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

University of Washington

ECE 241

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OUTLINE

Part 1: Finishing up Python Basics

- Conditional Statements
- Loops
- Functions

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- Math operations with Numpy

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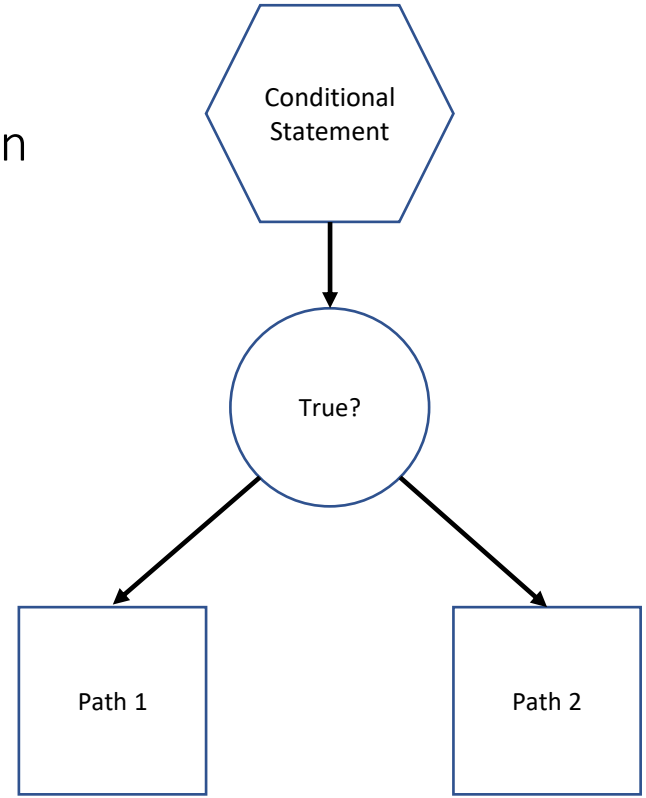
CONDITIONAL STATEMENTS, FUNCTIONS, LOOPS

CONDITIONAL STATEMENTS

Types of conditional statements in Python

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



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')
```

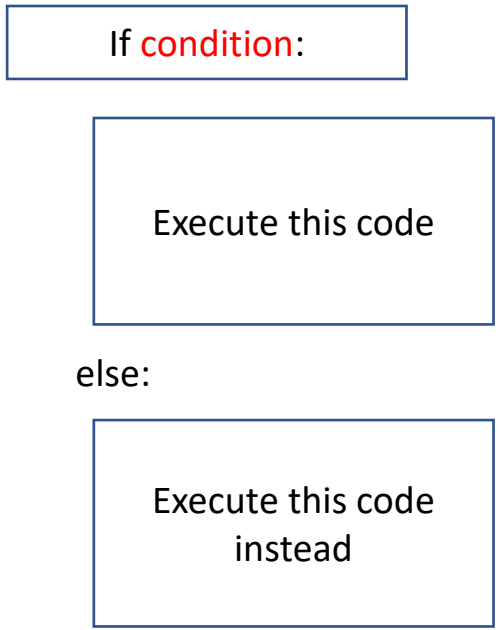
```
num2 is larger than num1
```

```
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

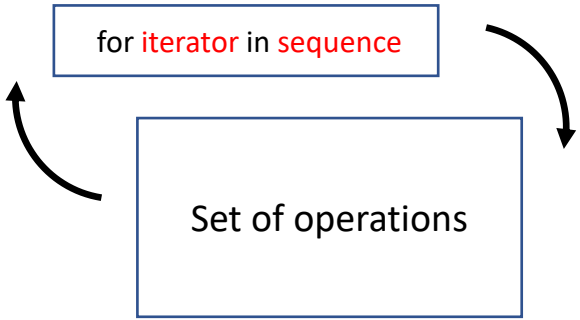
Code example

```
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 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
```

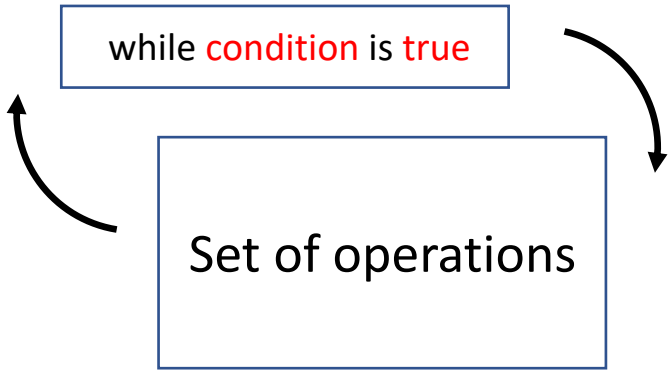
Iterate through sequence

```
# 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
```

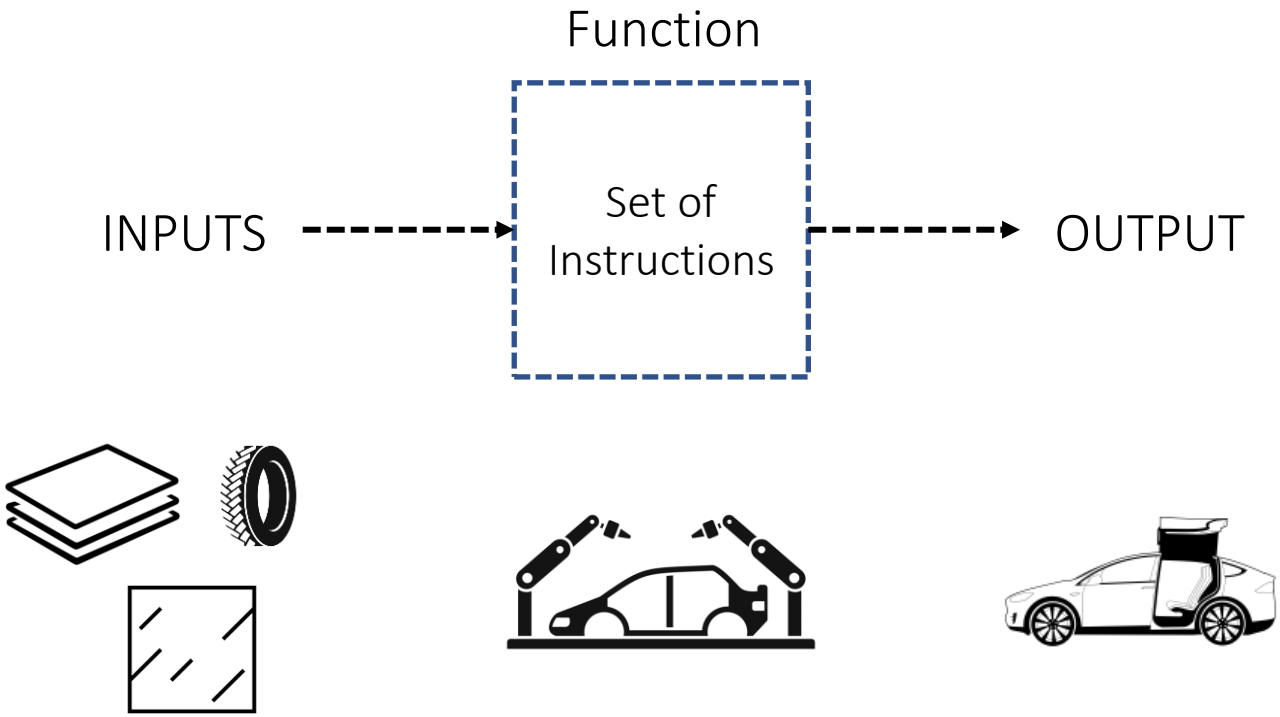
```
1
4
9
16
```

```
In [1]: x = 1

        while(x > 0):

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

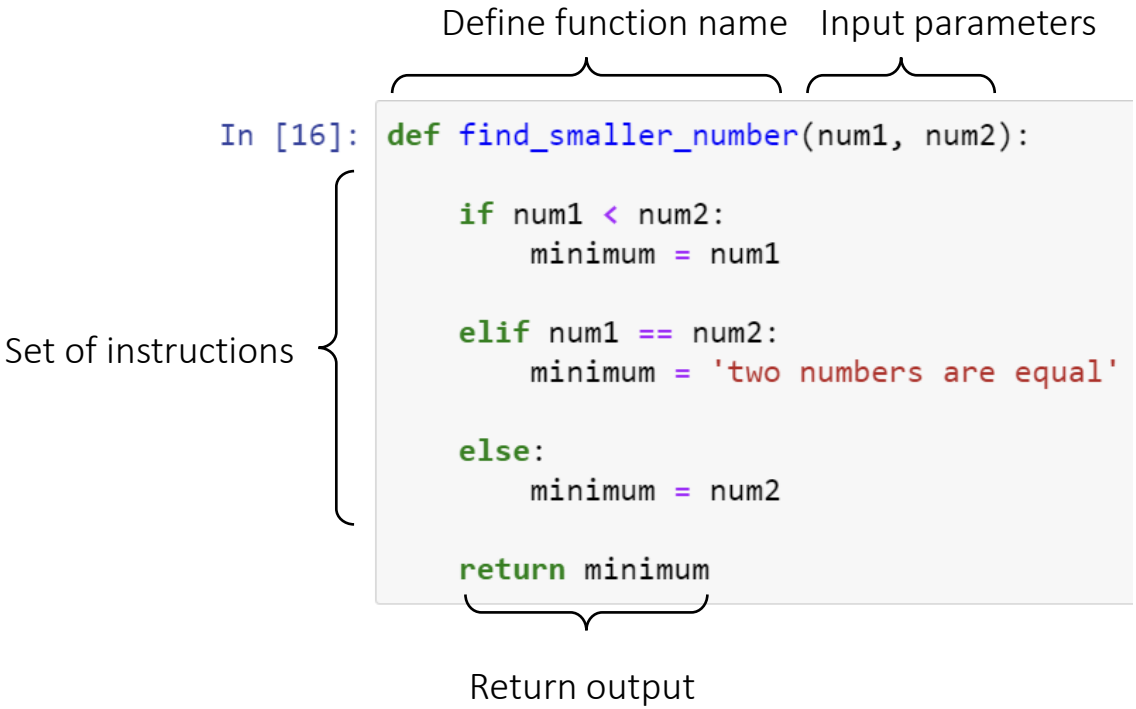
```
This loop will never end!!
This loop will never end!!
This loop will never end!!
```

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

FUNCTIONS



DEFINING A FUNCTION



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

```
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))
```

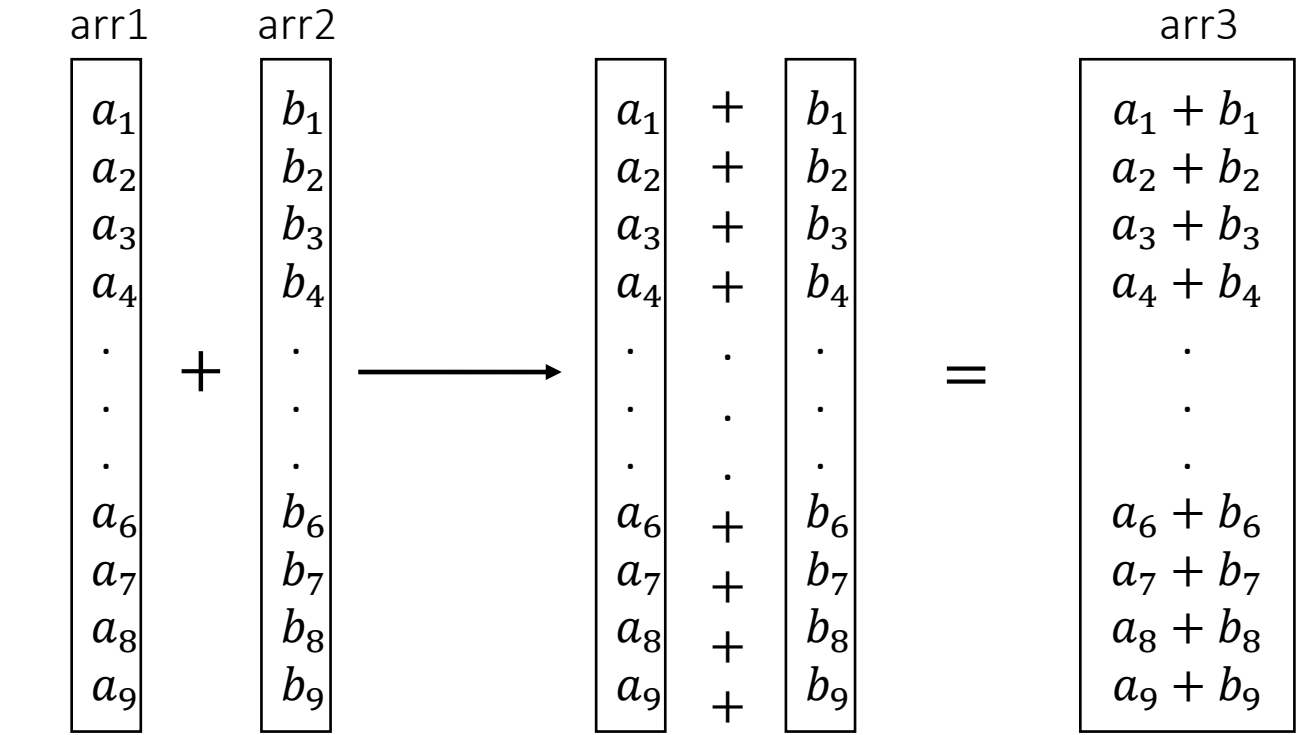
```
Array dimensions:  (5,)
Array dimensions:  (3, 5)
Array type:  <class 'numpy.ndarray'>
```

From Numpy commands

```
# 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



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”

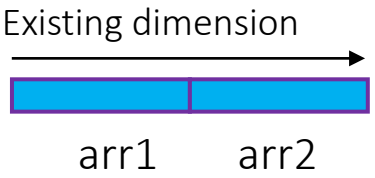
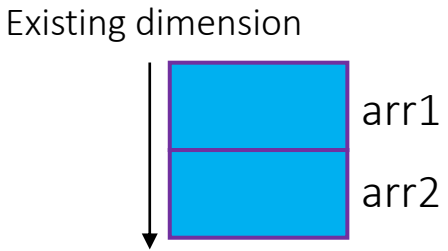
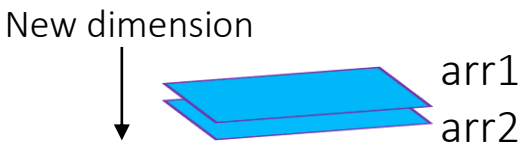
NUMPY ARITHMATIC OPERATORS

	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`

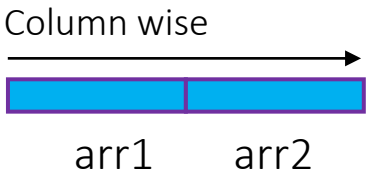
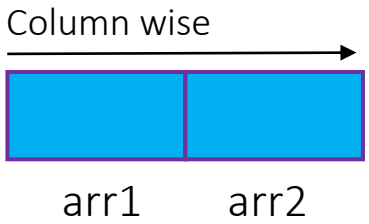
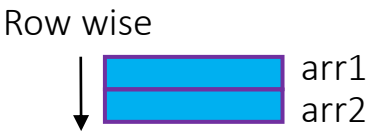
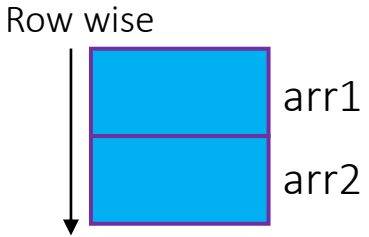
USEFUL NUMPY OPERATIONS: COMBINING ARRAYS

	Operator	Example
Concatenation	np.concatenate()	`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()		
np.vstack()		

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)	
Cosine	np.cos(x)	
Tangent	np.tan(x)	

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

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

```
[0.84147098 0.90929743 0.14112001]
```

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

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

```
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

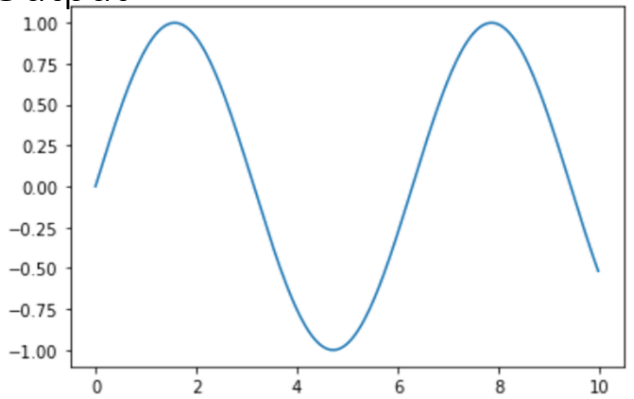
Import Matplotlib

```
#%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

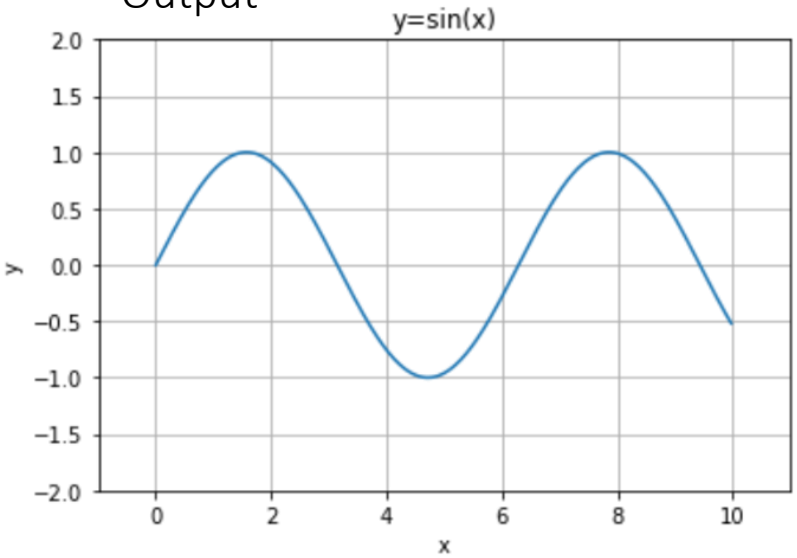


LABELING YOUR PLOTS

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

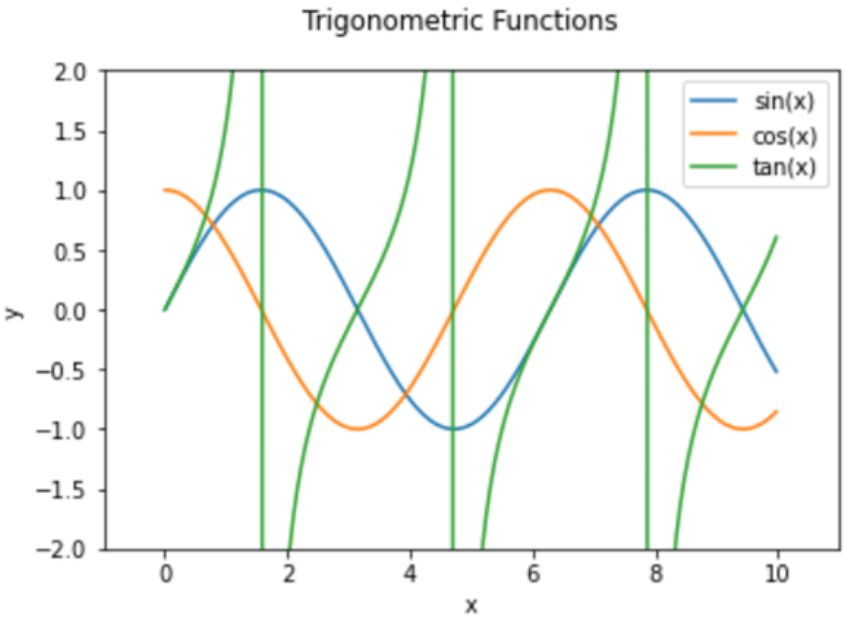


MULTIPLE PLOTS

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



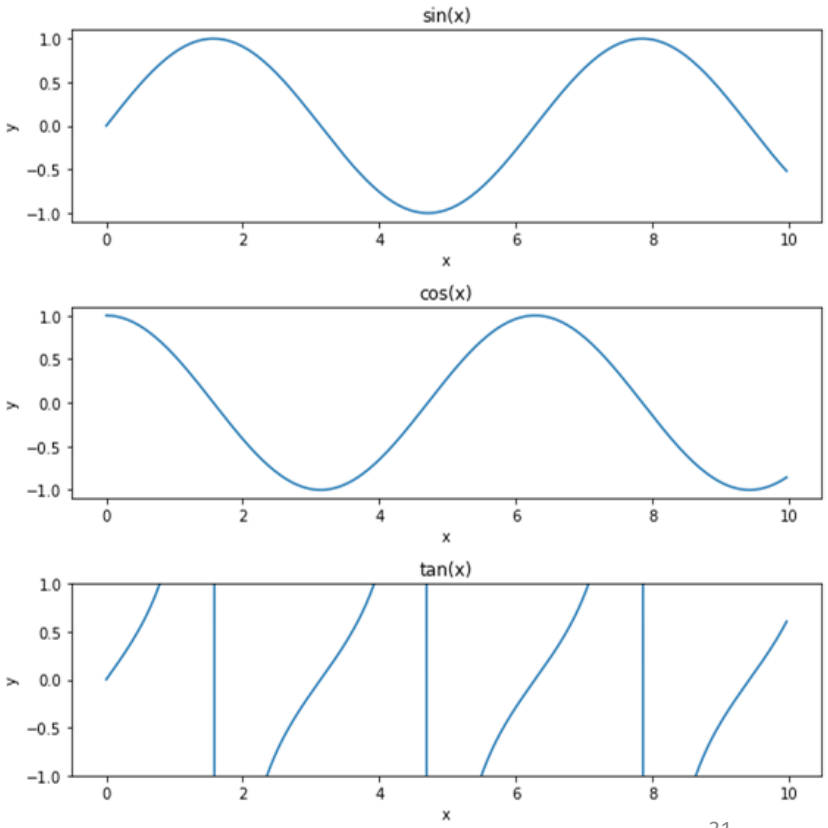
CREATING SUBPLOTS

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()
```

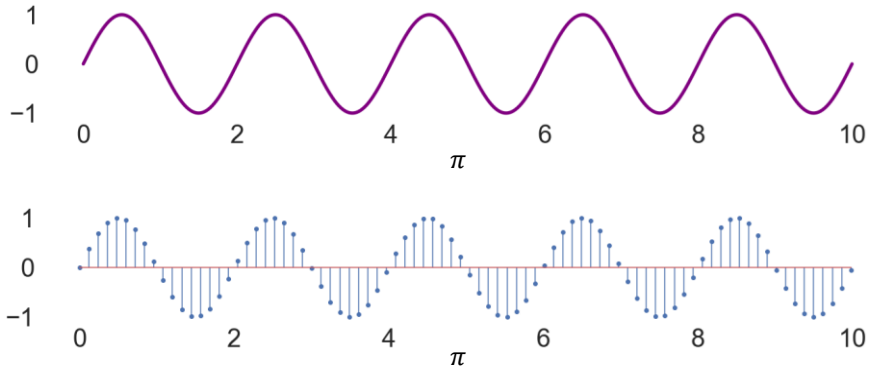
Official documentation:
https://matplotlib.org/stable/tutorials/introductory/usage.html#sphx-glr-tutorials-introductory-usage-py

Output



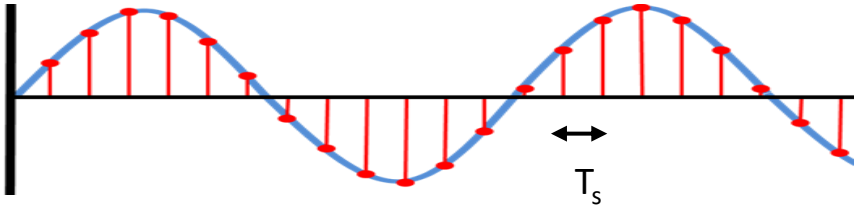
READ/WRITE/PLAY AUDIO DATA

DIGITAL AUDIO DATA

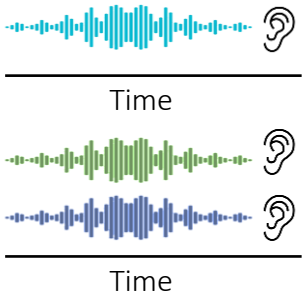


Analog sound waveform

Digital representation of a sound (array)



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



Mono (1 channel)

Stereo (2 channels)

Channels

PLAYING AUDIO FILES: Ipython.display.audio

```
In [29]: import IPython.display as ipd

In [30]: ipd.Audio('train32.wav')
```

Out[30]:

Import Ipython.display

Load audio with ipd.Audio()

Interface for audio playback

READING 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
```

Import wavfile from scipy.io

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

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

Load audio and extract information

```
print(type(data2), data2.shape)
```

```
<class 'numpy.ndarray'> (109708, 2)
```

2nd output from wav.read() is a numpy array containing sound waveform

WRITING AUDIO WITH scipy.io

Stereo (2 channels)
Original tuba11.wav

Mono (1 channel)
New ptuba_single_channel.wav

Example Task

```
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

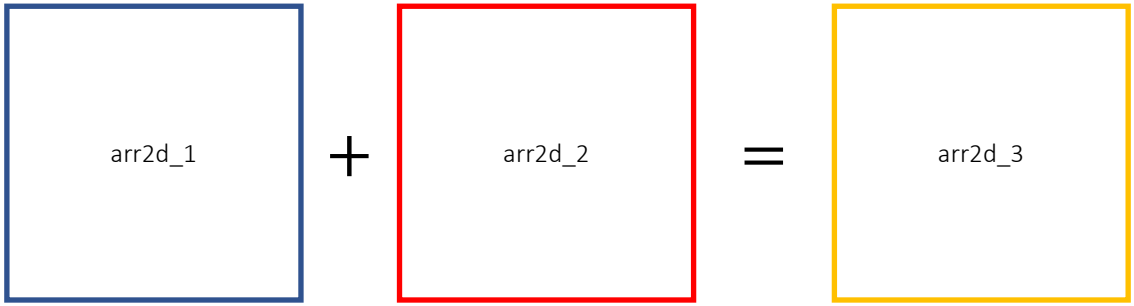
```
ipd.Audio('ptuba_single_channel.wav')
```

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_3[0, 0] = arr2d_1[0, 0] + arr2d_2[0, 0]

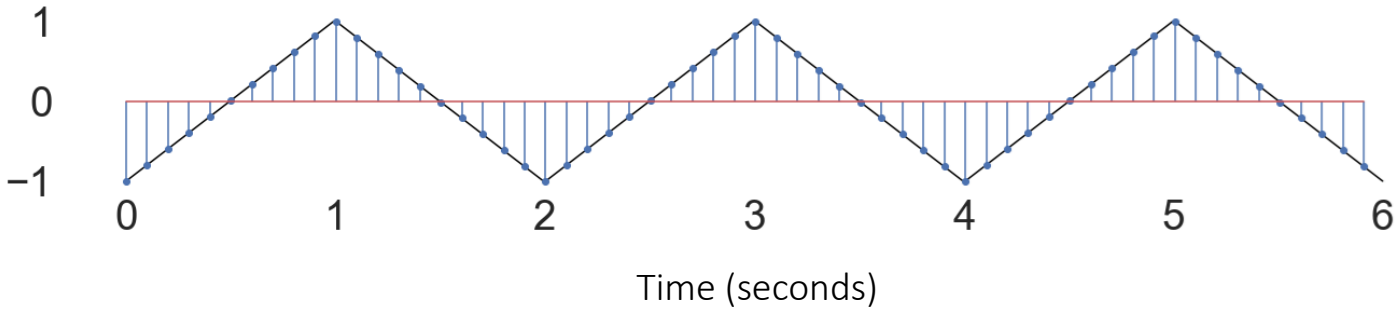
arr2d_3[0, 1] = arr2d_1[0, 1] + arr2d_2[0, 1]

.
.
.

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

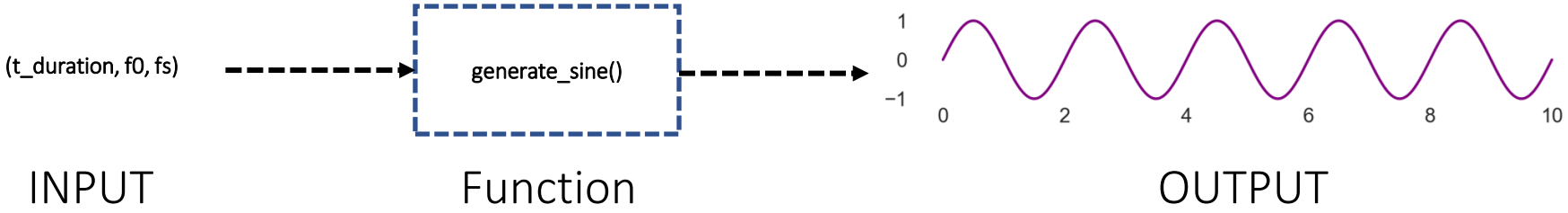
- In lab2_report_template.ipynb, we provided numpy array variables ‘array2d_1’ and ‘array2d_2’. Both have dimensions (1000, 1000).
- We want to perform elementwise addition between two and create a new array called ‘array2d_3’.
- Your task is to implement this operation in two ways:
  - Using a loop 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



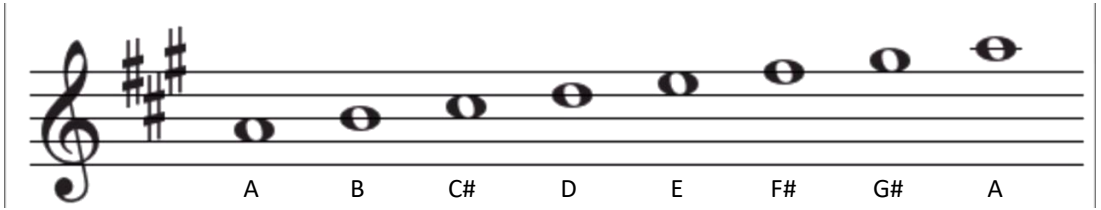
- One of the popular waveform in signal analysis is a triangular wave.
- Your task is to implement a triangular wave shown above by using appropriate Numpy functions and Python commands.
- The waveform should have **amplitude** of 1 and **frequency** of 0.5Hz. Use the **sampling frequency** of 10Hz
- 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



- 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.

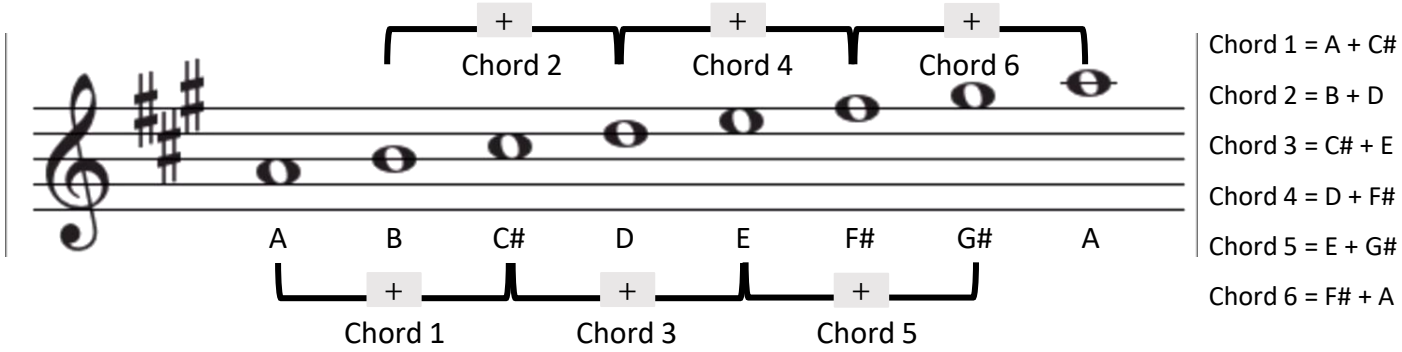
EXERCISE 4: Notes Synthesis



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 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 and scale them to int 16 format to conform to wav file standard.
- Write the concatenated notes with name “a_major_scale.wav” and play it using Ipython.display.audio to validate your notes.

EXERCISE 5: Chord Synthesis



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 and scale them to int16 format to conform with wav file standard.
- Concatenate 6 chords into a single 1D array and write into audio file with a name “6_chords.wav”. Play with ipython.display.audio to validate the synthesized chords.

SUPPLEMENTARY:

FUNCTION CALL ERROR &
LOOKING UP FUNCTION DOCUMENTATION

FUNCTION CALL ERROR VIA INCORRECT ARGUMENT

```
1 import numpy as np
```

```
1 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
```

```
1 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
```

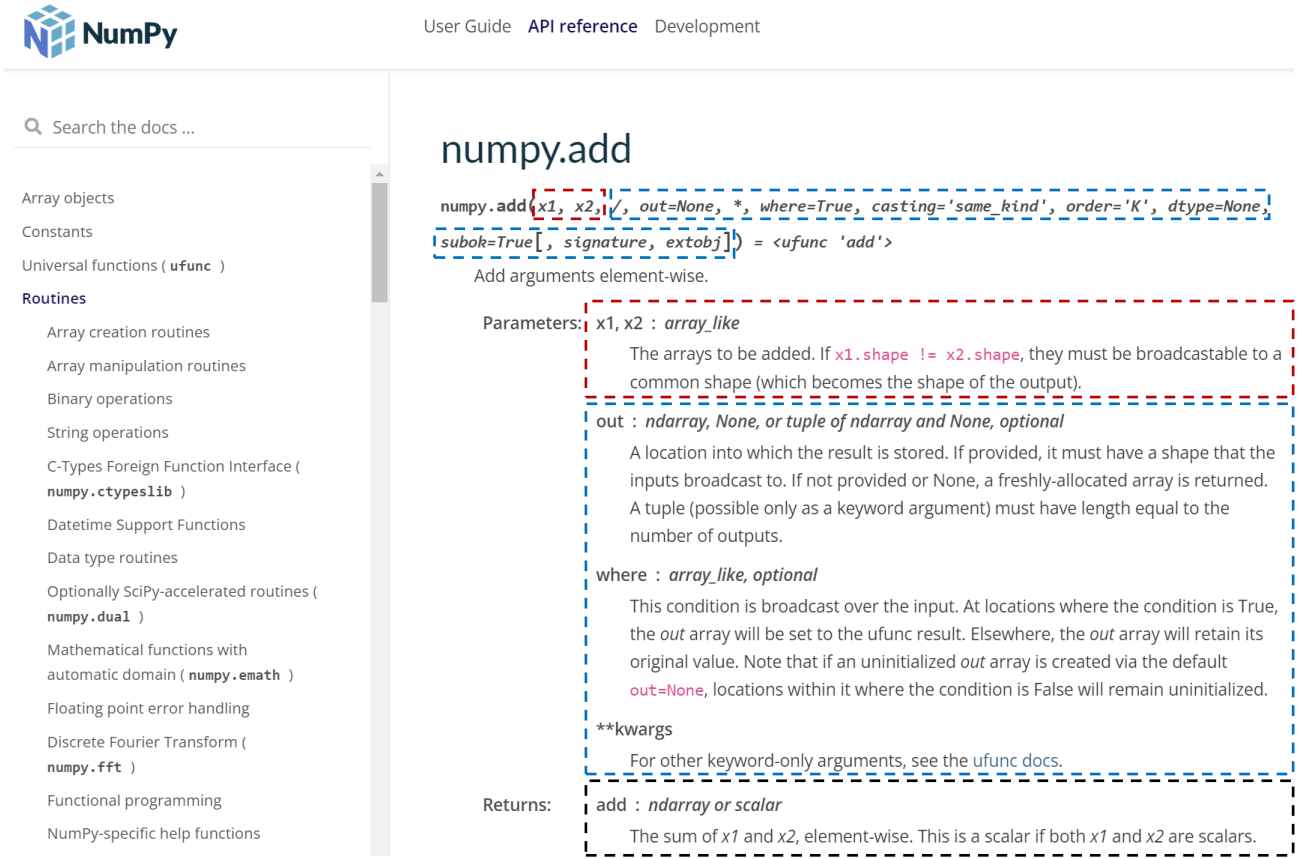
Incorrect function arguments

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

```
60
```

Correct function arguments

LOOKING UP FUNCTION DOCUMENTATION



User defined arguments

Optional arguments
(already have default values)

Function Output

FUNCTION CALL ERROR VIA INCORRECT ARGUMENT

```
1 import numpy as np
```

```
1 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
```

```
1 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
```

Incorrect function arguments

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

```
60
```

Correct function arguments