LAB 2: FINISHING UP PYTHON BASICS, NUMPY & WORKING WITH AUDIO DATA

University of Washington

EE 241

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OUTLINE

Part 1: Finishing up Python Basics

- Conditional Statements
- Loops
- Functions

Part 2: Introduction to Numpy

- Numpy arrays
- Array operations in Numpy
- Useful Numpy functions
- Math operations with Numpy

Part 3: Plotting with matplotlib

- Basic plotting
- Labeling your plots
- Multiple plots
- Subplots

Part 4: Audio I.O.

- Digital audio data
- Read/write/play audio files

Part 5: Lab Assignments

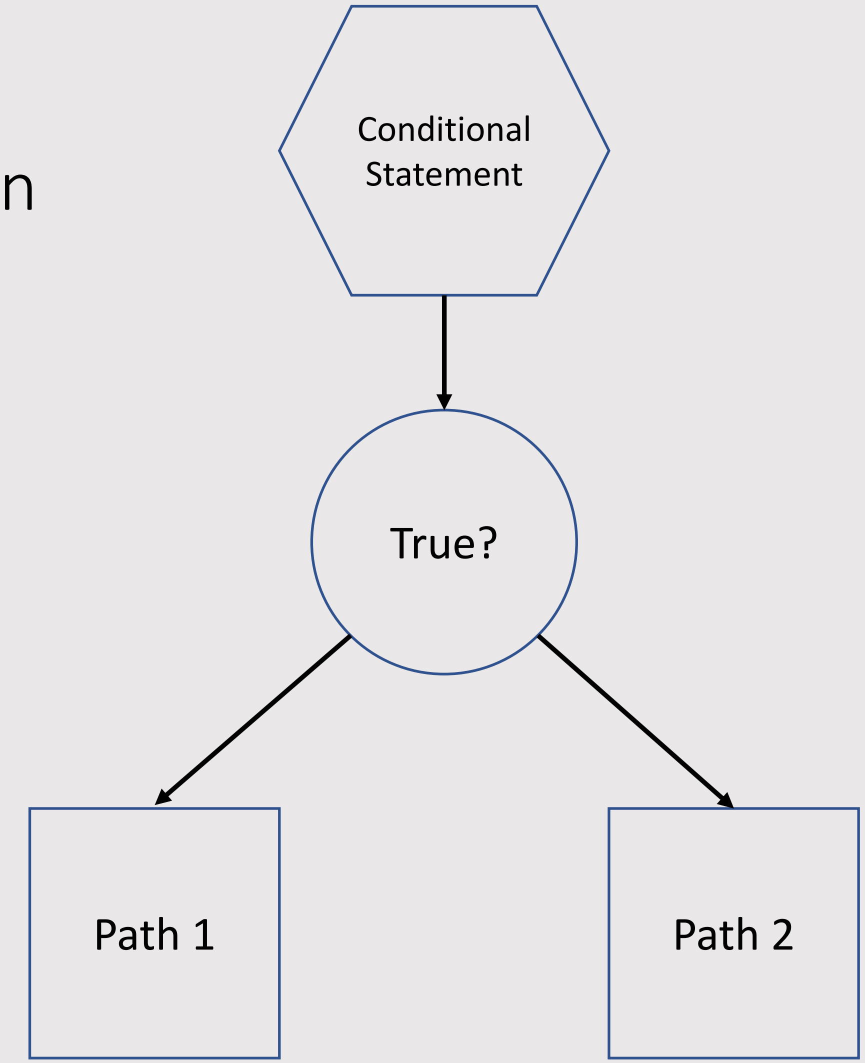
- Exercise 1 – 5

CONDITIONAL STATEMENTS, FUNCTIONS, LOOPS

CONDITIONAL STATEMENTS

Types of conditional statements in Python

- If
- If-else
- If-elif-else



Conditional Statement

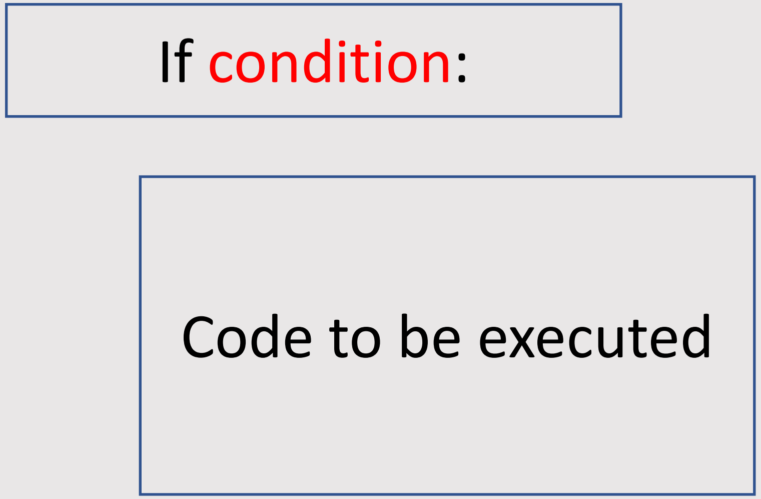
True?

Path 1

Path 2

CONDITIONAL STATEMENTS: if

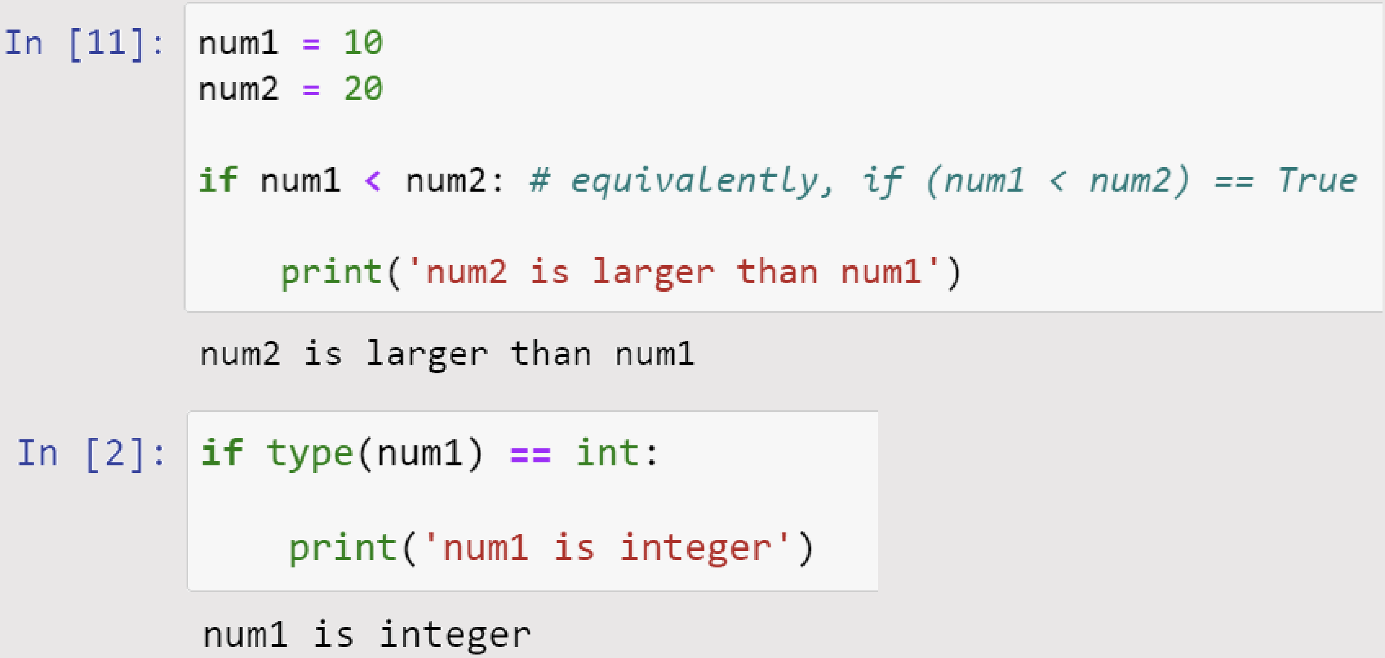
Implementation structure



If condition:

Code to be executed

Code example

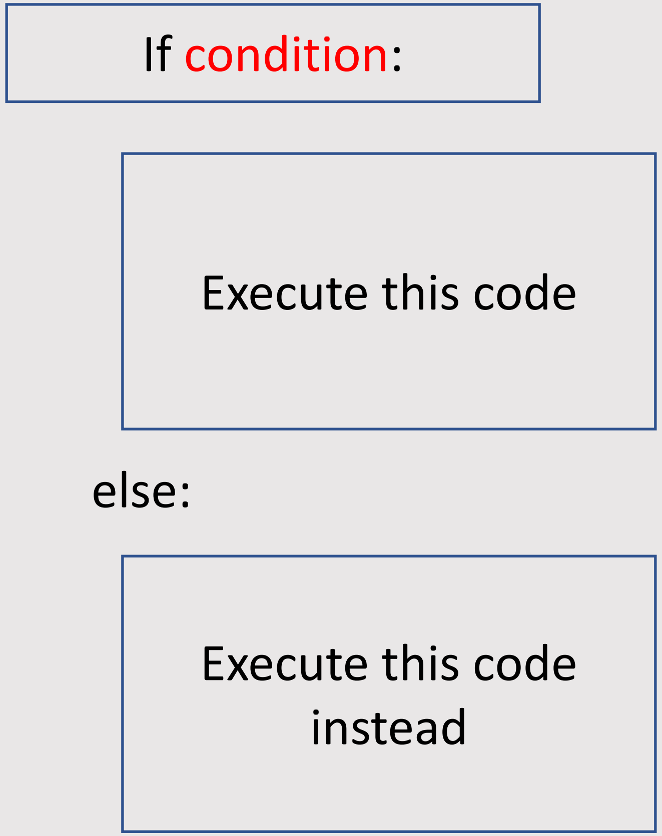


```
In [11]: num1 = 10
         num2 = 20

         if num1 < num2: # equivalently, if (num1 < num2) == True

             print('num2 is larger than num1')

         num2 is larger than num1
```

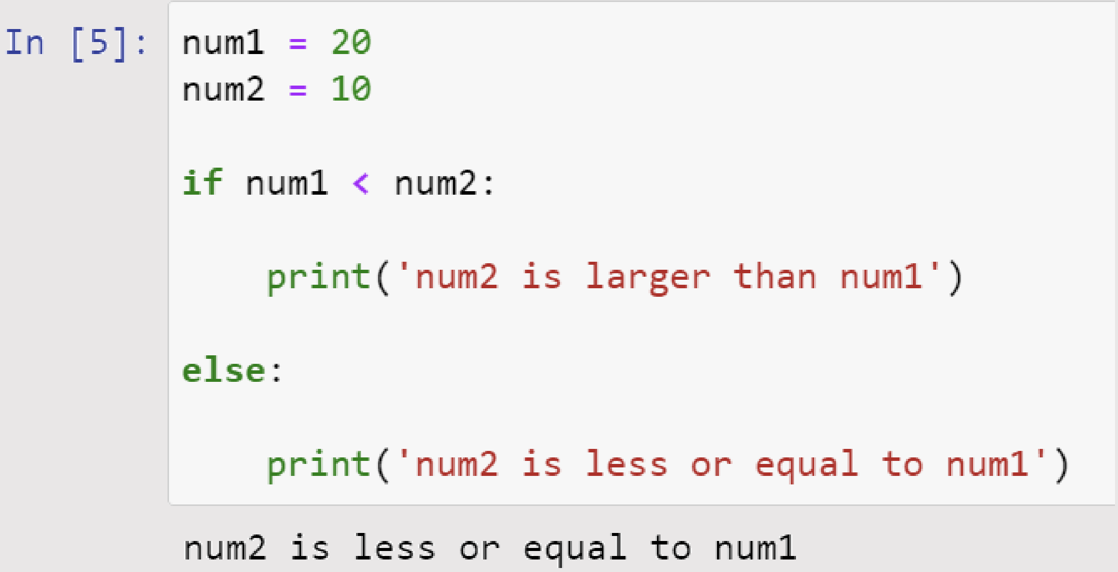
```
In [2]:  if type(num1) == int:

             print('num1 is integer')

         num1 is integer
```

CONDITIONAL STATEMENTS: if-else

Implementation structure



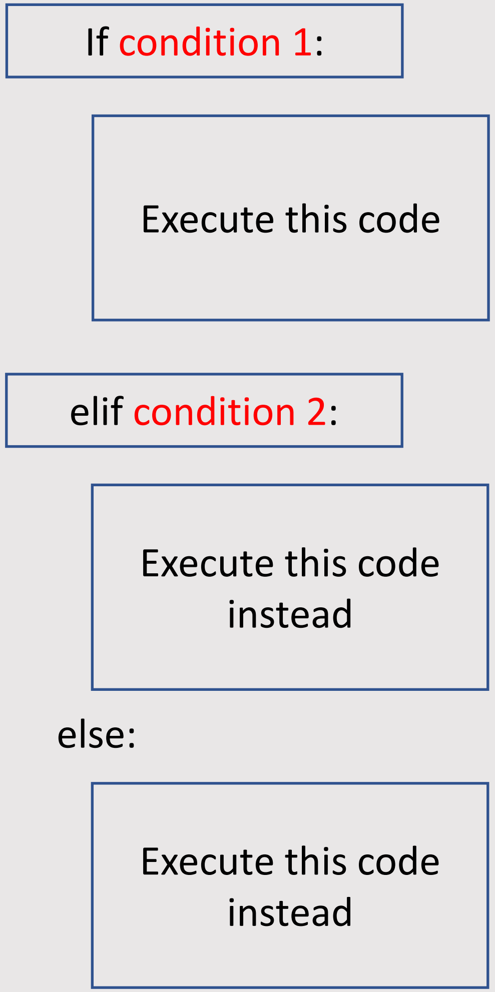
Code example



```
In [5]: num1 = 20
        num2 = 10

        if num1 < num2:

            print('num2 is larger than num1')

        else:

            print('num2 is less or equal to num1')

num2 is less or equal to num1
```

CONDITIONAL STATEMENTS: if-elif-else

Implementation structure



If condition 1:

Execute this code

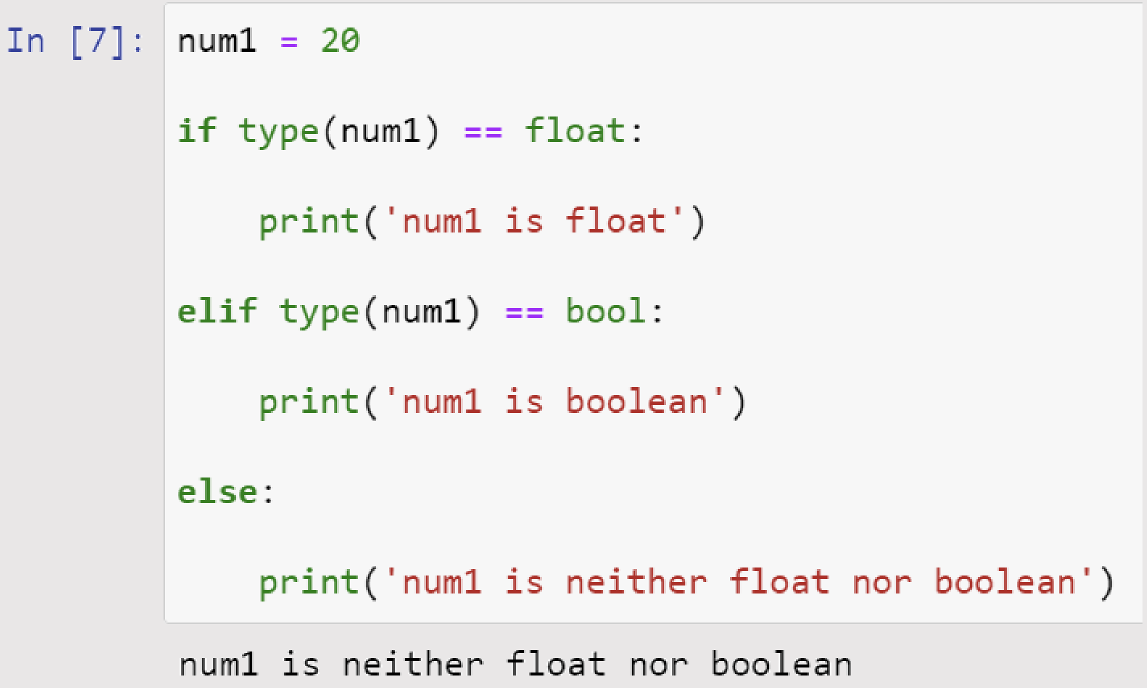
elif condition 2:

Execute this code instead

else:

Execute this code instead

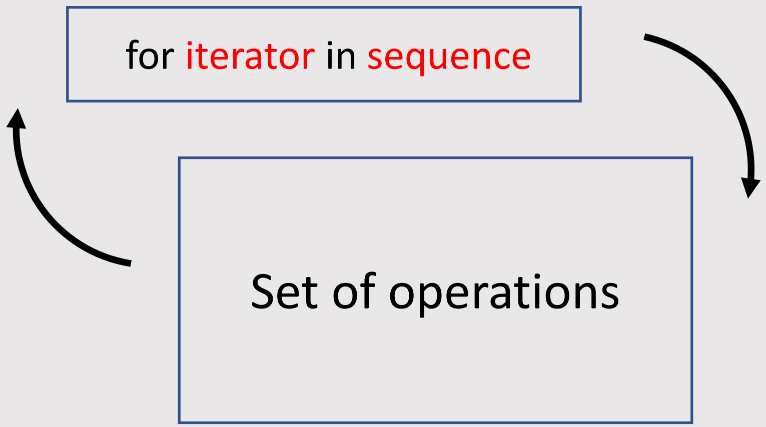
Code example



```
In [7]: num1 = 20

        if type(num1) == float:

            print('num1 is float')

        elif type(num1) == bool:

            print('num1 is boolean')

        else:

            print('num1 is neither float nor boolean')

        num1 is neither float nor boolean
```

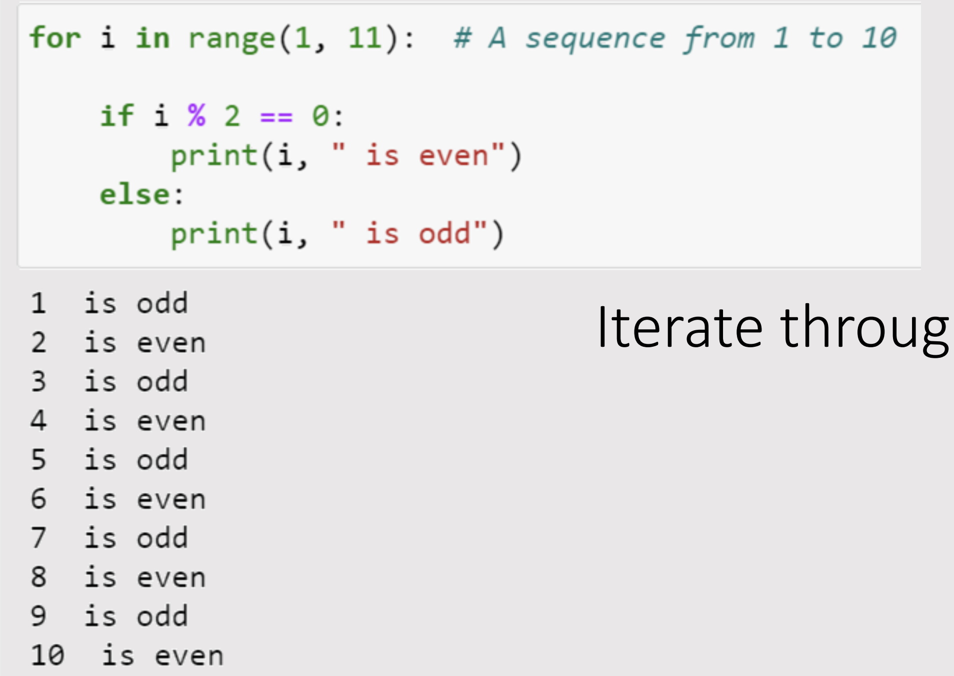
Note: You can have multiple elif conditions between if and else

LOOPS: for LOOP



for iterator in sequence

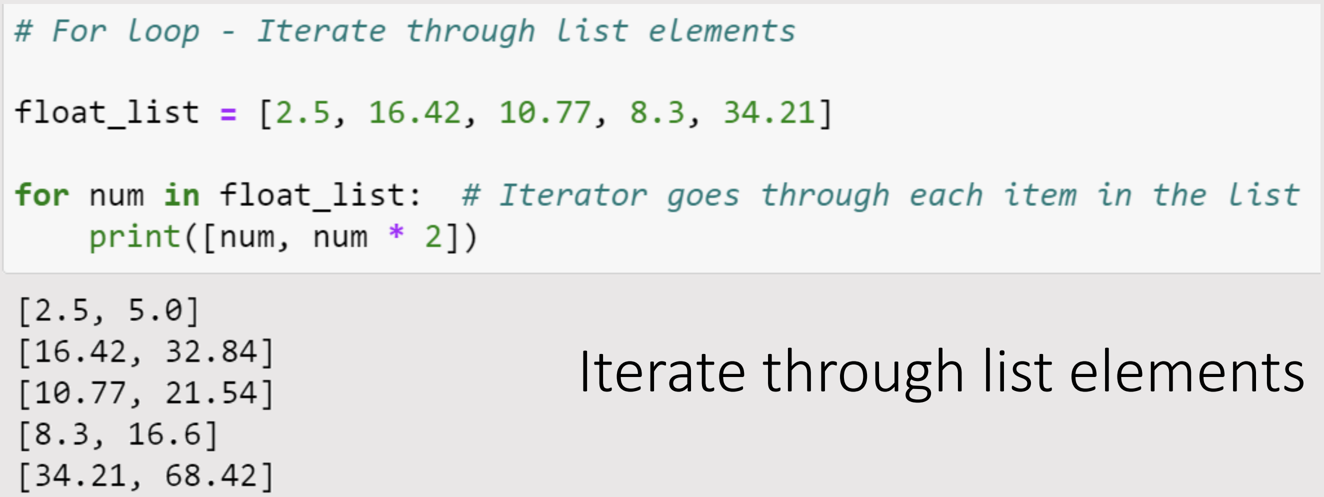
Set of operations



```python
for i in range(1, 11):   # A sequence from 1 to 10

    if i % 2 == 0:
        print(i, " is even")
    else:
        print(i, " is odd")
```

```
1  is odd
2  is even
3  is odd
4  is even
5  is odd
6  is even
7  is odd
8  is even
9  is odd
10  is even
```

Iterate through sequence

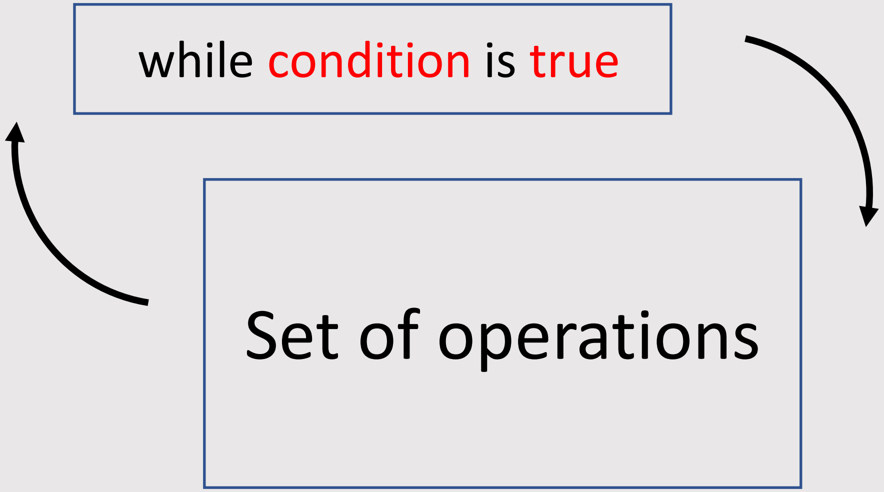


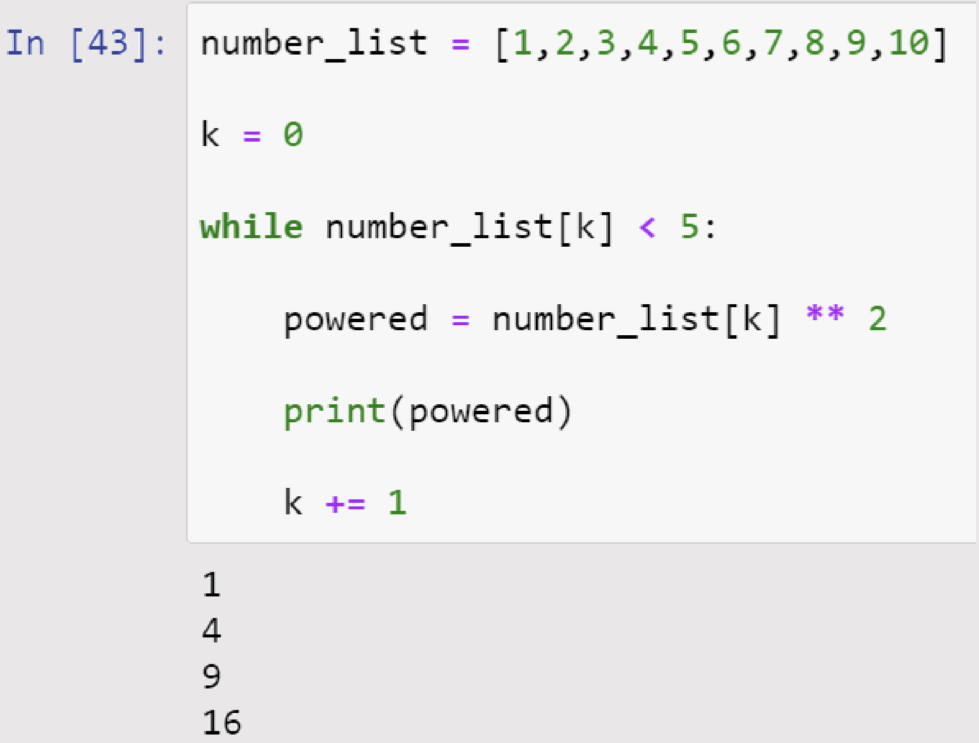
```python
# For Loop - Iterate through list elements

float_list = [2.5, 16.42, 10.77, 8.3, 34.21]

for num in float_list:  # Iterator goes through each item in the list
    print([num, num * 2])
```

```
[2.5, 5.0]
[16.42, 32.84]
[10.77, 21.54]
[8.3, 16.6]
[34.21, 68.42]
```

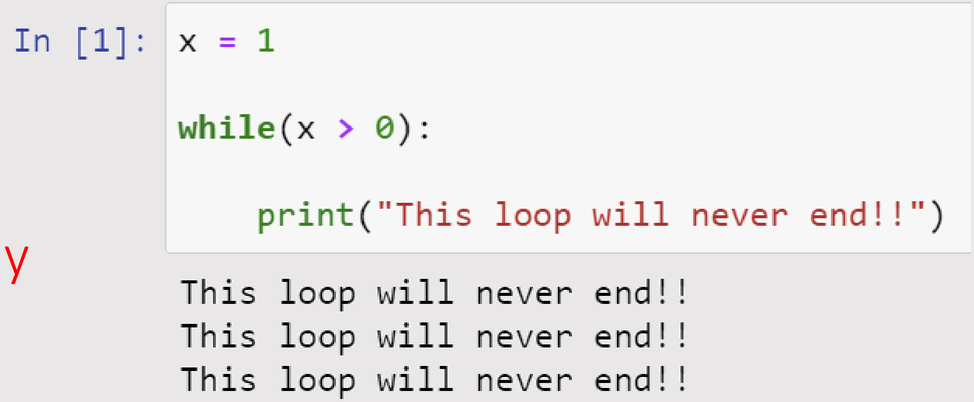
Iterate through list elements

LOOPS: while LOOP





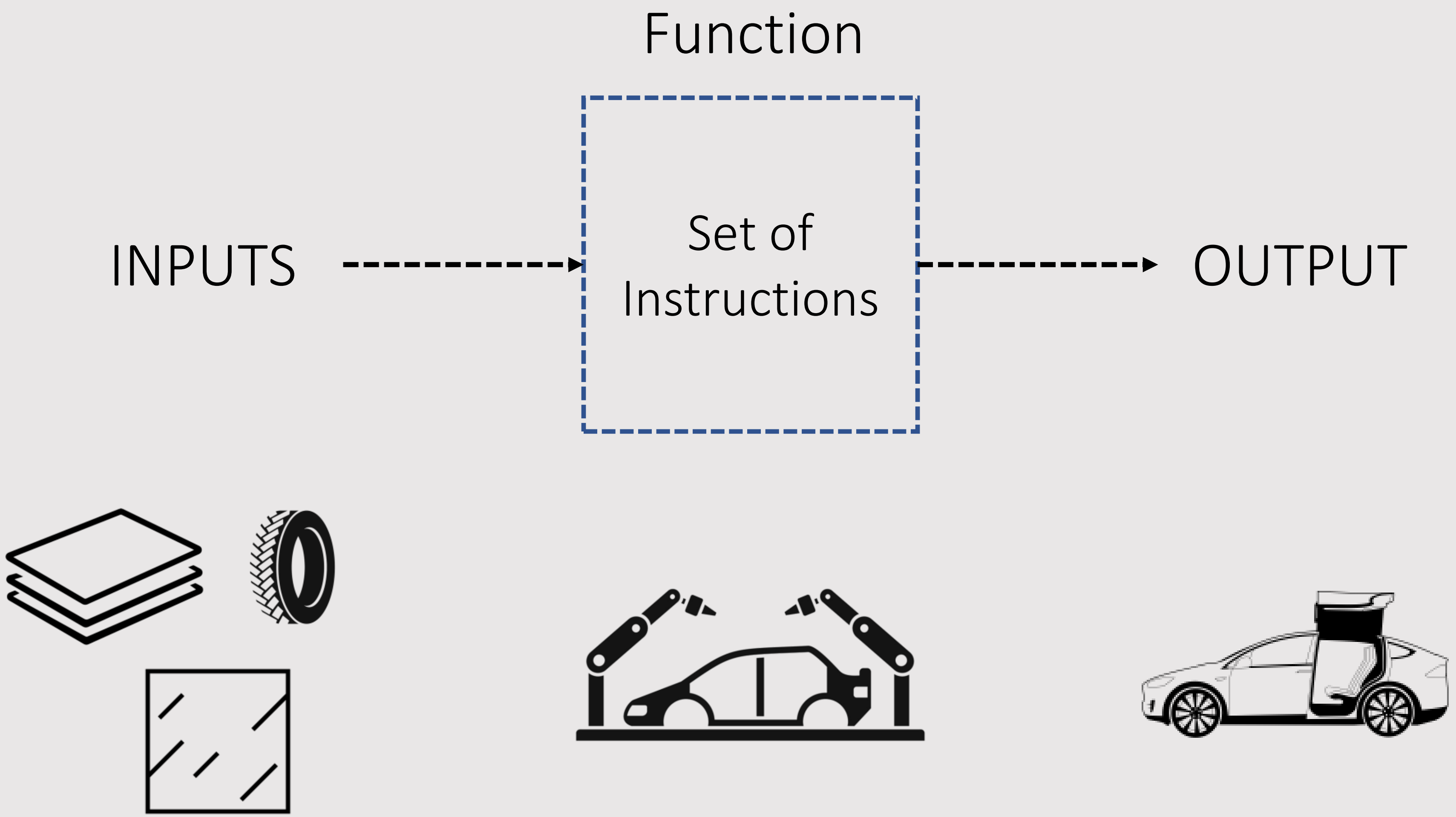
```
In [43]: number_list = [1,2,3,4,5,6,7,8,9,10]

         k = 0

         while number_list[k] < 5:

             powered = number_list[k] ** 2

             print(powered)

             k += 1

1
4
9
16
```



```
In [1]: x = 1

        while(x > 0):

            print("This loop will never end!!")

This loop will never end!!
This loop will never end!!
This loop will never end!!
```

Note: while loop has a potential to run infinitely if not set correctly

FUNCTIONS



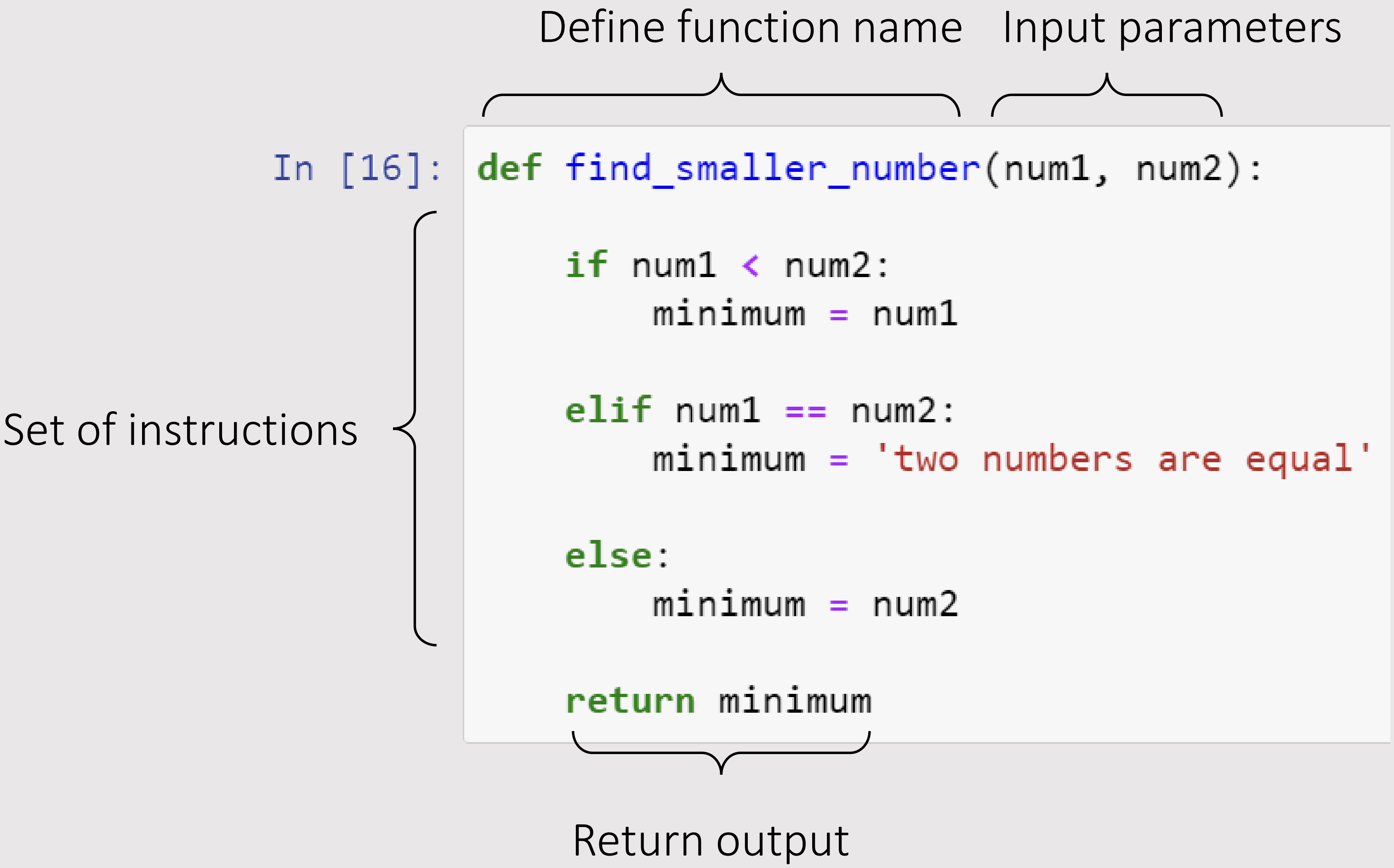
Function

INPUTS

Set of Instructions

OUTPUT

DEFINING A FUNCTION



Define function name

Input parameters

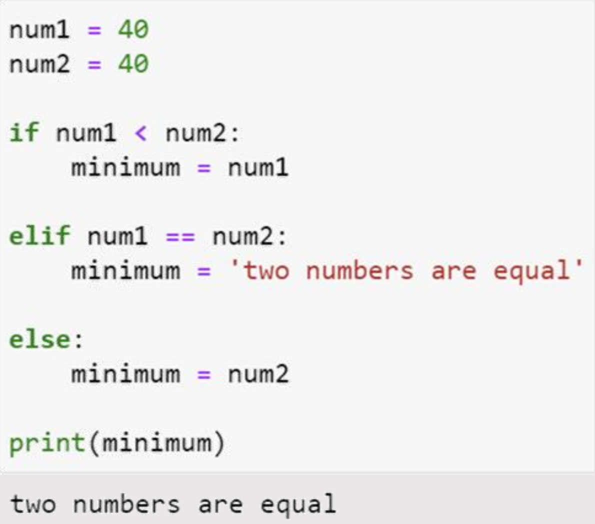
```
In [16]: def find_smaller_number(num1, num2):

             if num1 < num2:
                 minimum = num1

             elif num1 == num2:
                 minimum = 'two numbers are equal'

             else:
                 minimum = num2

             return minimum
```

Set of instructions

Return output

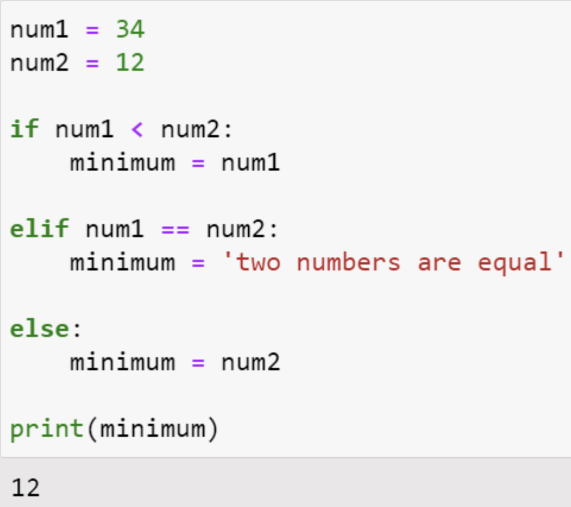
WHY USE FUNCTIONS?

Without a function



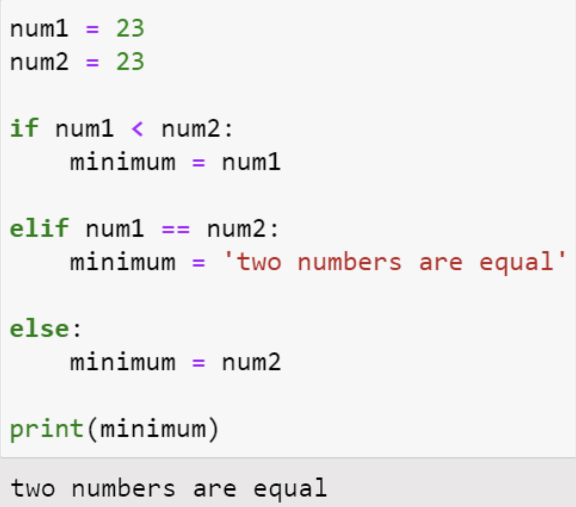
```
num1 = 40
num2 = 40

if num1 < num2:
    minimum = num1

elif num1 == num2:
    minimum = 'two numbers are equal'

else:
    minimum = num2

print(minimum)
```

```
two numbers are equal
```



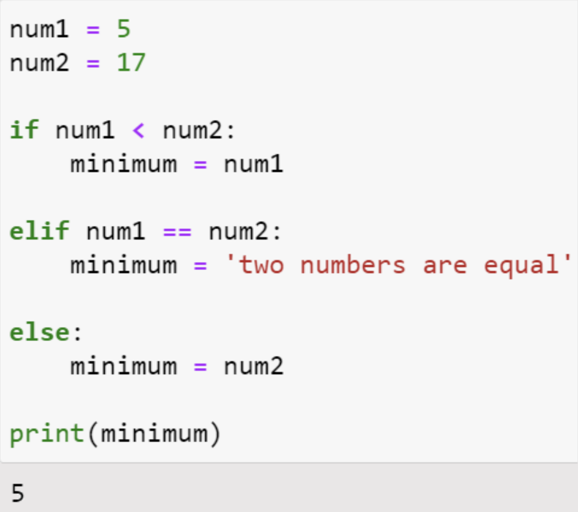
```
num1 = 34
num2 = 12

if num1 < num2:
    minimum = num1

elif num1 == num2:
    minimum = 'two numbers are equal'

else:
    minimum = num2

print(minimum)
```

```
12
```



```
num1 = 23
num2 = 23

if num1 < num2:
    minimum = num1

elif num1 == num2:
    minimum = 'two numbers are equal'

else:
    minimum = num2

print(minimum)
```

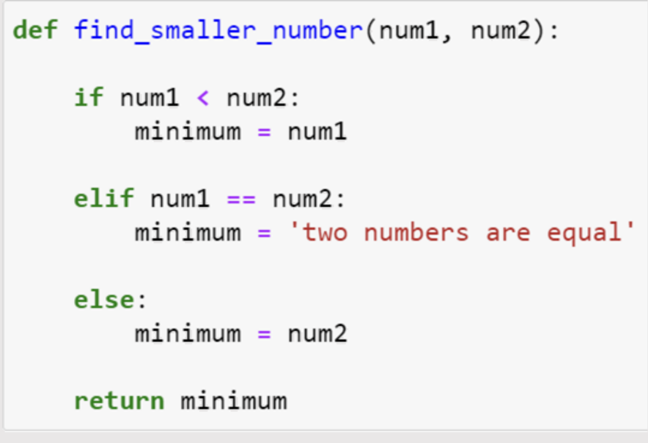
```
two numbers are equal
```



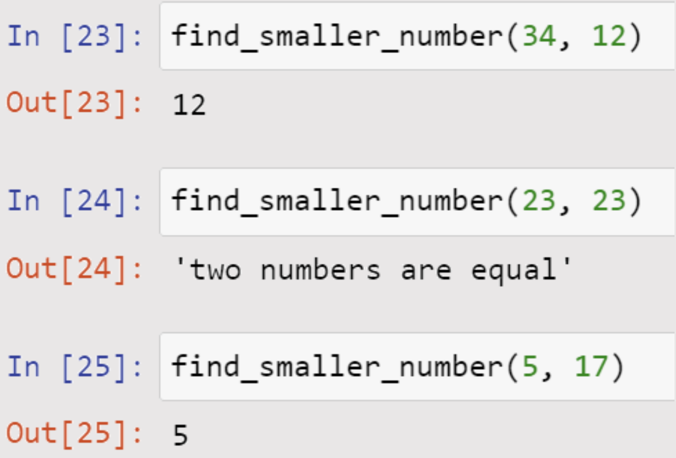
```
num1 = 5
num2 = 17

if num1 < num2:
    minimum = num1

elif num1 == num2:
    minimum = 'two numbers are equal'

else:
    minimum = num2

print(minimum)
```

```
5
```

With a function



```
def find_smaller_number(num1, num2):

    if num1 < num2:
        minimum = num1

    elif num1 == num2:
        minimum = 'two numbers are equal'

    else:
        minimum = num2

    return minimum
```



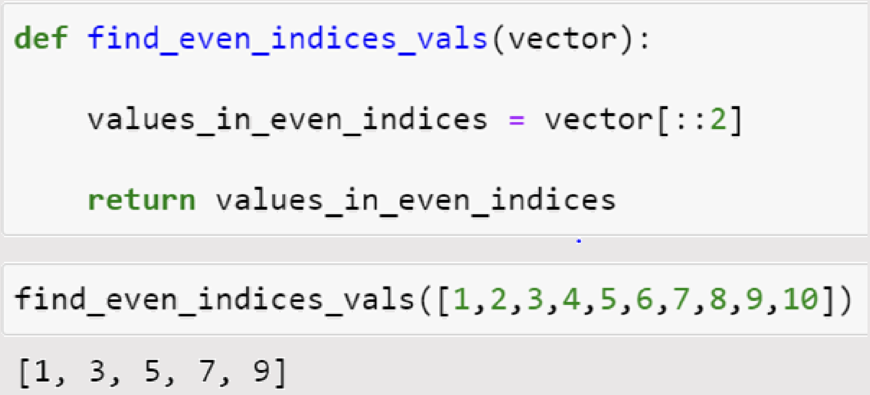
```
In [23]: find_smaller_number(34, 12)

Out[23]: 12

In [24]: find_smaller_number(23, 23)

Out[24]: 'two numbers are equal'

In [25]: find_smaller_number(5, 17)

Out[25]: 5
```

Functions make complex set of operations reusable

Any variable defined within a function is ‘Local’.

FUNCTIONS: EXAMPLES

Find values of even indices

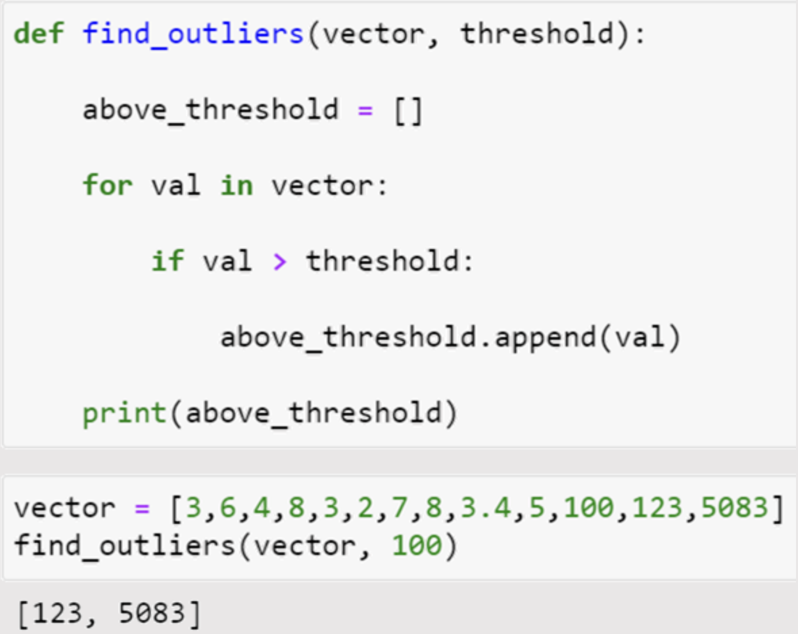


```
def find_even_indices_vals(vector):

    values_in_even_indices = vector[::2]

    return values_in_even_indices
```

```
find_even_indices_vals([1,2,3,4,5,6,7,8,9,10])
```

```
[1, 3, 5, 7, 9]
```

Find values > set threshold

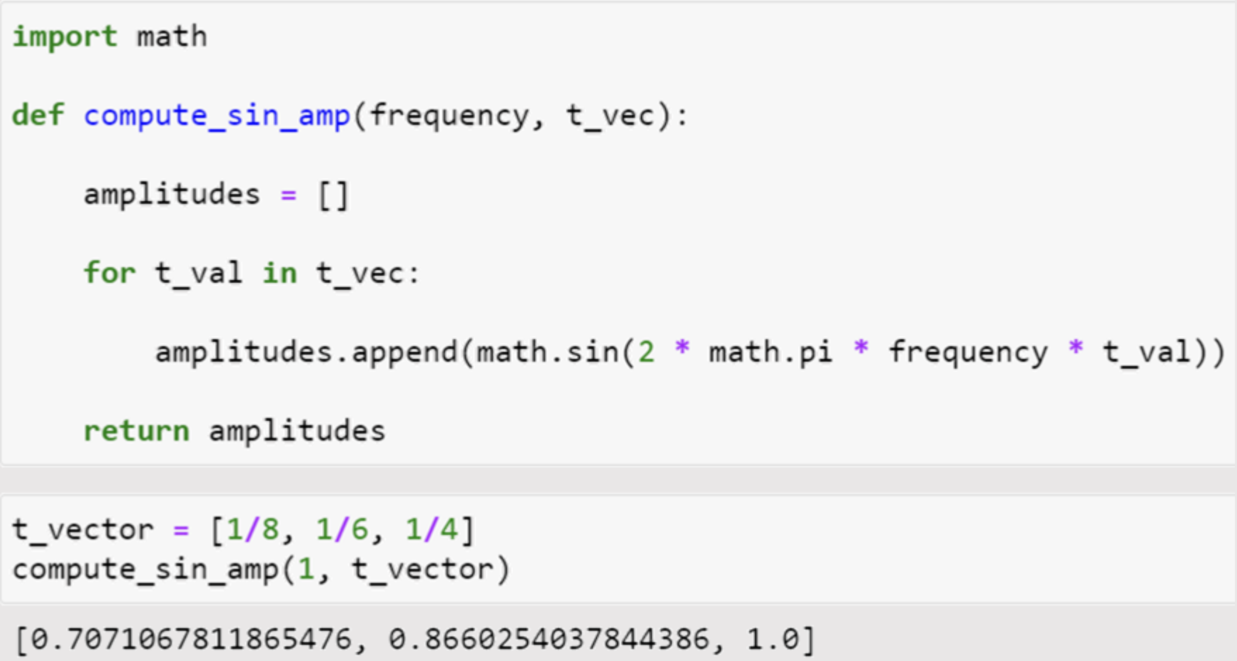


```
def find_outliers(vector, threshold):

    above_threshold = []

    for val in vector:

        if val > threshold:

            above_threshold.append(val)

    print(above_threshold)
```

```
vector = [3,6,4,8,3,2,7,8,3.4,5,100,123,5083]
find_outliers(vector, 100)
```

```
[123, 5083]
```

Find sine values with a given frequency



```
import math

def compute_sin_amp(frequency, t_vec):

    amplitudes = []

    for t_val in t_vec:

        amplitudes.append(math.sin(2 * math.pi * frequency * t_val))

    return amplitudes
```

```
t_vector = [1/8, 1/6, 1/4]
compute_sin_amp(1, t_vector)
```

```
[0.7071067811865476, 0.8660254037844386, 1.0]
```

Note: You can call defined functions within a function

INTRODUCTION TO NUMPY

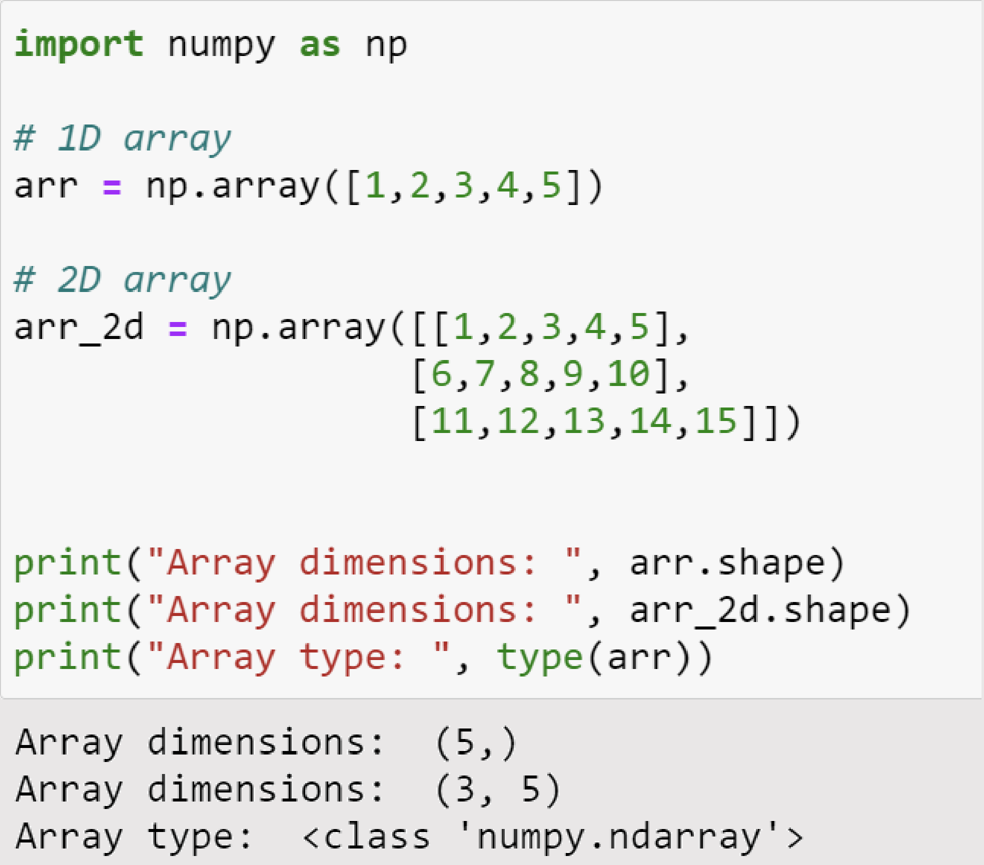
WHAT IS NUMPY?

Fundamental package for scientific computing in Python

- Supports multi-dimensional array object
- Provides assortment of mathematical routines for arrays
- Fast array operations through pre-compiled C
- Support array-wide broadcasting for operations
- Included in Anaconda 3

CONSTRUCTING NUMPY ARRAYS

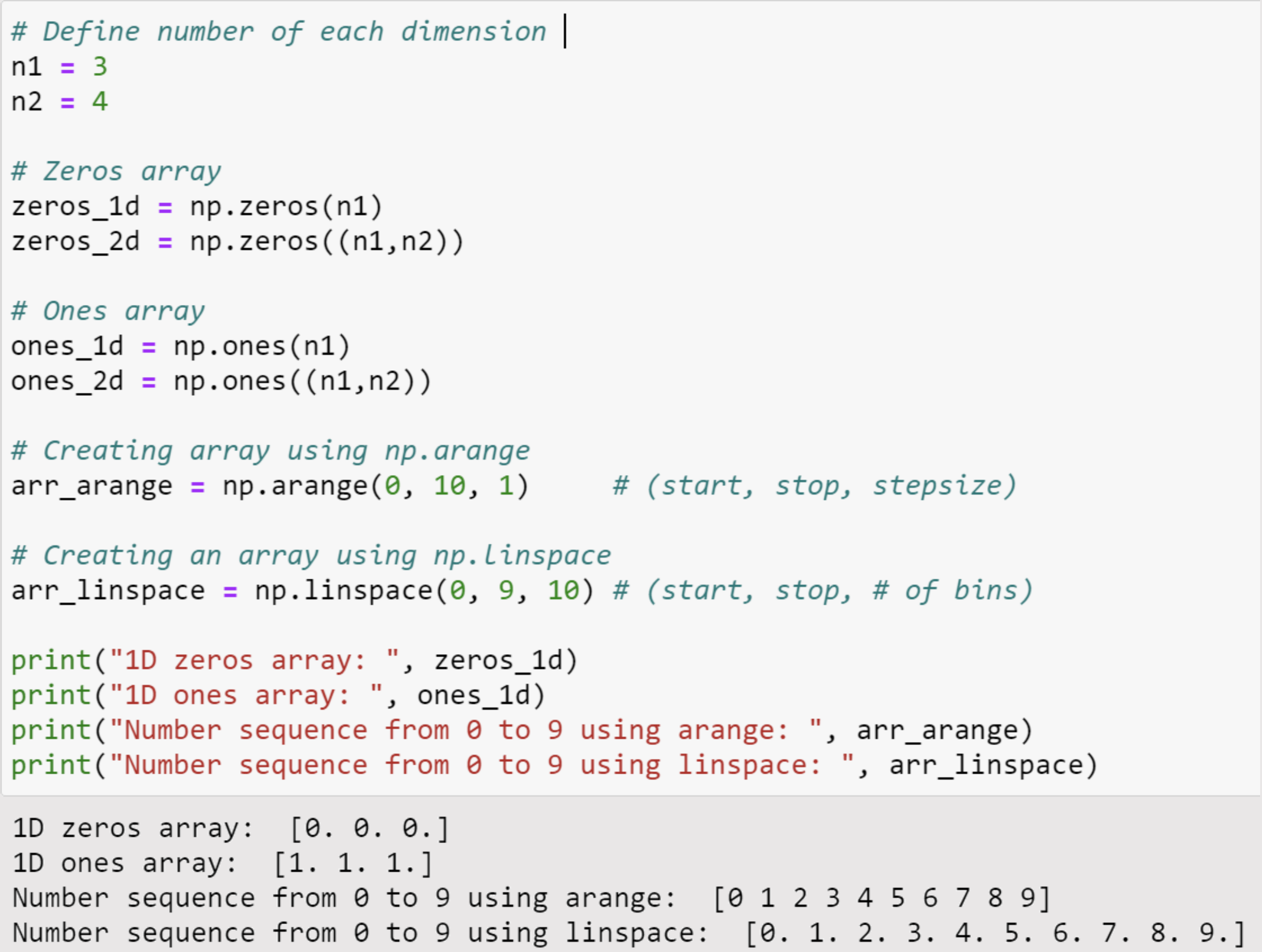
From Python lists



```python
import numpy as np

# 1D array
arr = np.array([1,2,3,4,5])

# 2D array
arr_2d = np.array([[1,2,3,4,5],
                  [6,7,8,9,10],
                  [11,12,13,14,15]])


print("Array dimensions: ", arr.shape)
print("Array dimensions: ", arr_2d.shape)
print("Array type: ", type(arr))
```

```
Array dimensions:  (5,)
Array dimensions:  (3, 5)
Array type:  <class 'numpy.ndarray'>
```

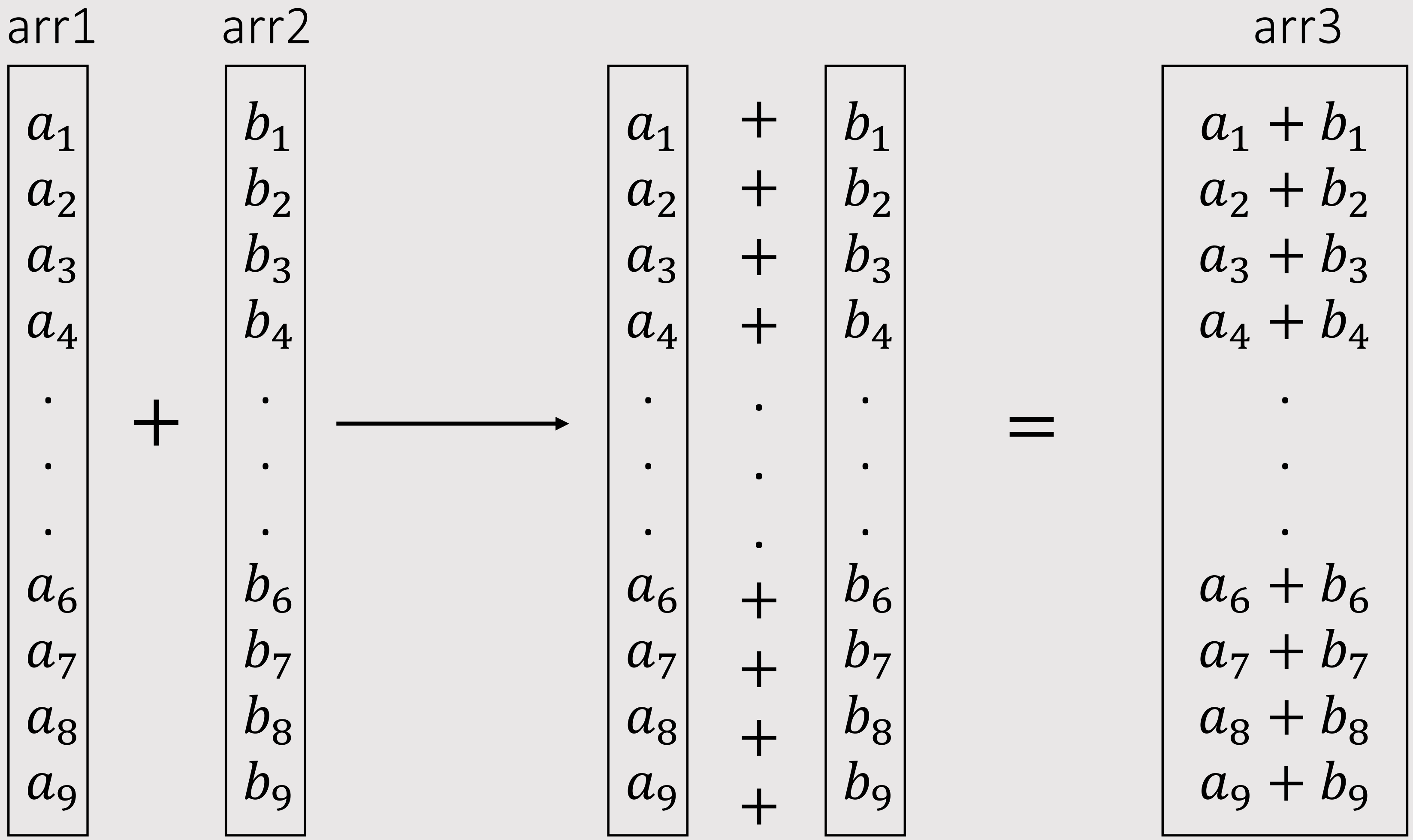
From Numpy commands



```python
# Define number of each dimension
n1 = 3
n2 = 4

# Zeros array
zeros_1d = np.zeros(n1)
zeros_2d = np.zeros((n1,n2))

# Ones array
ones_1d = np.ones(n1)
ones_2d = np.ones((n1,n2))

# Creating array using np.arange
arr_arange = np.arange(0, 10, 1)     # (start, stop, stepsize)

# Creating an array using np.linspace
arr_linspace = np.linspace(0, 9, 10) # (start, stop, # of bins)

print("1D zeros array: ", zeros_1d)
print("1D ones array: ", ones_1d)
print("Number sequence from 0 to 9 using arange: ", arr_arange)
print("Number sequence from 0 to 9 using linspace: ", arr_linspace)
```

```
1D zeros array:  [0. 0. 0.]
1D ones array:  [1. 1. 1.]
Number sequence from 0 to 9 using arange:  [0 1 2 3 4 5 6 7 8 9]
Number sequence from 0 to 9 using linspace:  [0. 1. 2. 3. 4. 5. 6. 7. 8. 9.]
```

ARRAY-WIDE OPERATIONS IN NUMPY



$$\overset{\text{arr1}}{\begin{array}{|c|}\hline a_1\\ a_2\\ a_3\\ a_4\\ .\\ .\\ .\\ a_6\\ a_7\\ a_8\\ a_9\\ \hline\end{array}} + \overset{\text{arr2}}{\begin{array}{|c|}\hline b_1\\ b_2\\ b_3\\ b_4\\ .\\ .\\ .\\ b_6\\ b_7\\ b_8\\ b_9\\ \hline\end{array}} \longrightarrow \begin{array}{|c|}\hline a_1\\ a_2\\ a_3\\ a_4\\ .\\ .\\ .\\ a_6\\ a_7\\ a_8\\ a_9\\ \hline\end{array} \begin{array}{c} +\\ +\\ +\\ +\\ .\\ .\\ .\\ +\\ +\\ +\\ +\end{array} \begin{array}{|c|}\hline b_1\\ b_2\\ b_3\\ b_4\\ .\\ .\\ .\\ b_6\\ b_7\\ b_8\\ b_9\\ \hline\end{array} = \overset{\text{arr3}}{\begin{array}{|c|}\hline a_1+b_1\\ a_2+b_2\\ a_3+b_3\\ a_4+b_4\\ .\\ .\\ .\\ a_6+b_6\\ a_7+b_7\\ a_8+b_8\\ a_9+b_9\\ \hline\end{array}}$$

numpy.add(arr1, arr2)

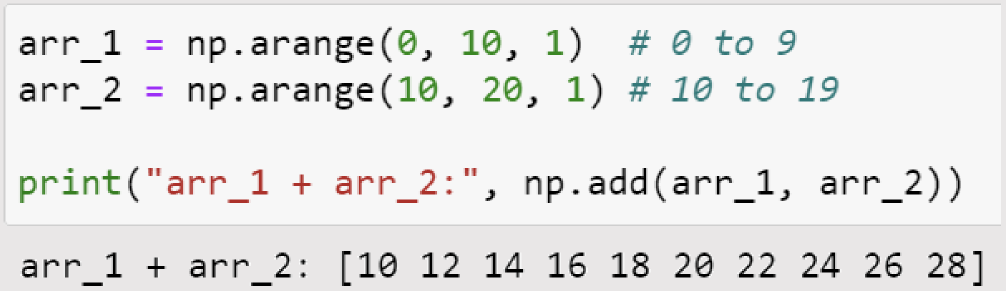
NUMPY ARITHMATIC OPERATORS

Operator

Example

Addition

np.add()

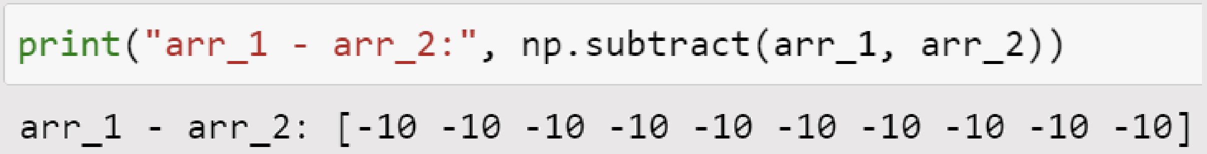


```
arr_1 = np.arange(0, 10, 1)  # 0 to 9
arr_2 = np.arange(10, 20, 1) # 10 to 19

print("arr_1 + arr_2:", np.add(arr_1, arr_2))
```

```
arr_1 + arr_2: [10 12 14 16 18 20 22 24 26 28]
```

Subtraction

np.subtract()

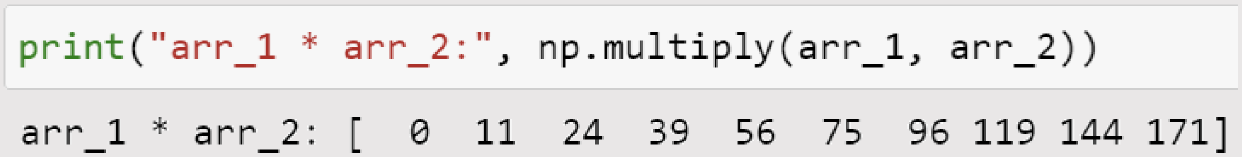


```
print("arr_1 - arr_2:", np.subtract(arr_1, arr_2))
```

```
arr_1 - arr_2: [-10 -10 -10 -10 -10 -10 -10 -10 -10 -10]
```

Multiplication

np.multiply()



```
print("arr_1 * arr_2:", np.multiply(arr_1, arr_2))
```

```
arr_1 * arr_2: [  0  11  24  39  56  75  96 119 144 171]
```

Note: The syntax assumes “import numpy as np”

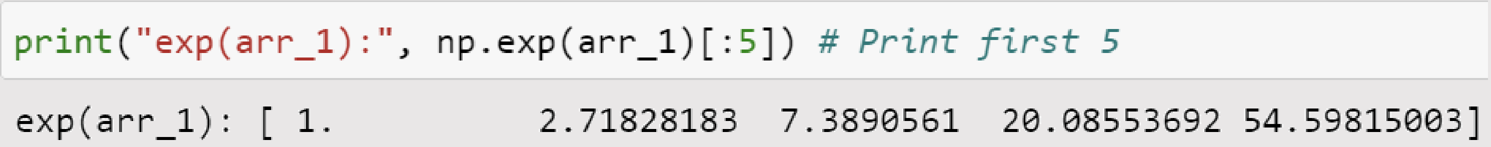
NUMPY ARITHMATIC OPERATORS

Operator

Example

Exponent

np.exp()

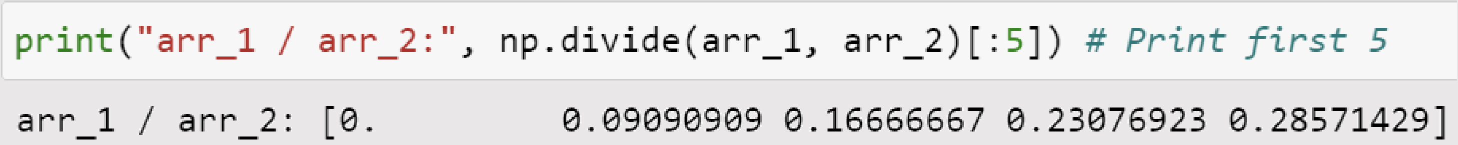


```
print("exp(arr_1):", np.exp(arr_1)[:5]) # Print first 5
```

```
exp(arr_1): [ 1.          2.71828183  7.3890561  20.08553692 54.59815003]
```

Division

np.divide()

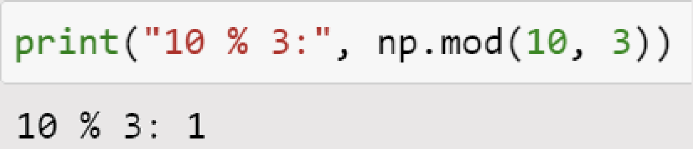


```
print("arr_1 / arr_2:", np.divide(arr_1, arr_2)[:5]) # Print first 5
```

```
arr_1 / arr_2: [0.         0.09090909 0.16666667 0.23076923 0.28571429]
```

Modulo

np.mod()



```
print("10 % 3:", np.mod(10, 3))
```

```
10 % 3: 1
```

USEFUL NUMPY OPERATIONS: COMBINING ARRAYS

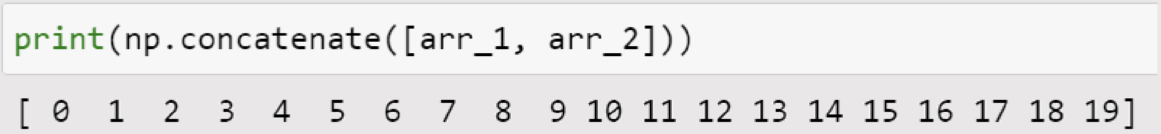
	Operator	Example
Concatenation	np.concatenate()	see below

Operator

Example

Concatenation

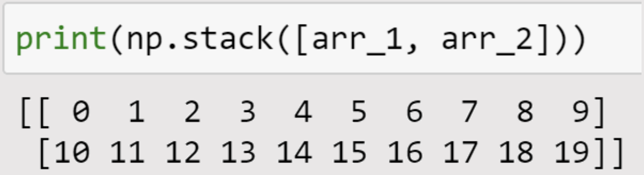
np.concatenate()



```
print(np.concatenate([arr_1, arr_2]))

[ 0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19]
```

Stack Dimensions

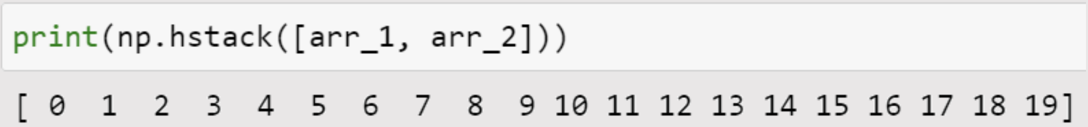
np.stack()



```
print(np.stack([arr_1, arr_2]))

[[ 0  1  2  3  4  5  6  7  8  9]
 [10 11 12 13 14 15 16 17 18 19]]
```

Horizontal Stack

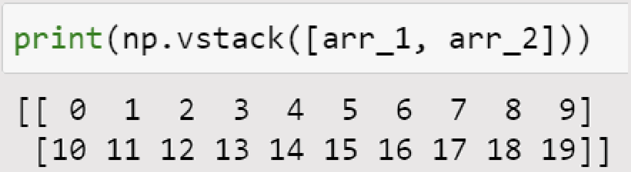
np.hstack()



```
print(np.hstack([arr_1, arr_2]))

[ 0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19]
```

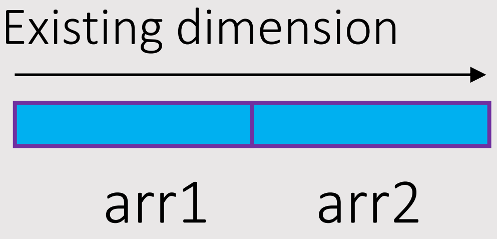
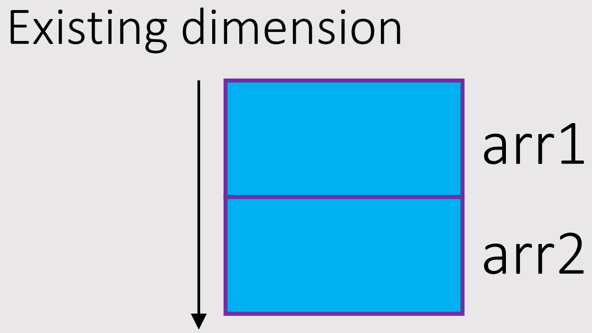
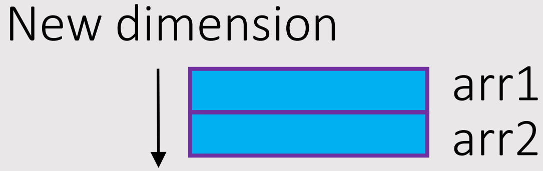
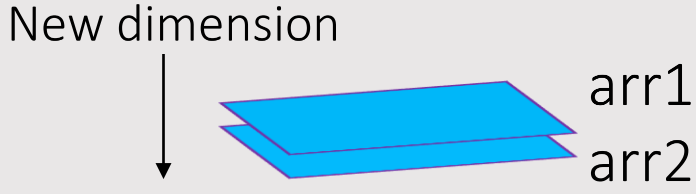
Vertical Stack

np.vstack()

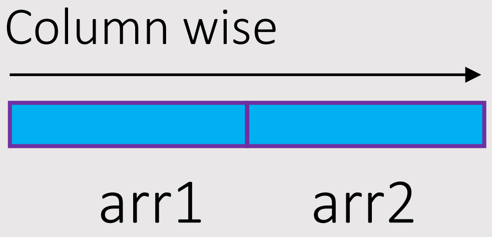
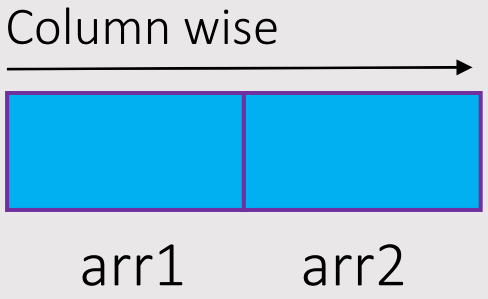
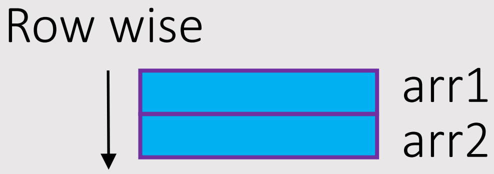
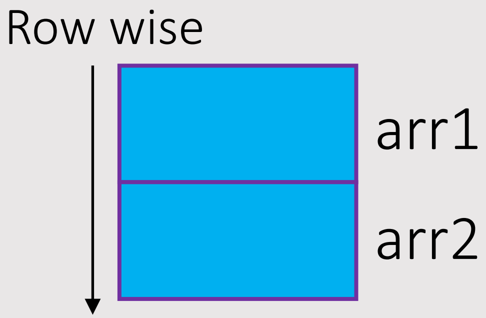


```
print(np.vstack([arr_1, arr_2]))

[[ 0  1  2  3  4  5  6  7  8  9]
 [10 11 12 13 14 15 16 17 18 19]]
```

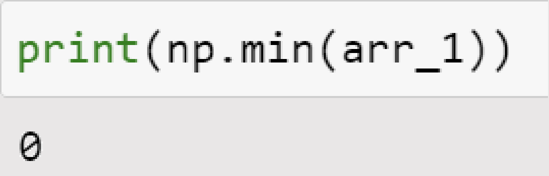
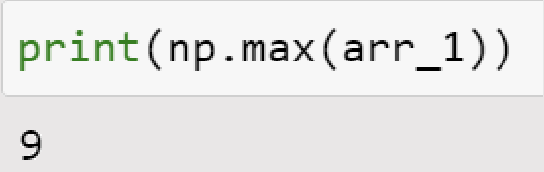
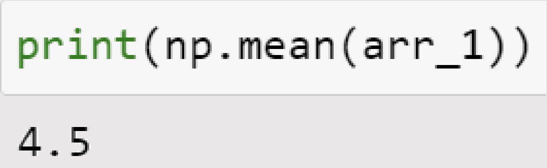
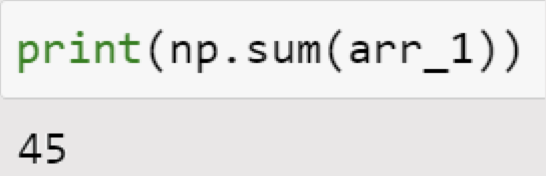
USEFUL NUMPY OPERATIONS: COMBINING ARRAYS

Operator	1D	2D
np.concatenate()		
np.stack()		

USEFUL NUMPY OPERATIONS: COMBINING ARRAYS

Operator	1D	2D
np.hstack()	 Column wise arr1 arr2	 Column wise arr1 arr2
np.vstack()	 Row wise arr1 arr2	 Row wise arr1 arr2

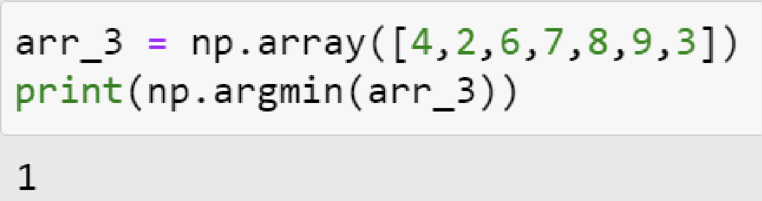
USEFUL NUMPY OPERATIONS: CHARACTERISTIC VALUES OF ARRAYS

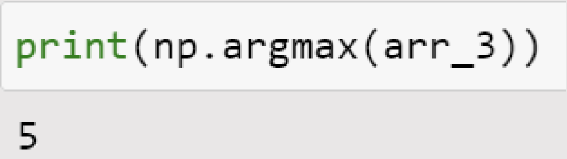
	Operator	Example
Minimum Value	np.min()	 `print(np.min(arr_1))` `0`
Maximum Value	np.max()	 `print(np.max(arr_1))` `9`
Mean Value	np.mean()	 `print(np.mean(arr_1))` `4.5`
Summed Value	np.sum()	 `print(np.sum(arr_1))` `45`

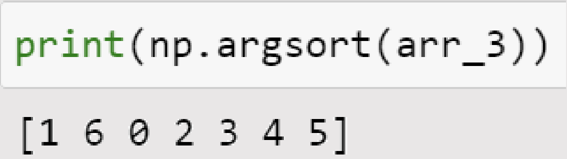
Note: axis parameter allows you to compute characteristic value alongside specific axis - e.g. np.sum(arr_1, axis =0): summation along row axis.

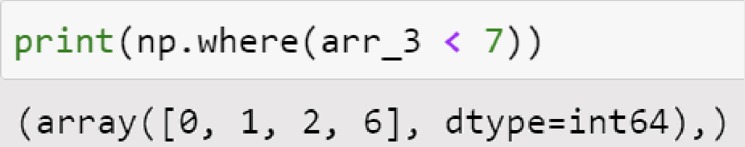
USEFUL ARRAY OPERATIONS: INDEXING ARRAYS

	Operator	Example

Minimum Value Index	np.argmin()	
		`arr_3 = np.array([4,2,6,7,8,9,3])`
		`print(np.argmin(arr_3))`
		`1`

Maximum Value Index	np.argmax()	
		`print(np.argmax(arr_3))`
		`5`

Sort Indices (low to high)	np.argsort()	
		`print(np.argsort(arr_3))`
		`[1 6 0 2 3 4 5]`

Find Indices satisfying a Condition	np.where()	
		`print(np.where(arr_3 < 7))`
		`(array([0, 1, 2, 6], dtype=int64),)`

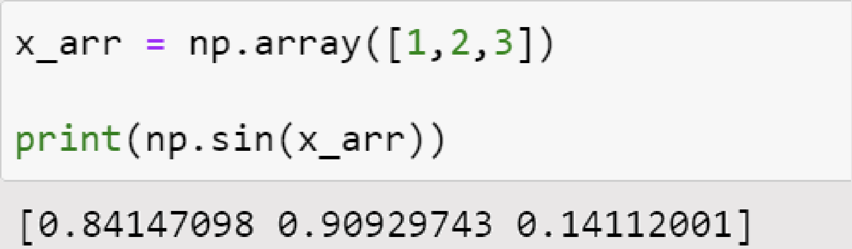
MATH OPERATORS WITH NUMPY

Operator

Example

Sine

np.sin(x)

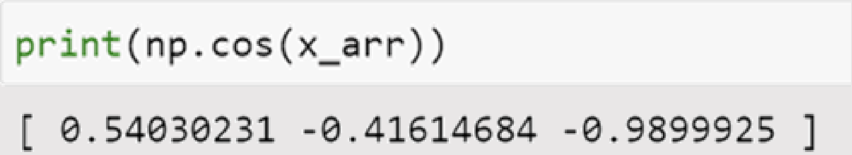


```
x_arr = np.array([1,2,3])

print(np.sin(x_arr))
```

```
[0.84147098 0.90929743 0.14112001]
```

Cosine

np.cos(x)

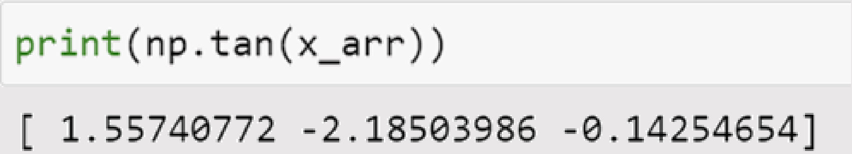


```
print(np.cos(x_arr))
```

```
[ 0.54030231 -0.41614684 -0.9899925 ]
```

Tangent

np.tan(x)



```
print(np.tan(x_arr))
```

```
[ 1.55740772 -2.18503986 -0.14254654]
```

Note: Trigonometric functions require radians as inputs

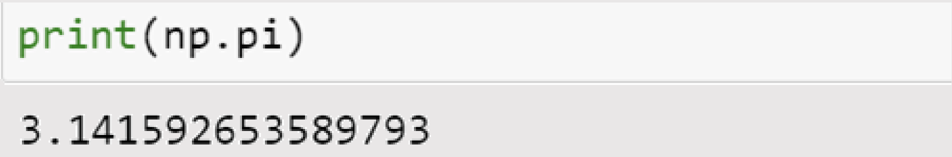
MATH OPERATORS WITH NUMPY

Operator

Example

Pi

np.pi

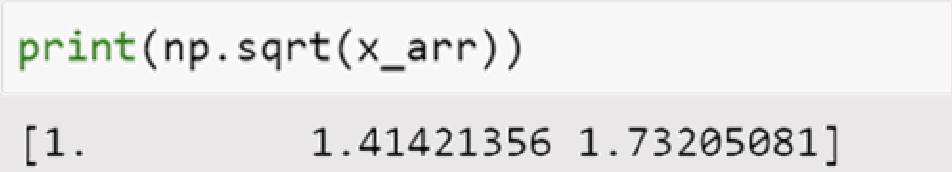


```
print(np.pi)
```

```
3.141592653589793
```

Square Root

np.sqrt(x)



```
print(np.sqrt(x_arr))
```

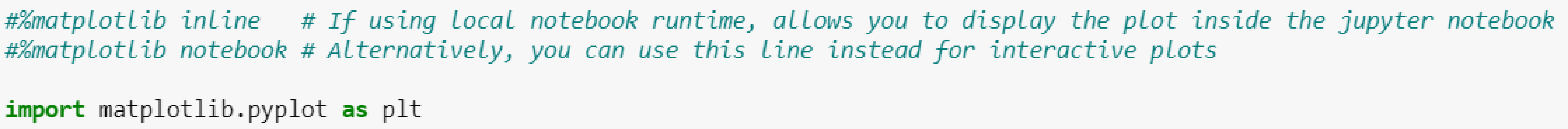
```
[1.         1.41421356 1.73205081]
```

More functions: https://numpy.org/doc/stable/reference/routines.math.html

PLOTTING WITH MATPLOTLIB

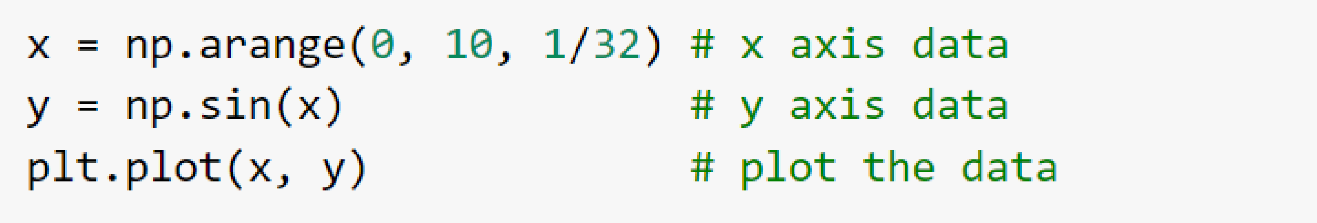
BASIC PLOTTING WITH MATPLOTLIB

Import Matplotlib



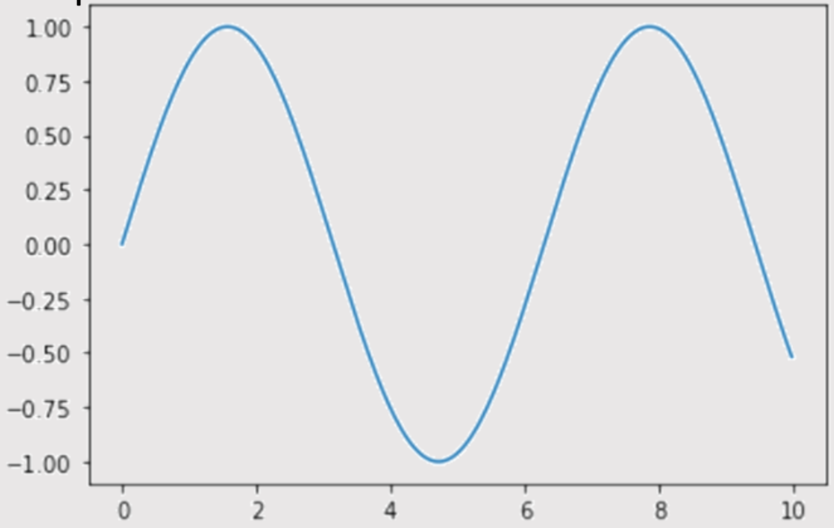
```
#%matplotlib inline   # If using local notebook runtime, allows you to display the plot inside the jupyter notebook
#%matplotlib notebook # Alternatively, you can use this line instead for interactive plots

import matplotlib.pyplot as plt
```

Code



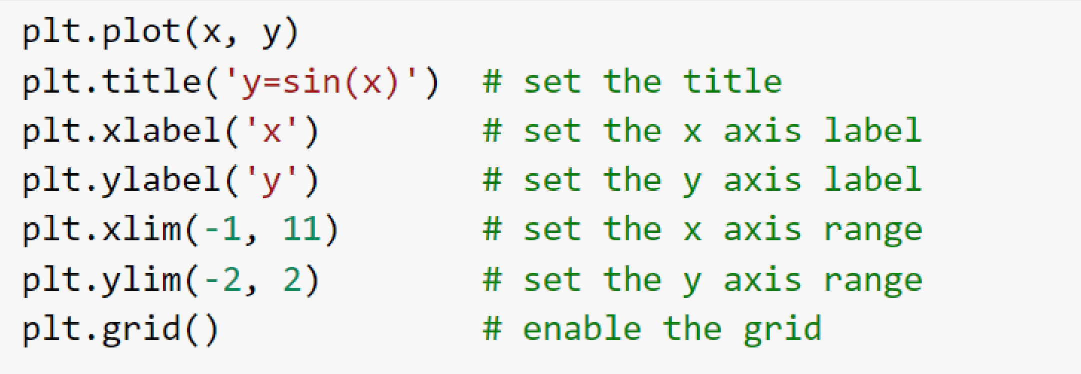
```
x = np.arange(0, 10, 1/32) # x axis data
y = np.sin(x)              # y axis data
plt.plot(x, y)             # plot the data
```

Output



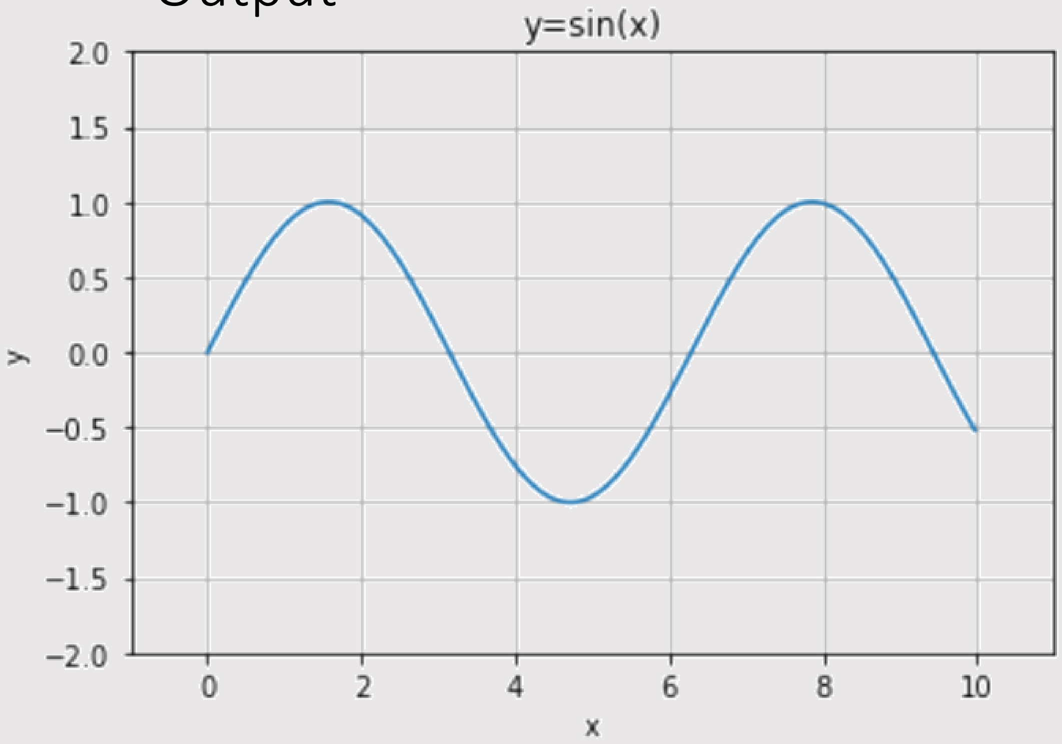
LABELING YOUR PLOTS

Code



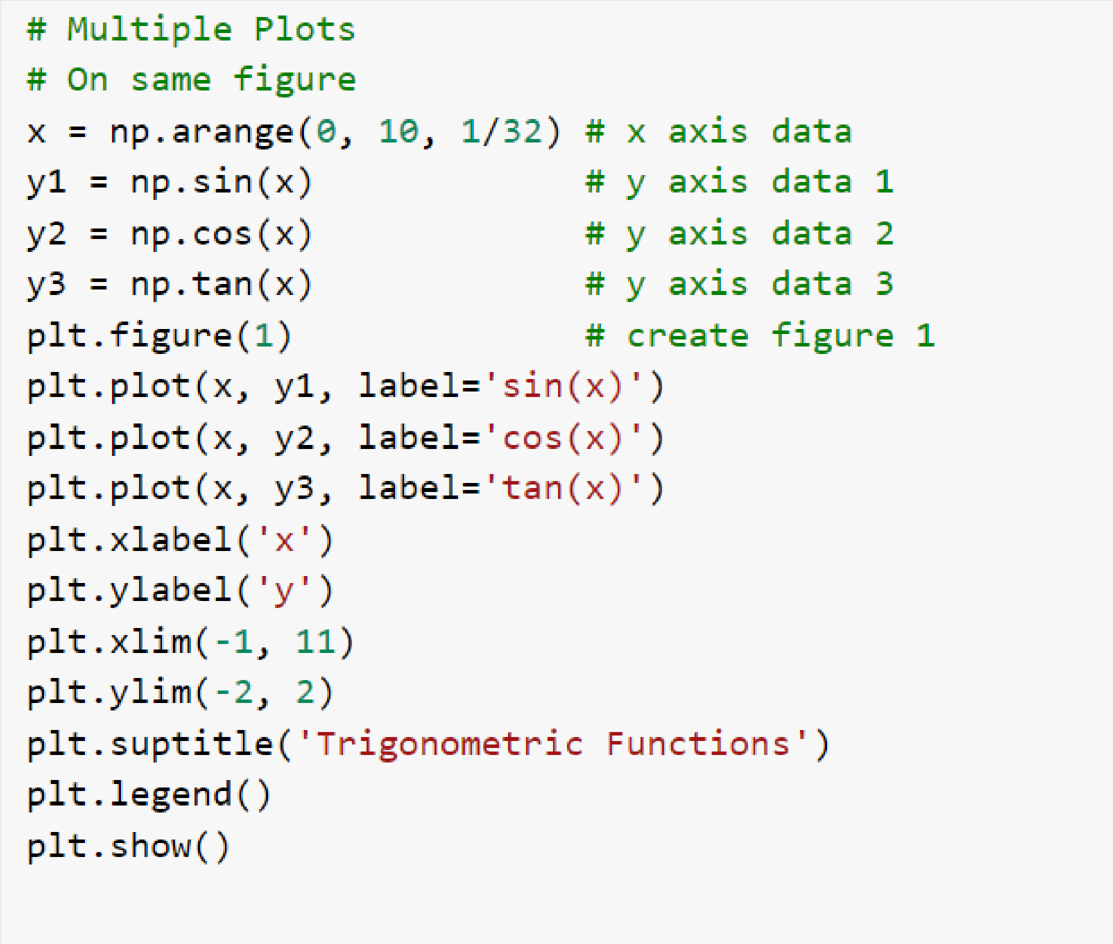
```
plt.plot(x, y)
plt.title('y=sin(x)')  # set the title
plt.xlabel('x')        # set the x axis label
plt.ylabel('y')        # set the y axis label
plt.xlim(-1, 11)       # set the x axis range
plt.ylim(-2, 2)        # set the y axis range
plt.grid()             # enable the grid
```

Output



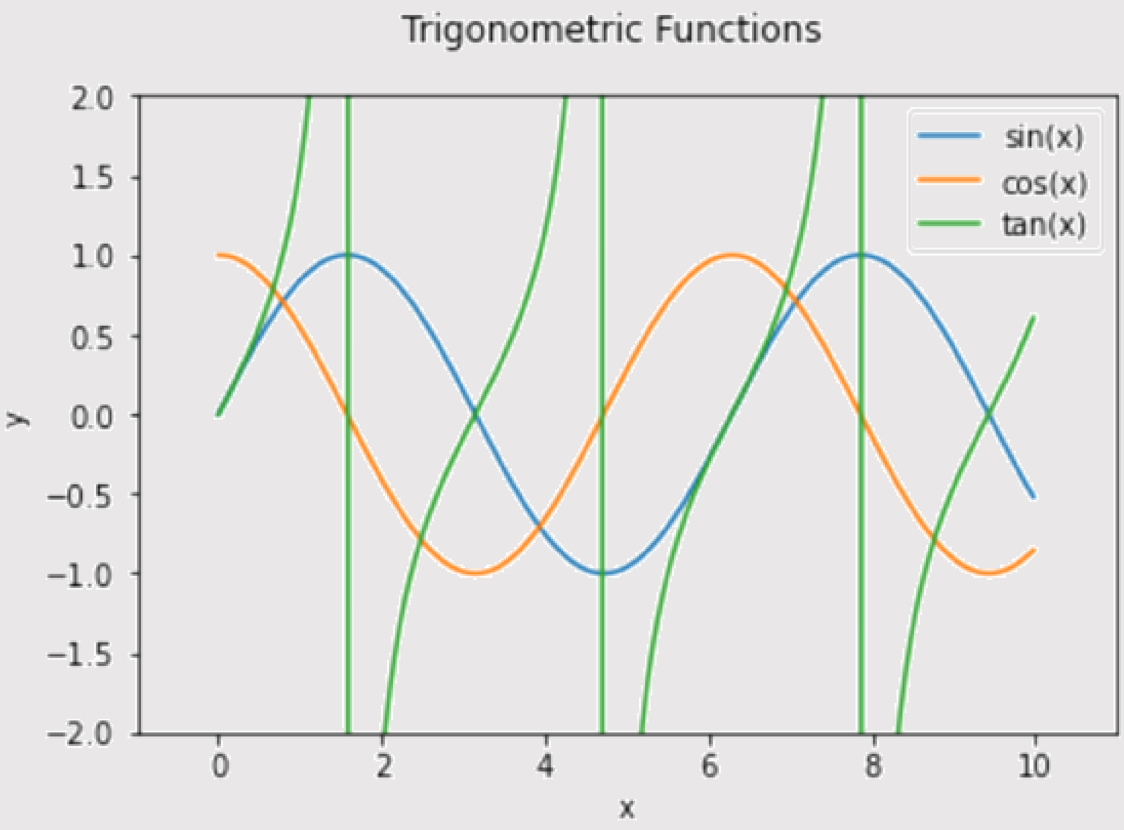
MULTIPLE PLOTS

Code



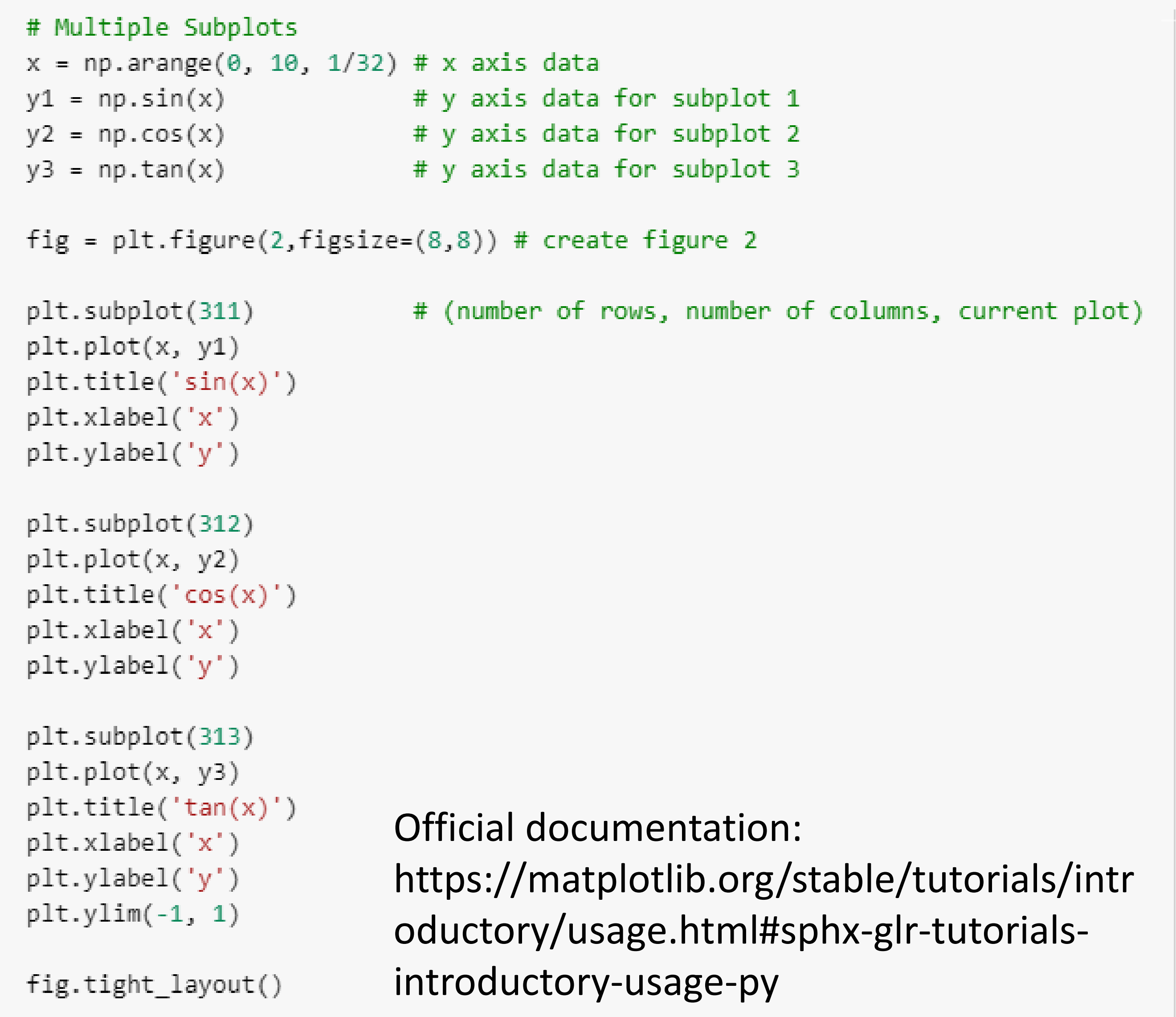
```
# Multiple Plots
# On same figure
x = np.arange(0, 10, 1/32) # x axis data
y1 = np.sin(x)             # y axis data 1
y2 = np.cos(x)             # y axis data 2
y3 = np.tan(x)             # y axis data 3
plt.figure(1)              # create figure 1
plt.plot(x, y1, label='sin(x)')
plt.plot(x, y2, label='cos(x)')
plt.plot(x, y3, label='tan(x)')
plt.xlabel('x')
plt.ylabel('y')
plt.xlim(-1, 11)
plt.ylim(-2, 2)
plt.suptitle('Trigonometric Functions')
plt.legend()
plt.show()
```

Output



CREATING SUBPLOTS

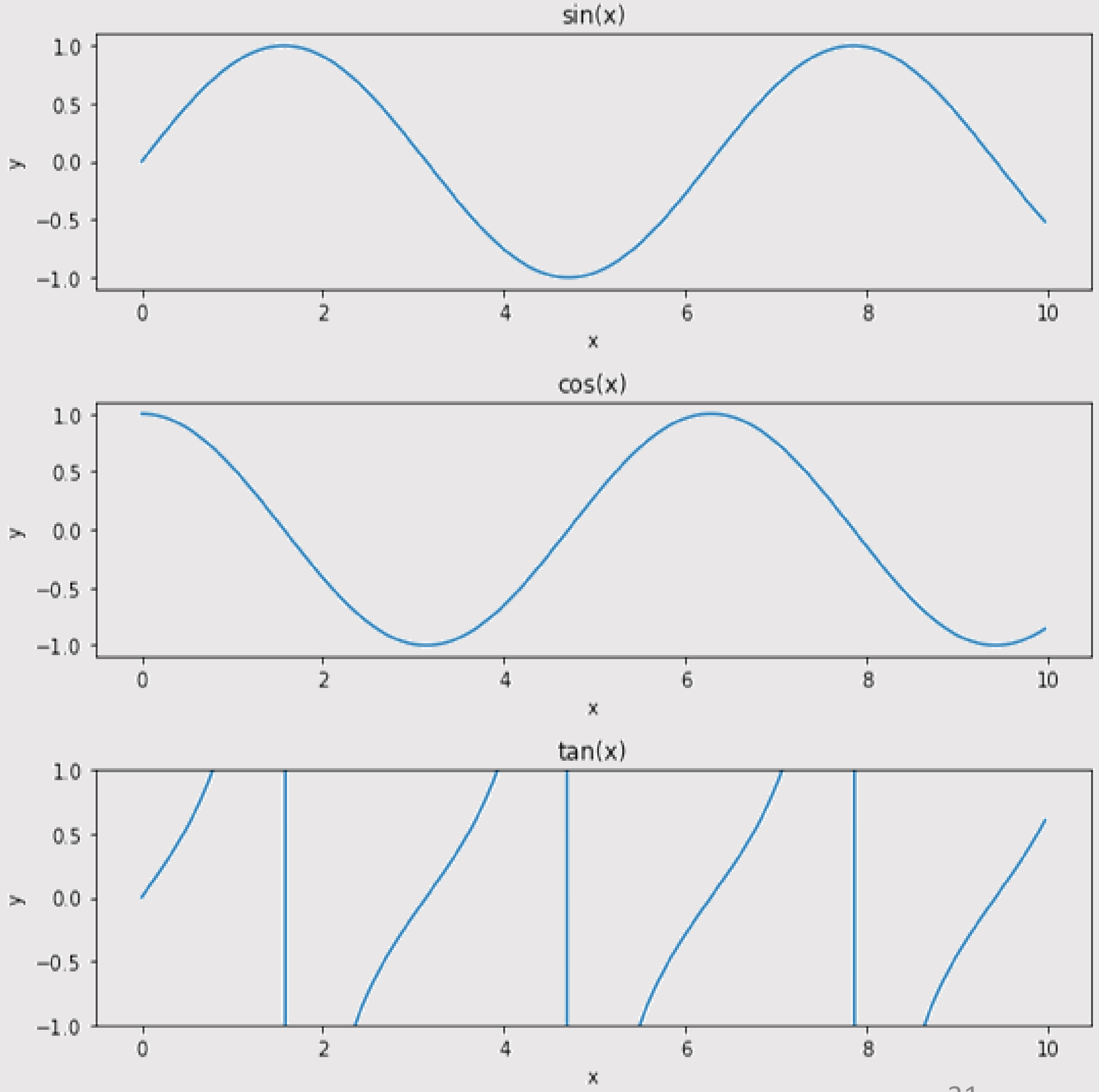
Code



```
# Multiple Subplots
x = np.arange(0, 10, 1/32) # x axis data
y1 = np.sin(x)             # y axis data for subplot 1
y2 = np.cos(x)             # y axis data for subplot 2
y3 = np.tan(x)             # y axis data for subplot 3

fig = plt.figure(2,figsize=(8,8)) # create figure 2

plt.subplot(311)           # (number of rows, number of columns, current plot)
plt.plot(x, y1)
plt.title('sin(x)')
plt.xlabel('x')
plt.ylabel('y')

plt.subplot(312)
plt.plot(x, y2)
plt.title('cos(x)')
plt.xlabel('x')
plt.ylabel('y')

plt.subplot(313)
plt.plot(x, y3)
plt.title('tan(x)')
plt.xlabel('x')
plt.ylabel('y')
plt.ylim(-1, 1)

fig.tight_layout()
```

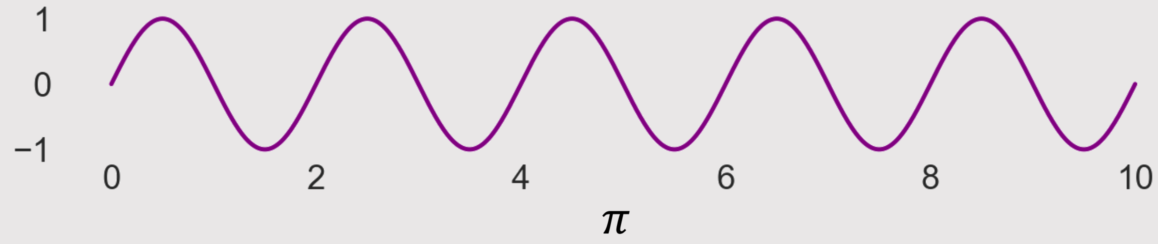
Official documentation: https://matplotlib.org/stable/tutorials/introductory/usage.html#sphx-glr-tutorials-introductory-usage-py

Output



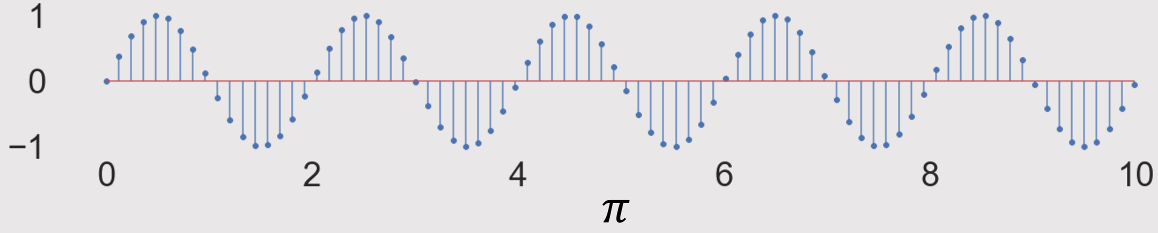
READ/WRITE/PLAY AUDIO DATA

DIGITIAL AUDIO DATA

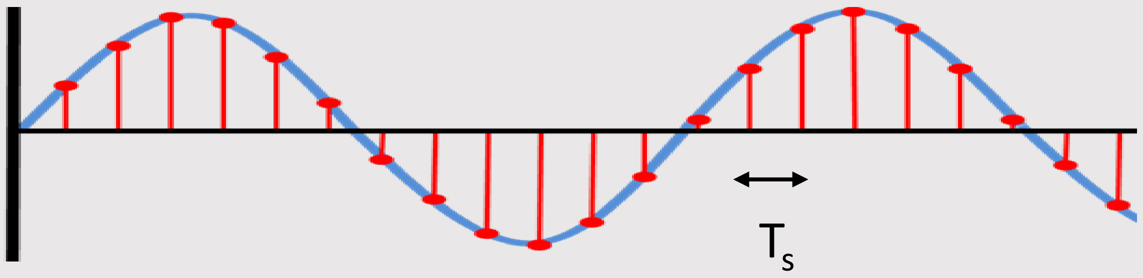


Analog sound waveform

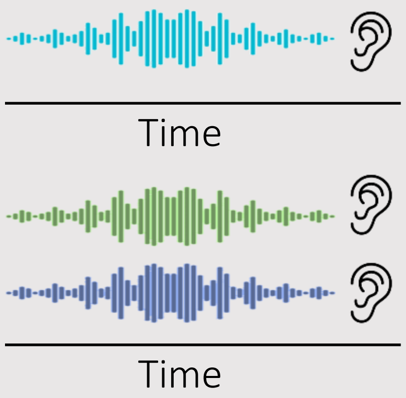
↓



Digital representation of a sound (array)



Sampling frequency (Hz): $F_s = 1/T_s$

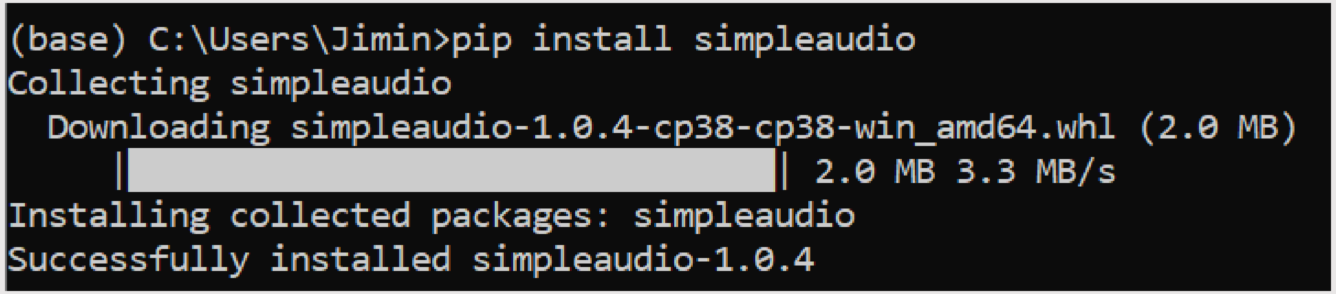


Mono (1 channel)

Stereo (2 channels)

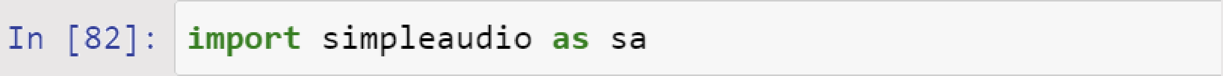
Channels

READING AND PLAYING AUDIO FILES: simpleaudio



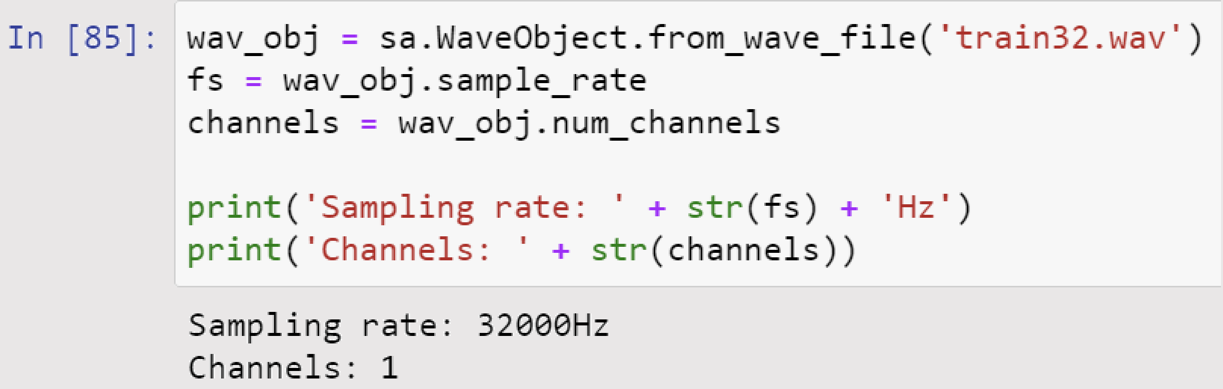
```
(base) C:\Users\Jimin>pip install simpleaudio
Collecting simpleaudio
  Downloading simpleaudio-1.0.4-cp38-cp38-win_amd64.whl (2.0 MB)
     |████████████████████████████████| 2.0 MB 3.3 MB/s
Installing collected packages: simpleaudio
Successfully installed simpleaudio-1.0.4
```

Installing simpleaudio package
(Anaconda Prompt for Windows)



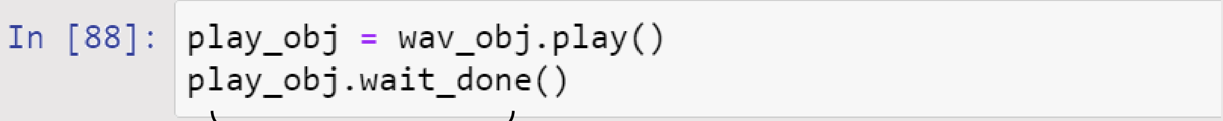
```
In [82]: import simpleaudio as sa
```

Import simpleaudio



```
In [85]: wav_obj = sa.WaveObject.from_wave_file('train32.wav')
         fs = wav_obj.sample_rate
         channels = wav_obj.num_channels

         print('Sampling rate: ' + str(fs) + 'Hz')
         print('Channels: ' + str(channels))

         Sampling rate: 32000Hz
         Channels: 1
```

Load audio and extract information

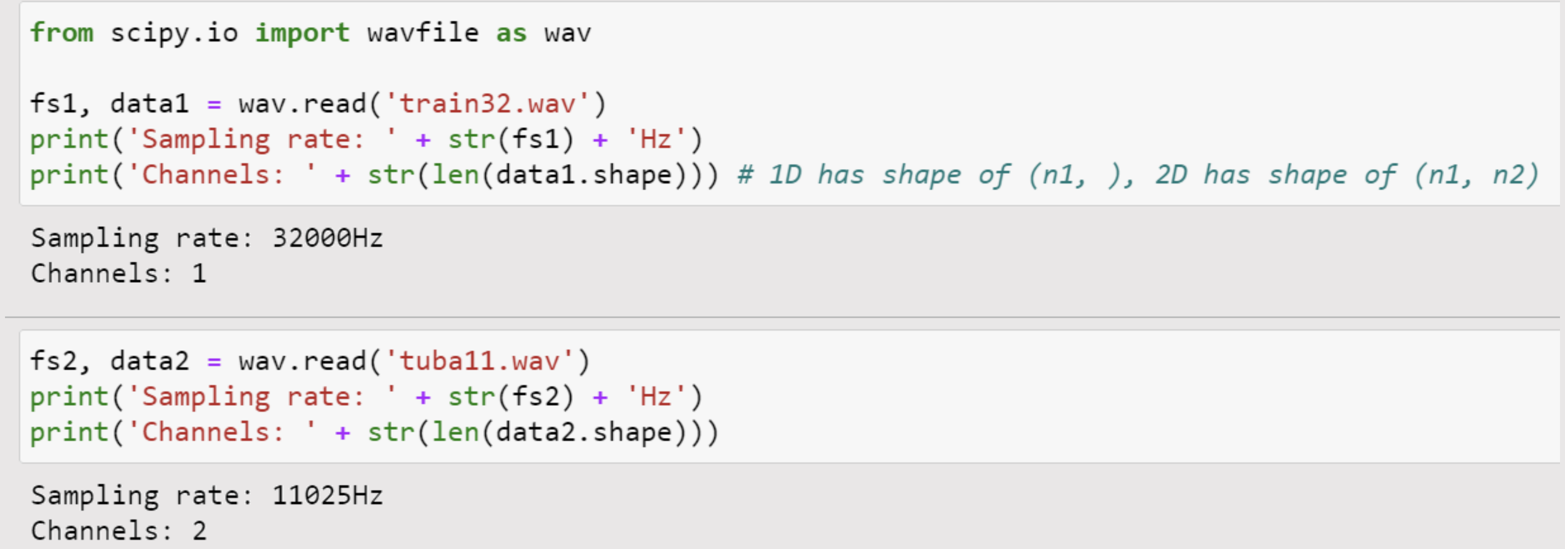


```
In [88]: play_obj = wav_obj.play()
         play_obj.wait_done()
```

Play the audio

Necessary to create delays between audios when playing multiple sounds

READING AND PLAYING AUDIO FILES: scipy.io



```
from scipy.io import wavfile as wav

fs1, data1 = wav.read('train32.wav')
print('Sampling rate: ' + str(fs1) + 'Hz')
print('Channels: ' + str(len(data1.shape))) # 1D has shape of (n1, ), 2D has shape of (n1, n2)
```

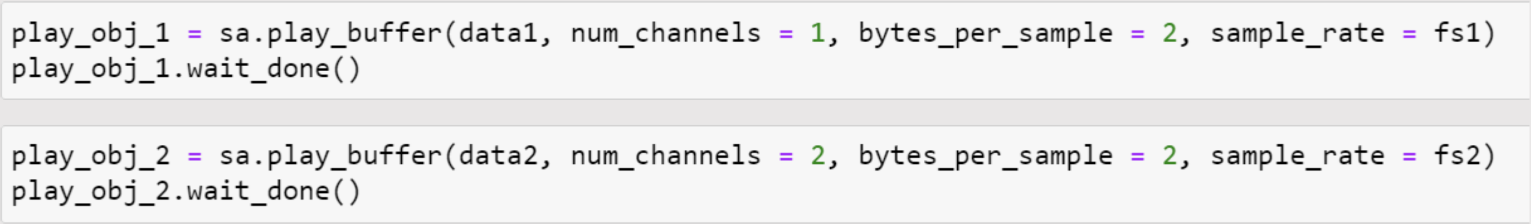
```
Sampling rate: 32000Hz
Channels: 1
```

```
fs2, data2 = wav.read('tuba11.wav')
print('Sampling rate: ' + str(fs2) + 'Hz')
print('Channels: ' + str(len(data2.shape)))
```

```
Sampling rate: 11025Hz
Channels: 2
```

Import scipy.io

Load audio and extract information

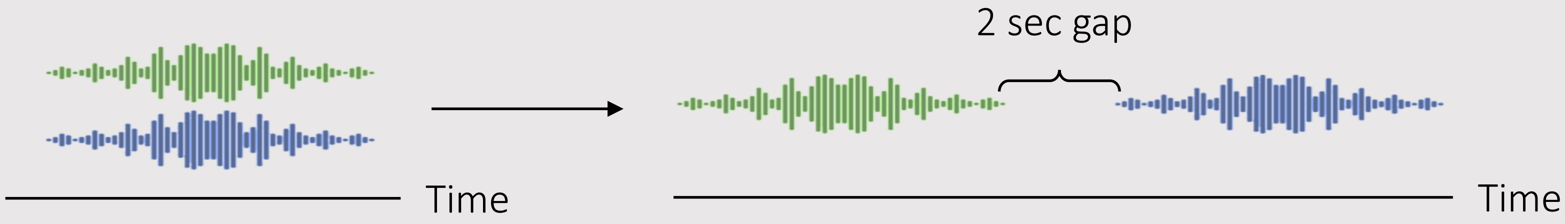


```
play_obj_1 = sa.play_buffer(data1, num_channels = 1, bytes_per_sample = 2, sample_rate = fs1)
play_obj_1.wait_done()
```

```
play_obj_2 = sa.play_buffer(data2, num_channels = 2, bytes_per_sample = 2, sample_rate = fs2)
play_obj_2.wait_done()
```

Play audio using simpleaudio

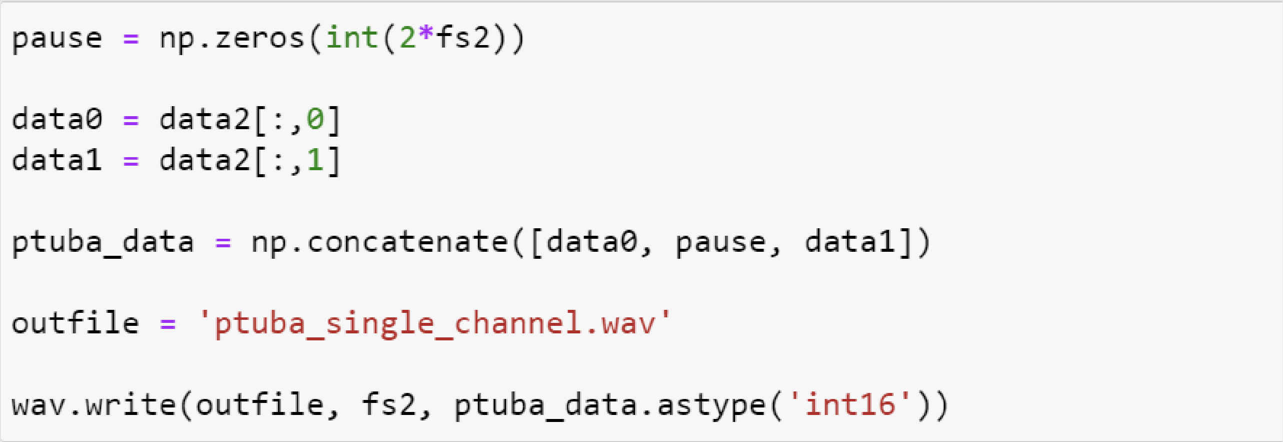
WRITING AUDIO WITH scipy.io



Example Task

Stereo (2 channels)
Original tuba11.wav

Mono (1 channel)
New ptuba_single_channel.wav



```
pause = np.zeros(int(2*fs2))

data0 = data2[:,0]
data1 = data2[:,1]

ptuba_data = np.concatenate([data0, pause, data1])

outfile = 'ptuba_single_channel.wav'

wav.write(outfile, fs2, ptuba_data.astype('int16'))
```

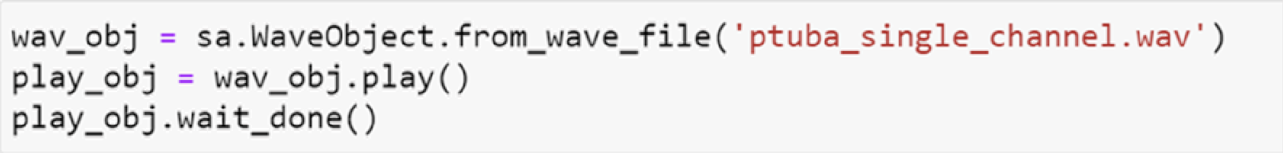
Create an array corresponding to 2 sec gap

Extract both channels from audio data

Concatenate channel 1 data + gap + channel 2 data

Set the name of the new audio file

Write new audio file with correct sampling frequency



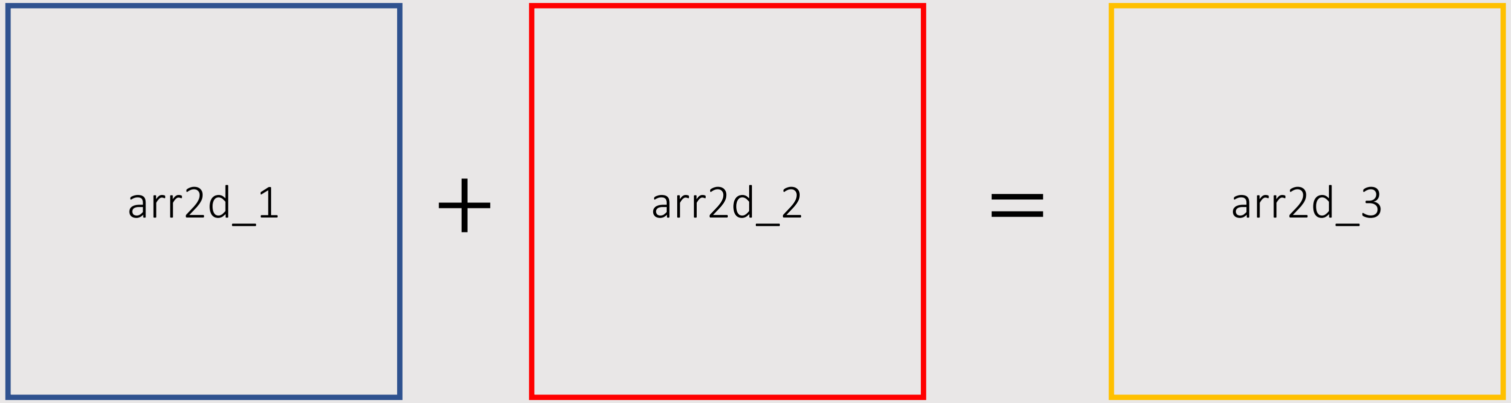
```
wav_obj = sa.WaveObject.from_wave_file('ptuba_single_channel.wav')
play_obj = wav_obj.play()
play_obj.wait_done()
```

Validate the new audio file by playing it

LAB ASSIGNMENTS

Download ipynb template in Canvas page:
Assignments/Lab 2 report -> click “Lab 2 Report Templates”

EXERCISE 1: Loops vs Numpy operations



arr2d_1 + arr2d_2 = arr2d_3

arr2d_3[0, 0] = arr2d_1[0, 0] + arr2d_2[0, 0]

arr2d_3[0, 1] = arr2d_1[0, 1] + arr2d_2[0, 1]

.

.

.

arr2d_3[N, N] = arr2d_1[N, N] + arr2d_2[N, N]

- In lab2_report_template.ipynb, we provided numpy array variables ‘array2d_1’ and ‘array2d_2’. Both have dimensions (1000, 1000).

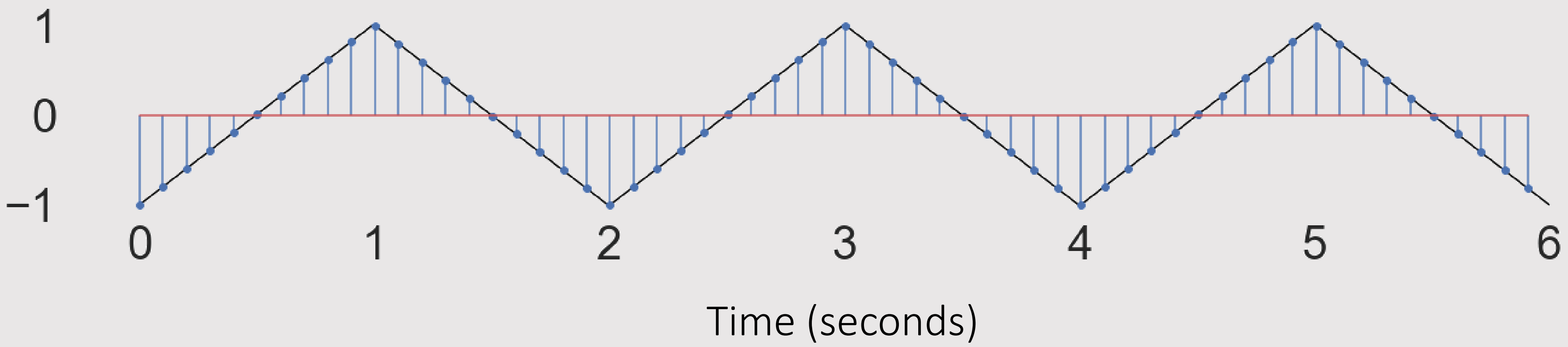
- We want to perform elementwise addition between two and create a new array called ‘array2d_3’.

- Your task is to implement this operation in two ways:
  - Using a loop without numpy (using two nested loop)
  - Using an appropriate numpy function

- Run pre-written code to ensure two outputs are equal.

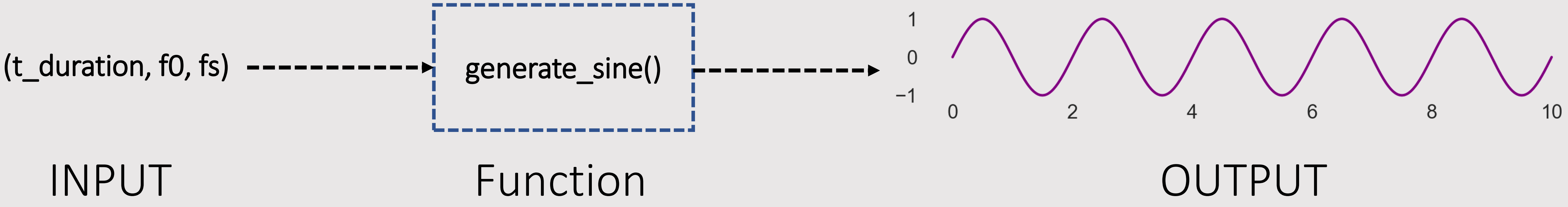
- Measure and compare the computation time for each operation using the code in the template. Report which operation is faster and by how much.

EXERCISE 2: Generate Triangular Waveform



- One of the popular waveform in signal analysis is a triangular wave.
- Your task is to implement a triangular wave shown above by using appropriate Numpy functions and Python commands.
- The waveform should have **amplitude** of 1 and **frequency** of 0.5Hz. Use the **sampling frequency** of 10Hz
- Validate your code by plotting the waveform in the time range of **0 – 6 seconds** as shown above. You can use plt.stem() function in matplotlib to generate the stem plot style.

EXERCISE 3: Sinusoidal Generator


(t_duration, f0, fs)

generate_sine()

INPUT

Function

OUTPUT

- Construct a function generate_sine() which given time duration, wave frequency and sampling frequency, outputs two 1D numpy arrays each corresponding to time points and sine wave form.

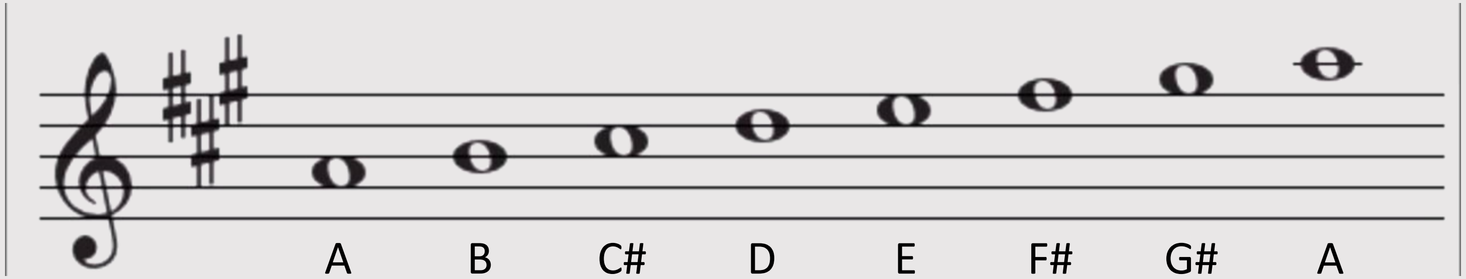
- The function should accept following parameters
  - t_duration – Time duration in seconds which the sine wave is defined
  - f0 – Wave frequency
  - fs – Sampling frequency

- Note that you need to convert Hz to angular frequency using $\omega = 2\pi f_0$ for np.sin().

- Test your function against with three given sets of (t_duration, f0, fs) in Lab2_Report_Template.ipynb.

- Plot three sine waveforms using 3 x 1 subplots. Include proper time axis, title and labels for each subplot.

EXERCISE 4: Notes Synthesis



- For this exercise we will synthesize 8 notes for A-Major scale shown above

- Using the generate_sine() function, synthesize 8 notes that make up A-Major scale. Each note should last 1 second.

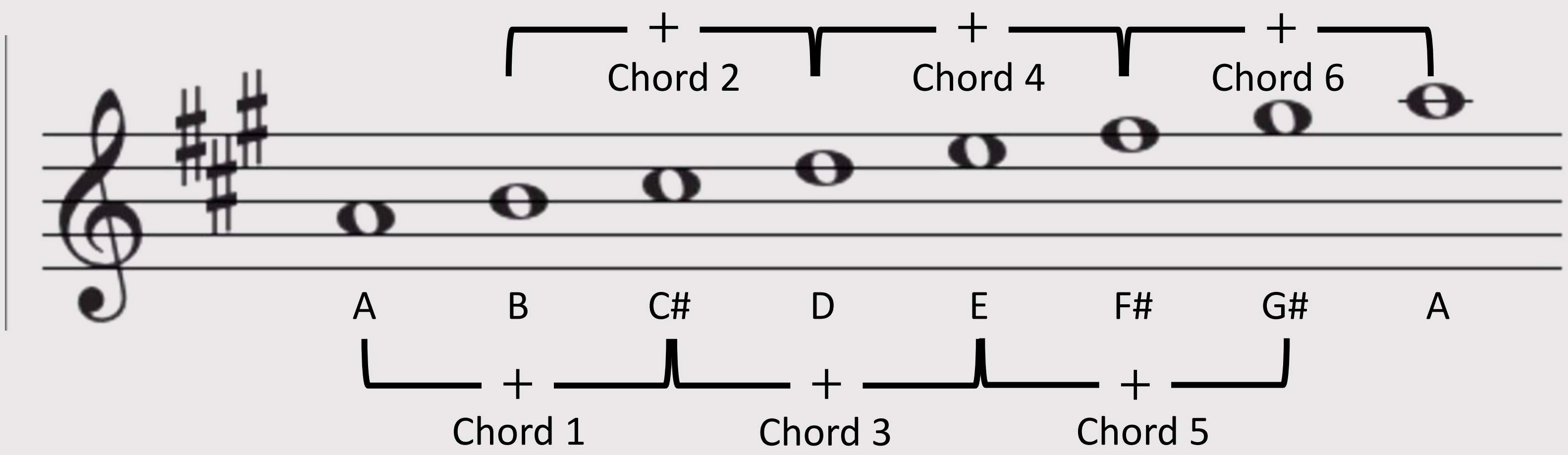
- For each note, use sampling rate $f_s = 8000$ and **amplitude = 1**

- Once all 8 notes are constructed, concatenate them into a single 1D array.

- Play the concatenated notes using simpleaudio and write it into an audio file with name “a_major_scale.wav”.

Note	Frequency (Hz)
A	220
B	$220 * 2^{\frac{2}{12}}$
C#	$220 * 2^{\frac{4}{12}}$
D	$220 * 2^{\frac{5}{12}}$
E	$220 * 2^{\frac{7}{12}}$
F#	$220 * 2^{\frac{9}{12}}$
G#	$220 * 2^{\frac{11}{12}}$
A	440

EXERCISE 5: Chord Synthesis



Chord 1 = A + C#

Chord 2 = B + D

Chord 3 = C# + E

Chord 4 = D + F#

Chord 5 = E + G#

Chord 6 = F# + A

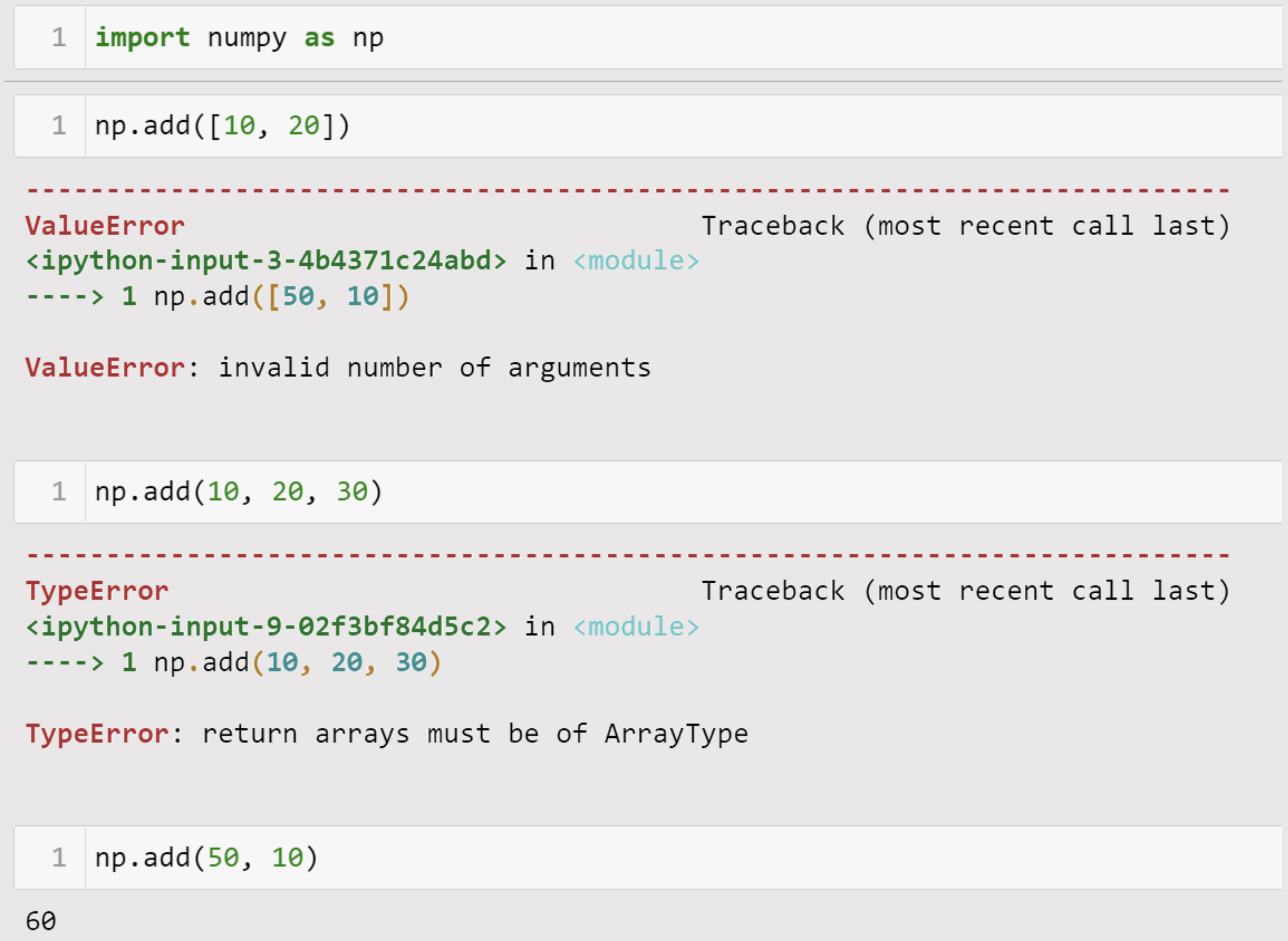
Note	Frequency (Hz)
A	220
B	$220 * 2^{\frac{2}{12}}$
C#	$220 * 2^{\frac{4}{12}}$
D	$220 * 2^{\frac{5}{12}}$
E	$220 * 2^{\frac{7}{12}}$
F#	$220 * 2^{\frac{9}{12}}$
G#	$220 * 2^{\frac{11}{12}}$
A	440

- For this exercise, we will expand upon exercise 4 to synthesize music chords – i.e. set of pitches consisting of multiple notes
- For example, a chord could be A + B or B + C# + D, etc
- Generate 6 chords as shown above figure – each chord consists of **addition of two notes** and should last for 1s with sampling frequency of 8000Hz.
- Make sure you normalize the amplitude of the chord between -1 and 1 to be compatible with simpleaudio standard.
- Concatenate 6 chords into a single 1D array and write into audio file with a name “6_chords.wav”

SUPPLEMENTARY:

FUNCTION CALL ERROR & LOOKING UP FUNCTION DOCUMENTATION

FUNCTION CALL ERROR VIA INCORRECT ARGUMENT



```
import numpy as np
```

```
np.add([10, 20])
```

```
---------------------------------------------------------------------------
ValueError                                Traceback (most recent call last)
<ipython-input-3-4b4371c24abd> in <module>
----> 1 np.add([50, 10])

ValueError: invalid number of arguments
```

```
np.add(10, 20, 30)
```

```
---------------------------------------------------------------------------
TypeError                                 Traceback (most recent call last)
<ipython-input-9-02f3bf84d5c2> in <module>
----> 1 np.add(10, 20, 30)

TypeError: return arrays must be of ArrayType
```

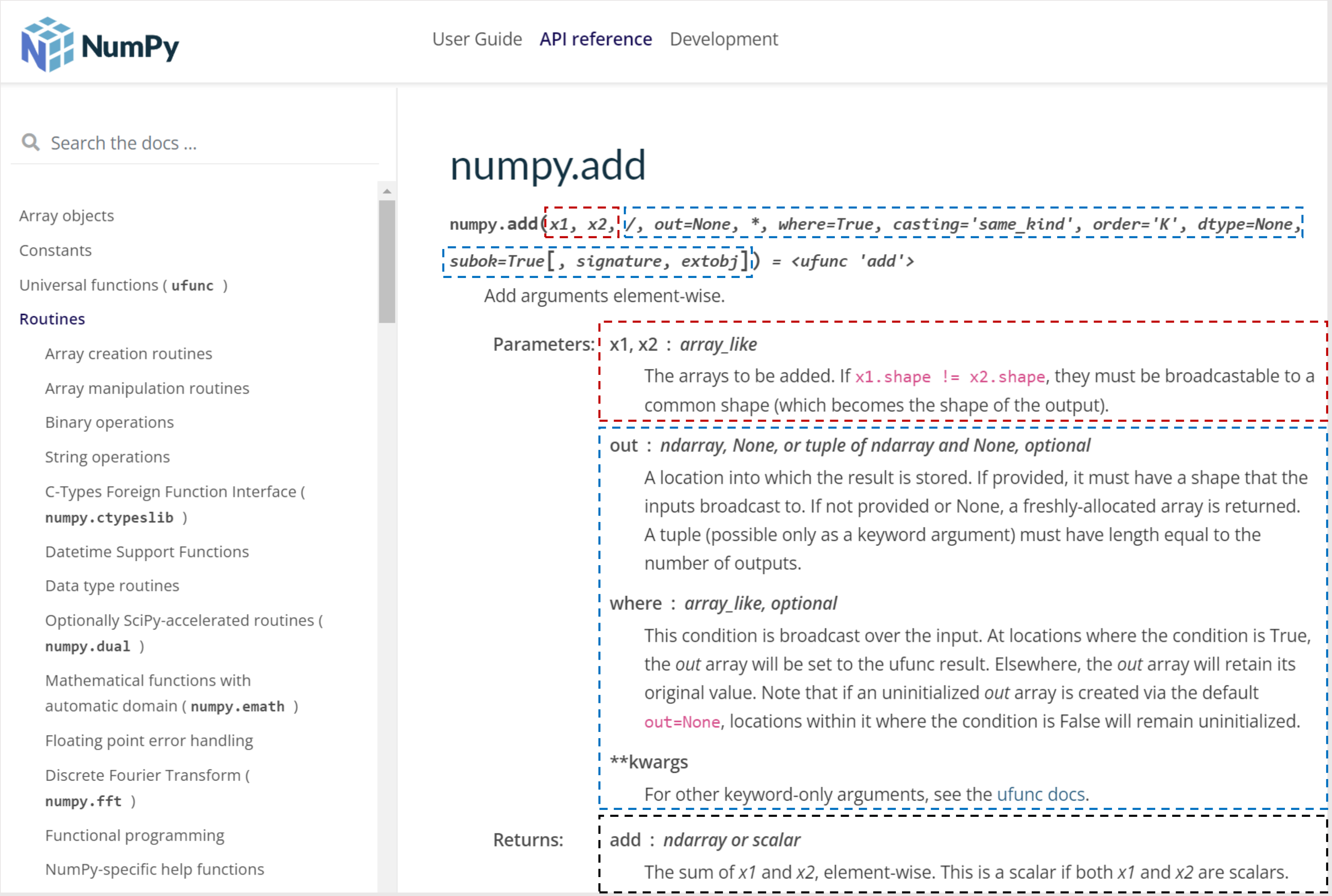
```
np.add(50, 10)
```

```
60
```

Incorrect function arguments

Correct function arguments

LOOKING UP FUNCTION DOCUMENTATION


NumPy
User Guide
API reference
Development
Search the docs ...
Array objects
Constants
Universal functions (ufunc)
Routines
Array creation routines
Array manipulation routines
Binary operations
String operations
C-Types Foreign Function Interface (numpy.ctypeslib)
Datetime Support Functions
Data type routines
Optionally SciPy-accelerated routines (numpy.dual)
Mathematical functions with automatic domain (numpy.emath)
Floating point error handling
Discrete Fourier Transform (numpy.fft)
Functional programming
NumPy-specific help functions

numpy.add

```
numpy.add(x1, x2, /, out=None, *, where=True, casting='same_kind', order='K', dtype=None,
subok=True[, signature, extobj]) = <ufunc 'add'>
```

Add arguments element-wise.

Parameters:

x1, x2 : *array_like*

The arrays to be added. If `x1.shape != x2.shape`, they must be broadcastable to a common shape (which becomes the shape of the output).

out : *ndarray, None, or tuple of ndarray and None, optional*

A location into which the result is stored. If provided, it must have a shape that the inputs broadcast to. If not provided or None, a freshly-allocated array is returned. A tuple (possible only as a keyword argument) must have length equal to the number of outputs.

where : *array_like, optional*

This condition is broadcast over the input. At locations where the condition is True, the *out* array will be set to the ufunc result. Elsewhere, the *out* array will retain its original value. Note that if an uninitialized *out* array is created via the default `out=None`, locations within it where the condition is False will remain uninitialized.

**kwargs

For other keyword-only arguments, see the ufunc docs.

Returns:

add : *ndarray or scalar*

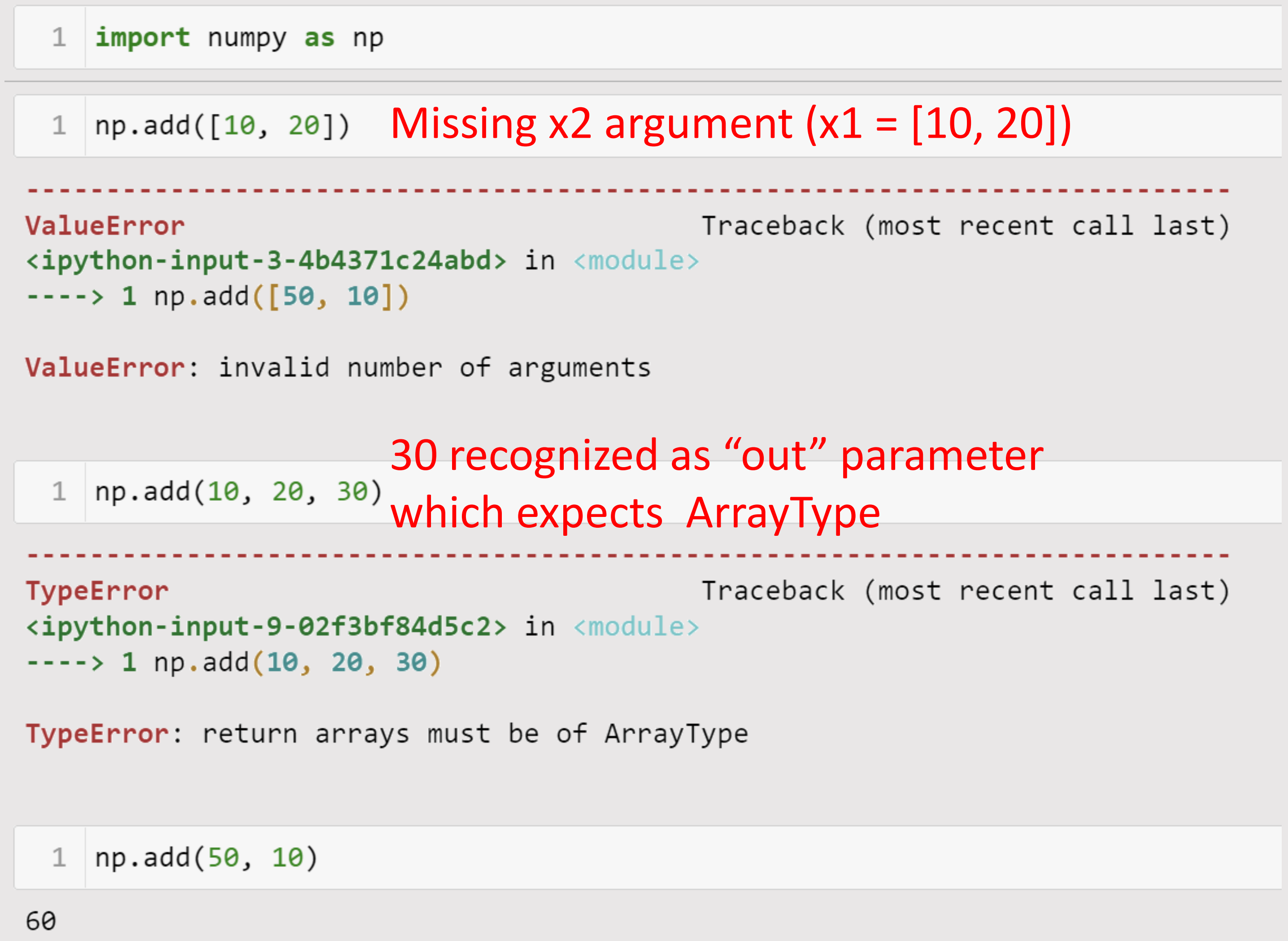
The sum of *x1* and *x2*, element-wise. This is a scalar if both *x1* and *x2* are scalars.

User defined arguments

Optional arguments
(already have default values)

Function Output

FUNCTION CALL ERROR VIA INCORRECT ARGUMENT



```
import numpy as np
```

```
np.add([10, 20])
```

Missing x2 argument (x1 = [10, 20])

```
---------------------------------------------------------------------------
ValueError                                Traceback (most recent call last)
<ipython-input-3-4b4371c24abd> in <module>
----> 1 np.add([50, 10])

ValueError: invalid number of arguments
```

```
np.add(10, 20, 30)
```

30 recognized as “out” parameter
which expects ArrayType

```
---------------------------------------------------------------------------
TypeError                                 Traceback (most recent call last)
<ipython-input-9-02f3bf84d5c2> in <module>
----> 1 np.add(10, 20, 30)

TypeError: return arrays must be of ArrayType
```

```
np.add(50, 10)
```

```
60
```

Incorrect function arguments

Correct function arguments