CS135
Introduction to Machine Learning

Lecture 1: Python Programming for ML

Overview:

- ❑ Python Installation
- ❑ Python Basics
- ❑ Advanced Data Type
- ❑ Functions
- ❑ Control Flow
- ❑ Modules
- ❑ Classes and Objects (Supplemental)

Python

- Open source **general-purpose** language.
- Object Oriented, Procedural, Functional
- Powerful library of Modules
- Great interactive environment

- Downloads: https://www.anaconda.com/download/#macos
- Documentation: https://docs.python.org/3/
- Pep8 Style Guidelines: https://www.python.org/dev/peps/pep-0008/
  - Hitchhiker's Guide: http://docs.python-guide.org/en/latest/writing/style/
- The Hitchhiker's Guide to Python: http://docs.python-guide.org/en/latest/

Batteries Included

- Advanced data structures (lists, dictionaries) part of language
- Numerical, math, statistics
  - `numpy, scipy`: matlab-like functionality
  - `pandas`: R-like data frames
  - `matplotlib`: beautiful plots
- File and directory access
- Data compression and archiving
- Cryptography
- Multithreading, OS
- Networking/Internet/WWW protocols
- Multimedia
- Optimization
- …

Python Installation

- Anaconda Installation
  https://docs.anaconda.com/anaconda/install/

Silent mode install

You can use silent mode to automatically accept default settings and have no screen prompts appear during installation.

Installing Anaconda on a non-networked machine

1. Obtain a local copy of the appropriate Anaconda installer for the non-networked machine. You can copy the Anaconda installer to the target machine using many different methods including, but not limited to, a portable hard drive, USB drive or CD.

2. After copying the installer to the non-networked machine, follow the installation instructions for your operating system.

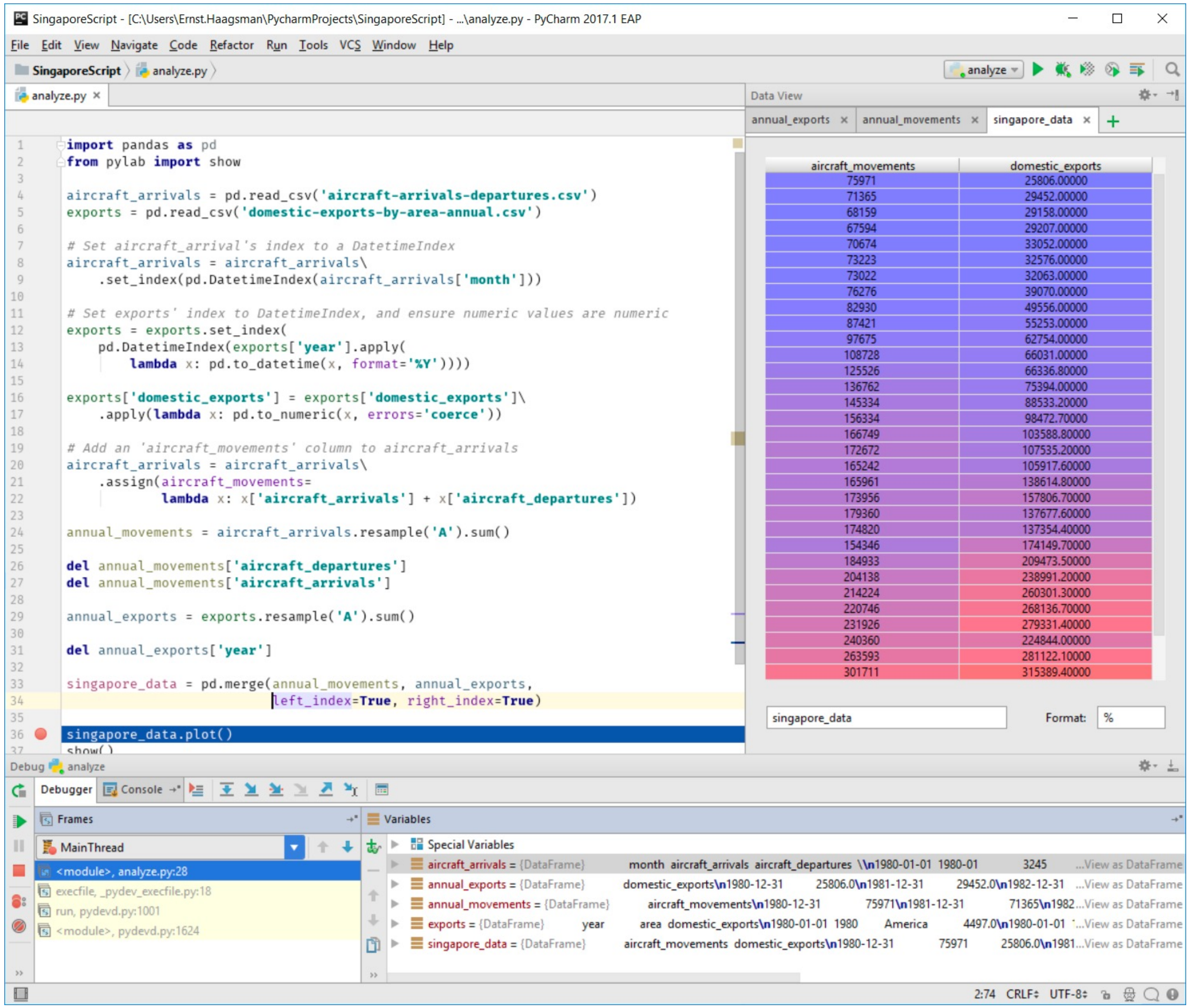
Detailed installation information

For installation instructions, see the following:

- Installing on Windows
- Installing on macOS
- Installing on Linux
- Installing on Linux POWER8
- Verifying your installation
- Anaconda installer file hashes
- Updating from older versions
- Uninstalling Anaconda

Python IDE

- [PyCharm]



Running Python: The Python Interpreter

```
$python
Python 2.7.10 (default, Jul 14 2015, 19:46:27)
[GCC 4.2.1 Compatible Apple LLVM 6.0 (clang-600.0.39)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> 3*(7+2)
27
>>> CTRL-D                            # to exit
>>> CTRL-Z                           # to exit (Windows)
```

Executing Python programs

- Write a program in pycharm
  - Save it with a .py file extension

- To execute:
  - From the command line type

    ```
    python <filename>.py
    ```
  - Press ‘Run’ in PyCharm
  - Press ‘Debug’ in PyCharm (debug mode)

Tufts

A Simple Example

```
x = 34 - 23          # A comment.
y = "Hello"          # Another one.
z = 3.45
if z == 3.45 or y == "Hello":
      x = x + 1
      y = y + " World"     # String concat.
print(x)
print(y)
```

Output:

```
12
Hello World
```


Tufts

Enough to Understand the Code

- Assignment uses **=** and comparison uses **==**.

- For numbers `+ - * / %` are as expected.
  - Special use of + for string concatenation.
  - Special use of % for string formatting (as with printf in C)

- Logical operators are words (`and`, `or`, `not`) **not** symbols

- The basic printing command is `print()`.

- The first assignment to a variable **creates it**.
  - Variable types **do not** need to be declared.
  - Python figures out the variable types on its own.

Basic Datatypes

- **Integers (default for numbers)**

```
z = 5 / 2          # Answer is 2, integer division.
```

- **Floats**

```
x = 3.456
```

- **Strings**
  - Can use " " or ' ' to specify.

    ```
    "abc" 'abc'                             #Same thing
    ```

  - Unmatched can occur within the string.

    ```
    "matt's"
    ```

  - Use triple double-quotes for multi-line strings or strings than contain both ' and " inside of them:

    ```
    """a'b"c"""
    ```


Tufts

Whitespace

Whitespace is meaningful in Python!!!!!: especially indentation and placement of newlines

- Use a newline to end a line of code.
  - Use \ when must go to next line prematurely.

- **No** braces **{ }** to mark blocks of code in Python… Use consistent indentation instead.
  - The first line with *less* indentation is outside of the block.
  - The first line with *more* indentation starts a nested block.

- Often a colon **:** appears at the start of a new block. (e.g., for if statements, function and class definitions.)

Comments

- Start comments with # – the rest of line is ignored.
- Can include a """documentation string""" as the first line of any new function or class that you define.
- The development environment, debugger, and other tools like help() use it: it's good style to include one.

```
def my_function(x, y):
    """This is the docstring. This function
    does blah blah blah."""
    # The code would go here...
```


Tufts

Assignment Statements

```
>>> a = 1                    #int
>>> b = 1.5                  #float
>>> c = 'banana'             #str
>>> d = "apple"              #"…" same as '…'
>>> print(a,b,c,d)
1 1.5 banana apple
>>> e = (a >= b)             #Boolean expression
>>> print(e)
False
```


Tufts

Accessing Non-Existent Names

If you try to access a name before it's been properly created (by placing it on the left side of an assignment), you'll get an error.

```
>>> y
NameError: name 'y' is not defined
>>> y = 3
>>> y
3
```

Multiple Simultaneous Assigments

```
>>> x, y = 2, 3
>>> x
2
>>> y
3
```

Naming Rules

- Names are case sensitive and cannot start with a number. They can contain letters, numbers, and underscores.

```
bob Bob _bob _2_bob_ bob_2 BoB
```

- Reserved words:

```
and, assert, break, class, continue, def, del, elif, else,
except, exec, finally, for, from, global, if, import, in,
is, lambda, not, or, pass, print, raise, return, try, while
```


Tufts

Basic Operators

- Binary ops on numbers

```
>>> a = 1
>>> b = 1.5
>>> print(a+b, a-b, a/b, a*b, 2**b)
2.5 -0.5 0.666666666667 1.5 2.8284271247461903
>>> print(5/2, 1.*5/2,  5%2 , 5.1//2)
2 2.5 1 2.0
```

- Some overloaded to work on strings

```
>>> 'banana'+'_'+'apple'      #concatenation
'banana_apple'
>>> 4*('appricot'+' ')        #replication
'appricot appricot appricot appricot '
```

Casting

```
>>> a = '1.5'
>>> b = float(a)+2                          #cast as number
>>> print('Bank Balance: $' + str(b))          #cast as str
Bank Balance: $3.5

>>> print(eval('1+2*(1/3.0)’))
                    #evaluate string as python expression
1.66666666667
```


Tufts

Print to console

```
>>> b = 3
>>> print(f'Bank Balance: ${b}')        #f str
Bank Balance: $3

>>> print('Bank Balance: ${}'.format(b))  #format str
Bank Balance: $3

>>> print('Bank Balance: $' + b)       #concat str
Bank Balance: $3
```

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- ❑ **Advanced Data Types**
- ❑ Functions
- ❑ Control Flow
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Sequence Types (a.k.a. Collections, Containters)

1. **Tuple**
   - A simple *immutable* ordered sequence of items
   - items can be of mixed types, including collections
2. **String**
   - *Immutable*
   - Conceptually very much like a tuple
3. **List**
   - *Mutable* ordered sequence of items of mixed types

Similar Syntax

- **All three sequence types (tuples, strings, and lists) share much of the same syntax and functionality.**

- Key difference:
  - **Tuples** and **strings** are *immutable*
  - **Lists** are *mutable*

- Most operations shown in this section can be applied to all sequence types

Tufts

Definitions

- Tuples are defined using parentheses (and commas).

```
>>> tu = (23, 'abc', 4.56, (2,3), 'def')
```

- Lists are defined using square brackets (and commas).

```
>>> li = ['abc', 34, 4.34, 23]
```

- Strings are defined using quotes (", ', or """)

```
>>> st = "Hello World"
>>> st = 'Hello World'
>>> st = """This is a multi-line string
that uses triple quotes."""
```

Accessing Elements

- We can access individual members of a tuple, list, or string using square bracket “array” notation.
- Note that all are 0 based…

```
>>> tu = (23, 'abc', 4.56, (2,3), 'def')
>>> tu[1]                    # Second item in the tuple
'abc'

>>> li = ["abc", 34, 4.34, 23]
>>> li[1]                    # Second item in the list
34

>>> st = 'Hello World'
>>> st[1]                    # Second character in string
'e'
```

Positive and Negative Indices

```
>>> t = (23, 'abc', 4.56, (2,3), 'def')
```

Positive index: count from first element, starting with 0.

```
>>> t[1]
'abc'
```

Negative lookup: count from last element, starting with –1.

```
>>> t[-3]
4.56
```


Tufts

Slicing: Return a Copy of a Subset

```
>>> t = (23, 'abc', 4.56, (2,3), 'def')
```

Get subsequence.

```
>>> t[1:3]
('abc',4.56)
```

Omit the first index to make a copy starting from the beginning of the container.

```
>>> t[:3]
(23, 'abc',4.56)
```

Omit the second index to make a copy starting at the first index and going to the end of the container.

```
>>> t[2:]
(4.56, (2,3), 'def')
```

Copy the Entire Sequence

To make a copy of the entire sequence, use [:].

```
>>> t[:]
(23, 'abc', 4.56, (2,3), 'def')
```

Note the difference between these two assignments

```
>>> list2 = list1    # 2 names refer to same list
                     # Changing one affects both

>>> list2 = list1[:] # Creates new independent copy
```


Tufts

Membership test

Boolean test whether a value is inside a container:

```
>>> t = [1,2,3,4,5]
>>> 3 in t
True
>>> 6 in t
False
>>> 6 not in t
True
```

For strings, also tests for substrings

```
>>> a = 'abcde'
>>> 'c' in a
True
>>> 'cd' in a
True
```

Note: `in` also used in syntax of `for` *loops* and *list comprehensions*

Concatenation

The + operator produces a new tuple, list, or string whose value is the concatenation of its arguments:

```
>>> (1, 2, 3) + (4, 5, 6)
(1, 2, 3, 4, 5, 6)

>>> [1, 2, 3] + [4, 5, 6]
[1, 2, 3, 4, 5, 6]

>>> "Hello" + " " + "world"
"Hello world"
```

Replication

The * operator produces a new tuple, list, or string that repeats the original content

```
>>> (1, 2, 3) * 3
(1, 2, 3, 1, 2, 3, 1, 2, 3)

>>> [1, 2, 3] * 3
[1, 2, 3, 1, 2, 3, 1, 2, 3]

>>> "Hello" * 3
"HelloHelloHello"
```

Mutability: Tuples are Immutable

```
>>> t = (23, 'abc', 4.56, (2,3), 'def')
>>> t[2] = 3.14
Traceback (most recent call last):
   File "", line 1, in -toplevel-
     tu[2] = 3.14
TypeError: object doesn't support item assignment
```

You can't change a tuple.

You *can* make a fresh tuple and assign its reference to a previously used variable name.

```
>>> t = (23, 'abc', 3.14, (2,3), 'def')
```

Mutability: Lists are Mutable

```
>>> li = ['abc', 23, 4.34, 23]
>>> li[1] = 45
>>> li
['abc', 45, 4.34, 23]
```

- **You can change a list *in place*. (i.e., no additional memory used)**
- **Variable li still points to the same memory location after assignment**
- **No free lunch: supporting mutability makes lists *slower* than tuples.**

Operations Only on Lists

```
>>> li = [1, 11, 3, 4, 5]

>>> li.append('a')        # Our first exposure to an object method
>>> li
[1, 11, 3, 4, 5, 'a']

>>> li.insert(2, 'i')
>>> li
[1, 11, 'i', 3, 4, 5, 'a']

>>> li.sort()
[1, 3, 4, 5, 11, 'a', 'i']

>>> help(li)          # see all methods that can be applied to a list
```

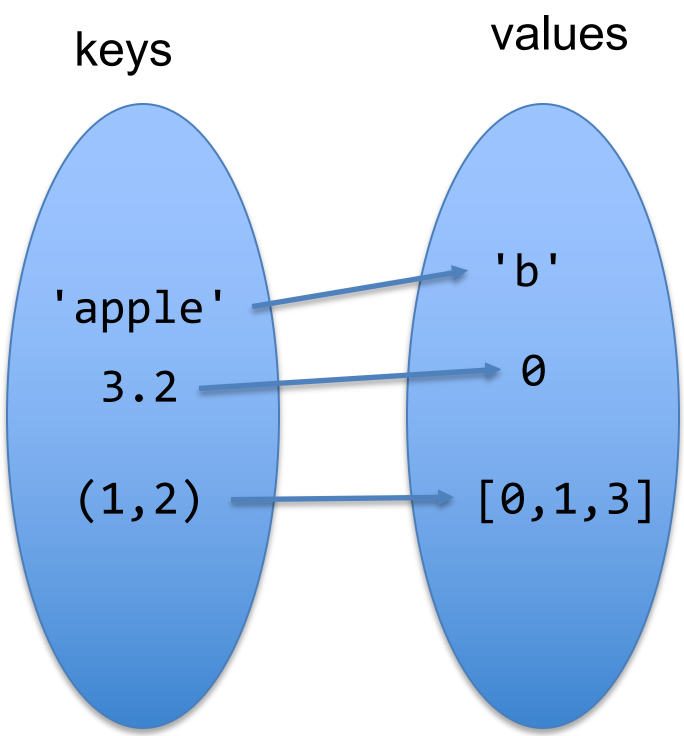
Tuples vs. Lists

- **Lists are slower but more powerful than tuples**
- **Is your data going to be *accessed* but *not changed*?**
  - **Use tuple**
- **Do you need to support modifications?**
  - **Use list**
- **Convert between tuples and lists through casting:**

```
>>> li = list(tu)
>>> tu = tuple(li)
```

Dictionaries: a Mapping type

- **Dictionaries store a *mapping* between a set of *keys* and a set of *values***
  - Keys can be any *immutable* type
  - Values can be any type
- **You can define, modify, view, lookup, and delete key-value pairs in the dictionary**



Dictionary Examples

```
>>> d = {'user':'bozo', 'pswd':1234}
>>> d['user']
'bozo'
>>> d['pswd']
1234
>>> d['banana']
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
KeyError: 'banana'
```

```
# Change value for existing key
>>> d = {'user':'bozo', 'pswd':1234}
>>> d['user'] = 'clown'
>>> d
{'pswd': 1234, 'user': 'clown'}
```

```
# Add new key-value pair
>>> d['id'] = 25
>>> d
{'id': 25, 'pswd': 1234, 'user': 'clown'}
```

```
# remove key-value map
>>> d = {'user':'bozo', 'p':1234, 'i':34}
>>> del d['user']
>>> d
{'i': 34, 'p': 1234}
>>> d.clear()
>>> d
{}
```

```
#change value for existing key
>>> d = {'user':'bozo', 'p':1234, 'i':34}
>>> d.keys()              # List of keys
['i', 'p', 'user']
>>> d.values()            # List of values
[34, 1234, 'bozo']
>>> d.items()             # List of pairs as tuples.
[('i', 34), ('p', 1234), ('user', 'bozo')]
```

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if statement

```
if x == 3:
    print "X equals 3."              #indentation defines blocks!
elif x == 2:
    print "X equals 2."
else:
    print "X equals something else."
print "This is outside the 'if'."
```

while statement

Fibonacci Series:

```
>>> a, b = 0, 1                     #multiple var assignment
>>> while a < 10:
        print(a)                     #indentation defines block!
        a, b = b, a+b
0
1
1
2
3
5
8
```

for loop

Primality Test:

```
for n in range(2, 10):
    for x in range(2, n):
        if n % x == 0:
            print(n, 'equals', x, '*', n//x)
            break
    else:                                    # executed only if loop does not break early
         print(n, 'is a prime number’)
```

```
2 is a prime number
3 is a prime number
4 equals 2 * 2
5 is a prime number
6 equals 2 * 3
7 is a prime number
8 equals 2 * 4
9 equals 3 * 3
```

Lists made out of other lists: List Comprehension

```
li = range(10)
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]


squares = [x**2 for x in li]
print squares
[0, 1, 4, 9, 16, 25, 36, 49, 64, 81]


even_squares = [x for x in squares if x%2==0]
[0, 4, 16, 36, 64]


[ (x,1) for x in even_squares]
[(0, 1), (4, 1), (16, 1), (36, 1), (64, 1)]


[ range(x)  for x in range(4)]
[[], [0], [0, 1], [0, 1, 2]]


[  y   for x in range(4) for y in range(x)]              # "nested" for loop
[0, 0, 1, 0, 1, 2]
```


Tufts

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Function Definitions

- `def` **creates a function and assigns it a name**
- `return` **sends a result back to the caller**
- **Arguments are passed *by assignment***
- **Arguments and return types are *not declared*:**

```
def <name>(arg1, arg2, ..., argN):
    <statements>
    return <value>

def times(x,y):
    return x*y
```


Tufts

Optional Arguments

- Can define default values for arguments that need not be passed

```
def func(a, b, c=10, d=100):
    print(a, b, c, d)

>>> func(1,2)
1 2 10 100

>>> func(1,2,3,4)
1 2 3 4
```


Tufts

Gotchas

- **All functions return a value:**
  - If no return statement, function returns None

- **Functions can be used like *any other data type*! They can be**
  - Arguments to other functions
  - Return values of other functions
  - Assigned to variables
  - Parts of tuples, lists, etc.

```
def square(x):
        return x * x

>>> z = square
>>> z(2)
4
>>> map(square,[1,2,3,4])          # map's 1st input is a function!
[1, 4, 9, 16]
```


Tufts

Anonymous Functions: the `lambda` operator

```
def square(x):
        return x * x

>>> map(square, [1,2,3,4])
[1, 4, 9, 16]

>>> map( lambda x: x*x , [1,2,3,4])
[1, 4, 9, 16]


def power_generator(n):
        return lambda x : x ** n     #power_generator returns a function!

>>> square = power_generator(2)
>>> cube = power_generator(3)

>>> map(square, [1,2,3,4])
[1, 4, 9, 16]
>>> map(cube, [1,2,3,4])
[1, 8, 27, 64]
```

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Tufts

Python Modules

- ❑ Modules comprise functions and variables defined in separate files
- ❑ Functions or variables from a module are imported using from or import

```
from numpy import sqrt                  #imports only sqrt
sqrt(2343523)

import numpy                            #imports entire module
numpy.sqrt(2343523)

import numpy as np                      #imports entire module as "np"
np.sqrt(2343523)

from numpy import *                     #imports everything in module
sqrt(1243)
exp(-1.23)
```

- ❑ Type `help(module)` to see module functionality

numpy

- Functions galore:

```
exp,log,log10,sin,cos,tan,sqrt,...
```

- Numerical Arrays and Matrices!

```
import numpy as np
a = np.array([1.0, 2.0, 2.1])
b = np.array([2.0, 1.0, -3.1])

print a + b                             #vector addition
[ 3.  3. -1.]

print np.dot(a,b)                       #vector dot product
-2.51

print np.outer(a,b)                     #vector outer product
[[ 2.    1.   -3.1 ]
 [ 4.    2.   -6.2 ]
 [ 4.2   2.1  -6.51]]
```

numpy.linalg

```
help(numpy.linalg)

NAME
    numpy.linalg

FILE
    /Library/Python/2.7/site-packages/numpy-1.11.0-py2.7-macosx-10.10-intel.egg/numpy/linalg/__init__.py

DESCRIPTION
    Core Linear Algebra Tools
    -------------------------
    Linear algebra basics:

    - norm            Vector or matrix norm
    - inv             Inverse of a square matrix
    - solve           Solve a linear system of equations
    - det             Determinant of a square matrix
    - lstsq           Solve linear least-squares problem
    - pinv            Pseudo-inverse (Moore-Penrose) calculated using a singular
                      value decomposition
    - matrix_power    Integer power of a square matrix

    Eigenvalues and decompositions:

    - eig             Eigenvalues and vectors of a square matrix
    - eigh            Eigenvalues and eigenvectors of a Hermitian matrix
    - eigvals         Eigenvalues of a square matrix
    - eigvalsh        Eigenvalues of a Hermitian matrix
    - qr              QR decomposition of a matrix
    - svd             Singular value decomposition of a matrix
    - cholesky        Cholesky decomposition of a matrix

    Tensor operations:

    - tensorsolve     Solve a linear tensor equation
    - tensorinv       Calculate an inverse of a tensor
```

A few useful modules

- See documentation for following modules:

```
scipy                   # Numerical integration, linear algebra,
                        # signal processing, Fourier transforms
numpy.random            # Sample random numbers
argparse                # parse command line arguments
sklearn                 # Machine learning algorithms
sklearn.linear_model    # Linear & logistic regression
sys                     # I/O
time                    # time utilities
matplotlib.pyplot       # plotting tools
```

Use Docstrings!

```
class atom(object):
    """This will be shown whenever someone calls help(atom), along
    with list of public methods """

    def symbol(self):
        """This will be shown whenever someone
        calls help(atom.symbol) or help(x.symbol)
        where x is an atom object"""
        return Atno_to_Symbol[atno]
```


Tufts

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What is an Object?

- A data structure that contains *variables* and *methods*

- Object Oriented Design abides by the principles of:
  - **Encapsulation**:

    —dividing the code into a ***public*** interface, and a ***private implementation*** of that interface
  - **Polymorphism**:

    —the ability to ***overload*** standard operators so that they have appropriate behavior based on their context
  - **Inheritance**:

    —the ability to create subclasses that contain specializations of their parents

Example

```
class atom(object):
    def __init__(self,atno,x,y,z):
        self.atno = atno
        self.position = (x,y,z)

    def symbol(self): # a class method
        return Atno_to_Symbol[atno]

    def __str__(self): # overloads str() function
        return '%d %10.4f %10.4f %10.4f' % \
            (self.atno, self.position[0],
            self.position[1],self.position[2])

>>> at = atom(6,0.0,1.0,2.0)
>>> print at
6     0.0000     1.0000     2.0000
>>> at.symbol()
'C'
```


Tufts

Atom Class

- Overloaded the default constructor •
- Defined class variables (`atno,position`) and a class method (`symbol`)
  - accessed as `self.atno` within the class definition
  - accessed as `at.atno` outside class for atom `at`
- Good way to manage shared memory:
  - instead of passing long lists of arguments, encapsulate some of this data into an object, and pass the object.
  - much cleaner, easier to interpret programs result
- **Overloaded** the str() operator
- We now want to use the atom class to build molecules...

Tufts

Molecules

```
class molecule:
    def __init__(self,name='Generic'):
        self.name = name
        self.atomlist = []
    def addatom(self,atom):
        self.atomlist.append(atom)
    def __str__(self):
        s = 'This is a molecule named %s\n' % self.name
        s = s +'It has %d atoms\n' % len(self.atomlist)
        for atom in self.atomlist:
            s  = s  + str(atom) + '\n'
        return s
```


Tufts

Using the Molecule Class

```
>>> mol = molecule('Water')
>>> mol.addatom(at)
>>> mol.addatom(atom(1,0.,0.,1.))
>>> mol.addatom(atom(1,0.,1.,0.))
>>> print(mol)
This is a molecule named Water
It has 3 atoms
8      0.0000      0.0000      0.0000
1      0.0000      0.0000      1.0000
1      0.0000      1.0000      0.0000
```

- Note that the str function calls the atoms str function
  - Code reuse: only have to type the code that prints an atom once; this means that if you change the atom specification, you only have one place to update.

Inheritance

```
class dna_molecule(molecule):
    def clone(self):
        new_molecule  = dna_molecule(molecule.name)
        for at in self.atomlist:
            new_molecule.addatom(atom(at.atno,
                                      at.position[0],
                                      at.position[1],
                                      at.position[2]))
         return new_molecule
```

- `__init__`, `__str__`, and `addatom` are *inherited* from the parent class (`molecule`)!
- **`dna_molecule`** is augmented with an additional method (clone)
- Another example of code reuse

Tufts

Overriding Parent Methods

```
class dna_molecule(molecule):
    def __init__(self,name='DNA molecule',isOrganic=True):
        self.isOrganic=isOrganic
        super(dna_molecule, self).__init__(name)
    def clone(self):
        new_molecule  = dna_molecule(molecule.name)
        for at in self.atomlist:
            new_molecule.addatom(atom(at.atno,
                                      at.position[0],
                                      at.position[1],
                                      at.position[2]))
         return new_molecule
```

- A parent method (`__init__`) gets a new definition, using also the parent definion

Private and public variables and methods

- In Python anything with two leading underscores is private

__a, __my_variable

- Anything with one leading underscore is semiprivate, and you should feel guilty accessing this data directly.

_b

- Sometimes useful as an intermediate step to making variable private

Overloading Operators

__contains__(...)
x.__contains__(y) <==> y in x

__eq__(...)
x.__eq__(y) <==> x==y

__ge__(...)
x.__ge__(y) <==> x>=y

__add__(...)
x.__add__(y) <==> x+y

__lt__(...)
x.__lt__(y) <==> x<y

__mul__(...)
x.__mul__(n) <==> x*n