Matplotlib: Python Plotting

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Matplotlib: Python Plotting

- Overview
  - Anatomy of a figure
    - Figures and axes
  - 2D plotting
    - Standard line plotting
    - Other plotting + text annotation
  - 3D plotting
    - 3D axes + 3D line/surface plotting
  - Other plotting
    - Contours + image visualization

Matplotlib: Python Plotting

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- Matplotlib
  - Mathematical plotting library
  - Python extension for graphics
    - Suited for visualization of data and creation of high-quality figures
    - Extensive package for 2D plotting, and add-on toolkits for 3D plotting
    - **Pyplot**: MATLAB-like procedural interface to the object-oriented API
  - Import convention

```
from matplotlib import pyplot as plt
import matplotlib.pyplot as plt
```

Matplotlib: Python Plotting

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- Matplotlib
  - Mathematical plotting library
  - Interactive matplotlib sessions
    - IPython console

```
%matplotlib
```

    - Jupyter notebook

```
%matplotlib inline
%matplotlib notebook
```

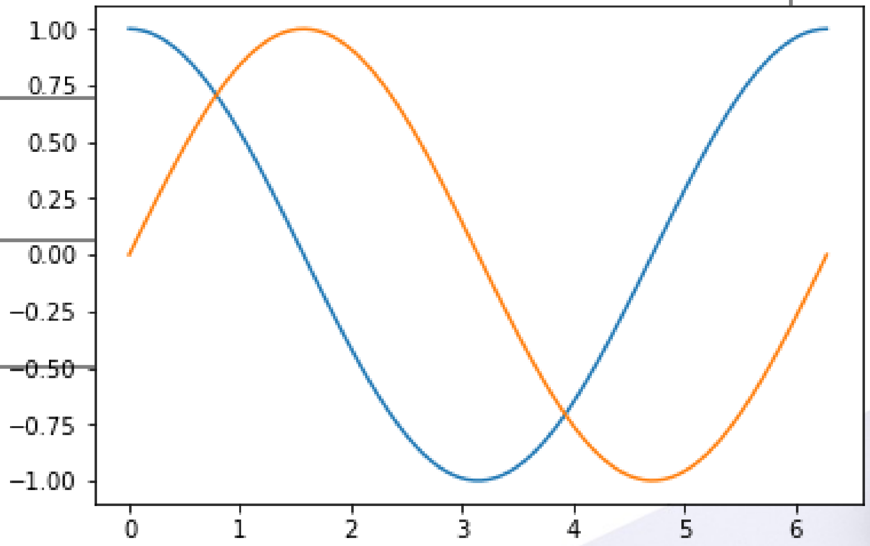
Matplotlib: Python Plotting

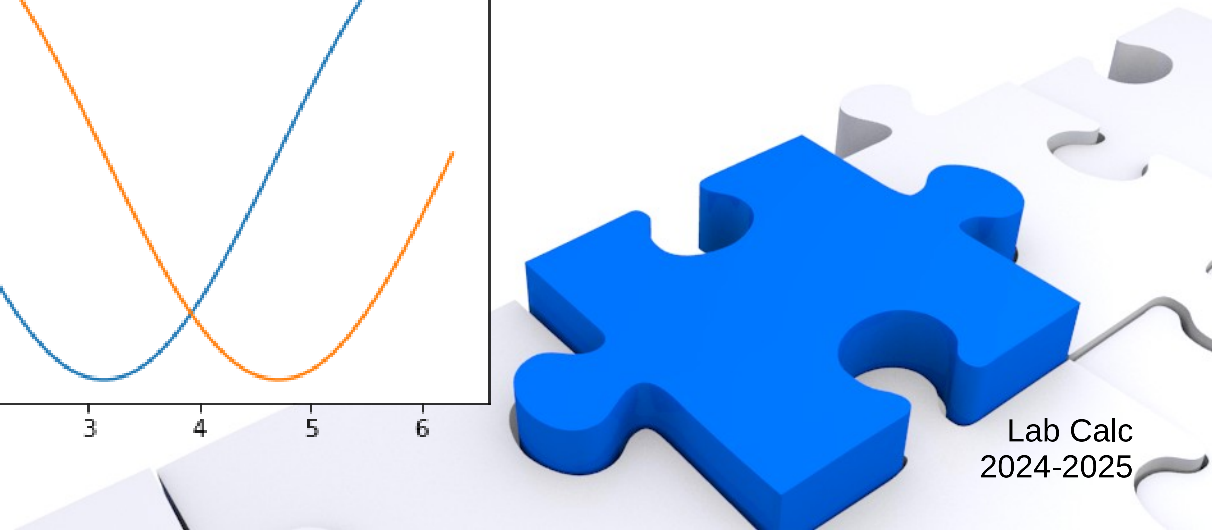
- A simple plot
  - Syntax is array-based

```
In [1]: x = np.linspace(0, 2.0*np.pi, 100)
In [2]: cx, sx = np.cos(x), np.sin(x)
In [3]: plt.plot(x, cx)
   ...: plt.plot(x, sx)
```

  - If not interactive, also write:

```
   ...: plt.show()
```





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- A simple plot
  - Default settings (see also `plt.rcParams`)

```
In [3]: plt.figure(figsize=(6.0, 4.0), dpi=72.0)
   ...: plt.subplot(1, 1, 1)
   ...: plt.plot(x, cx, color='#1f77b4',
   ...:          linewidth=1.5, linestyle='-')
   ...: plt.plot(x, sx, color='#ff7f0e',
   ...:          linewidth=1.5, linestyle='-')
   ...: plt.xlim(-0.1*np.pi, 2.1*np.pi)
   ...: plt.xticks(np.linspace(0, 6, 7))
   ...: plt.ylim(-1.1, 1.1)
   ...: plt.yticks(np.linspace(-1, 1, 9))
```

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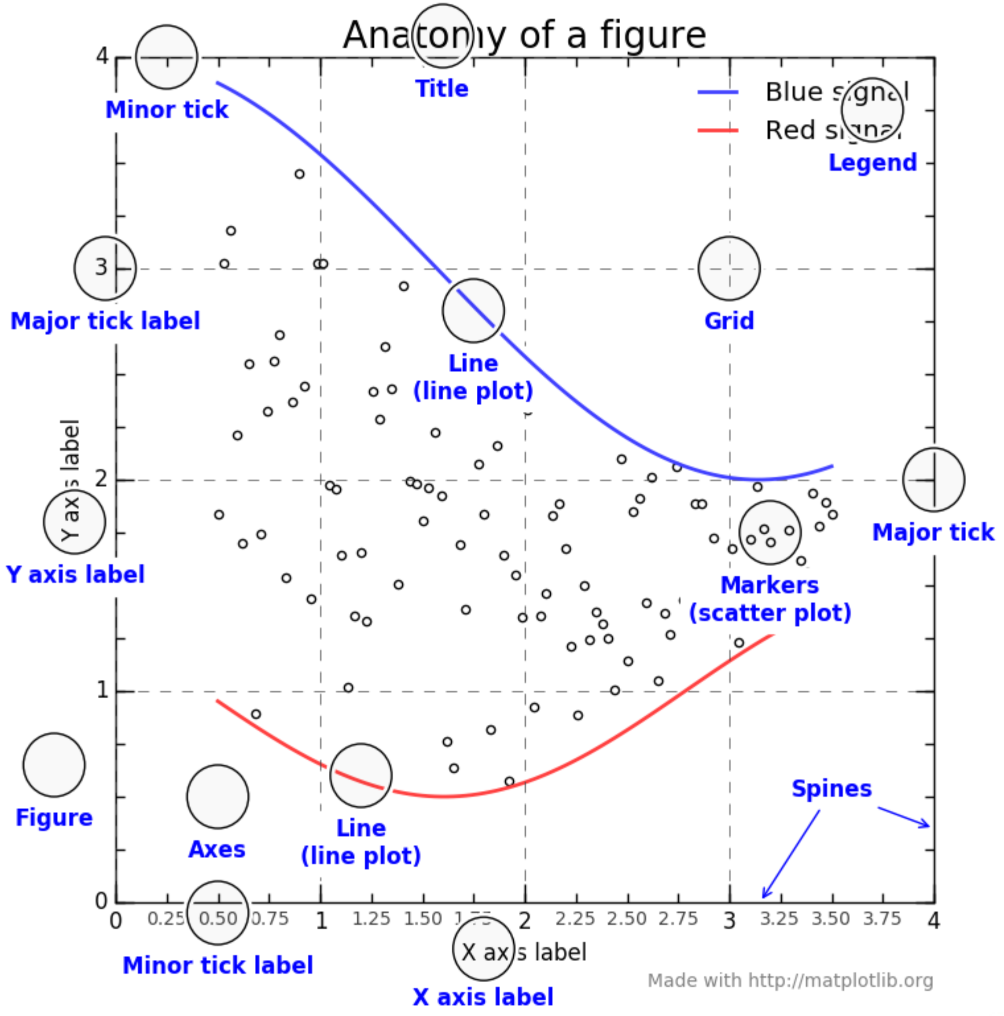
- Anatomy



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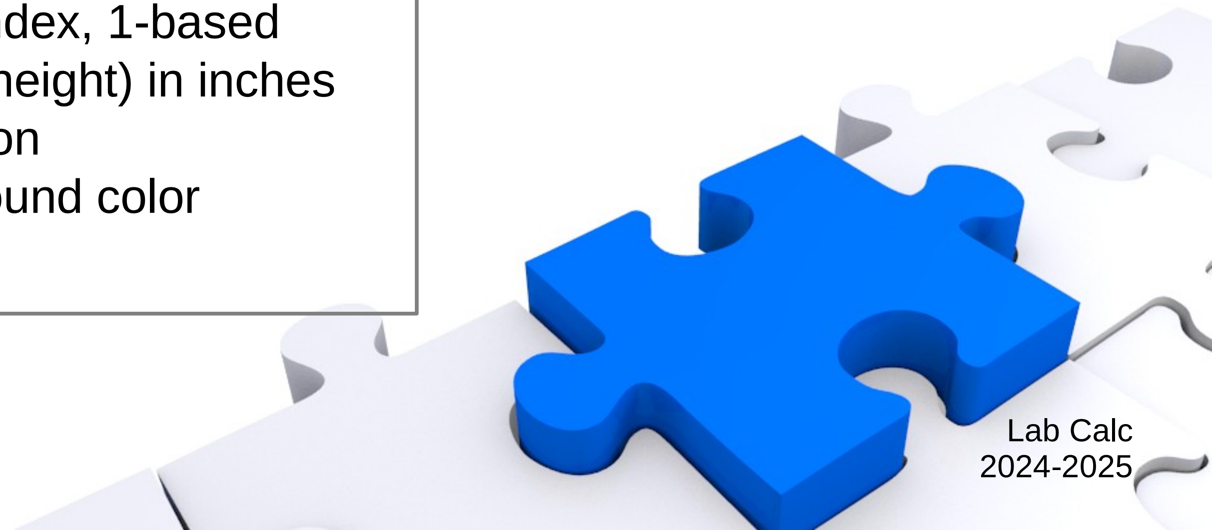
- Anatomy
  - Hierarchical structure
  - Figure
    - The overall window on which everything is drawn
    - Components: one or more axes, suptitle, ...

```
plt.figure(num=None,
           figsize=None,
           dpi=None,
           facecolor=None,
           ...)
```

figure index, 1-based
(width, height) in inches
resolution
background color



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- Anatomy
  - Axes
    - The area on which the data is plotted
    - Belongs to a figure, placed arbitrarily (`axes`) or in grid (`subplot`)
    - Components: x/y-axis, ticks, spines, labels, title, legend, ...
    - All methods of active axes are directly callable via Pyplot interface

```
plt.axes((left, bottom, width, height), **kwargs)
plt.subplot(nrows, ncols, index, **kwargs)
**kwargs: facecolor=None, polar=False, ...
```

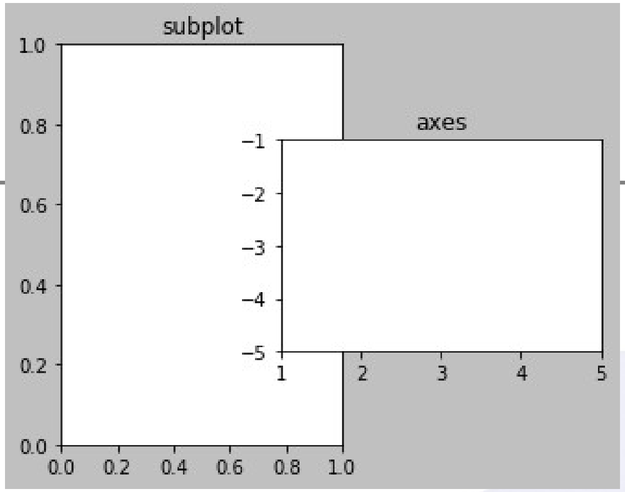
Matplotlib: Python Plotting

- Anatomy
  - Axes components
    - Get or set limits: `plt.xlim`, `plt.ylim`, `plt.axis`
      - `left, right = plt.xlim()`
      - `plt.xlim(left, right)`
      - `plt.axis((left, right, bottom, top)), plt.axis('equal')`
    - Get or set ticks: `plt.xticks`, `plt.yticks`
      - `locs, labels = plt.xticks()`
      - `plt.xticks(np.arange(3), ('a', 'b', 'c'))`
    - Set labels: `plt.xlabel(txt), plt.ylabel(txt)`
    - Set title: `plt.title(txt)`
    - Others: `plt.box(), plt.grid(), ...`

Matplotlib: Python Plotting

- Anatomy
  - Example

```
In [1]: plt.figure(facecolor='silver')
   ...: plt.subplot(1, 2, 1)
   ...: plt.title('subplot')
   ...: plt.axes((0.4, 0.3, 0.4, 0.4))
   ...: plt.xlim(1, 5)
   ...: plt.ylim(-5, -1)
   ...: plt.title('axes')
```



Matplotlib: Python Plotting

- 2D plotting
  - Standard line plotting: basic syntax

```
plt.plot(y)
plt.plot(x, y)
plt.plot(x, y, 'clm')
```

- Connect data points (x, y) with optional format string
- Color (c): `b, g, r, c, m, y, k, w`
- Linestyle (l): `-, --, -., :`
- Marker (m): `o, *, ., +, x, s, d, ^, <, >, p, h, ...`

Matplotlib: Python Plotting

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- 2D plotting
  - Standard line plotting: advanced syntax

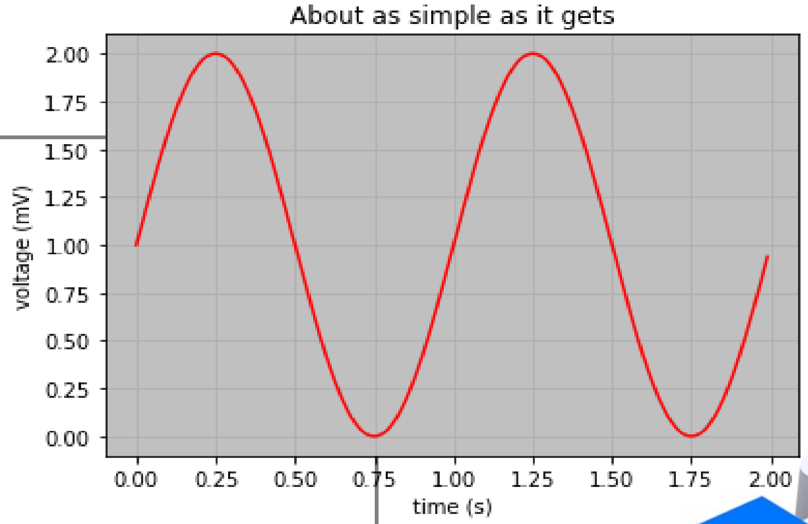
```
plt.plot(x, y, **kwargs)
**kwargs: color, linestyle, linewidth, marker,
          markeredgecolor, markeredgewidth,
          markerfacecolor, markersize, label, ...
```

  - Multiple plots per axes possible
  - Legend:

```
plt.legend(('a', 'b', 'c'), loc='upper right')
```

Matplotlib: Python Plotting

- 2D plotting
  - For full plot details, check out `plt.plot?`
  - Example

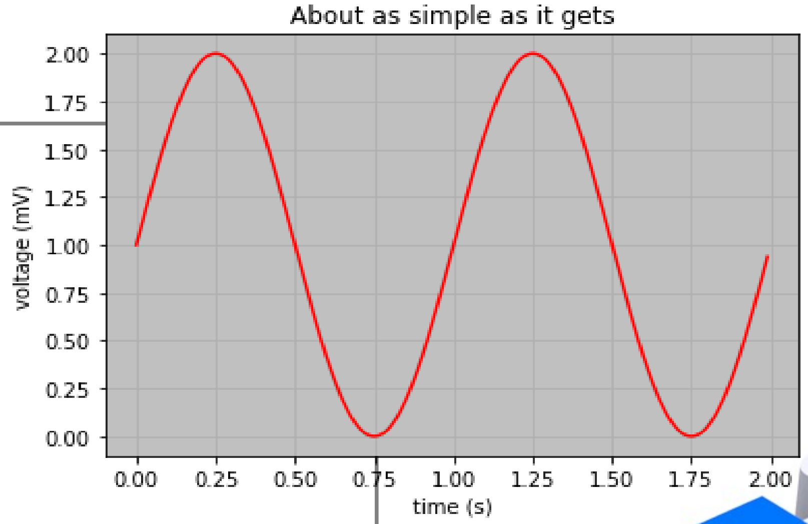



```
In [1]: t = np.arange(0.0, 2.0, 0.01)
   ...: s = 1.0 + np.sin(2.0*np.pi*t)
In [2]: plt.axes(facecolor='silver')
   ...: plt.plot(t, s, 'r')
   ...: plt.xlabel('time (s)')
   ...: plt.ylabel('voltage (mV)')
   ...: plt.title('About as simple as it gets')
   ...: plt.grid()
```

Matplotlib: Python Plotting

- 2D plotting
  - Plotting methods are actually connected to axes
    - Pyplot provides an interface to the active axes

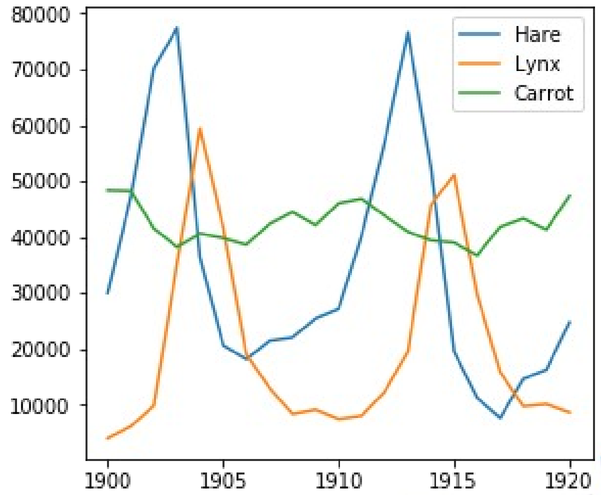
```
In [1]: t = np.arange(0.0, 2.0, 0.01)
   ...: s = 1.0 + np.sin(2.0*np.pi*t)
In [2]: ax = plt.axes()
   ...: ax.plot(t, s, 'r')
   ...: ax.set(facecolor='silver',
   ...:        xlabel='time (s)',
   ...:        ylabel='voltage (mV)',
   ...:        title='About as simple as it gets')
   ...: ax.grid()
```



Matplotlib: Python Plotting

- 2D plotting
  - Example: data statistics
    - Data in the file “populations.txt” describes the populations of hares, lynxes and carrots in northern Canada during 20 years

```
# year   hare     lynx    carrot
1900     30e3     4e3     48300
1901     47.2e3   6.1e3   48200
1902     70.2e3   9.8e3   41500
...
```

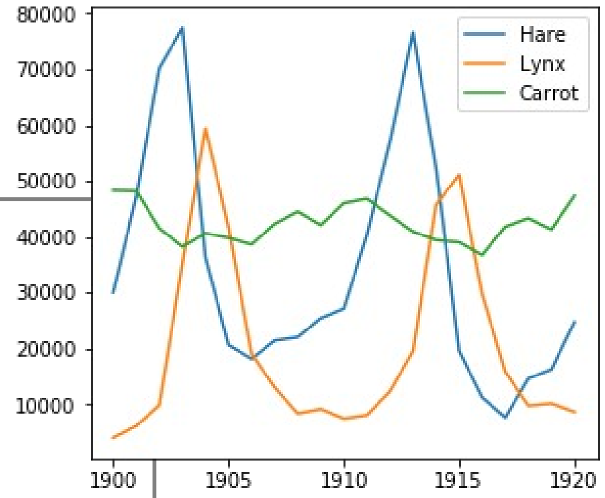


    - Load the data and plot it
    - Compute the mean populations over time
    - Which species has the highest population each year?

Matplotlib: Python Plotting

- 2D plotting
  - Example: data statistics
    - Load the data and plot it

```
In [1]: data = np.loadtxt('populations.txt')
In [2]: year, hares, lynxes, carrots = data.T
In [3]: plt.axes((0.2, 0.1, 0.6, 0.8))
   ...: plt.plot(year, hares)
   ...: plt.plot(year, lynxes)
   ...: plt.plot(year, carrots)
   ...: plt.xticks(np.arange(1900, 1921, 5))
   ...: plt.yticks(np.arange(1, 9) * 10000)
   ...: plt.legend(('Hare', 'Lynx', 'Carrot'))
```



Matplotlib: Python Plotting

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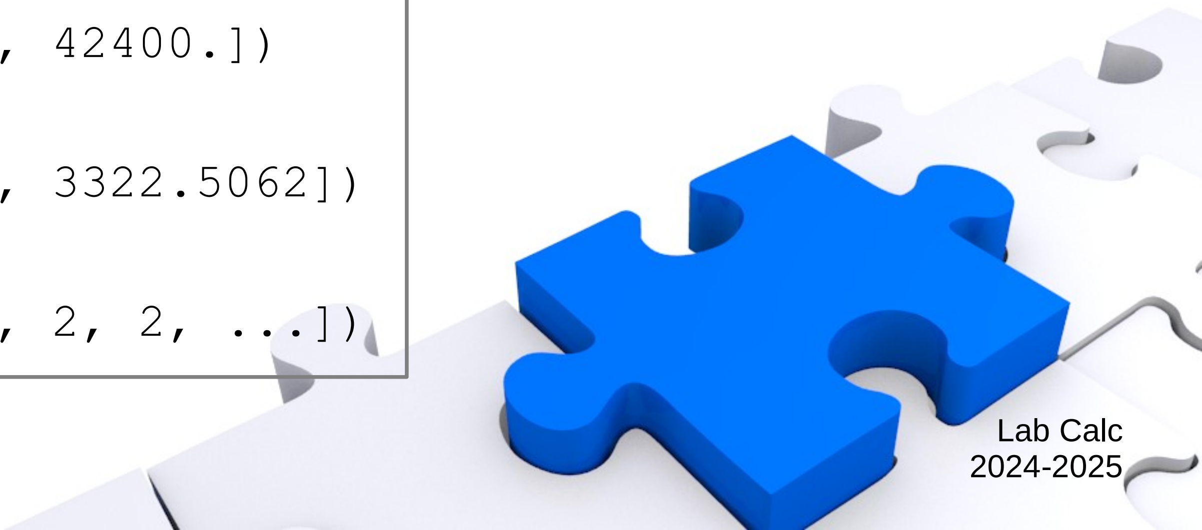
- 2D plotting
  - Example: data statistics
    - Compute the mean populations over time
    - Which species has the highest population each year?

```
In [4]: populations = data[:, 1:]
In [5]: populations.mean(axis=0)
Out[5]: array([34080.9524, 20166.6667, 42400.])
In [6]: populations.std(axis=0)
Out[6]: array([20897.9065, 16254.5915, 3322.5062])
In [7]: populations.argmax(axis=1)
Out[7]: array([2, 2, 0, 0, 1, 1, 2, 2, 2, 2, ...])
```



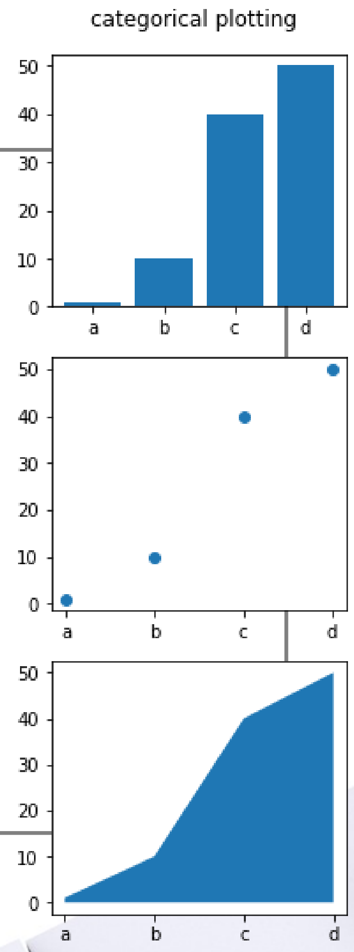
Matplotlib: Python Plotting

- 2D plotting
  - Other plotting
    - Log plots: `plt.loglog(x, y)`, `plt.semilogx(x, y)`, `plt.semilogy(x, y)`
    - Polar plots: `plt.polar(theta, r)`
    - Scatter plots: `plt.scatter(x, y)`
    - Bar graphs: `plt.bar(x, height)`, `plt.barh(y, width)`
    - Pie charts: `plt.pie(x)`
    - Histogram: `plt.hist(x, bins=None)`
    - Filled curves: `plt.fill(x, y)`, `plt.fill_between(x, y1, y2=0)`
  - For full `method` details, check out `plt.method?`

Matplotlib: Python Plotting

- 2D plotting
  - Example

```
In [1]: names = ['a', 'b', 'c', 'd']
   ...: values = [1, 10, 40, 50]
In [2]: plt.figure(figsize=(3, 9))
   ...: plt.subplot(3, 1, 1)
   ...: plt.bar(names, values)
   ...: plt.subplot(3, 1, 2)
   ...: plt.scatter(names, values)
   ...: plt.subplot(3, 1, 3)
   ...: plt.fill_between(names, values)
   ...: plt.suptitle(
   ...:    'categorical plotting', y=0.92)
```



Matplotlib: Python Plotting

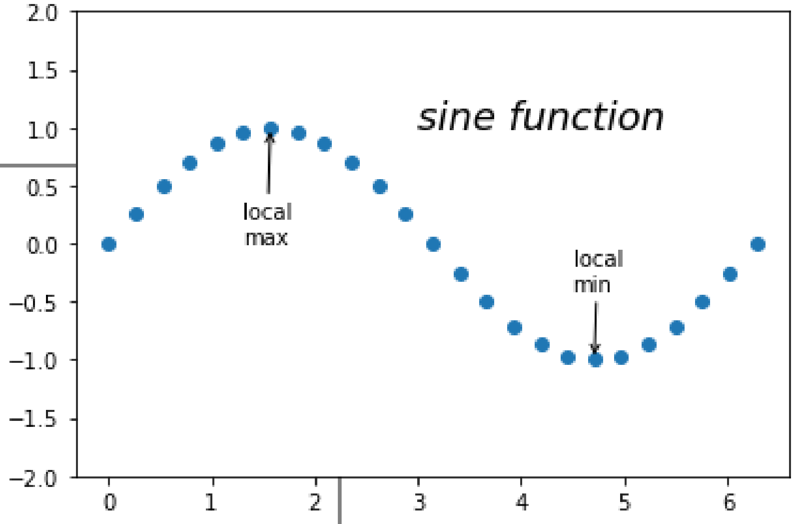
- 2D plotting
  - Text
    - Axes text: `plt.title(txt), plt.xlabel(txt), plt.ylabel(txt)`
    - Plain text: `plt.text(x, y, txt)`
    - Annotation: `plt.annotate(txt, xy=(x, y), xytext=(xt, yt), arrowprops={'arrowstyle':'->'})`
    - Extensive math rendering engine
      - Support for TeX markup inside dollar signs ($)
      - Use raw strings (precede the quotes with an 'r')

```
plt.title('alpha > beta')          # normal text
plt.title(r'$\alpha > \beta$')     # math text
```

Matplotlib: Python Plotting

- 2D plotting
  - Example

```
In [1]: x = np.linspace(0, 2.0*np.pi, 25)
In [2]: plt.scatter(x, np.sin(x))
   ...: plt.ylim(-2, 2)
   ...: plt.text(3, 1, 'sine function',
   ...:   fontsize=18, style='italic')
   ...: plt.annotate('local\nmax',
   ...:   xy=(np.pi/2.0, 1), xytext=(1.3, 0),
   ...:   arrowprops={'arrowstyle':'->'})
   ...: plt.annotate('local\nmin',
   ...:   xy=(np.pi*3.0/2.0, -1), xytext=(4.5, -0.4),
   ...:   arrowprops={'arrowstyle':'->'})
```



Matplotlib: Python Plotting

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- 3D plotting
  - Module `mplot3d`
    - This toolkit adds simple 3D plotting to matplotlib with same “look-and-feel”
    - It supplies an axes object that can create a 2D projection of a 3D scene

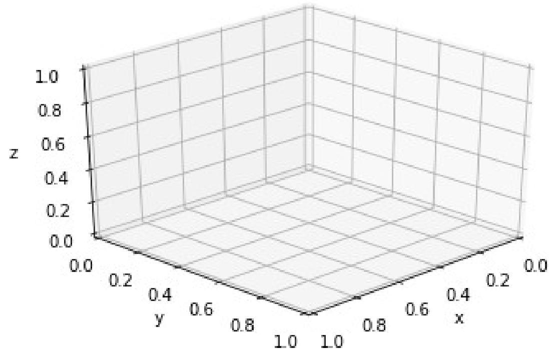
```
from mpl_toolkits import mplot3d
```

  - Creation of 3D axes object
    - Use `ax = mplot3d.Axes3D(fig)`
    - Use any standard axes creation method with keyword `projection='3d'`
      - `ax = plt.subplot(111, projection='3d')`

Matplotlib: Python Plotting

- 3D plotting
  - 3D axes properties
    - Z-axis: `ax.set(..., zlabel='z', zticks=(-1,0,1))`
    - Orientation: `ax.view_init(elev=30, azim=45)`

```
In [1]: ax = plt.axes(projection='3d')
   ...: ax.view_init(elev=30, azim=45)
   ...: ax.set(xlabel='x', ylabel='y', zlabel='z')
```



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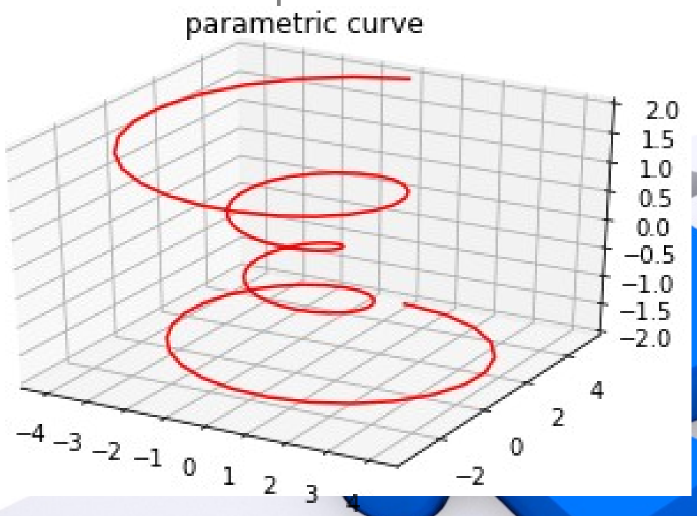
- 3D plotting
  - Natural plot extensions
    - Line plots: `ax.plot(x, y, z)`, `ax.plot3D(x, y, z)`
    - Scatter plots: `ax.scatter(x, y, z)`, `ax.scatter3D(x, y, z)`

```
In [1]: theta = np.linspace(-4*np.pi, 4*np.pi, 100)
   ...: z = np.linspace(-2, 2, 100)
   ...: r = z**2 + 1
   ...: x = r * np.sin(theta)
   ...: y = r * np.cos(theta)
In [2]: ax = plt.axes(projection='3d')
   ...: ax.plot(x, y, z, 'r')
   ...: ax.set(title='parametric curve')
```



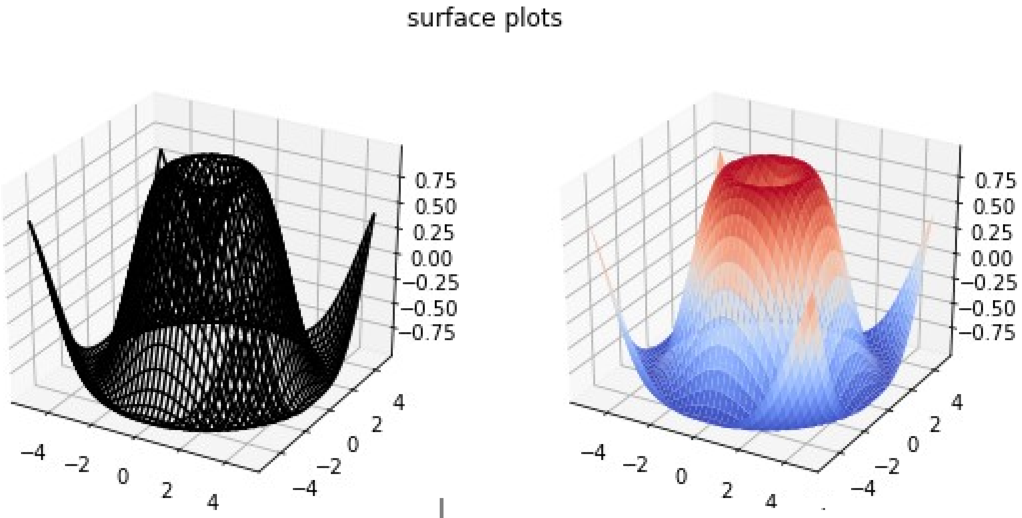
Matplotlib: Python Plotting

- 3D plotting
  - Surface plotting
    - Wireframe plot: `ax.plot_wireframe(X, Y, Z)`
    - Surface plot: `ax.plot_surface(X, Y, Z)`
  - Surface options
    - Create coordinate matrices from coordinate vectors
      - `X, Y = np.meshgrid(x, y, sparse=False, copy=True)`
    - Color maps: mapping between numeric values and colors
      - Use keyword `cmap`
      - Manipulated via module `matplotlib.cm`
      - Examples: jet, hot, coolwarm, bone, . . .

Matplotlib: Python Plotting

- 3D plotting
  - Example

```
In [1]: x = np.arange(-5, 5, 0.25)
   ...: y = np.arange(-5, 5, 0.25)
   ...: X, Y = np.meshgrid(x, y)
   ...: R = np.sqrt(X**2 + Y**2)
   ...: Z = np.sin(R)
In [2]: plt.figure(figsize=(10, 4))
   ...: plt.suptitle('surface plots')
   ...: ax1 = plt.subplot(1, 2, 1, projection='3d')
   ...: ax1.plot_wireframe(X, Y, Z, color='black')
   ...: ax2 = plt.subplot(1, 2, 2, projection='3d')
   ...: ax2.plot_surface(X, Y, Z, cmap='coolwarm')
```



Matplotlib: Python Plotting

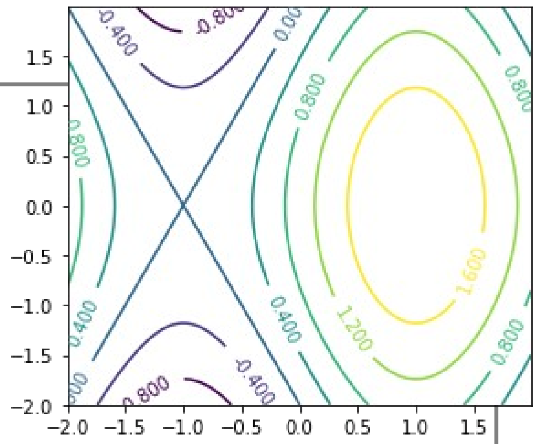
- Contour plotting
  - Contour lines: basic syntax

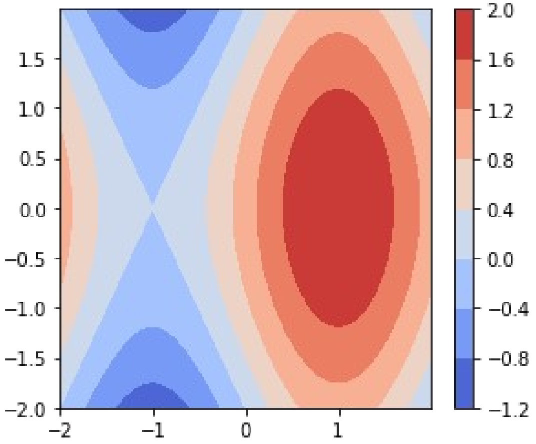
```
plt.contour(Z)
plt.contour(X, Y, Z)
plt.contour(X, Y, Z, levels)
```

  - Other contour functions:
    - Filled contours: `plt.contourf(X, Y, Z, levels)`
    - Contour identification: `plt.clabel(cs), plt.colorbar(cs)`
    - 3D contour lines (mplot3d): `ax.contour(X, Y, Z, levels)`

- Contour plotting
  - Example

```
In [1]: t = np.arange(-2, 2, 0.01)
   ...: X, Y = np.meshgrid(t, t)
   ...: Z = np.sin(X * np.pi / 2)
   ...:   + np.cos(Y * np.pi / 4)
In [2]: plt.figure(figsize=(10, 4))
   ...: plt.subplot(1, 2, 1)
   ...: cs = plt.contour(X, Y, Z)
   ...: plt.clabel(cs)
   ...: plt.subplot(1, 2, 2)
   ...: cs = plt.contourf(X, Y, Z, cmap='coolwarm')
   ...: plt.colorbar(cs)
```





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- Image plotting
  - Image
    - A matrix of color intensities (via color map)
    - A matrix of RGB or RGBA colors (3D array of dept = 3 or 4)
  - Image plots: basic syntax

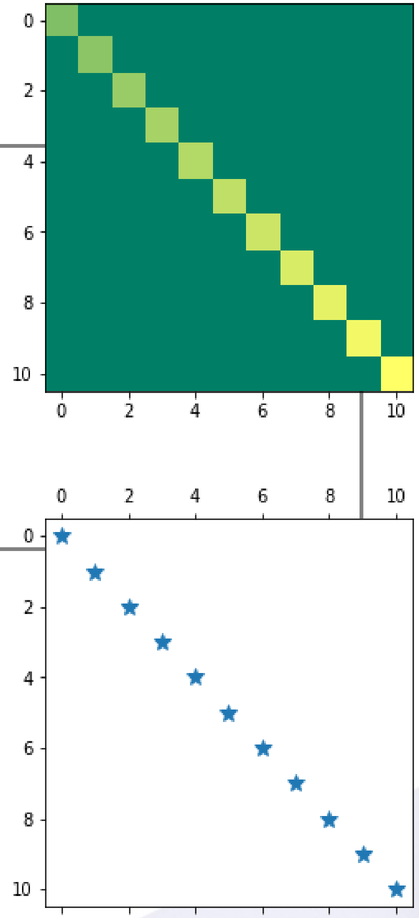
```
plt.imshow(img)
```

  - Other matrix visualization:
    - Matrix values: `plt.matshow(A)`
    - Matrix sparsity: `plt.spy(A)`

Matplotlib: Python Plotting

- Image plotting
  - Example

```
In [1]: A = np.diag(np.arange(10, 21))
In [2]: plt.figure(figsize=(10, 4))
   ...: plt.subplot(2, 1, 1)
   ...: plt.imshow(A, cmap='summer')
   ...: plt.subplot(2, 1, 2)
   ...: plt.spy(A, marker='*')
```



Matplotlib: Python Plotting

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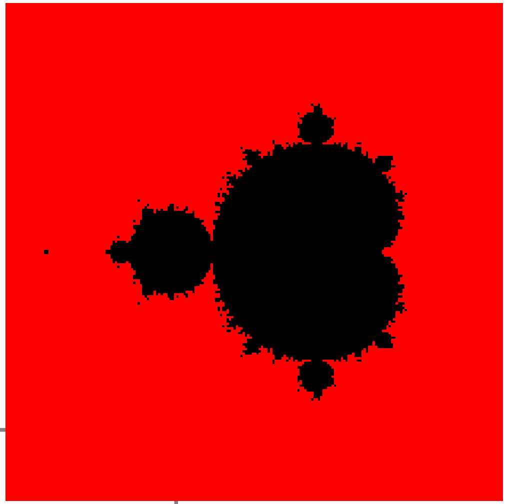
- Image plotting
  - Example: Mandelbrot set
    - Fractal set of complex numbers
    - Definition: any c for which $z_{i+1} = z_i^2 + c$ does not diverge, starting from $z_0 = 0$
    - Property: $\lim_{i\to\infty} \sup | z_{i+1} | \leq 2$ for any valid c



```
In [1]: def mandelbrot(nx, ny, max_it=20):
   ...:     # TODO
   ...:     return M
In [2]: M = mandelbrot(501, 501, 50)
   ...: plt.imshow(M.T, cmap='flag')
   ...: plt.axis('off')
```

Matplotlib: Python Plotting

- Image plotting
  - Example: Mandelbrot set

```
In [1]: def mandelbrot(nx, ny, max_it=20):
   ...:     x = np.linspace(-2.0, 1.0, nx)
   ...:     y = np.linspace(-1.5, 1.5, ny)
   ...:     C = x[:,np.newaxis]
   ...:         + 1.0j*y[np.newaxis,:]
   ...:     Z = C.copy()
   ...:     M = np.ones((nx, ny), dtype=bool)
   ...:     for i in range(max_it):
   ...:         Z[M] = Z[M]**2 + C[M]
   ...:         M[np.abs(Z) > 2] = False
   ...:     return M
```

Matplotlib: Python Plotting

- Colors
  - Predefined colors
    - abbreviation: b, g, r, c, m, y, k, w
    - full name: blue, green, red, cyan, magenta, yellow, black, white, ...
  - RGB/RGBA code
    - tuple of three or four float values in [0, 1]
    - a hexadecimal RGB or RGBA string
  - Black and white
    - string representation of a float value in [0, 1]
  - All string specifications of color are case-insensitive

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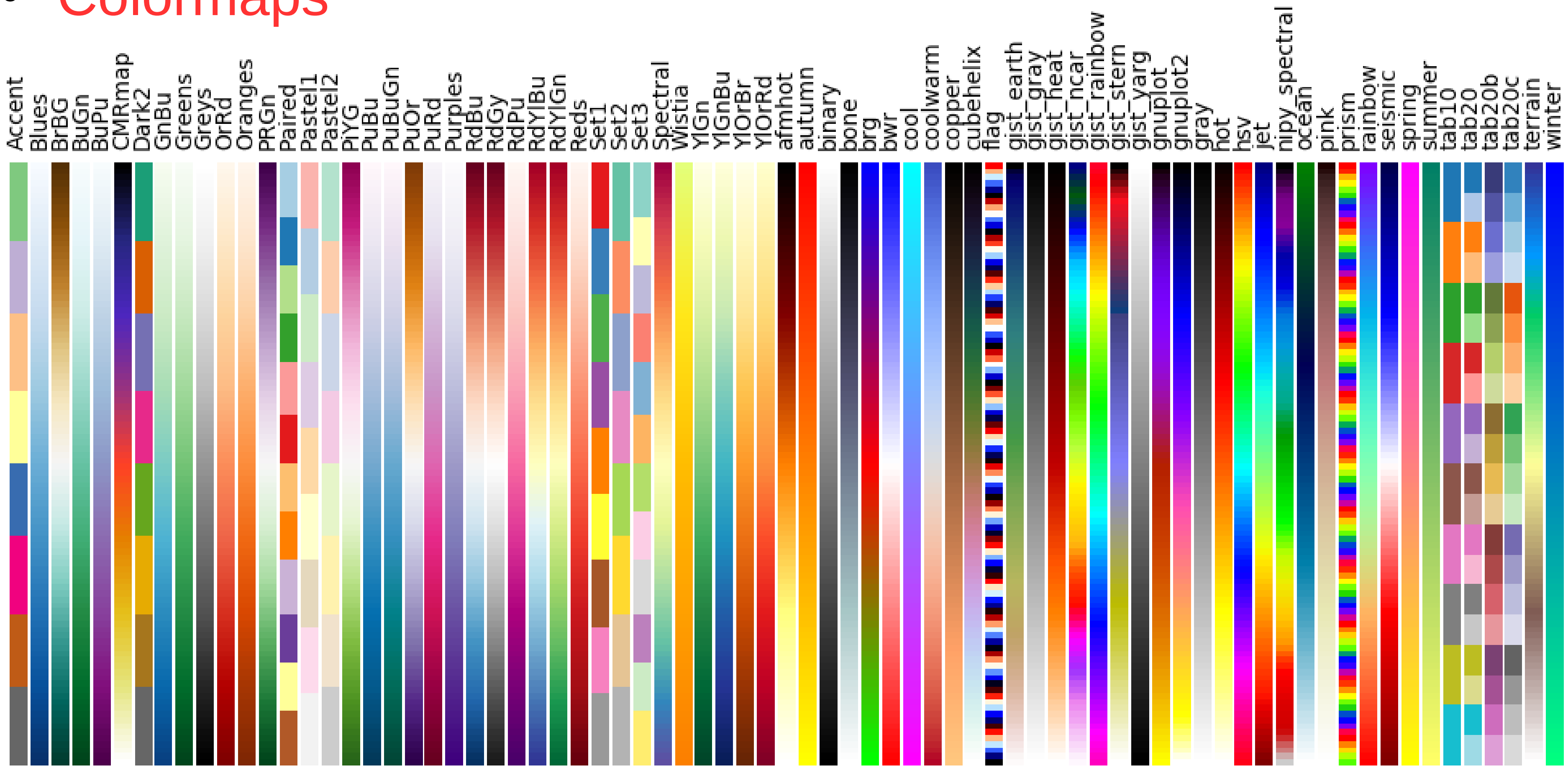
- Colormaps



Matplotlib: Python Plotting

- Input and output
  - Save figures

```
In [1]: plt.plot([1, 2, 4, 2])
   ...: plt.savefig('plot.png', format='png')
```

    - Most backends support png, pdf, eps, svg

  - Image I/O

```
In [1]: img = plt.imread('elephant.png')
In [2]: plt.imshow(img)
In [3]: plt.imsave('new_elephant.png', img)
```