Python Tutorial – Part I: Introduction

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Overview

1. What is Python?
   - Origins, Features, Framework for Scientific Computing
2. Program Development with Python
   - Working with the Terminal
   - Integrated Development Environments
3. Elements of Python Programming
   - Data Types, Variables, Arithmetic Expressions, Strings, Program Control, and Functions
4. First Program (Evaluate and Plot Sigmoid Function)
5. Builtin Collections (Lists, Dictionaries, and Sets)
6. Numerical Python (NumPy)

Numerical Python

(NumPy)

Numerical Python (NumPy)

Introduction to NumPy

Numerical Python (NumPy) is an open source Python library that contains computational support for n-dimensional array objects, along with mathematical methods to operate on them.

Key Features:

- Create 0-d, 1-d and 2-d arrays. 3-d blocks.
- Operations on array elements (e.g., min, max, sort).
- Operations on arrays (e.g., reshape, stack).
- Compute matrix properties. Solve matrix equations.

Installation

```
prompt >> pip3 install numpy
```

Numerical Data Types in NumpPy

dtype	Variants	Description
int	int8, int16, int32, int64	Integers
uint	uint8, uint16, uint32, uint64	Unsigned integers
bool	bool	Boolean (True or False)
float	float16, float32, float64, float128	Floating-point numbers
complex	complex64, complex128, complex256	Complex-valued floating point numbers

Working with NumPy

Example 1: Create 0-d, 1-d, and 2-d arrays ...

```
a = np.array(101);   # <-- create 0-d array.
print (a)

a = np.array( [ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10] ); # <-- create 1-d array of
print (a)

a = np.array( ["The", "Brown", "Fox"] ); # <-- array of charcter strings.
a = np.append(a, "!")

for i in a:                              # <-- loop over array indices ...
   print(i)
```

Output:

```
101
[ 1  2  3  4  5  6  7  8  9 10]
The
Brown
Fox
!
```

Working with NumPy

Example 2: Print each array element and its index ...

```
# Create array of character strings ...

a = np.array( ["The", "Brown", "Fox", "!"] );

for i,e in enumerate(a):
    print("--- Index: {}, was: {}".format(i, e))
```

Output:

```
--- Index: 0, was: The
--- Index: 1, was: Quick
--- Index: 2, was: Brown
--- Index: 3, was: Fox
--- Index: 4, was: !
```

Working with NumPy

Example 3: Sort array elements ...

```
# Sort array of floating point numbers ...

a = np.array( [ 2.3, 1.0, 4.5, -13.0, 100.0, 43, -15.0, 0.0 ] )
print(a);
print(np.sort(a));

# Sort array of state abbreviations ...

a = np.array( ["MD", "CA", "RI", "UT", "LA", "AL", "WA", "OR", "CO"] )
print(a);
print(np.sort(a))
```

Output:

```
--- Sort array of floating-point numbers ...
[  2.3   1.    4.5 -13.  100.   43.  -15.    0. ]
[-15.  -13.    0.    1.    2.3   4.5  43.  100. ]
--- Sort array of state abbreviations ...
['MD' 'CA' 'RI' 'UT' 'LA' 'AL' 'WA' 'OR' 'CO']
['AL' 'CA' 'CO' 'LA' 'MD' 'OR' 'RI' 'UT' 'WA']
```

Working with NumPy

Example 4: Create two-dimensional array ...

```
c = np.array( [ ( 0, 1, 4, 3, 2), ( 3, 4, 5, 6, 7),
                ( 6, 7, 8, 9,10), ( 9,10,11,12,13) ] );

PrintMatrix("C", c);        # <-- print formatted matrix ....

print("    Min: {}".format(np.min(c)))
print("    Max: {}".format(np.max(c)))
print("    Average: {}".format(np.average(c)))
print("    Max array index: {}".format(np.argmax(c)))
```

Output:

```
Matrix: C
   0.000    1.000    4.000    3.000    2.000
   3.000    4.000    5.000    6.000    7.000
   6.000    7.000    8.000    9.000   10.000
   9.000   10.000   11.000   12.000   13.000

Min: 0                Average: 6.5
Max: 13               Max array index: 19
```

Working with NumPy

Example 5: Create three-dimensional array block ...

```
c = np.array( [ [ ( 0, 1), (3, 4) ], [(5, 6), (7, 8) ] ] );
print(c)
```

Output:

```
[ [ [0 1]
    [3 4] ]

  [ [5 6]
    [7 8] ] ]
```

Working with NumPy

Example 6: Reshape 1-d array $\longrightarrow$ 2-d matrix ...

```
d1 = np.arange(20);      # <-- create 1-d test array ...
print(d1);

d1 = d1.reshape(4,5);    # <-- reshape to (4x5) array ...
PrintMatrix("(4x5)", d1 );
```

Output:

```
--- 1-d test array:

  [ 0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19]

--- Reshape to (4x5) matrix ...

Matrix: (4x5)
    0.000    1.000    2.000    3.000    4.000
    5.000    6.000    7.000    8.000    9.000
   10.000   11.000   12.000   13.000   14.000
   15.000   16.000   17.000   18.000   19.000
```

Working with NumPy

Example 7: Create horizontal and vertical array stacks ...

```
d1 = np.array( [ ( 0, 1), ( 3, 4) ] );   # <-- create test arrays ...
d2 = np.array( [ ( 5, 6), ( 7, 8) ] );

PrintMatrix("d1", d1 ); PrintMatrix("d2", d2 );

h1 = np.hstack((d1, d2));                # <-- create horizontal stack ...
PrintMatrix( "np.hstack(d1, d2)", h1 );
h2 = np.vstack((d1, d2));                # <-- create vertical stack ...
PrintMatrix( "np.vstack(d1, d2)", h2 );
```

Output:

```
Matrix: d1                    Matrix: np.hstack(d1, d2)
   0.000    1.000                 0.000    1.000    5.000    6.000
   3.000    4.000                 3.000    4.000    7.000    8.000

Matrix: d2                    Matrix: np.vstack(d1, d2)
   5.000    6.000                 0.000    1.000
   7.000    8.000                 3.000    4.000
                                  5.000    6.000
                                  7.000    8.000
```

Working with NumPy

Example 8: Exercise np.zeros() and np.eye() ...

```
matrix02 = np.zeros(shape=(4, 4))   # <-- create (4x4) array of zeros.
PrintMatrix("matrix02", matrix02 );

matrix03 = np.eye(4, dtype = float) # <-- create (4x4) identidy matrix.
PrintMatrix("matrix03", matrix03 );
```

Output:

```
Matrix: matrix02
   0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000

Matrix: matrix03
   1.000    0.000    0.000    0.000
   0.000    1.000    0.000    0.000
   0.000    0.000    1.000    0.000
   0.000    0.000    0.000    1.000
```

Working with NumPy

Example 9: Reshape arrays of random numbers

```
matrix06 = np.random.random((20,1));    # <-- create (20x1) array
PrintMatrix("matrix06", matrix06 );     #     of random numbers.

PrintMatrix ( "matrix06 (reshaped)",    # <-- reshape to (10x2).
              matrix06.reshape(10,2) )
```

Abbreviated Output:

```
--- Original (20x1) matrix

Matrix: matrix06
   0.326
   0.459
   0.545
   .....
   0.803
   0.014
   0.291
```

```
--- Reshape to (10x2) matrix ...

Matrix: matrix06 (reshaped)
   0.326    0.459
   0.545    0.419
   0.537    0.632
   .....    .....
   .....    .....
   0.165    0.803
   0.014    0.291
```

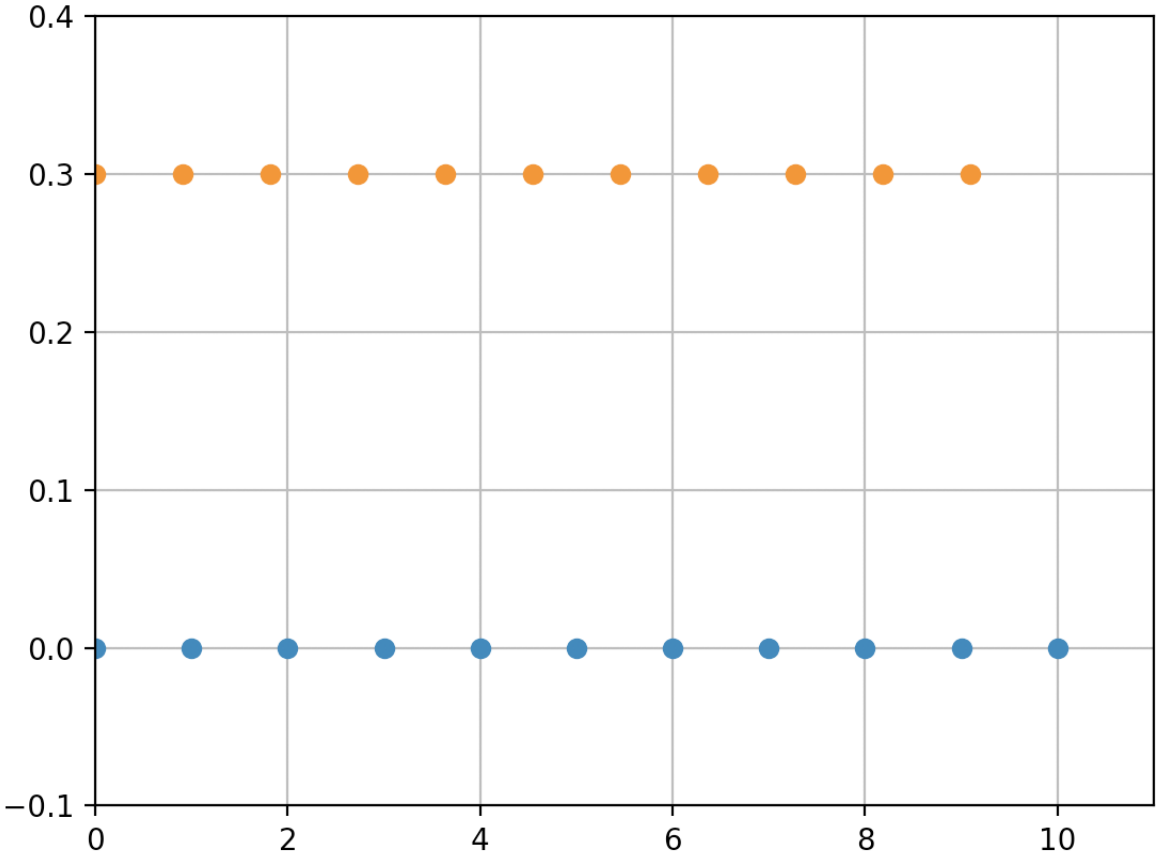
Working with NumPy

Example 10: Generate and plot linear space of coordinates:

```
# ==============================================================================
# TestLinspace01.py: Generate arrays of coordinates with np.linspace(), then plot.
# ==============================================================================

import numpy as np  # Make numpy available using np.
import matplotlib.pyplot as plt

def main():
    # Generate arrays of x coordinates with np.linspace() ...

    Npoints = 11
    x1 = np.linspace(0, 10, num = Npoints, endpoint=True);
    x2 = np.linspace(0, 10, num = Npoints, endpoint=False);

    # Plot coordinates ...

    y = np.zeros(Npoints)
    plt.plot(x1, y, 'o')
    plt.plot(x2, y + 0.3, 'o')
    plt.ylim( [-0.1, 0.4] )
    plt.xlim( [ 0.0, 11] )
    plt.grid(); plt.show()

# call the main method ...

main()
```

Working with NumPy

Program Output:



Working with NumPy

Example 11: Solve family of matrix equations:

$$\begin{bmatrix} 3 & -6 & 7 \\ 9 & 0 & -5 \\ 5 & -8 & 6 \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 3 \\ 3 \\ -4 \end{bmatrix} \tag{4}$$

Part I: Theoretical Considerations:

- A unique solution $\{X\} = [A^{-1}] \cdot \{B\}$ exists when $[A^{-1}]$ exists (i.e., $\det[A] \neq 0$). Expanding det(A) about the first row gives:

$$\begin{aligned} det(A) &= 3\det\begin{bmatrix} 0 & -5 \\ -8 & 6 \end{bmatrix} + 6\det\begin{bmatrix} 9 & -5 \\ 5 & 6 \end{bmatrix} + 7\det\begin{bmatrix} 9 & 0 \\ 5 & -8 \end{bmatrix}, \\ &= 3(0-40) + 6(54+25) + 7(-72-0) = -150. \end{aligned} \tag{5}$$

Working with NumPy

Part II: Program Source Code:

```
# ================================================================
# TestMatrixEquations01.py: Compute solution to matrix equations.
#
# Written by: Mark Austin                                November 2022
# ================================================================

import numpy as np
from numpy.linalg import matrix_rank

# Function to print two-dimensional matrices ...

def PrintMatrix(name, a):
    print("Matrix: {:s} ".format(name) );
    for row in a:
        for col in row:
            print("{:8.3f}".format(col), end=" ")
        print("")

# main method ...

def main():
    print("--- Enter TestMatrixEquations01.main()      ... ");
    print("--- ======================================= ... ");

    print("--- Part 1: Create test matrices ... ");
```

Working with NumPy

Part II: Program Source Code: (Continued) ...

```
    A = np.array( [ [ 3, -6,  7],
                    [ 9,  0, -5],
                    [ 5, -8,  6] ]);
    PrintMatrix("A", A);

    B = np.array([ [3], [3], [-4] ]);
    PrintMatrix("B", B);

    print("--- Part 2: Check properties of matrix A ... ");

    rank = matrix_rank(A)
    det  = np.linalg.det(A)

    print("--- Matrix A: rank = {:f}, det = {:f}  ...".format(rank, det) );

    print("--- Part 3: Solve A.x = B ... ");

    x = np.linalg.solve(A, B)
    PrintMatrix("x", x);

    print("--- ======================================= ... ");
    print("--- Leave TestMatrixEquations01.main()      ... ");

# call the main method ...

main()
```

Working with NumPy

Part III: Program Output:

```
# Part 1: Create test matrices ...

Matrix: A
   3.000   -6.000    7.000
   9.000    0.000   -5.000
   5.000   -8.000    6.000

Matrix: B
   3.000
   3.000
  -4.000

# Part 2: Check properties of matrix A ...

Matrix A: rank = 3.000000, det = -150.000000  ...
```

```
# Part 3: Solve A.x = B ...

Matrix: x
   2.000
   4.000
   3.000
```