

# Lecture 0 Python Tutorial

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# Software Setup

- ▶ Working on cloud (recommended)
  - ▶ [GitHub Codespace](#), [Google Colaboratory](#)
  - ▶ free access to hardware with preinstalled packages
- ▶ Working on local machine

```
$ python3 -m venv e6930 # virtual environment
                        (isolated from system-wide packages)
$ source e6930/bin/activate
$ pip3 install numpy
$ cd e6930
$ python3 homework.py    # run script or just
                        $ python3 to enter interactive mode
$ deactivate
```

# The Road Ahead...

① Built-in Functionality

② External Packages

# Basic Data Type: Numbers

```
x = 3
print(type(x)) # print "<class 'int'>"
print(x)       # print "3"
print(x + 1)    # addition; print "4"
print(x - 1)    # subtraction; print "2"
print(x * 2)    # multiplication; print "6"
print(x ** 2)   # exponentiation; print "9"
x += 1
print(x)        # print "4"
x *= 2
print(x)        # print "8"
y = 2.5
print(type(y)) # print "<class 'float'>"
print(y, y + 1, y * 2, y ** 2) # print "2.5 3.5
                               5.0 6.25"
```

# Basic Data Type: Booleans

```
t = True
f = False
print(type(t)) # print "<class 'bool'>"
print(t and f) # logical AND; print "False"
print(t or f)  # logical OR; print "True"
print(not t)   # logical NOT; print "False"
print(t != f)  # logical XOR; print "True"
```

# Basic Data Type: Strings

```
a = 'hello'      # single quotes string literals
b = "world"      # double quotes string literals
print(a)         # print "hello"
print(len(a))    # string length; print "5"
ab = a + ' ' + b # concatenation
print(ab)        # print "hello world"
ab12 = '%s %s %d' % (a, b, 12) # format
print(ab12)      # print "hello world 12"
print(a.capitalize()) # capitalize; print "Hello"
print(a.upper())     # uppercase; print "HELLO"
print(a.rjust(7))    # right-justify with space
                    # padding; print " hello"
print(a.center(7))   # center with space padding;
                    # print " hello "
print(a.replace('l', '(ell)')) # replace all
                    # instances of one substring with another; print
                    # "he(ell)(ell)o"
print(' world '.strip())      # strip leading
                    # and trailing whitespace; print "world"
```

# Immutableables

```
x = 5          # primitives/immutableables (cannot be
               # modified in-place)
y = x          # deep copy/pass by value
print(y is x)  # test if x and y refer to same
               # object; print "True"
y = 10         # y points to new object
print(x)       # x is not affected; print "5"
print(y is x)  # x and y refer to different
               # objects; print "False"
print(id(x))   # check address of int object (on
               # heap) that x points to, but no direct way to
               # check address of x as reference (on stack)
print(id(y))   # x and y store different addresses
```

## Container: Lists

```
xs = [3, 1, 2]      # create list (ordered)
print(xs[2])        # print "2"
print(xs[-1])       # negative index counts from
                    # list end; print "2"
xs[2] = 'foo'       # can contain different types
print(xs)           # print "[3, 1, 'foo']"
xs.append('bar')    # add new element to list end
print(xs)           # print "[3, 1, 'foo', 'bar']"
x = xs.pop()        # remove and return last element
print(x)            # print "bar"
```



## Container: List Slicing

```
nums = list(range(5))    # create list of integers
print(nums)              # print "[0, 1, 2, 3, 4]"
print(nums[2:4])         # slice from index 2 to 4
                          # (exclusive); print "[2, 3]"
print(nums[2:])          # slice from index 2 to
                          # end; print "[2, 3, 4]"
print(nums[:2])          # slice from start to
                          # index 2 (exclusive); print "[0, 1]"
print(nums[:])           # slice of whole list;
                          # print "[0, 1, 2, 3, 4]"
print(nums[:-1])         # slice indices can be
                          # negative; print "[0, 1, 2, 3]"
nums[2:4] = [8, 9]       # assign new sublist to a
                          # slice
print(nums)              # print "[0, 1, 8, 9, 4]"
```

# Container: List Comprehension

```
animals = ['cat', 'dog', 'monkey']  
for animal in animals:  
    print(animal)  # print "cat", "dog", "monkey",  
                   each on its own line  
  
nums = [0, 1, 2, 3, 4]  
even_squares = [x ** 2 for x in nums if x % 2 ==  
                 0]  # list comprehension  
print(even_squares)  # print "[0, 4, 16]"
```

# Container: Dictionaries

```
d = {'cat': 'cute', 'dog': 'furry'} # create new
    dictionary (key-value pairs)
print(d['cat'])                     # get entry; print "cute"
print('cat' in d)                   # check if dictionary has a
    given key; print "True"
d['fish'] = 'wet'                   # set entry
print(d['monkey'])                  # KeyError: 'monkey' not a
    key of d
print(d.get('monkey', 'N/A'))       # get element with
    default; print "N/A"
print(d.get('fish', 'N/A'))         # print "wet"
del d['fish']                        # remove element
print(d.get('fish', 'N/A'))         # "fish" is no
    longer a key; print "N/A"
```

## Container: Dictionary Comprehension

```
d = {'person': 2, 'cat': 4, 'spider': 8}
for animal in d:
    legs = d[animal]
    print('A %s has %d legs' % (animal, legs))
# print "A person has 2 legs", "A cat has 4 legs",
#     "A spider has 8 legs"

nums = [0, 1, 2, 3, 4]
even_num_to_square = {x: x ** 2 for x in nums if x
                      % 2 == 0}
print(even_num_to_square)  # print "{0: 0, 2: 4,
                          4: 16}"
```

# Container: Sets

```
animals = {'cat', 'dog'}    # create set (unordered
                             collection of distinct elements)
print('cat' in animals)    # check if element is in
                             a set; print "True"
print('fish' in animals)   # print "False"
animals.add('fish')        # add element
print('fish' in animals)   # print "True"
print(len(animals))        # number of elements;
                             print "3"
animals.add('cat')         # adding existing
                             element does nothing
print(len(animals))        # print "3"
animals.remove('cat')      # remove element
print(len(animals))        # print "2"
```

## Container: Set Comprehension

```
animals = {'cat', 'dog', 'fish'}  
for idx, animal in enumerate(animals):  
    print('#%d: %s' % (idx + 1, animal))  
# print "#1: fish", "#2: dog", "#3: cat"  
  
from math import sqrt  
nums = {int(sqrt(x)) for x in range(30)}  
print(nums)  # print "{0, 1, 2, 3, 4, 5}"
```

# Container: Tuples

```
t = (5, 6)          # create tuple (immutable
                    # ordered list)
print(type(t))      # print "<class 'tuple'>"
d = {(x, x + 1): x for x in range(10)} # create
    # dictionary with tuple keys
print(d[t])         # print "5"
print(d[(1, 2)])    # print "1"
```

# Mutables

```
num1 = [1, 2, 3, 4, 5]  # non-primitives/mutables
                        (can be modified in-place)
num2 = num1              # shallow copy/pass by reference
                        (indeed still pass by value of 'reference')
print(num2 is num1)      # num1 and num2 refer to
                        same object; print "True"
num2[0] = 10             # also affect num1
print(num1[0])           # print "10"
print(num2 is num1)      # print "True"
print(id(num1))
print(id(num2))          # num1 and num2 are different
                        references (holding same address on stack,
                        stack overflow?) pointing to same object on
                        heap (buffer overflow?)
```



# Function

```
def hello(name, loud=False):  
    if loud:  
        print('HELLO, %s!' % name.upper())  
    else:  
        print('Hello, %s' % name)  
  
hello('Bob')                # print "Hello, Bob"  
hello('Fred', loud=True)    # print "HELLO, FRED!"
```

# Class: Encapsulation

```
class Vehicle:  # superclass; encapsulation
    def __init__(self, make, model, year):
        self.make = make
        self.model = model
        self.year = year

    def display_info(self):
        print(f"Vehicle Info: {self.year} {self.
              make} {self.model}")

    def start_engine(self):
        print("Engine started")
```

# Class: Inheritance & Polymorphism

```
class Car(Vehicle): # subclass; inheritance
    def __init__(self, make, model, year, doors):
        super().__init__(make, model, year)
        self.doors = doors

    def display_info(self): # method overriding;
        polymorphism
        super().display_info()
        print(f"Number of doors: {self.doors}")

    def honk(self):
        print("Car honks: Beep beep!")

car = Car("Toyota", "Camry", 2020, 4)
car.display_info() # print "Vehicle Info: 2020
                  Toyota Camry", "Number of doors: 4"
car.start_engine() # print "Engine started"
car.honk()         # print "Car honks: Beep beep!"
```

# The Road Ahead...

① Built-in Functionality

② External Packages

# NumPy: Arrays

```
import numpy as np

a = np.array([1, 2, 3], dtype=np.int64) # create
    1-D array (neither row nor column vector)
print(type(a))                        # print "<class 'numpy.
    ndarray'>"
print(a.shape)                        # print "(3,)"
print(a[0], a[1], a[2])               # print "1 2 3"
a[0] = 5                              # in-place modification
print(a)                              # print "[5, 2, 3]"

b = np.array([[1,2,3],[4,5,6]])      # create 2-D
    array (including row or column vector)
print(b.shape)                        # print "(2, 3)"
print(b[0, 0], b[0, 1], b[1, 0])     # print "1 2 4"
c = np.array([[1, 2, 3]])            # row vector
print(c.shape)                        # print "(1, 3)"
d = np.array([[1], [2], [3]])        # column vector
print(d.shape)                        # print "(3, 1)"
```

## NumPy: Arrays (Cont'd)

```
a = np.zeros((2,2))    # array of all zeros
print(a)               # print "[[ 0.  0.]
                        #           [ 0.  0.]]"

b = np.ones((1,2))     # array of all ones
print(b)               # print "[[ 1.  1.]]"

c = np.full((2,2), 7)  # constant array
print(c)               # print "[[ 7.  7.]
                        #           [ 7.  7.]]"

d = np.eye(2)          # identity matrix
print(d)               # print "[[ 1.  0.]
                        #           [ 0.  1.]]"

e = np.random.random((2,2)) # random array
print(e)               # "[[ 0.91940167  0.08143941]
                        #      [ 0.68744134  0.87236687]]"

print(e.dtype)         # print "float64"
```

## NumPy: Array Indexing

```
a = np.array([[1,2,3,4], [5,6,7,8], [9,10,11,12]])
b = a[:2, 1:3]    # slice (:) to extract subarray
print(b)          # print "[[2 3]
                  #           [6 7]]"

print(a[0, 1])    # print "2"
b[0, 0] = 77      # b[0, 0], a[0, 1] point to same
                  # data, so changing one will change the other
print(a[0, 1])    # print "77"

r1 = a[1, :]      # integer indexing, 1-D array
r2 = a[1:2, :]    # slice indexing, 2-D array
print(r1, r1.shape) # print "[5 6 7 8] (4,)"
print(r2, r2.shape) # print "[[5 6 7 8]] (1, 4)"
c1 = a[:, 1]
c2 = a[:, 1:2]
print(c1, c1.shape) # print "[77  6 10] (3,)"
print(c2, c2.shape) # print "[[77]
                  #           [ 6]
                  #           [10]] (3, 1)"
```

## NumPy: Array Indexing (Cont'd)

```
a = np.array([[1,2], [3, 4], [5, 6]])
print(a[[0, 0], [1, 1]]) # returned array has
                           shape (3,); print "[2 2]"
print(np.array([a[0, 1], a[0, 1]])) # equivalent
b = np.array([0, 1, 0]) # index array
print(a[np.arange(3), b]) # select one element
                           from each row; print "[ 1  4  5]"
a[np.arange(3), b] += 10 # mutate one element
                           from each row
print(a)                  # print "array([[11,  2],
                           #                [ 3,  14],
                           #                [15,  6]])"

bool_idx = (a > 10) # find elements bigger than 10
print(bool_idx)     # print "[[ True False]
                    #                [False  True]
                    #                [ True False]]"
print(a[bool_idx])  # print "[11 14 15]"
print(a[a > 10])    # equivalent
```



## NumPy: Array Math

```
x = np.array([[1,2],[3,4]], dtype=np.float64)
y = np.array([[5,6],[7,8]], dtype=np.float64)

print(x + y)           # elementwise sum
print(np.add(x, y))    # print "[[ 6.0  8.0]
                        #           [10.0 12.0]]"

print(x - y)           # elementwise difference
print(np.subtract(x, y)) # print "[[-4. -4.]
                        #           [-4. -4.]]"

print(x * y)           # elementwise product
print(np.multiply(x, y)) # print "[[ 5. 12.]
                        #           [21. 32.]]"

print(x / y)           # elementwise division
print(np.divide(x, y)) # print "[[0.2 0.33333333]
                        #           [0.42857143 0.5]]"

print(np.sqrt(x))      # elementwise square root
                        # print "[[1. 1.41421356]
                        #           [1.73205081 2.]]"
```

## NumPy: Array Math (Cont'd)

```
x = np.array([[1,2],[3,4]]) # 2-D arrays
y = np.array([[5,6],[7,8]])
v = np.array([9,10])        # 1-D arrays
w = np.array([11, 12])

print(v.dot(w))              # inner product
print(np.dot(v, w))          # print "219"
print(v @ w)                 # equivalent; np.matmul(v, w)

print(x.dot(v))              # matrix-vector product
print(np.dot(x, v))          # print "[29 67]"
print(x @ v)                 # equivalent; np.matmul(x, v)
print(v.dot(x))              # vector-matrix product
print(np.dot(v, x))          # print "[39 58]"
print(v @ x)                 # equivalent; np.matmul(v, x)

print(x.dot(y))              # matrix-matrix product
print(np.dot(x, y))          # print "[[19 22]
                              #           [43 50]]"
print(x @ y)                 # equivalent; np.matmul(x, y)
```

## NumPy: Array Math (Cont'd)

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

print(np.sum(x))           # sum of all elements;
    print "10"
print(np.sum(x, axis=0))   # sum of each column;
    print "[4 6]"
print(np.sum(x, axis=1))   # sum of each row; print
    "[3 7]"

print(x.T)                 # print "[[1 3]
                           #           [2 4]]"
v = np.array([1,2,3])      # transpose of 1-D array
    does nothing
print(v.T)                 # print "[1 2 3]"
```

# NumPy: Array Broadcasting

```
# Outer product of vectors
v = np.array([1,2,3]) # v has shape (3,)
w = np.array([4,5])   # w has shape (2,)
print(np.reshape(v, (3, 1)) * w) # "[[ 4  5]
                                   #      [ 8 10]
                                   #      [12 15]]"

# Add vector to each row of a matrix
x = np.array([[1,2,3], [4,5,6]])
print(x + v) # "[[2 4 6]
              #      [5 7 9]]"

# Add vector to each column of a matrix
print((x.T + w).T)
print(x + np.reshape(w, (2, 1))) # "[[ 5  6  7]
                                   #      [ 9 10 11]]"

# Multiply matrix by a constant
print(x * 2) # "[[ 2  4  6]
              #      [ 8 10 12]]"
```

# PyTorch: Tensors

```
import torch

V = torch.tensor([1, 2, 3])          # create 1-D
                                     # tensor
print(V)                             # print "tensor([1, 2, 3])"
print(V[0])                          # print "tensor(1)"
print(V[0].item())                   # print "1"

M = torch.tensor([[1, 2], [3, 4]])  # create 2-D
                                     # tensor
print(M)                             # print "tensor([[1, 2],
                                     #                [3, 4]])"
print(M[0, :])                       # print "tensor([1, 2])"
print(M.view(1, 4))                  # reshape; print "tensor
                                     # ([1, 2, 3, 4])"

W = torch.tensor([5, 6, 7])
print(V + W)                         # print "tensor([6, 8, 10])"
```

```
from scipy import linalg, optimize, stats

# Solve linear system of equations
A = np.array([[3, 2, 0], [1, -1, 0], [0, 5, 1]])
b = np.array([2, 4, -1])
x = linalg.solve(A, b)
print(x)          # print "[ 2. -2.  9.]"

# Optimization
def f(x):
    return x**2 + 5 * np.sin(x)

result = optimize.minimize(f, x0=0)
print(result.x)    # print "[-1.11051081]"

# Statistics
data = np.array([1, 2, 2, 3, 4, 5, 6, 7, 8, 9])
mode = stats.mode(data)
print(mode.mode)   # print "[2]"
```

# Matplotlib

```
import matplotlib.pyplot as plt

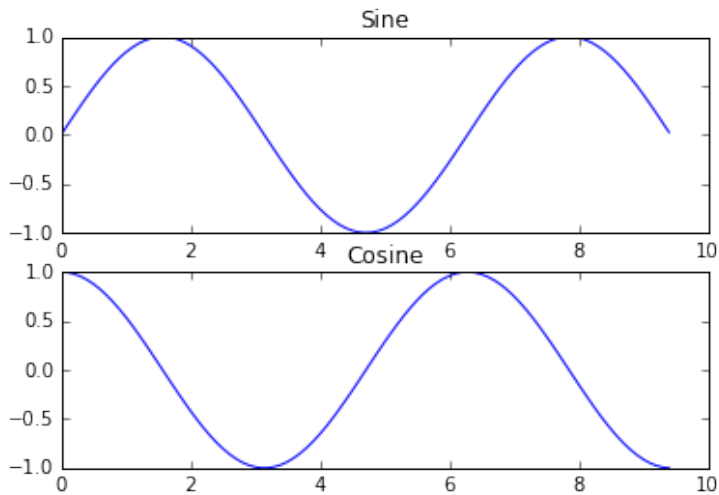
x = np.arange(0, 3 * np.pi, 0.1)  # grid points
y_sin = np.sin(x)
y_cos = np.cos(x)

plt.subplot(2, 1, 1)  # first subplot
plt.plot(x, y_sin)
plt.title('Sine')

plt.subplot(2, 1, 2)  # second subplot
plt.plot(x, y_cos)
plt.title('Cosine')

plt.show()  # display plots
```

## Matplotlib (Cont'd)





# References

- ▶ [cs231n.stanford.edu](https://cs231n.stanford.edu) – CS231n: Deep Learning for Computer Vision, by Stanford University
- ▶ [numpy.org](https://numpy.org) – NumPy package for scientific computing
- ▶ [pytorch.org](https://pytorch.org) – PyTorch package for deep learning
- ▶ [scipy.org](https://scipy.org) – SciPy package for scientific computing
- ▶ [matplotlib.org](https://matplotlib.org) – Matplotlib package for visualization