

Before we begin...

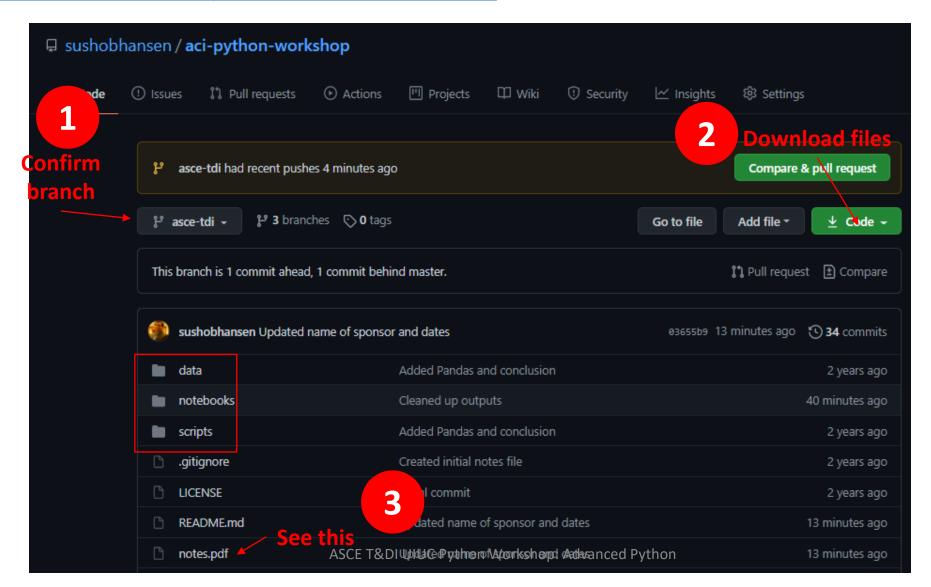
- Download and install Anaconda: https://www.anaconda.com/distribution/
- Or use an online IDE: https://repl.it/languages/python3

Who am I?

- Sushobhan Sen, PhD
- Postdoctoral associate at the University of Pittsburgh – I model pavements and the urban environment using computational techniques
- Languages I know: FORTARN, C/C++/C#, Python, Visual Basic, HTML, CSS, JavaScript, Latex, Bash, MATLAB
 - (I also speak a few human languages)
- More at: https://sushobhansen.github.io/
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Workshop Website: https://github.com/sushobhansen/aci-python-workshop/tree/asce-tdi



Learning Objectives: Advanced Python

- At the end of this workshop, participants will be able to:
 - Use numpy to define and use matrices, and read and process data from files
 - Use matplotlib to visualize data
 - Use scipy to process an image, analyze a sound wave, and fit data to a curve
 - Use pandas to read and analyze data (if we have time)
- We'll do all of this by solving several problems

Python Libraries

- You already know how to use Python (you should)
- Libraries extend Python's functionalities
- Almost all of them are open-source and free
- Some have great documentation, others iffy

Python Libraries

Libraries	Popular Applications
numpy, scipy	Numerical and scientific analysis (compa-
	rable to MATLAB)
matplotlib, seaborn, vtk	Scientific visualization
pandas	Data science
scikit-learn, tensorflow, py-	Machine learning and deep learning
torch	
scrapy, requests, selenium, PyPDF2	Data mining
geopandas, rasterio, raster-	Geospatial data analysis and GIS
stats, descartes, pySAL, ar-	
сру	
wxPython, tkinter, pyQt,	Graphical User Interface (GUI) develop-
pyGUI	ment
SQLAlchemy, postgreSQL	Database management
django, TurboGears, flask,	Web development
web2py	
OpenCV, scikit-image	Image and signal processing
MetPy, netCDF4, SatPy	Meteorology
mpi4py, cython, jython	High performance computing
biopython	Biology
astropy	Astronomy
scikit-chem	Chemistry
SymPy	Symbolic math (comparable to Mathemat-
	ica)
FiPy, OpenSeenPy	Finite element analysis
fluidity, fluidsim, fluiddyn,	Computational fluid dynamics
cfdpython	
Py2B, pySerial, instru-	Arduoino programming and IoT
mentino	
pyfin, QuantPy, pynance,	Finance and trading
analyzer, pyfolio	
nltk, spacy, polyglot	Natural language processing
pygame, arcade, cocos2d,	Game development and animation
PyODE	72 - 12 - 12 - 12 - 12 - 12 - 12 - 12 -

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Using libraries in Python

Import the whole library

```
1 import numpy as np
Alias
```

Import only some functions

```
3 | from scipy.optimize import curve_fit
```

Numpy

- Numerical Python library
 - Implements vectorization
 - Implements fast linear algebra libraries (BLAS and LAPACK)
- Very similar to using MATLAB many of the functions have the same name!
- Numpy works on arrays or matrices as a whole you shouldn't have to manipulate element by element

Numpy arrays

- Main data structure when using numpy
- A continuous block of memory

```
import numpy as np
a = np.array([[1,2,3],[4,5,6],[7,8,9]])
print(a)
print(type(a))
print(a.shape)
```

Array slicing and broadcasting

- Slicing: Using only parts of an array [row:column]
 - Numpy arrays are zero indexed, exclusive of second number
- Broadcasting: Converting one array dimension to another compatible one



Vectorization and Masking

- Vectorization: Manipulate all elements of an array simultaneously
- Masking: A Boolean array that can be passed to another array to get only some elements (vectorized version of an if-condition)



Challenge: Linear Algebra

• Solve:
$$\begin{cases} x + y + z = 6 \\ 2y + 5z = -4 \\ 2x + 5y - z = 27 \end{cases}$$

$$\begin{pmatrix} 1 & 1 & 1 \\ 0 & 2 & 5 \\ 2 & 5 & -1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 6 \\ -4 \\ 27 \end{pmatrix}$$

$$A*x = b$$



One library to rule them all

- Numpy is considered a fundamental library, so much so it's like a part of Python itself
- Almost all major numerical Python libraries are built on top of numpy
- We'll see more numpy functions later

Matplotlib

- Matrix Plotting Library
- PyPlot Python API
- Great for scientific data visualization, comparable to MATLAB
- Easy to make publication-quality charts

Plotting 1D Data

- Usually categorical variable on x-axis, continuous variable on y-axis
- E.g., Bar chart, Pie chart

```
%matplotlib inline
import numpy as np
from matplotlib import pyplot as plt

barnumber = np.arange(4)+1
barheight= np.random.uniform(5.0,10.0,(4,))

plt.bar(barnumber,barheight)
plt.xlabel('Bar Number')
plt.ylabel('Bar Height')
plt.title('Random Bar Heights')
plt.ylim([0,10])
plt.xticks(barnumber)
plt.show()
```

Go to Notebook

Plotting 2D Data

- Typical type of plotting
- Usually plot a function of the form y = f(x)
- Plot numerically i.e., plot points, maybe join with a curve
- E.g., line plot, scatter plot

Plotting a trigonometric function

• Plot
$$f(x) = \frac{\sin x + \cos x}{2}$$
 for $x \in [0^{\circ}, 360^{\circ}]$

```
1  x = np.linspace(0,360,1000)
2  y = (np.sin(x*np.pi/180.) + np.cos(x*np.pi/180.))/2.0
3  plt.plot(x,y)
4  plt.grid()
5  plt.xlabel('x (degrees)')
6  plt.ylabel('f(x)')
7  plt.show()
```

Multiple series in a single plot

• Plot $\begin{cases} e^{-x} \\ e^{-2x} \end{cases}$ for $x \in [0,2]$

```
1  x = np.linspace(0.,2.,1000)
2  y1 = np.exp(-x)
3  y2 = np.exp(-2.0*x)
4
5  plt.semilogy(x,y1,label='$e^{-x}$')
6  plt.semilogy(x,y2,label='$e^{-2x}$')
7  plt.xlabel('x')
8  plt.ylabel('f(x)')
9  plt.legend()
10  plt.grid(which='both')
11  plt.show()
```

Subplot & Data from a File

Plot data from data/weather.csv as a line and bar chart

```
hour, temperature, precip_prob =
           np.loadtxt('../data/weather.csv', dtype=np.float,
           delimiter=',',skiprows=1,unpack=True)
  plt.subplot(1,2,1)
   plt.plot(hour, temperature)
   plt.xlabel('Hour')
  plt.ylabel('Temperature ($^o$F)')
   plt.title('Temperature')
10
  plt.subplot(1,2,2)
12 plt.bar(hour, precip_prob)
13 plt.xlabel('Hour')
14 plt.ylabel('Probability (%)')
15 plt.title('Probability of Precipitation')
16 plt.show()
```

Go to Notebook

Plotting 3D Data

- Two ways:
 - Actual 3D isometric view (good for web apps, not good for publication): Not directly supported, available from mpl_toolkits
 - Contour plots (good for publication)
- Always plot over a mesh of points

Plot a 3D function

• Plot $f(x,y) = \sin(\sqrt{x^2 + y^2})$ for $(x,y) \in [-6,6]^2$

```
from mpl_toolkits import mplot3d
   x = np.linspace(-6,6,100)
                                           plt.contourf(X,Y,Z,50,cmap='spring')
   y = np.linspace(-6,6,100)
                                           plt.xlabel('x')
                                           plt.ylabel('y')
   X,Y = np.meshgrid(x,y)
                                           plt.colorbar(label='f(x,y)')
   Z = np.sin(np.sqrt(X**2+Y**2))
                                          plt.show()
   fig = plt.figure()
   ax = plt.axes(projection='3d')
11
   ax.contour3D(X, Y, Z, 50, cmap='spring')
   ax.set_xlabel('x')
   ax.set_ylabel('y')
```

Scipy

- Scientific Python Library
- Built on top of numpy, and follows it very closely (many common functions too)

Package	Application
scipy.cluster	Clustering (K-means) and vector quantiza-
	tion
scipy.constants	Mathematical constant
scipy.fftpack	Fast Fourier Transform
scipy.integrate	Integration
scipy.interpolate	Interpolation
scipy.io	Input/Output
scipy.linalg	Linear Algebra
scipy.ndimage	Image analysis
scipy.odr	Orthogonal regression
scipy.optimize	Optimization
scipy.signal	Signal processing
scipy.sparse	Sparse matrix manipulation
scipy.spatial	Spatial data and algorithms
scipy.special	Special functions
scipy.stats	Statistics

Challenge: Curve Fitting

- Use scipy.optimize.curve_fit() to fit an Intensity-Duration-Frequency (IDF) curve using data from data/idf.csv of the following form:
 - $I(t) = \frac{a}{t^{n}+c}$ (Chow et al)
 - I(t) is intensity (in/hr) as a function of storm duration (t) in hours.
 - a, n, c are empirical constants that are a function of the return period (frequency, in years)



Challenge: Image Processing

- Use scipy.ndimage to perform the following manipulations on the data/otter.png image:
 - View it
 - Rotate it by 10°
 - Sharpen it (use a Gaussian filter)
 - Detect its edges (use a Sobel filter)



Challenge: Fourier Transform

 Use scipy.fftpack.fft() to find the dominant frequency in the data/cat.csv file (it's a cat purring, listen to data/cat.wav)



Pandas

- A high-level data analysis package built on top of numpy, with further abstractions
- Most popular package for data science
- Basic data types: Series (1D) and Data Frames (2D)

Challenge: 2013 College Football Drives

 Read the data/drive.csv file in a pandas data frame, examine the data, and clean it

```
import numpy as np
import pandas as pd

df = pd.read_csv('../data/drive.csv')
df.head()

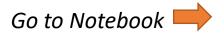
print(df.shape, df.columns, df.dtypes)
df['Game Code'][10:25]
df.describe()

df.isna().sum()

df = df.dropna()
```

Challenge: 2013 College Football Drives

- Using the pandas data frame, analyze the data and answer the following questions:
 - What was the distribution of the ways that drives ended?
 - Of the drives that ended in a touchdown, what was the distribution of the time of possession?
 - Which team made the most yards per play on average?



Conclusion



Further Resources

- Numpy and Scipy documentation: https://docs.scipy.org/doc/
- Matplotlib documentation: https://matplotlib.org/contents.html
- Pandas documentation: https://pandas.pydata.org/pandas-docs/stable/
- Free online courses:
 - Python for research: https://www.edx.org/course/using-python-for-research
 - Python for data science: https://www.edx.org/course/python-for-data-science-1