DM561

Linear Algebra with Applications

Intoduction to Python - Part 3

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[*Based on booklet Python Essentials*]

Outline

1. Matplotlib
2. Other Data Visualization Libraries
3. Pandas

Outline

Matplotlib Library in Ipython

In IPython functions with % are extra functions of IPython that add functionalities to the environment. They are called magic functions. Other useful magic function are `%timeit` to determine running time of a command and `%run` to run a script from a file.

```
>>> %matplotlib inline
>>> import matplotlib.pyplot as plt
```

Plotting a Polynomial Function

Let's plot the following polynomial of degree 3:

$$P_3(x) = x^3 - 7x + 6 = (x-1)(x-2)(x+3)$$

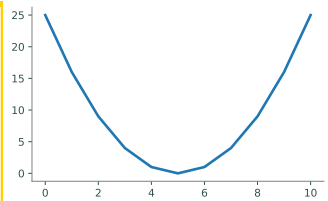
The `numpy` function `numpy.poly1d` takes an array of coefficients of length n+1 (try `numpy.polyfit?`):

`a[0] * x**n + a[1] * x**(n-1) + ... + a[n-1]*x + a[n]`

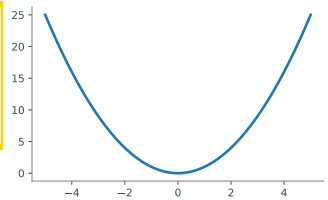
```
>>> import numpy as np
>>> a=[1,0,-7,6]
>>> P=np.poly1d(a)
>>> print(P)
   3
1 x - 7 x + 6

>>> x = np.linspace(-3.5, 3.5, 500)
>>> plt.plot(x, P(x), '-')
>>> plt.axhline(y=0)
>>> plt.title('A polynomial of order 3');
```

Line Plots

```
>>> import numpy as np
>>> from matplotlib import pyplot as plt

>>> y = np.arange(-5,6)**2
>>> y
array([25, 16, 9, 4, 1, 0, 1, 4, 9, 16, 25])

# Visualize the plot.
>>> plt.plot(y)   # Draw the line plot.
[<matplotlib.lines.Line2D object at 0x10842d0>]
>>> plt.show()    # Reveal the resulting plot.
```




```
>>> x = np.linspace(-5, 5, 50)
>>> y = x**2      # Calculate the range of f(x) = x**2.
>>> plt.plot(x,y)
>>> plt.show()
```



Interactive Plotting

- `plt.ion()`
- `plt.clf()`
- `plt.ioff()`

In IPython Notebook.

- `%matplotlib inline` shows the plot
- `%matplotlib notebook` shows the plot and provides controls to interact with the plot

Plot Customization

For `plt.plot()`

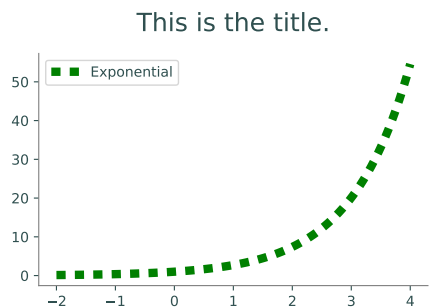
Key	Color
`'b'`	blue
`'g'`	green
`'r'`	red
`'c'`	cyan
`'k'`	black

Key	Style
`'-'`	solid line
`'--'`	dashed line
`'-.'`	dash-dot line
`':'`	dotted line
`'o'`	circle marker

Other functions

Function	Description
`legend()`	Place a legend in the plot
`title()`	Add a title to the plot
`xlim()` / `ylim()`	Set the limits of the x- or y-axis
`xlabel()` / `ylabel()`	Add a label to the x- or y-axis

```
>>> x1 = np.linspace(-2, 4, 100)
>>> plt.plot(x1, np.exp(x1), 'g:', ↩
    linewidth=6, label="Exponential")
>>> plt.title("My title", fontsize=18)
>>> plt.legend(loc="upper left")
>>> plt.show()
```



Layout

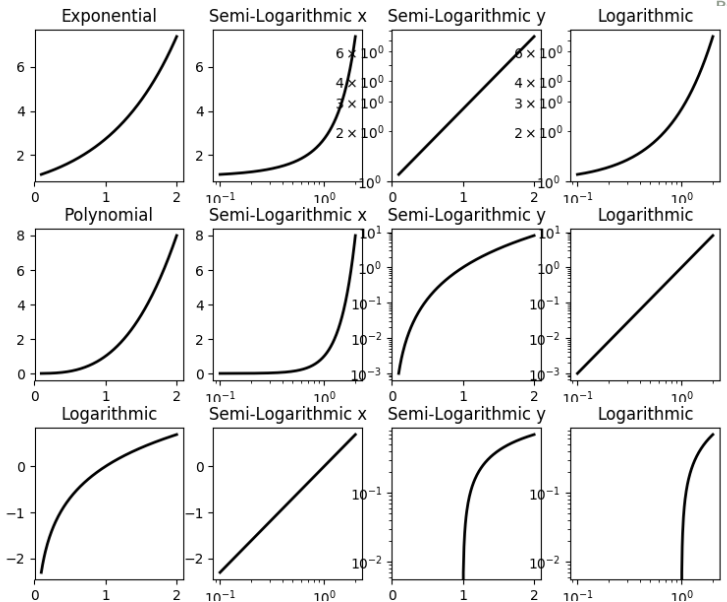
Function	Description
`axes()`	Add an axes to the current figure
`figure()`	Create a new figure or grab an existing figure
`gca()`	Get the current axes
`gcf()`	Get the current figure
`subplot()`	Add a single subplot to the current figure
`subplots()`	Create a figure and add several subplots to it

```
# 3. Use plt.subplots() to get the figure and all subplots simultaneously.
>>> fig, axes = plt.subplots(1, 2)
>>> axes[0].plot(x, 2*x)
>>> axes[1].plot(x, x**2)
```

Compare `axes()` vs `axis()` (access properties of the current plot)

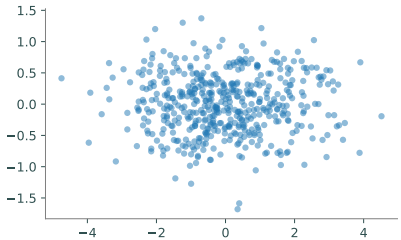
```
import numpy as np
from matplotlib import pyplot as plt

def make_figure(x,f,name):
    plt.figure(figsize=(9,2))
    ax1 = plt.subplot(141)
    ax1.plot(x, f(x), 'k', lw=2)
    plt.title(name)

    ax2 = plt.subplot(142)
    ax2.semilogx(x, f(x), 'k', lw=2)
    ax2.set_title("Semi-Logarithmic x")

    ax3 = plt.subplot(143)
    ax3.semilogy(x, f(x), 'k', lw=2)
    ax3.set_title("Semi-Logarithmic y")

    ax4 = plt.subplot(144)
    ax4.loglog(x, f(x), 'k', lw=2)
    ax4.set_title("Logarithmic")
    plt.savefig(name+".png")
```

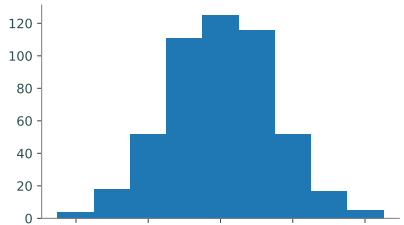
```
xx = np.linspace(.1, 2, 200)
make_figure(xx, lambda xx: np.exp(xx), ↩
    "Exponential")
make_figure(xx, lambda xx: xx**3, "↩
    Polynomial")
make_figure(xx, lambda xx: np.log(xx), ↩
    "Logarithmic")
```


Exponential
Semi-Logarithmic x
Semi-Logarithmic y
Logarithmic
Polynomial
Semi-Logarithmic x
Semi-Logarithmic y
Logarithmic
Logarithmic
Semi-Logarithmic x
Semi-Logarithmic y
Logarithmic

Scatter Plots and Histograms

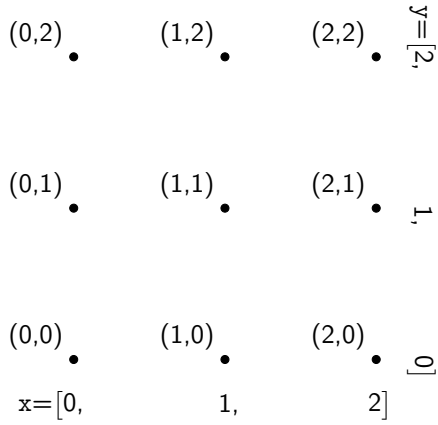
```
>>> x = np.random.normal(scale=1.5, size=500)
>>> y = np.random.normal(scale=0.5, size=500)

>>> ax1 = plt.subplot(121)
>>> ax1.plot(x, y, 'o', markersize=5, alpha=.5) # transparent circles

>>> ax2 = plt.subplot(122)
>>> ax2.hist(x, bins=np.arange(-4.5, 5.5))
>>> plt.show()
```





3D Surfaces

`np.meshgrid()` given two 1-dimensional coordinate arrays, creates two corresponding coordinate matrices: `(X[i,j], Y[i,j]) = (x[i],y[j])`.



$$X = \begin{vmatrix} 0 & 1 & 2 \\ 0 & 1 & 2 \\ 0 & 1 & 2 \end{vmatrix}$$

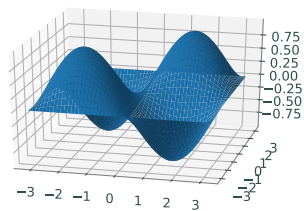
$$Y = \begin{vmatrix} 2 & 2 & 2 \\ 1 & 1 & 1 \\ 0 & 0 & 0 \end{vmatrix}$$

```
>>> x, y = [0, 1, 2], [3, 4, 5]      # A rough domain over [0,2]x[3,5].
>>> X, Y = np.meshgrid(x, y)         # Combine the 1-D data into 2-D data.
>>> for trows in zip(X,Y):
...     print(trows)
...
(array([0 1 2]), array([3 3 3]))
(array([0 1 2]), array([4 4 4]))
(array([0 1 2]), array([5 5 5]))
```

3D Surfaces

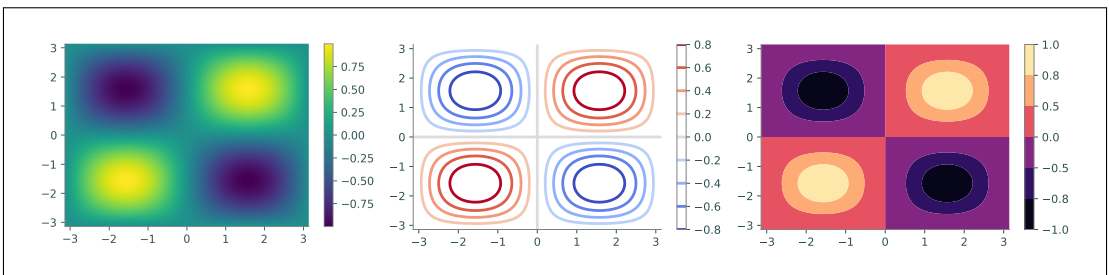
$$g(x, y) = \sin(x)\sin(y)$$

```
>>> x = np.linspace(-np.pi, np.pi, 200)
>>> y = np.copy(x)
>>> X, Y = np.meshgrid(x, y)
>>> Z = np.sin(X) * np.sin(Y)

# Draw the corresponding 3-D plot using some ↩
    extra tools.
>>> from mpl_toolkits.mplot3d import Axes3D
>>> fig = plt.figure()
>>> ax = fig.add_subplot(1,1,1, projection='3d')
>>> ax.plot_surface(X, Y, Z)
>>> plt.show()
```



Heat Map and Contour Plot

```
>>> x = np.linspace(-np.pi, np.pi, 100)
>>> y = x.copy()
>>> X, Y = np.meshgrid(x, y)
>>> Z = np.sin(X) * np.sin(Y)       # Calculate g(x,y) = sin(x)sin(y).
# Plot the heat map of f over the 2-D domain.
>>> plt.subplot(131)
>>> plt.pcolormesh(X, Y, Z, cmap="viridis")
>>> plt.colorbar()
>>> plt.xlim(-np.pi, np.pi)
>>> plt.ylim(-np.pi, np.pi)
# Plot a contour map of f with 10 level curves.
>>> plt.subplot(132)
>>> plt.contour(X, Y, Z, 10, cmap="coolwarm")
>>> plt.colorbar()
# Plot a filled contour map, specifying the level curves.
>>> plt.subplot(133)
>>> plt.contourf(X, Y, Z, [-1, -.8, -.5, 0, .5, .8, 1], cmap="magma")
>>> plt.colorbar()
>>> plt.show()
```


3
2
1
0
−1
−2
−3
−3 −2 −1 0 1 2 3
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
1.0
0.8
0.5
0.0
−0.5
−0.8
−1.0

Animations

1. Calculate all data that is needed for the animation.
2. Define a figure explicitly with `plt.figure()` and set its window boundaries.
3. Draw empty objects that can be altered dynamically.
4. Define a function to update the drawing objects.
5. Use `matplotlib.animation.FuncAnimation()`.

```
from matplotlib.animation import FuncAnimation
from mpl_toolkits.mplot3d import Axes3D

def sine_animation():
    # 1. Calculate the data to be animated.
    x = np.linspace(0, 2*np.pi, 200)[:-1]
    y = np.sin(x)    #
    # 2. Create a figure and set the window boundaries of the axes.
    fig = plt.figure()
    plt.xlim(0, 2*np.pi)
    plt.ylim(-1.2, 1.2) #
    # 3. Draw an empty line. The comma after 'drawing' is crucial.
    drawing, = plt.plot([],[])  #
    # 4. Define a function that updates the line data.
    def update(index):
        drawing.set_data(x[:index], y[:index])
        return drawing,                    # Note the comma!
    # 5.
    a = FuncAnimation(fig, update, frames=len(x), interval=10)
```

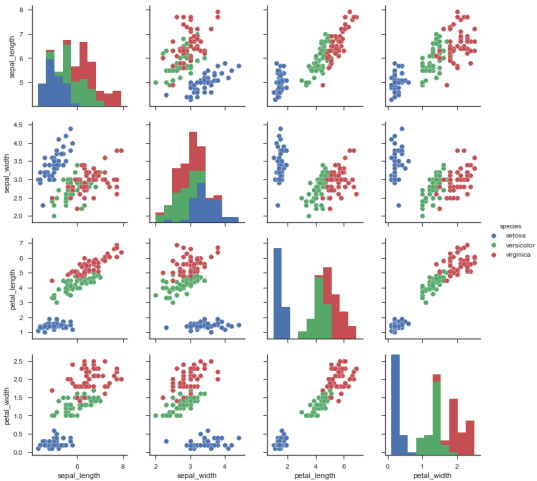
Further Reading and Tutorials

- https://www.labri.fr/perso/nrougier/teaching/matplotlib/.
- https://matplotlib.org/users/pyplot_tutorial.html.
- http://www.scipy-lectures.org/intro/matplotlib/matplotlib.html.
- https://matplotlib.org/2.0.0/examples/animation/index.html

Outline

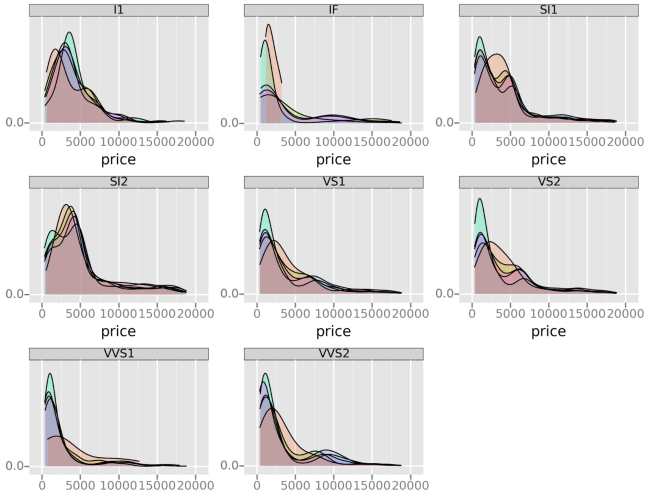
Seaborn

A high-level library on the top of Matplotlib. It's easier to generate certain kinds of plots: eg, heat maps, time series, and violin plots.



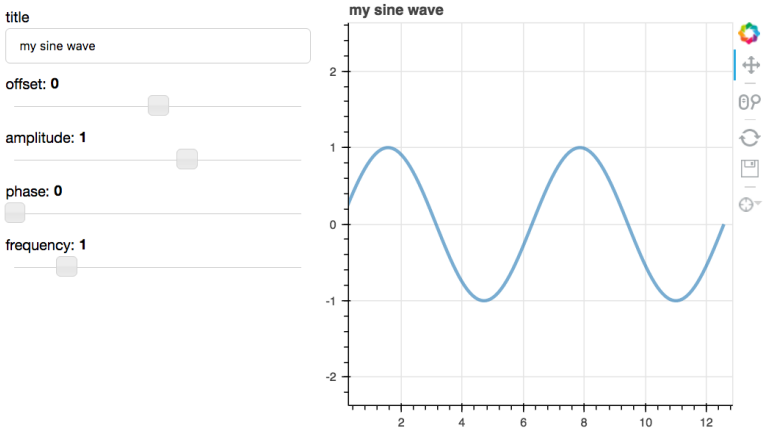
ggplot

Based on R's ggplot2 and the Grammar of Graphics



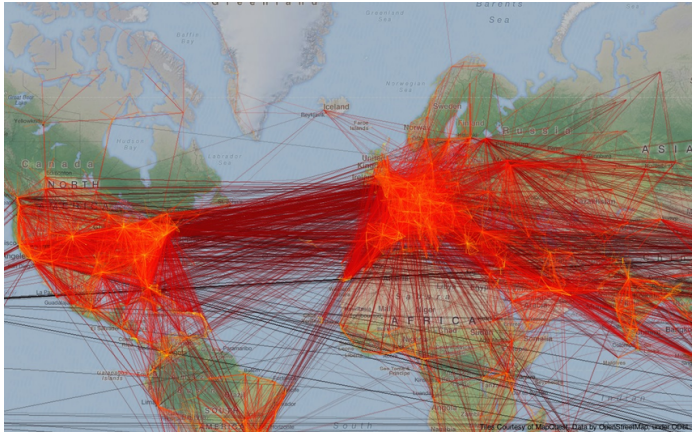
Bokeh, Plotly, Gleam, Dash and Altair

Create interactive, web-ready plots, as JSON objects, HTML documents, or interactive web applications.
Bokeh is based on the Grammar of Graphics like ggplot.
Gleam is inspired by R's Shiny package.



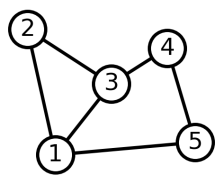
Geoplotlib, Leaflet and MapBox

Toolbox for plotting geographical data: map-type plots, like choropleths, heatmaps, and dot density maps.



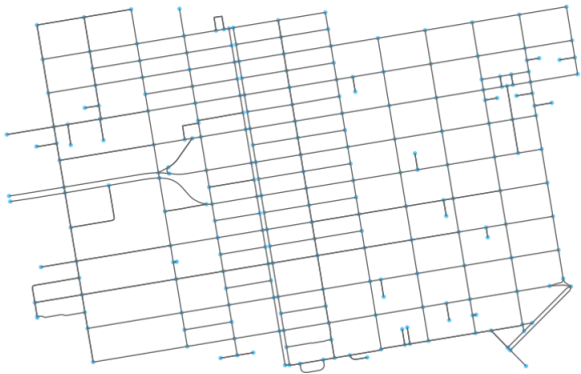
Graph Algorithms, Graph Drawings

```
import matplotlib.pyplot as plt

G = nx.Graph()
G.add_edge(1, 2)
G.add_edge(1, 3)
G.add_edge(1, 5)
G.add_edge(2, 3)
G.add_edge(3, 4)
G.add_edge(4, 5)

# explicitly set positions
pos = {1: (0, 0), 2: (-1, 0.3), 3: (2, 0.17), 4: (4, 0.255), 5: (5, 0.03)}

nx.draw_networkx(G, pos)

# Set margins for the axes so that nodes aren't clipped
ax = plt.gca()
ax.margins(0.20)
plt.axis("off")
plt.show()
```



Street Networks

```
import osmnx as ox
G = ox.graph_from_bbox(37.79, 37.78, -122.41, -122.43, network_type='drive')
G_projected = ox.project_graph(G)
ox.plot_graph(G_projected)
```



Outline

Pandas Data Structures: Series

Pandas library for data management and analysis that combines functionality of NumPy, MatPlotLib, and SQL

- `Series` is a one-dimensional array that can hold any datatype, similar to a `ndarray` but with an `index` that gives a label to each entry.

```
>>> import pandas as pd
>>>
>>> # Initialize Series of student grades
>>> math = pd.Series(np.random.randint(0,100,4), ['Mark', 'Barbara', 'Eleanor',↩
     'David'])
>>> english = pd.Series(np.random.randint(0,100,5), ['Mark', 'Barbara', 'David'↩
    , 'Greg', 'Lauren'])
```

Pandas Data Structures: Data Frames

- `DataFrame` is a collection of multiple `Series`. It can be thought of as a 2-dimensional array, where each row is a separate datapoint and each column is a feature of the data. The rows are labelled with an `index` (as in a `Series`) and the columns are labelled in the attribute `columns`.

```
>>> # Create a DataFrame of student grades
>>> grades = pd.DataFrame({"Math": math, "English": english})
>>> grades
          Math  English
Barbara   52.0     73.0
David     10.0     39.0
Eleanor   35.0      NaN
Greg       NaN     26.0
Lauren     NaN     99.0
Mark      81.0     68.0
```

Summary

1. Matplotlib

2. Other Data Visualization Libraries

3. Pandas