Data 301 Data Analytics
Python for Data Analytics

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Intoduction

*R*ecall:

- A Python *module* or *library* is code written by others for a specific purpose.
- Whenever coding, make sure to look for modules that are already written for you to make your development faster!
- Modules are imported using the import command:

```
import <modulename>
```

Useful Python Modules

- Today we be discuss some useful Python modules for data analytics:
  - NumPy (http://www.numpy.org/) - N-dimensional arrays, integrating C/C++ and Fortran code, linear algebra, Fourier transform, and random numbers
  - SciPy (http://www.scipy.org/) - numerical integration and optimization
  - pandas (http://pandas.pydata.org/) - data structures, reading/writing data, data merging/joining/slicing/grouping, time series
  - `scikit-learn` (https://scikit-learn.org/stable/) - machine learning (built on NumPy, SciPy, and matplotlib)

Charts

In addition, we will also explore a useful module for creating visualizations in Python.

- matplotlib http://matplotlib.org/ - foundational 2D plotting

N.B. here are numerous graphing and chart libraries:

- ggplot http://ggplot.yhathq.com/ - based on R's ggplot2
- pygal http://pygal.org/en/stable/ - dynamic chart library
- Bokeh http://bokeh.pydata.org/ - goal is to produce charts similar to D3.js for browsers
- Seaborn http://stanford.edu/ mwaskom/software/seaborn/ - based on matplotlib and designed for statistical graphics
- NVD3 https://github.com/areski/python-nvd3

SciPy

- SciPy (pronounced “Sigh Pie") is group of Python libraries for scientific computing.
- SciPy includes functions for some advanced math problems as listed on this slide, as well as data visualization.
- Using data visualization methods is the best way to communicate with others. Showing them meaningful results of analysis. These libraries enable you to create graphs, charts and maps.

matplotlib

- matplotlib is the most widely used plotting library in Python.
- N.B. to have plots appear in Jupyter Notebook will use the command:

  ```
  %matplotlib inline
  ```

  (if you are not using Jupyter notebook, you don't need this)

pyplot

- matplotlib.pyplot is a commonly used sub-library.
- It is standard practice to shorten matplotlib.pyplot to plt:

```
import matplotlib.pyplot as plt
```

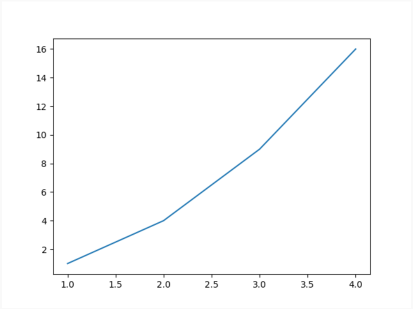
  This will save us some typing (eg. we can type plt.bar) instead of matplotlib.pyplot.bar)
- See a helpful pyplot tutorial

dotted module names

Packages are a way of structuring Python's module namespace by using *dotted module names*. For example, the module name A.B designates a submodule named B in a package named A.

As a very simple first example (from pyplot tutorial), lets create a line chart:

```
# x-values = 1,2,3,4
# y-values = 1,4,9,16
plt.plot([1, 2, 3, 4], [1, 4, 9, 16])
# plot wont be shown until we call:
plt.show()
```



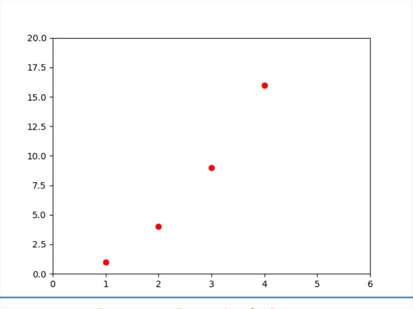
We can change the plot from lines - to points o and from blue (b) to red (r).

```
plt.plot([1, 2, 3, 4], [1, 4, 9, 16], 'ro')
```

Additionally we can change the axis ranges:

```
# x-axis from 0--6, y-axis from 0--20
plt.axis([0, 6, 0, 20])
plt.show()
```

See here for more plotting options.



`numpy`

- In `matplotlib` were limited to working with lists.
- To get over this limitation, we will generally also import the `numpy` module (pronounced *num-pie*) to make use of `numpy` `arrays`.
- These arrays can be used for both input and output objects and perform fast array calculations.
- Common practice is to shorten this module name to `np` using `import numpy as np`
- See a helpful numpy tutorial

numpy arrays

A **numpy array** is a grid of values, all of the same type, and is indexed by a tuple of nonnegative integers.

rank The number of dimensions is the rank of the array

shape the shape of an array is a tuple of integers giving the size of the array along each dimension.

Consider the following examples taken from the pyplot tutorial

```
# Create a rank 1 array
>>> a = np.array([1, 2, 3])
>>> a[0] = 5   # Change an element of the array
>>> print(a.shape) # Prints "(3,)"
>>> a
array([5, 2, 3])
```

numpy arrays

Create a rank 2 array using Python nested lists, and access elements using square brackets:

```
>>> b = np.array([[1,2,3],[4,5,6]])
>>> print(b.shape)  # Prints "(2, 3)"
>>> b
array([[1, 2, 3],
       [4, 5, 6]])
# extract element in row 1 (index 1) and column 3 (index 2)
>>> b[1,2]
6
>>> b[(1,2)] # can also index using a tuple
6
# more examples:
>>> print(b[0,2],b[1,0])
3 4
```

numpy arrays indexing

Similar to Python lists, numpy arrays can be sliced. Since arrays may be multidimensional, you must specify a slice for each dimension of the array:

```
>>> b
array([[1, 2, 3],
       [4, 5, 6]])
>>> # first row:
>>> b[0, :]
array([1, 2, 3])
>>> # second column
>>> b[:,1]
array([2, 5])
>>> # first 2 rows and columns 1 and 2
b[:2, 1:3]
```

numpy arrays

np.arrange return evenly spaced values within a given interval. Eg, evenly sampled points between 0 and 5 at 0.2 intervals

```
>>> t = np.arange(0, 1, 0.2)
# array([0. , 0.2, 0.4, 0.6, 0.8])
```

General usage: `np.arrange(start,stop,step)`.

- as before `start` and `step` defaults to 0 and 1, resp.

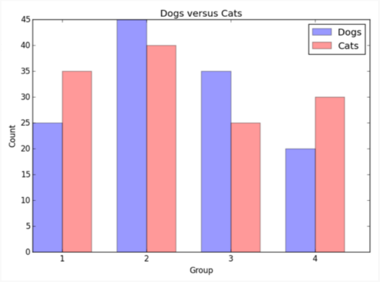
There are a number of other methods for array creation as well:

```
>>> a = np.zeros((2,2))   # Create a 2x2 array of  zeros
>>> b = np.ones((1,2))    # Create a 1x2 array of  ones
>>> c = np.full((2,2), 7) # Creates 2x2 a  array of 7s
```

matplotlib - Bar Chart Example

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

# number of dogs/group
data1 = [25,45,35,20]
# number of cats/group
data2 = [35,40,25,30]
index = np.arange(len(data1))
bar_width = 0.35
opacity = 0.4
# cont'd on next slide
```



```
>>> # to create arrays for rect position
>>> index = np.arange(len(data1))
>>> index
array([0, 1, 2, 3])
```

matplotlib - Bar Chart Example

```
# continued from previous slide
rects1 = plt.bar(index, data1, bar_width, alpha=opacity,
                 color='b', label='Dogs')
rects2 = plt.bar(index + bar_width, data2, bar_width,
                 alpha=opacity, color='r', label='Cats')
plt.xlabel('Group')
plt.ylabel('Count')
plt.title('Dogs versus Cats')
plt.xticks(index + bar_width, ('1', '2', '3', '4'))
plt.legend()
plt.tight_layout() # to remove whitespace
plt.show()
```

N.B.:

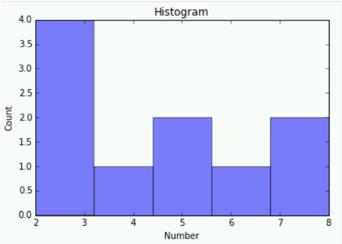
```
>>> index + bar_width
array([0.35, 1.35, 2.35, 3.35])
```

Some comments

- Python starts plotting everything in the background and wont display the graph until `plot.show()` is called.
- matplotlib colours are given here
  - eg. `r` for red `c` for cyan `k` for black
  - you can also use full names (`'green'`), hex strings (`'#008000'`), or RGB/RGBA tuples (`(0,1,0,1)`).
- The `label` argument will be used when we call `plt.legend()`
  - the colours, and labels will be generated automatically (using the `plt.x/ylabel`)

matplotlib - Histograms

Python histograms



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

num_bins = 5
x = [5,3,8,5,2,7,2,4,6,2]
# saves output to variables
# (eg of tuple unpacking!)
n, bins, patches = plt.hist(x, num_bins,
          density=False, facecolor='blue', alpha=0.5)

plt.xlabel('Number')
plt.ylabel('Count')
plt.title('Histogram')
plt.show()
```

matplotlib - Histograms comments

`bins` partition our range of values into a subsets

Histograms count the number of observations falling into each bin

n: is the number of counts in each bin of the histogram

bins: is the left hand edge of each bin, example:

```
>>> bins
array([2. , 3.2, 4.4, 5.6, 6.8, 8. ])
```

patches: is the individual patches used to create the histogram, e.g a collection of rectangles:

```
>>> print(patches[1])
Rectangle(xy=(3.2, 0), width=1.2, height=1, angle=0)
```

`density` is a logical object that is False (or 0) if you want the y-axis to be in terms of counts, and True (or 1) when plotting the probability densities

SciPy stats

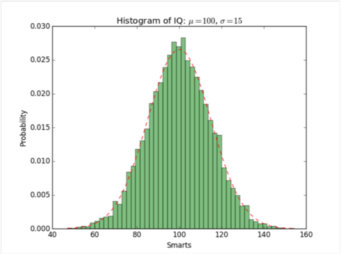
- Another helpful module is `scipy.stats`
- This module contains a large number of probability distributions as well as a growing library of statistical functions.
- We will use the `norm.pdf` compare the probability density function (pdf) or a normal distribution with random data generated from a normal distribution.
  - The normal distribution is a bell shaped distribution with a mean (i.e. center) given my μ (or `mu` in the code) and a standard deviation of σ (or `sigma` in the code).
  - We generate random normal data using the numpy.random.randn function (which return samples from the "standard normal"[1] distribution).
- N.B. we use TeX markup in the title eg. `$\mu$` appears μ

[1]Normal distribution with a μ=0, $\sigma = 1$

matplotlib - Histogram Example (2)

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

mu = 100
sigma = 15
x = mu+sigma*np.random.randn(10000)
num_bins = 50
n, bins, patches = plt.hist(x, num_bins, edgecolor="k",
                            density=1, facecolor='green', alpha=0.5)
y = scipy.stats.norm.pdf(bins, mu, sigma)
plt.plot(bins, y, 'r--')
plt.xlabel('Smarts')
plt.ylabel('Probability')
plt.title(r'Histogram of IQ: $\mu=100$, $\sigma=15$')
plt.subplots_adjust(left=0.15)
plt.show()
```



Exercise

1. How does your plot change when you update the number of bins from the previous example from `50` to `10`.
2. How does your plot change when you delete the `edgecolor = "k"`? (remember `k` stands for black)
3. How does your plot change when you set `density` to False?
4. How does your plot change when you set the `facecolor` to `'g'`?
5. How does your plot change when you set `alpha` to `0.1`?

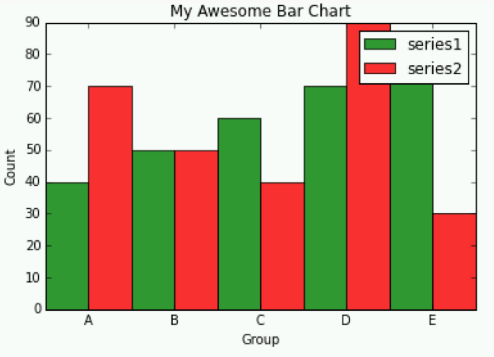
Try in Charts

Example 16

Write a program to create a bar chart for this data:

```
series1 = [40, 50, 60, 70, 80]
series2 = [70, 50, 40, 90, 30]
```

Output:



SciPy stats

- In addition the `scipy.stats` module has the `linregress` function for performing linear regression.
- The gerenal syntax is:

```
scipy.stats.linregress(x, y)
```

- The above calculate a linear least-squares regression for two sets of measurements: the explanatory variable `x` and the response variable `y`.

SciPy Linear Regression Example

```
from scipy import stats
import numpy as np
import matplotlib.pyplot as plt
x = np.array([5, 7, 9, 11, 13, 15])
y = np.array([11, 14, 20, 24, 29, 31])
slope, intercept, r_value, p_value,
... slope_std_error = stats.linregress(x, y)
```

Save the resulting tuple to variables that we can use later,. . .

SciPy Linear Regression Example

Find the residuals, (observed y values minus the predicted y values produced by our fitted model):

```
predict_y = intercept + slope * x
print("Predicted y-values:",predict_y)
pred_error = y - predict_y
print("Prediction error:",pred_error)
```

Compute the residual standard error (a measure of prediction error)

```
degr_freedom = len(x) - 2
residual_std_error = np.sqrt(np.sum(pred_error**2)/degr_freedom)
print("Residual error:",residual_std_error)
```

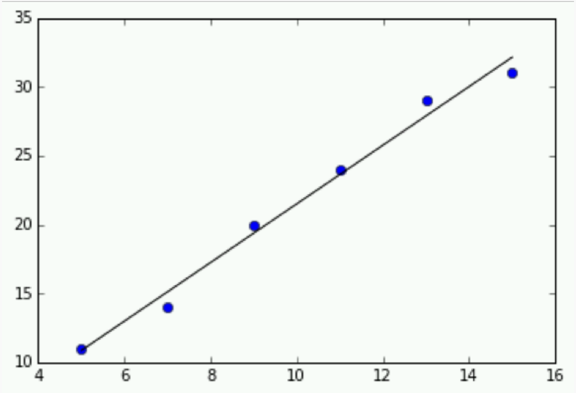
Output:

```
Predicted y-values: [10.85714286 15.11428571 ....
Prediction error: [ 0.14285714 -1.11428571  0.62857143  ...
Residual error: 1.041976144503454
```

SciPy Linear Regression Example

Plot the raw data with the fitted regression line:

```
plt.plot(x, y, 'o') # o for points
plt.plot(x, predict_y, 'k-') # - for line, k for black
plt.show()
```



SciPy - K-means Clustering

Scipy also provides routines for conducting *k*-means clustering and vector quantization.

The input of k-means algorithm:

- **k** the number of clusters to generate
- **x** the set of observations to cluster

The output of k-means algorithm:

- a set of centroids, one for each of the k clusters.
- a classification vector: an observation is assigned to the cluster whose centroid is closest to it.

SciPy - K-means Clustering

```
from numpy import vstack,array
from numpy.random import rand
from scipy.cluster.vq import kmeans,vq

# creates a 300x2 array of data
data = vstack((rand(150,2) + array([.5,.5]),rand(150,2)))
# computing K-Means with K = 2 (2 clusters)
centroids,_ = kmeans(data,2)
# assign each sample to a cluster
idx,_ = vq(data,centroids)
```

Some comments

`rand(150,2)` generates an np.array with 150 rows and 2 columns with random numbers from the interval $[0,1)$ more here

Alternatively, we could have used a loop and See `numpy.asarray`

```
import random as rnd
import numpy as np
data = []
for i in range(0,100):
    data.append([rnd.random(), rnd.random()])

# need to convert to array for kmeans
data = np.asarray(data)
# looks like:
# array([[0.78056987, 0.62426341],
       [0.96726103, 0.9859364 ],
       [1.35816411, 1.4966473 ],
       ....
```

Some comments

`vstack` stack arrays in sequence vertically (row wise).

```
>>> a = np.array([1, 2, 3])
>>> b = np.array([[2, 3, 4], [5,6,7]])
>>> np.vstack((a,b))
array([[1, 2, 3],
       [2, 3, 4],
       [5, 6, 7]])
```

Tip:

When you import a function named `myfunction` from a module named `mymodule` *via* `import mymodule` you need to use the dot notation, i.e. `mymodule.myfunction` to use it. If you import the function *via* `from mymodule import myfunction`, you can access the function by calling it directly, i.e `myfunction`

Some comments

The notation `,_` means we'll be taking the first element of the tuple outputed from kmeans() (i.e. the $k \times N$ centroid array) and ignore the second argument.

```
# a simple example (2 gets thrown away)
>>> A,_ = [1,2] # A = 1
>>>  _,B = [1,2] # B=2
>>> A,_,_ = [1,2,3] # A = 1
```

Alternatively, we may think of this notation as doing the following:

```
>>> km = kmeans(data,2)
>>> type(km)
<class 'tuple'>
>>> centroids = km[0]
>>> centroids
array([[0.45706156, 0.53454601],
       [1.00664659, 1.02451566]])
```

SciPy - K means Clustering (2)

```
>>> # Move data into individual lists based on clustering
... clusters = []
>>> for i in range(0, numclusters):
...     clusters.append([[],[]])
...
>>> clusters
[[[], []], [[], []]]
```

Creates a nested Pyhon list. First element is of `clusters` contains the data points from members assigned to group 0, the second elements contains the data pairs assigned to group 1.

```
# run after the code from the next slide:
clusters[0][0] # x values from cluster 0 (blue)
clusters[0][1] # y values from cluster 0 (blue)
clusters[1][0] # x values from cluster 1 (red)
clusters[1][1] # y values from cluster 1 (red)
```

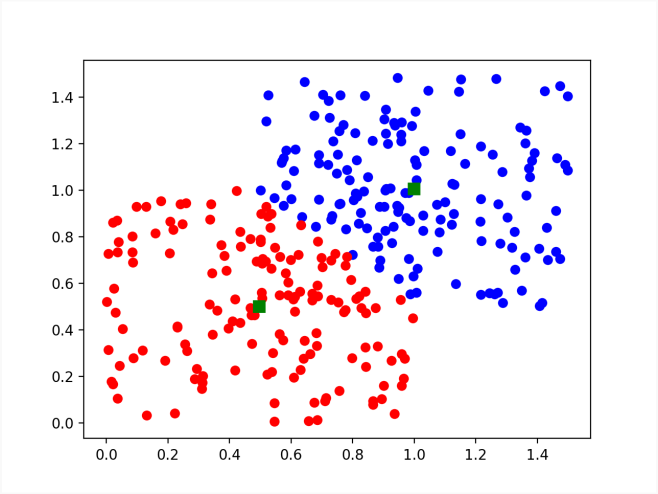
SciPy - K means Clustering (3)

```
for i in range(0,len(idx)):
    clusterIdx = idx[i]
    # saving the x values for cluster = clusterIdx
    clusters[clusterIdx][0].append(data[i][0])
    # saving the y values for cluster = clusterIdx
    clusters[clusterIdx][1].append(data[i][1])

# Plot data points and cluster centroids
# 'ob' for blue points (group index 0)
# 'or' for red points (group index 1)
plt.plot(clusters[0][0],clusters[0][1],'ob',
             clusters[1][0],clusters[1][1],'or')
# centroids[:,0] = first column for centroid of group 0
# centroids[:,1] = second column for centroid of group 1
plt.plot(centroids[:,0],centroids[:,1],'sg',markersize=8)
plt.show()
```

SciPy - K means Clustering

The plot argument `ob`/`or` stands for blue and red circle markers, resp. See more on plot formatting here.

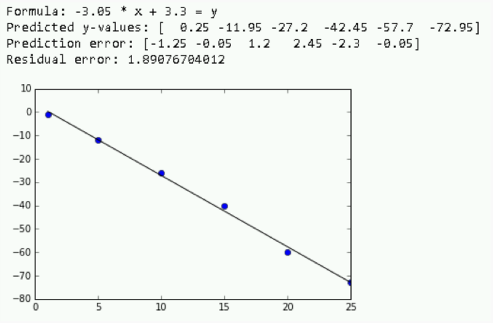


Example 17

Write a program that uses SciPy to perform a linear regression on this data set:

```
x = [1, 5, 10, 15, 20, 25]
y = [-1, -12, -26, -40, -60, -73]
```

Output:



```
Formula: -3.05 * x + 3.3 = y
Predicted y-values: [  0.25 -11.95 -27.2  -42.45 -57.7  -72.95]
Prediction error: [-1.25 -0.05  1.2   2.45 -2.3  -0.05]
Residual error: 1.89076704012
```

scikit-learn and BeautifulSoup

scikit-learn (`http://scikit-learn.org/`) is a machine learning library for Python.
Features:

- classification
- regression
- clustering
- dimensionality reduction

BeautifulSoup (`http://www.crummy.com/software/BeautifulSoup/`) is a library to make it easy to search, navigate, and extract data from HTML and XML documents.

Python - Databases

- MySQL is a popular open source relational database management system.
- We can access this data via Python using the `mysql.connector` module. See the developer guide and W3schools tutorial for more details
  - notes on connecting
  - notes on creating tables
  - notes on querying
- Note that this code will require that we are on UBC secure wifi (off campus we must connect with VPN).

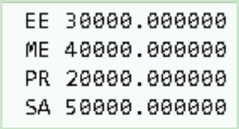
Try it - Databases

Example 18

Write a program that queries the WorksOn database and returns the employees grouped by title where the employee name is after `'J'`. The output should display their title and the average salary for that title. Connection info:

```
cnx = mysql.connector.connect(user='data301',
password='ubc', host='cosc304.ok.ubc.ca',
database='WorksOn')
```

Output:



```
EE 30000.000000
ME 40000.000000
PR 20000.000000
SA 50000.000000
```

answer

```
import mysql.connector
try:
    cnx=mysql.connector.connect(user='data301', password='ubc',
    host='cosc304.ok.ubc.ca',database='WorksOn')
    cursor = cnx.cursor()
    query = ("SELECT title, AVG(salary) as avgSalary
    FROM emp WHERE ename >= 'J' GROUP BY title")
    cursor.execute(query)
    for (title, avgSalary) in cursor:
        print(title, avgSalary)
    cursor.close()
except mysql.connector.Error as err:
    print(err)
finally:
    cnx.close()
```

MapReduce

Map-Reduce is a technique for processing large data sets in a functional manner. See the Wikipedia article

The technique was invented by Google and is implemented in a variety of systems including Python, NoSQL databases, and a Big Data system called Hadoop.

In Hadoop, map takes as input key-value pairs and outputs key-value pairs. The shuffle step will move pairs to particular machines based on keys. The reduce step takes a list of key-value pairs (with same key) and reduces to one value.

It is possible to code map/reduce functions in Python for use in Hadoop cluster.

MapReduce

Simpler version of Map-Reduce in Python without a cluster:

Map function takes as input a list and a function then applies function to each element of the list to produce a new list as output

Filter function only keeps list elements where filter function is True

Reduce function takes result of map/filter and produces single value from list

N.B. The reduce function has been moved to the `functools` module for Python3 with creator noting "*99% of the time an explicit for loop is more readable*"

`map`

General usage: `map(function_to_apply, list_of_inputs)`

Data: $a_1, a_2, \dots, a_n$ (could be elements in a tuple or a list)
Function: $f(x)$

Calling `map(`$f(x)$, Data`)` would return

$$f(a_1), f(a_2), \dots f(a_n)$$

`filter`

General usage: `filter(function_to_apply, list_of_inputs)`

Data: $a_1, a_2, \ldots, a_n$ (could be elements in a tuple or a list)
Function: $f(x)$ (this function should return `True` or `False`

Calling `map(`$f(x)$`, Data)` would return:

all a_is for which $f(a_i)$ returns True

`reduce`

General usage: `reduce(function_to_apply, list_of_inputs)`

Data: $a_1, a_2, \ldots, a_n$ (could be elements in a tuple or a list)
Function: $f(x, y)$

Calling `reduce(`$f(x, y)$, Data`)` would perform:

Step 1: $val_1 = f(a_1, a_2)$

Step 2: $val_2 = f(val_1, a_3)$

Step 3: $val_3 = f(val_2, a_4)$

$\ldots$

Step n-1 $val_{n-1} = f(val_{n-2}, a_n)$

and return: val_{n-1}

Python - MapReduce Example

```
import functools     # For Reduce

data = [1, 2, 3, 4, 5, 6]

def triple(x):  # function to be used with map
    return x*3

def myfilter(x): # function to be used with filter
    if x % 2 == 0:
        return True
    return False

def sum(x, y):      # function to be used with reduce
    return x+y
```

Python - `map` Example

```
>>> result = list(map(triple, data))
>>> print("Result after map:",result)
Result after map: [3, 6, 9, 12, 15, 18]
```

To see this using a for loop:

```
>>> items = [1, 2, 3, 4, 5, 6]
>>> output = []
>>> for i in items:
...     val = triple(i)
...     output.append(val)
...
>>> print(output)
[3, 6, 9, 12, 15, 18]
```

Python - `filter` Example

```
>>> result = list(filter(myfilter, result))
>>> print("Result after filter:",result)
Result after filter: [6, 12, 18]
```

Alternatively using a for loop:

```
>>> items = [3, 6, 9, 12, 15, 18]
>>> output = []
>>> for i in items:
...     val = myfilter(i)
...     if val:
...         output.append(i)
...
>>> print(output) # returns all the even numbers
[6, 12, 18]
```

Python - `reduce` Example

```
>>> result = functools.reduce(sum, result)
>>> print("Result after reduce:",result)
Result after reduce: 36
```

To see this using a loop:

```
>>> items = [6, 12, 18]
>>> val = items[0]
>>> item2 = items[1:]
>>> for a in item2:
...     val = sum(val,a)
...
>>> print(val)
36
```

- Notice that when using `map`, the items in the result are values returned by the function `triple`.
- In contrast, the values returned by `myfilter` in `filter(f, ...)` are not outputted results themselves, but rather an index of the values that returned `True`.
- The values returned by the `reduce` function returns a *single* result.

Try It - MapReduce

Example 19

Write a map-reduce program that during the map step will subtract 2 from each element. The reduce step should return the product of all the elements in the list.

Pandas

- `Pandas` is a very popular Python library for data analysis.
- The library provides “high-performance, easy-to-use data analysis tools for the Python programming language” [Source: pandas.pydata.org]
- By importing this module, you can create *data frame* which are two dimensional tables consisting of column and row labels (like a spreadsheet).
- It is designed to provided easy indexing functionality.

Installing pandas

- The easiest way to install pandas is to use the Anaconda distribution.
- With Anaconda you can install pandas and any dependencies by typing the following in Terminal/Command Prompt:

```
$ conda install pandas
```

- Check to see if you have installed pandas properly in Python:

```
>>> import pandas
>>> pandas.__version__
'0.24.2'
```

- Read more on pandas install using other methods here.

- At the core of pandas are three data structures:

Conclusion

Python has many libraries to help with data analysis tasks:

- reading and write to files
- csv module for processing CSV files
- Biopython for bioinformatics
- numerous chart libraries including matplotlib and ggplot
- SciPy - collection of libraries for scientific computing
- libraries for web access and parsing (BeautifulSoup)
- database access libraries and connectors

The `try-except statement` is used to handle exceptions so that the program may continue when an error condition occurs.

Objectives

- Open, read, write, and close text files
- Process CSV files including using the csv module
- Define: IPv4/IPv6 address, domain, domain name, URL
- Read URLs using urllib.request.
- Define: exception, exception handling
- Use try-except statement to handle exceptions and understand how each of try, except, else, finally blocks are used
- Import Python modules
- Use Biopython module to retrieve NCBI data and perform BLAST
- Build charts using matplotlib
- Perform linear regression and k-means clustering using SciPy
- Connect to and query the MySQL database using Python
- Write simple Map-Reduce programs