COMP7035

Python for Data Analytics and Artificial Intelligence

Numpy/Matplotlib

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What we will learn?

Topic		Hours
I.	Python Fundamentals A. Program control and logic B. Data types and structures C. Function D. File I/O	12
II.	Numerical Computing and Data Visualization Tools and libraries such as A. NumPy **B. Matplotlib** C. Seaborn	9
III.	Exploratory Data Analysis (EDA) with Python Tools and libraries such as A. Pandas B. Sweetviz	9
IV.	Artificial Intelligence and Machine Learning with Python Tools and libraries such as A. Keras B. Scikit-learn	9

Numpy Broadcasting

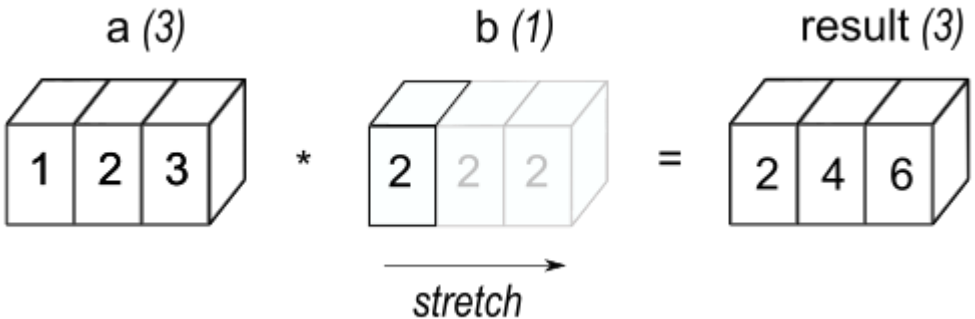
- The term broadcasting describes how NumPy treats arrays with different shapes during arithmetic operations.
- Scalar will be broadcasted to all elements in an array with different shapes.

```
>>> a = np.array([1.0, 2.0, 3.0])
>>> b = np.array([2.0, 2.0, 2.0])
>>> a * b
array([2.,  4.,  6.])
```

With same shapes

```
import numpy as np
a = np.array([1.0, 2.0, 3.0])
b = 2.0
print(a * b)
```

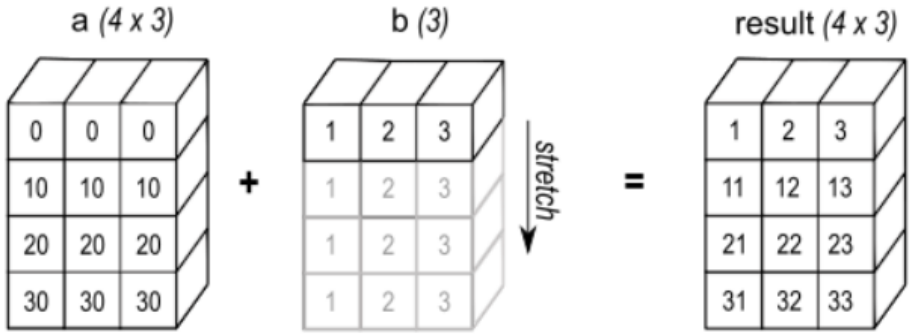
With different shapes



General broadcasting rule

- Broadcasting for two arrays
  - *A one-dimensional array added to a two-dimensional array results in broadcasting if number of 1-d array elements matches the number of 2-d array columns.*

```
import numpy
a = np.array([[ 0.0,  0.0,  0.0],
              [10.0, 10.0, 10.0],
              [20.0, 20.0, 20.0],
              [30.0, 30.0, 30.0]])
b = np.array([1.0, 2.0, 3.0])
print(a + b)
```



General broadcasting rule

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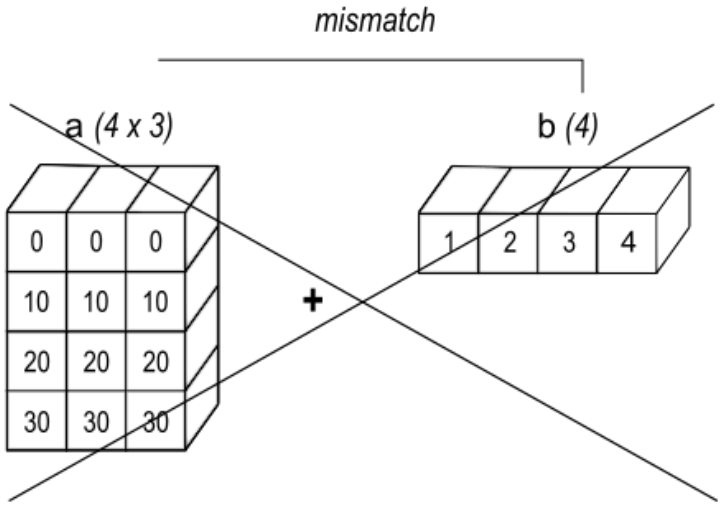
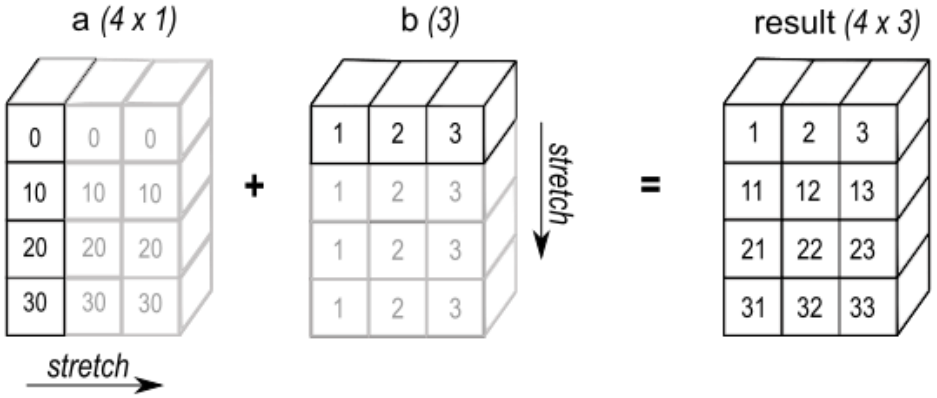


Different column numbers. Not ALLOWED!!!

General broadcasting rule

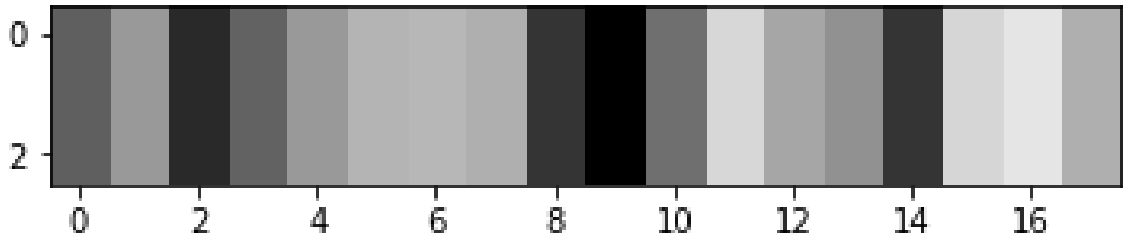
- Broadcasting provides a convenient way of taking the outer product (or any other outer operation) of two arrays. The following example shows an outer addition operation of two 1-d arrays:

```
a = np.array([0.0, 10.0, 20.0, 30.0])
b = np.array([1.0, 2.0, 3.0])
print(a[:, np.newaxis])
a[:, np.newaxis] + b
```



`np.newaxis: Create a new axis for array`

Let us make it more clear

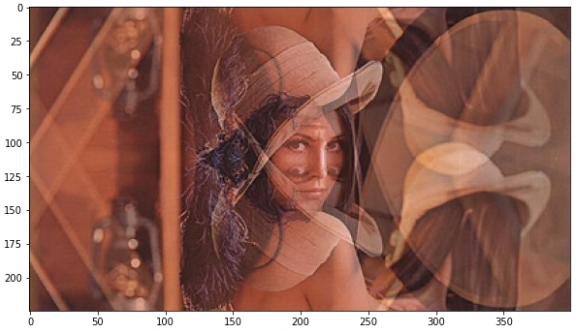



```
img = np.zeros((3, 18, 3))
arr = np.random.random((1, 18, 1))*1000
kkk = (img + arr).astype(np.uint8)
plt.imshow(kkk)
```

Practical examples for broadcasting

- Image blending

After image flip

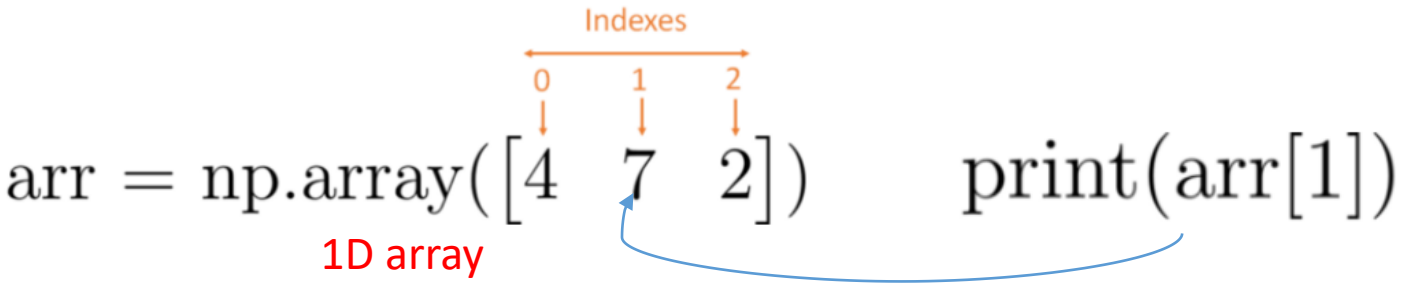


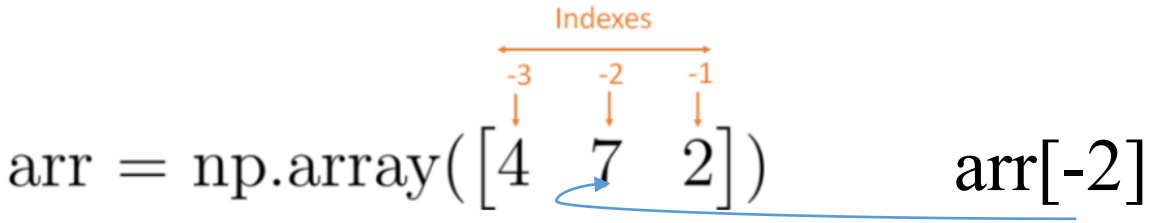
Blended image

```
img = plt.imread('lena.jpg')
img0 = plt.imread('lena.jpg')
img0 = np.flipud(img0)
print(img.dtype)
# uint8
dst = (img * 0.6 + img0 * 0.4).astype(np.uint8)    # Blending them in
plt.figure(figsize=(10, 10))
plt.imshow(dst)
```

Array Element Access

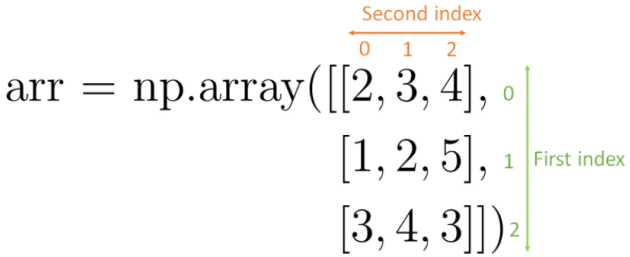
- From 1D to 2D

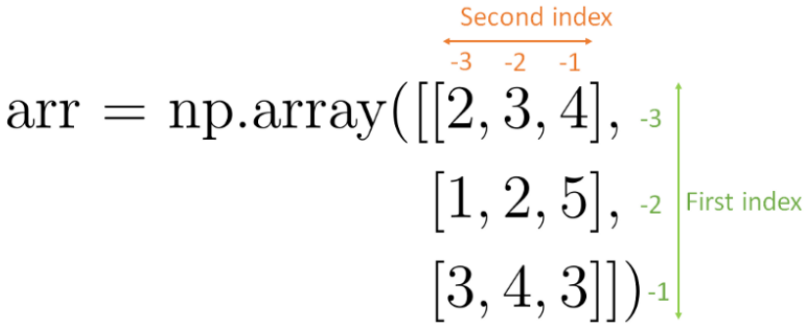


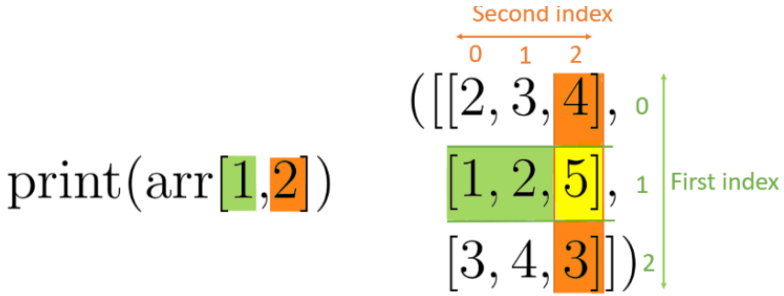


Array Element Access

- From 1D to 2D

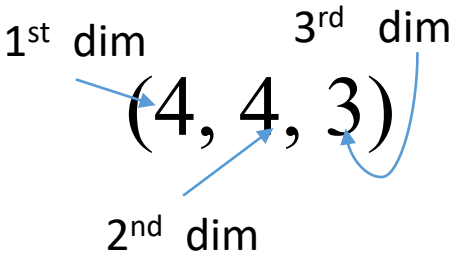


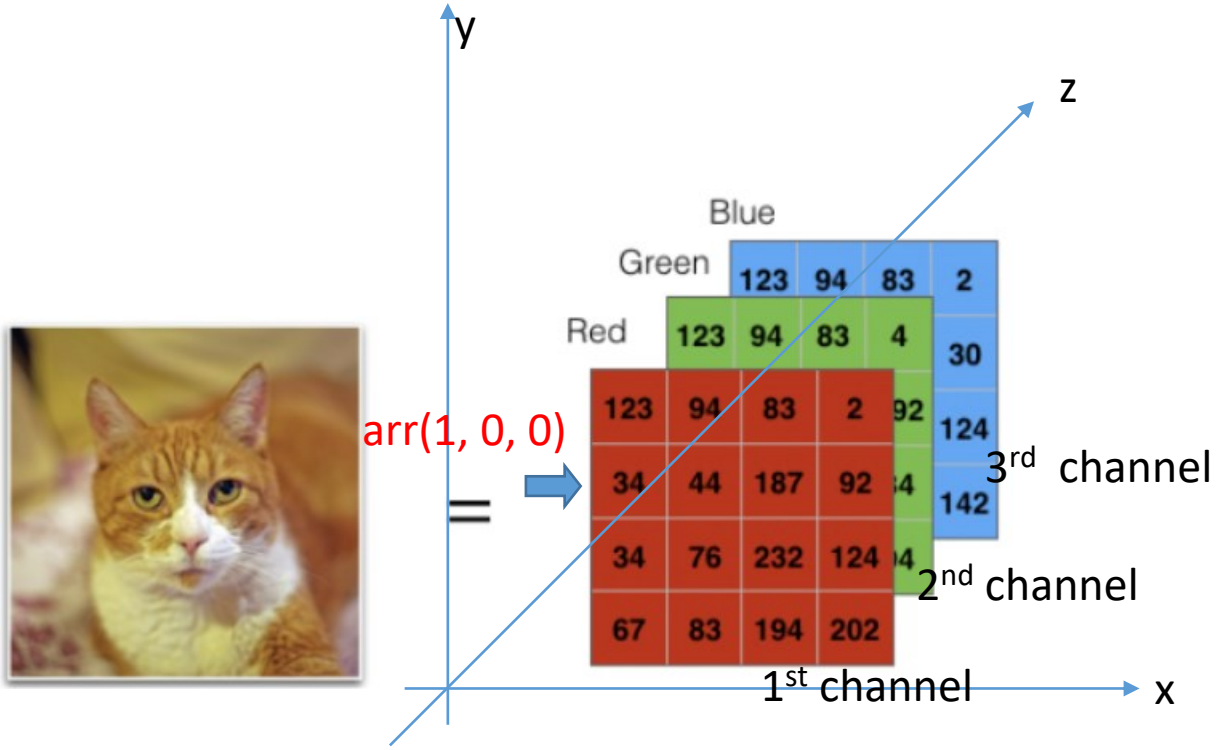




print(arr[-2, -3])

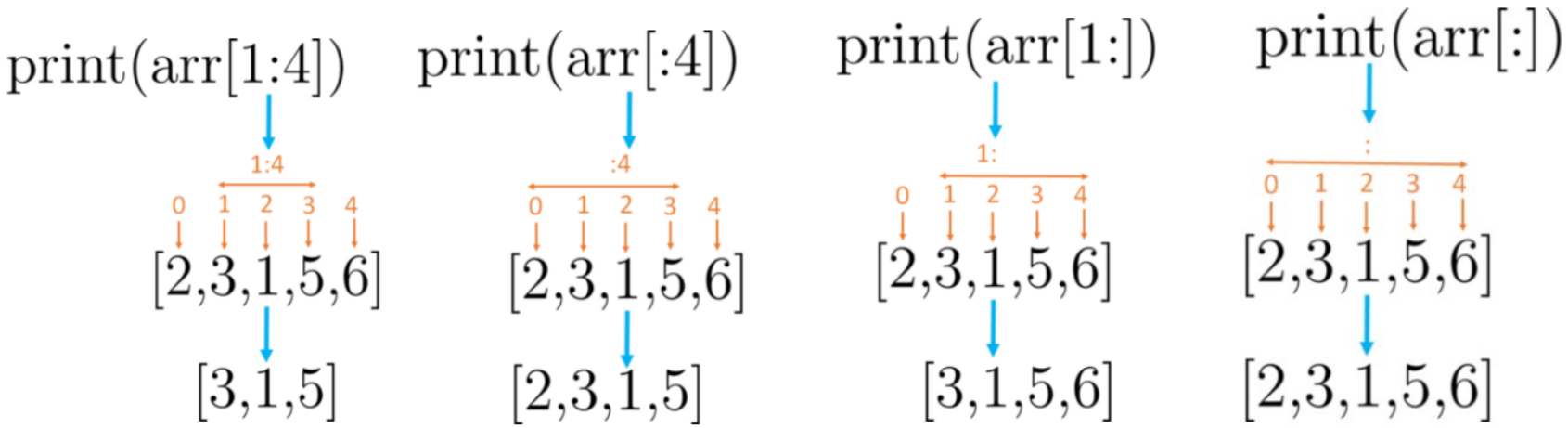
Array Element Access





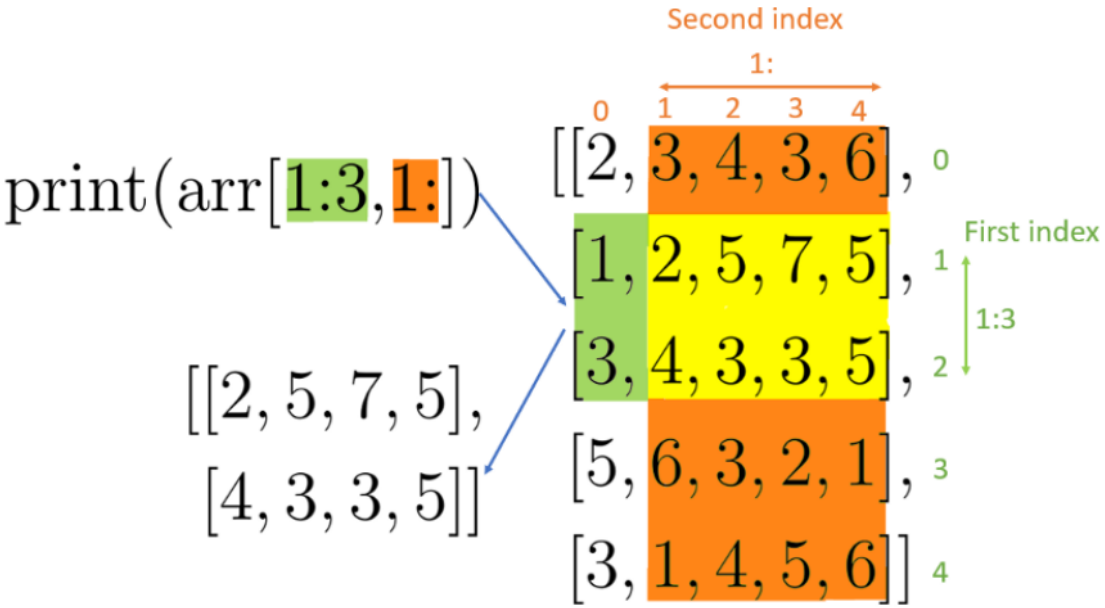
NumPy Array Slicing

- To slice a one dimensional array, we provide a start and an end number separated by a semicolon (:). The range then starts at the start number and **one before the end number**.
- When you want to get the whole array from the start until the element with index 3, I could write: print(arr[0:4]).
- To get from the first index all the way to the end of the array, I can write it without providing a slicing end



NumPy Array Slicing

- For 2D Array



Examples about array slicing

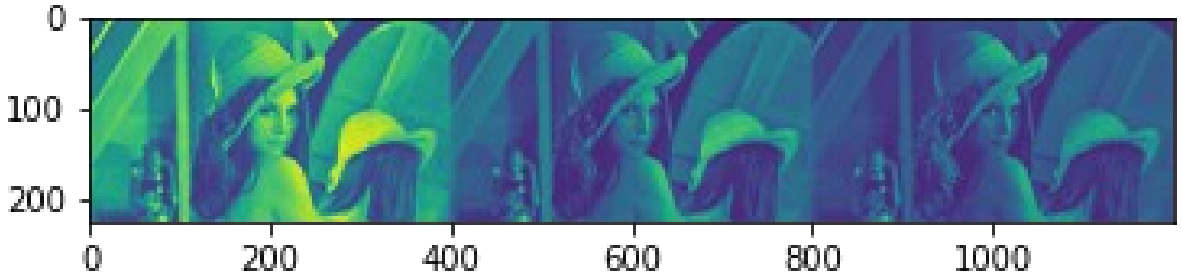
- Image slicing

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

im = plt.imread('lena.jpg')

plt.imshow(im)
print(im.shape) #(225, 400, 3)

im_trim1 = im[128:225, 128:384]
plt.imshow(im_trim1)
print(im_trim1.shape) #(97, 256, 3)
```

We do not specify the third axis which means we take them all

A small exercise for you

Original image



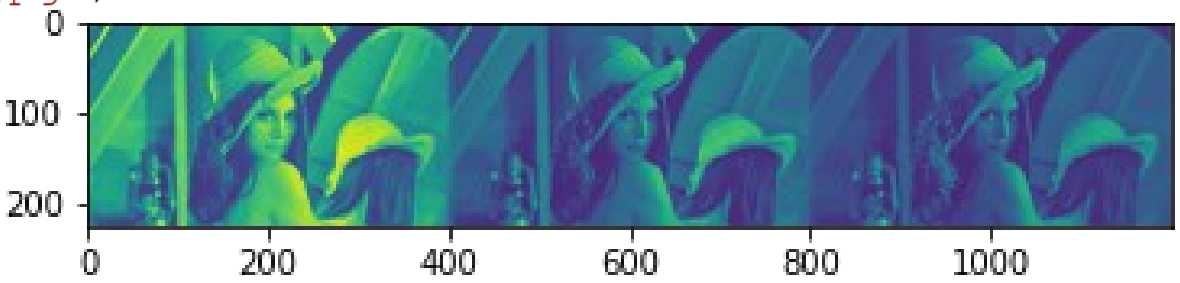
First channel Second channel Third channel

Please write a program to transfer the image from its original status to the separated R G B channel, and then show them in the above forms.

The functions you may need: np.concatenate((arr1, arr2, arr3), axis = decided by you)

A small exercise for you

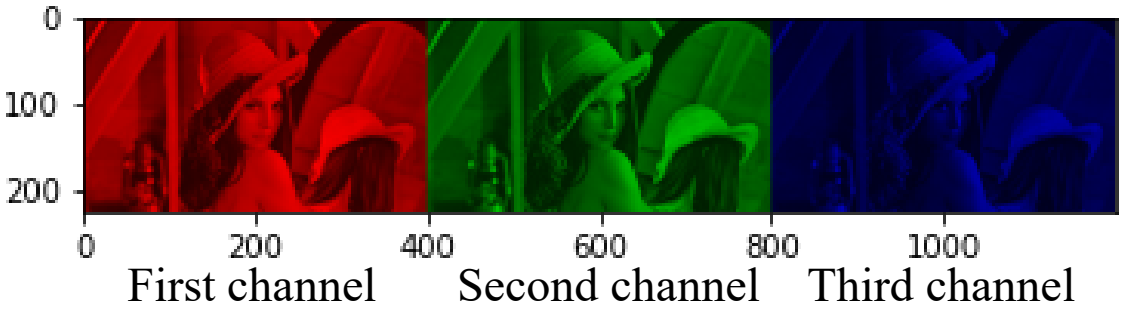
```
import numpy as np
import matplotlib.pylab as plt

im = plt.imread('lena.jpg')

im_R = im[:,:,0]
im_G = im[:,:,1]
im_B = im[:,:,2]

im_RGB = np.concatenate((im_R, im_G, im_B), axis=0)

plt.imshow(im_RGB)
```



Make them red, green, and blue

Make other channels be zero, but still ensure it to be a three-channel matrix

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

im = plt.imread('lena.jpg')

im_R = im.copy()
im_R[:,:,1]=0
im_R[:,:,2]=0
im_G = im.copy()
im_G[:,:,0] = 0
im_G[:,:,2] = 0
im_B = im.copy()
im_B[:,:, 0] = 0
im_B[:,:, 1] = 0

im_RGB = np.concatenate((im_R, im_G, im_B), axis=1)

plt.imshow(im_RGB)
```



Pyplot

- Pyplot is a collection of functions to plot figures
- We only introduce some of its main functions.
- If your feel interested in more, please refer to:

https://matplotlib.org/stable/api/_as_gen/matplotlib.pyplot.plot.html

Import it like this!!!

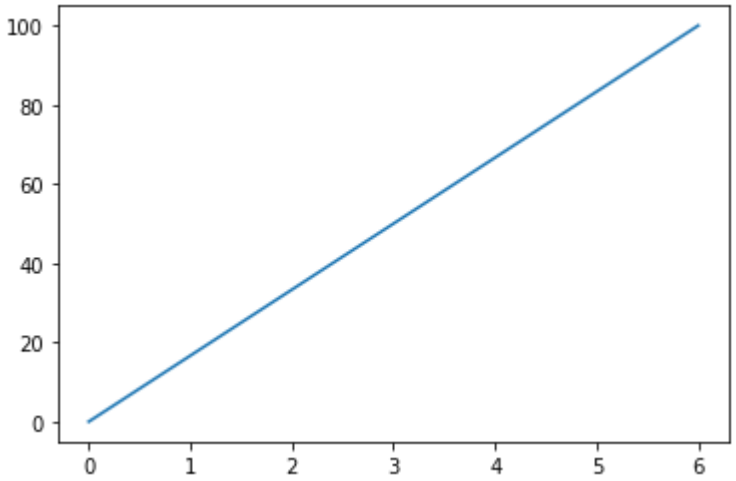
```
import matplotlib.pyplot as plt
```

Pyplot

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

x = np.array([0, 6])
y = np.array([0, 100])

plt.plot(x, y)
plt.show()
```

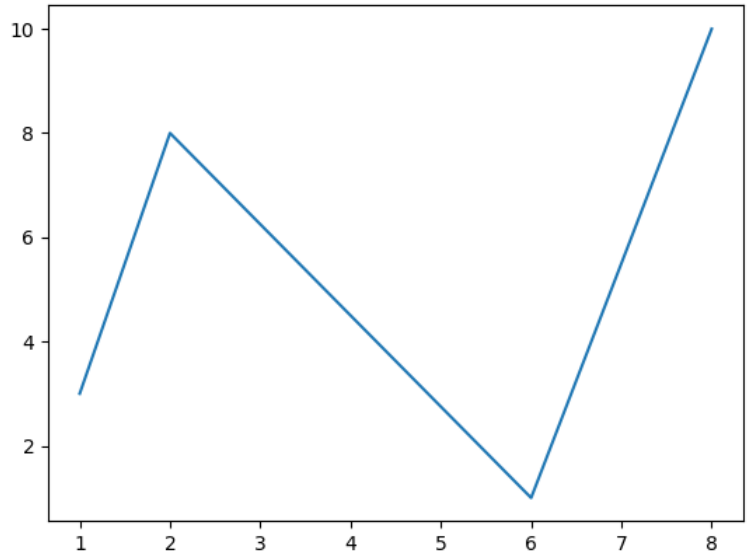
First point

Second point



Exercise 2

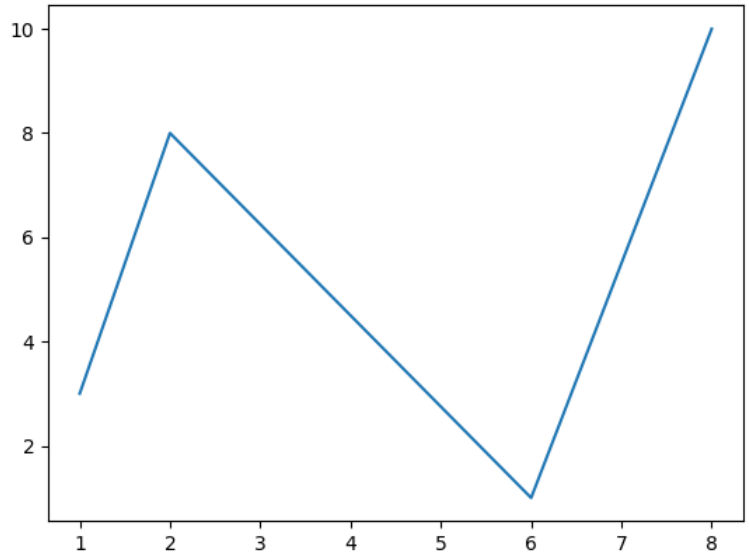
- We have four points (1, 3) , (2, 8) , (6, 1) , (8, 10). Please plot them.



Answer

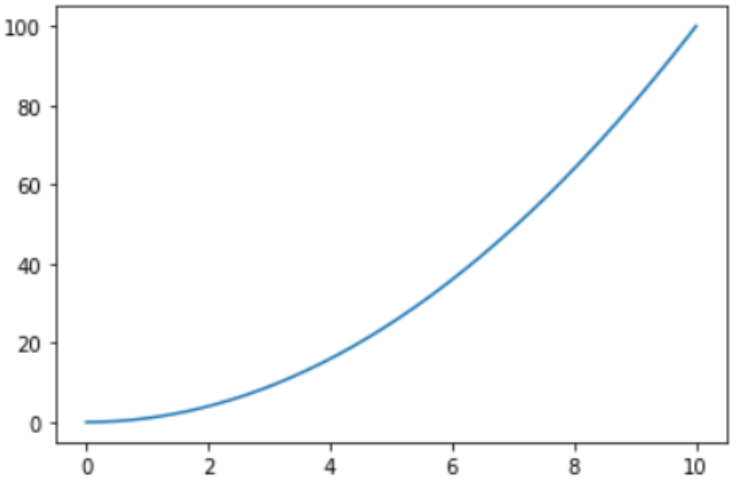
- We have four points (1, 3) , (2, 8) , (6, 1) , (8, 10). Please plot them.

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

xpoints = np.array([1, 2, 6, 8])
ypoints = np.array([3, 8, 1, 10])

plt.plot(xpoints, ypoints)
plt.show()
```



PyPlot

```
import numpy as np
import matplotlib.pyplot as plt
x = np.linspace (0, 10, 1000)
y = np.power(x, 2)
plt.plot(x, y)
plt.show()
```



To plot the curve of the following mathematical function:

$y = x^2$

```
np.linspace(start, stop, num=50)
```

Return evenly spaced numbers over a specified interval [*start*, *stop*]. Star and stop are both inclusive

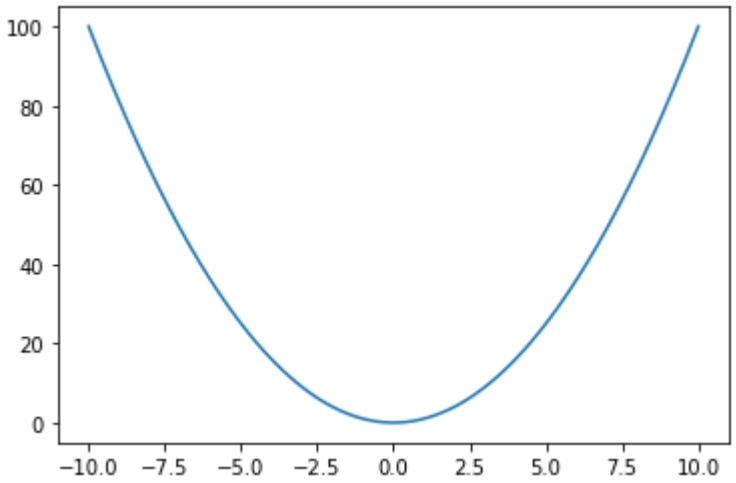
Can we change the x axis to negative value?

PyPlot

```
import numpy as np
import matplotlib.pyplot as plt
x = np.linspace (-10, 10, 1000)
y = np.power(x, 2)
plt.plot(x, y)
plt.show()
```

To plot the curve of the following mathematical function:

$y = x^2$



A small exercise for you

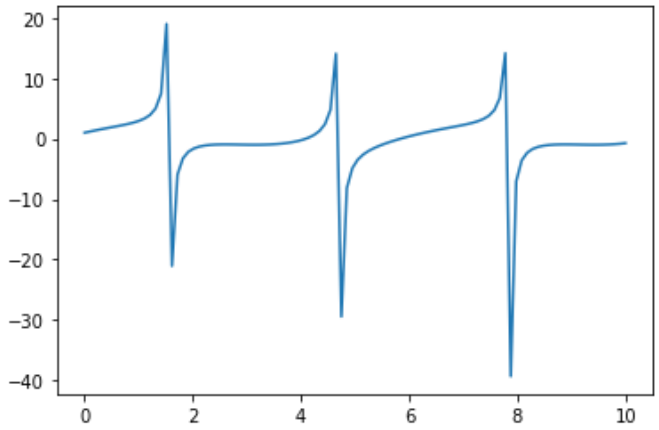
1. Please plot a figure for $y = cos(x) + sin(x) + tan(x)$ between 0 to 10000
2. Please plot a figure for $f = sin^2(x-2)e^{-x^2}$ between -10 to 10

`np.e`

Answer 1

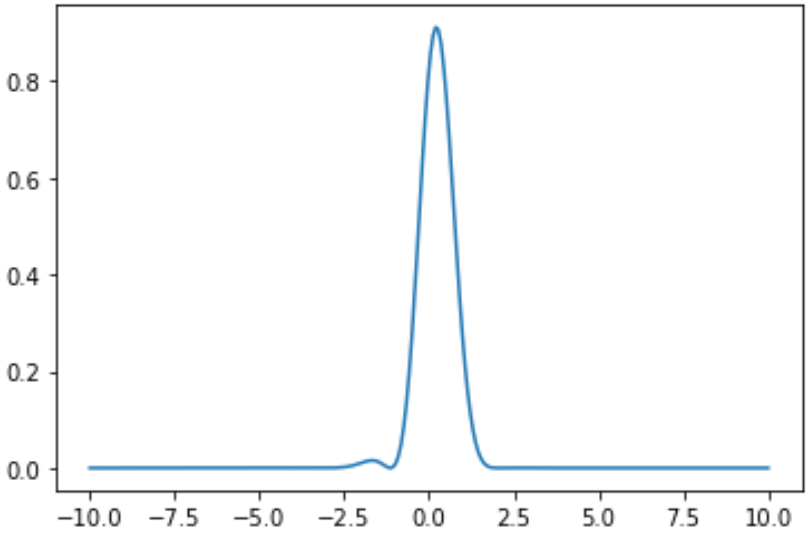
- Please plot a figure for $y = \sin(x) + \cos(x) + \tan(x)$

```
import numpy as np
import matplotlib.pyplot as plt
x = np.linspace (0, 10, 100)
y = np.cos(x) + np.sin(x) + np.tan(x)
plt.plot(x, y)
plt.show()
```



Answer 2

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

x = np.linspace(-10,10,256)
f =(np.sin(x-2))**2*(np.e)**(-x**2)

plt.plot(x,f)
plt.show()
```



More about Pyplot

- `linspace` returns evenly spaced numbers over a specified interval.
  - Can plot any figures under Cartesian coordinate system
- It can be used to implement more kinds of coordinate system.

Can you try them?

```
theta = np.linspace(0, 2 * np.pi, 100)
```

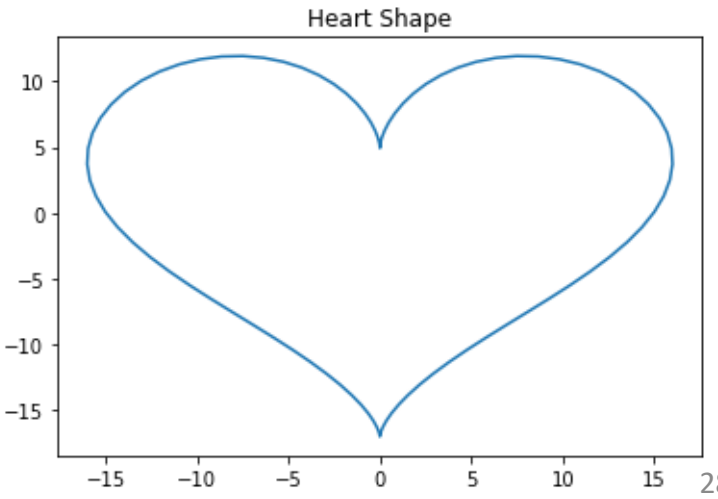
$$x = 16 * sin(\theta)^3$$

$$y = 13 * cos(\theta) - 5 * cos(2\theta) - 2 * cos(3\theta) - cos(4\theta)$$

Answer

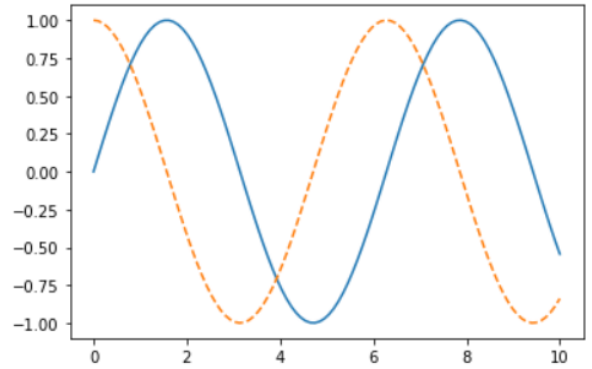
This is a figure under the polar coordinate system

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

# Creating equally spaced 100 data in range 0 to 2*pi
theta = np.linspace(0, 2 * np.pi, 100)

# Generating x and y data
x = 16 * ( np.sin(theta) ** 3 )
y = 13 * np.cos(theta) - 5* np.cos(2*theta) -
 2 * np.cos(3*theta) - np.cos(4*theta)

# Plotting
plt.plot(x, y)
plt.title('Heart Shape')
plt.show()
```

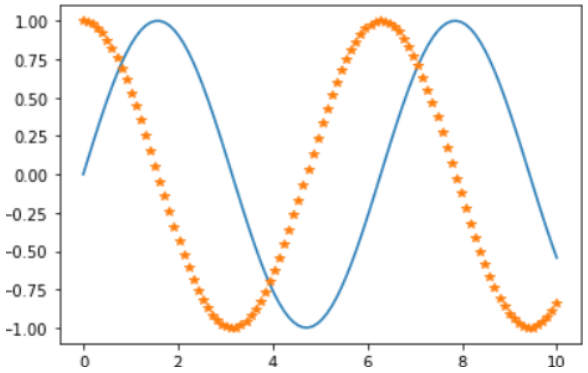


Plot with different styles

```
x = np.linspace(0, 10, 100)
plt.plot(x, np.sin(x), '-')
plt.plot(x, np.cos(x), '--');
```




```
x = np.linspace(0, 10, 100)
plt.plot(x, np.sin(x), '-')
plt.plot(x, np.cos(x), '*');
```



Change style

```
x = np.linspace(0, 10, 100)
plt.plot(x, np.sin(x), 'g', marker='o')
plt.plot(x, np.cos(x), 'r', marker='s')
```

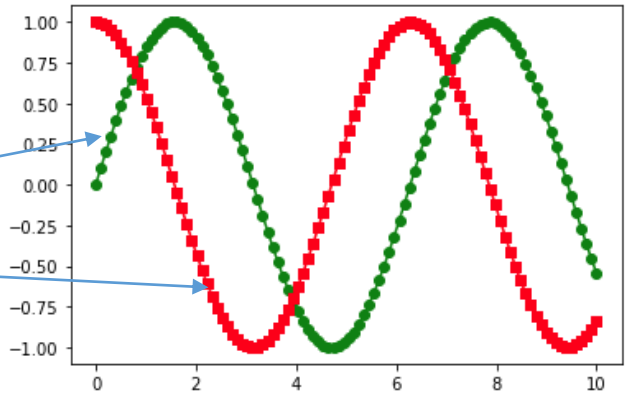
```
x = np.linspace(0, 10, 100)
plt.plot(x, np.sin(x), 'm', marker='X')
plt.plot(x, np.cos(x), 'y', marker='$...$')
```

character	color
'b'	blue
'g'	green
'r'	red
'c'	cyan
'm'	magenta
'y'	yellow
'k'	black
'w'	white

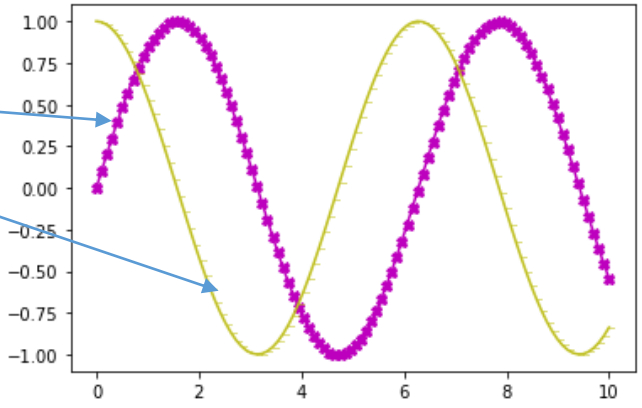
Marker style can be found below:
https://matplotlib.org/stable/api/markers_api.html

Change style

```
x = np.linspace(0, 10, 100)
plt.plot(x, np.sin(x), 'g', marker='o')
plt.plot(x, np.cos(x), 'r', marker='s')
```




```
x = np.linspace(0, 10, 100)
plt.plot(x, np.sin(x), 'm', marker='X')
plt.plot(x, np.cos(x), 'y', marker='$...$')
```



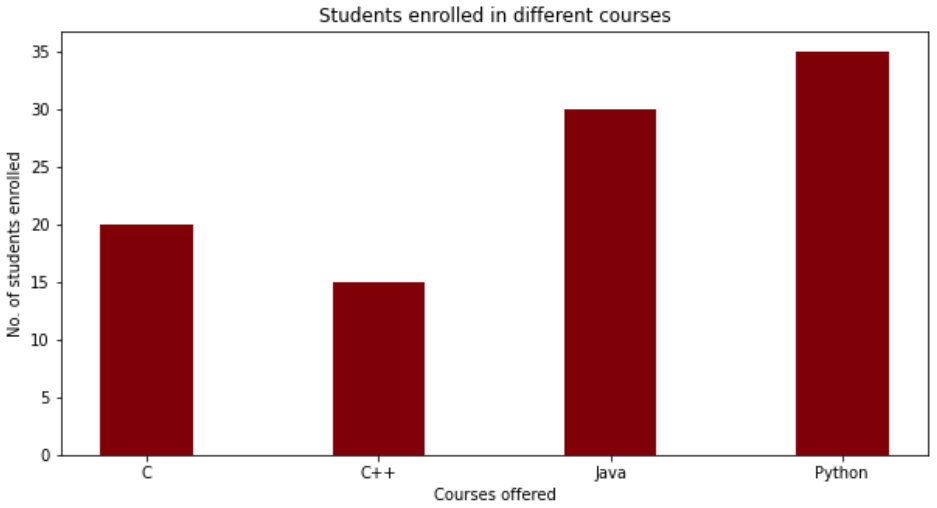
Marker style can be found below:
https://matplotlib.org/stable/api/markers_api.html

Plot Bar

- The bars are positioned at *x* with the given *align*ment. Their dimensions are given by *height* and *width*.

matplotlib.pyplot.bar(*x*, *height*, *width=0.8)*

```
# creating the dataset
data = {'C':20, 'C++':15, 'Java':30,
        'Python':35}
courses = list(data.keys())
values = list(data.values())

fig = plt.figure(figsize = (10, 5))

# creating the bar plot
plt.bar(courses, values, color ='maroon',
        width = 0.4)

plt.xlabel("Courses offered")
plt.ylabel("No. of students enrolled")
plt.title("Students enrolled in different courses")
plt.show()
```

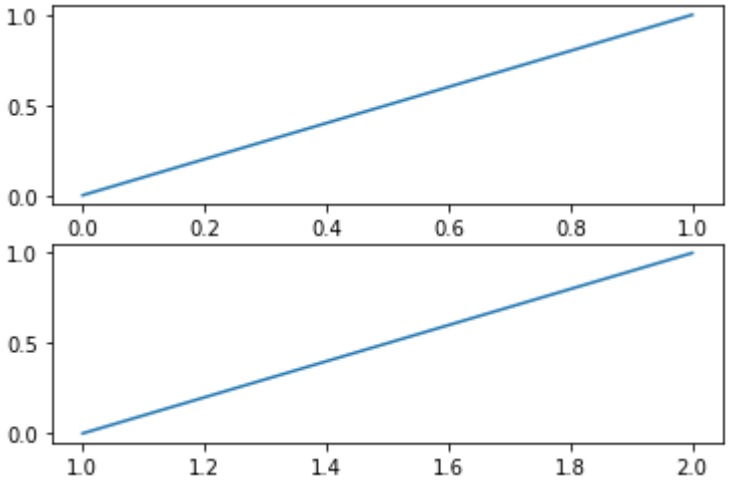


subplots(*nrows=1, ncols=1*)

- subplots creates a figure and a grid of subplots with a single call, while providing reasonable control over how the individual plots are created
- Return two values: fig: the figure to be ploted ax: ***array of Axes***

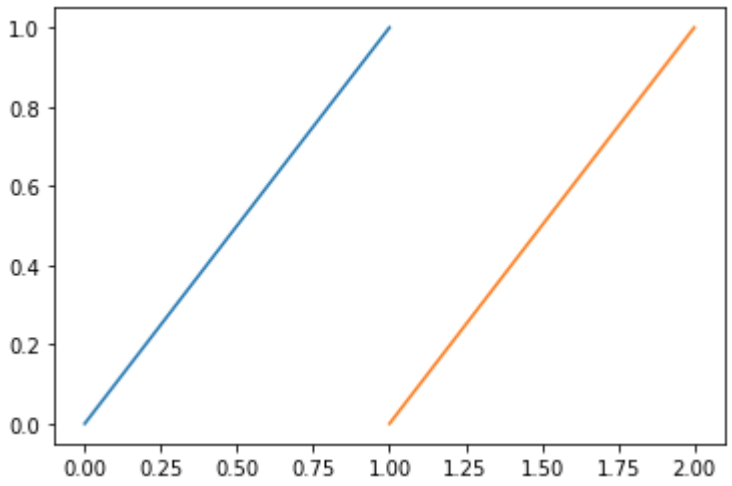
A class

```
import matplotlib.pyplot as plt

fig = plt.figure()

# Plot first figure
ax = fig.subplots(2)
ax[0].plot([0, 1], [0, 1])
ax[1].plot([1, 2], [0, 1])
plt.show()
```



subplots()

```
import matplotlib.pyplot as plt

fig = plt.figure()

# Plot first figure
ax = fig.subplots()

ax.plot([0, 1], [0, 1])
ax.plot([1, 2], [0, 1])
plt.show()
```



Animation

When data becomes available to replace the existing output, the *clear_output* will be called immediately before the new data is added.

```
import matplotlib.pyplot as plt
from matplotlib import animation
import numpy as np
from IPython.display import display, clear_output

fig = plt.figure() #Create a canvas to be painted
x = np.linspace(0, 10, 5)
y = x**2

ax = fig.subplots() #Create the subcanvas
l = ax.plot(x, y) #Define the data in x and y axix
l = l[0]

def animate(i):
  l.set_data(x[:i],y[:i])
  return l

for i in range(len(x)):
    animate(i)
    clear_output(wait=True) #clear_output to clear the output of a cell.
    display(fig)

plt.show()
```

```
x:[0.  2.5  5.  7.5  10. ]
y:[0.  6.25 25. 56.25 100.]
```

1st iteration: i=0 x[:0] y[:0]
2nd iteration: i=1 x[:1] y[:1]
3rd iteration: i=2 x[:2] y[:2]
4th iteration: i=3 x[:3] y[:3]
5th iteration: i=4 x[:4] y[:4]

Function in Lambda Style

- A lambda function can take any number of arguments, but can only have one expression.

```
def g(x):
    return x+1
```

```
g = lambda x:x+1
```

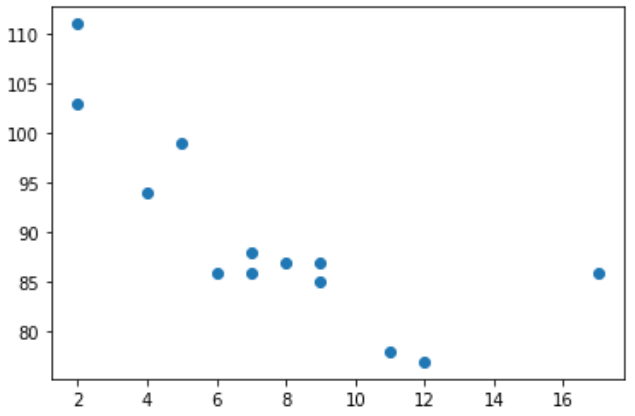
```
def animate(i):
    l.set_data(x[:i],y[:i])
    return l
```

```
animate = lambda i: l.set_data(t[:i], x[:i])
```

PyPlot: Scatter

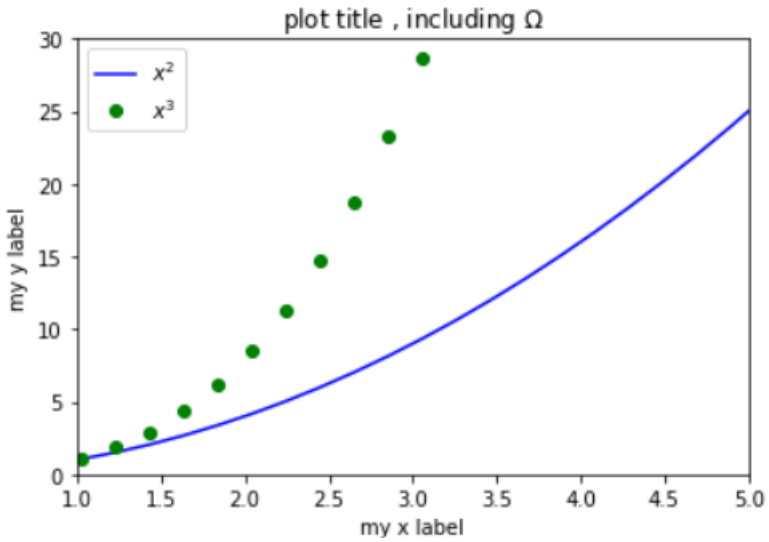
- The scatter() function plots one dot for each observation. It needs two arrays of the same length, one for the values of the x-axis, and one for values on the y-axis:

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

x = np.array([5,7,8,7,2,17,2,9,4,11,12,9,6])
y = np.array([99,86,87,88,111,86,103,87,94,78,77,85,86])

plt.scatter(x, y)
plt.show()
```



Adding multiple lines and a legend

```
#Adding multiple lines and a legend

import numpy as np
import matplotlib.pyplot as plt

x = np.linspace (0, 10, 50)
y1 = np.power(x, 2)
y2 = np.power(x, 3)
plt.plot(x, y1, 'b-', label='$x^2$')
plt.plot(x, y2, 'go', label='$x^3$')
plt.xlim((1, 5))
plt.ylim((0, 30))
plt.xlabel('my x label')
plt.ylabel('my y label')
plt.title('plot title , including $\Omega$')
plt.legend()
```



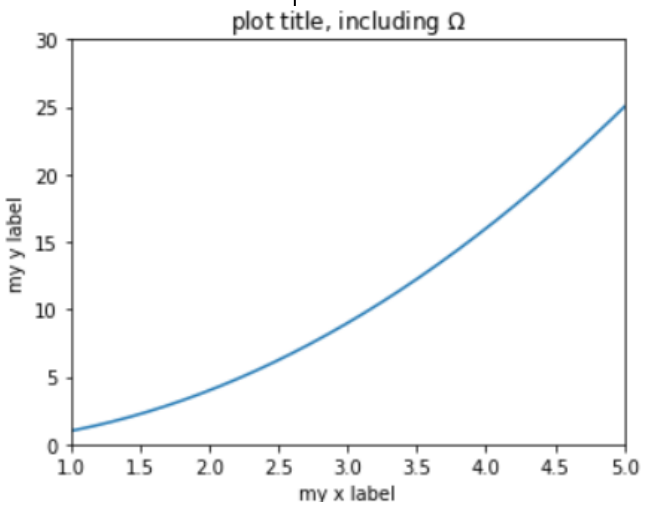
To plot the curve of the following mathematical function:

$y_1 = x^2 \quad y_2 = x^3$

Make your figure more clear

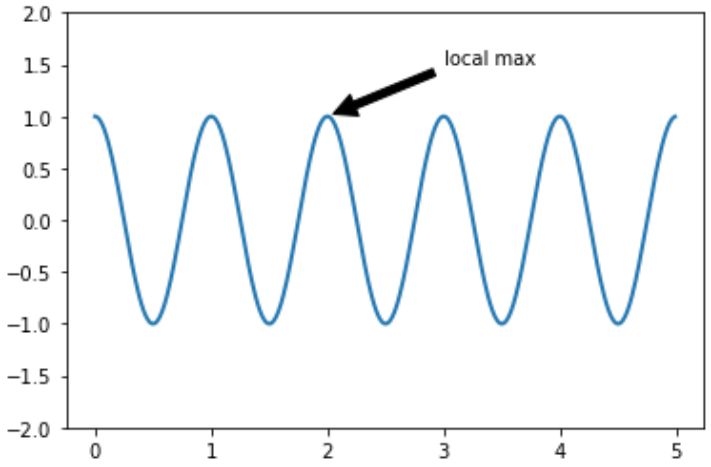
```
#Adding titles and labels
import numpy as np
import matplotlib.pyplot as plt

f, ax = plt.subplots(1, 1, figsize=(5,4))
x = np.linspace(0, 10, 1000)
y = np.power(x, 2)
ax.plot(x, y)
ax.set_xlim((1, 5)) #Set the x-axis view limits.
ax.set_ylim((0, 30)) #Set the y-axis view limits.
ax.set_xlabel('my x label') #set the y label here
ax.set_ylabel('my y label') #set the x label here
ax.set_title('plot title, including $\Omega$') # set the title here
plt.tight_layout()
```

Give your figure some labels!



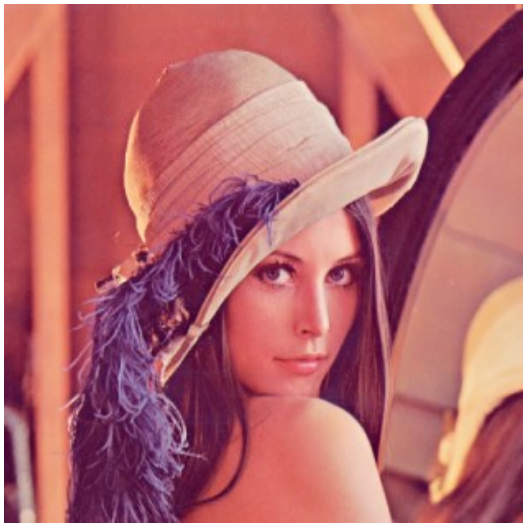
Annotate your figure

```
ax = plt.subplot()

t = np.arange(0.0, 5.0, 0.01)
s = np.cos(2*np.pi*t)
line, = plt.plot(t, s, lw=2) #lw = Linewidth

plt.annotate('local max', xy=(2, 1), xytext=(3, 1.5),
             arrowprops=dict(facecolor='black', shrink=0.05),
             )

plt.ylim(-2, 2)
plt.show()
```



At last, A story about Lena figure

- Lenna or Lena is a standard test image used in the field of image processing since 1973
- It is a picture of the Swedish model Lena Söderberg captured in 1960s for Playboy magazine.



1960s

Lenna attended a research conference in 1997

She attended ICIP 2015 in Québec