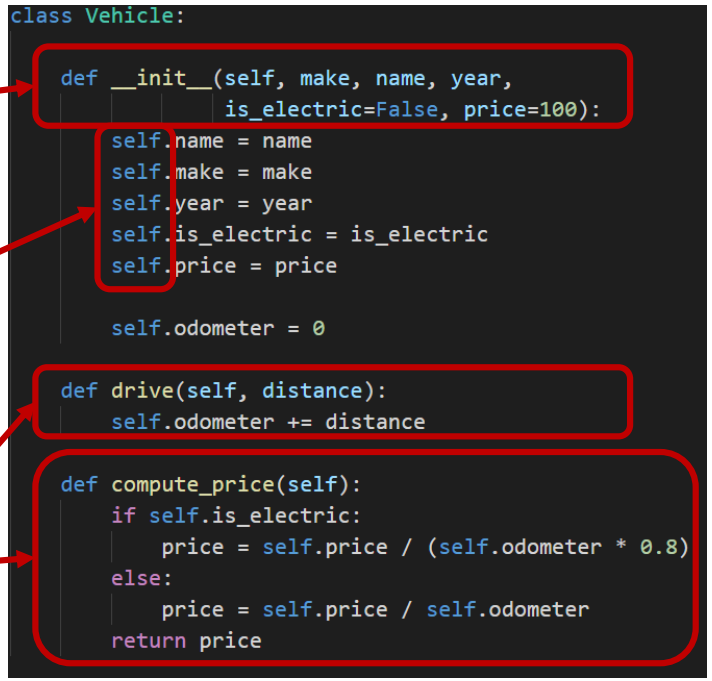
```
def do_something(number):
    for i in number:
        print(f'Hello {i}')

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**

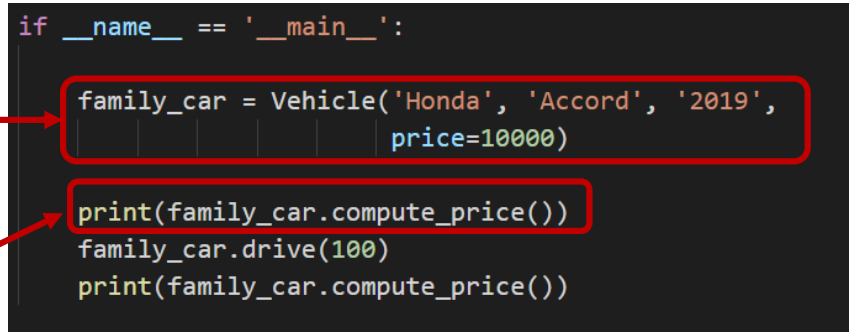


# To use a class

Instantiate a class,

get an **instance**

Call an instance method



# 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

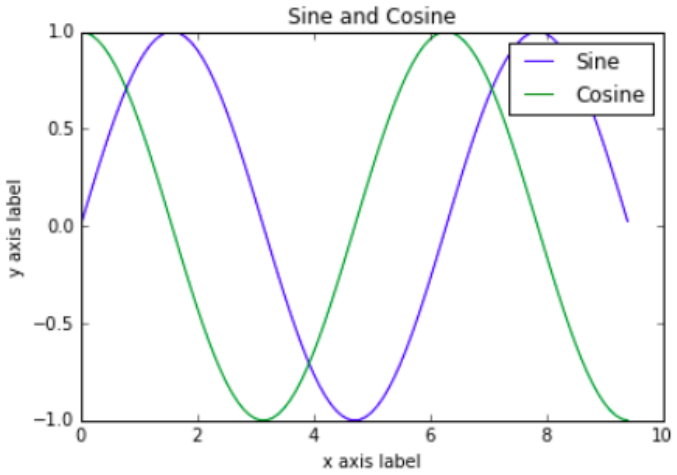
```
my_dict = {i: i ** 2 for i in range(10)}
my_set = {i ** 2 for i in range(10)}
```

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()
```