Python
NumPy

Mathematical Computing with Python (NumPy)

Quick Recap : List

A list is a collection of values. You can individually add, remove, or update these values. A single list can contain multiple data types.

List

```
distance=[10,15,17,26]
time=[.30,.47,.55,1.20]
```

Collection of values

Multiple types (heterogeneous)

Add, remove, update

Limitations of ists

Though you can change individual values in a list, you cannot apply a mathematical operation over the entire list.

```
distance=[10,15,17,26]
time=[.30,.47,.55,1.20]
```

```
speed=distance/time
```

← Mathematical operation over the entire “distance” and “time” lists

```
---------------------------------------------------------------------------
TypeError                                 Traceback (most recent call last)
<ipython-input-37-b779bad68500> in <module>()
----> 1 speed=distance/time

TypeError: unsupported operand type(s) for /: 'list' and 'list'
```

← Error

Why Numpy

Numerical Python (NumPy) supports multidimensional arrays over which you can easily apply mathematical operations.

```
distance=[10,15,17,26]
time=[.30,.47,.55,1.20]
```

```
import numpy as np
```

← Import NumPy

```
np_distance = np.array(distance)
np_time=np.array(time)
speed=np_distance/np_time
```

} Create “distance” and “time” NumPy arrays

← Mathematical function applied over the entire “distance” and “time” arrays

```
speed
```

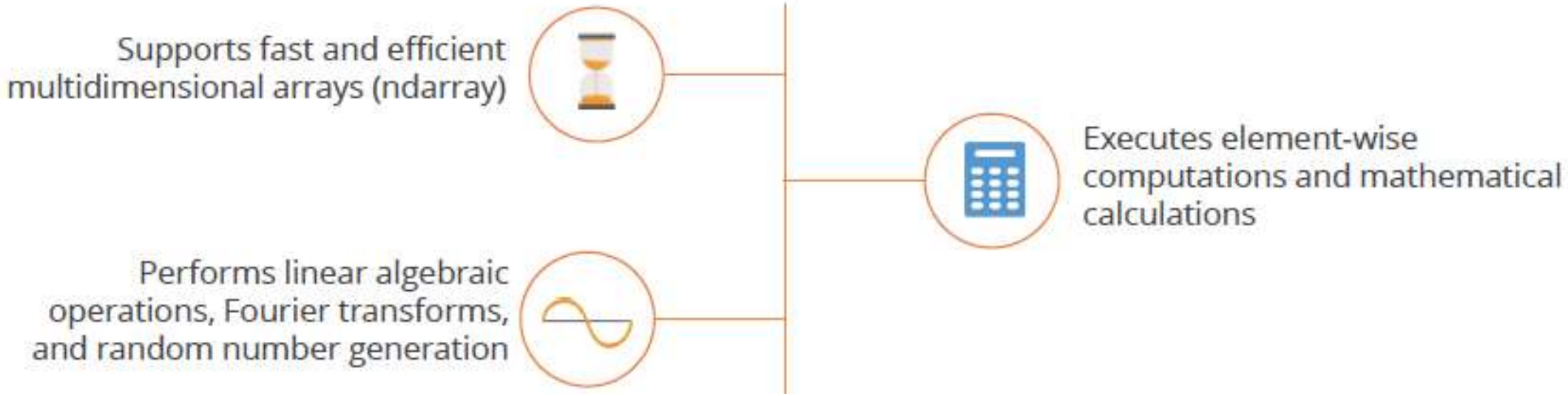
```
array([ 33.33333333,  31.91489362,  30.90909091,  21.66666667])
```

← Output

NumPy Overview

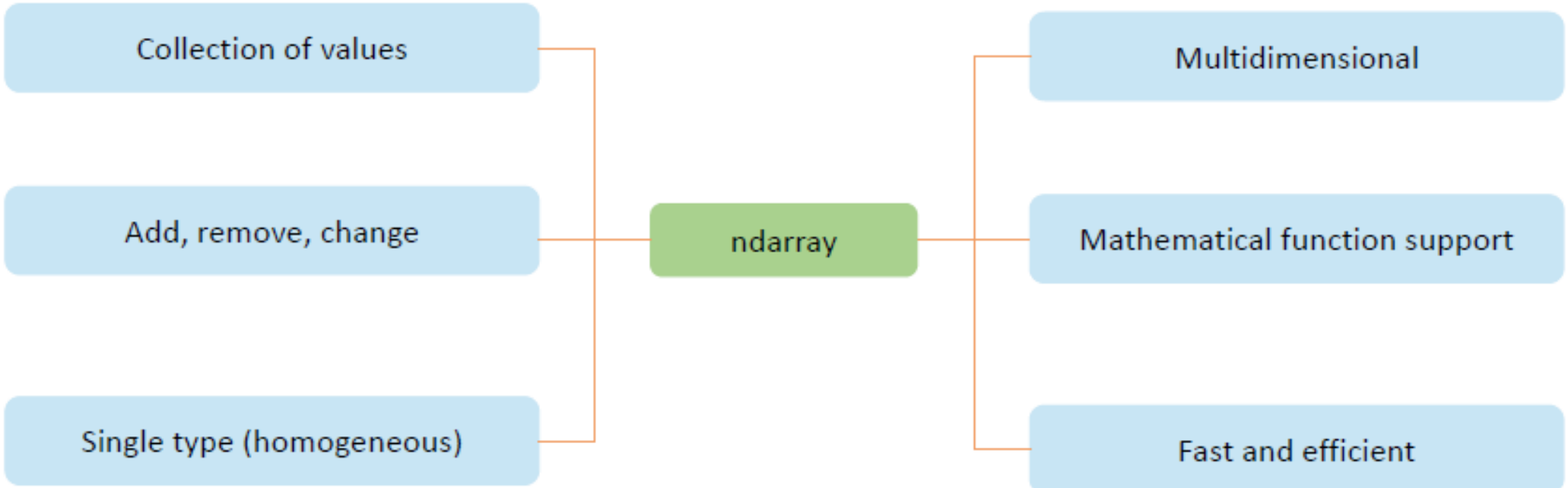
NumPy is the foundational package for mathematical computing in Python.

It has the following properties:



Properties of ndarray

An array in NumPy has the following properties:



Data Science

Knowledge Check – Sequence it Right !

The code here is buggy. You have to correct its sequence to debug it.

1

```
distance=[10,15,17,26]
time=[.30,.47,.55,1.20]
```

2

```
np_distance = np.array(distance)
np_time=np.array(time)
```

3

```
import numpy as np
```

4

```
speed=np_distance/np_time
```

```
speed
```

```
array([ 33.33333333,  31.91489362,  30.90909091,  21.66666667])
```

Data Science

Knowledge Check – Sequence it Right !

The code here is buggy. You have to correct its sequence to debug it.

1

```
distance=[10,15,17,26]
time=[.30,.47,.55,1.20]
```

2

```
import numpy as np
```

3

```
np_distance = np.array(distance)
np_time=np.array(time)
```

4

```
speed=np_distance/np_time
```

```
speed
```

```
array([ 33.33333333,  31.91489362,  30.90909091,  21.66666667])
```

Types of Arrays

Arrays can be one-dimensional, two dimensional, three-dimensional, or multi-dimensional.

One-Dimensional Array

Printed as rows

array([5, 7,9]) ← 1 axis rank 1

Length = 3

5	7	9
0	1	2

x axis

Two-Dimensional Array

Printed as matrices (2x3)

array([[0, 1, 2],
[5, 6, 7]]) ← 2 axes rank 2

Length = 3

y axis

0 (0,0)	1 (0,1)	2 (0,2)
5 (1,0)	6 (1,1)	7 (1,2)

x axis

Three-Dimensional Array

Printed as list of matrices (3x3x3)

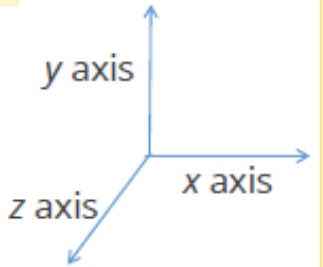
```
array([[[ 0, 1, 2],
        [ 3, 4, 5],
        [ 6, 7, 8]],

       [[ 9, 10, 11],
        [12, 13, 14],
        [15, 16, 17]],

       [[18, 19, 20],
        [21, 22, 23],
        [24, 25, 26]]])
```

← 3 axes rank 3

Length = 3



Data Science

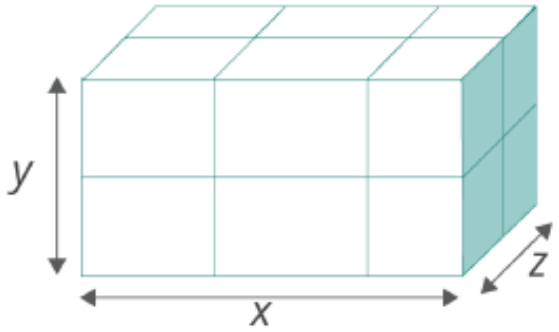
Class and Attributes of ndarray-.ndim

Numpy's array class is "ndarray," also referred to as "numpy.ndarray." The attributes of ndarray are:

- ndarray.ndim
- ndarray.shape
- ndarray.size
- ndarray.dtype

This refers to the number of axes (dimensions) of the array. It is also called the rank of the array.

Two axes or 2D array



Three axes or 3D array

Concept | Example

Data Science

Class and Attributes of ndarray-.ndim

Numpy's array class is "ndarray," also referred to as "numpy.ndarray." The attributes of ndarray are:

- ndarray.ndim
- ndarray.shape
- ndarray.size
- ndarray.dtype

The array "np_city" is one-dimensional, while the array "np_city_with_state" is two-dimensional.

```
In [108]: np_city = np.array(['NYC', 'LA', 'Miami','Houston'])

In [109]: np_city.ndim
Out[109]: 1

In [110]: np_city_with_state = np.array([['NYC', 'LA', 'Miami','Houston'],['NY', 'CA', 'FL','TX']])

In [111]: np_city_with_state.ndim
Out[111]: 2
```

Concept | Example

Data Science

Class and Attributes of ndarray-.shape

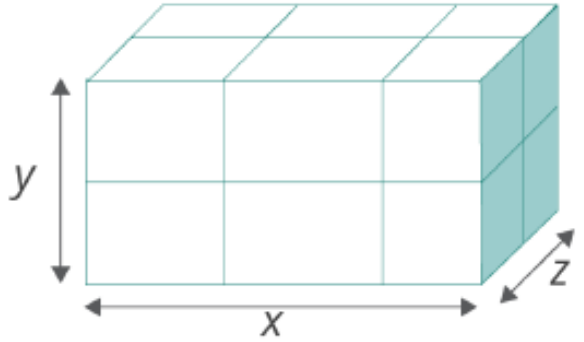
Numpy's array class is "ndarray," also referred to as "numpy.ndarray." The attributes of ndarray are:

- ndarray.ndim
- ndarray.shape
- ndarray.size
- ndarray.dtype

This consists of a tuple of integers showing the size of the array in each dimension. The length of the "shape tuple" is the rank or ndim.

2 rows, 3 columns

Shape: (2, 3)



2 rows, 3 columns, 2 ranks

Shape: (2, 3, 2)

Concept | Example

Data Science

Class and Attributes of ndarray-.shape

Numpy's array class is "ndarray," also referred to as "numpy.ndarray." The attributes of ndarray are:

- ndarray.ndim
- ndarray.shape
- ndarray.size
- ndarray.dtype

The shape tuple of both the arrays indicate their size along each dimension.

```
In [108]: np_city = np.array(['NYC', 'LA', 'Miami','Houston'])

In [110]: np_city_with_state = np.array([['NYC', 'LA', 'Miami','Houston'],['NY', 'CA', 'FL','TX']])

In [112]: np_city.shape
Out[112]: (4L,)

In [113]: np_city_with_state.shape
Out[113]: (2L, 4L)
```

Concept | Example

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Class and Attributes of ndarray-.size

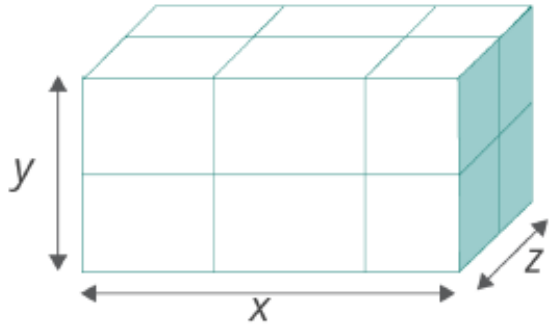
Numpy's array class is "ndarray," also referred to as "numpy.ndarray." The attributes of ndarray are:

- ndarray.ndim
- ndarray.shape
- ndarray.size
- ndarray.dtype

It gives the total number of elements in the array. It is equal to the product of the elements of the shape tuple.

Array contains 6 elements

Array a = (2, 3)
Size = 6



Array contains 12 elements

Array b = (2, 3, 2)
Size = 12

Concept | Example

Data Science

Class and Attributes of ndarray-.size

Numpy's array class is "ndarray," also referred to as "numpy.ndarray." The attributes of ndarray are:

- ndarray.ndim
- ndarray.shape
- ndarray.size
- ndarray.dtype

Look at the examples to see how the shape tuples of the arrays are used to calculate their size.

```
In [112]: np_city.shape
Out[112]: (4L,)

In [113]: np_city_with_state.shape
Out[113]: (2L, 4L)

In [114]: np_city.size
Out[114]: 4

In [115]: np_city_with_state.size
Out[115]: 8
```

Concept | Example

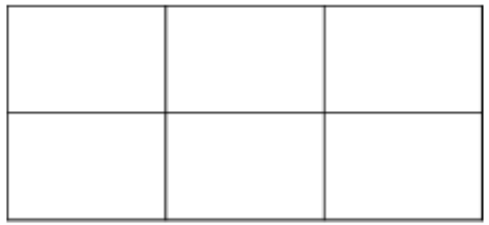
Data Science

Class and Attributes of ndarray-.dtype

Numpy's array class is "ndarray," also referred to as "numpy.ndarray." The attributes of ndarray are:

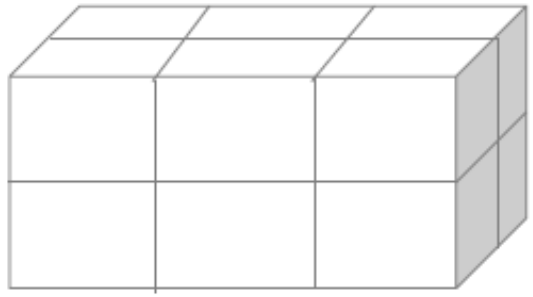
- ndarray.ndim
- ndarray.shape
- ndarray.size
- ndarray.dtype

It's an object that describes the type of the elements in the array. It can be created or specified using Python.



Array contains integers

Array a = [3, 7, 4]
[2, 1, 0]



Array contains floats

Array b = [1.3, 5.2, 6.7]
[0.2, 8.1, 9.4]

[2.6, 4.2, 3.9]
[7.8, 3.4, 0.8]

Concept | Example

Data Science

Class and Attributes of ndarray-.dtype

Numpy's array class is "ndarray," also referred to as "numpy.ndarray." The attributes of ndarray are:

- ndarray.ndim
- ndarray.shape
- ndarray.size
- ndarray.dtype

Both the arrays are of "string" data type (dtype) and the longest string is of length 7, which is "Houston."

```
In [116]: np_city
Out[116]: array(['NYC', 'LA', 'Miami', 'Houston'],
                dtype='|S7')

In [117]: np_city_with_state
Out[117]: array([['NYC', 'LA', 'Miami', 'Houston'],
                 ['NY', 'CA', 'FL', 'TX']],
                dtype='|S7')

In [118]: np_city_with_state.dtype
Out[118]: dtype('S7')
```

Concept | Example

Basic Operations

Using the following operands, you can easily apply various mathematical, logical, and comparison operations on an array.

Mathematical Operations

Addition	+
Subtraction	-
Multiplication	*
Division	/
Exponentiation	**

Logical Operations

And	&
Or	|
Not	~

Comparison Operations

Greater	>
Greater or equal	>=
Less	<
Less or equal	<=
Equal	==
Not equal	!=

Basic Operation – Example

NumPy uses the indices of the elements in each array to carry out basic operations. In this case, where we are looking at a dataset of four cyclists during two trials, vector addition of the arrays gives the required output.

```
In [99]: first_trial_cyclist =[10,15,17,26]
```
First trial

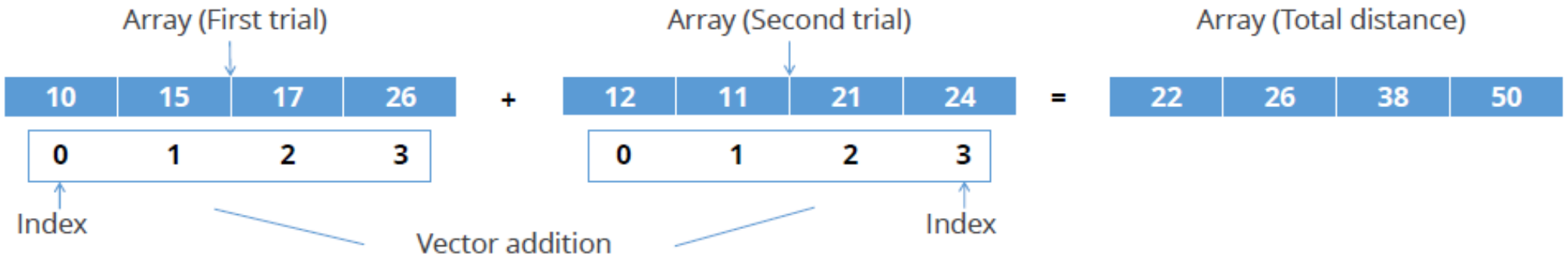
```
In [100]: second_trial_cyclist =[12,11,21,24]
```
Second trial

```
In [101]: np_first_trial_cyclist = np.array(first_trial_cyclist)
```

```
In [102]: np_second_trial_cyclist = np.array(second_trial_cyclist)
```

```
In [103]: np_first_trial_cyclist+np_second_trial_cyclist
```
Total distance

```
Out[103]: array([22, 26, 38, 50])
```



Data Science

Accessing Array Elements: Indexing

You can access an entire row of an array by referencing its axis index.

1st set data 2nd set data

```
In [117]: cyclist_trials = np.array([[10,15,17,26],[12,11,21,24]])
```
← Create 2D array using cyclist trial data shown earlier

```
In [118]: first_trial =cyclist_trials[0]
```
← First trial data

```
In [119]: first_trial
Out[119]: array([10, 15, 17, 26])
```

```
In [120]: second_trial = cyclist_trials[1]
```
← Second trial data

```
In [121]: second_trial
Out[121]: array([12, 11, 21, 24])
```

2D array containing cyclists' data

10	15	17	26
12	11	21	24

← First trial (axis 0)

← Second trial (axis 1)

Accessing Array Elements: Indexing (contd.)

You can refer the indices of the elements in an array to access them. You can also select a particular index of more than one axis at a time.

```
In [122]: first_cyclist_firstTrial = cyclist_trials[0][0]
```

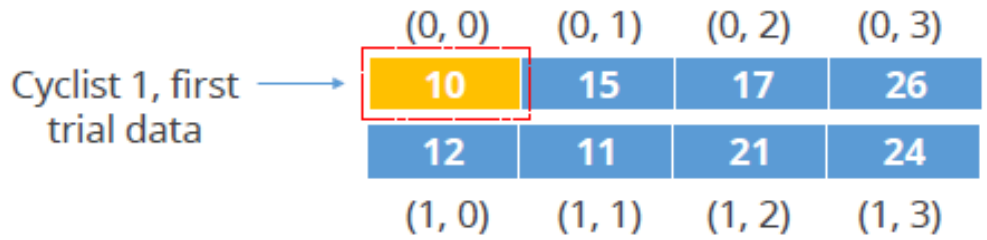
First cyclist: first trial data

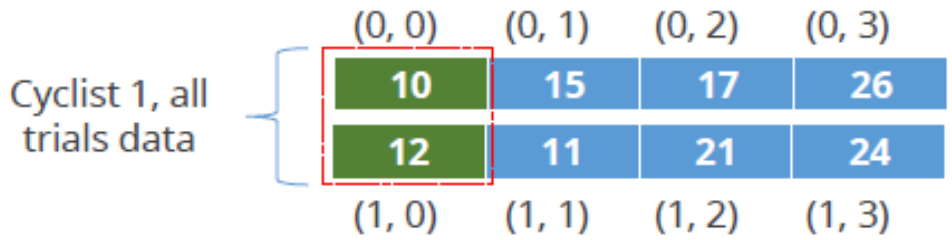
```
In [123]: first_cyclist_firstTrial
Out[123]: 10
```

```
In [124]: first_cyclist_all_trials = cyclist_trials[:,0]
```

First cyclist: all trial data
(Use ":" to select all the rows of an array)

```
In [125]: first_cyclist_all_trials
Out[125]: array([10, 12])
```





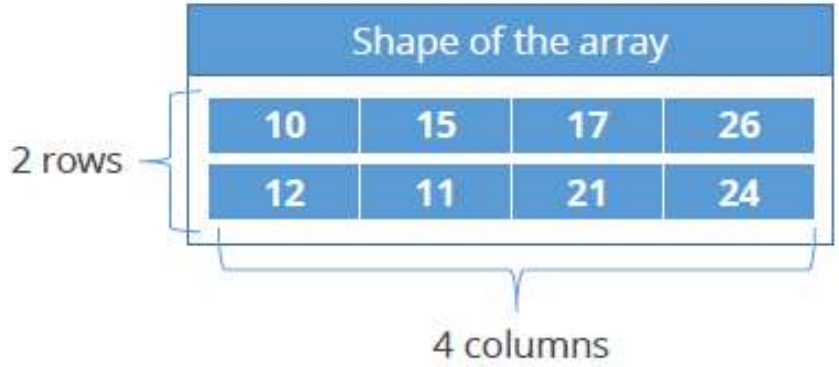
Accessing Array Elements: Slicing

Use the slicing method to access a range of values within an array.

Shape of the array

```
In [152]: cyclist_trials.shape
Out[152]: (2L, 4L)

In [153]: two_cyclist_trial_data=cyclist_trials[:,1:3]

In [154]: two_cyclist_trial_data
Out[154]: array([[15, 17],
                 [11, 21]])
```

Slicing the array data [: , 1 : 3]
where 1 is inclusive but 3 is not



Accessing Array Elements: Iteration

Use the iteration method to go through each data element present in the dataset.

```
In [117]: cyclist_trials = np.array([[10,15,17,26],[12,11,21,24]])

In [153]: two_cyclist_trial_data=cyclist_trials[:,1:3]

In [154]: two_cyclist_trial_data

Out[154]: array([[15, 17],
                 [11, 21]])

In [159]: for iterate_cyclist_trials_data in cyclist_trials:
              print (iterate_cyclist_trials_data)

          [10 15 17 26]
          [12 11 21 24]

In [160]: for iterate_two_cyclist_trial_data in two_cyclist_trial_data:
              print (iterate_two_cyclist_trial_data)

          [15 17]
          [11 21]
```

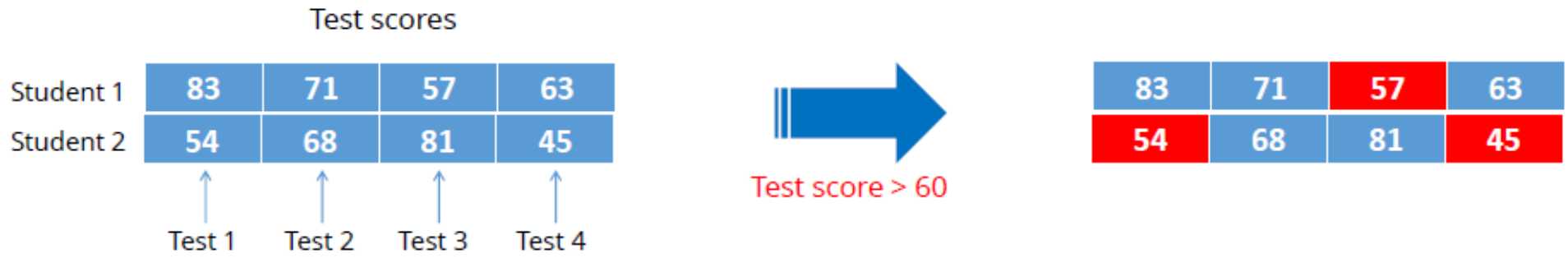
Iterate with "for loop" through entire dataset

Iterate with "for loop" through the "two cyclist" datasets

Data Science

Indexing with Boolean Arrays

Boolean arrays are useful when you need to select a dataset according to set criteria. Here, the original dataset contains test scores of two students. You can use a Boolean array to choose only the scores that are above a given value.




```
In [234]: test_scores =np.array([[83,71,57,63],[54,68,81,45]])

In [235]: passing_score = test_scores>60

In [236]: passing_score

Out[236]: array([[ True,  True, False,  True],
                 [False,  True,  True, False]], dtype=bool)

In [237]: test_scores[passing_score]

Out[237]: array([83, 71, 63, 68, 81])
```

Setting the passing score

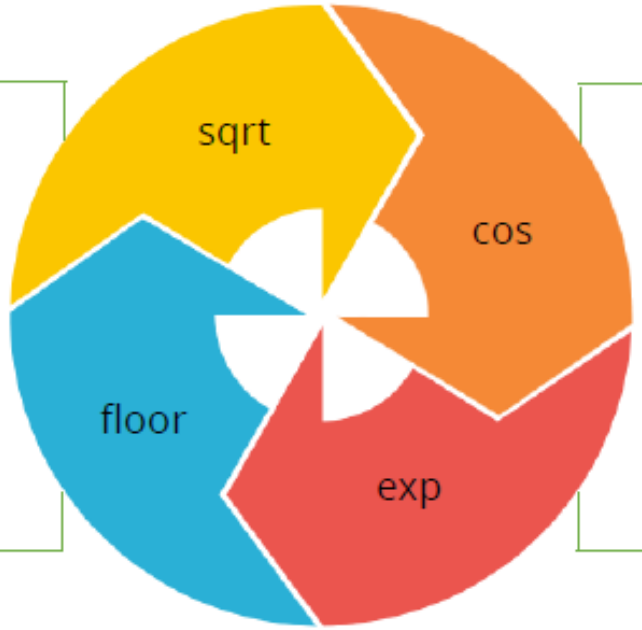
Shows data elements which fit the criteria (Boolean array)

Send "passing score" as an argument to "test scores" object

Universal Functions (ufunc)

NumPy provides useful mathematical functions called Universal Functions. These functions operate element-wise on an array, producing another array as output. Some of these functions are listed here:

sqrt function provides the square root of every element in the array.



cos function gives cosine values for all elements in the array.

floor function returns the largest integer value of every element in the array.

exp function performs exponentiation on each element.

ufunc-Examples

Let's look at some common ufunc examples:

```
In [186]: np_sqrt = np.sqrt([2,4,9,16])
```

Numbers for which square root will be calculated

```
In [187]: np_sqrt
Out[187]: array([ 1.41421356,  2.        ,  3.        ,  4.        ])
```

Square root values

```
In [188]: from numpy import pi
          np.cos(0)
Out[188]: 1.0
```

Import pi*

```
In [189]: np.sin(pi/2)
Out[189]: 1.0
```

```
In [190]: np.cos(pi)
Out[190]: -1.0
```

Trigonometric functions

```
In [191]: np.floor([1.5,1.6,2.7,3.3,1.1,-0.3,-1.4])
Out[191]: array([ 1.,  1.,  2.,  3.,  1., -1., -2.])
```

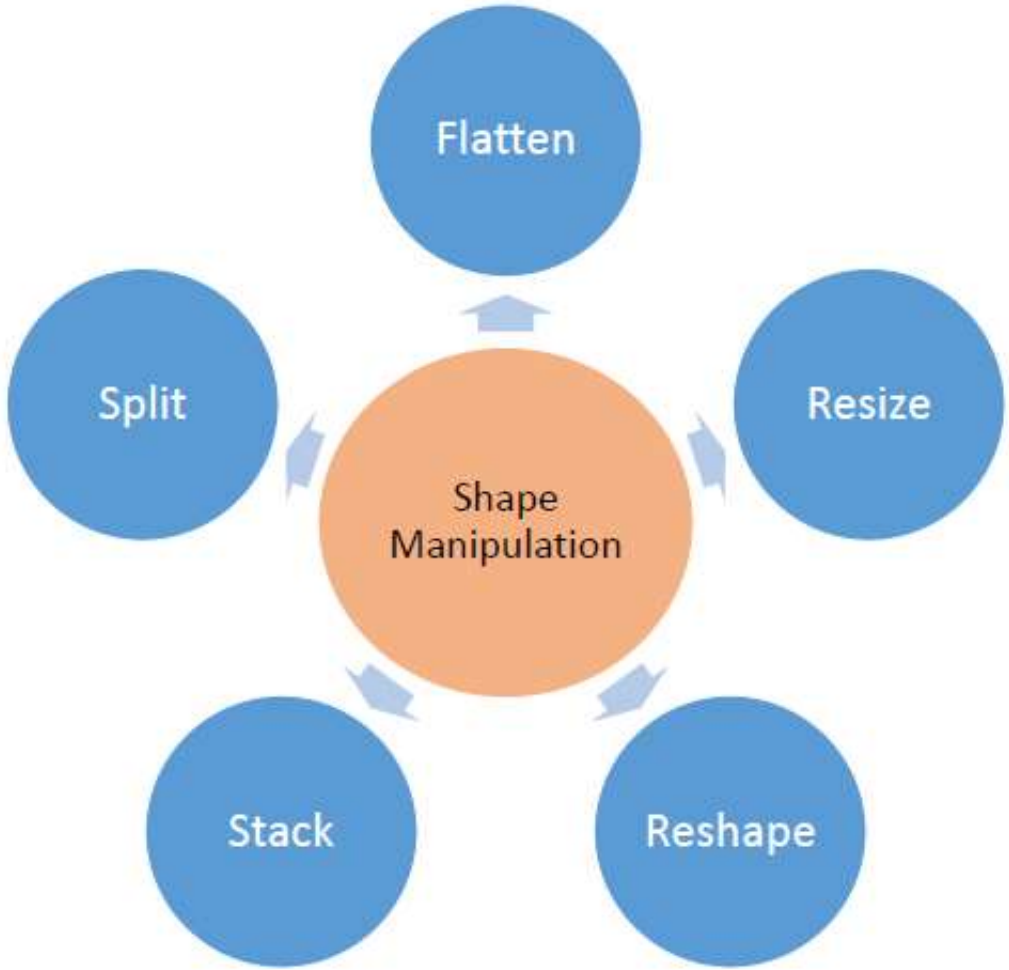
Return the floor of the input element wise

```
In [192]: np.exp([0,1,5])
Out[192]: array([   1.        ,    2.71828183,  148.4131591 ])
```

Exponential functions for complex mathematical calculations

Shape Manipulation

You can use certain functions to manipulate the shape of an array to do the following:



Shape Manipulation - Example

You can use certain functions to manipulate the shape of an array to do the following:

```
In [383]: new_cyclist_trials = np.array([[10,15,17,26,13,19],[12,11,21,24,14,23]])

In [384]: new_cyclist_trials.ravel()
```

Flattens the dataset

```
Out[384]: array([10, 15, 17, 26, 13, 19, 12, 11, 21, 24, 14, 23])

In [385]: new_cyclist_trials.reshape(3,4)
```

Changes or reshapes the dataset to 3 rows and 4 columns

```
Out[385]: array([[10, 15, 17, 26],
                 [13, 19, 12, 11],
                 [21, 24, 14, 23]])

In [386]: new_cyclist_trials.resize(2,6)
```

Resizes again to 2 rows and 6 columns

```
In [387]: new_cyclist_trials

Out[387]: array([[10, 15, 17, 26, 13, 19],
                 [12, 11, 21, 24, 14, 23]])

In [388]: np.hsplit(new_cyclist_trials,2)
```

Splits the array into two

```
Out[388]: [array([[10, 15, 17],
                  [12, 11, 21]]), array([[26, 13, 19],
                  [24, 14, 23]])]

In [389]: new_cyclist_1 = np.array([10,15,17,26,13,19])

In [390]: new_cyclist_2 = np.array([12,11,21,24,14,23])

In [391]: np.hstack((new_cyclist_1,new_cyclist_2))
```

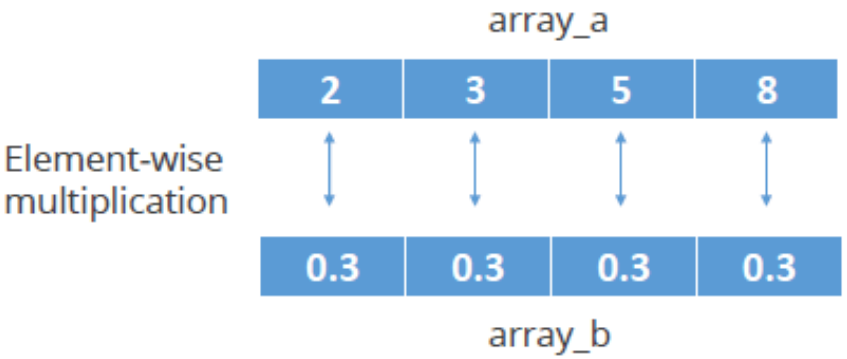
Stacks the arrays together

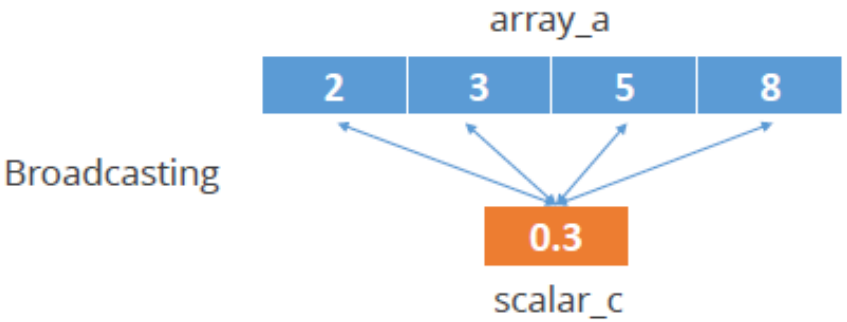
```
Out[391]: array([10, 15, 17, 26, 13, 19, 12, 11, 21, 24, 14, 23])
```

Broadcasting

NumPy uses broadcasting to carry out arithmetic operations between arrays of different shapes. In this method, NumPy automatically broadcasts the smaller array over the larger array.

```
In [9]: import numpy as np

In [10]: #Create two arrays of the same shape
         array_a = np.array([2, 3, 5, 8])
         array_b = np.array([.3, .3, .3, .3])

In [11]: #Multiply arrays
         array_a * array_b

Out[11]: array([ 0.6,  0.9,  1.5,  2.4])

In [12]: #Create a variable with a scalar value
         scalar_c = .3

In [13]: #Multiply 1D array with a scalar value
         array_a * scalar_c

Out[13]: array([ 0.6,  0.9,  1.5,  2.4])
```





Broadcasting - Constraints

Though broadcasting can help carry out mathematical operations between different-shaped arrays, they are subject to certain constraints as listed below:

```
In [9]: import numpy as np

In [10]: #Create two arrays of the same shape
         array_a = np.array([2, 3, 5, 8])
         array_b = np.array([.3, .3, .3, .3])

In [11]: #Multiply arrays
         array_a * array_b

Out[11]: array([ 0.6,  0.9,  1.5,  2.4])

In [14]: #Create array of a different shape
         array_d = np.array([4, 3])

In [15]: array_a * array_d
---------------------------------------------------------------------------
ValueError                                Traceback (most recent call last)
<ipython-input-15-43adcf6f7a54> in <module>()
----> 1 array_a * array_d

ValueError: operands could not be broadcast together with shapes (4,) (2,)
```

- When NumPy operates on two arrays, it compares their shapes element-wise. It finds these shapes compatible only if:
  - Their dimensions are the same or
  - One of them has a dimension of size 1.
- If these conditions are not met, a "ValueError" is thrown, indicating that the arrays have incompatible shapes.

Data Science

Broadcasting - Example

Let's look at an example to see how broadcasting works to calculate the number of working hours of a worker per day in a certain week.

```
In [246]: np_week_one =np.array([105, 135, 195, 120, 165])
          np_week_two =np.array([123, 156, 230, 200, 147])
```

Week one earnings

Week two earnings

```
In [247]: total_earning = np_week_one+np_week_two
```

Element-wise operation

```
In [248]: total_earning
Out[248]: array([228, 291, 425, 320, 312])
```

Total earning for 2 weeks

```
In [249]: np_week_one_hrs = np_week_one / 15
```

Calculate week one hours

Hourly wage

```
In [250]: np_week_one_hrs
Out[250]: array([ 7,  9, 13,  8, 11])
```

Number of working hours per day in week one

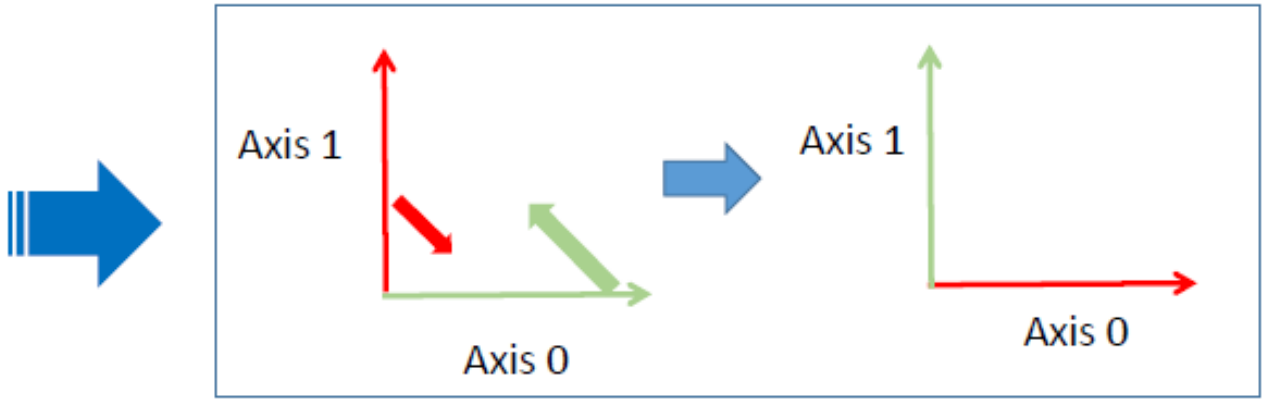
Data Science

Linear Algebra - Transpose

NumPy can carry out linear algebraic functions as well. The “transpose()” function can help you interchange rows as columns, and vice-versa.

transpose()

83	71	57	63
54	68	81	45




```
In [397]: test_scores =np.array([[83,71,57,63],[54,68,81,45]])

In [398]: test_scores.transpose()

Out[398]: array([[83, 54],
                 [71, 68],
                 [57, 81],
                 [63, 45]])
```

Data Science

Linear Algebra – Inverse and Trace Functions

Using NumPy, you can also find the inverse of an array and add its diagonal data elements.

np.linalg.inv()

```
In [411]: inverse_array =np.array([[10,20],[15,25]])

In [412]: np.linalg.inv(inverse_array)

Out[412]: array([[-0.5,  0.4],
                 [ 0.3, -0.2]])
```

Inverse of the given array

* Can be applied **only** on a square matrix

np.trace()

```
In [420]: trace_array =np.array([[10,20],[22,31]])

In [421]: np.trace(trace_array)

Out[421]: 41
```

Sum of diagonal elements “10” and “31”

? Quiz

Q2. The np.trace() methods gives the sum of _____.

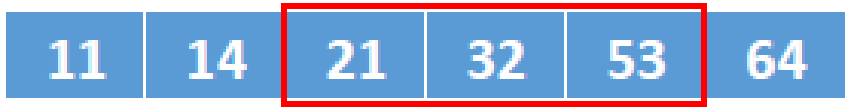
a. the entire array

b. the diagonal elements from left to right

c. the diagonal elements from right to left

d. consecutive rows of an array

Q3. Which statement will slice the highlighted data?



a. [3 : 5]

b. [3 : 6]

c. [2 : 5]

d. [2 : 4]

Assignment

Assignment 01

Problem | Instructions

Evaluate the dataset of the Summer Olympics, London 2012 to:

- Find and print the name of the country that won maximum gold medals,
- Find and print the countries who won more than 20 gold medals,
- Print the medal tally,
- Print each country name with the corresponding number of gold medals, and
- Print each country name with the total number of medals won.

```
olympic_country=['GBR','China','RUS','US','KOR','JPN','GER']
olympic_country_Gold=[29,38,24,46,13,7,11]
olympic_country_Silver=[17,28,25,28,8,14,11]
olympic_country_Bronze=[19,22,32,29,7,17,14]
```