Lecture 2 - Part 1: Introduction to numpy and scipy

1 What's Numpy?

- **NumPy** is a Python library used for scientific computing and data analysis.
- It provides efficient tools for working with large arrays and matrices of numerical data, In particular, NumPy provides objects such as n-dimensional arrays.
- Libraries written in lower-level languages, such as C, can operate on data stored in Numpy 'ndarray' without copying any data.
- NumPy also includes a wide range of mathematical functions for performing various mathematical operations, such as linear algebra, Fourier analysis, and statistics.
- NumPy facilitates and optimizes the storage and manipulation of numerical data, especially when dealing with large arrays. This is known as "array-oriented computing".
- In summary, the NumPy module is the basic tool used in all scientific and numerical calculations in Python due to its power, speed, and flexibility.

2 How to install NumPy:

You can use the pip package manager to install NumPy by running the command

```
pip install numpy
```

in the command prompt or Anaconda prompt. # How to import NumPy: To use NumPy in your Python code, you first need to import it using the `import` statement. You can import NumPy by adding the following line at the top of your Python script or Jupyter Notebook:

```
import numpy as np
```

This statement creates an alias "np" for NumPy, which is a common convention used by most developers working with NumPy. # Documentation - You can use https://docs.scipy.org/doc/. - Asking For Help:

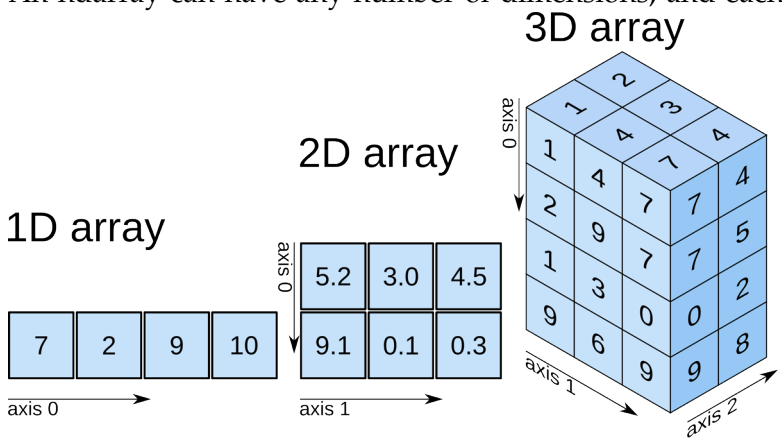
```
np.info(np.ndarray.dtype)
```

- For interactive help, you can use the symbol `?`, for example:

```
np.array?
1 Docstring:
2 array(object, dtype=None, *, copy=True, order='K', subok=False, ndmin=0, like=None)
3
4 Create an array.
5 ...
```

3 NumPy N-dimensional array (ndarray):

- NumPy's ndarray is a multi-dimensional container for homogeneous numerical data, meaning that all elements in the array should be of the same data type.
- An ndarray can have any number of dimensions, and each dimension is called an "axis".



3.1 How to create ndarray:

Ndarrays are created using the `numpy.array` function, which takes a list or tuple of values as input and returns an ndarray object.

```
a = np.array([1,2,3]) #1D array
b = np.array([(1.5,2,3), (4,5,6)], dtype = float) #2D array
c = np.array([[(1.5,2,3), (4,5,6)], [(3,2,1), (4,5,6)]], dtype = float) #3D array
```

3.2 Some important NumPy array creation functions:

function	Description
`np.zeros`	Produce an array of all *0s* with the given shape and data type
`np.ones`	Produce an array of all *1s* with the given shape and data type
`np.arange`	Like the built-in range but returns an ndarray instead of a list
`np.linspace`	Create an array of evenly spaced values (number of samples)
`np.full`	Produce an array of the given shape and data type with all values set to the indicated 'fill value';
`np.eye`*or*`np.identity`	Create a square N × N identity matrix (1s on the diagonal and 0s elsewhere)
`np.random.random`	Create an array with random values
`np.empty`	Create new arrays by allocating new memory, but do not populate with any values like ones and zeros

examples:

```
np.zeros((3,4)) #Create an array of zeros
np.ones((2,3,4),dtype=np.int16) #Create an array of ones
np.arange(10,25,5) #Create an array of evenly spaced values (step value)
np.linspace(0,2,9) #Create an array of evenly spaced values (number of samples)
np.full((2,2),7) #Create a constant array
np.eye(2) #Create a 2X2 identity matrix
```

```
np.random.random((2,2)) #Create an array with random values
np.random.randint(2, size=(3,3))
np.empty((3,2)) #Create an empty array
```

3.3 Why not just use Python lists for calculations instead of creating a new type of array using numpy?

There are several reasons for this: - Python lists are very general (also called high-level objects). They can contain any object ⇒ dynamic typing. They do not support mathematical operations. - NumPy arrays are statically typed and homogeneous. - The type of the elements is determined when the array is created ⇒ no more dynamic typing. - Similarly, the size of the array is fixed at creation ⇒ optimized memory storage. - Due to static typing, mathematical functions such as matrix multiplication and addition can be implemented using a compiled language (C and Fortran).

Example:

```
%timeit [i**2 for i in range(1000)]
a = np.arange(1000)
%timeit a**2
```

3.4 Data types in numpy:

NumPy provides several data types that can be used to create arrays.

Type	*Code*	*Decription*
bool	?	Boolean (True or False) stored as a byte
*int*8	*i*1	Byte (-128 to 127)
*int*16	*i*2	Integer (-32768 to 32767)
*int*32	*i*4	Integer (-2 ** 31 to 2 ** 31 - 1)
*int*64	*i*8	Integer (-2 ** 63 to 2 ** 63 - 1)
*uint*8	*u*1	Unsigned integer (0 to 255)
*uint*16	*u*2	Unsigned integer (0 to 65535)
*uint*32	*u*4	Unsigned integer (0 to 2 ** 32 - 1)
*uint*64	*u*8	Unsigned integer (0 to 2 ** 64 - 1)
*float*16	*f*2	Half precision float
*float*32	*f*4	Single precision float
*float*64	*f*8	Double precision float
*complex*64	*c*8	Complex number, represented by two 32-bit floats
*complex*128	*c*16	Complex number, represented by two 64-bit floats
*string_*	*S*	Fixed-length ASCII string type (1 byte per character); for example, to create a string data type with length 10, use 'S10'

Example:

```
a = np.array([1, 2, 3], dtype=?)
print(a)
a = np.array([1, 2, 3], dtype=f4)
print(a)
```

3.5 Getting arrays dimensions and Data type in numpy

- To get the dimensions of an array, we can use the `shape` attribute. For example, for an array `a`, we can get its dimensions as follows:

```
a = np.array([[1, 2, 3], [4, 5, 6]])
print(a.shape)
```

- To get the number of dimensions of an array, we can use the `ndim` attribute. For example:

```
a = np.array([[1, 2, 3], [4, 5, 6]])
print(a.ndim)
```

- To get the data type of an array, we can use the `dtype` attribute. For example:

```
a = np.array([1, 2, 3], dtype=np.float32)
print(a.dtype)
```

- We can also explicitly convert the data type of an array using the `astype()` method. For example:

```
a = np.array([1, 2, 3], dtype=np.int32)
b = a.astype(np.float32)
print(b.dtype)
```

3.6 Array mathematics in numpy:

3.6.1 Arithmetic Operations

Subtraction, Addition, Division, Multiplication (item per item): NumPy provides element-wise arithmetic operations for arrays. You can perform addition, subtraction, multiplication, and division on arrays by simply using the appropriate operator (`+`, `-`, `*`, `/`) between them. The operations are performed on each corresponding element of the arrays. For example:

```
a = np.array([1, 2, 3])
b = np.array([4, 5, 6])

# Addition
c = a + b
print(c)  # Output: [5 7 9]

# Subtraction
d = a - b
print(d)  # Output: [-3 -3 -3]

# Multiplication
e = a * b
print(e)  # Output: [ 4 10 18]

# Division
f = a / b
print(f)  # Output: [0.25 0.4  0.5 ]
```

element-wise mathematical functions: NumPy provides several mathematical functions that operate element-wise on arrays. For example,

```
import numpy as np

a = np.array([1, 4, 9])

# Square root
b = np.sqrt(a)
print(b)  # Output: [1. 2. 3.]

# Sine
c = np.sin(a)
print(c)  # Output: [ 0.84147098 -0.7568025   0.41211849]

# Cosine
d = np.cos(a)
print(d)  # Output: [ 0.54030231 -0.65364362 -0.91113026]
```

3.6.2 Comparison

In NumPy, we can compare arrays element-wise using comparison operators such as `==`, `!=`, `<`, `>`, `<=`, and `>=`. When performing element-wise comparisons, the result is a boolean array of the same shape as the original arrays. For example:

```
a = np.array([1, 2, 3])
b = np.array([1, 2, 4])

print(a == b)  # [ True  True False]
print(a != b)  # [False False  True]
print(a < b)   # [False False  True]
print(a > b)   # [False False False]
print(a <= b)  # [ True  True  True]
print(a >= b)  # [ True  True False]
```

we can also perform element-wise comparisons between a scalar value and an array:

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

print(a == b)  # [False  True False]
print(a != b)  # [ True False  True]
print(a < b)   # [ True False False]
print(a > b)   # [False False  True]
print(a <= b)  # [ True  True False]
print(a >= b)  # [False  True  True]
```

any(), all(), and sum() with condition:

- `all()` returns True if all the elements in the input array evaluate to True. Otherwise, it returns False.
- `any()` returns True if any of the elements in the input array evaluate to True. Otherwise, it returns False.

Here are some examples:

```
import numpy as np

a = np.array([1, 2, 3, 4])
b = np.array([0, 2, 4, 6])
c = np.array([-1, 2, -3, 4])

# using all() method
print(np.all(a > 0))   # True
print(np.all(b > 0))   # False
print(np.all(c > 0))   # False

# using any() method
print(np.any(a == 2))  # True
print(np.any(b == 1))  # False
print(np.any(c == -3)) # True
```

- In NumPy, we can perform sum with condition using the `np.sum()` function with a boolean mask as input. The boolean mask is created using a comparison operator (`>`, `<`, `==`, etc.) on an array, which creates a boolean array of the same shape with True where the condition is met and False where it is not.

```
import numpy as np

# Create an array
arr = np.array([[1, 2, 3], [4, 5, 6], [7, 8, 9]])

# Sum all elements that are greater than 5
sum_greater_than_5 = np.sum(arr[arr > 5])

print(sum_greater_than_5) # Output: 30
```

3.6.3 Arrays statistics functions:

NumPy provides many built-in statistical functions that can be used to perform various statistical operations on arrays. Here are some of the commonly used statistical functions in NumPy:

function	*Description*
np.mean()	Calculates the arithmetic mean of an array along a specified axis.
np.median()	Computes the median of an array along a specified axis.
np.std()	Computes the standard deviation of an array along a specified axis.
np.var()	Computes the variance of an array along a specified axis.
np.min()	Computes the minimum value of an array along a specified axis.
np.max()	Computes the maximum value of an array along a specified axis.
np.argmin()	Return the index of the minimum value
np.argmax()	Return the index of the maximum value
np.sum()	Computes the sum of all the elements in an array along a specified axis.
np.prod()	Computes the product of all the elements in an array along a specified axis.
np.cumsum()	Computes the cumulative sum of the elements in an array along a specified axis.

Here's an example of how to use some of these functions:

```
import numpy as np

a = np.array([[1, 2, 3], [4, 5, 6], [7, 8, 9]])

print(np.mean(a))           # 5.0
print(np.median(a))         # 5.0
print(np.std(a))            # 2.5819888974716112
print(np.var(a))            # 6.666666666666667
print(np.min(a,axis=1))      # [1 4 7]
print(np.max(a))            # 9
print(np.sum(a))            # 45
print(np.prod(a))           # 362880
print(np.cumsum(a))         # [ 1  3  6 10 15 21 28 36 45]
```

3.6.4 Arrays algebraic and form operations:

Dot product The `dot()` function in NumPy performs matrix multiplication or dot product of two arrays.

```
A = np.array([[1, 2], [3, 4], [5, 6]])
B = np.array([[7, 8], [9, 10]])

# Matrix multiplication of A and B
C = np.dot(A, B )# or C = A @ B
print(C)
```

Transposition The `transpose()` function can be called on a NumPy array to create a new array with the rows and columns flipped. For example, the following code creates a 2D array arr and then transposes it using the `transpose()` function:

```
arr = np.array([[1, 2], [3, 4]])
transposed_arr = np.transpose(arr)
print(transposed_arr)
```

Alternatively, the `T` attribute can be used to transpose an array. For example:

```
arr = np.array([[1, 2], [3, 4]])
transposed_arr = arr.T
print(transposed_arr)
```

Reshaping: Changing the shape of an array while maintaining the same number of elements.

```
import numpy as np
a = np.array([[1, 2], [3, 4], [5, 6]])
print("Original array:\n", a)
# Output:
# Original array:
#  [[1 2]
#   [3 4]
#   [5 6]]

b = a.reshape((2, 3))
print("Reshaped array:\n", b)
# Output:
# Reshaped array:
#  [[1 2 3]
#   [4 5 6]]
```

Broadcasting: Performing operations on arrays with different shapes and sizes.

```
import numpy as np
a = np.array([1, 2, 3])
b = np.array([[4], [5], [6]])
c = a + b
print("Result array:\n", c)
# Output:
# Result array:
#  [[5 6 7]
#   [6 7 8]
#   [7 8 9]]
```

Concatenation: Joining two or more arrays along a specified axis.

```
import numpy as np
a = np.array([[1, 2], [3, 4]])
b = np.array([[5, 6]])
c = np.concatenate((a, b), axis=0)
print("Concatenated array:\n", c)
# Output:
```

```
# Concatenated array:
#  [[1 2]
#   [3 4]
#   [5 6]]
```

Stacking: Joining two or more arrays along a new axis.

```
import numpy as np
a = np.array([1, 2, 3])
b = np.array([4, 5, 6])
c = np.stack((a, b), axis=0)
print("Stacked array:\n", c)
# Output:
# Stacked array:
#  [[1 2 3]
#   [4 5 6]]
```

3.6.5 Splitting:

Splitting an array into smaller arrays along a specified axis.

```
import numpy as np
a = np.array([[1, 2, 3], [4, 5, 6], [7, 8, 9], [10, 11, 12]])
b, c = np.split(a, 2, axis=0)
print("First split array:\n", b)
print("Second split array:\n", c)
# Output:
# First split array:
#  [[1 2 3]
#   [4 5 6]]
# Second split array:
#  [[ 7  8  9]
#   [10 11 12]]
```

3.6.6 flattened array

`ravel()` is a function in NumPy that returns a flattened array. It means that it returns a 1-dimensional array that contains all the elements of the input array. The returned array is always a copy of the original array, so modifying it does not affect the original array.

Here is an example of how to use `ravel()`:

```
import numpy as np

# Create a 2-dimensional array
arr = np.array([[1, 2], [3, 4]])

# Flatten the array using ravel()
flat_arr = arr.ravel()
```

```
# Print the original and flattened arrays
print("Original array:\n", arr)
print("Flattened array:\n", flat_arr)
```

3.7 Copying Arrays

In NumPy, arrays can be copied in different ways, depending on the desired behavior. Here are some ways to copy arrays in NumPy:

1- **Shallow copy**: In this type of copy, a new array object is created, but the data is not copied. Instead, a reference to the original data is used. Shallow copy can be made using the `view()` method.

2- **Deep copy**: In this type of copy, a completely new array and data are created. Deep copy can be made using the `copy()` method. Example:

```
import numpy as np

arr1 = np.array([1, 2, 3])
arr2 = arr1.view()

print(arr1)
print(arr2)

arr2[0] = 0
print("Shallow copy")
print(arr1)
print(arr2)

arr2=arr1.copy()
arr2[2] = 4
print("Deep copy")
print(arr1)
print(arr2)
```

3.8 Sorting Arrays

Sorting an array in numpy can be done using the `sort()` function. By default, it sorts the array in ascending order.

Here is an example:

```
import numpy as np

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

print(arr)
#output
#[1 2 3 4 5]
```

If you want to sort a two-dimensional array, you can use the `sort()` function with the axis parameter. By default, it sorts each row independently.

Here is an example:

```
import numpy as np

arr = np.array([[3, 2, 1],
                [6, 5, 4],
                [9, 8, 7]])

arr.sort(axis=1)
#output
#[[1 2 3]
# [4 5 6]
# [7 8 9]]
print(arr)
```