Python

Introduction to NumPy

In this lecture

- Difference between Python Lists and NumPy Arrays
- Introduction to NumPy (**Num**erical **Py**thon)
- Creating a NumPy array and type differences
- NumPy Array Functions
- 1D indexing and slicing
- 2D indexing and slicing
- Joining Arrays
- NumPy Arithmetic and Operations
- NumPy Vectorization, Broadcasting and Boolean Masking

Lists in Python

Lists

- A list in Python does use the subscript operator [ ] typically associated with an array. Elements in this list are also indexed.
- The list will maintain a pointer (reference) to objects, rather the integer values (remember Python types are **classes**).
- Lists in python are resizable, unlike static arrays which are fixed.
- Python lists can store elements of different types, whereas arrays are declared to store values of one type.

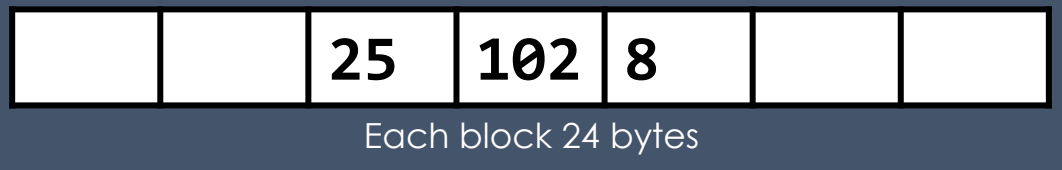
Lists and Arrays

Python List

[27, "Python", 89.13]

Array

[25, 102, 8]



List

In[ ]:
```
1 | l = [1,2,3,4,5,6]
2 | l
3 |
```

List

In[ ]:
```
1 | l = [1,2,3,4,5,6]
2 | l
3 |
```

Out[]: [1, 2, 3, 4, 5, 6]

List

In[ ]:

```
1 | l = [1,2,3,4,5,6]
2 | l[0]
3 |
```

List

In[ ]:
```
1 | l = [1,2,3,4,5,6]
2 | l[0]
3 |
```

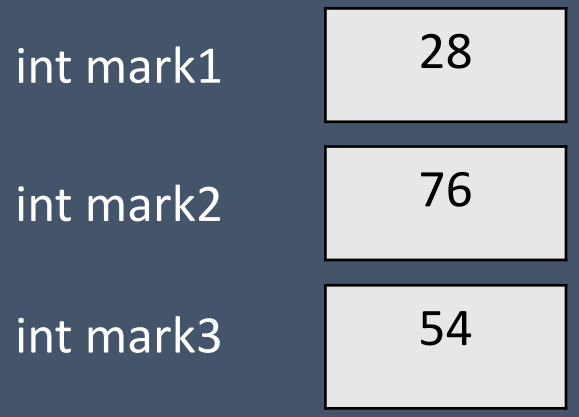
Out[]: 1

Array

Array

- The items in an array are called **elements**.
- We specify how many elements an array will have when we declare the size of the array **(if 'fixed-size'),** unlike flexible sized collections (ArrayList).
- Elements are numbered and can referred to by number inside the [ ] is called the **index**. This is used when data is input and output.
- Can only store data if it **matches the type** the array is declared with.

Array visualisation



int[] marks = new int[8];

marks[0]	28
marks[1]	76
marks[2]	54
marks[3]	9
marks[4]	27
marks[5]	65
marks[6]	45
marks[7]	17

An Array is a structure that can hold multiple values in individual elements (positions)

Lists vs Arrays

- **List can store data of different types**
- **Array (numpy arrays) store data of the same type**
- We can refer to elements in both a list and array via the [ ]

NumPy

NumPy

- **Num**erical **Py**thon (NumPy) is a package full of methods that can perform useful operations on data.
- NumPy provides a convenient API (Application Programmable Interface) that provides a way to ‘interface’ with / operate on data.
- It reintroduces types which is more coding but more efficient way to search/sort/store data than the ‘loosely’ typed nature of Python that we’ve seen so far.

More documentation available at: https://numpy.org

NumPy array

- NumPy arrays are different to Python Lists.
- NumPy arrays reintroduce the ‘typed’ nature of more ‘verbose’ languages (C, C++, Java), where everything is explicitly typed.
- NumPy arrays operate like arrays from C and Java where they declared to store data of one type (only integers), unlike Python and JS, which can store data of different types.
- NumPy arrays therefore data is ‘cast’ – floating point numbers to integers, or in some cases – an error is produced (strings to integers).

Import NumPy

In[ ]:
```
1 | import numpy as np
2 | np
3 |
```

Import NumPy

In[ ]:
```
1 | import numpy as np
2 | np
3 |
```

Out[]:
```
<module 'numpy' from
'/Users/nick/anaconda3/lib/python3.11/
site-packages/numpy/__init__.py'>
```

Same cell

In[ ]:

```
1 | import numpy as np
2 | a = np.array([1,2,3,4,5,6])
3 | a
```

Separate cells

In[ ]:
```
1 | import numpy as np
```

In[ ]:
```
1 | a = np.arange(3)
2 | a
```

np.array

Integer array

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

Integer array

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

Out[]:
```
array([1, 2, 3, 4, 5, 6])
```

Floating points

In[ ]:
```
1 | a = np.array([3.14,2,3,4,5])
2 | a
3 |
```

Floating points

In[ ]:
```
1 | a = np.array([3.14,2,3,4,5])
2 | a
3 |
```

Out[]:
```
array([3.14, 2. , 3. , 4., 5. ])
```

Notice how the ‘integers’ have all been upcast to ‘floats’!

Floating points

In[ ]:
```
1 | a = np.array([1,2,3],dtype='float32')
2 | a
3 |
```

Explicit command to upcast the integers to floats

Floating points

In[ ]:
```
1 | a = np.array([1,2,3],dtype='float32')
2 | a
3 |
```

Out[]: array([1., 2., 3., 4.], dtype=float32)

Explicit command to upcast the integers to floats

Array of arrays

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

Array of arrays

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

Out[]:
```
array([[1, 2, 3],
       [4, 5, 6]])
```

Array functions

arange

In[ ]:
```
1 | a = np.arange(3)
2 | a
3 |
```

arange

In[ ]:
```
1 | a = np.arange(3)
2 | a
3 |
```

Out[]:
```
array([0, 1, 2])
```

arange

In[ ]:
```
1 | a = np.arange(10)
2 | a
3 |
```

arange

In[ ]:
```
1 | a = np.arange(10)
2 | a
3 |
```

Out[]:
```
array([0, 1, 2, 3, 4, 5, 6, 7, 8, 9])
```

zeros

In[ ]:
```
1 | a = np.zeros(6)
2 | a
3 |
```

zeros

In[ ]:
```
1 | a = np.zeros(6)
2 | a
3 |
```

Out[]:
```
array([0., 0., 0., 0., 0., 0.])
```

ones

In[ ]:
```
1 | a = np.ones(6)
2 | a
3 |
```

ones

In[ ]:
```
1 | a = np.ones(6)
2 | a
3 |
```

Out[]:
```
array([1., 1., 1., 1., 1., 1.])
```

Multi-dim

In[ ]:
```
1 | a = np.ones((3, 2))
2 | a
3 |
```

Multi-dim

In[ ]:
```
1 | a = np.ones((3, 2))
2 | a
3 |
```

Out[]:
```
array([[1., 1.],
       [1., 1.],
       [1., 1.]])
```

‘other’ multi-dim

In[ ]:
```
1 | a = np.full((2, 2), 5)
2 | a
3 |
```

‘other’ multi-dim

In[ ]:
```
1 | a = np.full((2, 2), 5)
2 | a
3 |
```

Out[]:
```
array([[5, 5],
       [5, 5]])
```

‘other’ multi-dim

In[ ]:
```
1 | a = np.full((3, 3), 7)
2 | a
3 |
```

‘other’ multi-dim

In[ ]:
```
1 | a = np.full((3, 3), 7)
2 | a
3 |
```

Out[]:
```
array([[7, 7, 7],
       [7, 7, 7],
       [7, 7, 7]])
```

eye

In[ ]:
```
1 | a = np.eye(2)
2 | a
3 |
```

eye

In[ ]:
```
1 | a = np.eye(2)
2 | a
3 |
```

Out[]:
```
array([[1., 0.],
       [0., 1.]])
```

eye

In[ ]:
```
1 | a = np.eye(3)
2 | a
3 |
```

eye

In[ ]:
```
1 | a = np.eye(3)
2 | a
3 |
```

Out[]:
```
array([[1., 0., 0.],
       [0., 1., 0.],
       [0., 0., 1.]])
```

Random 0-1

In[ ]:
```
1 | a = np.random.random((2,2))
2 | a
3 |
```

Random 0-1

In[ ]:
```
1 | a = np.random.random((2,2))
2 | a
3 |
```

Out[]:
```
array([[0.0951625, 0.5725122],
       [0.6251428, 0.7182715]])
```

Random 0 or 1

In[ ]:
```
1 | a = np.random.randint((2,2))
2 | a
3 |
```

Random 0 or 1

In[ ]:
```
1 | a = np.random.randint((2,2))
2 | a
3 |
```

Out[]:
```
array([1, 0])
```

Random 1D

In[ ]:

```
1 | a = np.random.randint(2, size=10)
2 | a
3 |
```

Random 1D

In[ ]:
```
1 | a = np.random.randint(2, size=10)
2 | a
3 |
```

Out[]:
```
array([0, 0, 1, 1, 1, 0, 0, 1, 0, 1])
```

Random 2D

In[ ]:
```
1 | a = np.random.randint(2, size=(2,2))
2 | a
3 |
```

Random 2D

In[ ]:
```
1 | a = np.random.randint(2, size=(2,2))
2 | a
3 |
```

Out[]:
```
array([[1, 1],
       [0, 1]])
```

Random 3 rows

In[ ]:
```
1 | a = np.random.randint(2, size=(3,2))
2 | a
3 |
```

Random 3 rows

In[ ]:
```
1 | a = np.random.randint(2, size=(3,2))
2 | a
3 |
```

Out[]:
```
array([[1, 0],
       [0, 0],
       [1, 0]])
```

Random 3 cols

In[ ]:
```
1 | a = np.random.randint(2, size=(2,3))
2 | a
3 |
```

Random 3 cols

In[ ]:
```
1 | a = np.random.randint(2, size=(2,3))
2 | a
3 |
```

Out[]:
```
array([[1, 0, 1],
       [0, 0, 1]])
```

Random 3x3

In[ ]:

```
1 | a = np.random.randint(3, size=(3,3))
2 | a
3 |
```

Random 3x3

In[ ]:
```
1 | a = np.random.randint(3, size=(3,3))
2 | a
3 |
```

Out[]:
```
array([[1, 2, 0],
       [1, 0, 1],
       [2, 2, 0]])
```

Random 3x3

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | a
3 |
```

Random 3x3

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | a
3 |
```

Out[]:
```
array([[8, 1, 4],
       [6, 2, 5],
       [7, 4, 3]])
```

Random 3D

In[ ]:

```
1 | a = np.random.randint(9, size=(3,3,3))
2 | a
3 |
```

Random 3D

```
Out[]: array([[[8, 1, 4],
               [6, 2, 5],
               [7, 4, 3]],

              [[8, 1, 4],
               [6, 2, 5],
               [7, 4, 3]],

              [[8, 1, 4],
               [6, 2, 5],
               [7, 4, 3]]])
```

Linear Spacing

In[ ]:
```
1 | a = np.linspace(0, 1, 10)
2 | a
3 |
```

Linear Spacing

In[ ]:
```
1 | a = np.linspace(0, 1, 10)
2 | a
3 |
```

Out[]:
```
array([0.  , 0.11111, 0.22222, 0.33333, 0.44444,
       0.55556, 0.66667, 0.77778, 0.88889, 1.])
```

10 evenly (linearly) spaced intervals between 0 and 1 (inclusive)

Linear Spacing

In[ ]:
```
1 | a = np.linspace(0, 1, 11)
2 | a
3 |
```

Linear Spacing

```
In[ ]: 1 | a = np.linspace(0, 1, 11)
       2 | a
       3 |
```

```
Out[]: array([0. , 0.1, 0.2, 0.3, 0.4, 0.5,
              0.6, 0.7, 0.8, 0.9, 1. ])
```

11 evenly (linearly) spaced intervals between 0 and 1 (inclusive)

Array Attributes

Attributes

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | print("size:", a.size)
3 | print("shape:", a.shape)
4 | print("dimensions:", a.ndim)
```

Attributes

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | print("size:", a.size)
3 | print("shape:", a.shape)
4 | print("dimensions:", a.ndim)
```

Out[]:
```
size: 9
shape: (3, 3)
dimensions: 2
```

Attributes

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3,3))
2 | print("size:", a.size)
3 | print("shape:", a.shape)
4 | print("dimensions:", a.ndim)
```

Attributes

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3,3))
2 | print("size:", a.size)
3 | print("shape:", a.shape)
4 | print("dimensions:", a.ndim)
```

Out[]:
```
size: 27
shape: (3, 3, 3)
dimensions: 3
```

Indexing

- Getting and setting the value of individual array elements:

  x[start : stop : step]

- If any of these are unspecified, they default to the values:
  - start=0,
  - stop=size of dimension,
  - step=1

Indexing

Sample array

In[ ]:
```
1 | a = np.arange(10)
2 | a
3 |
```

Out[]:
```
array([0, 1, 2, 3, 4, 5, 6, 7, 8, 9])
```

Access via index

In[ ]:
```
1 | a = np.arange(10)
2 | a[3]
3 |
```

Access via index

In[ ]:
```
1 | a = np.arange(10)
2 | a[3]
3 |
```

Out[]: 3

First 3 elements

In[ ]:
```
1 | a = np.arange(10)
2 | a[:3]
3 |
```

First 3 elements

In[ ]:
```
1 | a = np.arange(10)
2 | a[:3]
3 |
```

Out[]:
```
array([0, 1, 2])
```

Elements after 3

In[ ]:
```
1 | a = np.arange(10)
2 | a[3:]
3 |
```

Elements after 3

In[ ]:
```
1 | a = np.arange(10)
2 | a[3:]
3 |
```

Out[]:
```
array([3, 4, 5, 6, 7, 8, 9])
```

Subarray 3 - 6

In[ ]:
```
1 | a = np.arange(10)
2 | a[3:6]
3 |
```

Subarray 3 - 6

In[ ]:
```
1 | a = np.arange(10)
2 | a[3:6]
3 |
```

Out[]:
```
array([3, 4, 5])
```

3-6 step of 2

In[ ]:
```
1 | a = np.arange(10)
2 | a[3:6:2]
3 |
```

3-6 step of 2

In[ ]:
```
1 | a = np.arange(10)
2 | a[3:6:2]
3 |
```

Out[]:
```
array([3, 5])
```

Multiples of 3

In[ ]:
```
1 | a = np.arange(10)
2 | a[::3]
3 |
```

Multiples of 3

In[ ]:
```
1 | a = np.arange(10)
2 | a[::3]
3 |
```

Out[]:
```
array([0, 3, 6, 9])
```

Accessing rows and cols

Multi-dim access

- One commonly needed routine is to access a single row or column of an array.
- C and Java require a counter variable to do this manually. This counter increases as one iterates over the array.
- In Python, an easy way to do this is to combine both
  - Indexing [ ]
  - Slicing :
- NOTE: NumPy array slices return **views** whereas Python list slicing returns **copies** of array data.

Sample array

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | a
3 |
```

Out[]:
```
array([[8, 1, 4],
       [6, 2, 5],
       [7, 4, 3]])
```

Select all rows for col 0

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | a[:,0]
3 |
```

Out[]:
```
array([[8, 1, 4],
       [6, 2, 5],
       [7, 4, 3]])
```

Select all rows for col 0

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | a[:,0]
3 |
```

Out[]:
```
array([8, 6, 7])
```

Select all cols for row 0

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | a[0,:]
3 |
```

Out[]:
```
array([[8, 1, 4],
       [6, 2, 5],
       [7, 4, 3]])
```

Select all cols for row 0

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | a[0,:]
3 |
```

Out[]: array([8, 1, 4])

Select all cols for row 1

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | a[1,:]
3 |
```

Out[]:
```
array([[8, 1, 4],
       [6, 2, 5],
       [7, 4, 3]])
```

Select all cols for row 1

In[ ]:
```
1 | a = np.random.randint(9, size=(3,3))
2 | a[1,:]
3 |
```

Out[]:
```
array([6, 2, 5])
```

Joining Arrays

Concatenate

In[ ]:
```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = np.concatenate([a, b])
4 | c
```

Concatenate

In[ ]:
```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = np.concatenate([a, b])
4 | c
```

Out[]:
```
array([1, 2, 3, 4, 5, 6])
```

Hstack

In[ ]:
```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = np.hstack([a, b])
4 | c
```

Hstack

In[ ]:
```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = np.hstack([a, b])
4 | c
```

Out[]:
```
array([1, 2, 3, 4, 5, 6])
```

Vstack

In[ ]:
```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = np.vstack([a, b])
4 | c
```

Vstack

In[ ]:
```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = np.vstack([a, b])
4 | c
```

Out[]:
```
array([[1, 2, 3],
       [4, 5, 6]])
```

Vstack shape

In[ ]:
```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = np.vstack([a, b])
4 | print(c.shape)
```

Vstack shape

In[ ]:
```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = np.vstack([a, b])
4 | print(c.shape)
```

Out[]: (2, 3)

Arithmetic NumPy

Operator	Equivalent ufunc	Output
5 + 5	np.add	10
5 - 4	np.subtract	1
5 / 2	np.divide	2.5
50 % 4	np.mod	2 (remainder)
5 * 10	np.multiply	50
5 // 2	np.floor_divide	2 (round 2.5 down)
5 ** 2	np.power	25 (5 x 5)

Aggregation functions

Function Name	NaN safe	Description
np.sum	np.nansum	compute sum of elements
np.prod	np.nanprod	compute product of elements
np.median	np.nanmedian	compute median of elements
np.mean	np.nanmean	compute mean of elements
np.std	np.nanstd	compute standard deviation
np.var	np.nanvar	compute variance

Aggregation functions

Function Name	NaN safe	Description
np.min	np.nanmin	find minimum value
np.max	np.nanmax	find maximum value
np.argmin	np.nanargmin	find index of min value
np.argmax	np.nanargmax	find index of max value
np.percentile	np.nanpercentile	rank statistics of elem.
np.any	N/A	are any elements true
np.all	N/A	are all elements are true

Vectorization

Vectorized

In[ ]:

```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = np.sum(a * b)
4 | print(c)
```

Vectorized

In[ ]:
```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = np.sum(a * b)
4 | print(c)
```

Out[]: 32

Non-Vectorized

In[ ]:

```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = 0
4 | for i in range(len(a)):
5 |     c += a[i] * b[i]
6 | print(c)
```

Non-Vectorized

In[ ]:
```
1 | a = np.array([1,2,3])
2 | b = np.array([4,5,6])
3 | c = 0
4 | for i in range(len(a)):
5 |     c += a[i] * b[i]
6 | print(c)
```

Out[]: 32

Broadcasting

Broadcasting

In[ ]:
```
1 | a = np.array([[1,2,3], [4,5,6], [7,8,9]])
2 | b = np.array([10,20,30])
3 | c = a + b
4 | c
```

Broadcasting

In[ ]:
```
1 | a = np.array([[1,2,3], [4,5,6], [7,8,9]])
2 | b = np.array([10,20,30])
3 | c = a + b
4 | c
```

Out[]:
```
array([[11, 21, 31],
       [14, 25, 36],
       [17, 28, 39]])
```

Boolean Masking

Example

In[ ]:
```
1 | a = np.array([[1,2,3], [4,5,6], [7,8,9]])
2 | b = np.array([10,20,30])
3 | c = a + b
4 | c
```

Out[]:
```
array([[11, 21, 31],
       [14, 25, 36],
       [17, 28, 39]])
```

Boolean Mask

In[ ]:
```
1 | a = np.array([[1,2,3], [4,5,6], [7,8,9]])
2 | b = np.array([10,20,30])
3 | c = a + b
4 | mask = (c > 20)
5 | mask
```

Boolean Mask

In[ ]:
```
1 | a = np.array([[1,2,3], [4,5,6], [7,8,9]])
2 | b = np.array([10,20,30])
3 | c = a + b
4 | mask = (c > 20)
5 | mask
```

Out[]:
```
array([[False, True, True],
       [False, True, True],
       [False, True, True]])
```

Boolean Mask

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```
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Boolean Mask

In[ ]:
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5 | c[mask]
```

Out[]:
```
array([22, 33, 25, 36, 28, 39])
```

Challenge 1

Challenge 1

Write a Python script to create a random array with 1000 elements (each element in range [0,10)) and

compute the ***average***, ***variance***, **standard deviation** of the array elements.

Note: use 1 as random seed.

Documentation: https://docs.scipy.org/doc/numpy-1.13.0/reference/generated/numpy.random.randint.html

```
Average is 4.413

Variance is 8.216431

Standard deviation is 2.86643175394
```

Answer 1

Answer 1

```
import numpy as np

np.random.seed(1)

random_array = np.random.randint(10, size=(1000,1))

print('Average is ' + str(np.average(random_array)))
print('Variance is ' + str(np.var(random_array)))
print('Standard deviation is '+ str(np.std(random_array)))
```

Challenge 2

Challenge 2

Write a Python script that:

1. Create two random matrices of integers (each element in range [0,10), size =(3,4))
2. Multiply matrices element wise and save result in new variable
3. Sum each column and save array in new variable.
4. Find maximum value of array
5. Find maximum value index

Note: use 1 as random seed.

```
Maximum value is: 97

Index of Maximum value is: 3
```

Answer 2

Answer 2

```
import numpy as np

#Create two random matrices of integers (max posible value 10, size = (3,4))
np.random.seed(1) # seed for reproducibility
a = np.random.randint(10, size=(3, 4)) # Two-dimensional array
c = np.random.randint(10, size=(3, 4))

#Multiply matrices element wise
d = np.multiply(a, c)

#Sum Columns
e = np.sum(d,axis=0)

#Fin maximum value
print('Maximum value is: '+str(np.max(e)))

#Find Maximun value index
print('Index of Maximum value is: '+str(np.argmax(e)))
```