Python

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The Python Programming Language

- Interpreted - but can have modules written in C/C++
- Dynamically but strongly typed
  - dynamically typed - no need to declare variable types
  - strongly typed - restrictions on how variable of different types may be combined
- Object Oriented - everything is an object
- Allows multiple programming paradigms: OO, procedural, functional

Why use Python?

- Want a language easy to learn
  - Clean, clear syntax
  - Very few keywords
- Want to write a program fast
  - programs 2-10x shorter that the C,C++,Java equivalent
- Want to be able to read your code next year
  - ... or somebody else to read your code

Why use Python?

- You think that “batteries included” ia a good idea
  - it has an extensive standard library
  - 3rd party libraries availabe for just about anything
- *Because it makes programmig fun!*

Python Programs

- Text files, traditionally with a .py extension
  - .pyc and .pyo automatically generated when you run the program
- Programs vs Modules
  - a .py file can be program or a module
  - it's a program when executed directly

    ```
    $ python hello.py
    ```

  - it's a module when referenced via the `import` statement

    ```
    import hello
    ```

Programs and Modules

- `__name__` variable used to distinguish between the two
- usefull for regression testing
  - when executed as a program the test is executed
  - when imported as a module the test is not executed

```
if __name__ == "__main__":
  run_test()
```

Variables

- Variables need no declaration

```
>>> a=1
>>>
```

- Variables must be created before they can be used

```
>>> b
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
NameError: name ’b’ is not defined
>>>
```

Types

- Everything has a type

```
>>> a=1
>>> type(a)
<type 'int'>
>>> b='2'
>>> type(b)
<type 'str'>
>>> type(1.0)
<type 'float'>
```

- Strong typing

```
>>> a + b
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unsupported operand type(s) for +: 'int' and 'str'
```

Simple types

- Strings
  - May hold any data (including NULLs)

```
>>> s = 'Hello\nPython!'
>>> print s
Hello
Python!
```

  - Raw strings

```
>>> s = r"Hello\nPython!"
>>> print s
Hello\nPython!
```

  - Multiline strings

```
>>> s = """Hello
Python!"""
>>> print s
Hello
Python!
```

Simple types

- Integer - implemented using C longs
  - Like in C, division returns floor

```
>>> 7 / 2
3
```

- Long integer - have unlimited size

```
>>> 2**500
3273390607896141870013189696827599152216642046043064789483291368096133796404674554883270092325904157150886684127560071009217256545885393053328527589376L
```

- Float type implemented using C doubles

High level types

- Lists
  - Hold a sequence of items
- Tuples
  - Similar to lists, but immutable
- Dictionaries
  - Hold key-value pairs

Lists

- Hold a sequence of items
- May hold any types

```
>>> li = []
>>> li.append(3.0)
>>> li.extend(['a',"b",'Python'])
>>> len(li)
4
>>> li
[3.0, 'a', 'b', 'Python']
>> li[1]
'a'
>> li.index('Python')
3
>>> li[-2]
'b'
```

Lists

- List slicing

```
>>> li[1:3]
['b', 'c']
['b', 'c']
>>> li[1:-1]
['b', 'c', 'd']
```

- List operators

```
>>> li = ['a','b']*3
>>> li
['a', 'b', 'a', 'b', 'a', 'b']
>>> li = ['a','b']+['c','d']
>>> li
['a', 'b', 'c', 'd']
```

List comprehensions

- provide a concise way to create lists

```
>>> vec = [2, 4, 6]
>>> [3*x for x in vec]
[6, 12, 18]
>>> [3*x for x in vec if x > 3]
[12, 18]
>>> [(x, x**2) for x in vec]
[(2, 4), (4, 16), (6, 36)]
>>> vec1 = [2, 4, 6]
>>> vec2 = [4, 3, -9]
>>> [x*y for x in vec1 for y in vec2]
[8, 6, -18, 16, 12, -36, 24, 18, -54]
```

Tuples

- Similar to lists, but immutable
- Often used in place of simple structures

```
>>> point = (3,4)
>>> point
(3, 4)
```

- Automatic unpacking

```
>>> x,y = point
>>> x
3
```

- Used to return multiple values from functions

```
>>> x,y = GetPoint()
```

Dictionaries

- Hold key-value pairs
- Often called maps, or hash tables
- Keys may be any immutable objects, values may be any objects

```
>>> d = {}
>>> d[1] = "Python"
>>> d["hello"] = 1.0
>>> d[(1,2)] = 3
>>> d
{(1, 2): 3, 1: ’Python’, ’hello’: 1.0}
>>> d[’hello’]
1.0
>>> len(d)
3
```

Blocks

- Blocks are delimited by indentation
- Colon used to start a new block

```
if a>0:
    print "Computing␣square␣root"
    b = sqrt(a)
```

  - Many hate this when they first see it
  - Pyhton programmers come to love it
- Code gets to be more readable
  - Humans use identation anyway when reading code to determine its structure
  - Ever got bitten by the C code:

```
  if (a>0)
      printf("Computing␣square␣root\n");
      b = sqrt(a);
```

Conditionals

- if, elif, else

```
if condition:
    [block]
elif condition:
    [block]
else:
    [block]
```

Looping

- For loop

```
for el in iterable:
    [block]
```

  - The classic for loop

```
for i in range(100):
    print i
```

- While loop

```
while condition:
    [block]
```

- break, continue - the usual operation

Looping techniques

- Looping through dictionaries

```
>>> knights = {'gallahad': 'the␣pure', 'robin': 'the␣brave'}
>>> for k, v in knights.iteritems():
...     print k, v
...
gallahad the pure
robin the brave
```

- Using position and values inside the loop

```
>>> for i, v in enumerate(['tic', 'tac', 'toe']):
...     print i, v
...
0 tic
1 tac
2 toe
```

Looping techniques

- Looping throught multiple sequences at a time

```
>>> questions = ['name', 'quest', 'favorite␣color']
>>> answers = ['lancelot', 'the␣holy␣grail', 'blue']
>>> for q, a in zip(questions, answers):
...     print 'What␣is␣your␣{0}?␣␣It␣is␣{1}.'.format(q, a)
...
What is your name?  It is lancelot.
What is your quest?  It is the holy grail.
What is your favorite color?  It is blue.
```

Functions

- Function declaration

```
def function_name(argument_list):
    [block]
```

- Function arguments can have default values

```
def print_elements(sequence, sep = "␣"):
    print sep.join([str(k) for k in sequence])
```

- Functions are objects too
  - Can be passed to other functions, assigned to variables,...

```
>>> print_elements
<function print_sequence at 0xb7df4aac>
>>> print_sequence = print_elements
>>> type(print_sequence)
<type 'function'>
>>> print_sequence([1,2,3.0],'-')
1-2-3.0
```

Functions

- Keyword arguments

```
>>> print_elements(sep=';', sequence=[1,2,3])
1;2;3
```

- Variable number of arguments

```
def print_arguments(*arguments, **keyword_args):
    print "Positional arguments:", arguments
    print "Keyword arguments:", keyword_args
```

```
>>> print_arguments(1,2,3, sep='-', list=['a','b','c'], count=10)
Positional arguments: (1, 2, 3)
Keyword arguments: {'count': 10, 'list': ['a', 'b', 'c'], 'sep': '-'}
```

Classes

- Declaration

```
class ClassName(BaseClass):
    [block]
```

- Example

```
class Point:
    def __init__(self,x,y):
        self.x = x
        self.y = y

    def getPoint(self):
        return (self.x,self.y)
```

Classes

- Classes are objects too
  - Can be passed to functions, assigned to variables

```
>>> Point
<class __main__.Point at 0xb79e8cec>
```

- Classes get instantiated using call syntax

```
>>> p = Point(1,2)
>>> p
<__main__.Point instance at 0xb77734ec>
>>> p.x
1
>>> p.y
2
```

Classes

- The constructor has a special name: `__init__`
  - the destructor is called `__del__`
- The `self` parameter is the instance
  - similar to `this` from C++
  - it's explicit in Python, implicit in C++
  - the name `self` is just a convention, it can be called anything

Modules

- Each module has its own namespace
- Modules can be implemented in either Python or C/C++
- `import` statement makes a module visible

```
>>> import math
>>> math.sin(1.2)
0.93203908596722629
>>> sin(1.2)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
NameError: name 'sin' is not defined
>>> from math import sin
>>> sin(1.2)
0.93203908596722629
>>> from math import *          # import everything from module math
```

Docstrings

- convenient way of including documentation with the code

```
class Point:
    """Python␣class␣that␣models␣a␣point"""

    def __init__(self,x,y):
        """Class␣constructor"""
        self.x = x
        self.y = y

    def getPoint(self):
        """Returns␣point␣as␣a␣tuple␣(x,y)"""
        return (self.x,self.y)
```

```
>>> p = Point(1,2)
>>> p
<docstring.Point instance at 0xa1c0a8c>
>>> p.__doc__
'Python␣class␣that␣models␣a␣point'
>>> p.getPoint.__doc__
'Returns␣point␣as␣a␣tuple␣(x,y)'
```

Example

```
# file shape.py

class Shape:
   # constructor
   def __init__(self, initx, inity):
      self.moveTo(initx, inity)

   # accessors for x & y
   def getX(self):
      return self.x
   def getY(self):
      return self.y
   def setX(self, newx):
      self.x = newx
   def setY(self, newy):
      self.y = newy

   # move the shape position
   def moveTo(self, newx, newy):
      self.setX(newx)
      self.setY(newy)
   def moveBy(self, deltax, deltay):
      self.moveTo(self.getX() + deltax, self.getY() + deltay)

   # abstract draw method
   def draw(self):
      pass
```

Example

```python
# file rectangle.py

from shape import Shape

class Rectangle(Shape):

    # constructor
    def __init__(self, initx, inity, initwidth, initheight):
        Shape.__init__(self, initx, inity)
        self.setWidth(initwidth)
        self.setHeight(initheight)

    # accessors for width & height
    def getWidth(self):
        return self.width
    def getHeight(self):
        return self.height
    def setWidth(self, newwidth):
        self.width = newwidth
    def setHeight(self, newheight):
        self.height = newheight

    # draw the rectangle
    def draw(self):
        print "Drawing a Rectangle at:(%d,%d), width %d, height %d" % \
            (self.getX(), self.getY(), self.getWidth(), self.getHeight())
```

Example

```
# file circle.py

from shape import Shape

class Circle(Shape):

   # constructor
   def __init__(self, initx, inity, initradius):
      Shape.__init__(self, initx, inity)
      self.setRadius(initradius)

   # accessors for the radius
   def getRadius(self):
      return self.radius
   def setRadius(self, newradius):
      self.radius = newradius

   # draw the circle
   def draw(self):
      print "Drawing a Circle at:(%d,%d), radius %d" % \
         (self.getX(), self.getY(), self.getRadius())
```

Example

```python
# file test_shapes.py

from rectangle import Rectangle
from circle import Circle

def test_shapes():

   # set up lists to hold the shapes
   scribble = [Rectangle(10, 20, 5, 6), Circle(15, 25, 8)]

   # iterate through the lists and handle shapes polymorphically
   for each in scribble:
      each.draw()
      each.moveBy(100, 100)
      each.draw()

   # call a rectangle specific instance
   arec = Rectangle(0, 0, 15, 15)
   arec.setWidth(30)
   arec.draw()

if __name__ == "__main__":
    test_shapes()
```

```
$ python test_shapes.py
Drawing a Rectangle at:(10,20), width 5, height 6
Drawing a Rectangle at:(110,120), width 5, height 6
Drawing a Circle at:(15,25), radius 8
Drawing a Circle at:(115,125), radius 8
Drawing a Rectangle at:(0,0), width 30, height 15
```

Python for scientifical computing

- Many, many libraries
  - http://www.scipy.org/Topical_Software
- NumPy
  - the fundamental package needed for scientific computing with Python
- SciPy
  - variety of high level science and engineering modules together as a single package
- matplotlib
  - 2D plotting library which produces publication quality figures
- mlabwrap
  - high-level python to Matlab bridge that lets Matlab look like a normal python library

Numpy

- the fundamental package needed for scientific computing with Python
- a powerful N-dimensional array object
- tools for integrating C/C++ and Fortran code
- useful linear algebra, Fourier transform, random numbers capabilities
- http://www.scipy.org/NumPy_for_Matlab_Users

Numpy

- A taste of NumPy

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

```
>>> x = ones( (3,4) )
>>> x
array([[1., 1., 1., 1.],
       [1., 1., 1., 1.],
       [1., 1., 1., 1.]])
>>> x.shape                           # a tuple with the dimensions
(3, 4)
>>> a = random.normal(0,1,(3,4))      # random samples from a normal distribution
>>> a
array([[-1.20183817,  0.03338838,  1.09723418, -0.08546884],
       [-0.74220878,  0.34840145, -0.42426146, -0.46312178],
       [ 0.39493244,  1.78215556,  0.39265006, -0.45922891]]
```

Numpy

- http://www.scipy.org/Numpy_Example_List
- Example: svd()

```
>>> from numpy import *
>>> from numpy.linalg import svd
>>> A = array([[1., 3., 5.],[2., 4., 6.]])     # A is a (2x3) matrix
>>> U,sigma,V = svd(A)
>>> print U                                      # U is a (2x2) unitary matrix
[[-0.61962948 -0.78489445]
 [-0.78489445  0.61962948]]
>>> print sigma                                  # non-zero diagonal elements of Sigma
[ 9.52551809  0.51430058]
>>> print V                                      # V is a (3x3) unitary matrix
[[-0.2298477  -0.52474482 -0.81964194]
 [ 0.88346102  0.24078249 -0.40189603]
 [ 0.40824829 -0.81649658  0.40824829]]
>>> Sigma = zeros_like(A)                        # constructing Sigma from sigma
>>> n = min(A.shape)
>>> Sigma[:n,:n] = diag(sigma)
>>> print dot(U,dot(Sigma,V))                    # A = U * Sigma * V
[[ 1.  3.  5.]
 [ 2.  4.  6.]]
```

Scipy

- project which includes a variety of high level science and engineering modules together as a single package
  - linear algebra (including wrappers to BLAS and LAPACK)
  - optimization
  - integration
  - special functions
  - FFTs
  - signal and image processing
  - genetic algorithms
  - ODE solvers
  - others...

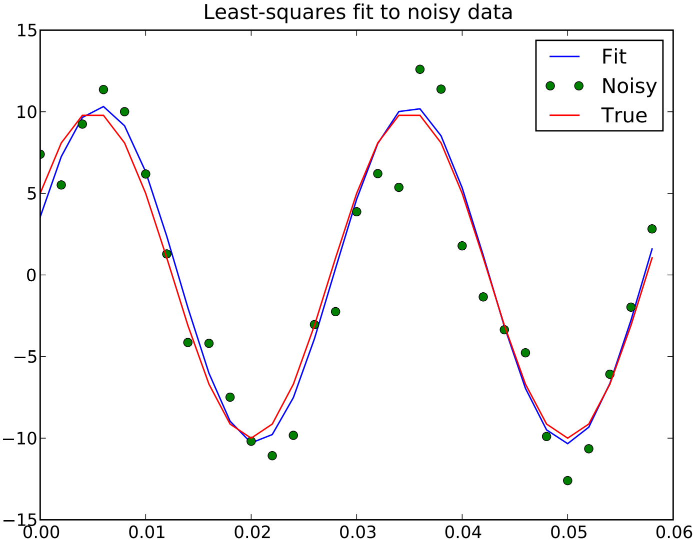
Scipy

- Example

```python
from numpy import *
from numpy.random import randn

x = arange(0,6e-2,6e-2/30)
A,k,theta = 10, 1.0/3e-2, pi/6
y_true = A*sin(2*pi*k*x+theta)
y_meas = y_true + 2*randn(len(x))

def residuals(p, y, x):
        A,k,theta = p
        err = y-A*sin(2*pi*k*x+theta)
        return err

def peval(x, p):
        return p[0]*sin(2*pi*p[1]*x+p[2])

p0 = [8, 1/2.3e-2, pi/3]

from scipy.optimize import leastsq
plsq = leastsq(residuals, p0, args=(y_meas, x))

# plotting
from pylab import *
clf()
plot(x,peval(x,plsq[0]),x,y_meas,'o',x,y_true)
title('Least-squares fit to noisy data')
legend(['Fit', 'Noisy', 'True'])

savefig('fig.pdf')
```

Scipy

- Example



Scipy

- Subpackages

```
>>> import scipy
>>> help(scipy)
...
odr                          --- Orthogonal Distance Regression
misc                         --- Various utilities that don't have another home.
sparse.linalg.eigen.arpack   --- Eigenvalue solver using iterative methods
fftpack                      --- Discrete Fourier Transform algorithms
io                           --- Data input and output
sparse.linalg.eigen.lobpcg   --- Locally Optimal Block Preconditioned
                                 Conjugate Gradient Method (LOBPCG)
special                      --- Airy Functions
lib.blas                     --- Wrappers to BLAS library
sparse.linalg.eigen          --- Sparse Eigenvalue Solvers
stats                        --- Statistical Functions
lib                          --- Python wrappers to external libraries
optimize                     --- Optimization Tools
maxentropy                   --- Routines for fitting maximum entropy models
integrate                    --- Integration routines
ndimage                      --- n-dimensional image package
linalg                       --- Linear algebra routines
spatial                      --- Spatial data structures and algorithms
interpolate                  --- Interpolation Tools
sparse.linalg                --- Sparse Linear Algebra
sparse.linalg.dsolve.umfpack --- :Interface to the UMFPACK library:
sparse.linalg.dsolve         --- Linear Solvers
lib.lapack                   --- Wrappers to LAPACK library
cluster                      --- Vector Quantization / Kmeans
signal                       --- Signal Processing Tools
sparse                       --- Sparse Matrices
...
```

SageMath

- http://www.sagemath.org/
- free open-source mathematics software system
- combines the power of many existing open-source packages into a common Python-based interface
- Mission: Creating a viable free open source alternative to Magma, Maple, Mathematica and Matlab.
- Can be used on the department machines:

  ```
  $ use sage
  ```

- Demo!

Questions?