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

- 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

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

```
%matplotlib
```

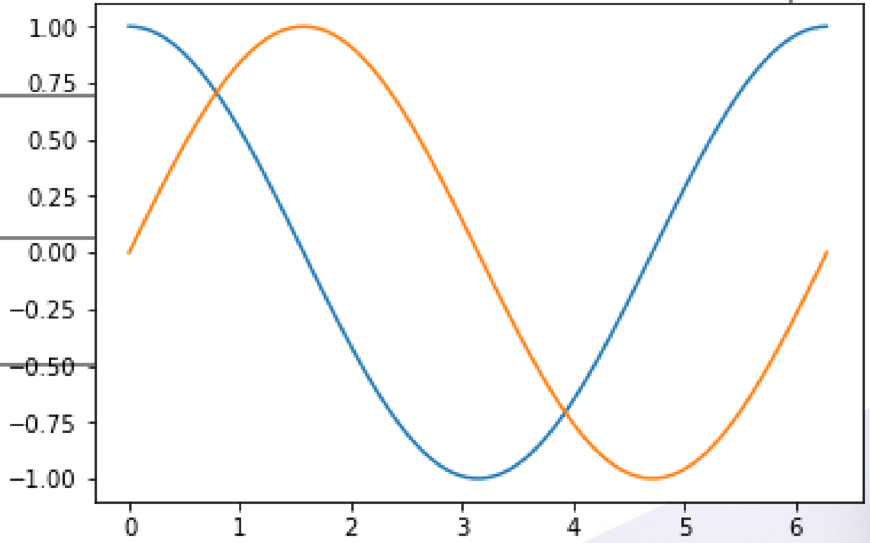
    - Jupyter notebook

```
%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)
```

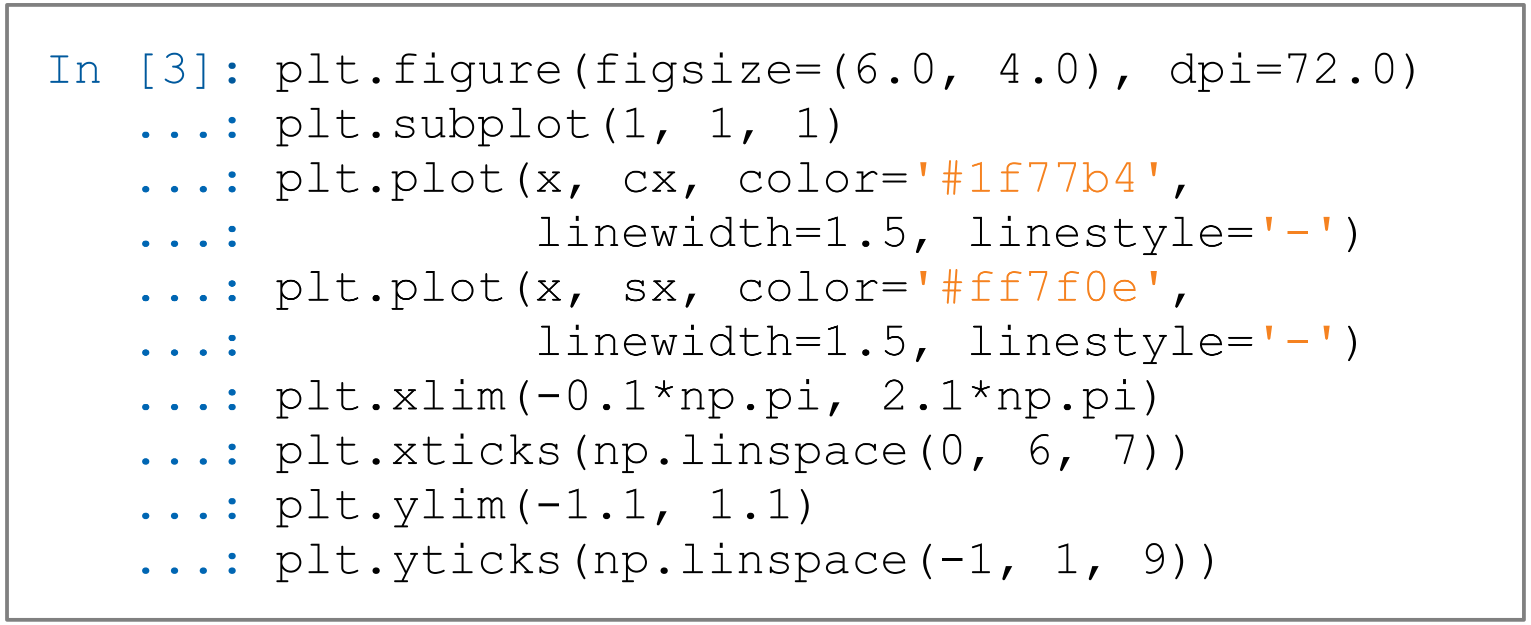


  - If not interactive, also write:

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

Matplotlib: Python Plotting

- 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))
```

Matplotlib: Python Plotting

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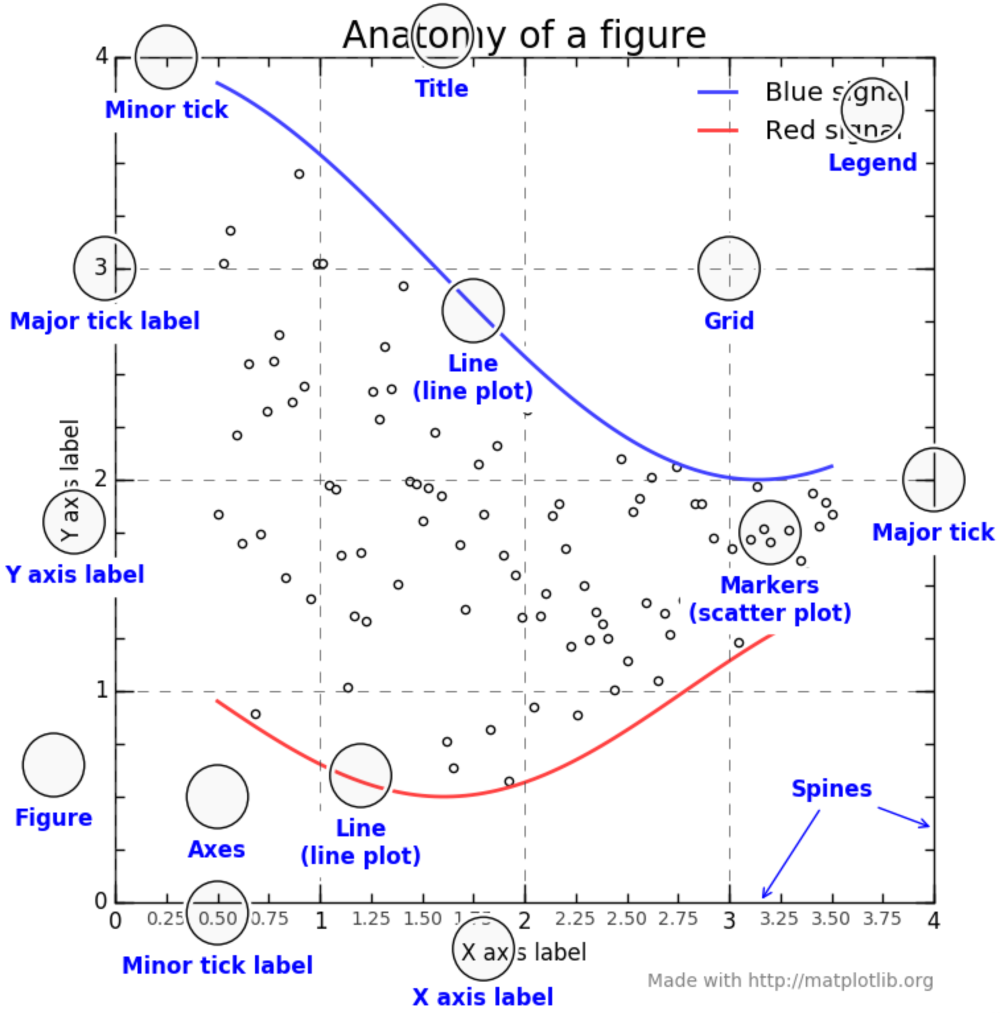
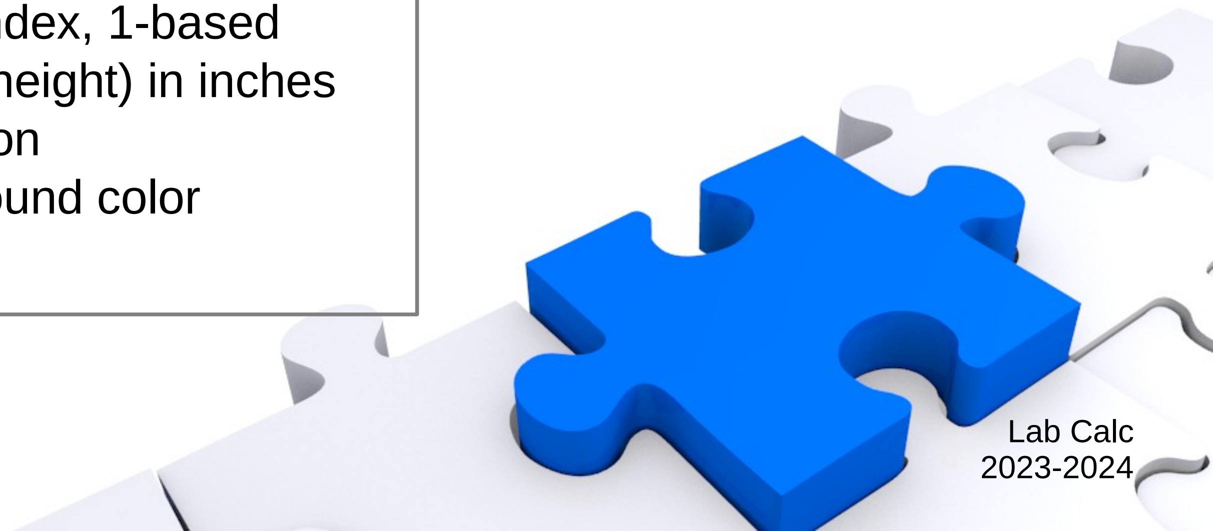
- Anatomy



Matplotlib: Python Plotting

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

```
plt.figure(num=None,              figure index, 1-based
           figsize=None,          (width, height) in inches
           dpi=None,              resolution
           facecolor=None,        background color
           ...)
```



Matplotlib: Python Plotting

- 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, ...
```

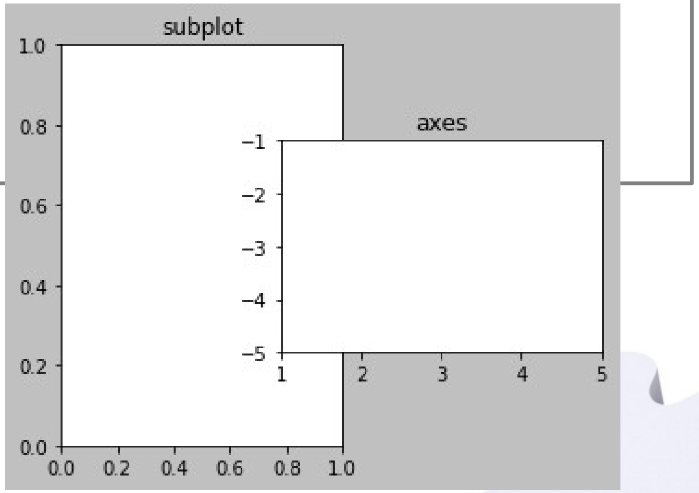
Matplotlib: Python Plotting

- 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

- 2D plotting
  - Standard line plotting: advanced syntax

```
plt.plot(x, y, **kwargs)

**kwargs: color, linestyle, linewidth, marker,
          markeredgecolor, markeredgewidth,
          markerfacecolor, markersize, label, ...
```

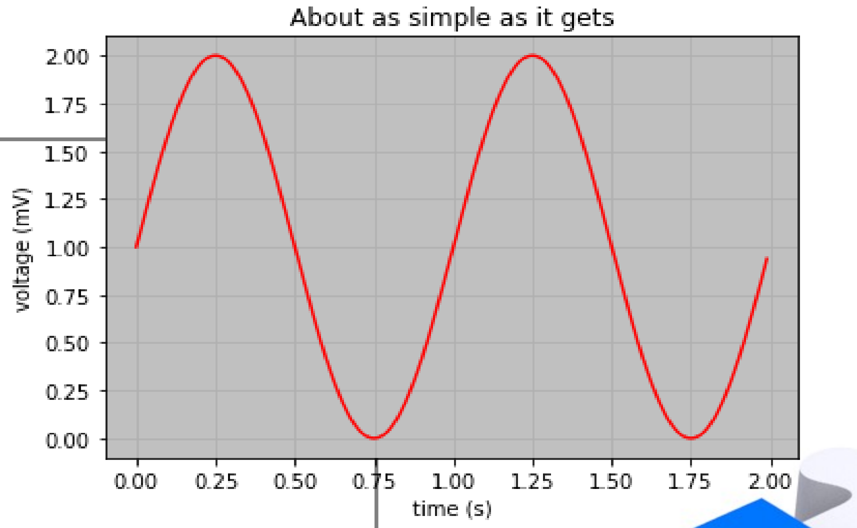
  - Multiple plots per axes possible
  - Legend:

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

Matplotlib: Python Plotting

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

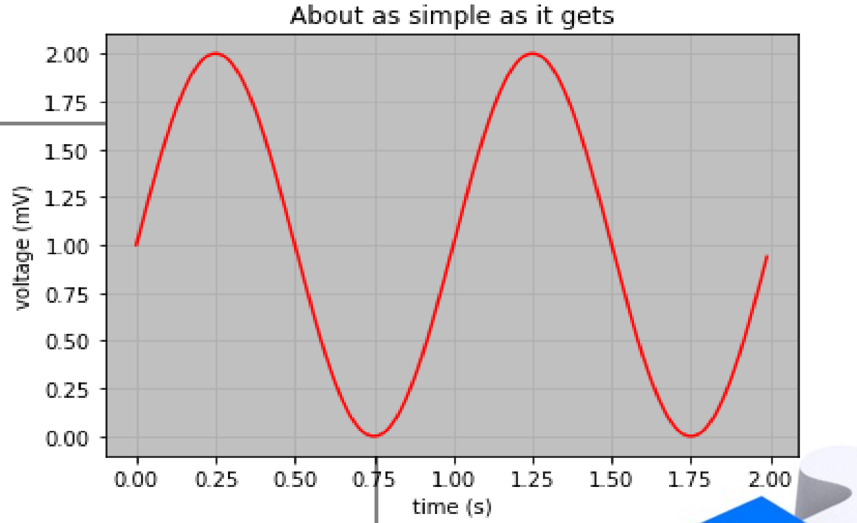
```
In [1]: t = np.arange(0.0, 2.0, 0.01)
   ...: s = 1.0 + np.sin(2.0*np.pi*t)
In [2]: plt.axes(facecolor='silver')
   ...: plt.plot(t, s, 'r')
   ...: plt.xlabel('time (s)')
   ...: plt.ylabel('voltage (mV)')
   ...: plt.title('About as simple as it gets')
   ...: plt.grid()
```



Matplotlib: Python Plotting

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

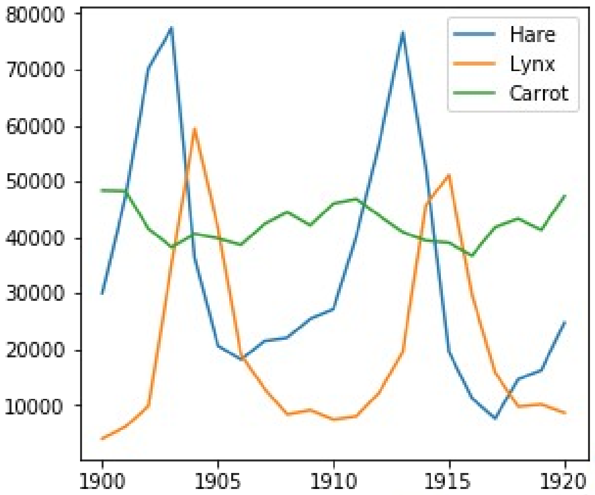
```
In [1]: t = np.arange(0.0, 2.0, 0.01)
   ...: s = 1.0 + np.sin(2.0*np.pi*t)
In [2]: ax = plt.axes()
   ...: ax.plot(t, s, 'r')
   ...: ax.set(facecolor='silver',
   ...:        xlabel='time (s)',
   ...:        ylabel='voltage (mV)',
   ...:        title='About as simple as it gets')
   ...: ax.grid()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



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
...
```

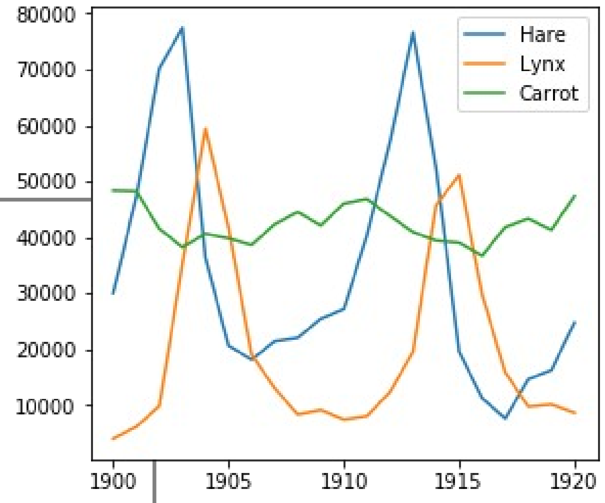


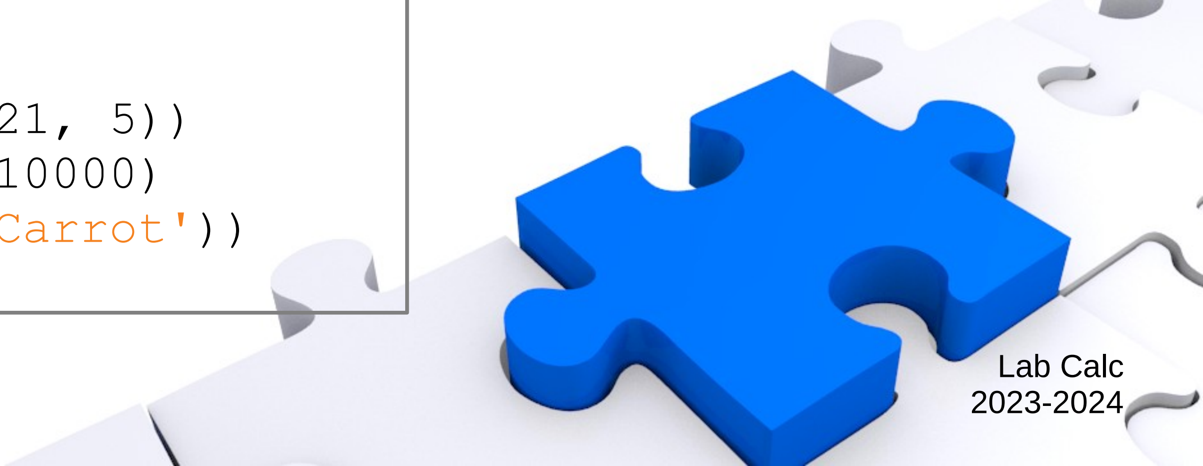
    - Load the data and plot it
    - Compute the mean populations over time
    - Which species has the highest population each year?

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'))
```

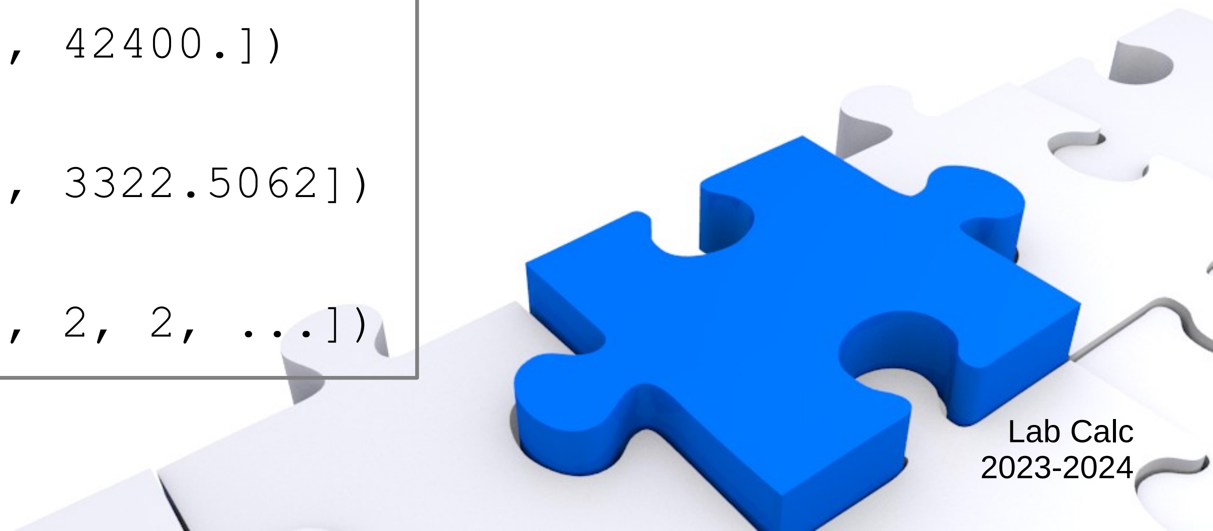




Matplotlib: Python Plotting

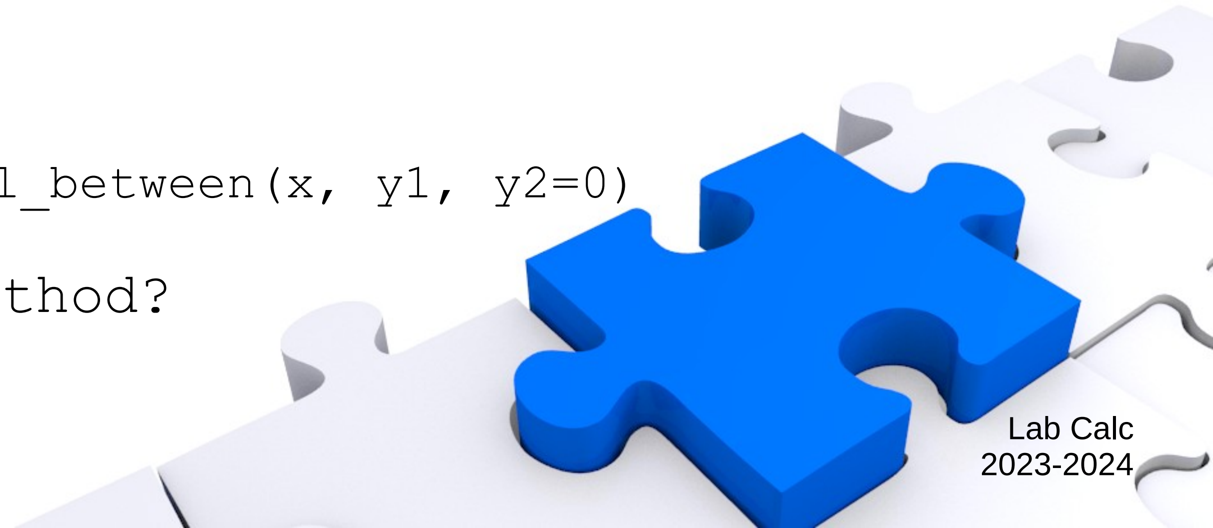
- 2D plotting
  - Example: data statistics
    - Compute the mean populations over time
    - Which species has the highest population each year?

```
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?`

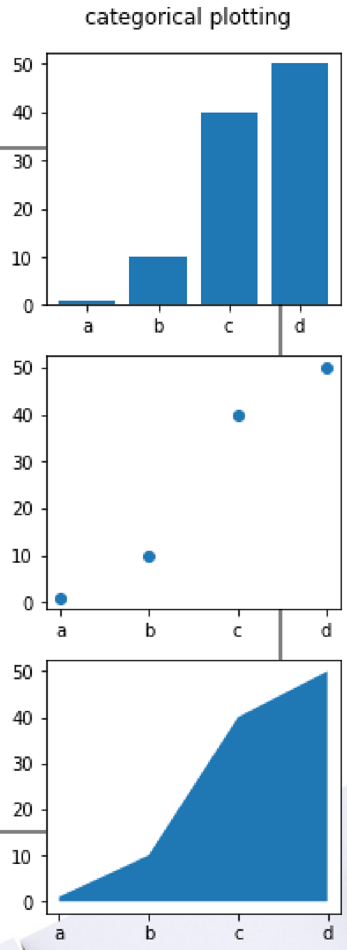


Matplotlib: Python Plotting

- 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')

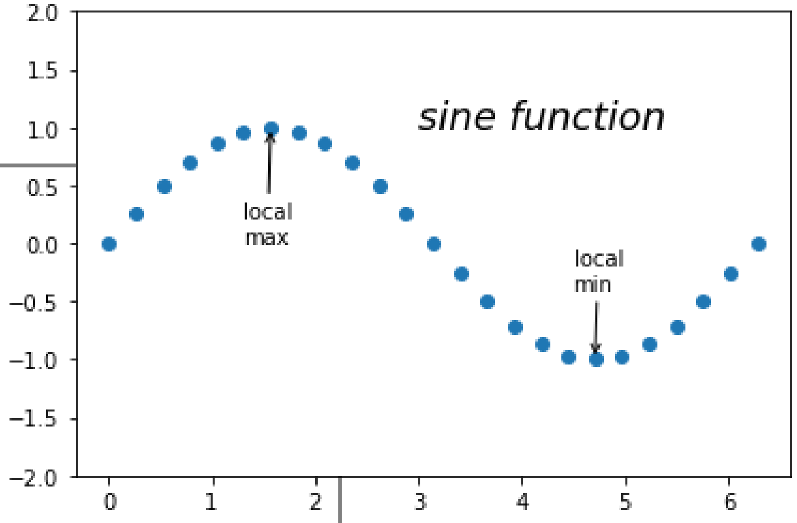
```
plt.title('alpha > beta')          # normal text
plt.title(r'$\alpha > \beta$')     # math text
```

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

- 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

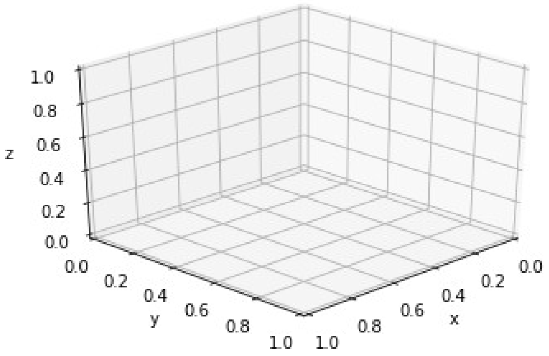
```
from mpl_toolkits import mplot3d
```

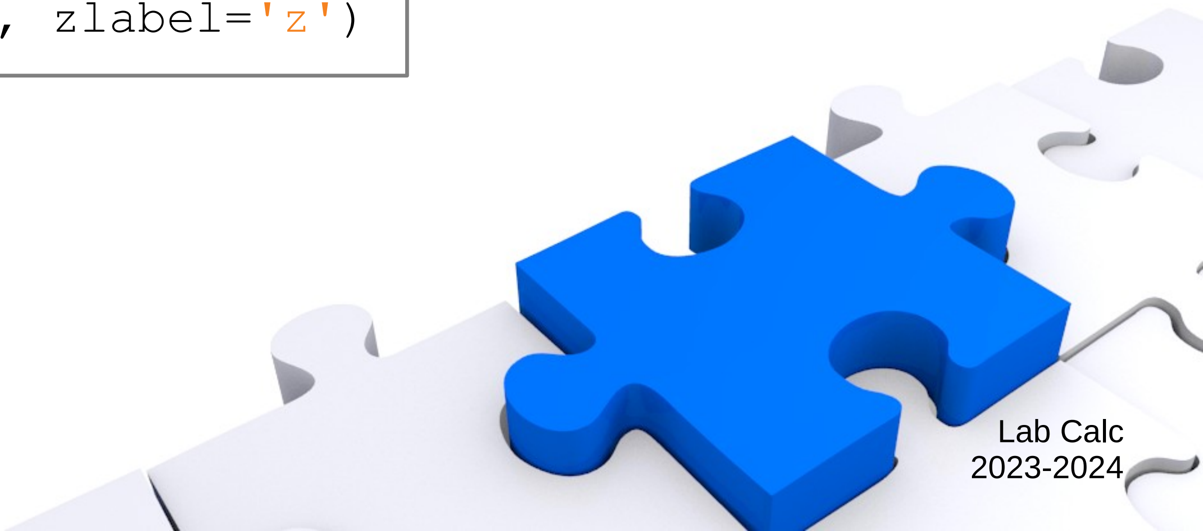
  - Creation of 3D axes object
    - Use `ax = mplot3d.Axes3D(fig)`
    - Use any standard axes creation method with keyword `projection='3d'`
      - `ax = plt.subplot(111, projection='3d')`

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')
```

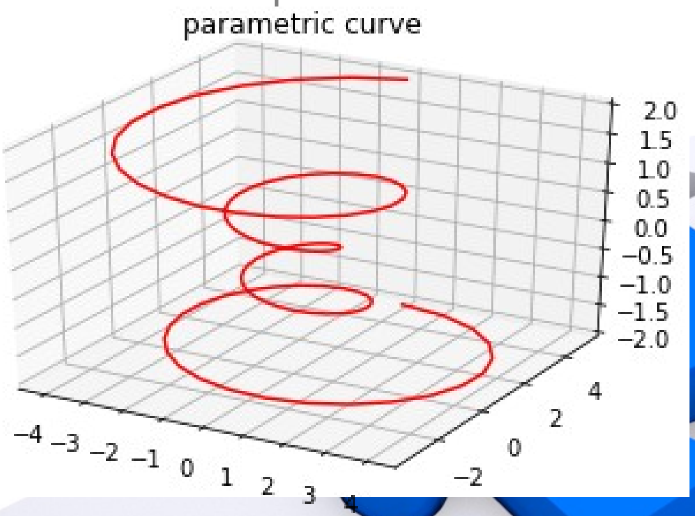




Matplotlib: Python Plotting

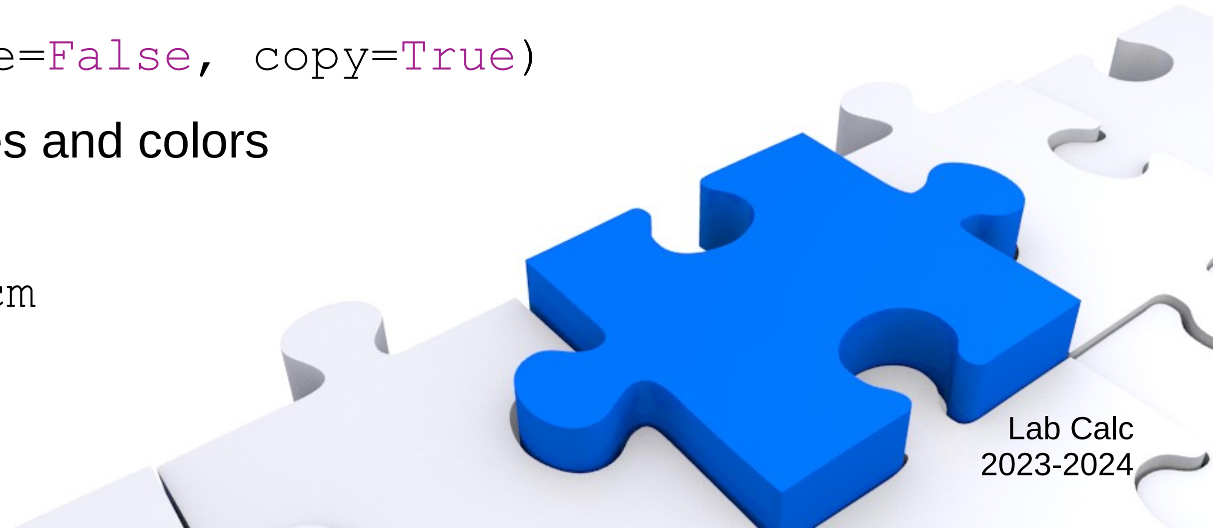
- 3D plotting
  - Natural plot extensions
    - Line plots: `ax.plot(x, y, z)`, `ax.plot3D(x, y, z)`
    - Scatter plots: `ax.scatter(x, y, z)`, `ax.scatter3D(x, y, z)`

```
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')
```


parametric curve

Matplotlib: Python Plotting

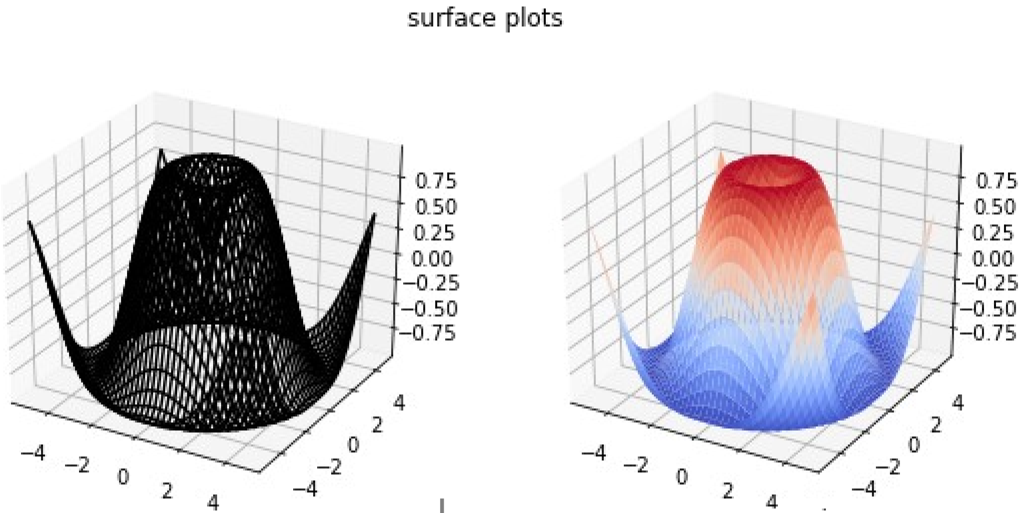
- 3D plotting
  - Surface plotting
    - Wireframe plot: `ax.plot_wireframe(X, Y, Z)`
    - Surface plot: `ax.plot_surface(X, Y, Z)`
  - Surface options
    - Create coordinate matrices from coordinate vectors
      - `X, Y = np.meshgrid(x, y, sparse=False, copy=True)`
    - Color maps: mapping between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

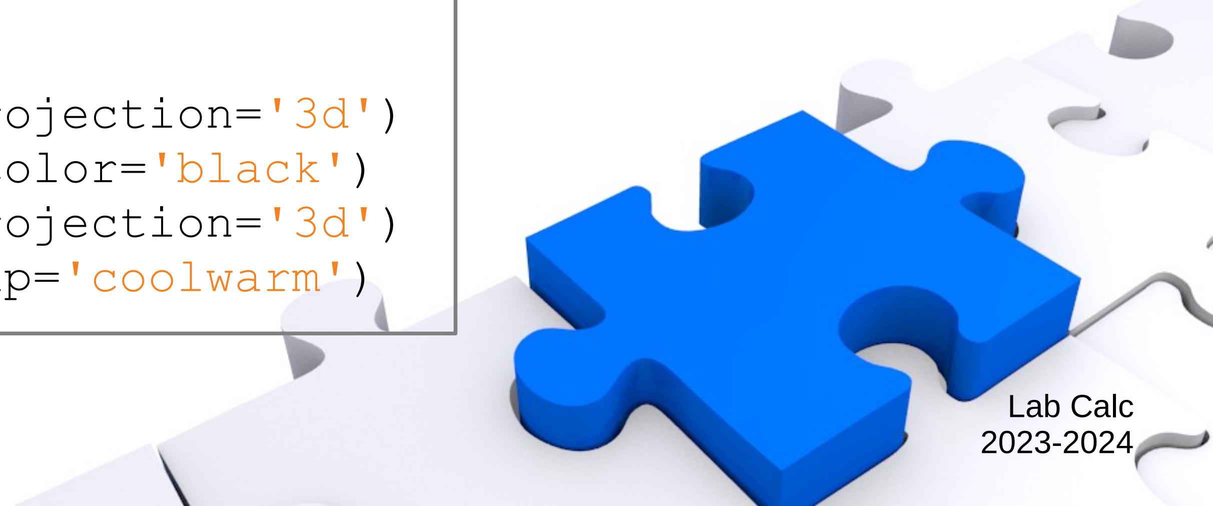


Matplotlib: Python Plotting

- 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')
```



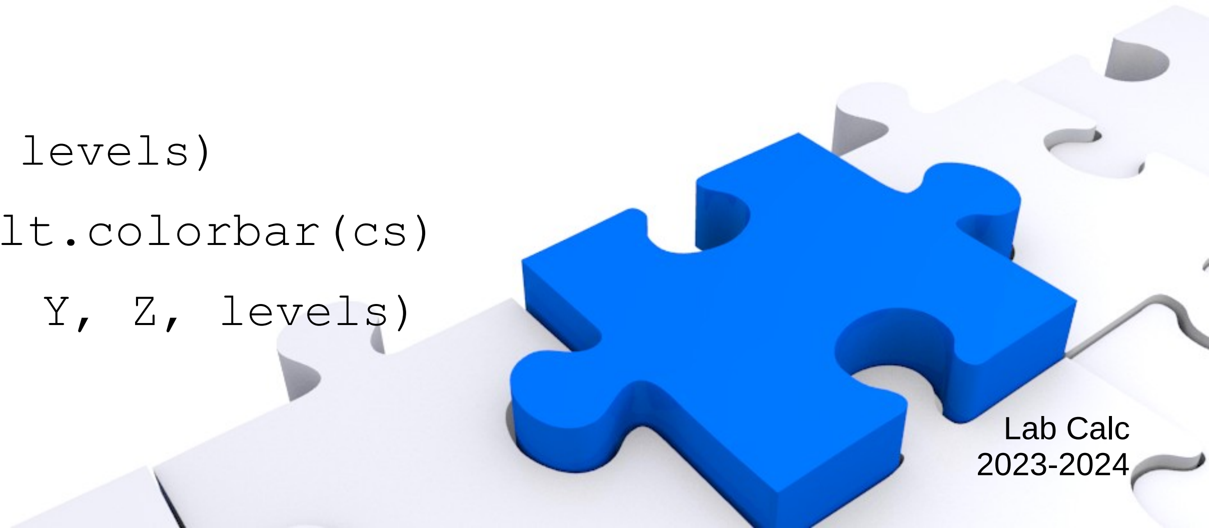


Matplotlib: Python Plotting

- Contour plotting
  - Contour lines: basic syntax

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

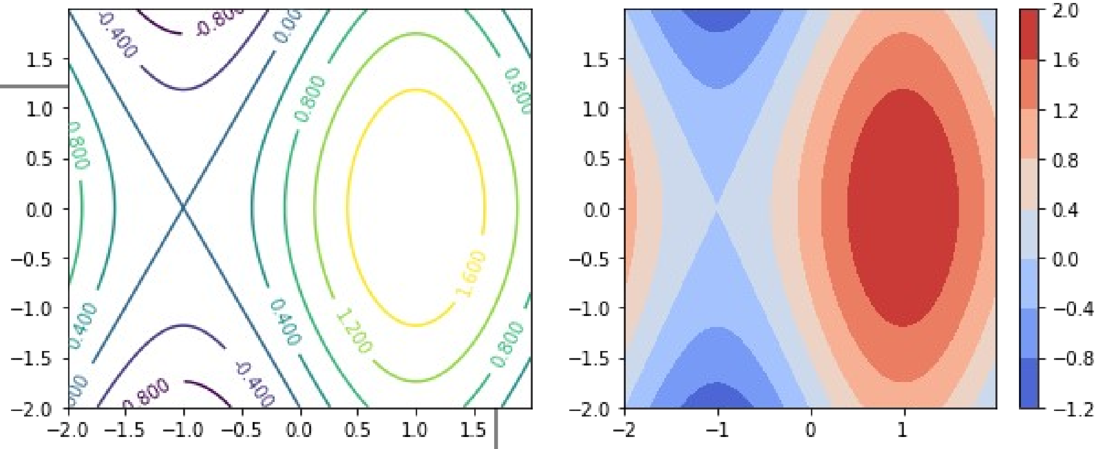
  - Other contour functions:
    - Filled contours: `plt.contourf(X, Y, Z, levels)`
    - Contour identification: `plt.clabel(cs), plt.colorbar(cs)`
    - 3D contour lines (mplot3d): `ax.contour(X, Y, Z, levels)`

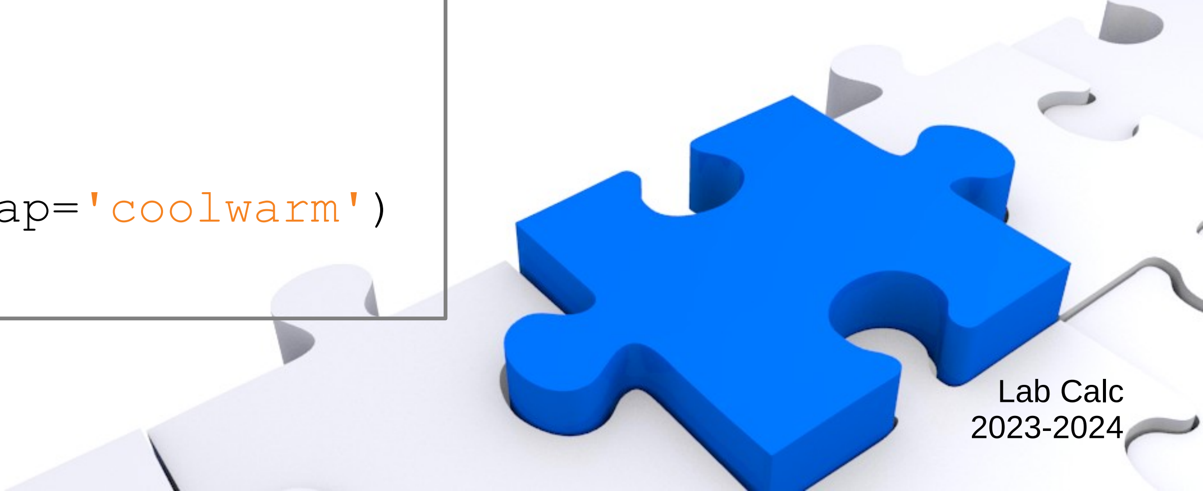


Matplotlib: Python Plotting

- 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)
```





Matplotlib: Python Plotting

- 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

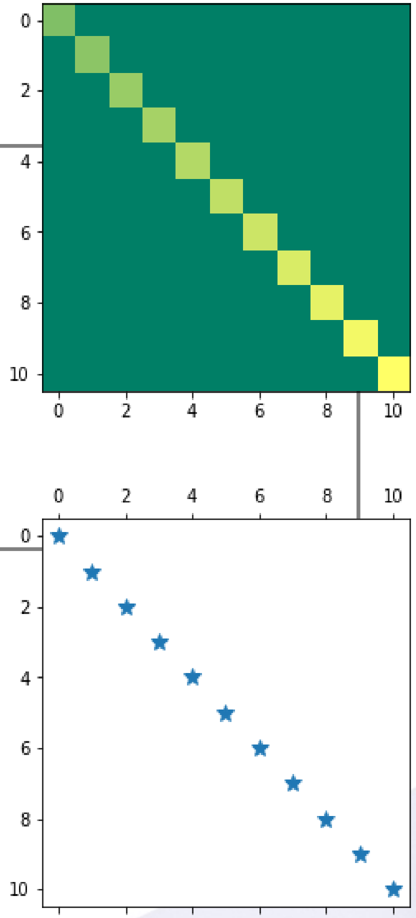
```
plt.imshow(img)
```

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

Matplotlib: Python Plotting

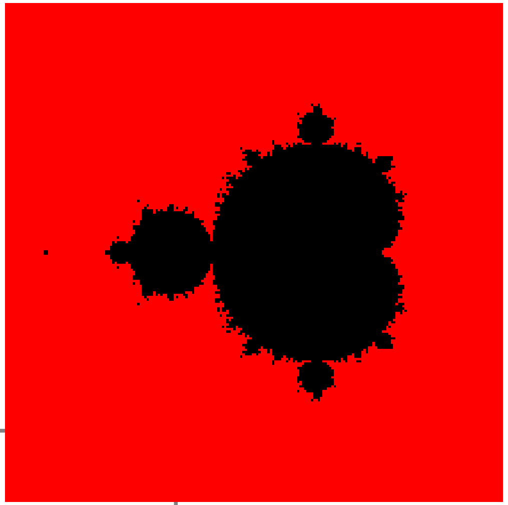
- Image plotting
  - Example

```
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

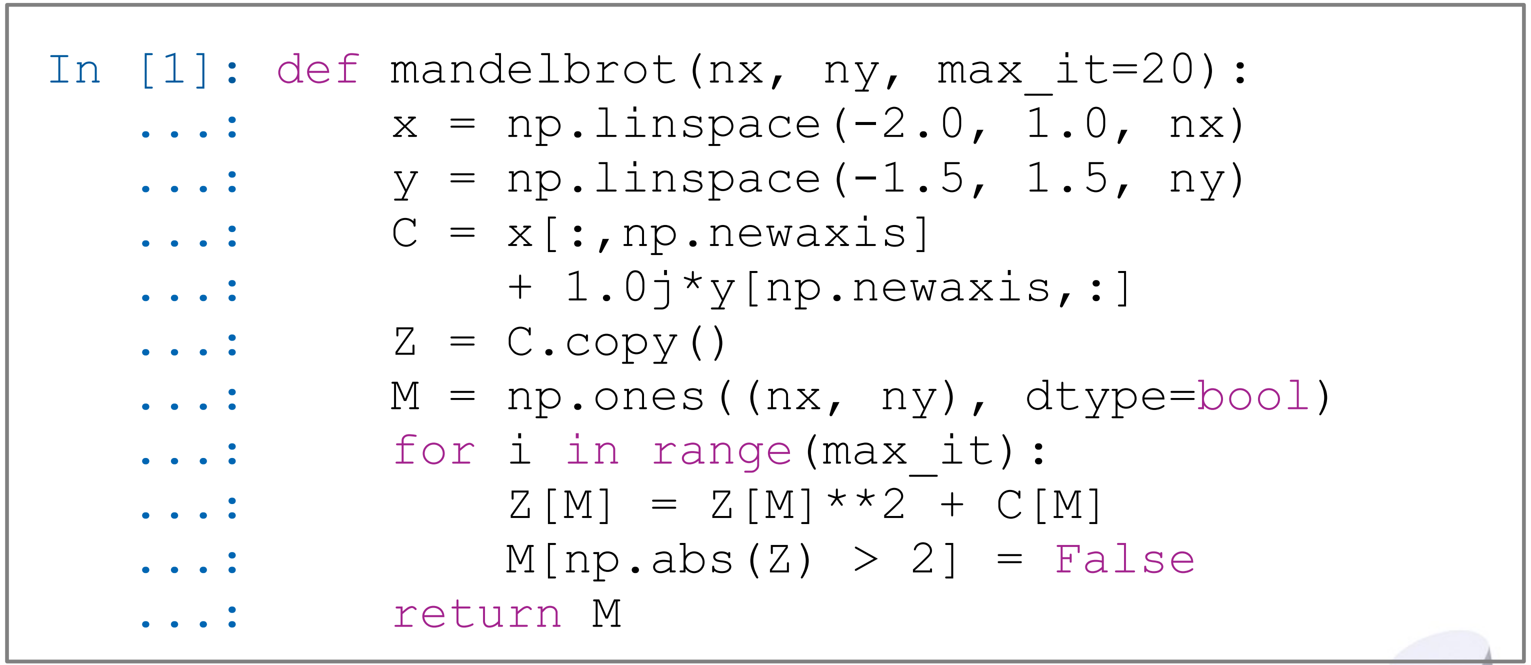
- Image plotting
  - Example: Mandelbrot set
    - Fractal set of complex numbers
    - Definition: any *c* for which $z_{i+1} = z_i^2 + c$ does not diverge, starting from $z_0 = 0$
    - Property: $\lim_{i \to \infty} \sup | z_{i+1} | \leq 2$ for any valid *c*



```
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

Matplotlib: Python Plotting

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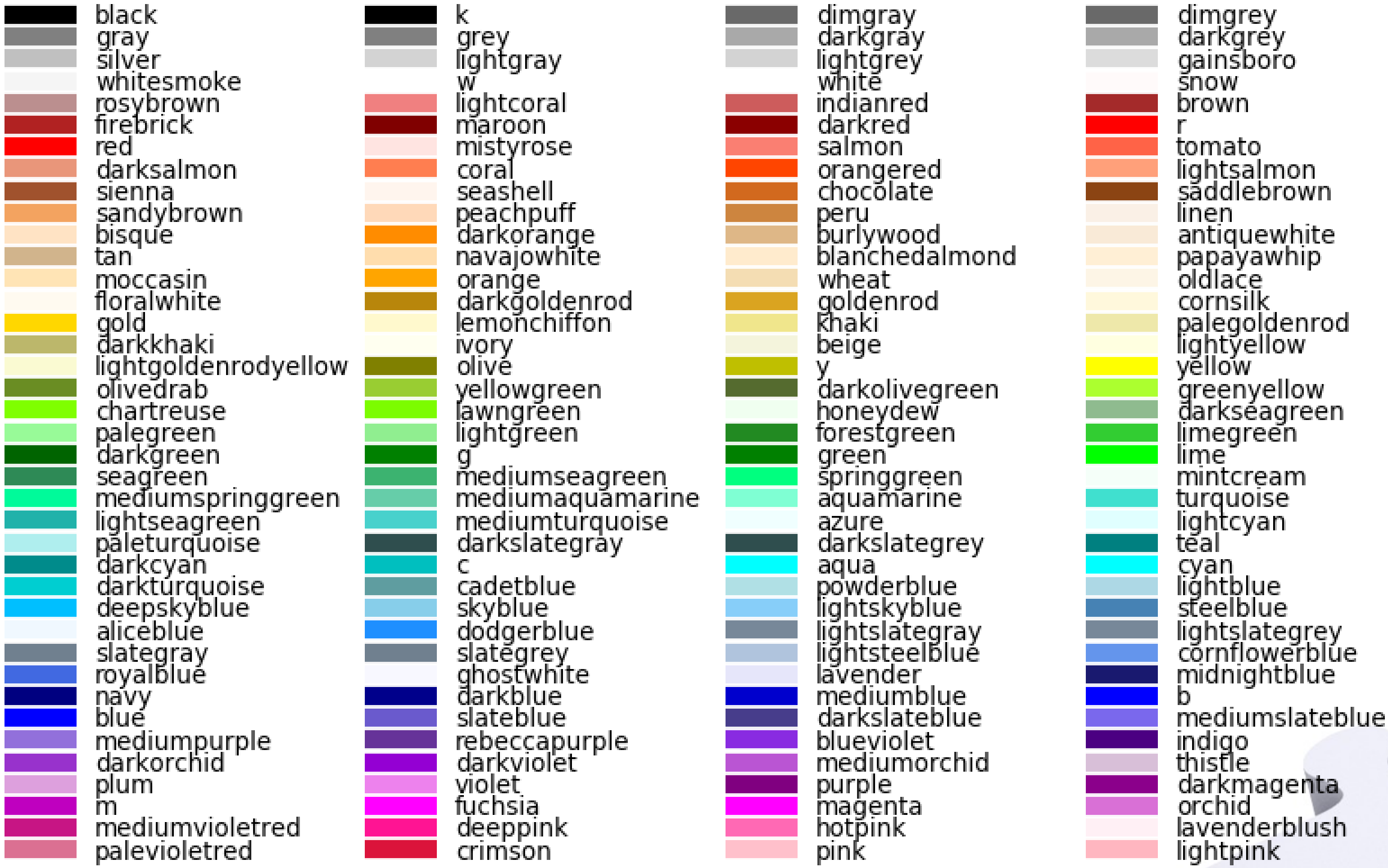
- 

black
gray
silver
whitesmoke
rosybrown
firebrick
red
darksalmon
sienna
sandybrown
bisque
tan
moccasin
floralwhite
gold
darkkhaki
lightgoldenrodyellow
olivedrab
chartreuse
palegreen
darkgreen
seagreen
mediumspringgreen
lightseagreen
paleturquoise
darkcyan
darkturquoise
deepskyblue
aliceblue
slategray
royalblue
navy
blue
mediumpurple
darkorchid
plum
m
mediumvioletred
palevioletred

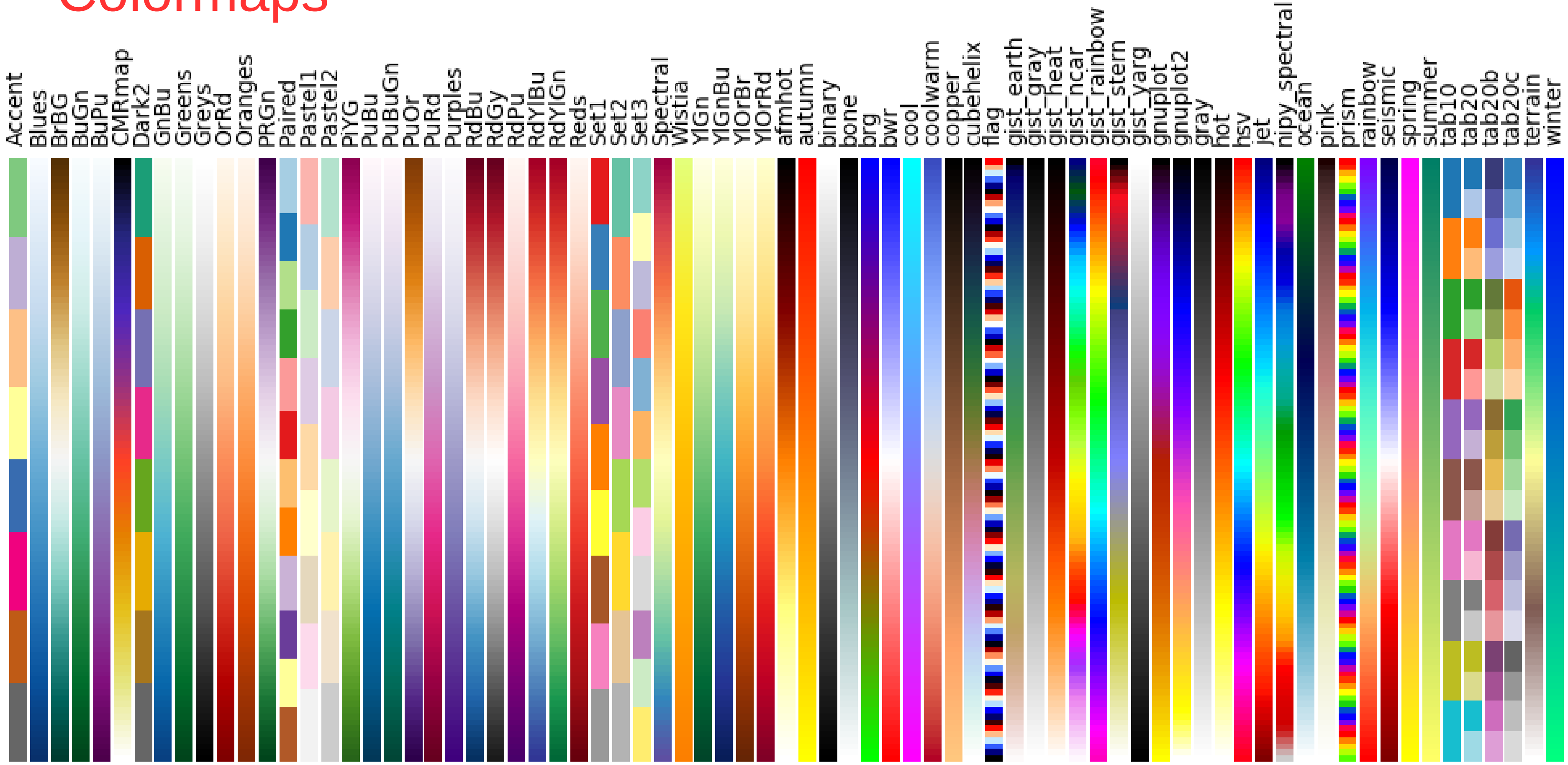
k
grey
lightgray
w
lightcoral
maroon
mistyrose
coral
seashell
peachpuff
darkorange
navajowhite
orange
darkgoldenrod
lemonchiffon
ivory
olive
yellowgreen
lawngreen
lightgreen
g
mediumseagreen
mediumaquamarine
mediumturquoise
darkslategray
c
cadetblue
skyblue
dodgerblue
slategrey
ghostwhite
darkblue
slateblue
rebeccapurple
darkviolet
violet
fuchsia
deeppink
crimson

dimgray
darkgray
lightgrey
white
indianred
darkred
salmon
orangered
chocolate
peru
burlywood
blanchedalmond
wheat
goldenrod
khaki
beige
y
darkolivegreen
honeydew
forestgreen
green
springgreen
aquamarine
azure
darkslategrey
aqua
powderblue
lightskyblue
lightslategray
lightsteelblue
lavender
mediumblue
darkslateblue
blueviolet
mediumorchid
purple
magenta
hotpink
pink

dimgrey
darkgrey
gainsboro
snow
brown
r
tomato
lightsalmon
saddlebrown
linen
antiquewhite
papayawhip
oldlace
cornsilk
palegoldenrod
lightyellow
yellow
greenyellow
darkseagreen
limegreen
lime
mintcream
turquoise
lightcyan
teal
cyan
lightblue
steelblue
lightslategrey
cornflowerblue
midnightblue
b
mediumslateblue
indigo
thistle
darkmagenta
orchid
lavenderblush
lightpink

Matplotlib: Python Plotting

- 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)
```