Data Processing, Analysis and Visualization in Python

Matplotlib

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Outline

- Introduction
- Line Plots
- Customizing Plots
- Scatter Plots
- Contour Plots
- Bar Plots
- Pie Charts
- Histograms

matplotlib

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What is Matplotlib?

- Matplotlib is a multi-platform data visualization library built on NumPy arrays, and designed to work with the broader SciPy stack.

NumPy matplotlib IPython SymPy pandas

https://matplotlib.org/

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What is Matplotlib?

- Conceived by John Hunter in 2002, originally as a patch to IPython for enabling interactive MATLAB-style plotting via gnuplot from the IPython command line.
  - Version 0.1 released in 2003.
- Supports many operating systems, graphics backends, and output formats.
- Newer packages and more modern APIs exist
  - R's ggplot
  - Seaborn and others which are built on top of matplotlib
  - Web visualization toolkits based on D3js and HTML5 canvas

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How do we display plots?

- There are three applicable contexts – using Matplotlib
  1. In a script
  2. In an IPython terminal
  3. In an IPython notebook

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How do we display plots?

- There are three applicable contexts – using Matplotlib
  1. In a script
     - Use `plt.show()`, which starts an event loop, looks for all currently active figure objects, and opens one or more interactive windows that display your figure or figures.
     - The `plt.show()` command does a lot under the hood, as it must interact with your system's interactive graphical backend.
     - `plt.show()` command should be used *only once* per Python session and is most often seen at the very end of the script.
  2. In an IPython terminal
  3. In an IPython notebook

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How do we display plots?

- There are three applicable contexts – using Matplotlib
  1. In a script
  2. In an IPython terminal
     - To enable interactive mode, use the `%matplotlib` magic command after starting ipython.
     - Any `plt` plot command will cause a figure window to open, and further commands can be run to update the plot.
     - Some changes will not draw automatically. To force an update, use `plt.draw()`. Using `plt.show()` is not required.
  3. In an IPython notebook

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How do we display plots?

- There are three applicable contexts – using Matplotlib
  1. In a script
  2. In an IPython terminal
  3. In an IPython notebook
     - `%matplotlib notebook` will lead to *interactive* plots embedded within the notebook
     - `%matplotlib inline` will lead to *static* images of your plot embedded in the notebook
       - After running this command (only once per session), any cell within the notebook that creates a plot will embed a PNG image of the resulting graphic

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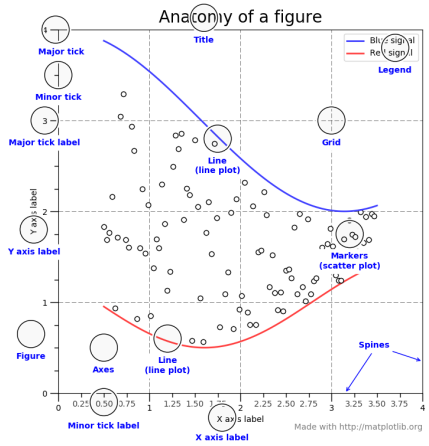
Anatomy of a figure



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Two interfaces in matplotlib

- Functional – a convenient MATLAB-style state-based interface
  - This interface is *stateful*: it keeps track of the "current" figure and axes, which are where all `plt` commands are applied.
  - You can get a reference to these using the `plt.gcf()` (get current figure) and `plt.gca()` (get current axes) routines.
  - Convenient for simple plots. Problematic, for example, once a second panel is created, how can we go back and add something to the first?
- Object Oriented – more powerful
  - This interface is available for more complicated situations, and for when more control over the figure is required.
  - Rather than depending on some notion of an "active" figure or axes, in the object-oriented interface the plotting functions are *methods* of explicit Figure and Axes objects.

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Importing matplotlib in functional interface

```
>>> import matplotlib as mpl
>>> mpl.__version__
'3.4.3'
>>> import matplotlib.pyplot as plt
```

- Understanding matplotlib's pyplot API is key to understanding how to work with plots:
  - ***matplotlib.pyplot.figure: Figure*** is the top-level container. It includes everything visualized in a plot including one or more ***Axes***.
  - ***matplotlib.pyplot.axes****: **Axes*** contain most of the elements in a plot**: *Axis, Tick, Line2D, Text,*** etc., and sets the coordinates. It is the area in which data is plotted. Axes include the x-Axis, y-Axis, and possibly a z-Axis, as well.

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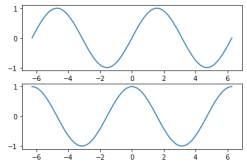
Functional interface

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

plt.figure()
plt.subplot(2, 1, 1) # (rows, columns, panel number)
x = np.linspace(-2*np.pi, 2*np.pi, 100)
plt.plot(x, np.sin(x))
# create the second panel and set current axis
plt.subplot(2, 1, 2)
plt.plot(x, np.cos(x))
```

Library with functions acting on variables and functions



plt_sin_cos_1.py

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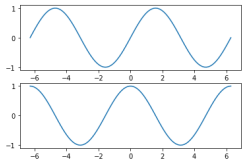
Object Oriented interface

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

fig, ax = plt.subplots(2)
x = np.linspace(-2*np.pi, 2*np.pi, 100)
ax[0].plot(x, np.sin(x))
ax[1].plot(x, np.cos(x))
```

Objects with methods acting on object



plt_sin_cos_2.py

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Line plots

- Show the change in value of an attribute with respect to a x-variable
- Can be used to visually compare the values of several related attributes

```
fig = plt.figure()
ax = plt.axes()
x = np.linspace(0, 10, 1000)
ax.plot(x, np.sin(x));
# Alternatively
plt.plot(x, np.sin(x))
```

plt_sin_cos_3.py

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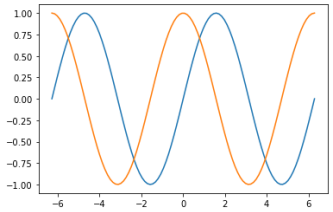
Line plots

- Show the change in value of an attribute with respect to a x-variable
- Can be used to visually compare the values of several related attributes

```
ax.plot(x, np.sin(x))
ax.plot(x, np.cos(x))
# Alternatively
plt.plot(x, np.sin(x))
plt.plot(x, np.cos(x))
```



plt_sin_cos_3.py

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Defining elements of a plot

- Plot elements add context to a plot, so the plot effectively conveys meaning to its viewers
  - You set line colors, styles, and widths to differentiate between different line objects
  - You set axes limits to make sure that your chart fits your data
  - You set axes tick marks and plot grids to make it easier and faster for the viewers to interpret your chart
  - You create a legend to label each line object
  - You can use subplots to visually compare changes in data values under different conditions, like different seasons, different locations, or in different years

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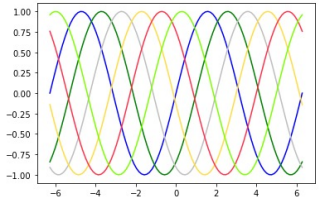
Line color

```
x = np.linspace(-2*np.pi, 2*np.pi, 100)

plt.plot(x, np.sin(x - 0), color='blue') # specify color by name
plt.plot(x, np.sin(x - 1), color='g') # short color code (rgbcmyk)
plt.plot(x, np.sin(x - 2), color='0.75') # Grayscale between 0 and 1
plt.plot(x, np.sin(x - 3), color='#FFDD44') # Hex code (RRGGBB from 00 to FF)
plt.plot(x, np.sin(x - 4), color=(1.0,0.2,0.3)) # RGB tuple, values 0 to 1
plt.plot(x, np.sin(x - 5), color='chartreuse'); # HTML color names
```



plt_sin_cos_4.py

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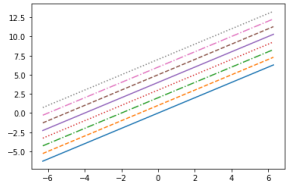
Line style

```
x = np.linspace(-2*np.pi, 2*np.pi, 100)

plt.plot(x, x + 0, linestyle='solid')
plt.plot(x, x + 1, linestyle='dashed')
plt.plot(x, x + 2, linestyle='dashdot')
plt.plot(x, x + 3, linestyle='dotted')
# For short, you can use the following codes:
plt.plot(x, x + 4, linestyle='-') # solid
plt.plot(x, x + 5, linestyle='--') # dashed
plt.plot(x, x + 6, linestyle='-.') # dashdot
plt.plot(x, x + 7, linestyle=':') # dotted
```



plt_sin_cos_5.py

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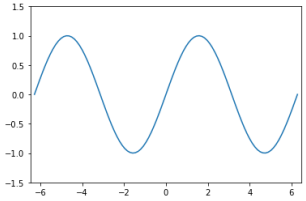
Axes limits

```
x = np.linspace(-2*np.pi, 2*np.pi, 100)

plt.plot(x, np.sin(x))
plt.xlim(-2*np.pi - 0.2, 2*np.pi + 0.2)
plt.ylim(-1.5, 1.5)
# Alternatively
#plt.axis([-2*np.pi - 0.2, 2*np.pi + 0.2, -1.5, 1.5]);
```



plt_sin_cos_6.py

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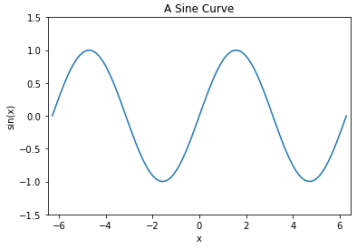
Labeling plots

```
x = np.linspace(-2*np.pi, 2*np.pi, 100)

plt.plot(x, np.sin(x))
plt.xlim(-2*np.pi - 0.2, 2*np.pi + 0.2)
plt.ylim(-1.5, 1.5)
plt.title("A Sine Curve")
plt.xlabel("x")
plt.ylabel("sin(x)")
```



plt_sin_cos_6.py

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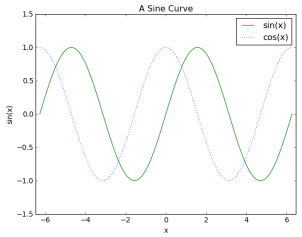
Legends

```
x = np.linspace(-2*np.pi, 2*np.pi, 100)


plt.xlim(-2*np.pi - 0.2, 2*np.pi + 0.2)
plt.ylim(-1.5, 1.5)
# Add titles & labels
plt.title("A Sine Curve")
plt.xlabel("x")
plt.ylabel("sin(x)")
# Add legends
plt.plot(x, np.sin(x), '-g', label='sin(x)')
plt.plot(x, np.cos(x), ':b', label='cos(x)')
# one unit in x is equal to one unit in y
plt.legend()
```



plt_sin_cos_7.py

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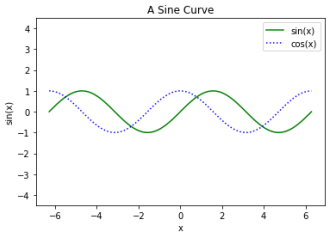
plt functions to ax methods translation

```
x = np.linspace(-2*np.pi, 2*np.pi, 100)
```

- plt.plot() → ax.plot()
- plt.legend() → ax.legend()
- but
- plt.xlabel() → ax.set_xlabel()
- plt.ylabel() → ax.set_ylabel()
- plt.xlim() → ax.set_xlim()
- plt.ylim() → ax.set_ylim()
- plt.title() → ax.set_title()



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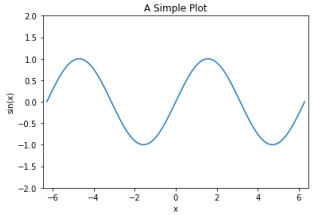
Set all properties at once

```
x = np.linspace(-2*np.pi, 2*np.pi, 100)


ax = plt.axes()
ax.plot(x, np.sin(x))
ax.set(xlim=(0, 10), ylim=(-2, 2), xlabel='x',
       ylabel='sin(x)', title='A Simple Plot')
```



plt_sin_cos_8.py

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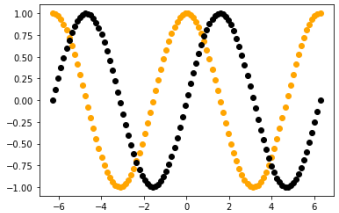
Scatter plot using scatter

```
x = np.linspace(-2*np.pi, 2*np.pi, 100)


y1 = np.sin(x)
y2 = np.cos(x)
plt.plot(x, y1, 'o', color='black')
plt.scatter(x, y2, marker='o', color='orange')
```



plt_sin_cos_9.py

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Scatter plot using scatter

- The primary difference of `plt.scatter()` from `plt.plot()` is that it can be used to create scatter plots where the properties of each individual point (size, fill color, edge color, etc.) can be individually controlled or mapped to data.

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

cm =['viridis', 'plasma', 'inferno', 'magma', 'cividis']
rng = np.random.RandomState(seed=int(t.time()))
x = rng.randn(100)
y = rng.randn(100)
colors = rng.rand(100)
sizes=1000*rng.rand(100)
plt.scatter(x,y,c=colors,s=sizes,alpha=0.3,cmap=cm[rng.randint(4)])
plt.colorbar() # show color scale
```

plt_scatter.py

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Plot or Scatter?

- `plt.scatter()` is more powerful and has the capability to render a different size and/or color for each point
- `plt.plot()` is more efficient for datasets with larger than a few thousand points, as the appearance of the points is the same for the entire dataset

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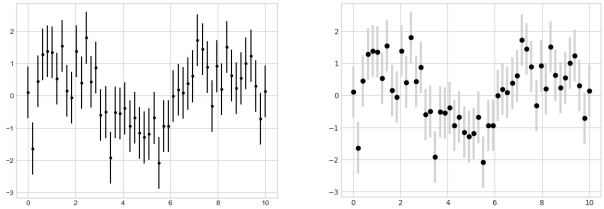
Plotting Error Bars

```
# Plotting Error Bars
>>> plt.style.use('seaborn-whitegrid')
>>> x = np.linspace(0, 10, 50)
>>> dy = 0.8
>>> y = np.sin(x) + dy * np.random.randn(50)
>>> plt.errorbar(x, y, yerr=dy, fmt='.k')
```



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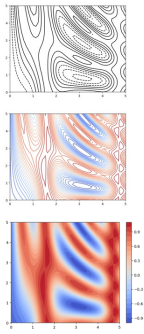
Contour Plots

```
>>> # Contour plots
>>> def f(x, y):
        return np.sin(x) ** 10 + np.cos(10 + y * x) * np.cos(x)

>>> x = np.linspace(0, 5, 50)
>>> y = np.linspace(0, 5, 40)

>>> X, Y = np.meshgrid(x, y) # Create 2D grid
>>> Z = f(X, Y)
>>> plt.contour(X, Y, Z, colors='black')
>>> plt.show()
>>> plt.contour(X, Y, Z, 20, cmap='coolwarm')
>>> plt.show()
>>> plt.contourf(X, Y, Z, 20, cmap='coolwarm')
>>> plt.colorbar()
>>> plt.show()
```



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Contour Plots Exercise

- Write a script which draws a contour plot (of your choice) for the following function:

$$f(x,y) = \cos\left(\frac{x}{2}\right) + \sin\left(\frac{y}{4}\right)$$

- for the range

- x: $x \in (0, 50, 2)$
- y: $y \in (0, 50, 3)$

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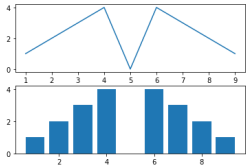
Bar plots

- Represents data attribute values within a particular data category by using bars of different heights
- Bar charts represent observation counts within categories



```
import matplotlib.pyplot as plt

plt.figure()
x = range(1,10)
y = [1,2,3,4,0,4,3,2,1]
plt.subplot(2, 1, 1) # (rows, columns, panel number)
plt.plot(x,y)
plt.subplot(2, 1, 2) # (rows, columns, panel number)
plt.bar(x, y)
```

plt_bar.py

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Bar plots

```
plt.figure()
x = range(1,10)
# Index 4 and 6 demonstrate overlapping cases
x1 = [1, 3, 4, 5, 6, 7, 9]
y1 = [4, 7, 2, 4, 7, 8, 3]
x2 = [2, 4, 6, 8, 10]
y2 = [5, 6, 2, 6, 2]
plt.bar(x1, y1, label='Blue Bar', color='b')
plt.bar(x2, y2, label='Green Bar', color='g')
plt.xlabel("bar number")
plt.ylabel("bar height")
plt.title("Bar Chart")
plt.legend()
```

plt_bar.py

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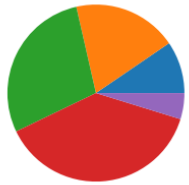
Pie charts

- Represents data attribute values using a circle and slices that comprise it
- A whole and entire set of categorical data is represented by the complete circle, and the proportions of observations that fall into the different categories are represented by proportionate pie slices

```
x = [1, 2, 3, 4, 0.5]
plt.pie(x)
plt.show()
```



plt_pie.py

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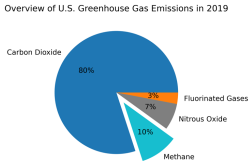
Pie charts

```
import matplotlib.pyplot as plt

fig = plt.figure()
x = [80, 10, 7, 3] # Raw data
labels = ['Carbon Dioxide', 'Methane', 'Nitrous Oxide',
          'Fluorinated Gases']
colors = ['tab:blue', 'tab:cyan', 'tab:gray', 'tab:orange']
explode = [0, 0.2, 0, 0]
fig, ax = plt.subplots()
ax.pie(x, labels = labels, colors = colors, autopct='%.0f%%',
explode = explode)
ax.set_title('Overview of U.S. Greenhouse Gas Emissions in 2019')
fig.savefig('greenhouse.png', dpi=600)
```



plt_pie.py

https://www.epa.gov/ghgemissions/overview-greenhouse-gases

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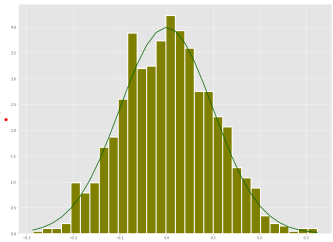
Histograms

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

mu, sigma = 0, 0.1 # mean and st. dev.
s = np.random.normal(mu, sigma, 1000)
nbins = 30
st.use('ggplot') # return grid
plt.figure(figsize = (16,12))
count, bins, ignored = plt.hist(s, nbins, density=True, color='olive')
plt.plot(bins, 1/(sigma * np.sqrt(2 * np.pi)) *
         np.exp( - (bins - mu)**2 / (2 * sigma**2) ),
         linewidth=2, color='darkgreen')
```



plt_hist.py

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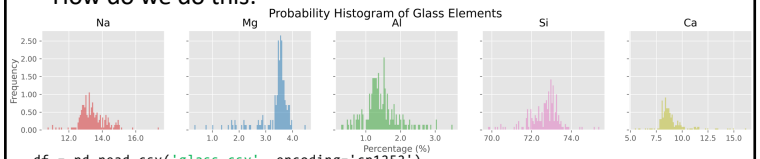
Histograms

- How do we do this:




```
df = pd.read_csv('glass.csv', encoding='cp1252')
…
elements = ['Na', 'Mg', 'Al', 'Si', 'Ca']
fig, axes = plt.subplots(1, 5, figsize=(17.5,2.5), dpi=600, sharex=False, sharey=True)
colors = ['tab:red', 'tab:blue', 'tab:green', 'tab:pink', 'tab:olive']
for i in range(len(elements)):
    na_data = df[elements[i]].values
    axes[i].hist(na_data, alpha=0.5, bins=100, density=True, stacked=True,
                 label=elements[i], color=colors[i])
    axes[i].set_title(elements[i])
…
axes[0].set_ylabel("Frequency"); axes[2].set_xlabel("Percentage (%)")
```

plt_hist_periodic_table.py

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Pandas and matplotlib – other plot types

- Plotting methods allow for a handful of plot styles other than the default line plot. These methods can be provided as the kind keyword argument to plot(), and include:
- 'bar' or 'barh' for bar plots
- 'hist' for histogram
- 'box' for boxplot
- 'kde' or 'density' for density plots
- 'area' for area plots
- 'scatter' for scatter plots
- 'hexbin' for hexagonal bin plots
- 'pie' for pie plots

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Plotting with missing data

- Pandas tries to be pragmatic about plotting DataFrames or Series that contain missing data.
- Missing values are dropped, left out, or filled depending on the plot type.
- If any of these defaults are not what you want, or you want to be explicit about how missing values are handled, consider fillna() or dropna() before plotting.

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Plotting with missing data

Plot Type	NaN Handling
Line	Leave gaps at NaNs
Line (stacked)	Fill 0's
Bar	Fill 0's
Scatter	Drop NaNs
Histogram	Drop NaNs (column-wise)
Box	Drop NaNs (column-wise)
Area	Fill 0's
KDE	Drop NaNs (column-wise)
Hexbin	Drop NaNs
Pie	Fill 0's

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Matplotlib drawbacks

- Prior to version 2.0, Matplotlib's defaults are not exactly the best choices. It was based off of MATLAB circa 1999, and this often shows.
- Matplotlib's API is relatively low level. Doing sophisticated statistical visualization is possible, but often requires a *lot* of boilerplate code.
- Matplotlib predated Pandas by more than a decade, and thus is not designed for use with Pandas DataFrames.
  - In order to visualize data from a Pandas DataFrame, you must extract each Series and often concatenate them together into the right format.

It would be nicer to have a plotting library that can intelligently use the DataFrame labels in a plot…

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