



March 24, 2021

Pittsburgh, PA

ASCE T&DI UIUC Python Workshop: Advanced Python

Before we begin...

- If you haven't already, go to <https://github.com/sushobhansen/aci-python-workshop/tree/asce-tdi> for course materials (**use the asce-tdi branch**)
- 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>

The screenshot shows the GitHub interface for the repository 'sushobhansen/aci-python-workshop'. The 'Code' tab is selected. A red circle with the number '1' and the text 'Confirm branch' points to the 'asce-tdi' branch dropdown. A red circle with the number '2' and the text 'Download files' points to the 'Code' button. A red circle with the number '3' and the text 'See this' points to the 'notes.pdf' file in the file list.

1 Confirm branch

2 Download files

3 See this

Repository: sushobhansen / aci-python-workshop

Navigation: Code, Issues, Pull requests, Actions, Projects, Wiki, Security, Insights, Settings

Notification: asce-tdi had recent pushes 4 minutes ago

Buttons: Compare & pull request, Go to file, Add file, Code

Branch: asce-tdi (3 branches, 0 tags)

Status: This branch is 1 commit ahead, 1 commit behind master.

Commits: sushobhansen Updated name of sponsor and dates (03655b9, 13 minutes ago, 34 commits)

File	Description	Time
data	Added Pandas and conclusion	2 years ago
notebooks	Cleaned up outputs	40 minutes ago
scripts	Added Pandas and conclusion	2 years ago
.gitignore	Created initial notes file	2 years ago
LICENSE	Initial commit	2 years ago
README.md	Updated name of sponsor and dates	13 minutes ago
notes.pdf	ASCE T&DI Update Python Workshop Advanced Python	13 minutes ago

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 (comparable to MATLAB)
matplotlib, seaborn, vtk	Scientific visualization
pandas	Data science
scikit-learn, tensorflow, pytorch	Machine learning and deep learning
scrapy, requests, selenium, PyPDF2	Data mining
geopandas, rasterio, rasterstats, descartes, pySAL, arcpy	Geospatial data analysis and GIS
wxPython, tkinter, PyQt, pyGUI	Graphical User Interface (GUI) development
SQLAlchemy, PostgreSQL	Database management
django, TurboGears, flask, web2py	Web development
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 Mathematica)
FiPy, OpenSeesPy	Finite element analysis
fluidity, fluidsim, fluiddyn, cfdpython	Computational fluid dynamics
Py2B, pySerial, instrumentino	Arduino programming and IoT
pyfin, QuantPy, pynance, analyzer, pyfolio	Finance and trading
nltk, spacy, polyglot	Natural language processing
pygame, arcade, cocos2d, PyODE	Game development and animation

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

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

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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

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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)

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Challenge: Linear Algebra

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

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

$$A * x = b$$

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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

```
1 %matplotlib inline
2 import numpy as np
3 from matplotlib import pyplot as plt
4
5 barnumber = np.arange(4)+1
6 barheight= np.random.uniform(5.0,10.0,(4,))
7
8 plt.bar(barnumber, barheight)
9 plt.xlabel('Bar Number')
10 plt.ylabel('Bar Height')
11 plt.title('Random Bar Heights')
12 plt.ylim([0,10])
13 plt.xticks(barnumber)
14 plt.show()
```

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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()
```

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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()
```

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Subplot & Data from a File

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

```
1 hour, temperature, precip_prob =  
2     np.loadtxt('../data/weather.csv', dtype=np.float,  
3     delimiter=',', skiprows=1, unpack=True)  
4  
5 plt.subplot(1,2,1)  
6 plt.plot(hour, temperature)  
7 plt.xlabel('Hour')  
8 plt.ylabel('Temperature (°F)')  
9 plt.title('Temperature')  
10  
11 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()
```

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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 $(x, y) \in [-6, 6]^2$

```
1 from mpl_toolkits import mplot3d
2
3 x = np.linspace(-6,6,100)
4 y = np.linspace(-6,6,100)
5
6 X,Y = np.meshgrid(x,y)
7 Z = np.sin(np.sqrt(X**2+Y**2))
8
9 fig = plt.figure()
10 ax = plt.axes(projection='3d')
11
12 ax.contour3D(X, Y, Z, 50, cmap='spring')
13 ax.set_xlabel('x')
14 ax.set_ylabel('y')
```

```
1 plt.contourf(X,Y,Z,50,cmap='spring')
2 plt.xlabel('x')
3 plt.ylabel('y')
4 plt.colorbar(label='f(x,y)')
5 plt.show()
```

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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 quantization
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)

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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)

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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`)

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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

```
1 import numpy as np
2 import pandas as pd
3
4 df = pd.read_csv('../data/drive.csv')
5 df.head()
```

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

```
1 df.isna().sum()
```

```
1 df = df.dropna()
```

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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?

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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>