NHERI SIMCENTER PROGRAMMING BOOTCAMP

JULY 22-26, 2019, AT UC BERKELEY'S RICHMOND FIELD STATION

PYTHON3

CREDITS

Prepared by

- **Peter Mackenzie-Helnwein**
- Research Associate Professor
  Department of Civil & Environmental Engineering
  University of Washington, Seattle, WA
- pmackenz@uw.edu

Presented by

- **Peter Mackenzie-Helnwein**

Last updated

- July 29, 2019 by Peter Mackenzie-Helnwein

INTRODUCTION

- What is Python?
  - Fully programmable and extendable scripting
  - Platform independent (PC, Mac, Linux, Raspberri Pi, Arduino, …)
  - OpenSource (no licensing issues)
  - Great prototype for C++
  - Does not replace C++

INTRODUCTION

- Where do I find help?
  1. Python documentation: https://docs.python.org/3.6/index.html
  2. Python tutorial: https://docs.python.org/3.6/tutorial/index.html
  3. Python library reference: https://docs.python.org/3.6/library/index.html
  4. Master Google
- Developer tools:
  1. **PyCharm CE**
  2. VS Code
  3. Vim, emacs
  4. Notepad, gedit

INTRODUCTION

- What is similar to C/C++?
  - Object oriented
  - Many data types
  - Same indexing as C/C++ (0 .. N-1)
  - Expandable; numerous free libraries
- What is similar to Matlab?
  - Easy scripting
  - Can be used as calculator on steroids

INTRODUCTION

- What is different to C/C++?
  - Interpreter language; no need for a compiler
  - No need for header files
  - Structure by indentation instead of { … }
  - No semi-colons “;”
- What is different to Matlab?
  - Python is primarily object oriented
  - [0..n-1] instead of [1:n]
  - Default parameter handling in functions is by address !!!
  - Python enforces structured code

PART 1.1: DATA TYPES

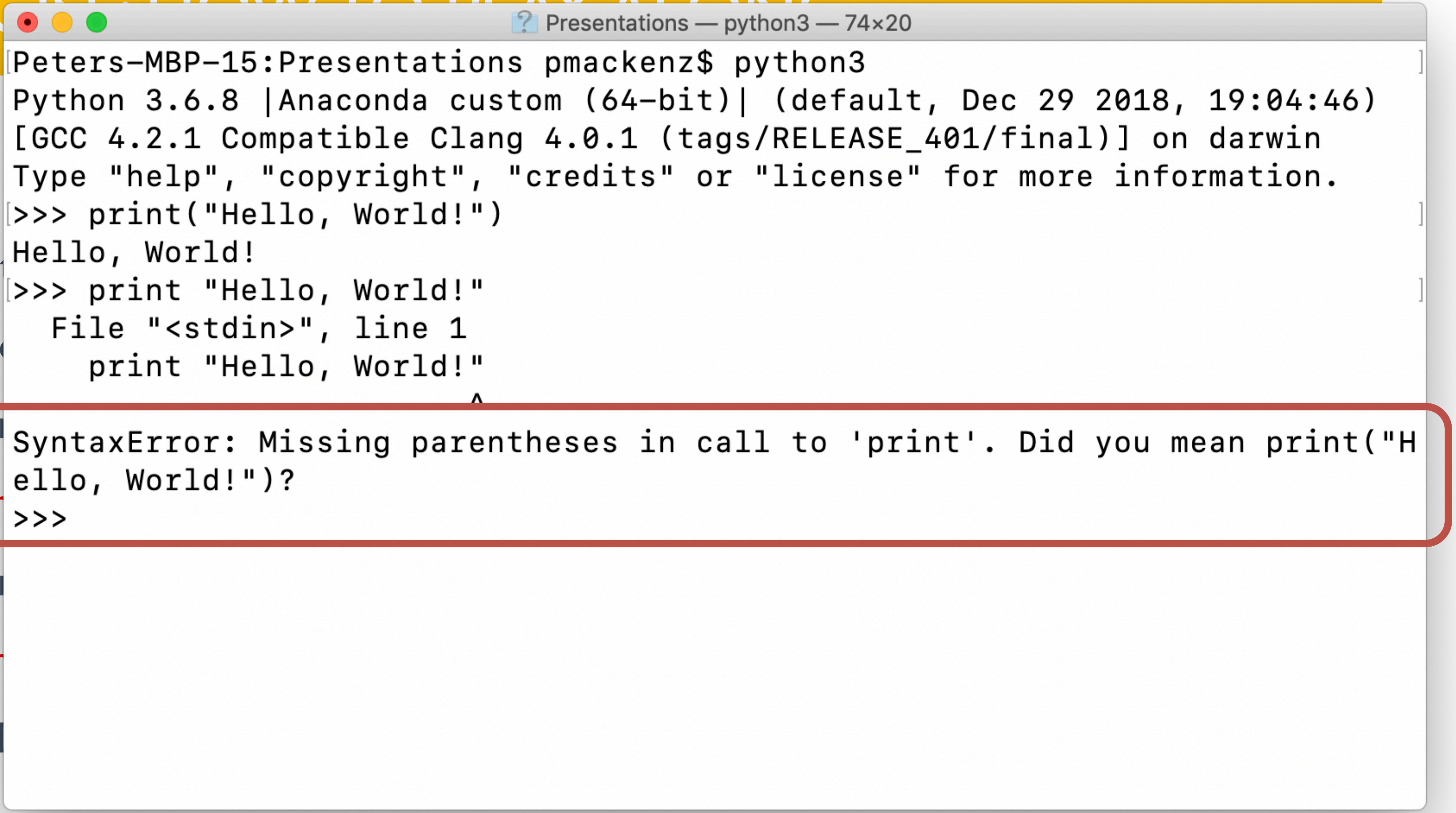
Basic Data Types

EXERCISE: HOW TO PLAY ALONG

- Open terminal
- $ python3
- >>> print("Hello, World!")
  - ____what did you get?_____
- >>> print "Hello, World!"
  - ____what did you get?_____
- >>> ^D (this is Ctrl-D)

EXERCISE: HOW TO PLAY ALONG

- Open
- $ pyth
- >>> pr
- ___wh
- >>> pr
- ___wh
- >>> ^I



```
Peters-MBP-15:Presentations pmackenz$ python3
Python 3.6.8 |Anaconda custom (64-bit)| (default, Dec 29 2018, 19:04:46)
[GCC 4.2.1 Compatible Clang 4.0.1 (tags/RELEASE_401/final)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> print("Hello, World!")
Hello, World!
>>> print "Hello, World!"
  File "<stdin>", line 1
    print "Hello, World!"
                        ^
SyntaxError: Missing parentheses in call to 'print'. Did you mean print("H
ello, World!")?
>>>
```

GETTING STARTED

- My first "Hello, world!"

```
>>> print( "Hello, world!" )
Hello, world!
>>>
```

- My first variables

```
>>> a = 3
>>> b = 2
>>> a/b
1
>>> b/a
0
```

Python 2.7

GETTING STARTED

- My first variables

```
>>> a = 3
>>> b = 2
>>> a/b
1
>>> b/a
0
```

Python 2.7

```
>>> a = 3.
>>> b = 2.
>>> a/b
1.5
>>> b/a
0.6666666666666667
```

GETTING STARTED

- Basic Variable types
  - Integer
  - Floating point (double, real*8, …)
  - Character
  - String

```
>>> a = 2
>>> b = 3.14126
>>> c = ‘A’
>>> s = “Peter Mackenzie”
```

GETTING STARTED

- Types in python

	Mutable	Immutable
Number		int, long, float
Sequence	list	tuple, str, unicode
Mapping	dict	
Other	object	

GETTING STARTED

- Int, long, float
  - Int: 2^16 (0:65535 or -32767:32768)
  - Long: 2^32
  - Float (64bit): ~base (2^53) * 10^(2^11)

- String
  - Array of characters: character ASCII(0:255)
  - Unicode: list of unicode characters u(0:65535)

GETTING STARTED

- Tuple
  - (item1,[item2 [, item3 [, item4 […]]]])
- List
  - [item1 [, item2, … , itemN]]

GETTING STARTED

- Tuple
  - (item1,[
- List
  - [item1[, i

```
IDLE 1.2.2
>>> a=[1,'a',‘Hello, world!']
>>> b=(1,'a','aaaa‘)
>>> b[1]
'a'
>>> a[1]
'a'
>>> a[1]=5
>>> a
[1, 5, 'Hello, world!']
>>> b[1]=5

Traceback (most recent call last):
  File "<pyshell#8>", line 1, in <module>
    b[1]=5
TypeError: 'tuple' object does not support item assignment
```

GETTING STARTED

- Dictionary
  - dict(key1=item1[, key2=item2 [, key3=item3 […]]])
  - { ‘key1’:item1[, ‘key2’:item2 [, ‘key3’:item3[, …]]] }

GETTING STARTED

- Dictio
  - dict(

```
>>> d = dict(name='Peter', age=42)
>>> d['name']
'Peter'
>>> d['age']
42

>>> d.keys()
['age', 'name']

>>> d.values()
[42, 'Peter']

>>> print ('The answer to everything is ',d['age'])
The answer to everything is 42

>>> for i in d.keys():
        print( i, d[i] )

age 42
name Peter
```

GETTING STARTED

- Sequences (tuple, list, str)

```
>>> my_list = (3.141267, 'a', "Hello, World!"
>>> print my_list
(3.141267, 'a', 'Hello, World!')

>>> for item in my_list:
        item

3.141267
'a'
'Hello, World!'

>>> for item in my_list:
        print( item )

3.141267
a
Hello, World!
```

```
>>> a='Hello, world!'
>>> for c in a:
         print(c)


H
e
l
l
o
,

w
o
r
l
d
!
```

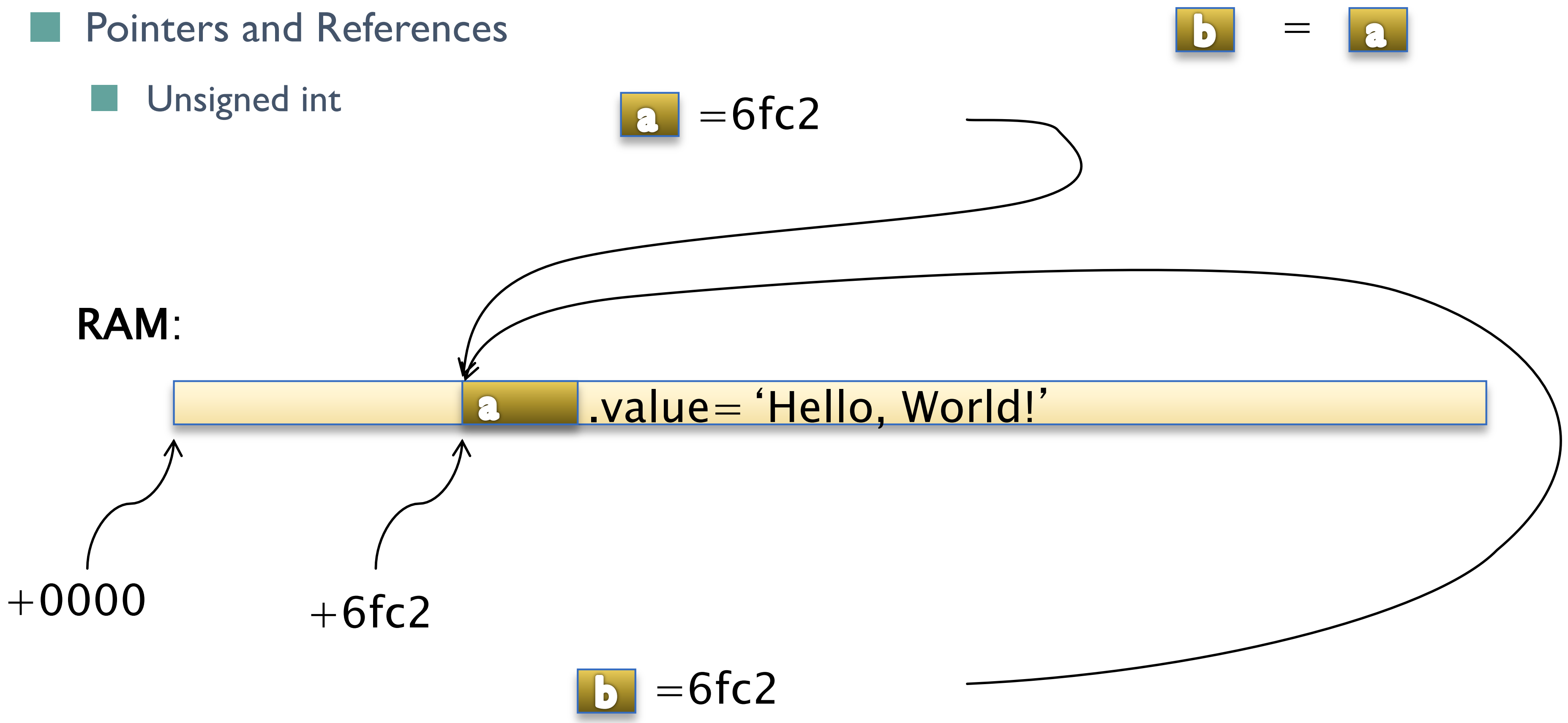
GETTING STARTED

- An unexpected problem, or is it?

```
>>> a=["Hello","World","!"]

>>> a
['Hello', 'World', '!']

>>> b=a

>>> b[0]
'Hello‘

>>> b[1]
'World'

>>> b[1]='Peter'

>>> b
['Hello', 'Peter', '!']

>>> a
['Hello', 'Peter', '!']
```

OTHER TYPES

- Pointers and References
  - Unsigned int

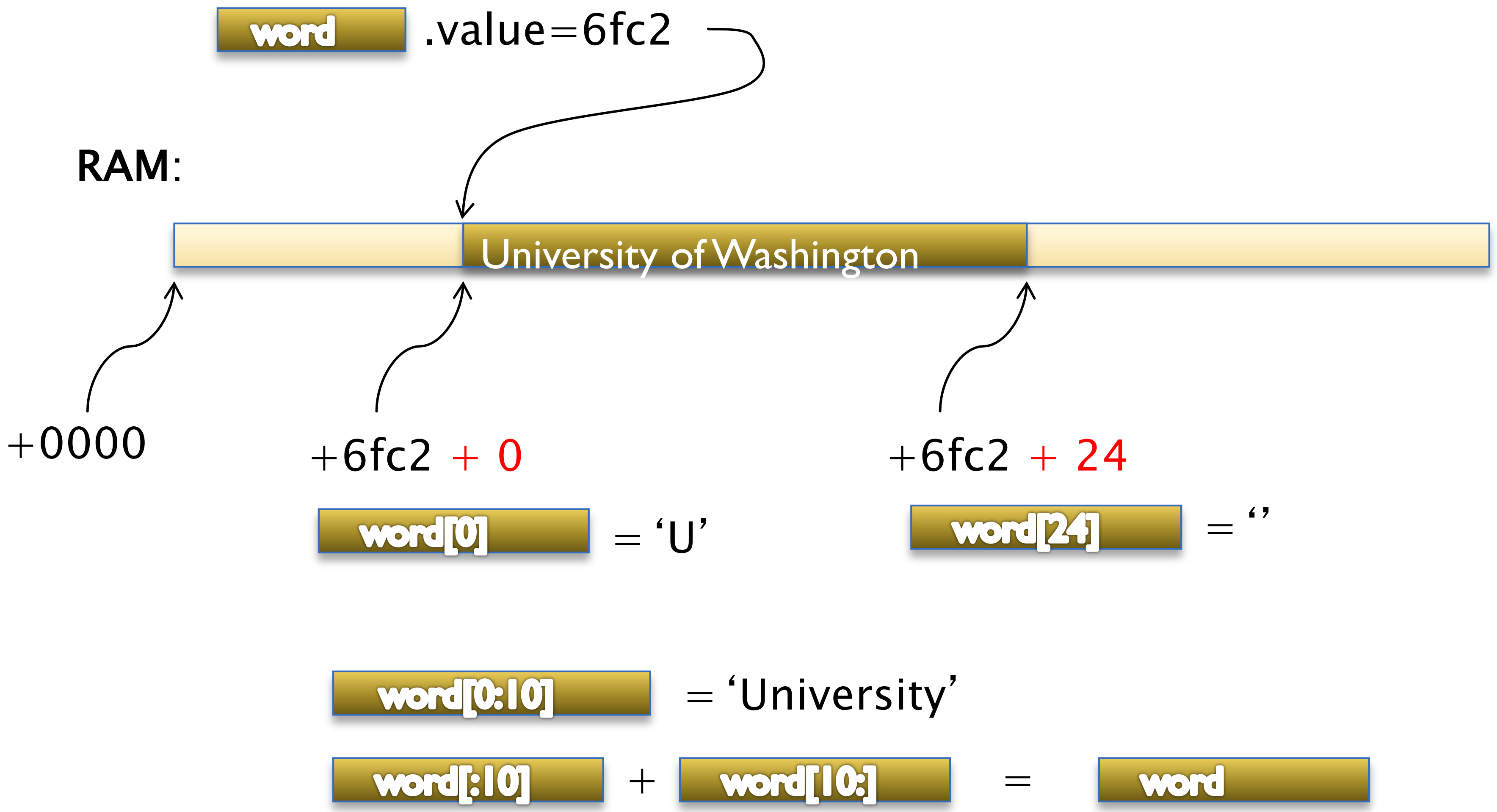


GETTING STARTED

- Ranges and slicing

```
>>> word='University of Washington'
>>> word
'University of Washington'

>>> len(word)
24

>>> word[1:10]
'niversity'

>>> p1 = word[1:10]
>>> len(p1)
9

>>> list(range(1,10))
[1, 2, 3, 4, 5, 6, 7, 8, 9]

>>> word[0:10]
‘University’
```

STRING SEGMENTS



FLOW CONTROL

- Boolean operations
  - ==
  - <
  - <=
  - >
  - >=
  - !=
  - not
  - and, or
- 0 = false
- not 0 = true

Exercise

- 17 < 365/21
- ‘Monday’ < ‘Friday’
- (100 – 99 – 1)
- sin(3.14127/3)

FLOW CONTROL

Exercise

- 17 <= 365/21 and ‘Monday’ < ‘Friday’
- ‘Monday’ < ‘Friday’ or cos(3.1427)
- (100 – 99) and sin(3.14127/3) or ‘Friday’ > ‘Monday’
- (100 – 99) and sin(3.14127/3) and ‘Friday’ > ‘Monday’
- (100 – 99) or sin(3.14127/3) and ‘Friday’ > ‘Monday’
- ((100 – 99) or sin(3.14127/3)) and ‘Friday’ > ‘Monday’
- ((100 – 99) or sin(3.14127/3)) or ‘Friday’ > ‘Monday’

CREATING LISTS

- Range

```
>>> range(3)
range(0, 3)
>>> list(range(3))
[0, 1, 2]

>>> list(range(3,10))
[3, 4, 5, 6, 7, 8, 9]

>>> list(range(3,10,2))
[3, 5, 7, 9]
```

- Slicing

```
>>> s="SimCenter BootCamp"
>>> s
'SimCenter BootCamp’

>>> s[3]
'C’

>>> s[0:10]
'SimCenter ‘      # see the extra space ?

>>> s[:10]
'SimCenter ‘

>>> s[10:]
'BootCamp’

>>> s[:10]+s[10:]
'SimCenter BootCamp'
```

PART 1.2: DATA TYPES

Flow Control

FLOW CONTROL

- LOOPS

```
# MATLAB

s = 10;
H = zeros(s);

for c = 1:s
    for r = 1:s
        H(r,c) = 1/(r+c-1);
    end
end
```

```
# Python
import numpy as np

s = 10
H = np.zeros((s,s))

for c in range(s):
    for r in range(s):
        H[r,c] = 1/(r+c+1)
```

`SimpleCode/hilbert.py`

FLOW CONTROL

- LOOPS – cont'd

```
>>> lst = ['SimCenter','BootCamp', 2019]
>>> for item in lst:
...         print(item)

SimCenter
BootCamp
2019
```

```
>>> s='SimCenter BootCamp 2019'
>>> for c in s:
...         print(c)
S
i
m
C
e
n
t
e
r

B
o
o
t
C
a
m
p

2
0
1
9
```

FLOW CONTROL

- IF THEN ELSE

```
# function definition

def cond(x):
    if x>0:
        print("{} is positive".format(x))
    elif x<0:
        print("{} is negative".format(x))
    else:
        print("{} is zero".format(x))

# execution
cond(3.14127)
cond(7-13)
cond(1./10.-0.1)
```

```
# function definition

def cond(x):
    b = 0
    if x>0:
        b = 1
        print("{} is positive".format(x))
    elif x<0:
        b = 2
        print("{} is negative".format(x))
    else:
        print("{} is zero".format(x))
    return b

# execution
cond(3.14127)
cond(7-13)
cond(1./10.-0.1)
```

`SimpleCode/condition.py`

FLOW CONTROL

- WHILE

```
def countdown(n):
    if n<1:
        return
    while n>0:
        print(n)
        n -= 1


# execution
countdown(10)
```

```
10
9
8
7
6
5
4
3
2
1
```

`SimpleCode/countdown.py`

FUNCTIONS

- Definition

```
def f(x):
    pass
```

```
def f(x):
    print("x = {}".format(x))
```

- Parameters
  - Call by address effects:
    - Lists are altered globally (call by address)
    - Duple cannot be altered and will trigger error
    - Floats and integers are handled by value -> require return

FUNCTIONS

- Definition

```
def factor(n):
    if n>1:
        return n*factor(n-1)
    else:
        return 1

# test the new function
print( factor(5) )
print( "11! = {}".format(factor(11)) )
```

```
def factor(n):
    if n>1:
        return n*factor(n-1)
    else:
        return 1


def prettyPrint(k):
    s = "{}! = {}"
    print(s.format(k, factor(k)))

# test the new function
prettyPrint(5)
prettyPrint( 11)
```

RESULTS:

```
5! = 120
11! = 39916800
```

FUNCTIONS

- Parameters
  - Call by address effects:
    - Lists are altered globally (call by address)
    - Duple cannot be altered and will trigger error
    - Floats and integers are handled by value -> require a return value

```
# function definition

def f(alist):
    retval = ‘’
    if len(alist) >= 3:
        retval = alist[2]
        alist[2]=‘Peter’
    return retval

# the executable portion

lst = [ ‘BootCamp’, 2019, ‘Somebody’ ]
print(lst)
print( f(lst) )
print(lst)
```

SimpleCode/parameters.py

EXERCISE

- Computing elements of the Fibonacci series

$$a_n = a_{n-1} + a_{n-2}$$

with

$$a_0 = a_1 = 1$$

- SimCenterBootcamp2019/Code/Python/Exercises/Fibonacci

PART 1.3: DATA TYPES – CONT'D

Scientific Data Types

NUMERIC ANALYSIS

- Vector, Matrix, and Tensor analysis requires multidimensional arrays.
- NumPy is a Python library for working with multidimensional arrays.
- The main data type is an array.
- An array is a set of elements, all of the same type, indexed by a vector of nonnegative integers.
- http://www.scipy.org/Tentative_NumPy_Tutorial

DATA TYPES

Scientific data types (numpy extension)

- array
- matrix

```
>>> a = [1,2,3]
>>> b = [5,6,7]
>>> a+b
[1, 2, 3, 5, 6, 7]

>>> b+a
[5, 6, 7, 1, 2, 3]
```

```
import numpy as np

>>> a = np.array([1,2,
>>> b = np.[5,6,7])
>>> a+b
array([ 6,  8, 10])

>>> b+a
array([ 6,  8, 10])

>>> np.dot(a,b)
38

>>> np.cross(a,b)
array([-4,  8, -4])
```

```
import numpy as np

>>> a=np.matrix([1,2,3])
>>> a
matrix([[1, 2, 3]])

>>> b=np.matrix([5,6,7])
>>> a*b
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "/Users/pmackenz/anaconda3/lib/python3.6/site-packages/numpy/matrixlib/defmatrix.py", line 215, in __mul__
    return N.dot(self, asmatrix(other))
ValueError: shapes (1,3) and (1,3) not aligned: 3 (dim 1) != 1 (dim 0)
>>> a*b.T
matrix([[38]])
```

USING MODULES (LIKE LIBRARIES IN C++)

```
import numpy

a = numpy.array([1,2,3])
```

```
import numpy as np

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

```
from numpy import array

a = array([1,2,3])
```

- ALWAYS start code with imports
- AFTER THAT, define functions and classes
- AFTER THAT, create a main
- AFTER THAT, execute that main

USING MODULES (LIKE LIBRARIES IN C++)

- Using import is the logic to split code into multiple files
- Have one main.py to start
- Place (groups of) functions (and classes) into their own files

`Calcs.py`

```
def dot(x, y):
    c = 0
    if len(x) == len(y):
        for i in range(len(x)):
            c += x[i]*y[i]
    return c
```

`printing.py`

```
def scalarprint(x):
    print("The scalar value is {}".format(x))

def vectorprint(x):
    print("The vector value is {}".format(x))
```

USING MODULES (LIKE LIBRARIES IN C++)

- Using import is the logic to split code into multiple files
- Have one main.py to start
- Place (groups of) functions (and classes) into their own files

`calcs.py`

```
def dot(x, y):
    c = 0
    if len(x) == len(y):
        for i in range(len(x)):
            c += x[i]*y[i]
    return c
```

`printing.py`

```
def scalarprint(x):
    print("The scalar value is {}".format(x))

def vectorprint(x):
    print("The vector value is {}".format(x))
```

`main.py`

```
from printing import *
from calcs import dot

if __name__ == '__main__':
    a = [1.,2.,3.]
    b = [4.,5.,6.]
    c = dot(a,b)
    vectorprint(a)
    vectorprint(b)
    scalarprint(c)
```

NUMERIC ANALYSIS

```
>>> from numpy import *

>>> a = array( [ 10, 20, 30, 40 ] )  # create an array out of a list
>>> a
array( [10, 20, 30, 40] )

>>> b = arange( 4 ) # create an array of 4 integers, from 0 to 3
>>> b
array([0, 1, 2, 3])

>>> c = linspace(-pi,pi,3)   # create an array of 3 evenly spaced samples from -pi to pi
>>> c
array( [-3.14159265, 0. , 3.14159265] )
```

```
>>> d = a + b**2 # element-wise operations
>>> d
array( [10, 21, 34, 49] )
```

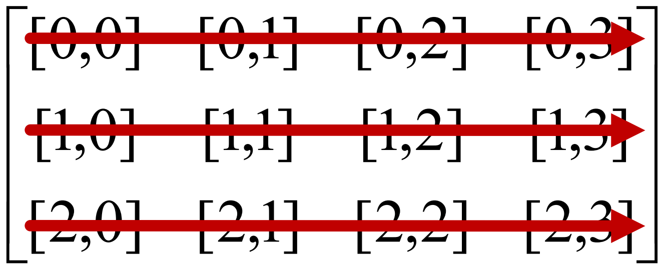
DATA TYPES WITHIN AN ARRAY

- ndarray.dtype
  an object describing the type of the elements in the array. Elements of an array are of identical type.

- ❑ standard Python types
- ❑ bool_
- ❑ character
- ❑ int_
- ❑ int8
- ❑ int16
- ❑ int32
- ❑ int64
- ❑ float_
- ❑ float8
- ❑ float16
- ❑ float32
- ❑ float64
- ❑ complex_
- ❑ complex64
- ❑ object_

MULTIDIMENSIONAL ARRAYS

```
>>> from numpy import *

>>> x = ones( (3,4) )
>>> x
array( [[ 1.,  1.,  1.,  1.],
        [ 1.,  1.,  1.,  1.],
        [ 1.,  1.,  1.,  1.]] )

>>> x.shape
(3, 4)
```



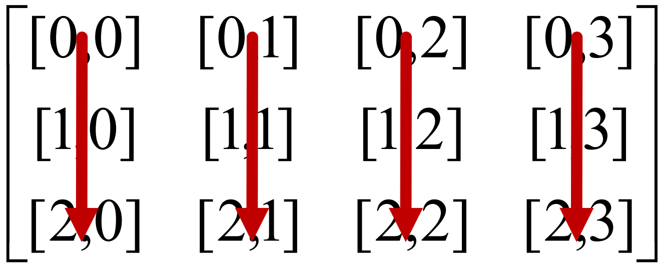
```
>>> x.ravel()
array([ 1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.,  1.])
```

[[0,0] [0,1] [0,2] [0,3] [1,0] [1,1] [1,2] [1,3] [2,0] [2,1] [2,2] [2,3]]

MULTIDIMENSIONAL ARRAYS

MATLAB

```
>> x = ones( (3,4) )
x =
     1.   1.   1.   1.
     1.   1.   1.   1.
     1.   1.   1.   1.

>> size(x)
ans =
     3  4
```



$$\begin{bmatrix} [0,0] & [0,1] & [0,2] & [0,3] \\ [1,0] & [1,1] & [1,2] & [1,3] \\ [2,0] & [2,1] & [2,2] & [2,3] \end{bmatrix}$$

```
>> x = reshape( x, 1, 12)
x =1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
```

$$[[0,0] \quad [1,0] \quad [2,0] \quad [0,1] \quad [1,1] \quad [2,1] \quad [0,2] \quad [1,2] \quad [2,2] \quad [0,3] \quad [1,3] \quad [2,3]]$$

MULTIDIMENSIONAL ARRAYS

```
>>> y=arange(8)
>>> y
array([0, 1, 2, 3, 4, 5, 6, 7])

>>> y.shape = (2,2,2)
>>> y
array( [[[0, 1],
         [2, 3]],

        [[4, 5],
         [6, 7]]] )
```

```
>>> y = arange(12).reshape((3,4))
>>> y
array([[ 0,  1,  2,  3],
       [ 4,  5,  6,  7],
       [ 8,  9, 10, 11]])
```

```
>>> y
array( [[[0, 1],
         [2, 3]],

        [[4, 5],
         [6, 7]]] )

>>> y[0,0,0]
0

>>> y[0,0,1]
1

>>> y[1,0,0]
4

>>> y[1,1,1]
7
```

ARRAY OPERATIONS

```
>>> A = array( [[1,2], [3,4]] )
>>> w = array( [1,3] )

>>> A
array([[1, 2],
       [3, 4]])

>>> w
array([1, 3])
```

```
>>> A*w
array([[ 1,  6],
       [ 3, 12]])
```

$\mathbf{A} * \mathbf{w} = ?$

```
>>> dot(A,w)
array([ 7, 15])
```

$= \mathbf{A} \cdot \mathbf{w}$

```
>>> dot(w,A)
array([10, 14])
```

$= \mathbf{w} \cdot \mathbf{A}$

```
>>> dot(w,w)
10
```

$= \mathbf{w} \cdot \mathbf{w}$

$$\mathbf{A} = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$$

$$\mathbf{w} = \begin{bmatrix} 1 \\ 3 \end{bmatrix} \equiv \begin{bmatrix} 1 & 3 \end{bmatrix}$$

$$\mathbf{w} = \begin{bmatrix} 1 & 3 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 3 \\ ? & ? \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 3 \\ 1 & 3 \end{bmatrix}$$

ARRAY MANIPULATIONS

```
>>> A = arange(12).reshape(3,4)
>>> print A
[[ 0  1  2  3]
 [ 4  5  6  7]
 [ 8  9 10 11]]

>>> A[:2,1:3]
array([[1, 2],
       [5, 6]])

>>> print A[:2,1:3]
[[1 2]
 [5 6]]

>>> print A[:,2]
[ 2  6 10]

>>> print A[0,:]
[0 1 2 3]
```

```
>>> v = array( [3,4,5] )
>>> w = array( [12,11,10] )
>>> print v
[3 4 5]
>>> print w
[12 11 10]

>>> print( column_stack( (v,w) ) )
[[ 3 12]
 [ 4 11]
 [ 5 10]]

>>> print( row_stack( (v,w) ) )
[[ 3  4  5]
 [12 11 10]]

>>> print( hstack( (v,w) ) )
[ 3  4  5 12 11 10]

>>> print( vstack( (v,w) ) )
[[ 3  4  5]
 [12 11 10]]
```

MATRIX OBJECTS

```
from numpy import matrix
from numpy import linalg

A = matrix( [[1,2,3],[11,12,13],[21,22,23]])       # Creates a matrix.
x = matrix( [[1],[2],[3]] )                   # Creates a matrix (like a column vector).
y = matrix( [[1,2,3]] )                       # Creates a matrix (like a row vector).

Print( A.T )          # Transpose of A.
Print( A*x )          # Matrix multiplication of A and x.
Print( A.I )          # Inverse of A.

Print( linalg.solve(A, x) )       # Solve the linear equation system.
```

MATRIX OBJECTS

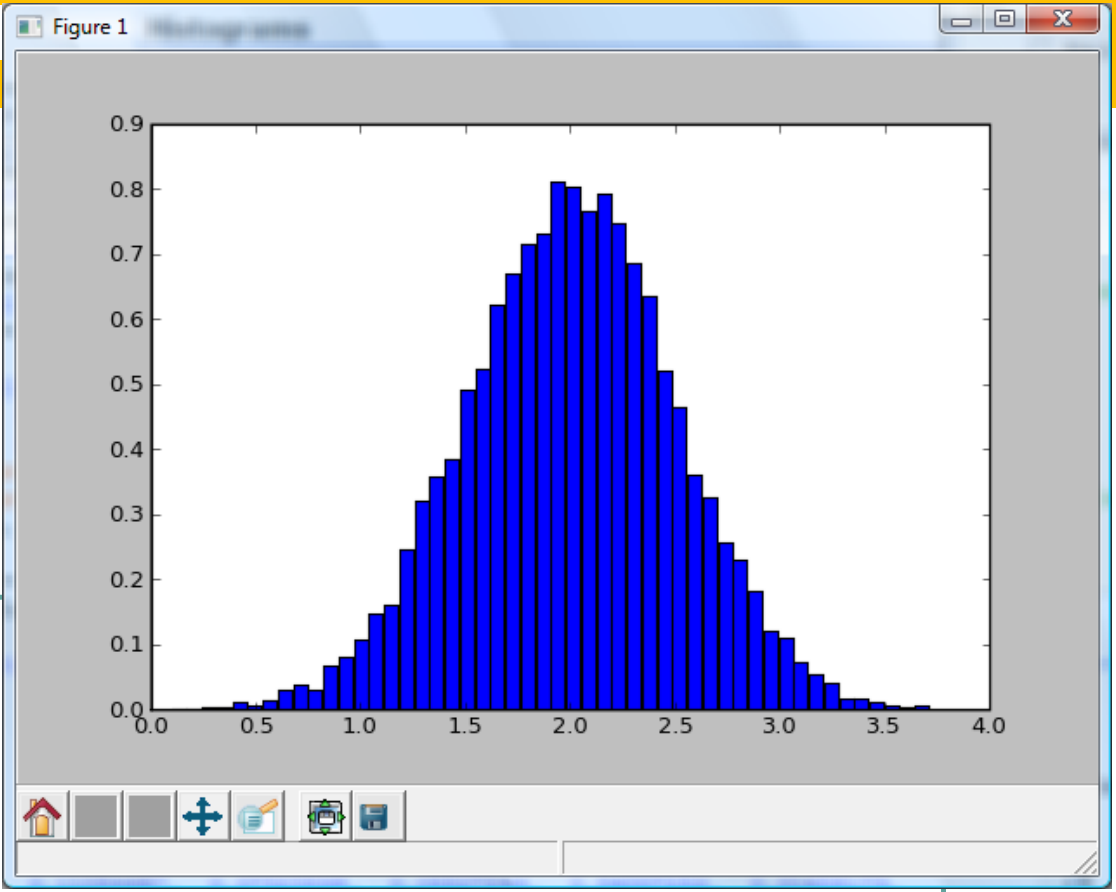
```
>>> A=matrix([[1,2],[3,4]])
>>> A
matrix([[1, 2],
        [3, 4]])

>>> B=matrix([[2,3],[5,7.]])
>>> B
matrix([[ 2.,  3.],
        [ 5.,  7.]])

>>> A*B
matrix([[ 12.,  17.],
      [ 26.,  37.]])

>>> B*A
matrix([[ 11.,  16.],
        [ 26.,  38.]])

>>> _.dtype
dtype('float64')
```

```
>>> C = array(A)

>>> C is A
False

>>> mat(C)
matrix([[1, 2],
        [3, 4]])

>>> C
array([[1, 2],
       [3, 4]])

>>> v = mat([[1],[3]])
>>> v
matrix([[1],
        [3]])

>>> A*v
matrix([[ 7],
        [15]])
```

SCIPY / MATPLOTL

- Linear algebra (eig, inverse, …)
- Statistics

```
import numpy
From matplotlib import pyplot

mu, sigma = 2, 0.5

v = numpy.random.normal(mu,sigma,10000)

pyplot.hist(v, bins=50, normed=1)        # matplotlib version (plot)
pyplot.show()
```



ORGANIZING YOUR CODE

Simple code – Single file

- Structure
    1. Imports first!
    2. Global functions, if any, second!
       (I usually avoid these and make them a class)
    3. Class definitions third!
    4. def main(): second to last
    5. Execute main() as last statement

ORGANIZING YOUR CODE

Complex code – Multiple files

- One file per function (or class)
- Name file the same as the class makes things easier
- Always have a main.py (not necessary but smart)
- Document your code

PART 2.1:

Object Oriented Programming

In Python

PROCEDURAL PROGRAMMING

- Functions

```
function val = my_function(x1, x2, ...)
```

$$\mathrm{f}(x) : \mathrm{R}^n \rightarrow \mathrm{R}$$

  - Has a return value

- Procedures

```
Procedure my_procedure(x1, x2, ...)
```

  - Does not have a return value

- Python / C++
  - All functions and procedures have return value

PROCEDURAL PROGRAMMING

- Functions/Procedures require a certain data structure to work on
  - Difficult to reuse procedures in different codes
  - Problems with procedures from different packages = different data structure
  - Data exposed in code = can be modified by mistake
  - Package upgrades may require changes in the data structure, thus affecting the entire code
  - Difficulty developing code in a group effort

OBJECT ORIENTED PROGRAMMING (OOP)

- Objects control both data and methods
  - Data
    - Private vs. public
  - Methods
    - Functions and procedures to manipulate own data
- Key ideas
  - Data integrity
    - User has no direct access to data
  - Easy upgrade without changes to the main code
    - Objects have a well defined interface
    - Access to data through access functions

OBJECT ORIENTED PROGRAMMING (OOP)

- Implementation

```
'''
Created on Apr 17, 2009

@author: Peter Mackenzie
'''

class MyClass (object):
    '''
    classdocs
    '''

    def __init__(self, params):
        '''
        Constructor
        '''

     # variables
     self.var1  = _some__default_value_

    def my_method1(self, params):
        pass
```

Class definition

Class constructor

Class variables (public)

Class method

OBJECT ORIENTED PROGRAMMING (OOP)

```
import problem1 as p

class genBase(object):
    '''
    classdocs
    '''

    def __init__(self, base = 10, value = 0):
        '''
        Constructor
        '''
        self.base = base
        self.value = p.to_base(base, value)


    def __str__(self):
        s = "{} ({} base)".format(self.value,
self.base)
        return s

    def Print(self):
        print("my value at base {} is
{}".format(self.base, self.value))
```

```
'''
Created on Apr 17, 2009

@author: Peter Mackenzie
'''

from genBase import *

x = genBase( 16,  6330 )
print(x)
x.Print()
```

genBase.__init__(16, 6330)

print(x.__str__())

x.Print()

```
18ba (16 base)
```

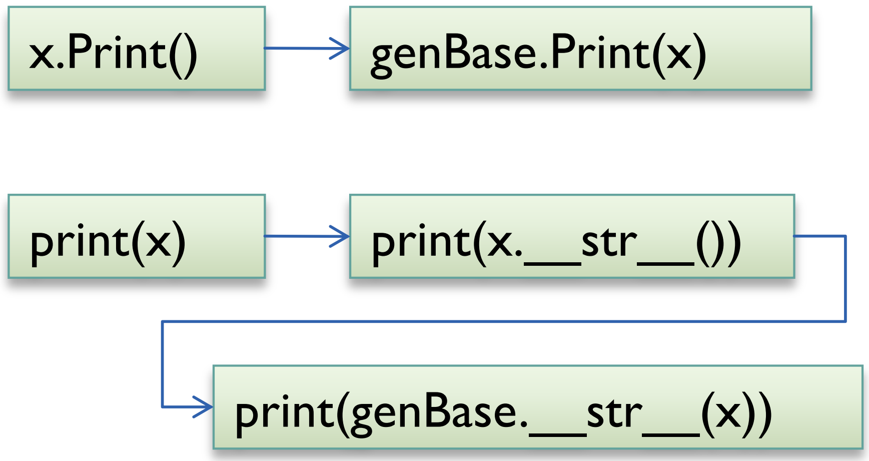
```
my value at base 16 is 18ba
```

OBJECT ORIENTED PROGRAMMING (OOP)

```
import problem1 as p

class genBase(object):
    '''
    classdocs
    '''

    def __init__(self, base = 10, value = 0):
        '''
        Constructor
        '''
        self.base = base
        self.value = p.to_base(base, value)


    def __str__(self):
        s = "{} ({} base)".format(self.value,
self.base)
        return s

    def Print(self):
        print("my value at base {} is
{}".format(self.base, self.value))
```

```
'''
Created on Apr 17, 2009

@author: Peter Mackenzie
'''


import  genBase

x = genBase( 16,  6330 )
print x
x.Print()
```

x.Print()



OBJECT ORIENTED PROGRAMMING (OOP)

```
import problem1 as p

class genBase(object):
    '''
    classdocs
    '''

    def __init__(self, base = 10, value = 0):
        '''
        Constructor
        '''
        self.base = base
        self.value = p.to_base(base, value)


    def __str__(self):
        s = "{} ({} base)".format(self.value, 
self.base)
        return s

    def Print(self):
        print("my value at base {} is 
{}".format(self.base, self.value)
```

```
import problem1 as p1
import problem2 as p2

class genBase(object):

    def __init__(self, base = 10, value = 0):
        '''
        Constructor
        '''
        v = p1.to_base(base, value)
        self.data = { 'BASE': base,  'VALUE': v}


    def __str__(self):
        s = "{} ({} base)".format( \
                    self.data['VALUE'], \
                    self.data['BASE'] )
        return s

    def Print(self):
        print("my value at base {} is 
{}".format( \
                     self.data['BASE'], \
                     self.data['VALUE'] )
```

OBJECT ORIENTED PROGRAMMING (OOP)

- More features: **Inheritance**
  - Classes can be derived from one or more base classes
  - The new class may
    - Use inherited data and methods
    - Add new data (variables)
    - Add new methods
    - Overload methods
    - Overload operators

OOP: INHERITANCE

Class definition

```
class Animal (object):
    def __init__(self, name='unknown'):
        self.name = name

    def sound(self):
        print(”{} is silent”.format(self.name))


class Cat (Animal):
    def sound(self):
        print(”{} is meowing.format(self.name))


class Dog (Animal):
    def sound(self):
        print(”{} is barking”.format(self.name))
```

Code example

```
from Animals import *

a = Animal('Hans')
b = Cat('Cleo')
c = Dog('Foster')
```

Cat.__init__(self, name) = Animal.__init__(self, name)
Cat.sound(self, name) = Animal.sound(self, name)

Cat.__init__(self, name) = Animal.__init__(self, name)
Cat.sound(self, name) = **independent**

OOP: INHERITANCE

Class definition

```
class Animal (object):
    def __init__(self, name='unknown'):
        self.name = name

    def sound(self):
        print(”{} is silent”.format(self.name))


class Cat (Animal):
    def sound(self):
        print(”{} is meowing”.format(self.name))

class Dog (Animal):
    def sound(self):
        print(”{} is barking”.format(self.name))
```

Code example

```
from Animals import *

a = Animal('Hans')
b = Cat('Cleo')
c = Dog('Foster')

a.sound()
b.sound()
c.sound()
```

OOP: INHERITANCE

Class definition

```
class Animal (object):
    def __init__(self, name='unknown'):
        self.name = name

    def sound(self):
        print("{} is silent".format(self.name))


class Cat (Animal):
    def sound(self):
        print("{} is meowing".for

class Dog (Animal):
    def sound(self):
        print("{} is barking".form
```

Code example

```
from Animals import *

a = Animal('Hans')
b = Cat('Cleo')
c = Dog('Foster')

a.sound()
b.sound()
c.sound()
```

OBJECT ORIENTED PROGRAMMING (OOP)

- Overloading Methods

  - Methods from a base class may be either used as is (inheritance) or replaced by an alternative method of identical name (overloading)
  - Examples:
    - Animal.__init__()
    - Animal.sound() – Cat.sound() – Dog.sound()

  - The object class has standard methods which can be overloaded as well

OBJECT ORIENTED PROGRAMMING (OOP)

- Overloading Default Methods
  - ___init___(self, args) Constructor
    - Set defaults / initiate variables
  - ___str___(self) convert self to string
    - Used in print statements
  - ___repr___(self) represent description of self as string (used for debugging)
  - ___len___(self) define/return length of object
  - ___getitem___(self, i) get indexed item
    - Needed for sequences (similar to list or tuple)

OBJECT ORIENTED PROGRAMMING (OOP)

- Example:
- Use a list to represent a vector and implement vector addition, subtraction, and the dot product

Default list behavior :

```
>>> a = [1,2,3]
>>> b = [4,6,8]
>>> a
[1, 2, 3]
>>> b
[4, 6, 8]
>>> a + b
[1, 2, 3, 4, 6, 8]
>>> b + a
[4, 6, 8, 1, 2, 3]
>>> a - b

Traceback (most recent call last):
  File "<pyshell#6>", line 1, in <module>
    a - b
TypeError: unsupported operand type(s) for -: 'list' and 'list'
```

OOP: OPERATOR OVERLOAD

Class definition

```
class Vector(object):

    def __init__(self, data):
        self.v = data

    def __str__(self):
        return str( self.v )

    def __len__(self):
        return len(self.v)

    def __getitem__(self, i):
        return self.v[i]

    def __div__(self, x):
        raise NotImplemented
```

Code example

```
from Vector import *

# define two vectors
v = Vector([1, 2, 3])
w = Vector([4, 6, 8])

print( "v:    {}".format(v))
print( "w:    {}".format(w))
```

```
v:    [1, 2, 3]
w:    [4, 6, 8]
```

OBJECT ORIENTED PROGRAMMING (OOP)

- Emulating numeric types:
  operator overload

  - ___add___(self, v)	return self + v
  - ___sub___(self, v)	return self - v
  - ___mul___(self, v)	return self * v
  - ___div___(self, v)		return self / v
  - ___pow___(self, v)	return self ** v
  - ___floordiv___(self, v)	return self // v
  - ___mod___(self, v)	return self % v

OOP: OPERATOR OVERLOAD

Class definition

```
class Vector(object):

    def __init__(self, data):
        self.v = data

    def __str__(self):
        return str( self.v )

    def __len__(self):
        return len(self.v)

    def __getitem__(self, i):
        return self.v[i]

    def __div__(self, x):
        raise NotImplemented
```

```
def __add__(self, x):
    if type(x) == Vector:
        w = self.v[:]
        for i in range(0,len(self)):
            w[i] += x[i]
        return Vector(w)
    else:
        raise TypeError

.
.
.
```

copy

OOP: OPERATOR OVERLOA

Class definition

```
class Vector(object):

    def __init__(self, data):
        self.v = data

    def __str__(self):
        return str( self.v )

    def __len__(self):
        return len(self.v)

    def __getitem__(self, i):
        return self.v[i]

    def __div__(self, x):
        raise NotImplemented
```

```
def __add__(self, x):
    if type(x) == Vector:
        w = self.v[:]
        for i in range(0,len(self)):
            w[i] += x[i]
        return Vector(w)
    else:
        raise TypeError

def __sub__(self, x):
    if type(x) == Vector:
        w = self.v[:]
        for i in range(0,len(self)):
            w[i] -= x[i]
        return Vector(w)
    else:
        raise TypeError

def __mul__(self, x):
    if type(x) == Vector:
        w = 0.0
        for i in range(0,len(self)):
            w += self.v[i] * x[i]
        return w
    else:
        raise TypeError
```

copy

copy

OOP: INHERITANCE

Code example

```
from Vector import *

# define two vectors
v = Vector([1, 2, 3])
w = Vector([4, 6, 8])

print("v: {}".format(v))
print("w: {}".format(w))

x = v + w
print("v + w: {}".format(x))

y = v – w
print("v – w: {}".format(y) )

z = v * w
print("v * w: {}".format(z))
```

Output

```
v:    [1, 2, 3]
w:     [4, 6, 8]


v + w: [5, 8, 11]


v - w: [-3, -4, -5]


v * w: 40.0
```

OOP: INHERITANCE

Code example

```
# from Vector import *
from VectorNoisy import *

# define two vectors
v = Vector([1, 2, 3])
w = Vector([4, 6, 8])

print("v: {}".format(v))
print("w: {}".format(w))

x = v + w
print("v + w: {}".format(x))

y = v – w
print("v – w: {}".format(y))

z = v * w
print("v * w: {}".format(z))
```

```
entering __init__()
entering __init__()
entering __str__()
v:     [1, 2, 3]
entering __str__()
w:     [4, 6, 8]
entering __add__()
entering __len__()
entering __getitem__()
entering __getitem__()
entering __getitem__()
entering __str__()
v + w: [5, 8, 11]
entering __sub__()
entering __len__()
entering __getitem__()
entering __getitem__()
entering __getitem__()
entering __str__()
v - w: [-3, -4, -5]
entering __mul__()
entering __len__()
entering __getitem__()
entering __getitem__()
entering __getitem__()
entering __str__()
v * w: 40.0
```

OBJECT ORIENTED PROGRAMMING (OOP)

- Comparison: operator overload

__lt__(self, v)	return self < v
__le__(self, v)	return self <= v
__eq__(self, v)	return self == v
__ne__(self, v)	return self != v
__gt__(self, v)	return self > v
__ge__(self, v)	return self >= v
__nonzero__(self)	return True or False

OBJECT ORIENTED PROGRAMMING (OOP)

- Emulating numeric types (binary action):
  operator overload

___and___(self, v)	return self & v
___or___(self, v)	return self | v
___xor___(self, v)	return self ^ v
___lshift___(self, v)	return self << v
___rshift___(self, v)	return self >> v

PART 3.1:

File I/O

and

Data processing

EXCEPTION HANDLING

NO ERROR SHOULD HAPPEN WITHOUT PROPER EXCEPTION HANDLING !

EXCEPTION HANDLING

- Built in form

```
x = 1/0

Traceback (most recent call last):
  File "C:\Users\Peter\workspace\Exceptions\src\demo.py", line 10, in <module>
    x = 1/0
ZeroDivisionError: integer division or modulo by zero
```

- Handling the run-time error

```
try:
    x = 1/0
except ZeroDivisionError:
    print("a division by zero occured")
    raise

a division by zero occured
Traceback (most recent call last):
  File "C:\Users\Peter\workspace\Exceptions\src\demo.py", line 11, in <module>
    x = 1/0
ZeroDivisionError: integer division or modulo by zero
```

EXCEPTION HANDLING

- Exception handling

```
try:
    a, b = 1, 0
    x = a / b
except ZeroDivisionError:
    print("a division by zero occured")
    raise
```

- Traditional

```
Import sys

a, b = 1, 0

If b == 0:
    print("a division by zero occured")
    sys.exit()
else:
    x = a / b
```

EXCEPTION HANDLING

- Exception class

```
class MyException(Exception):
    def __init__(self, val):
        self.value = val
    def __str__(self):
        return repr(self.value)

try:
    raise MyException('messed up')
except MyException, e:
    print("Exception triggered:", e.value)
```

```
Exception triggered: messed up
```

EXCEPTION HANDLING

Common application: file I/O

- Create a file object
  - `f = open(filename, mode)`
  - Mode = ‘r’ , ‘w’ , ‘a’ ,’ r+’ , ‘rb’ , ‘wb’
  - Raises an Exception if open fails
- Read from a file object
  - `line = f.readline()`
- Close file object on completion
  - `f.close()`

EXCEPTION HANDLING
COMMON APPLICATION: FILE I/O

```
import sys

try:
    f = open('somefile.txt','r')
except IOError:
    print("could not open file for reading”)
    try:
        print("creating file ... ", end=“”)
        f = open('somefile.txt','w')
        f.write( 'Peter was here ;-)’ )
        f.close()
        f = open('somefile.txt','r')
        print("success”)
    except IOError:
        print("failed”)
        sys.exit()

for line in f:
    print(line)

f.close()
```

1st run (file does not exist)

```
could not open file for reading
creating file ... success
Peter was here ;-)
```

2nd run (file exists)

```
Peter was here ;-)
```

EXCEPTION HANDLING

- General form of the try statement

```
try:
    statement(s)
except Error1:
    handling1
except (Error2, Error3):
    handling2
else:
    handing_the_unknown
    raise
finally:
    execute_after_all_exceptions
    cleanup_statements
```

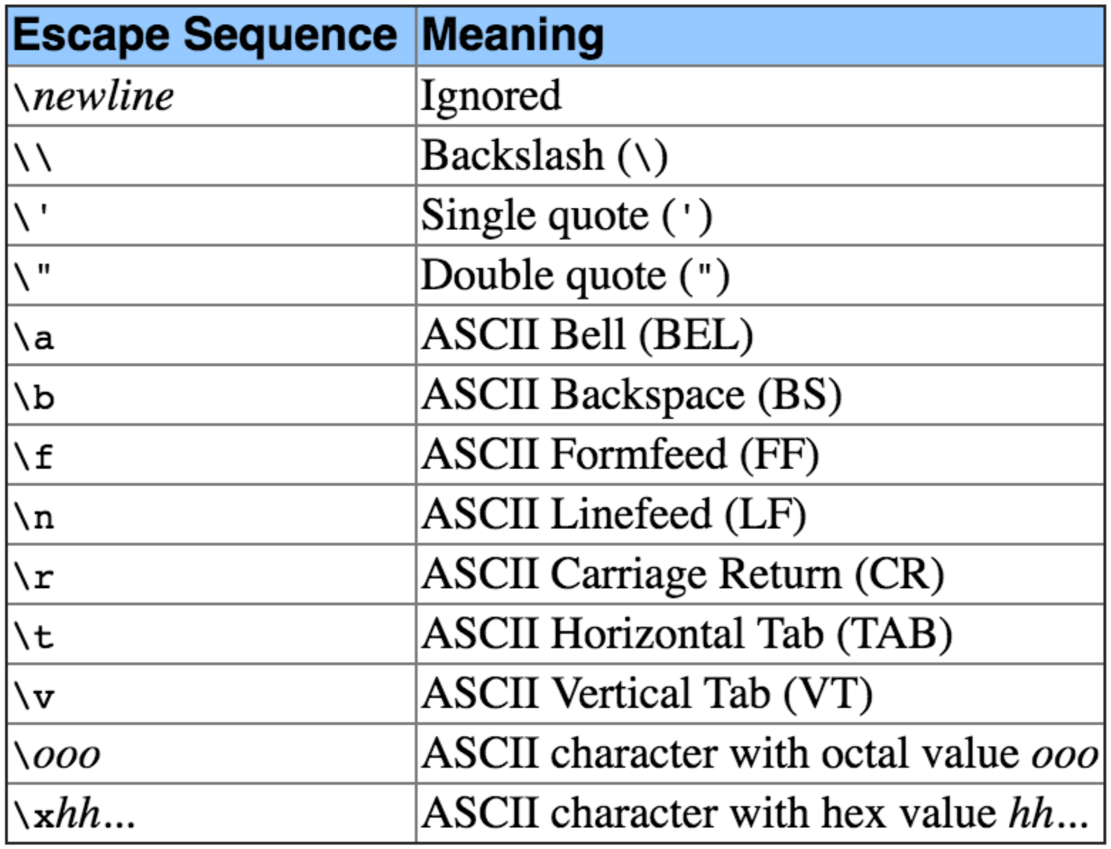
STRING MANIPULATION

- String Methods:
  - https://docs.python.org/3.6/library/stdtypes.html#text-sequence-type-str
  - https://docs.python.org/3.6/library/stdtypes.html#string-methods

- String Services:
  - https://docs.python.org/3.6/library/string.html

PARSING A STRING

- string.split(char)



Escape Sequence	Meaning
\newline	Ignored
`\\`	Backslash (\\)
`\'`	Single quote (')
`\"`	Double quote (")
`\a`	ASCII Bell (BEL)
`\b`	ASCII Backspace (BS)
`\f`	ASCII Formfeed (FF)
`\n`	ASCII Linefeed (LF)
`\r`	ASCII Carriage Return (CR)
`\t`	ASCII Horizontal Tab (TAB)
`\v`	ASCII Vertical Tab (VT)
\ooo	ASCII character with octal value *ooo*
\\x*hh...*	ASCII character with hex value *hh...*

PARSING A STRING

- string.strip()
- string.strip(“”)
- string.rstrip()
- string.lstrip()

- string.find(‘substring’)
- if substring in string: …

- string.replace(‘search string’, ‘replace string’)

ALTERNATIVE TOOLS

- Export excel as CSV (comma separated values)
- csv.py
  - https://docs.python.org/3/library/csv.html
  - Provides parsing and splitting and cleaning in a module

EXERCISE

- Go to Python/Exercises/ParsingFiles
- Write a code that
  1. Open the scores.csv file
  2. Sums up all the values in a line and stores the sum to a list (rowSum.append())
  3. Computes the column sums (colSum)
  4. Closes the file
  5. compute the sum of all rowSums and the sum of all colSums
  6. Show that both sums yield the same result (print)

EXERCISE

1. **Create a text file**
   - (using notepad) that contains at least 3 lines. (name it something like 'MySource.txt')
2. **Create a program that**
   - Opens that text file, reads and print it line per line
   - Opens a file named 'MyCopy.txt' in which it writes every line it reads from your file.
   - Design and implement exception handling for 'cannot open file for reading' and 'cannot open file for writing'.
   - Test your exception handling by triggering these exceptions (remove source file, try placing a copy in the directory where you want to write)

PART 4.1:

Data visualization

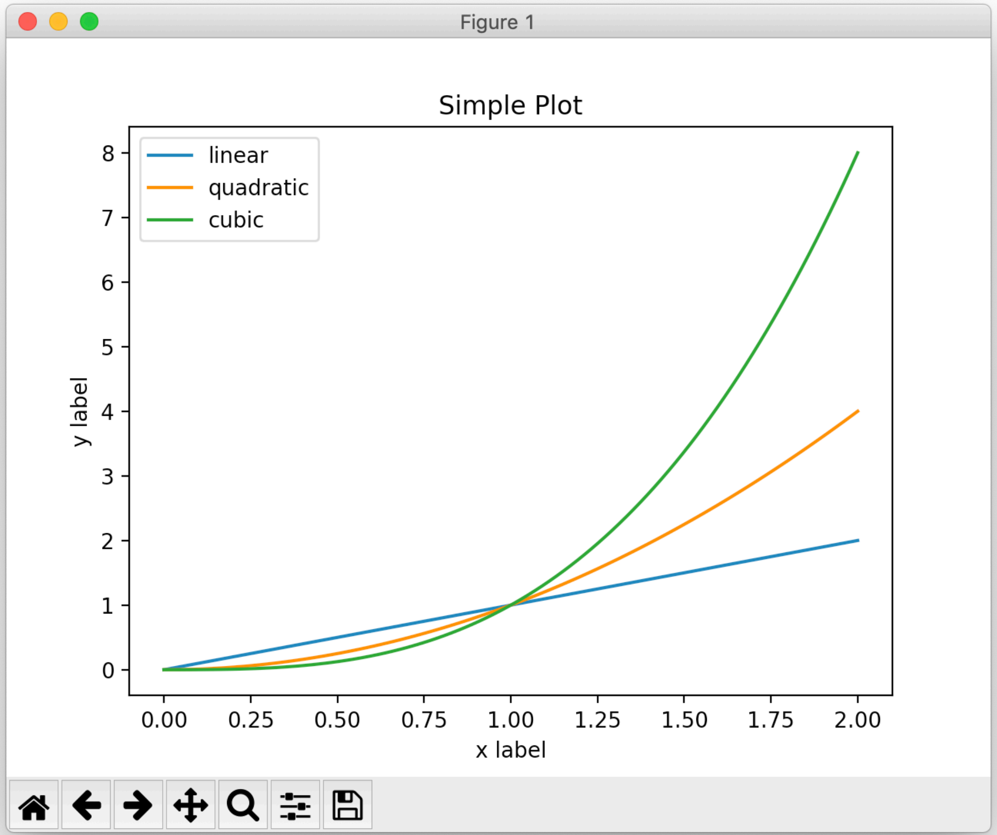
In Python

MATPLOTLIB

- WHAT IS MATPLOTLIB?
  - An OpenSource library for MATLAB-like plotting
  - Provides a simple to use widget – pyplot – that acts like figure() in MATLAB
  - Also provides a large set of functions to customize plotting
  - Integration into GUI (PyQt5)
  - Provides plotting without a display (in memory, direct to file)
- HOW TO GET STARTED?
  - https://matplotlib.org/tutorials/index.html

LINE GRAPHICS

```
import matplotlib.pyplot as plt
import numpy as np

x = np.linspace(0, 2, 100)

plt.plot(x, x, label='linear')
plt.plot(x, x**2, label='quadratic')
plt.plot(x, x**3, label='cubic')

plt.xlabel('x label')
plt.ylabel('y label')

plt.title("Simple Plot")

plt.legend()

plt.show()
```



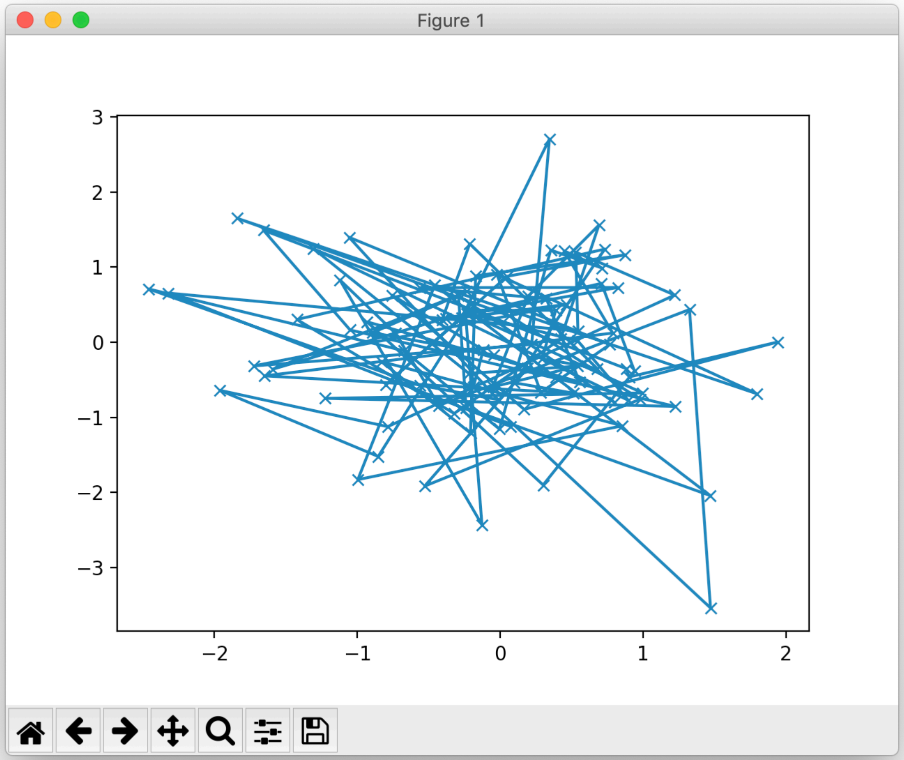
LINE GRAPHICS – SAVING TO FILE

```
import matplotlib.pyplot as plt
import numpy as np

x = np.linspace(0, 2, 100)

plt.plot(x, x, label='linear')
plt.plot(x, x**2, label='quadratic')
plt.plot(x, x**3, label='cubic')

plt.xlabel('x label')
plt.ylabel('y label')

plt.title("Simple Plot")

plt.legend()

plt.show()
```

```
import matplotlib.pyplot as plt
import numpy as np

x = np.linspace(0, 2, 100)

plt.plot(x, x, label='linear')
plt.plot(x, x**2, label='quadratic')
plt.plot(x, x**3, label='cubic')

plt.xlabel('x label')
plt.ylabel('y label')

plt.title("Simple Plot")

plt.legend()

#plt.show()

plt.savefig('ex2.png')
plt.savefig('ex2.jpg')
plt.savefig('ex2.pdf')
plt.savefig('ex2b.png', dpi=300)
```

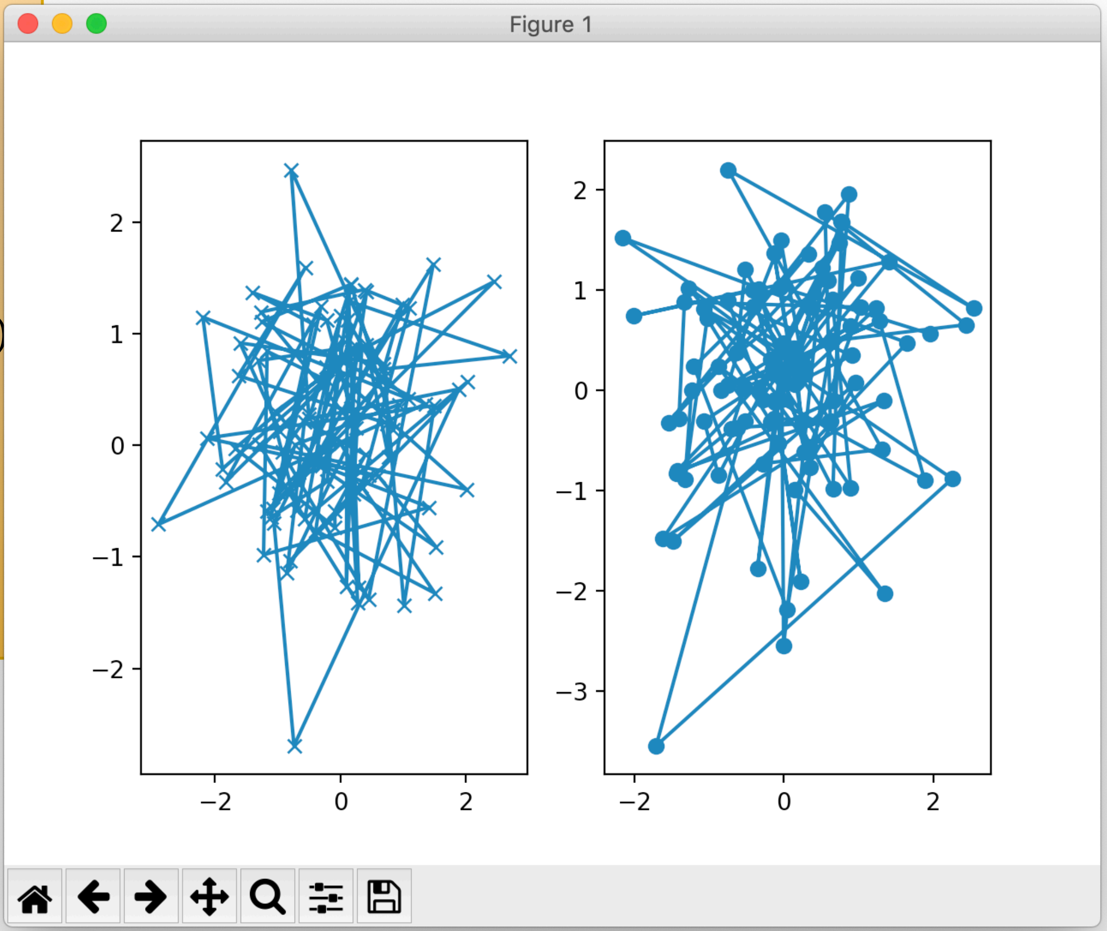
LINE GRAPHICS

```
import numpy as np
import matplotlib.pyplot as plt

def my_plotter(ax, data1, data2, param_dict):
    """
    A helper function to make a graph

    Parameters
        ax : Axes.   The axes to draw to
        data1 : array.   The x data
        data2 : array     The y data
        param_dict : dict      Dictionary of kwargs to pass to ax.plot

    Returns
        out : list       list of artists added
    """
    out = ax.plot(data1, data2, **param_dict)
    return out

# which you would then use as:

data1, data2 = np.random.randn(2, 100)
fig, ax = plt.subplots(1, 1)
my_plotter(ax, data1, data2, {'marker': 'x'})

plt.show()
```



LINE GRAPHICS

```
import numpy as np
import matplotlib.pyplot as plt

def my_plotter(ax, data1, data2, param_dict):
    out = ax.plot(data1, data2, **param_dict)
    return out

# which you would then use as:

data1, data2, data3, data4 = np.random.randn(4, 100)
fig, (ax1, ax2) = plt.subplots(1, 2)
my_plotter(ax1, data1, data2, {'marker': 'x'})
my_plotter(ax2, data3, data4, {'marker': 'o'})

plt.show()
```



PLOTTING W/O DISPLAY – BACKENDS

```
import numpy as np
import matplotlib.pyplot as plt

x = np.linspace(0, 2, 100)

plt.plot(x, x, label='linear')
plt.plot(x, x**2, label='quadratic')
plt.plot(x, x**3, label='cubic')

plt.xlabel('x label')
plt.ylabel('y label')

plt.title("Simple Plot")

plt.legend()

plt.show()
```

```
import matplotlib
matplotlib.use('Agg')
import matplotlib.pyplot as plt

x = np.linspace(0, 2, 100)

plt.plot(x, x, label='linear')
plt.plot(x, x**2, label='quadratic')
plt.plot(x, x**3, label='cubic')

plt.xlabel('x label')
plt.ylabel('y label')
plt.title("Simple Plot")
plt.legend()

ext = 'png'
figname = 'ex5.' + ext
plt.savefig(figname)
```

PART 4.2:

Data visualization

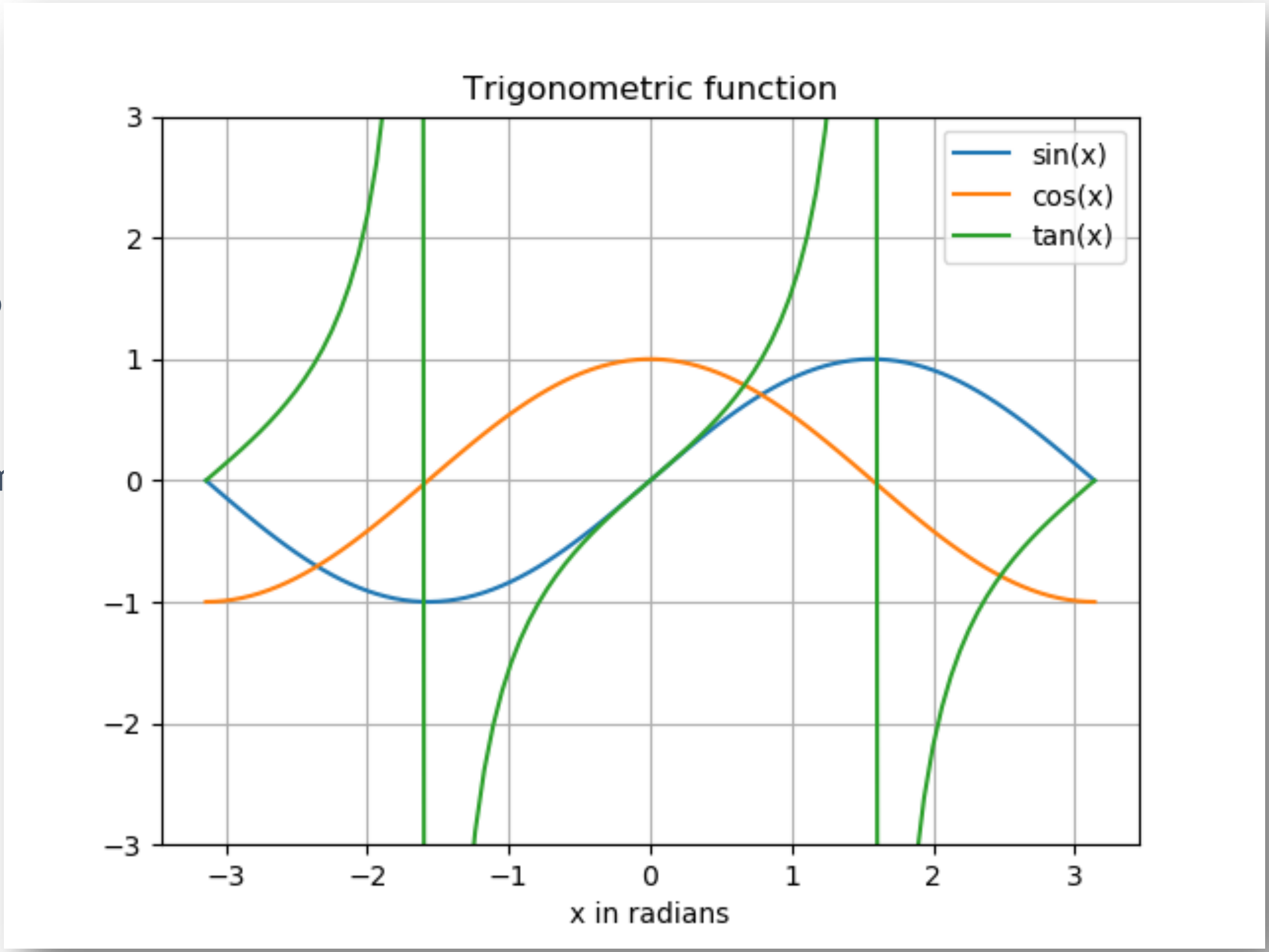
Exercise

EXERCISES

- Create a plot comparing sin(x), cos(x), tan(x) over the interval $-\pi \; \ldots + \pi$
- Make sure to have nice labels and legend
- Save the image to a png file

EXERCISES

- Create a p
- Make sure
- Save the in



PART 5.1:

Subprocesses

and

Interaction with the OS

SUBPROCESS MANAGEMENT

- The subprocess module allows you to spawn new processes, connect to their input/output/error pipes, and obtain their return codes.
- https://docs.python.org/3.6/library/subprocess.html
- https://pymotw.com/2/subprocess/ was helpful

SUBPROCESS – RUN()

```
subprocess.run([‘ls’,’-l’])
```

```
$ python3 list.py
total 8
-rw-r--r--  1 pmackenz  staff  47 Jul 23 15:33 list.py
```

subprocess.run(*args*, *, *stdin*=None, *input*=None, *stdout*=None, *stderr*=None, *shell*=False, *cwd*=None, *timeout*=None, *check*=False, *encoding*=None, *errors*=None, *env*=None)

SUBPROCESS – POPEN()

```
import subprocess

p = subprocess.Popen(['ls', '-l'], stdout=subprocess.PIPE)

res = p.communicate()[0]

s = res.decode(encoding='utf-8', errors='strict')
slist = s.strip().split('\n')

cnt = 0

for item in slist:
    print("{}: {}".format(cnt, item))
    cnt += 1
```

SUBPROCESS – POPEN()

```
import subprocess

p = subprocess.Popen(['greet'], stdin=subprocess.PIPE)

firstname = 'Peter'
lastname  = 'Mackenzie-Helnwein'

answers      = (firstname, lastname)
answerString = "\n".join(answers)
answerBytes  = answerString.encode(encoding='utf-8', errors='strict')

# send answers to STDIN
p.communicate(answerBytes)
```

USEFUL LIBRARIES

- pathlib
  - High-level path manipulation
  - https://docs.python.org/3/library/pathlib.html#module-pathlib
- os.path
  - Help with reading, checking, comparing file paths on various OS’
  - https://docs.python.org/3/library/os.path.html

PART 5.2:

Subprocess

Exercise

EXERCISE

- Create a python script that executes 'cat example.py'