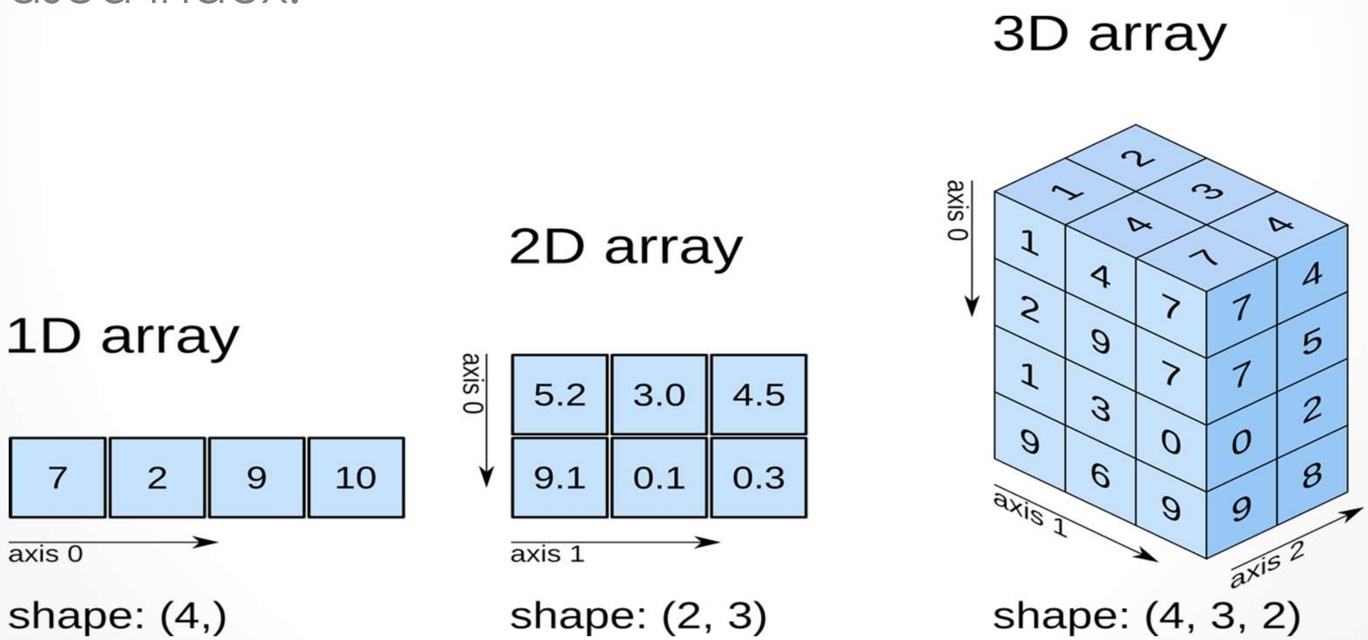
Introduction to Numpy

- **NumPy**, which stands for Numerical Python, is a library consisting of multidimensional array objects and a collection of routines for processing those arrays.
- Using NumPy, mathematical and logical operations on arrays can be performed.
- Using NumPy, a developer can perform the following operations −
  - Mathematical and logical operations on arrays.
  - Fourier transforms and routines for shape manipulation.
  - Operations related to linear algebra. NumPy has in-built functions for linear algebra and random number generation.

Array creation using Numpy

The most important object defined in NumPy is an N-dimensional array type called **ndarray**. It describes the collection of items of the same type. Items in the collection can be accessed using a zero-based index.



Arrays in NumPy

NumPy's main object is the homogeneous multidimensional array.

- It is a table of elements (usually numbers), all of the same type, indexed by a tuple of positive integers.
- In NumPy dimensions are called axes. The number of axes is rank.
- NumPy's array class is called ndarray. It is also known by the alias array.

```
[[ 1, 2, 3],
 [ 4, 2, 5]]
Here,
rank = 2 (as it is 2-dimensional or it has 2 axes)
first dimension(axis) length = 2, second dimension has length = 3
overall shape can be expressed as: (2, 3)
```

```python
# Python program to demonstrate basic array characteristics
import numpy as np

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

# Printing type of arr object
print("Array is of type: ", type(arr))

# Printing array dimensions (axes)
print("No. of dimensions: ", arr.ndim)

# Printing shape of array
print("Shape of array: ", arr.shape)

# Printing size (total number of elements) of array
print("Size of array: ", arr.size)

# Printing type of elements in array
print("Array stores elements of type: ", arr.dtype)
```

Output

```
Array is of type:
No. of dimensions:  2
Shape of array:  (2, 3)
Size of array:  6
Array stores elements of type:  int64
```

Array creation

- For example, you can create an array from a regular Python list or tuple using the array function. The type of the resulting array is deduced from the type of the elements in the sequences.
- Often, the elements of an array are originally unknown, but its size is known. Hence, NumPy offers several functions to create arrays with initial placeholder content. These minimize the necessity of growing arrays, an expensive operation.
- For example: np.zeros, np.ones, np.full, np.empty, etc.

Array creation

- To create sequences of numbers, NumPy provides a function analogous to range that returns arrays instead of lists.
- arange: returns evenly spaced values within a given interval. step size is specified.
- linspace: returns evenly spaced values within a given interval. num no. of elements are returned.
- Reshaping array: We can use reshape method to reshape an array. Consider an array with shape (a1, a2, a3, …, aN). We can reshape and convert it into another array with shape (b1, b2, b3, …, bM). The only required condition is:
- a1 x a2 x a3 … x aN = b1 x b2 x b3 … x bM . (i.e original size of array remains unchanged.)
- Flatten array: We can use flatten method to get a copy of array collapsed into one dimension. It accepts order argument. Default value is 'C' (for row-major order). Use 'F' for column major order.

Array creation using Numpy

```
# Python program to demonstrate array creation techniques
import numpy as np

# Creating array from list with type float
a = np.array([[1, 2, 4], [5, 8, 7]], dtype = 'float')
print ("Array created using passed list:\n", a)

# Creating array from tuple
b = np.array((1 , 3, 2))
print ("\nArray created using passed tuple:\n", b)

# Creating a 3X4 array with all zeros
c = np.zeros((3, 4))
print ("\nAn array initialized with all zeros:\n", c)
```

Output

```
Array created using passed list:
 [[ 1.  2.  4.]
 [ 5.  8.  7.]]

Array created using passed tuple:
 [1 3 2]

An array initialized with all zeros:
 [[ 0.  0.  0.  0.]
 [ 0.  0.  0.  0.]
 [ 0.  0.  0.  0.]]
```

Array creation using Numpy

```
# Create a constant value array of complex type
d = np.full((3, 3), 6, dtype = 'complex')
print ("\nAn array initialized with all 6s. Array type is complex:\n", d)

# Create an array with random values
e = np.random.random((2, 2))
print ("\nA random array:\n", e)

# Create a sequence of integers from 0 to 30 with steps of 5
f = np.arange(0, 30, 5)
print ("\nA sequential array with steps of 5:\n", f)

# Create a sequence of 10 values in range 0 to 5
g = np.linspace(0, 5, 10)
print ("\nA sequential array with 10 values between 0 and 5:\n", g)
```

Output

```
An array initialized with all 6s. Array type is complex:
 [[ 6.+0.j  6.+0.j  6.+0.j]
 [ 6.+0.j  6.+0.j  6.+0.j]
 [ 6.+0.j  6.+0.j  6.+0.j]]

A random array:
 [[ 0.46829566  0.67079389]
 [ 0.09079849  0.95410464]]

A sequential array with steps of 5:
 [ 0  5 10 15 20 25]

A sequential array with 10 values between 0 and 5:
 [ 0.          0.55555556  1.11111111  1.66666667  2.22222222  2.77777778
  3.33333333  3.88888889  4.44444444  5.        ]
```

Array creation using Numpy

```
# Reshaping 3X4 array to 2X2X3 array
arr = np.array([[1, 2, 3, 4],
                [5, 2, 4, 2],
                [1, 2, 0, 1]])

newarr = arr.reshape(2, 2, 3)

print ("\nOriginal array:\n", arr)
print ("Reshaped array:\n", newarr)

# Flatten array
arr = np.array([[1, 2, 3], [4, 5, 6]])
flarr = arr.flatten()

print ("\nOriginal array:\n", arr)
print ("Fattened array:\n", flarr)
```

Output

```
Original array:
 [[1 2 3 4]
 [5 2 4 2]
 [1 2 0 1]]
Reshaped array:
 [[[1 2 3]
  [4 5 2]]

 [[4 2 1]
  [2 0 1]]]

Original array:
 [[1 2 3]
 [4 5 6]]
Fattened array:
 [1 2 3 4 5 6]
```

Array Indexing

Knowing the basics of array indexing is important for analysing and manipulating the array object. NumPy offers many ways to do array indexing.

- Slicing: Just like lists in python, NumPy arrays can be sliced. As arrays can be multidimensional, you need to specify a slice for each dimension of the array.
- Integer array indexing: In this method, lists are passed for indexing for each dimension. One to one mapping of corresponding elements is done to construct a new arbitrary array.
- Boolean array indexing: This method is used when we want to pick elements from array which satisfy some condition.

```python
# Python program to demonstrate indexing in numpy
import numpy as np

# An exemplar array
arr = np.array([[-1, 2, 0, 4],
                [4, -0.5, 6, 0],
                [2.6, 0, 7, 8],
                [3, -7, 4, 2.0]])

# Slicing array
temp = arr[:2, ::2]
print ("Array with first 2 rows and alternate columns(0 and 2):\n", temp)

# Integer array indexing example
temp = arr[[0, 1, 2, 3], [3, 2, 1, 0]]
print ("\nElements at indices (0, 3), (1, 2), (2, 1), (3, 0):\n", temp)

# boolean array indexing example
cond = arr > 0 # cond is a boolean array
temp = arr[cond]
print ("\nElements greater than 0:\n", temp)
```

Output

```
Array with first 2 rows and alternatecolumns(0 and 2):
 [[-1.  0.]
 [ 4.  6.]]

Elements at indices (0, 3), (1, 2), (2, 1),(3, 0):
 [ 4.  6.  0.  3.]

Elements greater than 0:
 [ 2.   4.   4.   6.   2.6  7.   8.   3.   4.   2. ]
```

Operations on Single Array

We can use overloaded arithmetic operators to do element-wise operation on array to create a new array. In case of +=, -=, *= operators, the exsisting array is modified.

```python
# Python program to demonstrate
# basic operations on single array
import numpy as np

a = np.array([1, 2, 5, 3])

# add 1 to every element
print ("Adding 1 to every element:", a+1)

# subtract 3 from each element
print ("Subtracting 3 from each element:", a-3)

# multiply each element by 10
print ("Multiplying each element by 10:", a*10)

# square each element
print ("Squaring each element:", a**2)

# modify existing array
a *= 2
print ("Doubled each element of original array:", a)

# transpose of array
a = np.array([[1, 2, 3], [3, 4, 5], [9, 6, 0]])

print ("\nOriginal array:\n", a)
print ("Transpose of array:\n", a.T)
```

Output

```
Adding 1 to every element: [2 3 6 4]
Subtracting 3 from each element: [-2 -1  2  0]
Multiplying each element by 10: [10 20 50 30]
Squaring each element: [ 1  4 25  9]
Doubled each element of original array: [ 2  4 10  6]

Original array:
 [[1 2 3]
 [3 4 5]
 [9 6 0]]
Transpose of array:
 [[1 3 9]
 [2 4 6]
 [3 5 0]]
```

Unary operators

Many unary operations are provided as a method of ndarray class. This includes sum, min, max, etc. These functions can also be applied row-wise or column-wise by setting an axis parameter.

```python
# Python program to demonstrate unary operators in numpy
import numpy as np

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

# maximum element of array
print ("Largest element is:", arr.max())
print ("Row-wise maximum elements:", arr.max(axis = 1))

# minimum element of array
print ("Column-wise minimum elements:", arr.min(axis = 0))

# sum of array elements
print ("Sum of all array elements:", arr.sum())

# cumulative sum along each row
print ("Cumulative sum along each row:\n", arr.cumsum(axis = 1))
```

Output

```
Largest element is: 9
Row-wise maximum elements: [6 7 9]
Column-wise minimum elements: [1 1 2]
Sum of all array elements: 38
Cumulative sum along each row:
[[ 1  6 12]
 [ 4 11 13]
 [ 3  4 13]]
```

Random Array Generation

```
# Python program explaining numpy.random.randint() function

# importing numpy
import numpy as np

# output array
out_arr = np.random.randint(low = 0, high = 3, size = 5)
print ("Output 1D Array filled with random integers : ", out_arr)

out_arr1 = np.random.randint(low = 4, size =(2, 3))
print ("Output 2D Array filled with random integers : ", out_arr1)
out_arr3 = np.random.randint(2, 10, (2, 3, 4))
print ("Output 3D Array filled with random integers : ", out_arr3)
```

Random Array Generation

`random.random()`	Returns a random float number between 0 and 1
`random.uniform(10.5, 75.5)`	Returns a random float number between a range
`round(random.uniform(33.33, 66.66), 2)`	Returns a random float number up to 2 decimal places
`random.SystemRandom().uniform(5, 10)`	Returns a secure random float number
`numpy.random.uniform()`	Returns a random array of floats

Binary operators

These operations apply on array elementwise and a new array is created. You can use all basic arithmetic operators like +, -, /, , etc. In case of +=, -=, = operators, the existing array is modified.

```python
# Python program to demonstrate binary operators in Numpy
import numpy as np

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

# add arrays
print ("Array sum:\n", a + b)

# multiply arrays (elementwise multiplication)
print ("Array multiplication:\n", a*b)

# matrix multiplication
print ("Matrix multiplication:\n", a.dot(b))
```

Output

```
Array sum:
[[5 5]
 [5 5]]
Array multiplication:
[[4 6]
 [6 4]]
Matrix multiplication:
[[ 8  5]
 [20 13]]
```

Universal functions (ufunc)

NumPy provides familiar mathematical functions such as sin, cos, exp, etc. These functions also operate elementwise on an array, producing an array as output.

Note: All the operations we did above using overloaded operators can be done using ufuncs like np.add, np.subtract, np.multiply, np.divide, np.sum, etc.

```python
# Python program to demonstrate universal functions in numpy
import numpy as np

# create an array of sine values
a = np.array([0, np.pi/2, np.pi])
print ("Sine values of array elements:", np.sin(a))

# exponential values
a = np.array([0, 1, 2, 3])
print ("Exponent of array elements:", np.exp(a))

# square root of array values
print ("Square root of array elements:", np.sqrt(a))
```

Output

```
Sine values of array elements: [  0.00000000e+00   1.00000000e+00   1.22464680e-16]
Exponent of array elements: [  1.           2.71828183   7.3890561    20.08553692]
Square root of array elements: [ 0.          1.          1.41421356  1.73205081]
```

Sorting array

```python
import numpy as np
a = np.array([[1, 4, 2],
                [3, 4, 6],
            [0, -1, 5]])
# sorted array
print ("Array elements in sorted order:\n", np.sort(a, axis = None))
# sort array row-wise
print ("Row-wise sorted array:\n", np.sort(a, axis = 1))
# specify sort algorithm
print ("Column wise sort by applying merge-sort:\n",
                        np.sort(a, axis = 0, kind = 'mergesort'))
# Example to show sorting of structured array
# set alias names for dtypes
dtypes = [('name', 'S10'), ('grad_year', int), ('cgpa', float)]
# Values to be put in array
values = [('Hrithik', 2009, 8.5), ('Ajay', 2008, 8.7),
        ('Pankaj', 2008, 7.9), ('Aakash', 2009, 9.0)]
# Creating array
arr = np.array(values, dtype = dtypes)
print ("\nArray sorted by names:\n", np.sort(arr, order = 'name'))
print ("Array sorted by grauation year and then cgpa:\n",
                np.sort(arr, order = ['grad_year', 'cgpa']))
```

Output

```
Array elements in sorted order:
[-1  0  1  2  3  4  4  5  6]
Row-wise sorted array:
[[ 1  2  4]
 [ 3  4  6]
 [-1  0  5]]
Column wise sort by applying merge-sort:
[[ 0 -1  2]
 [ 1  4  5]
 [ 3  4  6]]

Array sorted by names:
[('Aakash', 2009, 9.0) ('Ajay', 2008, 8.7) ('Hrithik', 2009, 8.5)
 ('Pankaj', 2008, 7.9)]
Array sorted by grauation year and then cgpa:
[('Pankaj', 2008, 7.9) ('Ajay', 2008, 8.7) ('Hrithik', 2009, 8.5)
 ('Aakash', 2009, 9.0)]
```