



Python for Athena

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Python for Athena

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What Is Python?

ONE LINER

Python is an interpreted programming language that allows you to do almost anything possible with a compiled language (C/C++/Fortran) without requiring all the complexity.

PYTHON HIGHLIGHTS

- **Automatic garbage collection**
- **Dynamic typing**
- **Interpreted and interactive**
- **Object-oriented**
- **“Batteries Included”**
- **Free**
- **Portable**
- **Easy to Learn and Use**
- **Truly Modular**

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Who is using Python?

WALL STREET

Banks and hedge funds rely on Python for their high speed trading systems, data analysis, and visualization.

HOLLYWOOD

Digital animation and special effects:

- Industrial Light and Magic
- Imageworks
- Tippett Studios
- Disney
- Dreamworks

PETROLEUM INDUSTRY

Geophysics and exploration tools:

- ConocoPhillips
- Shell

GOOGLE

One of top three languages used at Google along with C++ and Java. Guido van Rossum worked there.

YOUTUBE

Highly scalable web application for delivering video content.

REDHAT

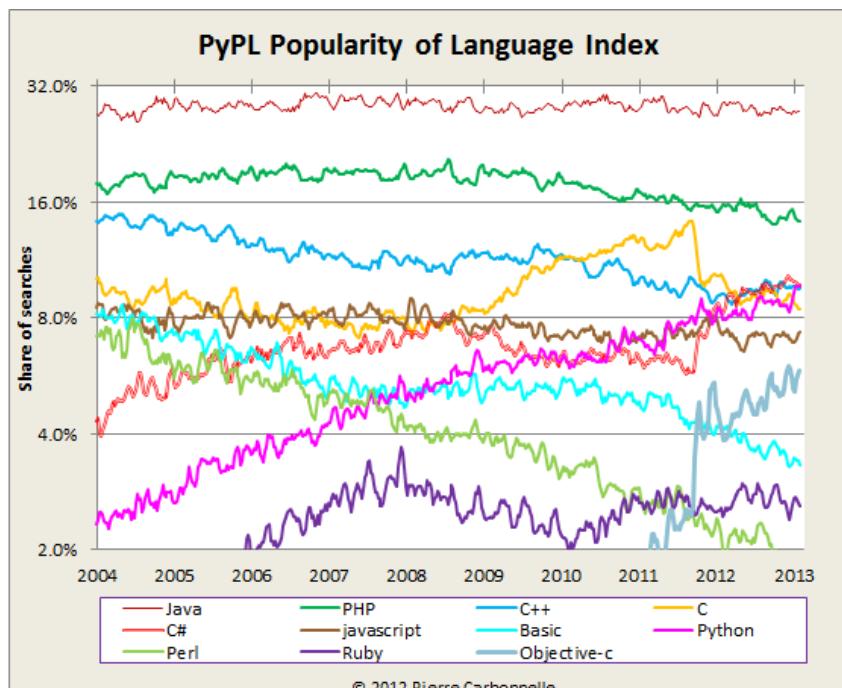
Anaconda, the Redhat Linux installer program, is written in Python.

PROCTER & GAMBLE

Fluid dynamics simulation tools.

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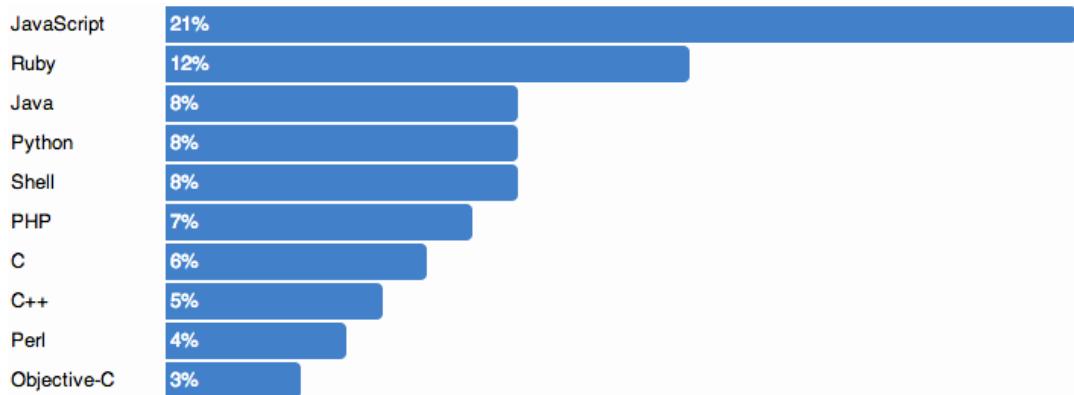
PYPL PopularitY of Programming Language index



* <https://sites.google.com/site/pydatalog/pypl/PyPL-Popularity-of-Programming-Language> (CC by 3.0 license)

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GitHub Top Languages 2013



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IPython

An enhanced
interactive Python shell

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Starting IPython

IPython can be started:

- w/ the pylab icon
- by typing `ipython --pylab` in any terminal/command prompt



```
Last login: Sun Aug 4 20:03:00 on ttys005
Admins-MacBook-Pro-2:~ jrocher ipython --pylab
Enthought Python Distribution - www.enthought.com

Python 2.7.3 | 64-bit | (default, Jun 14 2013, 18:17:36)
Type "copyright", "credits" or "license" for more information.

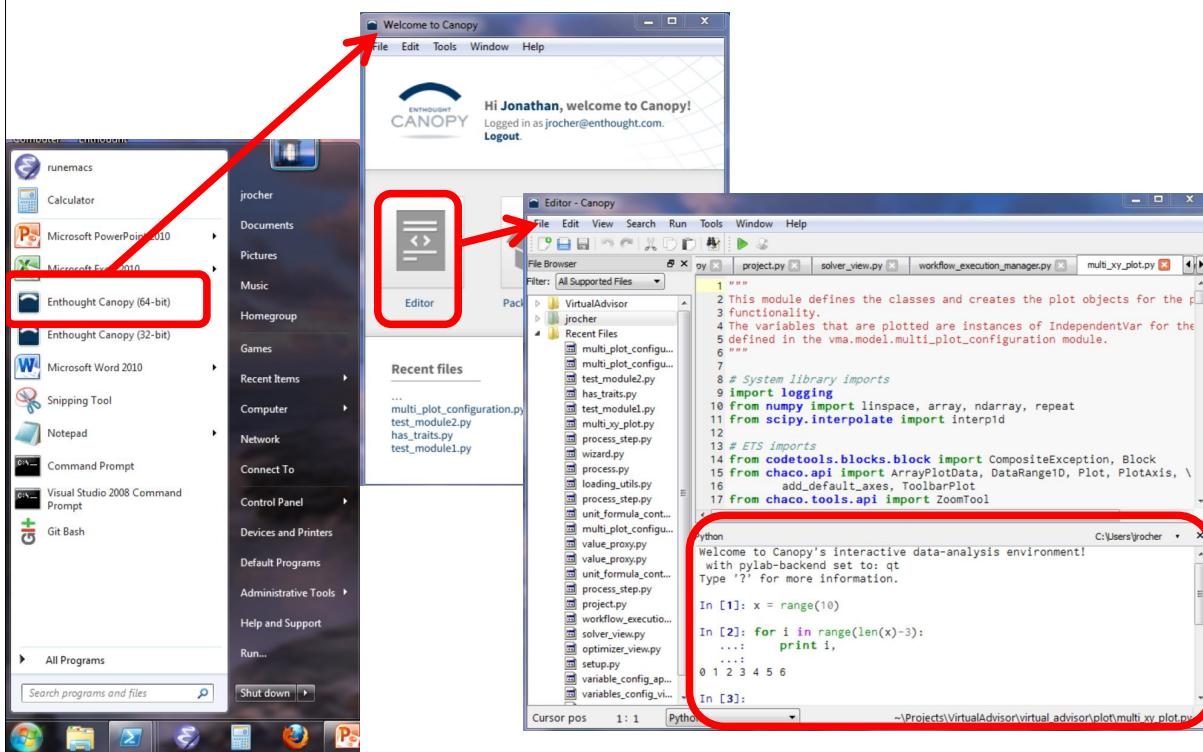
IPython 0.13.1 -- An enhanced Interactive Python.
?           --> Introduction and overview of IPython's features.
%quickref --> Quick reference.
help        --> Python's own help system.
object?     --> Details about 'object', use 'object??' for extra details.

Welcome to pylab, a matplotlib-based Python environment [backend: MacOSX]
For more information, type 'help(pylab)'.

In [1]:
```

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Starting IPython in Canopy



PyLab: Interactive Python Environment

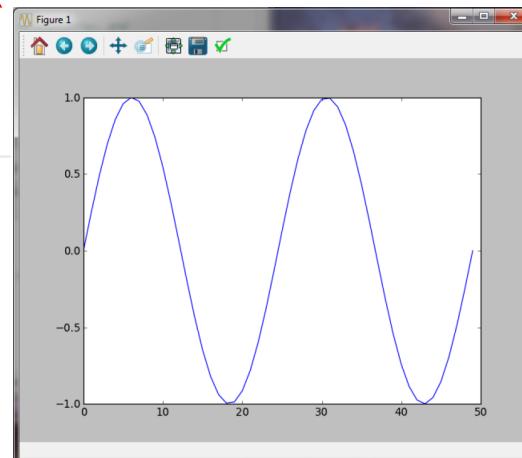
Python

```
In [4]: x = linspace(0, 4*pi)
In [5]: plot(sin(x))
Out[5]: [<matplotlib.lines.Line2D at 0x84909e8>]
In [6]: print sin(3*pi/4)
0.707106781187
In [7]: sin(3*pi/4) == sqrt(2)/2
Out[7]: True
In [8]:
```

The PyLab mode in IPython handles some gory details behind the scenes. It allows both the Python command interpreter (above) and the GUI plot window (right) to coexist. This involves a bit of multi-threaded magic.



PyLab also imports some handy functions into the command interpreter for user convenience.



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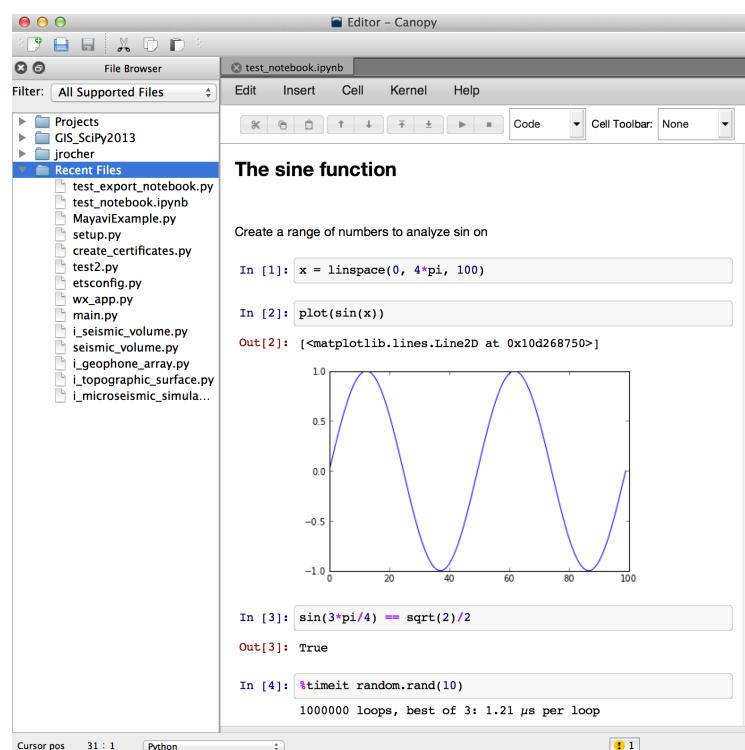
IPython notebook: exportable session

Contains in 1 file the inputs, the outputs, figures, plain text (markdown), titles and more...

- .ipynb files.
- Create a new one in Canopy by selecting:

File > New >

IPython notebook



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IPython

STANDARD PYTHON

```
In [1]: a=1
In [2]: a
Out[2]: 1
```

AVAILABLE VARIABLES

```
In [3]: b = [1,2,3]
# List available variables.
In [4]: %whos
Variable      Type      Data/Info
-----
a            int       1
b            list      n=3
```

RESET

```
# Remove user defined variables.
In [5]: %reset
In [6]: %whos
Interactive namespace is empty.
```



“%reset” also removes the names imported by PyLab, such as the plot command.

```
In [7]: plot
NameError: name 'plot' is not
defined
# Reload pylab.
In [8]: %pylab
Welcome to pylab,...
```

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Directory Navigation in IPython

```
# Change directory (note Unix style forward slashes!)
In [9]: cd c:/python_class/Demos/speed_of_light
c:\python_class\Datas\speed_of_light
```



Tab completion helps you find and type directory and file names.

```
# List directory contents (Unix style, not "dir").
In [10]: ls
Volume in drive C has no label.
Volume Serial Number is 5417-593D
Directory of c:\python_class\Datas\speed_of_light
09/01/2008  02:53 PM    <DIR>        .
09/01/2008  02:53 PM    <DIR>        ..
09/01/2008  02:48 PM           1,188 exercise_speed_of_light.txt
09/01/2008  02:48 PM          2,682,023 measurement_description.pdf
09/01/2008  02:48 PM           187,087 newcomb_experiment.pdf
09/01/2008  02:48 PM           1,312 speed_of_light.dat
09/01/2008  02:48 PM           1,436 speed_of_light.py
09/01/2008  02:48 PM           1,232 speed_of_light2.py
                           6 File(s)   2,874,278 bytes
                           2 Dir(s) 11,997,437,952 bytes free
```

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Directory Bookmarks

```
# Print working directory name (Unix style, not "cd").
In [11]: pwd
c:\python_class\Demos\speed_of_light

# Bookmark the demo and exercise directories, so we can return
# to them easily.
In [12]: cd ..
c:\python_class\Demos

In [13]: %bookmark demo
In [14]: cd ../Exercises
c:\python_class\Exercises

In [15]: %bookmark exer
In [16]: %bookmark -l
demo -> c:\python_class\Demos
exer -> c:\python_class\Exercises

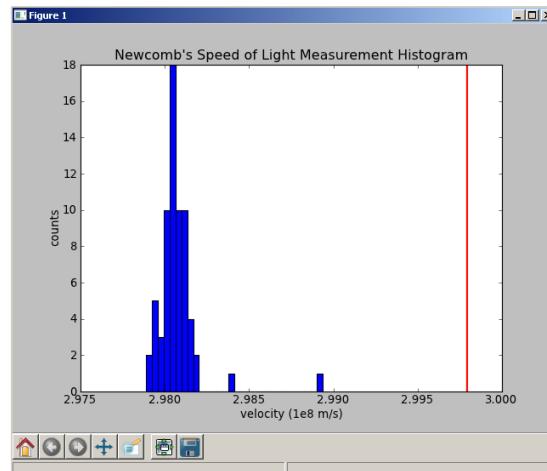
In [17]: cd demo
(bookmark:demo) -> c:\python_class\Demos
```

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Running Scripts in IPython

```
# tab completion
In [11]: %run speed_of_li
speed_of_light.dat  speed_of_light.py

# execute a python file
In [11]: %run speed_of_light.py
```



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Function Info

HELP USING ?

```
# Follow a command with '?' to print its documentation.
```

```
In [19]: len?
```

```
Type:          builtin_function_or_method
Base Class:   <type 'builtin_function_or_method'>
String Form:  <built-in function len>
Namespace:    Python builtin
Docstring:
len(object) -> integer
```

```
Return the number of items of a sequence or mapping.
```

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Function Info

SHOW SOURCE CODE USING ??

```
# Follow a command with '??' to print its source code.
```

```
In [43]: squeeze??
```

```
def squeeze(a):
```

```
    """Remove single-dimensional entries from the shape of a.
```

```
Examples
```

```
-----
```

```
>>> x = array([[[1,1,1],[2,2,2],[3,3,3]]])
```

```
>>> x.shape
```

```
(1, 3, 3)
```

```
>>> squeeze(x).shape
```

```
(3, 3)
```

```
"""
```

```
try:
```

```
    squeeze = a.squeeze
```

```
except AttributeError:
```

```
    return _wrapit(a, 'squeeze')
```

```
return squeeze()
```



?? can't show the source
code for "extension" functions
that are implemented in C.

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IPython History

HISTORY COMMAND

```
# list previous commands. Use
# 'magic' % because 'hist' is
# histogram function in pylab
In [3]: %hist
a=1
a
```

INPUT HISTORY

```
# list string from prompt[2]
In [4]: _i2
Out[4]: 'a\n'
```

OUTPUT HISTORY

```
# grab previous result
In [5]: _
Out[5]: 'a\n'

# grab result from prompt[2]
In [6]: _2
Out[6]: 1
```



The up and down arrows scroll through your ipython input history.

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Reading Simple Tracebacks

ERROR ADDING AN INTEGER TO A STRING

```
In [9]: 1 + "hello"
-----
TypeError      Traceback (most recent call last)
C:\...<ipython-input...> in <module>()
----> 1 1 + "hello"
TypeError: unsupported operand type(s) for +: 'int' and 'str'
```

Location and code where error occurred.

The “type” of error that occurred.

Short message about why it occurred.

ERROR TRYING TO ADD A NON-EXISTENT VARIABLE

```
# Again we fail when adding two variables, but note that the
# traceback tells us we have a completely different problem.
# In this case, our variable doesn't exist, so the operation fails.
In [10]: undefined_var + 1
...
NameError: name 'undefined_var' is not defined
```

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Language Introduction

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Interactive Calculator

```
# adding two values
>>> 1 + 1
2
# setting a variable
>>> a = 1
>>> a
1
# checking a variable's type
>>> type(a)
<type 'int'>
# an arbitrarily long integer
>>> a = 12345678901234567890
>>> a
12345678901234567890L
>>> type(a)
<type 'long'>
# Remove 'a' from the 'namespace'
>>> del a
>>> a
NameError: name 'a' is not
defined
```

```
# real numbers
>>> b = 1.4 + 2.3
>>> b
3.6999999999999997
# "prettier" version.
>>> print b
3.7
>>> type(b)
<type 'float'>
# complex numbers
>>> c = 2+1.5j
>>> c
(2+1.5j)
```

The four numeric types in Python on 32-bit architectures are:

 integer (4 byte)
 long integer (any precision)
 float (8 byte like C's double)
 complex (16 byte)

The numpy module, which we will see later, supports a larger number of numeric types.²⁰

More Interactive Calculation

ARITHMETIC OPERATIONS

```
>>> 1+2-(3*4/6)**5+(7%5)
-27
```

SIMPLE MATH FUNCTIONS

```
>>> abs(-3)
3
>>> max(0, min(10, -1, 4, 3))
0
>>> round(2.718281828)
3.0
```

OVERWRITING FUNCTIONS (!)

```
# don't do this
>>> max = 100

# ...some time later...
>>> x = max(4, 5)
TypeError: 'int' object is not
callable
```

TYPE CONVERSION

```
>>> int(2.718281828)
2
>>> float(2)
2.0
>>> 1+2.0
3.0
```

ALTERNATIVE NOTATIONS

```
>>> 0xFF
255
>>> 023 # octal!
19
>>> 6e3
6000.0
```

IN-PLACE OPERATIONS

```
>>> b = 2.5
>>> b += 0.5      # b = b + 0.5
>>> b
3.0
# Also -=, *=, /=, etc.
```

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Logical expressions, bool data type

COMPARISON OPERATORS

```
# <, >, <=, >=, ==, !=
>>> 1 >= 2
False
>>> 1 + 1 == 2
True
>>> 2**3 != 3**2
True
# Chained comparisons
>>> 1 < 10 < 100
True
```

bool DATA TYPE

```
>>> q = 1 > 0
>>> q
True
>>> type(q)
<type 'bool'>
```

and OPERATOR

```
>>> 1 > 0 and 5 == 5
True
# If first operand is false,
# the second is not evaluated.
>>> 1 < 0 and max(0,1,2) > 1
False
```

or OPERATOR

```
>>> a = 50
>>> a < 10 or a > 90
False
# If first operand is true,
# the second is not evaluated.
>>> a = 0
>>> a < 10 or a > 90
True
```

not OPERATOR

```
>>> not 10 <= a <= 90
True
```

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Strings

CREATING STRINGS

```
# using double quotes
>>> s = "hello world"
>>> print s
hello world
# single quotes also work
>>> s = 'hello world'
>>> print s
hello world
```

STRING OPERATIONS

```
# concatenating two strings
>>> "hello " + "world"
'hello world'

# repeating a string
>>> "hello " * 3
'hello hello hello '
```

STRING LENGTH

```
>>> s = "12345"
>>> len(s)
5
```

SPLIT/JOIN STRINGS

```
# split space-delimited words
>>> s = "hello world"
>>> wrd_lst = s.split()
>>> print wrd_lst
['hello', 'world']

# join words back together
# with a space in between
>>> space = ' '
>>> space.join(wrd_lst)
'hello world'
```

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A few string methods and functions

REPLACING TEXT

```
>>> s = "hello world"
>>> s.replace('world', 'Mars')
'hello Mars'
```

CONVERT TO UPPER CASE

```
>>> s.upper()
'HELLO WORLD'
```

REMOVE WHITESPACE

```
>>> s = "\t    hello    \n"
>>> s.strip()
'hello'
```

NUMBERS TO STRINGS

```
>>> str(1.1 + 2.2)
'3.3'
>>> repr(1.1 + 2.2)
'3.3000000000000003'
>>> str(1)
'1'
>>> hex(255)
'0xFF'
>>> oct(19)
'023'
```

STRINGS TO NUMBERS

```
>>> int('23')
23
>>> int('FF', 16)
255
>>> float('23')
23.0
```

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Available string methods

```
# list available methods on a string
>>> dir(s)
[...           'isspace',
'capitalize', 'istitle',
'center',     'isupper',
'count',      'join',
'decode',     'ljust',
'encode',     'lower',
'endswith',   'lstrip',
'expandtabs', 'partition',
'find',       'replace',
'format',    'rfind',
'index',     'rindex',
'isalnum',   'rjust',
'isalpha',   'rpartition',
'isdigit',   'rsplit',
'islower',   'rstrip',
```

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Multi-line Strings

TRIPLE QUOTES

```
# strings in triple quotes
# retain line breaks
>>> a = """hello
... world"""
>>> print a
hello
world
```

MULTI-LINE WITH PARENTHESES

```
# group strings using
# parentheses
>>> a = ("hello "
...       "world")
>>> print a
hello world
```

LINE CONTINUATION

```
# The \ character means line
# continuation. Be careful
# because it must be the last
# character on line.
>>> a = "hello " \
...      "world"
>>> print a
hello world
```

NEW LINE CHARACTER

```
# including the new line
>>> a = "hello\nworld"
>>> print a
hello
world
```

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String Formatting

str.format(*args, **kwargs)

The `format()` method replaces the ***replacement fields*** in the string with the values given as arguments. Any other text in the string remains unchanged. For example:

```
>>> '{0:2d}-{1}: {name}, ${price:.2f}'.format(7, 19, name='SC1', price=3.4)
' 7-19: SC1, $3.40'
```

Optional

Replacement field: {<field_name> :<format_spec>} }

- Delimited by curly brackets. (Use {{ and }} to include curly brackets in the output.)
- If `field_name` is an integer, it refers to a position in the positional arguments:
`>>> '{0} is greater than {1}'.format(100, 50)`
`'100 is greater than 50'`
- If `field_name` is a name, it refers to a *keyword argument*:
`>>> '{last}, {first}'.format(first='Ellen', last='Ripley')`
`'Ripley, Ellen'`

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String Formatting - Format Spec

```
>>> 'price: ${0:=-7.2f}'.format(3.4)
'price: $ 3.40'
```

The *format spec* is a sequence of characters including:

- the *alignment* option,
- the *sign* option,
- the *width* (and *.precision*) option
- the *type code*.

ALIGNMENT OPTION

Char Meaning

| | |
|---|---|
| < | Left aligned. |
| > | Right aligned. |
| = | (For numeric types only.) Pad after the sign but before the digits (e.g. +000000120). |
| ^ | Center within the available space. |

If an alignment character is given, it may be preceded by a *fill character*.

SIGN OPTION

For numbers only.

Char Meaning

| | |
|-------|---|
| + | Include a sign for positive and negative number. |
| - | Indicate sign for negative numbers only (default) |
| space | Include a leading space for positive numbers. |

STRING TYPE CODES

Type Meaning

s String. This is the default, and may be omitted.

INTEGER TYPE CODES

Type Meaning

| | |
|------|---|
| b | Binary format. |
| c | Character; converts int to unicode char. |
| d | Decimal integer (base 10). |
| o | Octal (base 8). |
| x | Hex (base 16), lower case. |
| X | Hex (base 16), upper case. |
| n | Number; same as 'd', but uses current locale. |
| None | Same as 'd'. |

FLOATING POINT TYPE CODES

Type Meaning

| | |
|------|--|
| e | Scientific notation. |
| E | Scientific notation, with upper case 'E'. |
| f | Fixed point. |
| F | Fixed point; same as 'f'. |
| g | General format. |
| G | General format; same as 'g', with upper case 'E' when necessary. |
| n | Number; same as 'g', but uses current locale. |
| % | Percentage. Multiplies by 100 and displays with 'f', followed by a percent sign. |
| None | Same as 'g'. |

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String Formatting - Examples

```
# Basic string formatting
>>> print '{} {} {}'.format('a', 'b', 'c')
a b c

# Numbered fields refer to the position of the arguments
>>> print '{2} {1} {0}'.format('a', 'b', 'c')
c b a

# Named fields refer to keyword arguments
>>> print '{color} {n} {x}'.format(n=10, x=1.5, color='blue')
blue 10 1.5

# Positional and keyword arguments can be combined
>>> print '{color} {0} {x} {1}'.format(10, 'foo', x=1.5, color='blue')
blue 10 1.5 foo

# Precision and padding
>>> from math import pi
>>> print '{0:10} {1:10d} {c:10.2f}'.format('foo', 5, c=2*pi)
foo          5           6.28
```

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String Formatting - Examples cont.

```
# Fixed point format (and a named keyword argument).
>>> print '[{x:5.0f}] [{x:5.1f}] [{x:5.2f}]'.format(x=12.3456)
[ 12] [ 12.3] [12.35]

# Sign options.
>>> '{:-f}; {:+f}'.format(3.14, -3.14)      # Default
'3.140000; -3.140000'
>>> '{:+f}; {:+f}'.format(3.14, -3.14)      # Use '+'
'+3.140000; -3.140000'
>>> '{: f}; {: f}'.format(3.14, -3.14)      # Use ' '
' 3.140000; -3.140000'

# Alignment (and using a numbered positional argument).
>>> print '[{0:<10s}] [{0:>10s}] [{0:^10s}]'.format('PYTHON')
[PYTHON      ] [      PYTHON] [  PYTHON  ]
# Alignment with fill character.
>>> print '[{0:*<10s}] [{0:*>10s}] [{0:*^10s}]'.format('PYTHON')
[PYTHON****] [*****PYTHON] [***PYTHON**]

# Different bases for an integer (hex, decimal, octal, binary).
>>> '{0:x} {0:d} {0:o} {0:b}'.format(254)
'FE 254 376 11111110'
```

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Formatting with %

FORMAT OPERATOR %

```
# the % operator formats values
# to strings using C conventions.
>>> s = "some numbers:"
>>> x = 1.34
>>> y = 2
>>> t = "%s %f, %d" % (s,x,y)
>>> print t
some numbers: 1.340000, 2

>>> y = -2.1
>>> print "%f\n%f" % (x,y)
1.340000
-2.100000

>>> print "% f\n% f" % (x,y)
1.340000
-2.100000

>>> print "%4.2f" % x
1.34
```

CONVERSION CODES

| Conversion | Meaning |
|------------|---|
| d or i | Signed integer decimal |
| o | Unsigned octal |
| u | Unsigned decimal |
| x | Unsigned hexadecimal (lowercase) |
| X | Unsigned hexadecimal (uppercase) |
| e | Floating point exponential format (lowercase) |
| E | Floating point exponential format (uppercase) |
| F or f | Floating point decimal format |
| G or g | Floating point format or exponential |
| c | Single character |
| r | Converts object using repr() |
| s | Converts object using str() |

CONVERSION FLAGS

| Flag | Meaning |
|---------|--|
| 0 | The conversion will be zero padded for numeric values. |
| - | The converted value is left adjusted (overrides the "0" conversion if both are given). |
| <space> | (a space) A blank should be left before a positive number (or empty string) produced by a signed conversion. |
| + | A sign character ("+" or "-") will precede the conversion (overrides a "space" flag). |

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List objects

LIST CREATION WITH BRACKETS

```
>>> a = [10,11,12,13,14]
>>> print a
[10, 11, 12, 13, 14]
```

CONCATENATING LIST

```
# simply use the + operator
>>> [10, 11] + [12, 13]
[10, 11, 12, 13]
```

REPEATING ELEMENTS IN LISTS

```
# the multiply operator
# does the trick
>>> [10, 11] * 3
[10, 11, 10, 11, 10, 11]
```

range(start, stop, step)

```
# the range function is helpful
# for creating a sequence
>>> range(5)
[0, 1, 2, 3, 4]

>>> range(2,7)
[2, 3, 4, 5, 6]

>>> range(2,7,2)
[2, 4, 6]
```

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Indexing

RETRIEVING AN ELEMENT

```
# list
# indices: 0 1 2 3 4
>>> a = [10,11,12,13,14]
>>> a[0]
10
```

SETTING AN ELEMENT

```
>>> a[1] = 21
>>> print a
[10, 21, 12, 13, 14]
```

OUT OF BOUNDS

```
>>> a[10]
Traceback (innermost last):
File "<interactive input>", line 1, in ?
IndexError: list index out of range
```

NEGATIVE INDICES

```
# negative indices count
# backward from the end of
# the list
#
# indices: -5 -4 -3 -2 -1
>>> a = [10,11,12,13,14]

>>> a[-1]
14
>>> a[-2]
13
```



The first element in an array has `index=0` as in C. *Take note Fortran programmers!*

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More on list objects

LIST CONTAINING MULTIPLE TYPES

```
# list containing integer,
# string, and another list
>>> a = [10,'eleven',[12,13]]
>>> a[1]
'eleven'
>>> a[2]
[12, 13]

# use multiple indices to
# retrieve elements from
# nested lists
>>> a[2][0]
12
```

Prior to version 2.5, Python was limited to sequences with ~2 billion elements. Python 2.5 can handle up to 2^{63} elements.

LENGTH OF A LIST

```
>>> len(a)
3
```

DELETING OBJECT FROM LIST

```
# use the del keyword
>>> del a[2]
>>> a
[10,'eleven']
```

DOES THE LIST CONTAIN x ?

```
# use in or not in
>>> a = [10,11,12,13,14]
>>> 13 in a
True
>>> 13 not in a
False
```

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Slicing

var[lower:upper:step]

Extracts a portion of a sequence by specifying a lower and upper bound.

The lower-bound element is included, but the upper-bound element *is not included*.

Mathematically: [lower, upper). The step value specifies the stride between elements.

SLICING LISTS

```
# indices:  
#      -5 -4 -3 -2 -1  
#      0  1  2  3  4  
>>> a = [10,11,12,13,14]  
# [10,11,12,13,14]  
>>> a[1:3]  
[11, 12]  
  
# negative indices work also  
>>> a[1:-2]  
[11, 12]  
>>> a[-4:3]  
[11, 12]
```

OMMITTING INDICES

```
# omitted boundaries are  
# assumed to be the beginning  
# (or end) of the list  
  
# grab first three elements  
>>> a[:3]  
[10, 11, 12]  
# grab last two elements  
>>> a[-2:]  
[13, 14]  
# every other element  
>>> a[::-2]  
[10, 12, 14]
```

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A few methods for list objects

some_list.append(x)

Add the element x to the end of the list some_list.

some_list.count(x)

Count the number of times x occurs in the list.

some_list.extend(sequence)

Concatenate sequence onto this list.

some_list.index(x)

Return the index of the first occurrence of x in the list.

some_list.insert(index, x)

Insert x before the specified index.

some_list.pop(index)

Return the element at the specified index. Also, remove it from the list.

some_list.remove(x)

Delete the first occurrence of x from the list.

some_list.reverse()

Reverse the order of elements in the list.

some_list.sort(cmp)

By default, sort the elements in ascending order. If a compare function is given, use it to sort the list.

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List methods in action

```
>>> a = [10,21,23,11,24]

# add an element to the list
>>> a.append(11)
>>> print a
[10,21,23,11,24,11]
# how many 11s are there?
>>> a.count(11)
2
# extend with another list
>>> a.extend([5,4])
>>> print a
[10,21,23,11,24,11,5,4]
# where does 11 first occur?
>>> a.index(11)
3
# insert 100 at index 2?
>>> a.insert(2, 100)
>>> print a
[10,21,100,23,11,24,11,5,4]

# pop the item at index=3
>>> a.pop(3)
23
# remove the first 11
>>> a.remove(11)
>>> print a
[10,21,100,24,11,5,4]
# sort the list (in-place)
# Note: use sorted(a) to
#       return a new list.
>>> a.sort()
>>> print a
[4,5,10,11,21,24,100]
# reverse the list
>>> a.reverse()
>>> print a
[100,24,21,11,10,5,4]
```

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Mutable vs. Immutable

MUTABLE OBJECTS

```
# Mutable objects, such as
# lists, can be changed
# in place.

# insert new values into list
>>> a = [10,11,12,13,14]
>>> a[1:3] = [5,6]
>>> print a
[10, 5, 6, 13, 14]
```



The cStringIO module treats strings like a file buffer and allows insertions. It's useful when working with large strings or when speed is paramount.

IMMUTABLE OBJECTS

```
# Immutable objects, such as
# integers and strings,
# cannot be changed in place.

# try inserting values into
# a string
>>> s = 'abcde'
>>> s[1:3] = 'xy'
Traceback (innermost last):
File "<interactive input>", line 1, in ?
TypeError: object doesn't support
slice assignment

# here's how to do it
>>> s = s[:1] + 'xy' + s[3:]
>>> print s
'axyde'
```

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Tuple – Immutable Sequence

TUPLE CREATION

```
>>> a = (10,11,12,13,14)
>>> print a
(10, 11, 12, 13, 14)
```

LENGTH-1 TUPLE

```
>>> (10,)
(10,)

>>> (10)
10
```



(10) is not a tuple,
but an integer
with parentheses.

PARENTHESES ARE OPTIONAL

```
>>> a = 10,11,12,13,14
>>> print a
(10, 11, 12, 13, 14)
```

TUPLES ARE IMMUTABLE

```
# create a list
>>> a = range(10,15)
[10, 11, 12, 13, 14]

# cast the list to a tuple
>>> b = tuple(a)
>>> print b
(10, 11, 12, 13, 14)

# try inserting a value
>>> b[3] = 23
TypeError: 'tuple' object doesn't
support item assignment
```

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Dictionaries

Dictionaries store *key/value* pairs. Indexing a dictionary by a *key* returns the *value* associated with it. The *key* must be immutable.

DICTIONARY EXAMPLE

```
# Create an empty dictionary using curly brackets.
>>> record = {}

# Each indexed assignment creates a new key/value pair.
>>> record['first'] = 'Jmes'
>>> record['last'] = 'Maxwell'
>>> record['born'] = 1831
>>> print record
{'first': 'Jmes', 'born': 1831, 'last': 'Maxwell'}

# Create another dictionary with initial entries.
>>> new_record = {'first': 'James', 'middle':'Clerk'}
# Now update the first dictionary with values from the new one.
>>> record.update(new_record)
>>> print record
{'first': 'James', 'middle': 'Clerk', 'last':'Maxwell', 'born':
1831}
```

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Accessing and deleting keys and values

ACCESS USING INDEX NOTATION

```
>>> print record['first']
James
```

ACCESS WITH get(key, default)

The `get()` method returns the value associated with a key; the optional second argument is the return value if the key is not in the dictionary.

```
>>> record.get('born', 0)
1831
>>> record.get('home', 'TBD')
'TBD'
>>> record['home']
KeyError: ...
```

REMOVE AN ENTRY WITH DEL

```
>>> del record['middle']
>>> record
{'born': 1831, 'first': 'James', 'last': 'Maxwell'}
```

REMOVE WITH pop(key, default)

`pop()` removes the key from the dictionary and returns the value; the optional second argument is the return value if the key is not in the dictionary.

```
>>> record.pop('born', 0)
1831
>>> record
{'first': 'James', 'last': 'Maxwell'}
>>> record.pop('born', 0)
0
```

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A few dictionary methods

some_dict.clear()

Remove all key/value pairs from the dictionary, `some_dict`.

some_dict.keys()

Return a list of all the keys in the dictionary.

some_dict.copy()

Create a copy of the dictionary

some_dict.values()

Return a list of all the values in the dictionary.

x in some_dict

Test whether the dictionary contains the key `x`.

some_dict.items()

Return a list of all the key/value pairs in the dictionary.

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Dictionary methods in action

```
# dict of animals:count pairs
>>> barn = {'cows': 1,
...             'dogs': 5,
...             'cats': 3}

# test for chickens
>>> 'chickens' in barn
False

# get a list of all keys
>>> barn.keys()
['cats', 'dogs', 'cows']

# get a list of all values
>>> barn.values()
[3, 5, 1]

# return key/value tuples
>>> barn.items()
[('cats', 3), ('dogs', 5),
 ('cows', 1)]

# How many cats?
>>> barn['cats']
3

# Change the number of cats.
>>> barn['cats'] = 10
>>> barn['cats']
10

# Add some sheep.
>>> barn['sheep'] = 5
>>> barn['sheep']
5
```

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Set objects

DEFINITION

A set is an *unordered collection of unique, immutable objects*.

CONSTRUCTION

```
# an empty set
>>> s = set()

# convert a sequence to set
>>> t = set([1,2,3,1])
# note removal of duplicates
>>> t
set([1, 2, 3])
```

ADD ELEMENTS

```
>>> t.add(5)
set([1, 2, 3, 5])
>>> t.update([5,6,7])
set([1, 2, 3, 5, 6, 7])
```

REMOVE ELEMENTS

```
# Remove an element. Raise
# exception if not in the set.
>>> t.remove(1)
>>> t
set([2, 3, 5, 6, 7])
# Remove and return an
# arbitrary element from the set.
>>> t.pop()
2
# Remove element from list
# if it exists.
>>> t.discard(3)
>>> t
set([5, 6, 7])
# Otherwise, do nothing.
>>> t.discard(20)
>>> t
set([5, 6, 7])
```

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Set Operations

OVERLAPPING SETS

```
>>> a = set([1,2,3,4])
>>> b = set([3,4,5,6])
```



UNION

```
>>> a.union(b)
set([1, 2, 3, 4, 5, 6])
>>> a | b
set([1, 2, 3, 4, 5, 6])
```



INTERSECTION

```
>>> a.intersection(b)
set([3, 4])
>>> a & b
set([3, 4])
```



DIFFERENCE

```
>>> a.difference(b)
set([1, 2])
>>> a - b
set([1, 2])
```



SYMMETRIC DIFFERENCE

```
>>> a.symmetric_difference(b)
set([1, 2, 5, 6])
>>> a ^ b #xor
set([1, 2, 5, 6])
```



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Set Containment

OVERLAPPING SETS

```
>>> a = set([1,2,3])
>>> b = set([1,2])
```



ISSUBSET

```
# Is b fully contained in a?
>>> b.issubset(a)
True
>>> b <= a
True
```

ISSUPERSET

```
# Does a fully contain b?
>>> a.issuperset(b)
True
>>> a >= b
True
```



There is also an immutable type of set called a frozenset (analogous to a tuple) which can be used as a dictionary key or an element of a set.

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Assignment of “simple” object

Assignment creates object references.

```
>>> x = 0
# This causes x and y to point
# to the same value.
>>> y = x
# Re-assigning y to a new value
# decouples the two variables.
>>> y = "foo"
>>> print x
0
```

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Assignment of Container object

Assignment creates object references.

```
>>> x = [0, 1, 2]
# This causes x and y to point
# to the same list.
>>> y = x
# A change to y also changes x.
>>> y[1] = 6
>>> print x
[0, 6, 2]
# Re-assigning y to a new list
# decouples the two variables.
>>> y = [3, 4]
```

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If statements

if/elif/else provides conditional execution of code blocks.

IF STATEMENT FORMAT

```
if <condition>:  
    <statement 1>  
    <statement 2>  
elif <condition>:  
    <statements>  
else:  
    <statements>
```

IF EXAMPLE

```
# a simple if statement  
>>> x = 10  
>>> if x > 0:  
...     print 'Hey!'  
...     print 'x > 0'  
... elif x == 0:  
...     print 'x is 0'  
... else:  
...     print 'x is negative'  
... < hit return >  
Hey!  
x > 0
```

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Test Values

- zero, **None**, “”, and empty objects are treated as `False`.
- All other objects are treated as `True`.

EMPTY OBJECTS

```
# empty objects test as false  
>>> x = []  
>>> if x:  
...     print 1  
... else:  
...     print 0  
... < hit return >  
0
```

It often pays to be explicit. If you are testing for an empty list, then test for:

```
if len(x) == 0:
```



This is clearer to future readers of your code. It also can avoid bugs where `x==None` may be passed in and unexpectedly go down this path.

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While loops

while loops iterate until a condition is met

```
while <condition>:
    <statements>
```

WHILE LOOP

```
# the condition tested is
# whether lst is empty
>>> lst = range(3)
>>> while lst:
...     print lst
...     lst = lst[1:]
... < hit return >
[0, 1, 2]
[1, 2]
[2]
```

BREAKING OUT OF A LOOP

```
# breaking from an infinite
# loop
>>> i = 0
>>> while True:
...     if i < 3:
...         print i,
...     else:
...         break
...     i = i + 1
... < hit return >
0 1 2
```

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For loops

for loops iterate over a sequence of objects

```
for <loop_var> in <sequence>:
    <statements>
```

TYPICAL SCENARIO

```
>>> for item in range(5):
...     print item,
... < hit return >
0 1 2 3 4

# For a large range, xrange()
# is faster and more memory
# efficient.
>>> for item in xrange(10**6):
...     print item,
... < hit return >
0 1 2 3 4 5 6 7 8 9 10 11 ...
```

LOOPING OVER A STRING

```
>>> for item in 'abcde':
...     print item,
... < hit return >
a b c d e
```

LOOPING OVER A LIST

```
>>> animals=['dogs','cats',
...             'bears']
>>> accum = ''
>>> for animal in animals:
...     accum += animal + ' '
... < hit return >
>>> print accum
dogs cats bears
```

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List Comprehension

LIST TRANSFORM WITH LOOP

```
# element by element transform of
# a list by applying an
# expression to each element
>>> a = [10,21,23,11,24]
>>> results=[]
>>> for val in a:
...     results.append(val+1)
>>> results
[11, 22, 24, 12, 25]
```

FILTER-TRANSFORM WITH LOOP

```
# transform only elements that
# meet a criteria
>>> a = [10,21,23,11,24]
>>> results=[]
>>> for val in a:
...     if val>15:
...         results.append(val+1)
>>> results
[22, 24, 25]
```

LIST COMPREHENSION

```
# list comprehensions provide
# a concise syntax for this sort
# of element by element
# transformation
>>> a = [10,21,23,11,24]
>>> [val+1 for val in a]
[11, 22, 24, 12, 25]
```

LIST COMPREHENSION WITH FILTER

```
>>> a = [10,21,23,11,24]
>>> [val+1 for val in a if val>15]
[22, 24, 25]
```

Consider using a list comprehension whenever you need to transform one sequence to another.

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Generator Expressions

Generator expressions are like list comprehensions without the brackets:

LIST COMPREHENSION

```
>>> set([str(i) for i in range(5)])
set(['1', '0', '3', '2', '4'])

# tests on sequences
>>> any([i >= 3 for i in range(5)])
True
>>> all([i >= 3 for i in range(5)])
False

# summation
>>> sum([i**2 for i in range(5)])
30
```

GENERATOR EXPRESSION

```
>>> set(str(i) for i in range(5))
set(['1', '0', '3', '2', '4'])

# tests on sequences
>>> any(i >= 3 for i in range(5))
True
>>> all(i >= 3 for i in range(5))
False

# summation
>>> sum(i**2 for i in range(5))
30
```

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Multiple assignments

FROM TUPLE TO TUPLE

```
# creating a tuple without ()
>>> d = 1,2,3
>>> d
(1, 2, 3)
```

```
# multiple assignments
>>> a,b,c = 1,2,3
>>> print b
2

# multiple assignments from a
# tuple
>>> a,b,c = d
>>> print b
2
```

FROM LIST TO TUPLE

```
# also works for lists
>>> a,b,c = [1,2,3]
>>> print b
2
```

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Looping Patterns

MULTIPLE LOOP VARIABLES

```
# Looping through a sequence of
# tuples allows multiple
# variables to be assigned.
>>> pairs = [(0,'a'),(1,'b'),
...             (2,'c')]
>>> for index, value in pairs:
...     print index, value
0 a
1 b
2 c
```

ENUMERATE

```
# enumerate -> index, item.
>>> y = ['a', 'b', 'c']
>>> for index, value in enumerate(y):
...     print index, value
0 a
1 b
2 c
```

ZIP

```
# zip 2 or more sequences
# into a list of tuples
>>> x = [0, 1, 2]
>>> y = ['a', 'b', 'c']
>>> zip(x,y)
[(0, 'a'), (1, 'b'), (2, 'c')]
>>> for index, value in zip(x,y):
...     print index, value
0 a
1 b
2 c
```

REVERSED

```
>>> z = [(0,'a'),(1,'b'),(2,'c')]
for index, value in reversed(z):
...     print index, value
2 c
1 b
0 a
```

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Looping over a dictionary

```
>>> d = {'a':1, 'b':2, 'c':3}
```

DEFAULT LOOPING (KEYS)

```
>>> for key in d:  
...     print key, d[key]  
a 1  
c 3  
b 2
```

LOOPING OVER KEYS (EXPLICIT)

```
>>> for key in d.keys():  
...     print key, d[key]  
a 1  
c 3  
b 2
```

LOOPING OVER VALUES

```
>>> for val in d.values():  
...     print val  
1  
3  
2
```

LOOPING OVER ITEMS

```
>>> for key, val in d.items():  
...     print key, val  
a 1  
c 3  
b 2
```

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Anatomy of a function

The keyword **def** indicates the start of a function.

Function arguments are listed, separated by commas. They are passed by *assignment*.

Indentation is used to indicate the contents of the function. It is *not* optional, but a part of the syntax.

```
def add(arg0, arg1):  
    """Add two numbers"""\n    a = arg0 + arg1  
    return a
```

A colon (:) terminates the function signature.

An optional **return** statement specifies the value returned from the function. If **return** is omitted, the function returns the special value **None**.

An optional **docstring** documents the function in a standard way for tools like ipython.

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Our new function in action

```
# We'll create our function
# on the fly in the
# interpreter.
>>> def add(x,y):
...     a = x + y
...     return a

# Test it out with numbers.
>>> val_1 = 2
>>> val_2 = 3
>>> add(val_1,val_2)
5

# How about strings?
>>> val_1 = 'foo'
>>> val_2 = 'bar'
>>> add(val_1,val_2)
'foobar'

# Functions can be assigned
# to variables.
>>> func = add
>>> func(val_1, val_2)
'foobar'

# How about numbers and strings?
>>> add('abc',1)
Traceback (innermost last):
File "<interactive input>", line 1, in ?
File "<interactive input>", line 2, in add
TypeError: cannot add type "int" to string
```

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Function Calling Conventions

POSITIONAL ARGUMENTS

```
# The "standard" calling
# convention we know and love.
>>> def add(x, y):
...     return x + y

>>> add(2, 3)
5
```

KEYWORD ARGUMENTS

```
# specify argument names
>>> add(x=2, y=3)
5

# or even a mixture if you are
# careful with order
>>> add(2, y=3)
5
```

DEFAULT VALUES

```
# Arguments can be
# assigned default values.
>>> def quad(x,a=1,b=1,c=0):
...     return a*x**2 + b*x + c

# Use defaults for a, b and c.
>>> quad(2.0)
6.0

# Set b=3. Defaults for a & c.
>>> quad(2.0, b=3)
10.0

# Keyword arguments can be
# passed in out of order.
>>> quad(2.0, c=1, a=3, b=2)
17.0
```

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Function Calling Conventions

VARIABLE NUMBER OF ARGS

```
# Pass in any number of
# arguments. Extra arguments
# are put in the tuple args.
>>> def foo(x, y, *args):
...     print x, y, args

>>> foo(2, 3, 'hello', 4)
2 3 ('hello', 4)
```

VARIABLE KEYWORD ARGS

```
# Extra keyword arguments
# are put into the dict kw.
>>> def bar(x, y=1, **kw):
...     print x, y, kw

>>> bar(1, y=2, a=1, b=2)
1 2 {'a': 1, 'b': 2}
```

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Function Calling Conventions

THE 'ANYTHING' SIGNATURE

```
# This signature takes any
# number of positional and
# keyword arguments.
>>> def foo(*args, **kw):
...     print args, kw

>>> foo(2, 3, x='hello', y=4)
(2, 3) {'x': 'hello', 'y': 4}
```

MULTIPLE FUNCTION RETURNS

```
# To return multiple values
# from a function, we return
# a tuple containing those
# values. This is a common
# use of multiple (tuple)
# assignment.
>>> def functions(x):
...     y1 = x**2 + x
...     y2 = x**3 + x**2 + 2*x
...     return y1, y2

>>> a, b = functions(c)
```

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Expanding Function Arguments

POSITIONAL ARGUMENT EXPANSION

```
>>> def add(x, y):
...     return x + y

# '*' in a function call
# converts a sequence into the
# arguments to a function.
>>> vars = [1,2]
>>> add(*vars)
3
```

KEYWORD ARGUMENT EXPANSION

```
>>> def bar(x, y=1, **kw):
...     print x, y, kw

# '**' expands a
# dictionary into keyword
# arguments for a function.
vars = {'y':3, 'z':4}
>>> bar(1, **vars)
1, 3, {'z': 4}
```

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Modules

EX1.PY

```
# ex1.py

PI = 3.1416

def sum(lst):
    tot = lst[0]
    for value in lst[1:]:
        tot = tot + value
    return tot

w = [0,1,2,3]
print sum(w), PI
```

FROM SHELL

```
[ej@bull ej]$ python ex1.py
6 3.1416
```

FROM INTERPRETER

```
# load and execute the module
>>> import ex1
6 3.1416
# get/set a module variable
>>> print ex1.PI
3.1416
>>> ex1.PI = 3.14159
>>> print ex1.PI
3.14159
# call a module function
>>> t = [2,3,4]
>>> ex1.sum(t)
```

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Modules cont.

INTERPRETER

```
# load and execute the module
>>> import ex1
6 3.1416
< edit file >
# import module again
>>> import ex1
# nothing happens!!!

# Use reload to force a
# previously imported library
# to be reloaded.
>>> reload(ex1)
10 3.14159
```

EDITED EX1.PY

```
# ex1.py version 2

PI = 3.14159

def sum(lst):
    tot = 0
    for value in lst:
        tot = tot + value
    return tot

w = [0,1,2,3,4]
print sum(w), PI
```

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Modules cont. 2

A Python file can be used as a script, or as a module, or both.

EX2.PY

```
# An example module that can
# be run as a script.
PI = 3.1416

def sum(lst):
    """ Sum the values in a
        list.
    """
    tot = 0
    for value in lst:
        tot = tot + value
    return tot

def add(x,y):
    " Add two values."
    a = x + y
    return a

def test():
    w = [0,1,2,3]
    assert( sum(w) == 6)
    print 'test passed'

# This code runs only if this
# module is the main program.
if __name__ == '__main__':
    test()
```

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import Variations

BASIC IMPORTS

```
# The most basic import
>>> import ex2
>>> ex2.PI
3.1416
```

ALIASING A NAME

```
# Use an 'alias'
>>> import ex2 as e2
>>> e2.PI
3.1416
```

IMPORTING SPECIFIC SYMBOLS

```
# Select specific names to
# bring into the local
# namespace.
>>> from ex2 import add, PI
>>> PI
3.1416
>>> add(2,3)
5
```

IMPORTING *EVERYTHING*

```
# Pull *everything* into the
# local namespace.
>>> from ex2 import *
>>> PI
3.1416
>>> add(3,4.5)
7.5
```

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Modules cont. 3

PACKAGES

Often a library will contain several modules. These may be organized in a hierarchical directory structure, and imported using "dotted module names". The first and the intermediate names (if any) are called "packages".

Example:

```
>>> from foo.bar import func
>>> from foo.baz import zap
```

bar.py and **baz.py** are modules in the package **foo**.

FILE STRUCTURE

```
foo/
  __init__.py
  bar.py (defines func)
  baz.py (defines zap)
```

- The directory **foo** must be in the python search path
- The file **__init__.py** indicates that **foo** is a package. It may be an empty file.
- In the simplest case:
 $package = \text{directory}$
 $module = \text{python file}$

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Standard Modules

Python has a large library of standard modules ("batteries included"):

- re** - regular expressions
- copy** – shallow and deep copy operations
- datetime** - time and date objects
- math, cmath** - real and complex math
- decimal, fractions** - arbitrary precision decimal and rational number objects
- os, os.path, shutil** - filesystem operations
- sqlite3** - internal SQLite database
- gzip, bz2, zipfile, tarfile** – compression and archiving formats
- csv, netrc** – file format handling
- xml** – various modules for handling XML
- htmllib** – an HTML parser
- httpplib, ftplib, poplib, socket, etc.** – modules for standard internet protocols

- cmd** – support for command interpreters
- pdb** – Python interactive debugger
- profile, cProfile, timeit** – Python profilers
- collections, heapq, bisect** – standard CS algorithms and data structures
- mmap** – memory-mapped files
- threading, Queue** – threading support
- multiprocessing** – process based 'threading'
- subprocess** – executing external commands
- pickle, cPickle** – object serialization
- struct** – interpret bytes as packed binary data

and many more... To see the content of one:
>>> dir(module_name)

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Setting up PYTHONPATH

PYTHONPATH is an environment variable (or set of registry entries on Windows) that lists the directories Python searches for modules.

WINDOWS

- Right-click on My Computer
- Click Properties
- Click Advanced Tab
- Click Environment Variables Button at the bottom of the Advanced Tab
 - Click New to create PYTHONPATH or
 - Click Edit to change existing PYTHONPATH
- Changes take effect in the next Command Prompt or IPython session.

UNIX: .cshrc

```
!! NOTE: The following should !!
!! all be on one line !!

setenv PYTHONPATH
$PYTHONPATH:$HOME/your_modules
```

UNIX: .bashrc

```
PYTHONPATH=$PYTHONPATH:$HOME/your
_modules
export PYTHONPATH
```

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Reading files

FILE INPUT EXAMPLE

```
>>> results = []
>>> f = open('c:\\rcs.txt','r')
# Read all the lines.
>>> lines = f.readlines()
>>> f.close()
# Discard the header.
>>> lines = lines[1:]

>>> for line in lines:
...     # split line into fields
...     fields = line.split()
...     # convert text to numbers
...     freq = float(fields[0])
...     vv = float(fields[1])
...     hh = float(fields[2])
...     # group & append to results
...     all = [freq,vv,hh]
...     results.append(all)
... < hit return >
```

PRINTING THE RESULTS

```
>>> for i in results: print i
[100.0, -20.30..., -31.20...]
[200.0, -22.70..., -33.60...]
```

EXAMPLE FILE: RCS.TXT

| #freq (MHz) | vv (dB) | hh (dB) |
|-------------|---------|---------|
| 100 | -20.3 | -31.2 |
| 200 | -22.7 | -33.6 |

 See demo/reading_files directory
for code.

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More compact version

ITERATING ON A FILE AND LIST COMPREHENSIONS

```
>>> results = []
>>> f = open('c:\\rcs.txt','r')
>>> f.readline()
'#freq (MHz)  vv (dB)  hh (dB) \\n'
>>> for line in f:
...     all = [float(val) for val in line.split()]
...     results.append(all)
... < hit return >
>>> for i in results:
...     print i
... < hit return >
```

EXAMPLE FILE: RCS.TXT

| #freq (MHz) | vv (dB) | hh (dB) |
|-------------|---------|---------|
| 100 | -20.3 | -31.2 |
| 200 | -22.7 | -33.6 |

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Writing files

FILE OUTPUT

```
>>> # Mode 'w': create new file:
>>> f = open('a.txt', 'w')
>>> f.write('Hello, world!')
>>> f.close()
>>> open('a.txt').read()
'Hello, world!'
>>> # Use the 'with' statement:
>>> with open('a.txt', 'w') as f:
....     f.write('Wow!')
....
>>> open('a.txt').read()
'Wow!'
>>> # Mode 'a': append to file:
>>> with open('a.txt', 'a') as f:
....     f.write(' Boo.')
....
>>> open('a.txt').read()
'Wow! Boo.'
```

REDIRECTED PRINT

```
>>> # Redirect output of a
>>> # print statement:
>>> f = open('a.txt', 'w')
>>> print >> f, "Here I am."
>>> f.close()
>>> open('a.txt').read()
'Here I am.\n'
```

WRITE AND READ

```
>>> f = open('a.txt', 'w+')
>>> print >> f, 12, 34, 56
>>> f.seek(3)
>>> f.read(2)
'34'
>>> f.close()
```

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Particle Class Example

SIMPLE PARTICLE CLASS

```
>>> class Particle(object):
...     # Initializer method
...     def __init__(self, m, v):
...         self.mass = m # Assign attribute values of new object
...         self.velocity = v
...     # Method for calculating object momentum
...     def momentum(self):
...         return self.mass * self.velocity
...     # A "magic" method defines object's string representation.
...     # Evaluating the repr recovers the Particle object.
...     def __repr__(self):
...         return "Particle({0}, {1})".format(
...             repr(self.mass), repr(self.velocity))
```

EXAMPLE

```
>>> a = Particle(3.2, 4.1)
>>> print a.momentum()
13.12
>>> a
Particle(3.2, 4.1)
```

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Overloading Addition

SIMPLE PARTICLE CLASS

Classes can override many behaviors using special method names — including numeric behavior.

```
...     def __add__(self, other)
...         if not isinstance(other, Particle):
...             return NotImplemented
...         mnew = self.mass + other.mass
...         vnew = (self.momentum() + other.momentum()) / mnew
...         return Particle(mnew, vnew)
```

EXAMPLE (cont.)

```
>>> b = Particle(8.6, 10.2)
>>> b, a
(Particle(8.6, 10.2), Particle(3.2, 4.1))
>>> c = a + b
>>> c
Particle(11.8, 8.545762711864406)
>>> print c.momentum()
100.84
```

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Sorting

IN-PLACE VS NEW LIST

```
# sorting
>>> x = ['s', 'o', 'r', 't']
# new list
>>> sorted(x)
['o', 'r', 's', 't']
# in-place
>>> x.sort()
>>> x
['o', 'r', 's', 't']

# reversing
# new list (note explicit 'list')
>>> x = ['b', 'a', 'c', 'k']
>>> list(reversed(x))
['k', 'c', 'a', 'b']
# in-place
>>> x.reverse()
>>> x
['k', 'c', 'a', 'b']
```

CUSTOM SORTS

```
# define a key function to
# transform values before
# comparing in a sort
>>> def ignore_case(x):
...     return x.lower()

>>> x = ['S', 'o', 'r', 'T']
>>> sorted(x)
['S', 'T', 'o', 'r']
>>> sorted(x, key=ignore_case)
['o', 'r', 'S', 'T']
```

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Sorting

SORTING CLASS INSTANCES

```
# comparison functions for a variety of particle values
>>> def by_mass(x):
...     return x.mass
>>> def by_momentum(x):
...     return x.momentum()
>>> def by_kinetic_energy(x):
...     return 0.5*x.mass*x.velocity**2

# sorting particles in a list by their various properties
>>> from particle import Particle
>>> x = [Particle(1.2,3.4), Particle(2.1,2.3), Particle(4.6,.7)]
>>> sorted(x, key=by_mass)
[(m:1.2, v:3.4), (m:2.1, v:2.3), (m:4.6, v:0.7)]

>>> sorted(x, key=by_momentum)
[(m:4.6, v:0.7), (m:1.2, v:3.4), (m:2.1, v:2.3)]

>>> sorted(x, key=by_kinetic_energy)
[(m:4.6, v:0.7), (m:2.1, v:2.3), (m:1.2, v:3.4)]
```

See demo/particle directory for sample code.

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Excellent source of help

<http://www.python.org/doc>

The screenshot shows the Python Documentation website. At the top, there's a navigation bar with links for "ABOUT", "NEWS", "DOCUMENTATION", "CURRENT DOCS", "BEGINNER'S GUIDE", "FAQS", "WIKI", "OTHER DOC RESOURCES", "PEP INDEX", "BOOK LIST", "TOPIC GUIDES", "NEW-STYLE CLASSES", "REGULAR EXPRESSIONS", "AUDIO/VISUAL TALKS", "DOWNLOAD", "COMMUNITY", "FOUNDATION", "CORE DEVELOPMENT", and "LINKS". Below the navigation bar is a search bar with a "search" button and links for "Advanced Search" and "Screen styles" (normal*, large, userpref). The main content area has sections for "Python Documentation", "Python 2.x", and "Python 3.x", each listing various documentation resources like "Download Current Documentation", "Search the online docs", and "Browse Current Documentation - (Module Index)".

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Error and Exception Handling

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Basic Exception Handling

ERROR ON LOG OF ZERO

```
>>> import math
>>> math.log10(10.0)
1.0
>>> math.log10(0.0)
Traceback (innermost last):
ValueError: math domain error
```

CATCHING ERROR AND CONTINUING

```
>>> a = 0.0
>>> try:
...     r = math.log10(a)
... except ValueError:
...     print 'Warning: overflow occurred. Value set to -100.0'
...     # set value to -100.0 and continue
...     r = -100.0
Warning: overflow occurred. Value set to -100.0
>>> print r
-100.0
```

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Exceptions

ACCESS TO THE EXCEPTION OBJECT

```
try:
    a = value_bag[key]
    r = math.log10(a)
except KeyError as error:
    print "Variable '%s' not found" % error.args
```



Exception Object

MULTIPLE EXCEPTION CLAUSES

```
try:
    a = value_bag[key]
    r = math.log10(a)
except KeyError as error:
    print "Variable '%s' not found" % error.args
except ValueError:
    print 'Warning: overflow occurred. Value set to -100.0'
    # set value to -100.0 and continue
    r = -100.0
```

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Exceptions

HANDLING MULTIPLE EXCEPTIONS IN ONE CODE BLOCK

```
try:
    a = value_bag[key]
    r = math.log10(a)
except (KeyError, ValueError) as error:
    print "an error occurred", error
```

CATCH ALL EXCEPTIONS

```
# If the Exception exception type is
# specified, almost all exceptions
# are caught. Note: Don't do this in
# libraries because it can "mask"
# unexpected exceptions, which
# should be passed to calling code.
try:
    employee = directory_lookup(name)
except Exception as e:
    print "An error occurred: %s" % e
```



You can also leave off the exception type completely and catch all exceptions, including SystemExit and KeyboardInterrupt. This can make it hard to stop execution of a program, so this is almost never a good idea.

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Exceptions – Finally Clause

TRY, FINALLY

```
# The finally clause always executes.  Use it for code that
# needs to "clean up" a resource whether the code executed
# successfully or not.

try:
    # We don't want others to use the radio_station object
    # while it is on the air.
    radio_station.on_air = True
    radio_station.broadcast("Pinball Wizard")
except KeyError as error:
    print "Could not find song '%s'" % error.args
finally:
    # If an exception occurs, or the song finishes,
    # the station is taken off air.
    radio_station.on_air = False
```

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Exceptions – Else Clause

TRY, ELSE

```
# The else clause only executes if an exception *does not*
# occur.

# An example from Python's standard tutorial.
#
# Print out the line count for all the file names passed in
# on the command line.
for arg in sys.argv[1:]:
    try:
        f = open(arg, 'r')
    except IOError:
        print 'cannot open', arg
    else:
        print arg, 'has', len(f.readlines()), 'lines'
        f.close()
```

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Raising Exceptions

RAISE

```
# Use the raise statement to raise an exception from your code.

def percent_range_check(percent):
    if not 0.0 <= percent <= 100.0:
        msg = "Percent value should be between 0 and 100"
        # This is the standard, Python 3.0 compatible
        # way to raise exceptions.
        raise ValueError(msg)

    # The following also works, but is deprecated. It will not work
    # in Python 3.0
    # raise ValueError, msg

>>> percent_range_check(101.0)
ValueError: Percent value should be between 0 and 100
```

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Error Messages

RAISE

```
# Use the raise statement to raise an exception from your code.

def percent_range_check(percent):
    if not 0.0 <= percent <= 100.0:
        msg = "Percent value should be between 0 and 100"
        raise ValueError(msg)

>>> percent_range_check(101.0)
ValueError: Percent value should be between 0 and 100
```

INFORMATIVE ERROR MESSAGES

```
# If possible, print out the offending value in error messages.
def percent_range_check2(percent):
    if not 0.0 <= percent <= 100.0:
        msg = "Percent (%3.2f) is not between 0 and 100" % percent
        raise ValueError(msg)

>>> percent_range_check2(101.0)
ValueError: Percent(101.00) is not between 0 and 100
```

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Warnings

WARNINGS

```
# Warnings alert users without halting execution.
import warnings

def percent_range_warning(percent):
    if not 0.0 <= percent <= 100.0:
        msg = "Percent(%3.2f) is not between 0 and 100" % percent
        warnings.warn(msg, RuntimeWarning)

# Warnings are different than exceptions because they don't halt execution.
>>> percent_range_warning(101.0)
RuntimeWarning: Percent(101.00) is not between 0 and 100

# You can choose to ignore certain types of warnings globally.
# allowable actions: error, ignore, always, default, once, module
>>> warnings.filterwarnings(action="ignore", category=RuntimeWarning)
>>> percent_range_warning(101.0)
<no output>
```

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Exception and Warnings Example

```
import warnings

def weighted_average(values, weights):
    """
    Return the average of all the values weighted by the weights array.
    Both values and weights are numpy arrays and must be the same length.
    The sum of the weights must be 1.0.
    """

    #ensure weights sum to (nearly) 1.0
    weights_total = sum(weights)
    if not allclose(weights_total, 1.0, atol=1e-8):
        msg = "The sum of the weights should usually be 1.0. "\
              "Instead, it was '%f'" % weights_total
        warnings.warn(msg)

    # Provide useful error message for unequal array lengths.
    if len(weights) != len(values):
        msg = "The values (len=%d) and weights (len=%d) arrays" \
              "must have the same lengths." % (len(values), len(weights))
        raise ValueError(msg)

    # weighted average calculation
    avg = sum(values * weights) / weights_total

    return avg
```

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Defining New Exceptions

EXCEPTION CLASSES

```
class LengthMismatchError(ValueError):
    """ Sequence of wrong length was used """
    pass

def check_for_length_mismatch(a, b):
    """ Compare the lengths of sequences a and b.  If they are different,
        raise a LengthMismatchError.
    """
    if len(a) != len(b):
        msg = "The two sequences do not have the same length " \
              "(%d!=%d)." % (len(a), len(b))
        raise LengthMismatchError(msg)

>>> check_for_length_mismatch([1,2],[1,2,3])
LengthMismatchError: The two sequences do not have the same length (2!=3).
```

CATCHING BASE EXCEPTIONS

```
# Catching either LengthMismatchError, or ValueError will catch our exception.
>>> try:
...     check_for_length_mismatch([1,2],[1,2,3])
... except ValueError:
...     print "exception caught"
exception caught
```

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Robust File IO Error Handling

TYPICAL FILE IO TRY BLOCKS

```
try:
    file = open(file_name, "rb")
    try:
        # Move into the file header and read the "name" field.
        file.seek(NAME_OFFSET)
        name = file.read(12)

        # Other file manipulation...

    finally:
        # Ensure File is closed, even if an exception occurs.
        file.close()
except IOError as err:
    # Handle file IO Errors that occur during opening the file or
    # reading data from the file here.  Use err(errno) to determine
    # the type of IOError if necessary.

    # Using the logging system to report unhandled exceptions.
    logging.exception("unexpected IOError")
```

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Using ‘with’ for File IO Error Handling

TYPICAL FILE IO TRY BLOCKS

```
# Enable the "with" statement feature within this module.  
# Not necessary for Python >= 2.6.  
from __future__ import with_statement  
  
try:  
    with open("myfile.txt", "rb") as file:  
        # Move into the file header and read the "name" field.  
        file.seek(NAME_OFFSET)  
        name = file.read(12)  
  
        # Other file manipulation...  
except IOError as err:  
    # Handle file IO Errors that occur during opening the file or  
    # reading data from the file here.  Use err(errno) to determine  
    # the type of IOError if necessary.  
  
    # Using the logging system to report unhandled exceptions.  
    logging.exception("unexpected IOError")
```

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Object Oriented Programming In Python

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Modeling a Power Plant

ATTRIBUTES

```
# Data that describes the
# modeled "object"

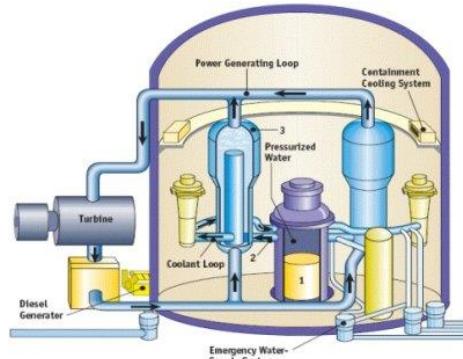
name: Comanche Peak
maximum_output: 2.3 Gigawatts
current_output: ? Gigawatts
status: normal
night_watchman: Homer Simpson (!)
...
```



BEHAVIORS (METHODS)

```
# tasks or operations that the
# model does.

start_up()
shut_down()
emergency_shutdown()
...
```



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Creating Objects

Object oriented programming unifies (encapsulates) attributes and behavior within a single definition, called a Class.

Instances, or Objects, of a class are specific manifestations of that class.

INSTANTIATING CLASS INSTANCES (OBJECTS)

```
Instance           Class
↓                 ↓
>>> plant_1 = PowerPlant(name='Comanche Peak')

# Create a 2nd instance from the same class
>>> plant_2 = PowerPlant(name='Susquehanna')
```

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Working with Objects

```
# Our befuddled friend.
>>> homer = Person(first='Homer', last='Simpson')

# Create the power plant he is in charge of...
>>> plant = PowerPlant(name='Comanche Peak', maximum_output=2.3,
                      night_watchman=homer)

# Start the plant using the 'start_up' method.
>>> plant.start_up()

# Homer does his thing.
>>> homer.eat('donut')
>>> homer.take_nap()

# Check the status (an attribute) of
# the plant. No Bueno.
>>> if plant.status != 'normal':
...     print 'status:', plant.status
...     homer.speak('Doh!')
...     plant.emergency_shutdown()
status: meltdown
Homer says 'Doh!'
```



Class Definition

```
class PowerPlant(object):

    # Constructor method
    def __init__(self, # self is ALWAYS the first argument.
                 name='', maximum_output=0.0, night_watchman=None):
        # assign passed-in arguments to new object
        self.name = name
        self.maximum_output = maximum_output
        self.night_watchman = night_watchman
        # Initialize other attributes.
        self.current_output = 0.0
        self.status = 'normal'

    # class methods
    def start_up(self):
        self.start_reactor_cooling_pump()
        self.reduce_boric_acid_concentration()
        self.remove_control_rods()

    def shut_down(self):
        ...
    <other methods>
```

Object Creation Process

CREATING A CLASS OBJECT

```
# What does Python do when it sees this line of code?
>>> plant = PowerPlant(name='Comanche Peak', maximum_output=2.3,
                      night_watchman=homer)
```

UNDER THE COVERS...

```
# The first step is to call the PowerPlant class' "magic"
# __new__ method to create the object. (This is a secret...)
new_object = PowerPlant.__new__(PowerPlant,
                                 name='Comanche Peak',
                                 maximum_output=2.3,
                                 night_watchman=homer)

# The second step is to call the magic "constructor" method, __init__.
# This is the method you will need to write...
PowerPlant.__init__(new_object,
                    name='Comanche Peak',
                    maximum_output=2.3,
                    night_watchman=homer)

# Python hands this newly created object back to you.
plant = new_object
```

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Particle Class Example

SIMPLE PARTICLE CLASS

```
>>> class Particle(object):
...     # Initializer method
...     def __init__(self, m, v):
...         self.mass = m # Assign attribute values of new object
...         self.velocity = v
...     # Method for calculating object momentum
...     def momentum(self):
...         return self.mass * self.velocity
...     # A "magic" method defines object's string representation.
...     # Evaluating the repr recovers the Particle object.
...     def __repr__(self):
...         return "Particle({0}, {1})".format(
...             repr(self.mass), repr(self.velocity))
```

EXAMPLE

```
>>> a = Particle(3.2, 4.1)
>>> print a.momentum()
13.12
>>> a
Particle(3.2, 4.1)
```

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Overloading Addition

SIMPLE PARTICLE CLASS

Classes can override many behaviors using special method names — including numeric behavior.

```
...     def __add__(self, other):
...         if not isinstance(other, Particle):
...             return NotImplemented
...         mnew = self.mass + other.mass
...         vnew = (self.momentum() + other.momentum()) / mnew
...         return Particle(mnew, vnew)
```

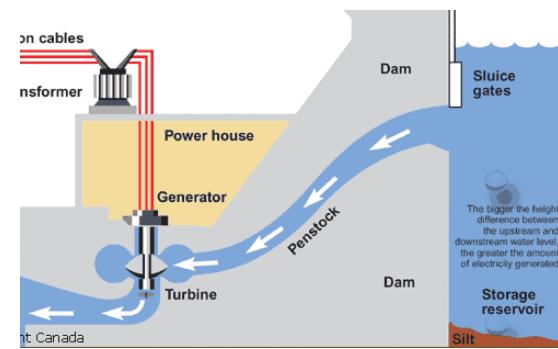
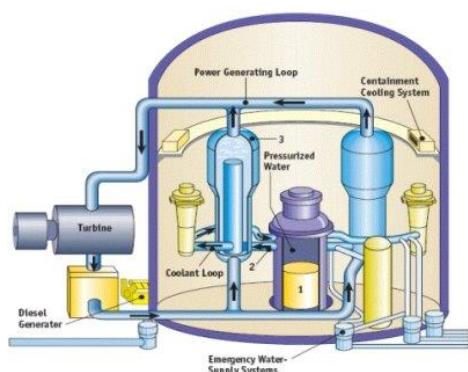
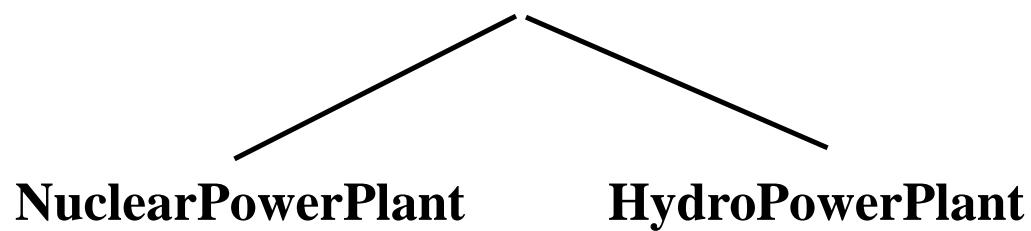
EXAMPLE (cont.)

```
>>> b = Particle(8.6, 10.2)
>>> b, a
(Particle(8.6, 10.2), Particle(3.2, 4.1))
>>> c = a + b
>>> c
Particle(11.8, 8.545762711864406)
>>> print c.momentum()
100.84
```

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Inheritance

PowerPlant



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Base Class

```

class PowerPlant(object):

    # Constructor method
    def __init__(self, # "self" is ALWAYS the first argument.
                 name='', maximum_output=0.0, night_watchman=None):
        # assign passed-in arguments to new object
        self.name = name
        self.maximum_output = maximum_output
        self.night_watchman = night_watchman
        # Initialize other attributes.
        self.current_output = 0.0
        self.status = 'normal'

    # Default implementation for methods
    def start_up(self):
        self.current_output = self.maximum_output

    def shut_down(self):
        self.current_output = 0.0

    ...

```

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Sub-Classing

```

# Derive 'specialized' classes from the PowerPlant base class.
# They will 'inherit' the methods of the base class.
class NuclearPowerPlant(PowerPlant):

    # over-ride methods that need custom behavior.
    def start_up(self):
        self.start_reactor_cooling_pump()
        self.reduce_boric_acid_concentration()
        self.remove_control_r rods()

    def shut_down(self):
        ...

```

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Using Super

```
# Use 'super' to call the "super-class" (parent class) methods.
class HydroPowerPlant(PowerPlant):

    def __init__(self, name='', river_name='',
                 maximum_output=0.0, night_watchman=None):

        # Use 'super' to call an over-ridden method from the
        # base class.
        super(HydroPowerPlant, self).__init__(name=name,
                                              maximum_output=maximum_output,
                                              night_watchman=night_watchman)
        self.river_name = river_name

    # over-ride methods that need custom behavior.
    def start_up(self):
        self.open_sluice_gate()
        self.unlock_turbine_shaft()
        self.remove_control_rods()
```

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Interchangeable Classes

```
# The same code will work without modification for a
# NuclearPowerPlant or a HydroPowerPlant.
>>> homer = Person(first='Homer', last='Simpson')

# Create the power plant he is in charge of...
>>> plant = HydroPowerPlant(name='Comanche Peak', maximum_output=2.3,
                           night_watchman=homer)

# Start the plant using the 'start_up' method.
>>> plant.start_up()

# Homer does his thing.
>>> homer.eat('donut')
>>> homer.take_nap()

# Check the status (an attribute) of the plant. No Bueno.
>>> if plant.status != 'normal':
...     print 'status:', plant.status
...     homer.speak('Doh!')
...     plant.emergency_shutdown()
status: Fish stuck in impeller.
Homer says 'Doh!'
```

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Advanced Python Topics

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Properties

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Properties: an example

```
# my_number.py
class MyNumberA(object):
    def __init__(self, number):
        self.number = number
    def set_number(self, value):
        if isinstance(value, basestring):
            self.number = eval(value)
        else:
            self.number = value
```

The `set_number` method allows the value to be an integer or a hex or binary string (e.g. '0xFF' or '0b1101').

```
>>> a = MyNumberA(number=13)
>>> a.number
13
>>> a.number = 200
>>> a.number
200
```

```
>>> a.set_number('0xFF')
>>> a.number
255
>>> a.number = '0xFFFF' # !!!
>>> a.number
'0xFFFF'
```

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Properties: definition

Wouldn't this be nice?

```
>>> a.number = '0xFFFF'
>>> a.number
65535
>>> a.number = '0b1101'
>>> a.number
13
```

The number magically converts a hex string or a binary string to the integer value.

We *can* do this, by creating a **property**. A property allows us to implement something that acts like an attribute, but attempting to get or set a value of the attribute actually results in a function call. `property()` is a built-in function in Python.

```
property(fget=None, fset=None, fdel=None, doc=None)
```

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Properties: application 1

```
# my_numberB.py
class MyNumberB(object):
    def __init__(self, number):
        self._number = number
    def _get_number(self):
        return self._number
    def _set_number(self, value):
        if isinstance(value, basestring):
            number = eval(value)
        else:
            number = value
        self._number = number
number = property(_get_number, _set_number)
```

| | |
|-------------------------------|-------------------------|
| >>> b = MyNumberB(number=100) | >>> b.number |
| >>> b.number | 255 |
| 100 | >>> b.number = '0b1101' |
| >>> b.number = '0xFF' | >>> b.number |
| | 13 |
| | 110 |

Properties: application 2

For example, the *energy* and *momentum* methods of the *Particle* class can be implemented as read-only properties:

```
# My_particle_class.py
class Particle(object):
    ...
    def _get_momentum(self):
        return self.mass * self.velocity
    def _get_energy(self):
        return 0.5 * self.mass * self.velocity**2
    def _not_allowed(self, value):
        raise RuntimeError("Can not set energy or momentum
                           directly.")
    energy = property(_get_energy, _not_allowed)
    momentum = property(_get_momentum, _not_allowed)
```

Properties

Then, for example:

```
>>> p = Particle(mass=3.0, velocity=4.0)
>>> p.momentum
12.0
>>> p.energy = 100
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
    File "particle_with_properties.py", line 23, in _not_allowed
      raise RuntimeError("can not set energy or momentum directly.")
RuntimeError: can not set energy or momentum directly.
```

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General Scoping Rules

Variables are looked up from namespaces in the following order:

- Local Function Scope
- Enclosing Function Scope
- Global Scope
- Built-in Scope

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Scoping Rules

LOCAL SCOPE

```
# a, b, c and d are all local
# variables in the function.
def foo(a,b):
    c = 1
    d = a + b + c
```

GLOBAL SCOPE

```
# If a requested variable is not
# found in the local scope, the
# "global" or module level scope
# is searched.

# global module level variable
c = 1

def foo(a,b):
    d = a + b + c
```

MODIFYING GLOBALS

```
# Modifying globals from within
# a local scope requires the
# global keyword.

c = 1

def foo():
    global c
    c = 2

>>> foo()
>>> print c
2
```

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Scoping Rules

BUILTIN SCOPE

```
# If not found in the local or
# global scope, the "builtin"
# scope is searched. 'len' is
# a builtin function.

def list_length(a):
    return len(a)

>>> a = [1,2,3]
>>> print list_length(a)
3

# The "builtin" functions are
# found in the special
# __builtin__ module
>>> import __builtin__
>>> __builtin__.len
<built-in function len>
```

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Class Scoping Rules

CLASS SCOPING

```
# global variable
var = 0

class MyClass(object):
    # class variable
    var = 1

    def access_class_c(self):
        print 'class var:', self.var

    def access_global_c(self):
        print 'global var:', var

    def write_class_c(self):
        # Modify the class variable.
        MyClass.var = 2
        print 'class var:', self.var

    def write_instance_c(self):
        # Create an instance variable.
        self.var = 3
        print 'instance var:', self.var
```

EXAMPLES

```
>>> obj = MyClass()
>>> obj.access_class_c()
class var: 1
>>> obj.access_global_c()
global var: 0
>>> obj.write_class_c()
class var: 2
>>> obj.write_instance_c()
instance var: 3
```



See
[demo/variable_scoping/class_scoping.py](#).

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Lexical Scoping Rules

NESTED SCOPE

```
# Nested functions have access
# to the enclosing function's
# variables.

def outer():
    a = 1
    def inner():
        print "a =", a
    inner()

>>> outer()
a = 1
```

FUNCTION CLOSURE

```
# The inner() function has access
# to the outer variables that it
# uses for its entire lifetime.

def outer():
    a = 1
    def inner():
        return a
    return inner #Note: returns
                 #function object!

>>> func = outer()
>>> print 'a (1):', func()
a (1): 1
```



See
[demo/variable_scoping/lexical_scoping.py](#).

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Partial Function Application (or Curries)

PARTIAL

```
# functools.partial "freezes"
# one or more arguments of a
# function to create a simplified
# signature and/or modify default
# arguments.

# By default, int uses base 10
# conversion from string to int.
>>> int('10010')
10010

# Create function to convert
# base 2 strings to ints.
>>> from functools import partial
>>> basetwo = partial(int, base=2)
>>> basetwo('10010')
18
```

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Decorators

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Func as objects and arguments

In Python, functions are first-class objects.

Function Objects

```
>>> def foo(x):
...     print x

# foo is of type 'function'.
>>> type(foo)
<type 'function'>

# Functions have a set of
# attributes, like other objects.
>>> dir(foo)
['__call__', ..., 'func_closure',
'func_code', 'func_defaults',
'func_dict', 'func_doc',
'func_globals', 'func_name']

# __call__ is the most important
>>> foo(42)
42
```

Passing Functions

```
# Since functions are objects,
# like everything else in Python,
# they can be passed as arguments
# to other functions!
>>> def foo(x):
...     print x
...
>>> def bar(f, x):
...     x += 1
...     f(x)
...
>>> bar(foo, 42)
43
```

Note: Python has a 'lambda' keyword for defining anonymous functions inline.

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Decorators

Decorators are functions which take a function as an argument and (usually) return another function.

Example

```
# A basic decorator
>>> def dec(f):
...     print "I am decorating function ", id(f)
...     return f
>>> declen = dec(len)
I am decorating function  2338768
>>> declen([10, 20, 30])
3
```

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Decorators

Example

```
# Makes a new function that will loudly call the original.
# Note the definition of new_func inside the definition of
# loud.
>>> def loud(f):
...     def new_func(*args, **kw):
...         print "Calling with", args, kw
...         rtn = f(*args, **kw)
...         print "Return value is", rtn
...         return rtn
...     return new_func
>>> loudlen = loud(len)          # Create a modified len().
>>> n = loudlen([10, 20, 30])   # Call it.
Calling with ([10, 20, 30],) {}
Return value is 3
>>> n
3
```

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Decorators

Python uses the '@' symbol to replace a function with its decorated version.

@ Notation

```
# Given a decorator dec', the phrasing...
def foo(x):
    print x
foo = dec(foo)

# can be replaced by...
@dec
def foo(x):
    print x

# If the decorator returns a function,
# decorations may be chained.
@dec1
@dec2
def foo(x):
    print x
```

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Decorator Examples

```
# A decorator that adds 1
def plus_one(f):
    def new_func(x):
        return f(x) + 1
    return new_func

# A decorator that multiplies by 2
def times_two(f):
    def new_func(x):
        return f(x) * 2
    return new_func

# A decorated function
@plus_one
@times_two
def foo(x):
    return int(x)

>>> foo(13)
```

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Decorator Factories

If you want to change the behavior of the decorator when you decorate, you do this by writing a decorator factory. A factory is a function that returns a decorator.

```
# A basic decorator generator
def super_dec(x, y, z):
    # The decorator we are creating
    def dec(f):
        # The function to return
        def new_func(*args, **kw):
            print x + y + z
            return f(*args, **kw)
        return new_func
    return dec
```

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Decorator Factory Example

```
# Appends a string to the function output
def append_string(s):
    def dec(f):
        def new_func(*args, **kw):
            new_s = f(*args, **kw) + s
            return new_s
        return new_func
    return dec

@append_string(", World")
def hello():
    return "Hello"
>>> hello()
Hello, World

@append_string(", Moon")
def goodnight():
    return "Goodnight"
>>> goodnight()
Goodnight, Moon
```

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Iterators, generators and coroutines

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Iterators

Iterators are anything that can be looped over. They shield users from implementation details of looping over an object. Classes that have `__iter__` and `next` methods can be used as iterators.

CLASS DEFINITION

```
class FootballRushIterator(object):
    def __init__(self, count=5):
        self.count = count

    def __iter__(self):
        # Prepare an iterable object.
        self._counter = 1
        return self

    def next(self):
        cnt = self._counter
        if cnt <= self.count:
            # Return the next element
            res = str(cnt) + " mississippi"
            self._counter += 1
            return res
        else:
            # Or signal the end of iteration.
            raise StopIteration
```

USING ITERATORS

```
>>> rusher = FootballRushIterator()
>>> for count in rusher:
...     print count
1 mississippi
2 mississippi
3 mississippi
4 mississippi
5 mississippi
```

(WITH GENERATOR)

```
def get_rusher(count=5):
    for i in range(count):
        yield "%d mississippi" % (i+1,)

>>> for count in get_rusher():
...     print count
```

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Generators

Generators are a special kind of function that contain a `yield` statement. These functions are really **iterator factories**. The returned iterator can be looped over or its `next()` method can be called directly to return elements from the sequence.

GENERATOR BASICS

```
def simple_generator():
    print 'first'
    yield 1
    print 'second'
    yield 2

>>> sequence = simple_generator()
>>> sequence.next()
first
1
>>> sequence.next()
second
2
>>> sequence.next()
Traceback (most recent call last):
  File "<stdin>" line 1, in ?
    StopIteration
```

USING GENERATORS

```
# Create a generator that returns the
# first N elements of the Fibonacci
# sequence.
def fib(N=10):
    a, b = 0, 1
    for count in range(N):
        yield b
        a, b = b, a+b

>>> fib_gen = fib(6)
>>> for value in fib_gen:
...     print value
1
1
2
3
5
8
```

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Generators --> CoRoutines

Generators can receive values as well using the return value of a `yield` expression: they are called **coroutines**.

COROUTINES BASICS

```
def receiving_generator():
    while True:
        val = (yield)
        print "Received", val

>>> sequence = receiving_generator()

# First next() call take to the first
# yield
>>> sequence.next()
>>> sequence.next()
Received None
>>> sequence.send(1)
Received 1
>>> sequence.send("hello")
Received hello

>>> sequence.close()
```

EMITTING AND RECEIVING

```
def emitting_receiving_generator():
    i = -1
    while True:
        i += 1
        val = (yield i)
        print "Received", val

>>> sequence = receiving_generator()

>>> sequence.next()
0
>>> sequence.next()
Received None
1
>>> sequence.send("hello")
Received hello
2
>>> sequence.close()
```

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Context managers and the `with` statement

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Introduction

- New in python 2.5, though it's then required to import it:
`from __future__ import with_statement`
- Context managers are objects that possess the `__enter__` and `__exit__` methods. They are used to define a sequence of **setup** and **tear-down** operations that the `with` statement will call automatically even if exceptions are raised, similar to a try/finally block.
- An example of a context manager is the file pointer which includes `f.close()` in its `__exit__` method.

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Example

CONTEXT CREATION

```
class MyContext(object):
    def __enter__(self):
        print "I entered"
        return self
    def __exit__(self, type, value, tb):
        print("Exception info: %s, %s, %s" % (type, value, tb))
        print "Before exiting important things to do... "
```

USING THE CONTEXT

```
>>> with MyContext() as c:
...     print "I am doing things..."
...     raise RuntimeError("Crash!")
I entered
I am doing things...
Exception info: 'RuntimeError',
Crash!, <traceback object at 0x824>
```

Before exiting important things to do...

RuntimeError: Crash!

>>> c

<__main__.MyContext at 0xa3c09b0>

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Dynamic Code Execution

EVAL

```
# The "eval" function will
# evaluate a Python expression
# within a given global and local
# namespace (dictionary).
# Both the global and local
# dictionary are optional.
# eval(expr, globals, locals)
>>> a = 1
>>> eval("a+1")
2

# Specify a local dictionary.
>>> local = dict(a=2)
>>> glob = {}
>>> eval("a+1", glob, local)
3
```

EXEC

```
# The "exec" statement will
# execute a Python statement
# within a given global and
# local namespace (dictionary).
# Both the global and local
# dictionary are optional.
# exec(stmt, globals, locals)
>>> a = 1
>>> exec("b = a+1")
>>> print b
2

# Specify a local dictionary.
>>> local = dict(a=2)
>>> glob = {}
>>> exec("b=a+1", glob, local)
>>> print local
{'a': 2, 'b': 3}
```



Careful about eval'ing/exec'ing an untrusted user's input: they have full access to python.

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exec with a dictionary-like namespace

EXEC

```
class LoudDict(dict):
    """ This dictionary announces whenever one of its values
        is get or set.
    """
    def __getitem__(self, key):
        value = super(LoudDict, self).__getitem__(key)
        print "retrieving %s which is %s" % (key, value)

        return value

    def __setitem__(self, key, value):
        print "setting %s = %s" % (key, value)
        super(LoudDict, self).__setitem__(key, value)

# Execute a statement in our "LoudDict" and watch it announce
# variable get/set during the execution.
>>> local = LoudDict(a=1)
>>> exec "b=a+1" in {}, local
retrieving a which is 1
setting b = 2
```



See demo/dictionary_like_exec.py

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Dynamic ByteCode Generation

COMPILE

```
# The "compile" function will generate bytecode from a Python
# expression or statement. It can then be evaluated multiple
# times without regenerating the bytecode each time.
# Syntax: compile(str, filename, mode)
>>> a = 1
>>> c=compile("a+2", "", "eval")
>>> eval(c)
3
>>> c=compile("b=a+2", "", "exec")
>>> exec(c)
>>> b
3
>>> a = 3
>>> exec(c)
>>> b
5
```



Careful about eval'ing/exec'ing an untrusted user's input: they have full access to python.

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csv – read and write CSV files

The `csv` module provides classes for reading and writing Comma Separated Value (CSV) files.

`csv.reader` - Read a list of comma-separated values from a file.

`csv.writer` - Output a list (or other iterable) to a file.

The format is configurable; in particular, the data delimiter does not have to be a comma.

Default “dialect” is compatible with Excel.

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CSV examples

READER

Sample data file “data.csv”:

```
"alpha 1", 100, -1.443
"beta 3", 12, -0.0934
"gamma 3a", 192, -0.6621
"delta 2a", 15, -4.515
```

```
>>> import csv
>>> rdr = csv.reader(
        open("data.csv"))
>>> for row in rdr:
...     print row
['alpha 1', ' 100', ' -1.443']
['beta 3', ' 12', ' -0.0934']
['gamma 3a', ' 192', ' -0.6621']
['delta 2a', ' 15', ' -4.515']
```

WRITER

```
>>> import csv
>>> data = [ ("One", 1, 1.5),
            ("Two", 2, 8.0) ]
>>> f = open("out.csv", "w")
>>> wrtr = csv.writer(f)
>>> wrtr.writerows(data)
>>> f.close()
```

Output file “out.csv”:

```
One,1,1.5
Two,2,8.0
```

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CSV options

OPTIONS (not a complete list)

delimiter: str (a single character)

The field separator character

doublequote: bool

If True, a quote inside a string is doubled.

If False, prefix the quote with escapechar.

escapechar: str (a single character)

The character that indicates the following character has no special meaning.

quotechar: str (a single character)

Character used to quote strings containing delimiters or other special characters.

quoting: one of csv.QUOTE_*

Controls when quotes should be generated by the writer and recognized by the reader.

EXAMPLE

```
>>> data
[ ('One', 1, 1.5), ('Two', 2, 8.0) ]
>>> f = open("out.txt", "w")
>>> wrtr = csv.writer(f,
...                     delimiter='|',
...                     quoting=csv.QUOTE_ALL)
>>> wrtr.writerows(data)
>>> f.close()
```

Output file “out.csv”:

```
"One"|"1"|"1.5"
"Two"|"2"|"8.0"
```

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Connecting to Databases

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DB-API 2.0

PEP (Python Enhancement Proposal) 249 detailed version 2.0 of the DB-API to promote consistency between Python front-ends to data-bases.

| Database | Module or Modules for Python 2.X |
|----------------------|---|
| Oracle | cx_Oracle, DCOracle2, mxODBC, pyodbc |
| PostgreSQL | psycopg2, PyGreSQL, pyPgSQL, mxODBC, pyodbc, pg8000 |
| MySQL | MySQLdb, mxODBC, pyodbc, myconnpy |
| Sqlite | sqlite3 (included in standard library) |
| Microsoft SQL Server | adodbapi, pymssql, mssql, mxODBC, pyodbc |
| Ingres | ingresdbi |
| IBM DB2 | lbum_db, PyDB2, ceODBC, mxODBC, pyodbc |
| Sybase ASE | Sybase, mxODBC |
| Sybase SQL Anywhere | mxODBC, sqlanydb |
| SAP DB | sdb.dbapi, sapdbapi, mxODBC, sdb.sql, sapdb |
| Informix | InformixDB, mxODBC, |
| Firebird | KInterbasdb |

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DB-API 2.0

Connect to the database

```
import <somedbmodule> as db
# Connect to the data-source
# Extra arguments typically
# include user and password
conn = db.connect(<dsn>, ...)
```

Get a cursor object

```
c = conn.cursor()
```

Execute SQL statements

```
c.execute("create table stocks(date
    text, trans text, symbol text, qty real,
    price real)")

c.execute("insert into stocks values
    ('2006-01-05','BUY','RHAT',100,35.14)")

conn.commit()
```

Execute SQL Statements (cont.)

```
t = ('2006-04-06', 'SELL',
      'IBM', 500, 53.00)
c.execute("insert into stocks values
    (?, ?, ?, ?)", t)
# some modules use a different
# place-holder instead of ?
# see db.paramstyle

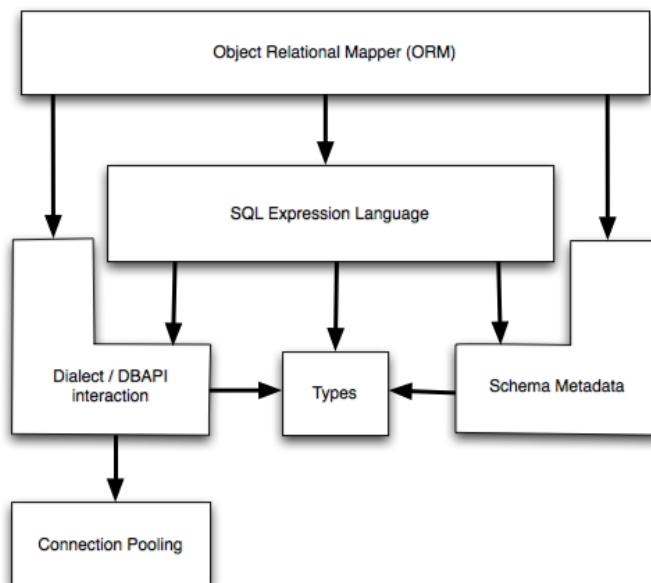
t = ('IBM',)
c.execute("select * from stocks where
    symbol=? order by price", t)
for row in c:
    print row
single = c.fetchone()
list_of_lists = c.fetchall()
```

Close cursor and connection

```
c.close()
conn.close()
```

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An ORM: SQLAlchemy



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Regular Expressions in Python

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What is a regular expression?

A regular expression is a pattern designed to match specific strings or sub-strings.

A regular expression can match very specific strings, as well as very general strings.

Once matched, specific fields in the string can be extracted or substituted. Information about the location, and type of match is stored in a `match` object.

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```
>>> import re
```

Some of the more common uses of the re API

```
>>> re.match(pattern, string[, flags])
>>> re.search(pattern, string[, flags])
    Matches (or search) the pattern against the string, returning a match object on
    success and None on failure (flags described later). re.match only searches for a
    match at the beginning of the string. re.search will search through the entire string.
```

```
>>> re.findall(pattern, string)
    Returns a list of matches of pattern in string. re.finditer returns an iterator.
```

```
>>> re.split(pattern, string[, maxsplit])
    Returns a list of sub-strings, delimited by the regular expression pattern. If maxsplit
    is specified only maxsplit splits will occur.
```

```
>>> re.sub(pattern, repl, string[, count])
    Returns a string where every occurrence matching the regular expression pattern in
    string is replaced by repl, unless count is reached (specifies how many
    substitutions to make).
```

```
>>> re.compile(pattern)
    Compiles the regex and returns a pattern object which can be used for searching,
    matching, substituting, .... match, search, findall ... are then methods of the object.
```

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Regular expression syntax

A regex pattern is composed of regular characters as well as various symbols for matching patterns in strings...below are some of the common symbols.

| | | | |
|-------|--|-----|--|
| . | Matches any character except newline | ? | Matches zero or 1 occurrences of the previous RE |
| \w | Matches any alphanumeric character | {m} | Matches <i>m</i> occurrences of the previous RE |
| \d | Matches any decimal digit, equal to [0-9] | | |
| \s | Matches whitespace, equal to [\t\n\r\f\v] | | |
| [...] | Indicates a set of characters which can be matched. Ranges can be specified using - (e.g. a-z, 0-9). | | |
| (...) | Groups characters/symbols into 1 block | | |
| | Stands for logical OR | | |
| ^ | Takes the complement of the following set | | |
| * | Causes the previous RE to match zero or more repetitions | | For e.g., ca*t matches 'ct', 'cat', 'caaaat', ... $(ab\d) (ac\d)$ matches 'ab1', 'ac9', ... $([^a-q]bd)$ matches 'rbd', '5bd', ... |
| + | Matches 1 or more repetitions of the previous RE | | |



ID \S and \W denote the complement of the same sets

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Match objects & groups

When a regular expression matches, a match object is returned.

```
>>> myString = "hello world"
>>> print re.match("hello (\w+)", myString)
<sre.SRE_Match object at 0x009E45E0>
```

Check if a match was successful, extract matched groups, location, ...

```
>>> myString = "hello there"
>>> match = re.match("hello (\w+)", myString)
>>> if match != None:
...     print match.group(1)
'there'
>>> print match.start, match.end
6 11
```

Groups are numbered left to right, based on open parenthesis...

```
>>> re.match("hello (\w+(\d+)* ) (\w+)", myString)
```



Nested groups count too!

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Regular expression example

`compile()` return a `re` pattern object

```
>>> patt1 = re.compile("hello\s+user\s+number\s+(\d+\.\d+)*")
```

Match one or more space characters

First group will match 1 or more digits

2nd group will match an *optional* dot then 1 or more digits. Optional because of *, dot is escaped with \ since it is a special symbol

```
>>> patt1 = re.compile("hello\s+user\s+number\s+(\d+\.\d+)*")
```

```
>>> s1 = "hello user number 87"
```

```
>>> s2 = "hello user number 87.34"
```

```
>>> m = patt1.match(s1)
```

```
>>> print m.group(1)
```

```
'87'
```

```
>>> m = patt1.match(s2)
```

```
>>> print m.groups()
```

```
('87', '.34')
```

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Parse the following text to extract the number and the type of all travellers:

"5 men, 7 dogs and 12 goats are travelling together."

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You can't parse [X]HTML with regex. Because HTML can't be parsed by regex. Regex is not a tool that can be used to correctly parse HTML. As I have answered in HTML-and-regex questions here so many times before, the use of regex will not allow you to consume HTML. Regular expressions are a tool that is insufficiently sophisticated to understand the constructs employed by HTML. HTML is not a regular language and hence cannot be parsed by regular expressions. Regex queries are not equipped to break down HTML into its meaningful parts. so many times but it is not getting to me. Even enhanced irregular regular expressions as used by Perl are not up to the task of parsing HTML. You will never make me crack. HTML is a language of sufficient complexity that it cannot be parsed by regular expressions. Even Jon Skeet cannot parse HTML using regular expressions. Every time you attempt to parse HTML with regular expressions, the unholy child weeps the blood of virgins, and Russian hackers pwn your webapp. Parsing HTML with regex summons tainted souls into the realm of the living. HTML and regex go together like love, marriage, and ritual infanticide. The <center> cannot hold it is too late. The force of regex and HTML together in the same conceptual space will destroy your mind like so much watery putty. If you parse HTML with regex you are giving in to Them and their blasphemous ways which doom us all to inhuman toil for the One whose Name cannot be expressed in the Basic Multilingual Plane, he comes. HTML-plus-regexp will liquify the nerves of the sentient whilst you observe, your psyche withering in the onslaught of horror. Regex-based HTML parsers are the cancer that is killing StackOverflow *it is too late it is too late we cannot be saved the transgression of a child ensures regex will consume all living tissue (except for HTML which it cannot, as previously prophesied) dear lord help us how can anyone survive this scourge using regex to parse HTML has doomed humanity to an eternity of dread torture and security holes, using regex as a tool to process HTML establishes a breach between this world and the dread realm of corrupt entities (like SGML entities, but more corrupt) a mere glimpse of the world of regex parsers for HTML will instantly transport a programmer's consciousness into a world of ceaseless screaming, he comes, the pestilent slithy regex-infection will devour your HTML parser, application and existence for all time like Visual Basic only worse he comes he comes do not fight he comes, his unholy radiance destroying all enlightenment, HTML tags leaking from your eyes like liquid pain, the song of regular expression parsing will extinguish the voices of mortal man from the sphere I can see it can you see it is beautiful the final snuffing of the lies of Man ALL IS LOST ALL IS LOST the pony he comes he comes he comes the ichor permeates all MY FACE MY FACE oh god no NO NOOO NO stop the angles are not real ZALGO IS TONY THE PONY, HE COMES*

Source: <http://stackoverflow.com/questions/1732348/regex-match-open-tags-except-xhtml-self-contained-tags>

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NumPy's fromregex

NumPy contains a function `fromregex` that can be used to convert arbitrary text files to (structured) arrays.

```
data = fromregex(file, pattern, dtype)

file: file-like object or filename string.
pattern: Regular expression to parse file with.
          Groups must correspond to fields in the
          dtype.
dtype: data-type for the structured array with
          field for each group in the regular
          expression.
```

Output is a structured array where each element is a match to the regular expression in the file.

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fromregex example

```
# Create the file
>>> f = open('test.dat', 'w')
>>> f.write("1312 foo\n1534 bar\n444 qux")
>>> f.close()

# match [digits, whitespaces, anything]
>>> regexp = "(\d+)\s+(\w+)"
>>> output = fromregex('test.dat', regexp,
...                      [('num', np.int64), ('key', 'S3')])
>>> output
array([(1312L, 'foo'), (1534L, 'bar'), (444L, 'qux')], 
      dtype=[('num', '<i8'), ('key', '|S3')])

>>> output['num']
array([1312, 1534, 444], dtype=int64)
```

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datetime – Dates and Times

```
>>> from datetime import date, time
```

DATE OBJECT

```
# date(year, month, day)
# date in Gregorian calendar,
# assuming its permanence
>>> d1 = date(2007, 9, 25)
>>> d2 = date(2008, 9, 25)
>>> d1.strftime('%A %m/%d/%y')
'Tuesday 09/25/07'

# difference is timedelta
>>> print d2 - d1
366 days, 0:00:00
>>> (d2-d1).days
366
>>> print date.today()
2008-09-24
```

TIME OBJECT

```
# time(hour, min, sec, us)
# local time of day
# always 24 hrs per day
>>> t1 = time(15, 38)
>>> t2 = time(18)
>>> t1.strftime('%I:%M %p')
'03:38 PM'

# difference is not supported
>>> print t2 - t1
Traceback ...
TypeError: unsupported operand ...
# use datetime objects for
# difference operation.
```

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datetime – Dates and Times

```
>>> from datetime import datetime, timedelta
```

DATETIME OBJECT

```
# datetime(year, month, day,
          hr, min, sec, us)
# combination of date and time
>>> d1 = datetime.now()
>>> print d1
2008-09-24 14:20:30.978207
>>> d2 = d1 + timedelta(30)
>>> d2.strftime('%A %m/%d/%y')
'Friday 10/24/08'

# creating datetime from
# a format string
>>> datetime.strptime('2/10/01',
                      '%m/%d/%y')
datetime.datetime(2001, 2, 10, 0, 0)
```

DATETIME FORMAT STRING

| Directive | Meaning |
|-----------|---|
| %a (%A) | Abbrev. (full) weekday name. |
| %w | Weekday number [0 (Sun), 6] |
| %b (%B) | Abbrev. (full) month name |
| %d | Day of month [01,31] |
| %H (%I) | Hour [00,23] ([01,12]) |
| %j | Day of the year [001,366] |
| %m | Month [01,12] |
| %M | Minute [0,59] |
| %p | AM or PM |
| %S | Second [00,61] |
| %U (%W) | Week number of the year [00,53] Sunday (Monday) as first day of week. |
| %y (%Y) | Year without (with) century [00,99] |

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Context managers and the `with` statement

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Introduction

- New in python 2.5, though it's then required to import it:
`from __future__ import with_statement`
- Context managers are objects that possess the `__enter__` and `__exit__` methods. They are used to define a sequence of **setup** and operations that the `with` statement will call automatically even if exceptions are raised, similar to a try/finally block.
- An example of a context manager is the file pointer which includes `f.close()` in its `__exit__` method.

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Example

CONTEXT CREATION

```
class MyContext(object):
    def __enter__(self):
        print "I entered"
        return self
    def __exit__(self, type, value, tb):
        print("Exception info: %s, %s, %s" % (type, value, tb))
        print "Before exiting important things to do... "
```

USING THE CONTEXT

```
>>> with MyContext() as c:
...     print "I am doing things..."
...     raise RuntimeError("Crash!")
I entered
I am doing things...
Exception info: 'RuntimeError',
Crash!, <traceback object at 0x824>
```

Before exiting important things
to do...

RuntimeError: Crash!

```
>>> c
<__main__.MyContext at
0xa3c09b0>
```

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sys module

```
>>> import sys
```

Some frequently used attributes and functions—see the reference manual for complete details.

Command Line Arguments

`sys.argv`

List of command line arguments.

`sys.argv[0]` is the name of the python script.

Example:

```
# File: print_args.py
import sys
print sys.argv
```

```
$ python print_args.py 1 foo
['print_args.py', '1', 'foo']
```

Exception Information

`sys.exc_info()`

Returns a tuple (type, value, traceback)

`sys.exc_clear()`

Clear all exception information.

```
>>> try:
...     x = 1/0
... except Exception:
...     print sys.exc_info()
...
(<type 'exceptions.ZeroDivisionError'>,
ZeroDivisionError('integer division or
modulo by zero',), <traceback object at
0x9a8c8>)
>>>
```

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sys module

Standard File Objects

`sys.stdin`
`sys.stdout`
`sys.stderr`

The interpreter's standard input, output and error streams.

`sys.__stdin__`
`sys.__stdout__`
`sys.__stderr__`

The original values of `sys.stdin`, `sys.stdout` and `sys.stderr` at the start of the program.

Exit

`sys.exit(arg)`

Exit from Python. `arg` is optional. It can be an integer giving the exit status (defaults to zero). If not an integer, `None` is equivalent to passing 0, and any other argument is printed to `sys.stderr` and the exit status is 1.

Python's module search path

`sys.path`

A list of strings that specifies the interpreter's search path for modules.

A program is free to modify this list dynamically.

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sys module

Platform Information

`sys.platform`

A string containing the platform identifier.

Windows: 'win32'

Mac OSX: 'darwin'

Linux: 'linux2'

`sys.getwindowsversion()`

Return a tuple that describes the version of Windows currently running: `major`, `minor`, `build`, `platform`, and `service_pack`. (More is included in Python 2.7.)

`>>> sys.platform`

'win32'

`>>> sys.getwindowsversion()`

(5, 1, 2600, 2, 'Service Pack 3')

Python Version

`sys.version`

A string containing information about the Python version.

`sys.version_info`

A tuple containing information about the Python version: `major`, `minor`, `micro`, `releaselevel` and `serial`.

`>>> sys.version`

'2.6.5 |EPD 6.2-2 (32-bit)| (r265:79063, May 7 2010, 13:28:19) [MSC v.1500 32 bit (Intel)]'

`>>> sys.version_info`

(2, 6, 5, 'final', 0)

See also the `platform` module in the standard library.

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os module

```
>>> import os
```

Path Operations

os.remove(path) **os.unlink(path)**
Remove a file from disk (file can be either the full path or a file from the current working directory will be removed).

os.chdir(path)
Change the current working directory to the provided path.

os.getcwd()
Return the current working directory.

os.listdir(path)
Return a list of strings containing all the files in the given path (does not include '.' or '..' in the listing).

Separation Constants

os.linesep (e.g. '\n' or '\r\n')
Line separator in text mode.

os.sep (e.g. '/' or '\\')
Path separator on file system.

os.pathsep (e.g. ':' or ';')
Search path separator (*i.e.* in environment variables).

Others

os.environ
Dictionary of all environment variables

os.urandom(len)
String of random bytes
os.error
Error object

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os.path

os.path – tests

os.path.isfile(path)
Test whether a path is a regular file.
os.path.isdir(path)
Test whether a path refers to an existing directory.
os.path.exists(path)
Test whether a path exists.
os.path.isabs(path)
Test whether a path is absolute.

os.path – split and join

os.path.split(path)
Split a pathname. Returns the tuple (head, tail).
os.path.join(a, *p)
Join two or more path components.

Others

os.path.abspath(path)
Return an absolute path.
os.path.dirname(path)
Return the directory component of a pathname.
os.path.basename(path)
Return the final component of a pathname.
os.path.splitext(path)
Split the extension from a pathname.
Returns (root, ext).
os.path.expanduser(path)
Expand ~ and ~user. If user or \$HOME is unknown, do nothing.

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Remote Call example — xmlrpclib

XMLRPC FACTORIAL SERVER – VERSION 1

```
from SimpleXMLRPCServer import SimpleXMLRPCServer

def fact(n):
    if n <= 1:
        return 1
    else:
        return n * fact(n-1)

# Start a server listening for requests on port 8001.
if __name__ == '__main__':
    server = SimpleXMLRPCServer(('localhost', 8001))
    # Register fact as a function provided by the server.
    server.register_function(fact)
    server.serve_forever()
```

CLIENT CODE – CALLS REMOTE FACTORIAL FUNCTION

```
>>> import xmlrpclib
>>> svr = xmlrpclib.Server("http://localhost:8001")
>>> svr.fact(10)
3628800
```

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Remote Call example — xmlrpclib

XMLRPC FACTORIAL SERVER – VERSION 2

```
from SimpleXMLRPCServer import SimpleXMLRPCRequestHandler, \
                               SimpleXMLRPCServer

def fact(n):
    if n <= 1:    return 1
    else:         return n * fact(n-1)
# Override the _dispatch() handler to call the requested function.
class my_handler(SimpleXMLRPCRequestHandler):
    def _dispatch(self, method, params):
        print "CALL", method, params
        return apply(eval(method), params)
# Start a server listening for requests on port 8001.
if __name__ == '__main__':
    server = SimpleXMLRPCServer(('localhost', 8001), my_handler)
    server.serve_forever()
```

CLIENT CODE – CALLS REMOTE FACTORIAL FUNCTION

```
>>> import xmlrpclib
>>> svr = xmlrpclib.Server("http://localhost:8001")
>>> svr.fact(10)
3628800
```

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Calling Subprocesses

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Executing other programs

```
>>> from subprocess import Popen, PIPE, STDOUT

p = Popen([cmd,arg1,...,argn], env=None, cwd=None, shell=False,
          stdin=None, stdout=None, stderr=None)
```

| | |
|------------------------------|---|
| <i>cmd,arg1,...,argn</i> | Command to run plus any arguments |
| stdin, stderr, stdout | Standard file handles: can be None (use handles of the current process), any open file descriptor, any open file object, or PIPE. (stderr can also be STDOUT for a redirect). |
| env | Dictionary of environment variables. If None, then the current process environment is used. |
| shell | Run the cmd in the shell if True |
| cwd | Directory to change to before executing the command. |

Command begins to execute immediately!

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Executing other programs

SIMPLE COMMAND EXECUTION

```
# On Windows
>>> Popen('dir', shell=True, cwd="c:\\\\")
Volume in drive C has no label.
Volume Serial Number is A080-3756

Directory of c:\\

08/30/2007 ... AUTOEXEC.BAT
08/30/2007 ... CONFIG.SYS
...
01/24/2009 ... Python25
01/24/2009 ... WINDOWS
          2 File(s)           0 bytes
          7 Dir(s)   1,401,319,424 bytes free

# On Unix (no shell needed)
>>> fid = open('simple.txt','w')
>>> Popen('ls', cwd='/usr', stdout=fid)
>>> fid.close()
```

simple.txt

```
bin
games
include
lib
lib32
lib64
local
sbin
share
src
X11R6
```

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Executing other programs

WAIT FOR TERMINATION

```
from subprocess import Popen
print "Starting..."
# sleep for 10 seconds
p = Popen(['sleep','10'])
# wait to finish
# and get return code
ret = p.wait()
# return code also stored
# in subprocess object
# after completion
print "Done", p.returncode

Starting
<10 seconds later>
Done 0
```

POLL PERIODICALLY

```
from subprocess import Popen
import sys
print "Starting..."
# sleep for 10 seconds
p = Popen(['sleep','10'])
# continue on with processing
print "Continuing",
k=0
while p.poll() is None:
    k += 1
    if (k % 100000) == 0:
        print k//100000,
        sys.stdout.flush()
    print
print "Done", p.returncode

Starting
Continuing 1 2 3 ... 45
Done 0
```

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Executing other programs

PIPES

"Pipes" are used to send and/or receive data from another process on the same machine.

```
# Setup process which will receive
# stdin through a PIPE and send
# stdout to a PIPE
>>> p = Popen(['python', 'count.py',
    'c'], stdin=PIPE, stdout=PIPE,
    stderr=PIPE)
>>> instr = "gatccatgca"
>>> out, err = p.communicate(instr)
>>> print out
3
```

count.py

```
import sys
letter = sys.argv[1]
data = sys.stdin.read()
print data.count(letter)
```

SHLEX TO CREATE COMPLEX COMMAND

```
>>> shlex.split('python count.py c')
['python', 'count.py', 'c']
```

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Multiprocessing

What is Multiprocessing?

The multiprocessing module provides access to task-based parallel computing using separate Python processes.

Multiprocessing has several features:

- part of Python's standard library,
- cross-platform,
- low-level parallel constructs: locks, queues, pipes, semaphores, shared memory access
- higher-level constructs: task pools with automatic scheduling, shared memory object wrappers, functional and iterator-like design support, etc.

The multiprocessing module is useful for:

- batch computing, embarrassingly parallel computations
- parallel computing with minimal shared state
- GUI programming: do calculations in a background process
- many, many others.

<http://docs.python.org/library/multiprocessing.html>

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Multiprocessing vs. Threading

The threading module provides thread-based parallelism to Python; in CPython, threads are limited by the Global Interpreter Lock.

Only one thread may hold the lock at any point in time, holding the lock allows that thread to execute Python instructions.

Multiprocessing provides a way around this performance limitation.

The **multiprocessing** module has a nearly identical API to the **threading** module; this is intentional.

Learn multiprocessing, you will learn majority of threading.

Primary differences:

- Threads share the same address space as the spawning thread, whereas processes have separate address spaces.
 - often more communication is required with processes; shared memory can mitigate.
- Spawning new processes is generally more expensive (memory, time) than spawning new threads.
- Trivial API differences.

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The Process Class

Process(target, name=None, args=(), kwargs={})

target: a callable object, called when the start() method is called

name: string, name to give to the process; default given if None

args: tuple, arguments to pass to the target when called

kwargs: dict, keyword args to pass to the target

The basic methods for Process objects are:

start(): start the process' activity

join([timeout]): block the calling process until the process finishes, or until timeout

is_alive(): True if process is still running, false otherwise

terminate(): Terminate the process; may cause deadlocks, synchronization errors, orphaned processes; use only when necessary.

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The Process Class

CREATING A PROCESS

```
import multiprocessing as mp
from time import sleep
from random import random

def worker(num):
    sleep(2.0 * random())
    name = mp.current_process().name
    print "worker {}, name: {}".format(num, name)

if __name__ == '__main__':
    master = mp.current_process().name
    print "Master name: {}".format(master)
    for i in range(2):
        p = mp.Process(target=worker, args=(i,))
        p.start()

# Close all child processes spawned
[p.join() for p in mp.active_children()]
```

OUTPUT

```
$ python basics.py
Master name: MainProcess
worker 1, name: Process-2
worker 0, name: Process-1
```

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Communication Between Processes

Multiprocessing provides a Queue class and a Pipe class for communicating between processes. Queue and Pipe objects are thread and process safe.

Queue – Communicate in one direction; put() and get() methods.

Pipe – two-ended Queue, each end has a send() and recv() method.

QUEUE BASICS

```
def worker(q):
    v = q.get() # blocking!
    print "got '{}' from parent".format(v)

if __name__ == '__main__':
    q = mp.Queue()
    p = mp.Process(target=worker, args=(q,))
    p.start() # blocks at q.get()
    v = 'parent'
    print "putting '{}' on queue".format(v)
    q.put(v)
    p.join()
```

OUTPUT

```
$ python queue_basic.py
putting 'parent' on queue
got 'parent' from parent
```

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Communication Between Processes

PIPE BASICS

```
import multiprocessing as mp

def worker(p):
    msg = 'whiskey tango fox trot'
    print "sending {!r} to parent".format(msg)
    p.send(msg)
    v = p.recv()
    print "got {!r} from parent".format(v)

if __name__ == '__main__':
    # The two ends of the pipe: the parent and the child connections
    p_conn, c_conn = mp.Pipe()
    p = mp.Process(target=worker, args=(c_conn,))
    p.start()

    msg = 'foobar'
    print "got {!r} from child".format(p_conn.recv())
    print "sending {!r} to child".format(msg)
    p_conn.send(msg)
    p.join()
```

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Synchronization

`Lock()` objects provide a low-level way to guarantee that code is executed by only one process at a time.

LOCK BASICS

```
import multiprocessing as mp

def print_lock(lk, i):
    name = mp.current_process().name
    lk.acquire()
    for j in range(100):
        print i, "from process", name
    lk.release()

if __name__ == '__main__':
    lk = mp.Lock()
    ps = [mp.Process(target=print_lock,
                      args=(lk,i))
          for i in range(100)]
    [p.start() for p in ps]
    [p.join() for p in ps]
```

USING THE WITH STATEMENT

```
import multiprocessing as mp

def print_lock(lk, i):
    name = mp.current_process().name
    with lk:
        for j in range(100):
            print i, "from process", name

if __name__ == '__main__':
    lk = mp.Lock()
    ps = [mp.Process(target=print_lock,
                      args=(lk,i))
          for i in range(100)]
    [p.start() for p in ps]
    [p.join() for p in ps] 180
```

Synchronization

`Event()` objects provide a way to notify other processes that something happened.

EVENT USAGE

```
import multiprocessing as mp

def wait_on_event(e):
    name = mp.current_process().name
    e.wait()
    print name, "finished waiting"

if __name__ == '__main__':
    e = mp.Event()
    ps = [mp.Process(target=wait_on_event, args=(e,))
          for i in range(10)]
    [p.start() for p in ps]
    print "e.is_set()", e.is_set()
    raw_input("press any key to set event")
    e.set()
```

Task Pools

`Pool()` objects provide a convenient way to perform embarrassingly parallel computations with automatic load balancing.

`Pool(processes=None, initializer=None, initargs=())`

processes – int, number of processes in pool, `cpu_count()` by default

initializer – callable, if not `None`, `initializer(*initargs)` is called by each process when starting.

Methods:

map(func, iterable, chunksize=None) – parallel equivalent of the `map()` builtin function. Blocks until result is ready and returns a list.

`map_async(func, iterable, chunksize=None, callback=None)`

Same as `map()`, nonblocking. Returns a result object.

`imap(func, iterable, chunksize=None)`

A version of `map` that returns an iterator instead of a list.

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Task Pools

BASIC POOL USAGE

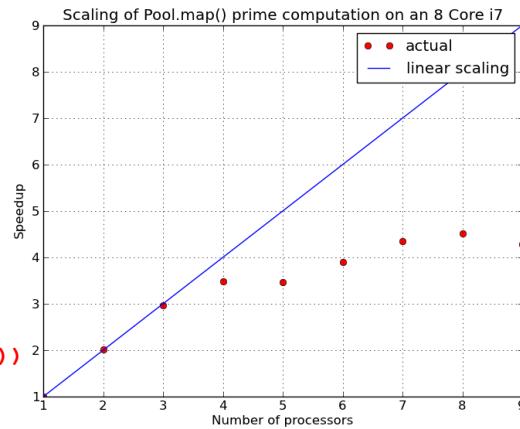
```
import multiprocessing as mp

def is_prime(num):
    # determine whether num is prime
    return (num, is_prime)

if __name__ == '__main__':
    # create a pool with cpu_count() procs.
    pl = mp.Pool()
    results = pl.map(is_prime, range(50, 100))
    for num, isp in results:
        if isp: print num, "is prime"
```

OUTPUT

```
$ python fermat_prime.py
53 is prime
59 is prime
61 is prime
67 is prime
...
...
```



Scaling computed for 10^6 integers while varying pool size. Max speedup is ~4.5X on 8 cores. This problem has high communication overhead.

See `demo_pool.py` for the code.

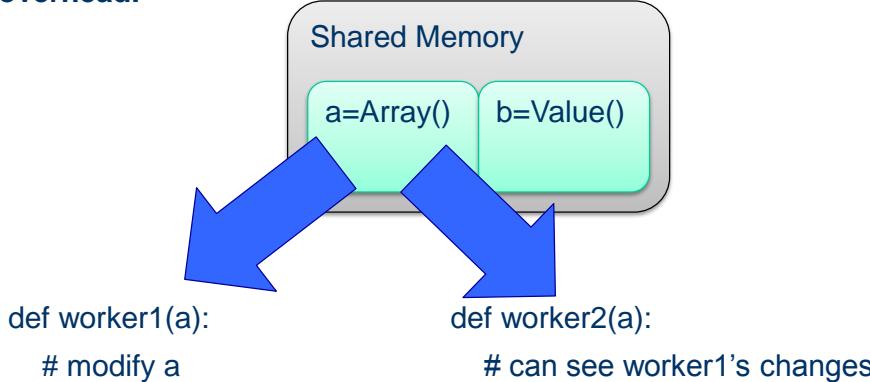
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Shared Memory

Multiprocessing provides the **Value** and **Array** classes for shared memory programming; there is also the **multiprocessing.sharedctypes** module to create ctypes objects and arrays in shared memory.

Passing a shared memory object to the args of a **Process()** object will pass a *proxy* to the target; the actual memory location is in shared memory (via mmap). Any modifications to the proxy object will be seen by all processes.

This allows parallel array computations without much communication overhead.



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Multiprocessing + NumPy

NumPy arrays can be made to view multiprocessing shared memory objects.

SHARED MEMORY VIEW

```

import multiprocessing as mp
from multiprocessing import sharedctypes
from numpy import ctypeslib

def fill_arr(arr_view, i):
    arr_view.fill(i)

if __name__ == '__main__':
    ra = sharedctypes.RawArray('i', 4)
    arr = ctypeslib.as_array(ra)
    arr.shape = (2, 2)
    p1 = mp.Process(target=fill_arr,
                    args=(arr[:1, :], 1))
    p2 = mp.Process(target=fill_arr,
                    args=(arr[1:, :], 2))
    p1.start(); p2.start()
    p1.join(); p2.join()
    print arr
  
```

OUTPUT

```

$ python shared_numpy.py
[[1 1]
 [2 2]]
  
```

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Multiprocessing and others

The multiprocessing module is typically used for non-numerical calculations, when Python's role as a glue between several concurrent processes can be used.

For numerical calculations, numerically-optimized third-party libraries such as PyMPI, MPI4Py, PyOpenCL, CLyther, PyCuda, etc. are typically used.

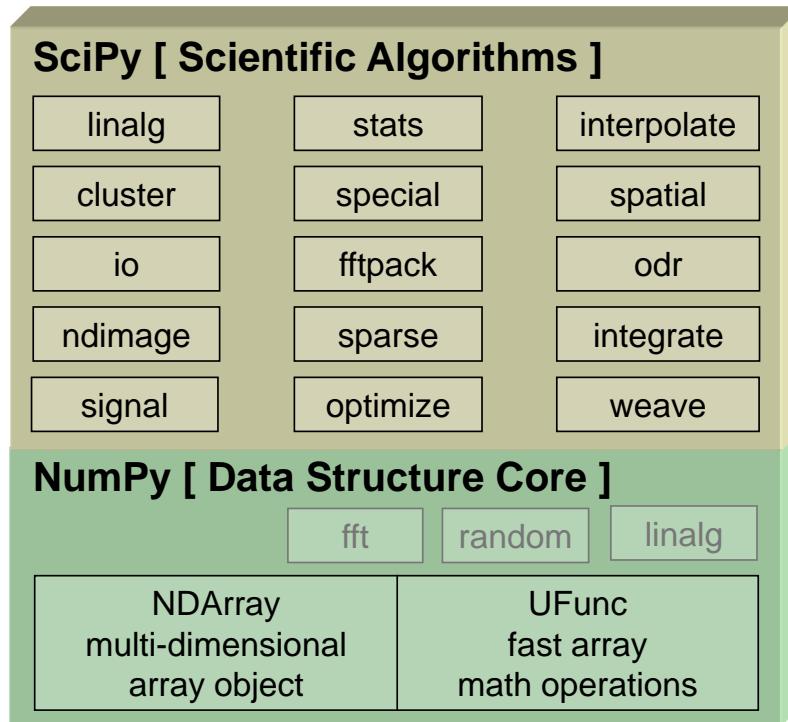
Multiprocessing is useful when one needs to add concurrency to an application without requiring external dependencies.

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NumPy

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NumPy and SciPy



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NumPy

- Website: <http://numpy.scipy.org/>
- Offers Matlab-ish capabilities within Python
- NumPy replaces Numeric and Numarray
- Developed by Travis Oliphant
- >100 “committers” to the project (github.com)
- NumPy 1.0 released October, 2006
- NumPy 1.7.1 released April, 2013
- ~45K downloads/month from SourceForge

This does not count:

- Linux distributions that include NumPy
- Enthought distributions that include NumPy

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Helpful Sites

SCIPY DOCUMENTATION PAGE

<http://docs.scipy.org/doc>

Scipy.org » Numpy and Scipy Documentation »

Numpy and Scipy Documentation

Welcome! This is the documentation for Numpy and Scipy.

For contributors:

- Write, review and proof the documentation
- Numpy developer guide

Latest: (development versions)

- Numpy Reference Guide [HTML+zip], [HTML+help (CHM)], [PDF]
- Numpy User Guide (DRAFT) [PDF]
- Scipy Reference Guide [HTML+zip], [CHM], [PDF]

Releases:

- Numpy 1.6 Reference Guide, [HTML+zip], [CHM], [PDF]
- Numpy 1.6 User Guide (DRAFT), [PDF]
- Scipy 0.9.0 Reference Guide, [HTML+zip], [PDF]
- Numpy 1.5 Reference Guide, [HTML+zip], [CHM], [PDF]

NumPy 1.6 User Guide (DRAFT) [PDF]

NUMPY EXAMPLES

http://www.scipy.org/Numpy_Example_List_With_Doc

| |
|------------------|
| Wiki |
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| Documentation |
| Mailing Lists |
| Download |
| Installing SciPy |
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| ... |

Numpy Example List Wi

This is an auto-generated version of Numpy Exam
Contents

1. ...
2. []
3. T
4. abs()
5. absolute()
6. accumulate
7. add()

apply_along_axis()

numpy.apply_along_axis(func1d, axis, arr, *args)

Execute func1d(arr[i],*args) where func1d takes 1-D arrays and arr is an N-d array. i varies so as to apply the function along the given axis for each 1-d subarray in arr.

Example:

```
>>> from numpy import *
>>> def myfunc(a):
...     return (a[0]+a[-1])/2
...
>>> b = array([[1,2,3],[4,5,6],[7,8,9]])
>>> apply_along_axis(myfunc,0,b)           # apply myf
array([4, 5, 6])
>>> apply_along_axis(myfunc,1,b)          # apply myfu
array([2, 5, 8])
```

Getting Started

IMPORT NUMPY

```
In [1]: from numpy import *
In [2]: __version__
Out[2]: 1.6.0
or
In [1]: from numpy import \
array, ...
```

Often at the command line, it is handy to import everything from NumPy into the command shell.

However, if you are writing scripts, it is easier for others to read and debug in the future if you use explicit imports.

USING IPYTHON -PYLAB

```
C:\> ipython --pylab
In [1]: array([1,2,3])
Out[1]: array([1, 2, 3])
```

IPython has a 'pylab' mode where it imports all of NumPy, Matplotlib, and SciPy into the namespace for you as a convenience. It also enables threading for showing plots.



While IPython is used for all the demos, '>>>' is used on future slides instead of 'In [1]:' to save space.

Array Operations

SIMPLE ARRAY MATH

```
>>> a = array([1,2,3,4])
>>> b = array([2,3,4,5])
>>> a + b
array([3, 5, 7, 9])
>>> a * b
array([ 2,  6, 12, 20])
>>> a ** b
array([ 1,  8,  81, 1024])
```



NumPy defines these constants:
 $\pi = 3.14159265359$
 $e = 2.71828182846$

MATH FUNCTIONS

```
# create array from 0 to 10
>>> x = arange(11.)

# multiply entire array by
# scalar value
>>> c = (2*pi)/10.
>>> c
0.62831853071795862
>>> c*x
array([ 0., 0.628,...,6.283])

# in-place operations
>>> x *= c
>>> x
array([ 0., 0.628,...,6.283])

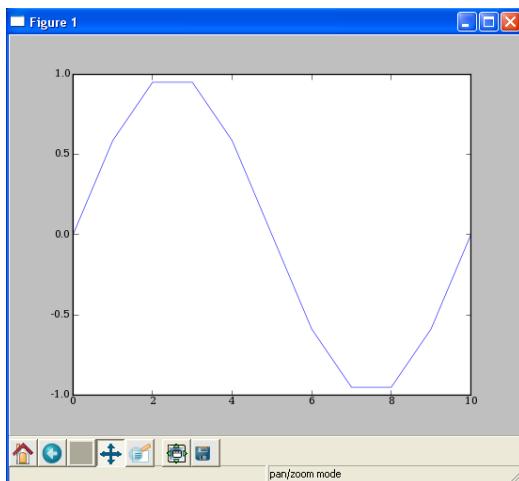
# apply functions to array
>>> y = sin(x)
```

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Plotting Arrays

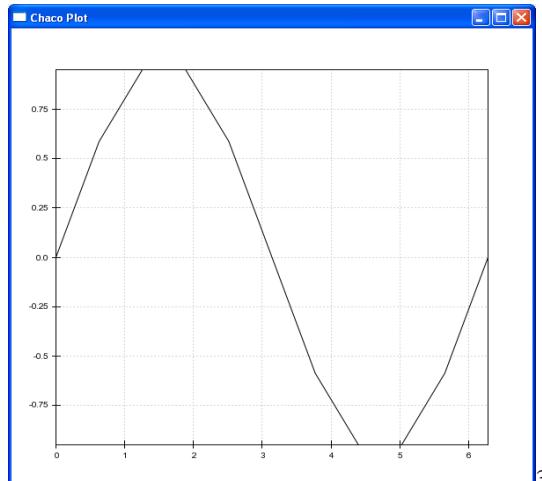
MATPLOTLIB

```
>>> plot(x,y)
```



CHACO SHELL

```
>>> from chaco import shell
>>> shell.plot(x,y)
```

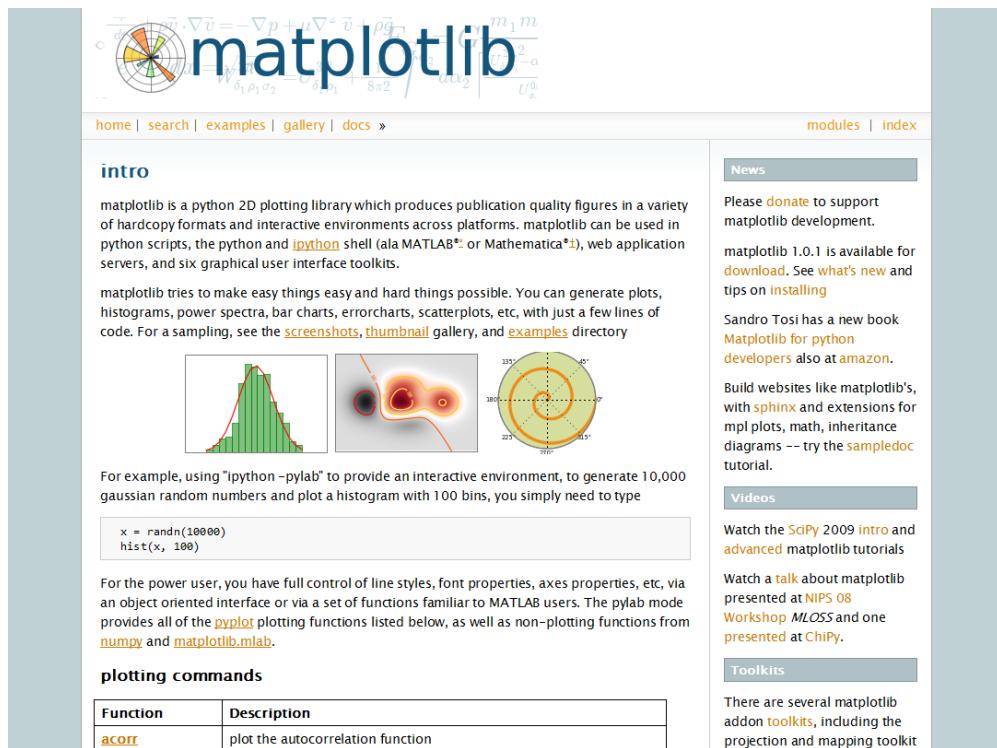


Matplotlib Basics

(an interlude)

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<http://matplotlib.org/>



The screenshot shows the official Matplotlib website at <http://matplotlib.org/>. The page features a large banner with mathematical equations and a logo. Below the banner, there's a navigation bar with links to 'home', 'search', 'examples', 'gallery', 'docs', 'modules', and 'index'. The main content area has a section titled 'intro' which describes Matplotlib as a Python 2D plotting library. It includes a histogram plot with a red curve overlay and a contour plot. A sidebar on the right contains sections for 'News', 'Videos', and 'Toolkits', each with links to external resources.

intro

matplotlib is a python 2D plotting library which produces publication quality figures in a variety of hardcopy formats and interactive environments across platforms. matplotlib can be used in python scripts, the python and [ipython](#) shell (ala MATLAB® or Mathematica®), web application servers, and six graphical user interface toolkits.

matplotlib tries to make easy things easy and hard things possible. You can generate plots, histograms, power spectra, bar charts, errorcharts, scatterplots, etc, with just a few lines of code. For a sampling, see the [screenshots](#), [thumbnail](#) gallery, and [examples](#) directory

For example, using "ipython -pylab" to provide an interactive environment, to generate 10,000 gaussian random numbers and plot a histogram with 100 bins, you simply need to type

```
x = randn(10000)
hist(x, 100)
```

For the power user, you have full control of line styles, font properties, axes properties, etc, via an object oriented interface or via a set of functions familiar to MATLAB users. The pylab mode provides all of the [pyplot](#) plotting functions listed below, as well as non-plotting functions from [numpy](#) and [matplotlib.mlab](#).

plotting commands

| Function | Description |
|-----------------------|-----------------------------------|
| acorr | plot the autocorrelation function |

News

Please [donate](#) to support matplotlib development.

matplotlib 1.0.1 is available for [download](#). See [what's new](#) and tips on [installing](#).

Sandro Tosi has a new book [Matplotlib for python developers](#) also at [amazon](#).

Build websites like matplotlib's, with [sphinx](#) and extensions for mpl plots, math, inheritance diagrams -- try the [sampledoc](#) tutorial.

Videos

Watch the [SciPy 2009 intro](#) and [advanced matplotlib tutorials](#)

Watch a [talk](#) about matplotlib presented at [NIPS 08](#)

Toolkits

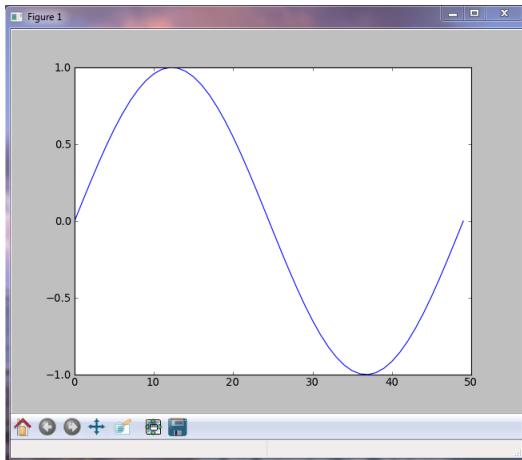
There are several matplotlib addon [toolkits](#), including the projection and mapping toolkit

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Line Plots

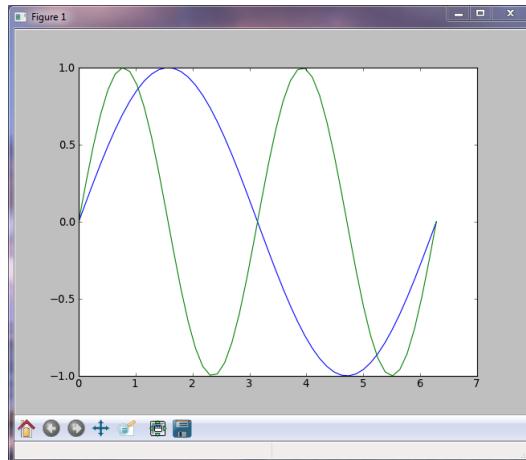
PLOT AGAINST INDICES

```
>>> x = linspace(0,2*pi,50)
>>> plot(sin(x))
```



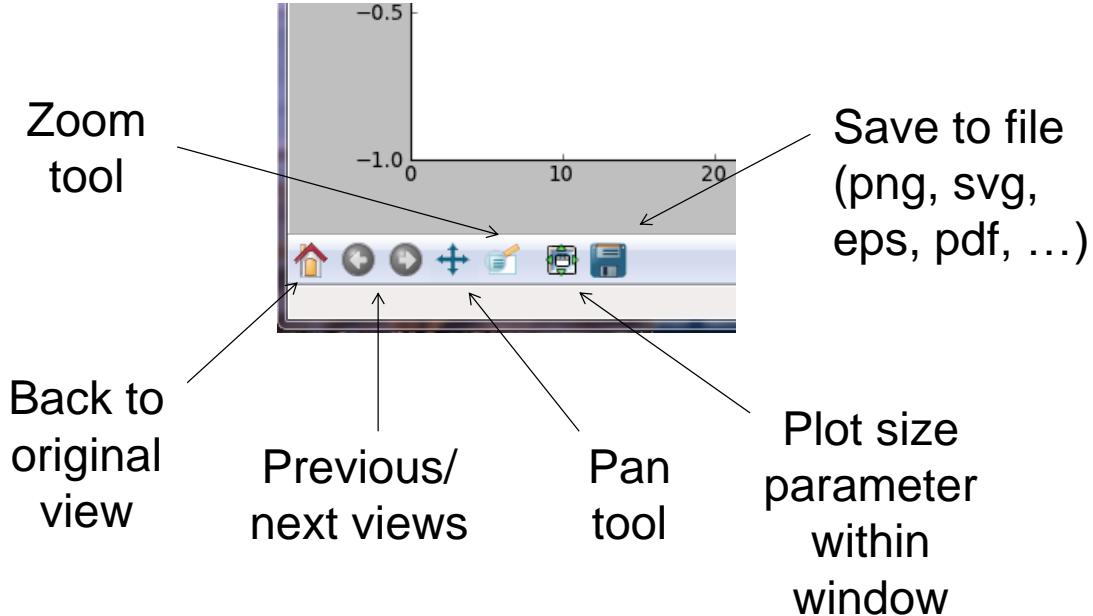
MULTIPLE DATA SETS

```
>>> plot(x, sin(x),
...         x, sin(2*x))
```



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Matplotlib Menu Bar

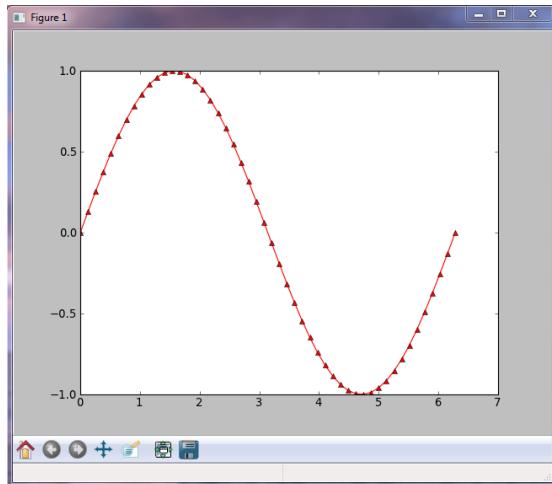


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Line Plots

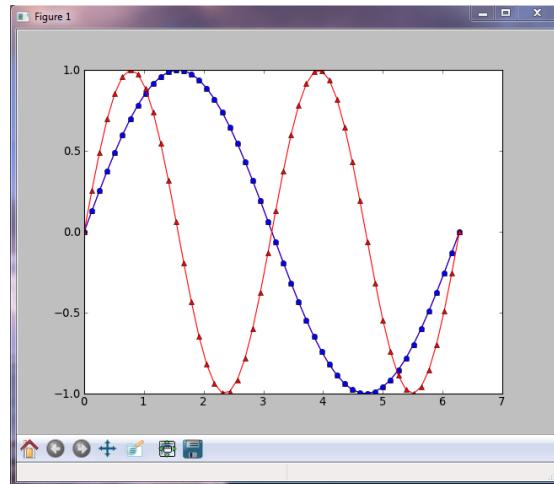
LINE FORMATTING

```
# red, dot-dash, triangles
>>> plot(x, sin(x), 'b-o',
...           x, sin(2*x), 'r-^')
```



MULTIPLE PLOT GROUPS

```
>>> plot(x, sin(x), 'b-o',
...           x, sin(2*x), 'r-^')
```

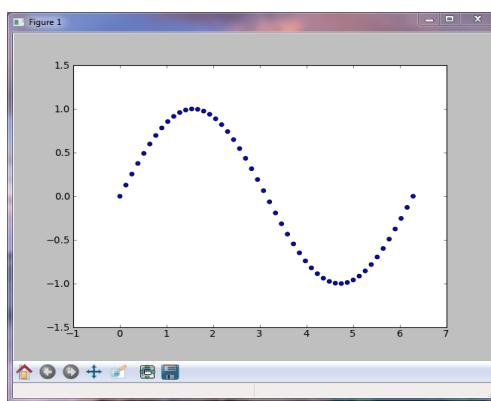


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Scatter Plots

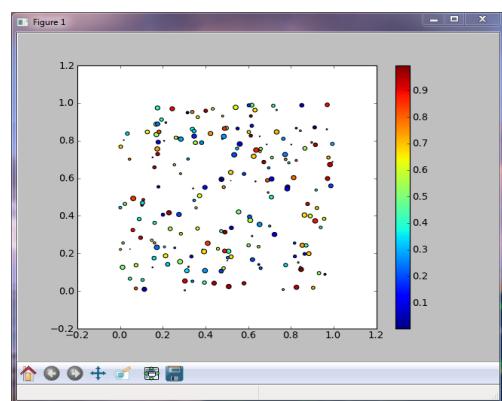
SIMPLE SCATTER PLOT

```
>>> x = linspace(0,2*pi,50)
>>> y = sin(x)
>>> scatter(x, y)
```



COLORMAPPED SCATTER

```
# marker size/color set with data
>>> x = rand(200)
>>> y = rand(200)
>>> size = rand(200)*30
>>> color = rand(200)
>>> scatter(x, y, size, color)
>>> colorbar()
```



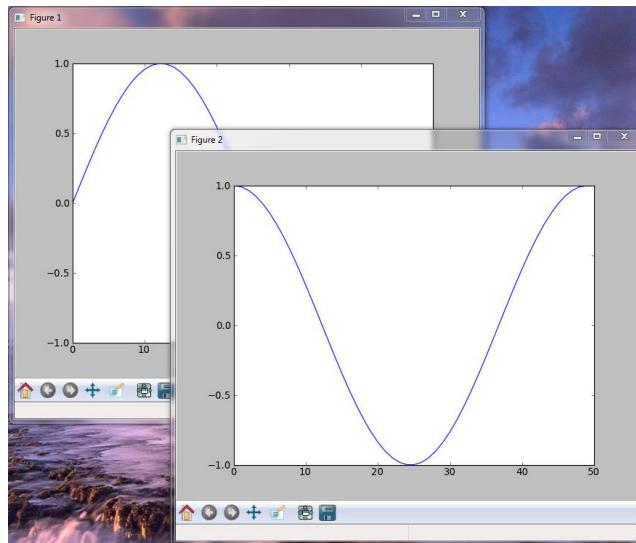
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Multiple Figures

```
>>> t = linspace(0,2*pi,50)
>>> x = sin(t)
>>> y = cos(t)

# Now create a figure
>>> figure()
>>> plot(x)

# Now create a new figure.
>>> figure()
>>> plot(y)
```



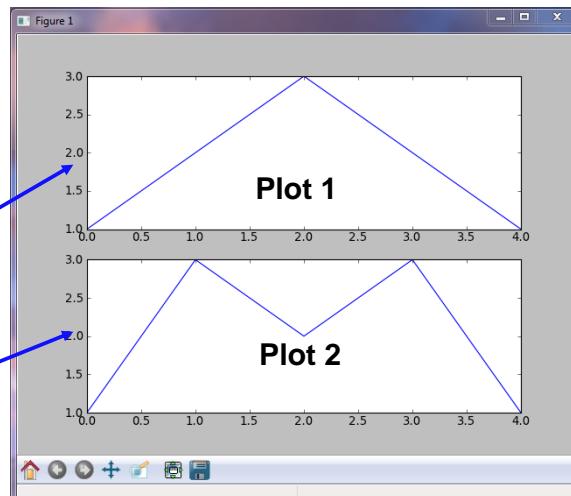
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Multiple Plots Using subplot

```
>>> x = array([1,2,3,2,1])
>>> y = array([1,3,2,3,1])

# To divide the plotting area
    columns
    |           |
>>> subplot(2, 1, 1)
    |           |
    rows       active plot
    |           |
>>> plot(x)

# Now activate a new plot
# area.
>>> subplot(2, 1, 2)
>>> plot(y)
```



If this is used in a python script, a call to the function `show()` is required.

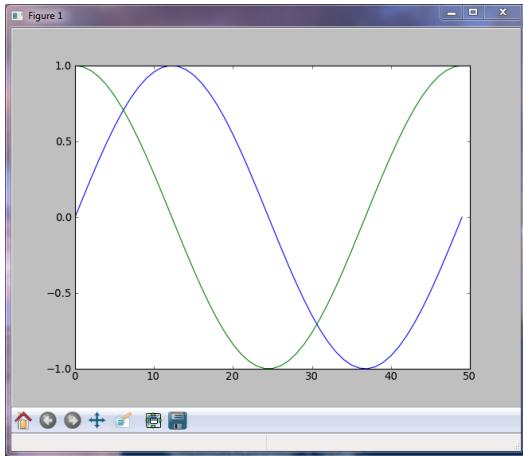
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Adding Lines to a Plot

MULTIPLE PLOTS

```
# By default, previous lines
# are "held" on a plot.

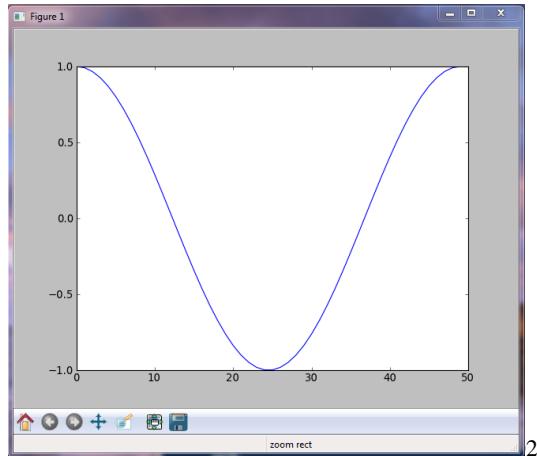
>>> plot(sin(x))
>>> plot(cos(x))
```



ERASING OLD PLOTS

```
# Set hold(False) to erase
# old lines

>>> plot(sin(x))
>>> hold(False)
>>> plot(cos(x))
```

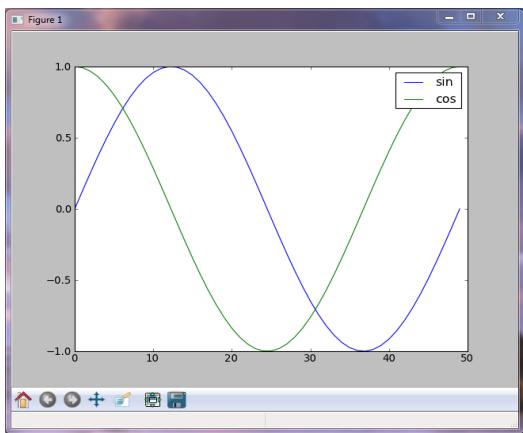


Legend

LEGEND LABELS WITH PLOT

```
# Add labels in plot command.

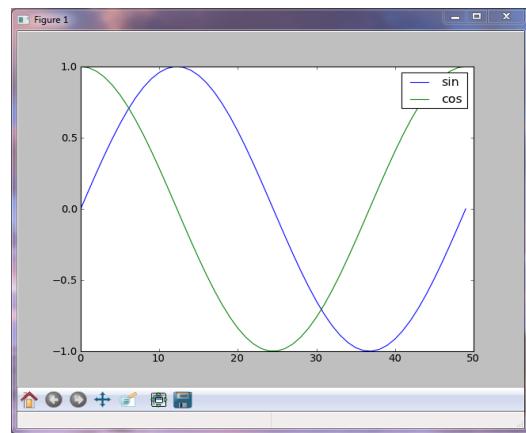
>>> plot(sin(x), label='sin')
>>> plot(cos(x), label='cos')
>>> legend()
```



LABELING WITH LEGEND

```
# Or as a list in legend().

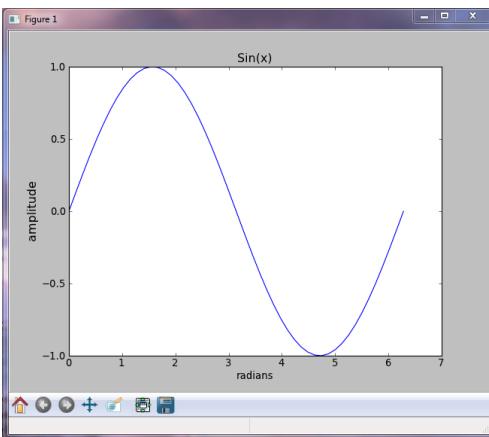
>>> plot(sin(x))
>>> plot(cos(x))
>>> legend(['sin', 'cos'])
```



Titles and Grid

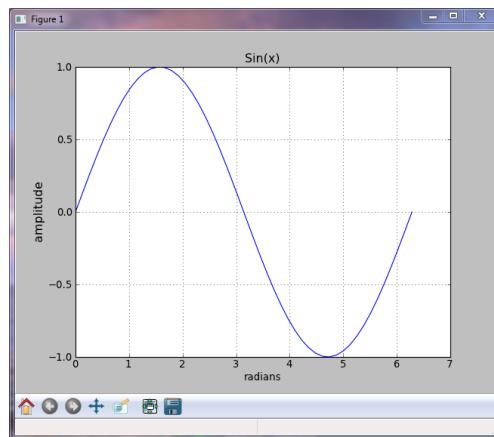
TITLES AND AXIS LABELS

```
>>> plot(x, sin(x))
>>> xlabel('radians')
# Keywords set text properties.
>>> ylabel('amplitude',
...         fontsize='large')
>>> title('Sin(x)')
```



PLOT GRID

```
# Display gridlines in plot
>>> grid()
```

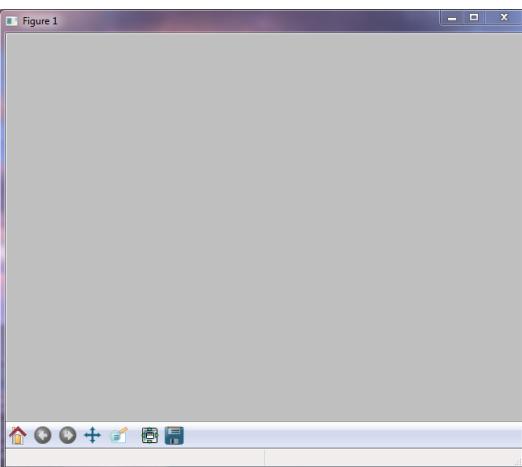


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Clearing and Closing Plots

CLEARING A FIGURE

```
>>> plot(x, sin(x))
# clf will clear the current
# plot (figure).
>>> clf()
```



CLOSING PLOT WINDOWS

```
# close() will close the
# currently active plot window.
>>> close()

# close('all') closes all the
# plot windows.
>>> close('all')
```

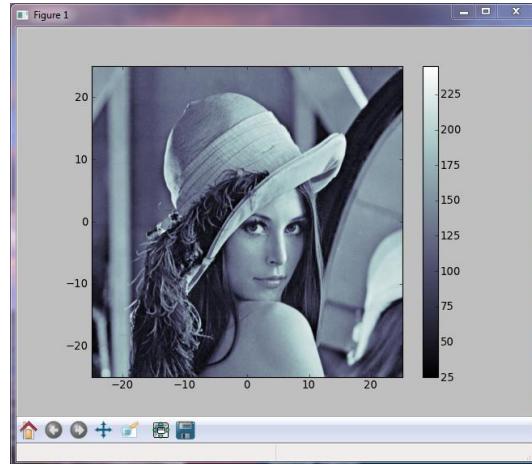
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Image Display

```
# Get the Lena image from scipy.
>>> from scipy.misc import lena
>>> img = lena()

# Display image with the jet
# colormap, and setting
# x and y extents of the plot.
>>> imshow(img,
...          extent=[-25,25,-25,25],
...          cmap = cm.bone)

# Add a colorbar to the display.
>>> colorbar()
```



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Plotting from Scripts

INTERACTIVE MODE

```
# In IPython, plots show up
# as soon as a plot command
# is called.
>>> figure()
>>> plot(sin(x))
>>> figure()
>>> plot(cos(x))
```

NON-INTERACTIVE MODE

```
# script.py
# In a script, you must call
# the show() command to display
# plots. Call it at the end of
# all your plot commands for
# best performance.
figure()
plot(sin(x))
figure()
plot(cos(x))

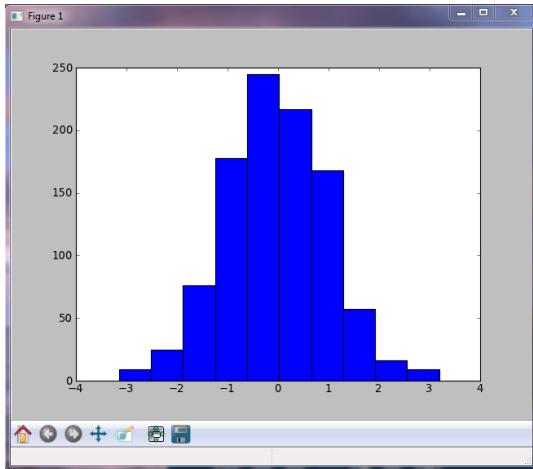
# Plots will not appear until
# this command is issued.
show()
```

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Histograms

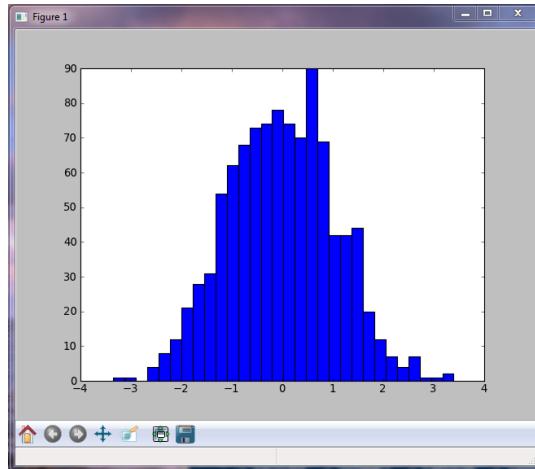
HISTOGRAM

```
# plot histogram
# defaults to 10 bins
>>> hist(randn(1000))
```



HISTOGRAM 2

```
# change the number of bins
>>> hist(randn(1000), 30)
```

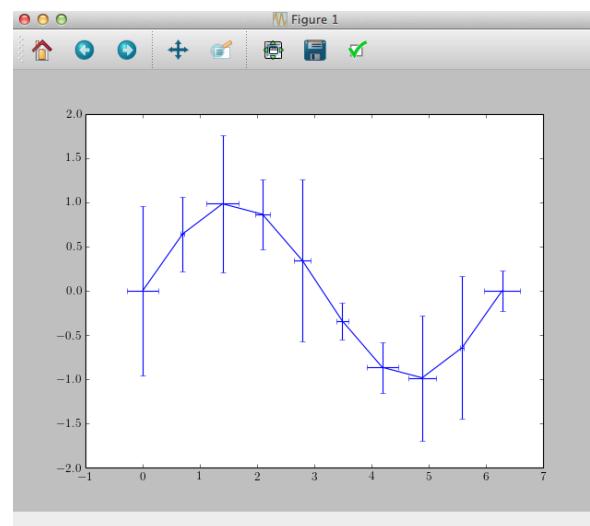


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Plots with error bars

ERRORBAR

```
# Assume points are known
# with errors in both axis
>>> x = linspace(0,2*pi,10)
>>> y = sin(x)
>>> yerr = rand(10)
>>> xerr = rand(10)/3
>>> errorbar(x, y, yerr, xerr)
```



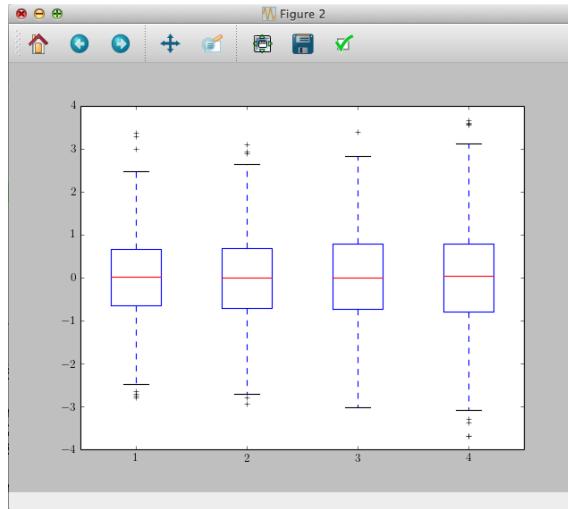
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Plots with error bars II

BOXPLOT

```
# Assume 4 experiments have measured a
# quantity with a certain medians and
# std deviations.

# Data
>>> from numpy.random import normal
>>> exp = [normal(0, 1+i/5, size=(500,))
           for i in np.arange(4.)]
>>> medians=[np.median(e) for e in exp]
>>> stds = [np.std(e) for e in exp]
# Plotting
>>> conf_intervals = [
    (med - std, med + std) for
    med, std in zip(medians, stds)]
>>> pos = np.arange(len(exp))+1
>>> boxplot(exp, sym='k+', 
            positions=pos,
            usermedians=medians,
            conf_intervals=conf_intervals)
```

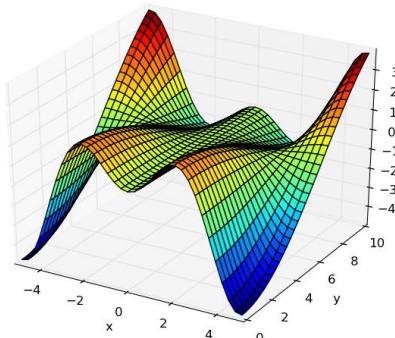


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3D Plots with Matplotlib

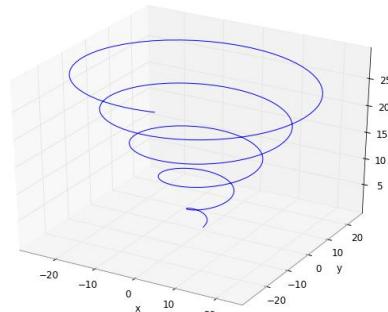
SURFACE PLOT

```
>>> from mpl_toolkits.mplot3d import
Axes3D
>>> x, y = mgrid[-5:5:35j, 0:10:35j]
>>> z = x*sin(x)*cos(0.25*y)
>>> fig = figure()
>>> ax = fig.gca(projection='3d')
>>> ax.plot_surface(x, y, z,
...     rstride=1, cstride=1,
...     cmap=cm.jet)
>>> xlabel('x'); ylabel('y')
```



PARAMETRIC CURVE

```
>>> from mpl_toolkits.mplot3d import
Axes3D
>>> t = linspace(0, 30, 1000)
>>> x, y, z = [t*cos(t), t*sin(t), t]
>>> fig = figure()
>>> ax = fig.gca(projection='3d')
>>> ax.plot(x, y, z)
>>> xlabel('x')
>>> ylabel('y')
```



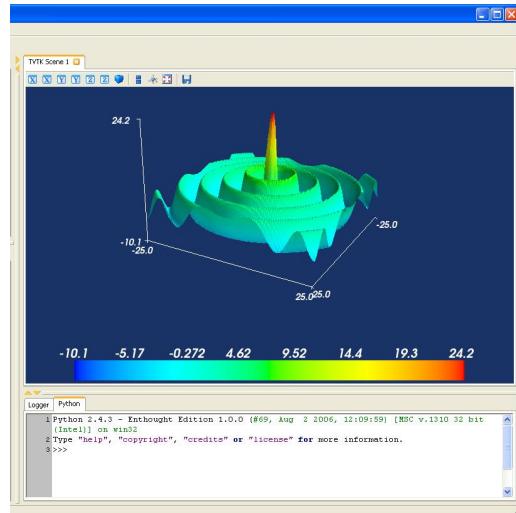
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Surface Plots with mlab

```
# Create 2D array where values
# are radial distance from
# the center of array.

>>> from numpy import mgrid
>>> from scipy import special
>>> x,y = mgrid[-25:25:100j,
...                 -25:25:100j]
>>> r = sqrt(x**2+y**2)
# Calculate Bessel function of
# each point in array and scale.
>>> s = special.j0(r)*25

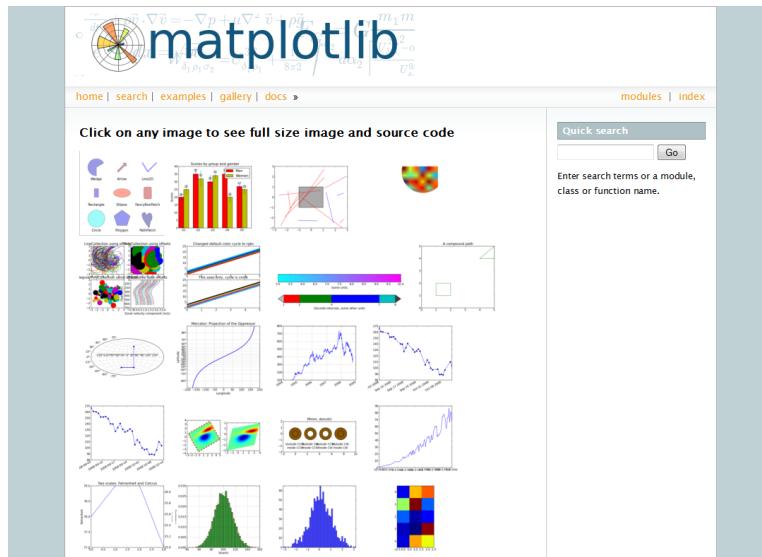
# Display surface plot.
>>> from mayavi import mlab
>>> mlab.surf(x,y,s)
>>> mlab.scalarbar()
>>> mlab.axes()
```



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More Details

- Simple examples with increasing difficulty: <http://matplotlib.org/examples/index.html>
- Gallery (huge): <http://matplotlib.org/gallery.html>



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Continuing NumPy...

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Introducing NumPy Arrays

SIMPLE ARRAY CREATION

```
>>> a = array([0,1,2,3])
>>> a
array([0, 1, 2, 3])
```

CHECKING THE TYPE

```
>>> type(a)
numpy.ndarray
```

NUMERIC ‘TYPE’ OF ELEMENTS

```
>>> a.dtype
dtype('int32')
```

BYTES PER ELEMENT

```
>>> a.itemsize
4
```

ARRAY SHAPE

```
# Shape returns a tuple
# listing the length of the
# array along each dimension.
>>> a.shape
(4,)
>>> shape(a)
(4,)
```

ARRAY SIZE

```
# Size reports the entire
# number of elements in an
# array.
>>> a.size
4
>>> size(a)
4
```

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Introducing NumPy Arrays

BYTES OF MEMORY USED

```
# Return the number of bytes
# used by the data portion of
# the array.
>>> a nbytes
16
```

NUMBER OF DIMENSIONS

```
>>> a.ndim
1
```

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Setting Array Elements

ARRAY INDEXING

```
>>> a[0]
0
>>> a[0] = 10
>>> a
array([10, 1, 2, 3])
```

FILL

```
# set all values in an array
>>> a.fill(0)
>>> a
array([0, 0, 0, 0])

# this also works, but may
# be slower
>>> a[:] = 1
>>> a
array([1, 1, 1, 1])
```

BEWARE OF TYPE COERCION

```
>>> a.dtype
dtype('int32')

# assigning a float into
# an int32 array truncates
# the decimal part
>>> a[0] = 10.6
>>> a
array([10, 1, 2, 3])

# fill has the same behavior
>>> a.fill(-4.8)
>>> a
array([-4, -4, -4, -4])
```

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Slicing

var[lower:upper:step]

Extracts a portion of a sequence by specifying a lower and upper bound.

The lower-bound element is included, but the upper-bound element is **not** included.

Mathematically: [lower, upper). The step value specifies the stride between elements.

SLICING ARRAYS

```
# indices: 0 1 2 3 4
>>> a = array([10,11,12,13,14])
# [10,11,12,13,14]
>>> a[1:3]
array([11, 12])

# negative indices work also
>>> a[1:-2]
array([11, 12])
>>> a[-4:3]
array([11, 12])
```

OMMITTING INDICES

```
# omitted boundaries are
# assumed to be the beginning
# (or end) of the list

# grab first three elements
>>> a[:3]
array([10, 11, 12])
# grab last two elements
>>> a[-2:]
array([13, 14])
# every other element
>>> a[::-2]
array([10, 12, 14])
```

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Multi-Dimensional Arrays

MULTI-DIMENSIONAL ARRAYS

```
>>> a = array([[ 0,  1,  2,  3],
              [10,11,12,13]])
>>> a
array([[ 0,  1,  2,  3],
       [10,11,12,13]])
```

SHAPE = (ROWS,COLUMNS)

```
>>> a.shape
(2, 4)
```

ELEMENT COUNT

```
>>> a.size
8
```

NUMBER OF DIMENSIONS

```
>>> a.ndim
2
```

GET/SET ELEMENTS

```
>>> a[1,3]
13
      ↑
      column
      ↓
      row

>>> a[1,3] = -1
>>> a
array([[ 0,  1,  2,  3],
       [10,11,12,-1]])
```

ADDRESS SECOND (ONETH) ROW USING SINGLE INDEX

```
>>> a[1]
array([10, 11, 12, -1])
```

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Arrays from/to ASCII files

BASIC PATTERN

```
# Read data into a list of lists,
# and THEN convert to an array.
file = open('myfile.txt')

# Create a list for all the data.
data = []

for line in file:
    # Read each row of data into a
    # list of floats.
    fields = line.split()
    row_data = [float(x) for x
                in fields]
    # And add this row to the
    # entire data set.
    data.append(row_data)

# Finally, convert the "list of
# lists" into a 2D array.
data = array(data)
file.close()
```

ARRAYS FROM/TO TXT FILES

Data.txt

```
-- BEGINNING OF THE FILE
% Day, Month, Year, Skip, Avg Power
01, 01, 2000, x876, 13 % crazy day!
% we don't have Jan 03rd
04, 01, 2000, xfed, 55
```

```
# loadtxt() automatically generates
# an array from the txt file
arr = loadtxt('Data.txt', skiprows=1,
              dtype=int, delimiter=",",
              usecols = (0,1,2,4),
              comments = "%")

# Save an array into a txt file
savetxt('filename', arr)
```

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Arrays to/from Files

OTHER FILE FORMATS

Many file formats are supported in various packages:

| File format | Package name(s) | Functions |
|-------------|--------------------------|--|
| txt | numpy | loadtxt, savetxt, genfromtxt, fromfile, tofile |
| csv | csv | reader, writer |
| Matlab | scipy.io | loadmat, savemat |
| hdf | pytables, h5py | |
| NetCDF | netCDF4, scipy.io.netcdf | netCDF4.Dataset, scipy.io.netcdf.netcdf_file |

This includes many industry specific formats:

| File format | Package name | Comments |
|----------------|-------------------------|--------------------------|
| wav | scipy.io.wavfile | Audio files |
| LAS/SEG-Y | Scipy cookbook, EPD | Data files in Geophysics |
| jpeg, png, ... | PIL, scipy.misc.pilutil | Common image formats |
| FITS | pyfits, astropy.io.fits | Image files in Astronomy |

Array Slicing

SLICING WORKS MUCH LIKE STANDARD PYTHON SLICING

```
>>> a[0,3:5]
array([3, 4])

>>> a[4:,4:]
array([[44, 45],
       [54, 55]])

>>> a[:,2]
array([2,12,22,32,42,52])
```

STRIDES ARE ALSO POSSIBLE

```
>>> a[2::2,:,:2]
array([[20, 22, 24],
       [40, 42, 44]])
```

| | | | | | |
|----|----|----|----|----|----|
| 0 | 1 | 2 | 3 | 4 | 5 |
| 10 | 11 | 12 | 13 | 14 | 15 |
| 20 | 21 | 22 | 23 | 24 | 25 |
| 30 | 31 | 32 | 33 | 34 | 35 |
| 40 | 41 | 42 | 43 | 44 | 45 |
| 50 | 51 | 52 | 53 | 54 | 55 |

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Slices Are References

Slices are references to memory in the original array.

Changing values in a slice also changes the original array.

```
>>> a = array((0,1,2,3,4))
      2
      # create a slice containing only the
      # last element of a
      >>> b = a[2:4]
      >>> b
      array([2, 3])
      >>> b[0] = 10

      # changing b changed a!
      >>> a
      array([ 0,  1, 10,  3,  4])
```

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Fancy Indexing

INDEXING BY POSITION

```
>>> a = arange(0,80,10)

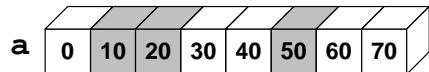
# fancy indexing
>>> indices = [1, 2, -3]
>>> y = a[indices]
>>> print y
[10 20 50]
```

INDEXING WITH BOOLEANS

```
# manual creation of masks
>>> mask = array([0,1,1,0,0,1,0,0], 
...                 dtype=bool)

# conditional creation of masks
>>> mask2 = a < 30

# fancy indexing
>>> y = a[mask]
>>> print y
[10 20 50]
```



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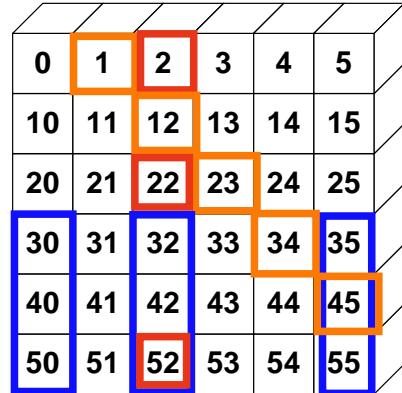
Fancy Indexing in 2-D

```
>>> a[(0,1,2,3,4), (1,2,3,4,5)]
array([ 1, 12, 23, 34, 45])

>>> a[3:,[0, 2, 5]]
array([[30, 32, 35],
       [40, 42, 45],
       [50, 52, 55]])

>>> mask = array([1,0,1,0,0,1],
...                 dtype=bool)

>>> a[mask,2]
array([2,22,52])
```

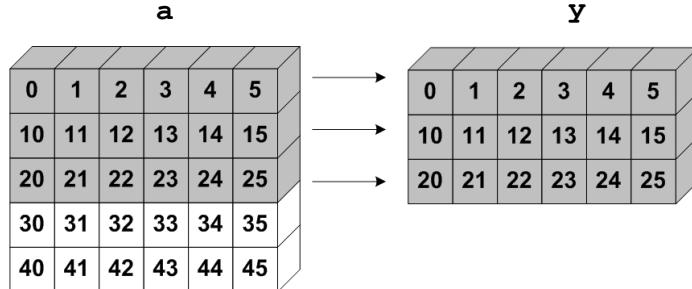


Unlike slicing, fancy indexing creates copies instead of a view into original array.

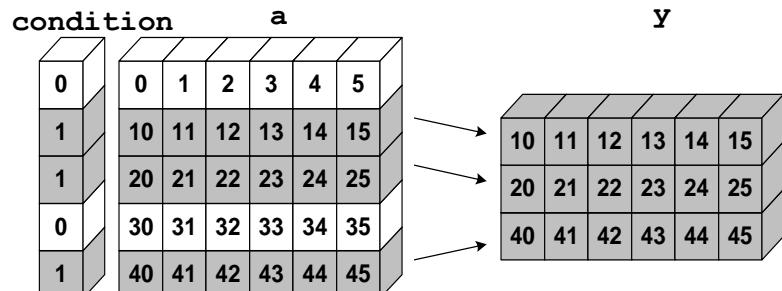
225

“Incomplete” Indexing

```
>>> y = a[:3]
```



```
>>> y = a[condition]
```

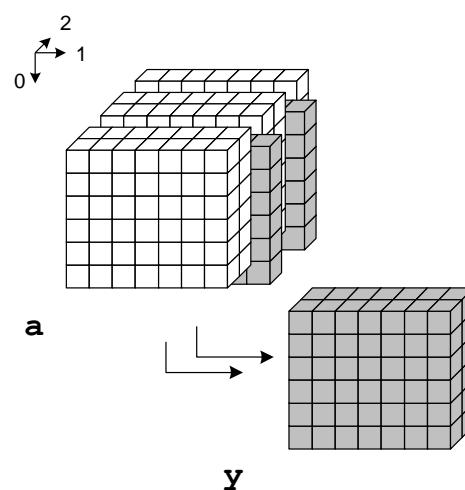


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3D Example

MULTIDIMENSIONAL

```
# retrieve two slices from a
# 3D cube via indexing
>>> y = a[:, :, [2, -2]]
```



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Where

1 DIMENSION

```
# find the indices in array
# where expression is True
>>> a = array([0, 12, 5, 20])
>>> a > 10
array([False, True, False,
       True], dtype=bool)

# Note: it returns a tuple!
>>> where(a > 10)
(array([1, 3]),)
```

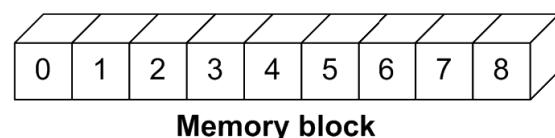
n DIMENSIONS

```
# In general, the tuple
# returned is the index of the
# element satisfying the
# condition in each dimension.
>>> a = array([[0, 12, 5, 20],
              [1, 2, 11, 15]])
>>> loc = where(a > 10)
>>> loc
(array([0, 0, 1, 1]),
array([1, 3, 2, 3]))

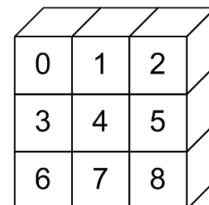
# Result can be used in
# various ways:
>>> a[loc]
array([12, 20, 11, 15])
```

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Array Data Structure



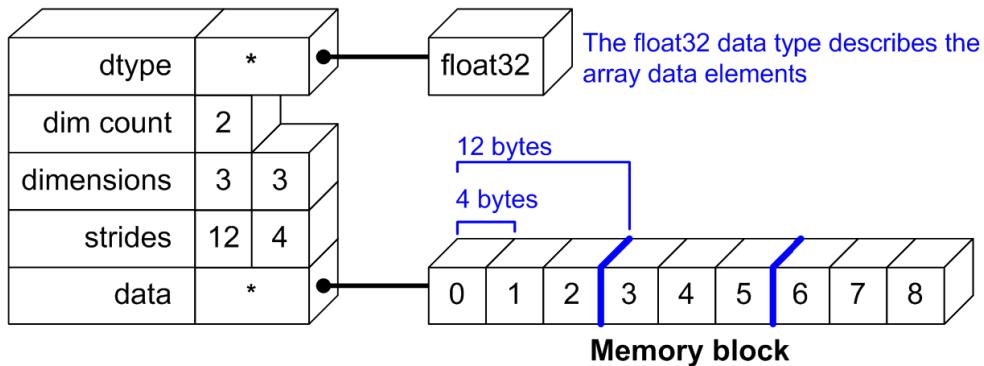
Python View:



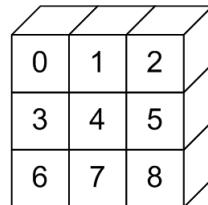
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Array Data Structure

NDArray Data Structure



Python View:



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Indexing with newaxis

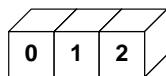
newaxis is a special index that inserts a new axis in the array at the specified location.

Each **newaxis** increases the array's dimensionality by 1.



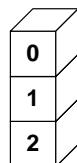
1 X 3

```
>>> shape(a)
(3,)
>>> y = a[newaxis,:]
>>> shape(y)
(1, 3)
```



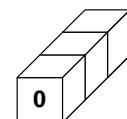
3 X 1

```
>>> y = a[:,newaxis]
>>> shape(y)
(3, 1)
```



1 X 1 X 3

```
> y = a[newaxis, newaxis, :]
> shape(y)
(1, 1, 3)
```



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“Flattening” Arrays

a.flatten()

`a.flatten()` converts a multi-dimensional array into a 1-D array. The new array is a *copy* of the original data.

```
# Create a 2D array
>>> a = array([[0,1],
              [2,3]])

# Flatten out elements to 1D
>>> b = a.flatten()
>>> b
array([0,1,2,3])

# Changing b does not change a
>>> b[0] = 10
>>> b
array([10,1,2,3])
>>> a
array([[0, 1],
       [2, 3]])
```

a.flat

`a.flat` is an *attribute* that returns an iterator object that accesses the data in the multi-dimensional array data as a 1-D array. It *references* the original memory.

```
>>> a.flat
<numpy.flatiter obj...>
>>> a.flat[:]
array(0,1,2,3)

>>> b = a.flat
>>> b[0] = 10
>>> a
array([[10,  1],
       [ 2,  3]])
```

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“(Un)raveling” Arrays

a.ravel()

`a.ravel()` is the same as `a.flatten()`, but returns a *reference* (or *view*) of the array if possible (i.e., the memory is contiguous). Otherwise the new array copies the data.

```
# create a 2-D array
>>> a = array([[0,1],
              [2,3]])

# flatten out elements to 1-D
>>> b = a.ravel()
>>> b
array([0,1,2,3])

# changing b does change a
>>> b[0] = 10
>>> b
array([10,1,2,3])
>>> a
array([[10,  1],
       [ 2,  3]])
```

a.ravel() MAKES A COPY

```
# create a 2-D array
>>> a = array([[0,1],
              [2,3]])

# transpose array so memory
# layout is no longer contiguous
>>> aa = a.transpose()
>>> aa
array([[0, 2],
       [1, 3]])

# ravel creates a copy of data
>>> b = aa.ravel()
array([0,2,1,3])

# changing b doesn't change a
>>> b[0] = 10
>>> b
array([10,1,2,3])
>>> a
array([[0,  1],
       [2,  3]])
```

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Reshaping Arrays

SHAPE

```
>>> a = arange(6)
>>> a
array([0, 1, 2, 3, 4, 5])
>>> a.shape
(6,)

# reshape array in-place to
# 2x3
>>> a.shape = (2,3)
>>> a
array([[0, 1, 2],
       [3, 4, 5]])
```

RESHAPE

```
# return a new array with a
# different shape
>>> a.reshape(3,2)
array([[0, 1],
       [2, 3],
       [4, 5]])

# reshape cannot change the
# number of elements in an
# array
>>> a.reshape(4,2)
ValueError: total size of new
array must be unchanged
```

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Transpose

TRANSPOSE

```
>>> a = array([[0,1,2],
...             [3,4,5]])
>>> a.shape
(2,3)
# Transpose swaps the order
# of axes. For 2-D this
# swaps rows and columns.
>>> a.transpose()
array([[0, 3],
       [1, 4],
       [2, 5]])

# The .T attribute is
# equivalent to transpose().
>>> a.T
array([[0, 3],
       [1, 4],
       [2, 5]])
```

TRANSPOSE RETURNS VIEWS

```
>>> b = a.T

# Changes to b alter a.
>>> b[0,1] = 30
>>> a
array([[ 0,  1,  2],
       [30,  4,  5]])
```

TRANSPOSE AND STRIDES

```
# Transpose does not move
# values around in memory. It
# only changes the order of
# "strides" in the array
>>> a.strides
(12, 4)

>>> a.T.strides
(4, 12)
```

236

Squeeze

SQUEEZE

```
>>> a = array([[1,2,3],
...             [4,5,6]])
>>> a.shape
(2, 3)

# insert an "extra" dimension
>>> a.shape = (2,1,3)
>>> a
array([[[0, 1, 2]],
       [[3, 4, 5]]])

# squeeze removes any
# dimension with length==1
>>> a = a.squeeze()
>>> a.shape
(2, 3)
```

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Diagonals

DIAGONAL

```
>>> a = array([[11,21,31],
...             [12,22,32],
...             [13,23,33]])

# Extract the diagonal from
# an array.
>>> a.diagonal()
array([11, 22, 33])

# Use offset to move off the
# main diagonal (offset can
# be negative).
>>> a.diagonal(offset=1)
array([21, 32])
```

DIAGONALS WITH INDEXING

```
# "Fancy" indexing also works.
>>> i = [0,1,2]
>>> a[i, i]
array([11, 22, 33])

# Indexing can also be used
# to set diagonal values...
>>> a[i, i] = 2
>>> i2 = array([0,1])
# upper diagonal
>>> a[i2, i2+1] = 1
# lower diagonal
>>> a[i2+1, i2] = -1
>>> a
array([[ 2,  1, 31],
       [-1,  2,  1],
       [13, -1,  2]])
```

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Complex Numbers

COMPLEX ARRAY ATTRIBUTES

```
>>> a = array([1+1j, 2, 3, 4])
array([1.+1.j, 2.+0.j, 3.+0.j,
      4.+0.j])
>>> a.dtype
dtype('complex128')

# real and imaginary parts
>>> a.real
array([ 1.,  2.,  3.,  4.])
>>> a.imag
array([ 1.,  0.,  0.,  0.])

# set imaginary part to a
# different set of values
>>> a.imag = (1,2,3,4)
>>> a
array([1.+1.j, 2.+2.j, 3.+3.j,
      4.+4.j])
```

CONJUGATION

```
>>> a.conj()
array([1.-1.j, 2.-2.j, 3.-3.j,
      4.-4.j])
```

FLOAT (AND OTHER) ARRAYS

```
>>> a = array([0., 1, 2, 3])

# .real and .imag attributes
# are available
>>> a.real
array([ 0.,  1.,  2.,  3.])
>>> a.imag
array([ 0.,  0.,  0.,  0.])

# but .imag is read-only
>>> a.imag = (1,2,3,4)
TypeError: array does not
have imaginary part to set 239
```

Array Constructor Examples

FLOATING POINT ARRAYS

```
# Default to double precision
>>> a = array([0,1.0,2,3])
>>> a.dtype
dtype('float64')
>>> a.nbytes
32
```

REDUCING PRECISION

```
>>> a = array([0,1.,2,3],
...            dtype=float32)
>>> a.dtype
dtype('float32')
>>> a.nbytes
16
```

UNSIGNED INTEGER BYTE

```
>>> a = array([0,1,2,3],
...            dtype=uint8)
>>> a.dtype
dtype('uint8')
>>> a.nbytes
4
```

ARRAY FROM BINARY DATA

```
# frombuffer or fromfile
# to create an array from
# binary data.
>>> a = frombuffer('foo',
...                  dtype=uint8)
>>> a
array([102, 111, 111])
# Reverse operation
>>> a.tofile('foo.dat')
```

NumPy dtypes

| Basic Type | Available NumPy types | Comments |
|------------------|--|---|
| Boolean | bool | Elements are 1 byte in size. |
| Integer | int8, int16, int32, int64, int128, int | int defaults to the size of long in C for the platform. |
| Unsigned Integer | uint8, uint16, uint32, uint64, uint128, uint | uint defaults to the size of unsigned long in C for the platform. |
| Float | float16, float32, float64, float, longfloat, | float is always a double precision floating point value (64 bits). longfloat represents large precision floats. Its size is platform dependent. |
| Complex | complex64, complex128, complex, longcomplex | The real and imaginary elements of a complex64 are each represented by a single precision (32 bit) value for a total size of 64 bits. |
| Strings | str, unicode | For example, dtype='S4' would be used for an array of 4-character strings. |
| Object | object | Represent items in array as Python objects. |
| Records | void | Used for arbitrary data structures. |

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Type Casting

ASARRAY

```
>>> a = array([1.5, -3],
...             dtype=float32)
>>> a
array([ 1.5, -3.], dtype=float32)

# upcast
>>> asarray(a, dtype=float64)
array([ 1.5, -3. ])

# downcast
>>> asarray(a, dtype=uint8)
array([ 1, 253], dtype=uint8)

# asarray is efficient.
# It does not make a copy if the
# type is the same.
>>> b = asarray(a, dtype=float32)
>>> b[0] = 2.0
>>> a
array([ 2., -3.], dtype=float32)
```

ASTYPE

```
>>> a = array([1.5, -3],
...             dtype=float64)
>>> a.astype(float32)
array([ 1.5, -3.], dtype=float32)

>>> a.astype(uint8)
array([ 1, 253], dtype=uint8)

# astype is safe.
# It always returns a copy of
# the array.
>>> b = a.astype(float64)
>>> b[0] = 2.0
>>> a
array([1.5, -3.])
```

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Array Calculation Methods

SUM FUNCTION

```
>>> a = array([[1,2,3],
   [4,5,6]])

# sum() defaults to adding up
# all the values in an array.
>>> sum(a)
21

# supply the keyword axis to
# sum along the 0th axis
>>> sum(a, axis=0)
array([5, 7, 9])

# supply the keyword axis to
# sum along the last axis
>>> sum(a, axis=-1)
array([ 6, 15])
```

SUM ARRAY METHOD

```
# a.sum() defaults to adding
# up all values in an array.
>>> a.sum()
21

# supply an axis argument to
# sum along a specific axis
>>> a.sum(axis=0)
array([5, 7, 9])
```

PRODUCT

```
# product along columns
>>> a.prod(axis=0)
array([ 4, 10, 18])

# functional form
>>> prod(a, axis=0)
array([ 4, 10, 18])
```

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Min/Max

MIN

```
>>> a = array([2.,3.,0.,1.])
>>> a.min(axis=0)
0.0

# Use NumPy's amin() instead
# of Python's built-in min()
# for speedy operations on
# multi-dimensional arrays.
>>> amin(a, axis=0)
0.0
```

MAX

```
>>> a = array([2.,3.,0.,1.])
>>> a.max(axis=0)
3.0
```

```
# functional form
>>> amax(a, axis=0)
3.0
```

ARGMIN

```
# Find index of minimum value.
>>> a.argmin(axis=0)
2

# functional form
>>> argmin(a, axis=0)
2
```

ARGMAX

```
# Find index of maximum value.
>>> a.argmax(axis=0)
1

# functional form
>>> argmax(a, axis=0)
1
```

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Statistics Array Methods

MEAN

```
>>> a = array([[1,2,3],
              [4,5,6]])

# mean value of each column
>>> a.mean(axis=0)
array([ 2.5,  3.5,  4.5])
>>> mean(a, axis=0)
array([ 2.5,  3.5,  4.5])
>>> average(a, axis=0)
array([ 2.5,  3.5,  4.5])

# average can also calculate
# a weighted average
>>> average(a, weights=[1,2],
...           axis=0)
array([ 3.,  4.,  5.])
```

STANDARD DEV./VARIANCE

```
# Standard Deviation
>>> a.std(axis=0)
array([ 1.5,  1.5,  1.5])

# variance
>>> a.var(axis=0)
array([2.25, 2.25, 2.25])
>>> var(a, axis=0)
array([2.25, 2.25, 2.25])
```

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Other Array Methods

CLIP

```
# Limit values to a range.

>>> a = array([[1,2,3],
              [4,5,6]])

# Set values < 3 equal to 3.
# Set values > 5 equal to 5.
>>> a.clip(3, 5)
array([[3, 3, 3],
       [4, 5, 5]])
```

ROUND

```
# Round values in an array.
# NumPy rounds to even, so
# 1.5 and 2.5 both round to 2.
>>> a = array([1.35, 2.5, 1.5])
>>> a.round()
array([ 1.,  2.,  2.])

# Round to first decimal place.
>>> a.round(decimals=1)
array([ 1.4,  2.5,  1.5])
```

PEAK TO PEAK

```
# Calculate max - min for
# array along columns
>>> a.ptp(axis=0)
array([3, 3, 3])
# max - min for entire array.
>>> a.ptp(axis=None)
```

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Summary of (most) array attributes/methods (1/4)

ENTHOUGHT

| BASIC ATTRIBUTES | |
|--------------------------|---|
| a.dtype | Numerical type of array elements: float 32, uint8, etc. |
| a.shape | Shape of array (m, n, o, ...) |
| a.size | Number of elements in entire array |
| a.itemsize | Number of bytes used by a single element in the array |
| a nbytes | Number of bytes used by entire array (data only) |
| a.ndim | Number of dimensions in the array |
| SHAPE OPERATIONS | |
| a.flat | An iterator to step through array as if it were 1D |
| a.flatten() | Returns a 1D copy of a multi-dimensional array |
| a.ravel() | Same as flatten(), but returns a "view" if possible |
| a.resize(new_size) | Changes the size/shape of an array in place |
| a.swapaxes(axis1, axis2) | Swaps the order of two axes in an array |
| a.transpose(*axes) | Swaps the order of any number of array axes |
| a.T | Shorthand for a.transpose() |
| a.squeeze() | Removes any length==1 dimensions from an array |

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Summary of (most) array attributes/methods (2/4)

ENTHOUGHT

| FILL AND COPY | |
|-----------------------|--|
| a.copy() | Returns a copy of the array |
| a.fill(value) | Fills an array with a scalar value |
| CONVERSION/COERCION | |
| a.tolist() | Converts array into nested lists of values |
| a.tostring() | Raw copy of array memory into a Python string |
| a.astype(dtype) | Returns array coerced to the given type |
| a.byteswap(False) | Converts byte order (big <->little endian) |
| a.view(type_or_dtype) | Creates a new ndarray that sees the same memory but interprets it as a new datatype (or subclass of ndarray) |
| COMPLEX NUMBERS | |
| a.real | Returns the real part of the array |
| a.imag | Returns the imaginary part of the array |
| a.conjugate() | Returns the complex conjugate of the array |
| a.conj() | Returns the complex conjugate of the array (same as conjugate) |

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Summary of (most) array attributes/methods (3/4)

ENTHOUGHT

| SAVING | |
|------------------------------------|--|
| a.dump(file) | Stores binary array data to <i>file</i> |
| a.dumps() | Returns a binary pickle of the data as a string |
| a.tofile(fid, sep="", format="%s") | Formatted ASCII output to a file |
| SEARCH/SORT | |
| a.nonzero() | Returns indices for all non-zero elements in the array |
| a.sort(axis=-1) | Sort the array elements in place, along <i>axis</i> |
| a.argsort(axis=-1) | Finds indices for sorted elements, along <i>axis</i> |
| a.searchsorted(b) | Finds indices where elements of <i>b</i> would be inserted in <i>a</i> to maintain order |
| ELEMENT MATH OPERATIONS | |
| a.clip(low, high) | Limits values in the array to the specified range |
| a.round(decimals=0) | Rounds to the specified number of digits |
| a.cumsum(axis=None) | Cumulative sum of elements along <i>axis</i> |
| a.cumprod(axis=None) | Cumulative product of elements along <i>axis</i> |

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Summary of (most) array attributes/methods (4/4)

ENTHOUGHT

REDUCTION METHODS

All the following methods “reduce” the size of the array by 1 dimension by carrying out an operation along the specified axis. If axis is None, the operation is carried out across the entire array.

| | |
|---------------------|--|
| a.sum(axis=None) | Sums values along axis |
| a.prod(axis=None) | Finds the product of all values along axis |
| a.min(axis=None) | Finds the minimum value along axis |
| a.max(axis=None) | Finds the maximum value along axis |
| a.argmax(axis=None) | Finds the index of the minimum value along axis |
| a.argmax(axis=None) | Finds the index of the maximum value along axis |
| a.ptp(axis=None) | Calculates a.max(axis) – a.min(axis) |
| a.mean(axis=None) | Finds the mean (average) value along axis |
| a.std(axis=None) | Finds the standard deviation along axis |
| a.var(axis=None) | Finds the variance along axis |
| a.any(axis=None) | True if any value along axis is non-zero (logical OR) |
| a.all(axis=None) | True if all values along axis are non-zero (logical AND) |

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Array Creation Functions

ARANGE

```
arange(start, stop=None, step=1,
       dtype=None)
```

Nearly identical to Python's `range()`. Creates an array of values in the range [start,stop) with the specified step value. Allows non-integer values for start, stop, and step. Default `dtype` is derived from the start, stop, and step values.

```
>>> arange(4)
array([0, 1, 2, 3])
>>> arange(0, 2*pi, pi/4)
array([ 0.000,  0.785,  1.571,
       2.356,  3.142,  3.927,  4.712,
      5.497])

# Be careful...
>>> arange(1.5, 2.1, 0.3)
array([ 1.5,  1.8,  2.1])
```

ONES, ZEROS

```
ones(shape, dtype=float64)
zeros(shape, dtype=float64)
```

`shape` is a number or sequence specifying the dimensions of the array. If `dtype` is not specified, it defaults to `float64`.

```
>>> ones((2,3), dtype=float32)
array([[ 1.,  1.,  1.],
       [ 1.,  1.,  1.]],
      dtype=float32)
>>> zeros(3)
array([ 0.,  0.,  0.])
```

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Array Creation Functions (cont.)

IDENTITY

```
# Generate an n by n identity
# array. The default dtype is
# float64.
>>> a = identity(4)
>>> a
array([[ 1.,  0.,  0.,  0.],
       [ 0.,  1.,  0.,  0.],
       [ 0.,  0.,  1.,  0.],
       [ 0.,  0.,  0.,  1.]])
>>> a.dtype
dtype('float64')
>>> identity(4, dtype=int)
array([[ 1,  0,  0,  0],
       [ 0,  1,  0,  0],
       [ 0,  0,  1,  0],
       [ 0,  0,  0,  1]])
```

EMPTY AND FILL

```
# empty(shape, dtype=float64,
#       order='C')
>>> a = empty(2)
>>> a
array([1.78021120e-306,
       6.95357225e-308])

# fill array with 5.0
>>> a.fill(5.0)
array([5.,  5.])

# alternative approach
# (slightly slower)
>>> a[:] = 4.0
array([4.,  4.])
```

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Array Creation Functions (cont.)

Linspace

```
# Generate N evenly spaced
# elements between (and
# including) start and
# stop values.
>>> linspace(0,1,5)
array([0., 0.25, 0.5, 0.75, 1.0])
```

Logspace

```
# Generate N evenly spaced
# elements on a log scale
# between base**start and
# base**stop (default base=10).
>>> logspace(0,1,5)
array([ 1., 1.77, 3.16, 5.62,
       10.])
```

Row Shortcut

```
# r_ and c_ are "handy" tools
# (cough hacks...) for creating
# row and column arrays.

# used like arange
# -- real stride value
>>> r_[0:1:.25]
array([ 0., 0.25, 0.5, 0.75])
```

```
# used like linspace
# -- complex stride value
>>> r_[0:1:5j]
array([0., 0.25, 0.5, 0.75, 1.0])

# concatenate elements
>>> r_[(1,2,3),0,0,(4,5)]
array([1, 2, 3, 0, 0, 4, 5])
```

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Array Creation Functions (cont.)

Mgrid

```
# Get equally spaced points
# in N output arrays for an
# N-dimensional (mesh) grid.

>>> x,y = mgrid[0:5,0:5]
>>> x
array([[0, 0, 0, 0, 0],
       [1, 1, 1, 1, 1],
       [2, 2, 2, 2, 2],
       [3, 3, 3, 3, 3],
       [4, 4, 4, 4, 4]])
>>> y
array([[0, 1, 2, 3, 4],
       [0, 1, 2, 3, 4],
       [0, 1, 2, 3, 4],
       [0, 1, 2, 3, 4],
       [0, 1, 2, 3, 4]])
```

Ogrid

```
# Construct an "open" grid
# of points (not filled in
# but correctly shaped for
# math operations to be
# broadcast correctly).

>>> x,y = ogrid[0:3,0:3]
>>> x
array([[0],
       [1],
       [2]])
>>> y
array([[0, 1, 2]])

>>> print x+y
[[0 1 2]
 [1 2 3]
 [2 3 4]]
```

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Matrix Objects

MATRIX CREATION

```
# Matlab-like creation from string
>>> A = mat('1,2,4;2,5,3;7,8,9')
>>> print A
Matrix([[1, 2, 4],
       [2, 5, 3],
       [7, 8, 9]])

# matrix exponents
>>> print A**4
Matrix([[ 6497,  9580,  9836],
       [ 7138, 10561, 10818],
       [18434, 27220, 27945]])

# matrix multiplication
>>> print A*A.I
Matrix([[ 1.,  0.,  0.],
       [ 0.,  1.,  0.],
       [ 0.,  0.,  1.]])
```

BLOCK MATRICES

```
# create a matrix from
# sub-matrices
>>> a = array([[1,2],
               [3,4]])
>>> b = array([[10,20],
               [30,40]])

>>> bmat('a,b;b,a')
matrix([[ 1,  2, 10, 20],
       [ 3,  4, 30, 40],
       [10, 20,  1,  2],
       [30, 40,  3,  4]])
```

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Trig and Other Functions

TRIGONOMETRIC

| | |
|---------------------------|-------------------------|
| <code>sin(x)</code> | <code>sinh(x)</code> |
| <code>cos(x)</code> | <code>cosh(x)</code> |
| <code>arccos(x)</code> | <code>arccosh(x)</code> |
| <code>arctan(x)</code> | <code>arctanh(x)</code> |
| <code>arcsin(x)</code> | <code>arcsinh(x)</code> |
| <code>arctan2(x,y)</code> | |

OTHERS

| | |
|---------------------------|---------------------------|
| <code>exp(x)</code> | <code>log(x)</code> |
| <code>log10(x)</code> | <code>sqrt(x)</code> |
| <code>absolute(x)</code> | <code>conjugate(x)</code> |
| <code>negative(x)</code> | <code>ceil(x)</code> |
| <code>floor(x)</code> | <code>fabs(x)</code> |
| <code>hypot(x,y)</code> | <code>fmod(x,y)</code> |
| <code>maximum(x,y)</code> | <code>minimum(x,y)</code> |

VECTOR OPERATIONS

| | |
|------------------------------------|-------------------------|
| <code>dot(x,y)</code> | <code>vdot(x,y)</code> |
| <code>inner(x,y)</code> | <code>outer(x,y)</code> |
| <code>cross(x,y)</code> | <code>kron(x,y)</code> |
| <code>tensordot(x,y[,axis])</code> | |

hypot(x,y)

Element by element distance
calculation using $\sqrt{x^2 + y^2}$

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More Basic Functions

TYPE HANDLING

```
iscomplexobj  real_if_close  isnan
iscomplex     isscalar      nan_to_num
isrealobj     isneginf     common_type
isreal        isposinf     typename
imag          isinf
real          isfinite
```

SHAPE MANIPULATION

```
atleast_1d    hstack       hsplit
atleast_2d    vstack       vsplit
atleast_3d    dstack       dsplit
expand_dims   column_stack split
apply_over_axes
apply_along_axis
```

OTHER USEFUL FUNCTIONS

```
fix           unwrap      roots
mod           sort_complex poly
amax          trim_zeros  any
amin          fliplr      all
ptp            flipud      disp
sum            rot90      unique
cumsum        eye
prod          diag
cumprod       select
diff          extract
angle         insert
nanmax
nanargmax
nanargmin
nanmin
```

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Vectorizing Functions

SCALAR SINC FUNCTION

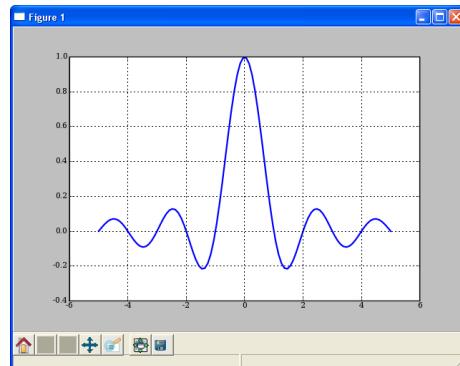
```
# special.sinc already available
# This is just for show.
def sinc(x):
    if x == 0.0:
        return 1.0
    else:
        w = pi*x
        return sin(w) / w
```

```
# attempt
>>> x = array((1.3, 1.5))
>>> sinc(x)
ValueError: The truth value of
an array with more than one
element is ambiguous. Use
a.any() or a.all()
```

SOLUTION

```
>>> from numpy import vectorize
>>> vsinc = vectorize(sinc)
>>> vsinc(x)
array([-0.1981, -0.2122])

>>> x2 = linspace(-5, 5, 101)
>>> plot(x2, vsinc(x2))
```



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Mathematical Binary Operators

```
a + b → add(a,b)
a - b → subtract(a,b)
a % b → remainder(a,b)
```

```
a * b → multiply(a,b)
a / b → divide(a,b)
a ** b → power(a,b)
```

MULTIPLY BY A SCALAR

```
>>> a = array((1,2))
>>> a*3.
array([3., 6.])
```

ELEMENT BY ELEMENT ADDITION

```
>>> a = array([1,2])
>>> b = array([3,4])
>>> a + b
array([4, 6])
```

ADDITION USING AN OPERATOR FUNCTION

```
>>> add(a,b)
array([4, 6])
```

IN-PLACE OPERATION

```
# Overwrite contents of a.
# Saves array creation
# overhead.
>>> add(a,b,a) # a += b
array([4, 6])
>>> a
array([4, 6])
```

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Comparison and Logical Operators

| | | | | | |
|----------------------------|----------------------|-------------------------|---------------------|--------------------------|----------------------|
| <code>equal</code> | <code>(==)</code> | <code>not_equal</code> | <code>(!=)</code> | <code>greater</code> | <code>(>)</code> |
| <code>greater_equal</code> | <code>(>=)</code> | <code>less</code> | <code>(<)</code> | <code>less_equal</code> | <code>(<=)</code> |
| <code>logical_and</code> | | <code>logical_or</code> | | <code>logical_xor</code> | |
| <code>logical_not</code> | | | | | |

2-D EXAMPLE

```
>>> a = array(((1,2,3,4),(2,3,4,5)))
>>> b = array(((1,2,5,4),(1,3,4,5)))
>>> a == b
array([[True, True, False, True],
       [False, True, True, True]])

# functional equivalent
>>> equal(a,b)
array([[True, True, False, True],
       [False, True, True, True]])
```



Be careful with if statements involving numpy arrays. To test for equality of arrays, don't do:

```
if a == b:
```

Rather, do:

```
if all(a==b):
```

For floating point,

```
if allclose(a,b):
```

is even better.

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Bitwise Operators

| | | |
|----------------------------------|------------------------------|-------------------------------------|
| <code>bitwise_and (&)</code> | <code>invert (~)</code> | <code>right_shift (>>)</code> |
| <code>bitwise_or ()</code> | <code>bitwise_xor (^)</code> | <code>left_shift (<<)</code> |

BITWISE EXAMPLES

```
>>> a = array((1,2,4,8))
>>> b = array((16,32,64,128))
>>> bitwise_or(a,b)
array([ 17,   34,   68,  136])

# bit inversion
>>> a = array((1,2,3,4), uint8)
>>> invert(a)
array([254, 253, 252, 251], dtype=uint8)

# left shift operation
>>> left_shift(a,3)
array([ 8, 16, 24, 32], dtype=uint8)
```



When possible, operation made bitwise are another way to **speed up** computations.

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Bitwise and Comparison Together

PRECEDENCE ISSUES

```
# When combining comparisons with bitwise operations,
# precedence requires parentheses around the comparisons.
>>> a = array([1,2,4,8])
>>> b = array([16,32,64,128])
>>> (a > 3) & (b < 100)
array([ False, False, True, False])
```

LOGICAL AND ISSUES

```
# Note that logical AND isn't supported for arrays without
# calling the logical_and function.
>>> a>3 and b<100
Traceback (most recent call last):
ValueError: The truth value of an array with more than one
element is ambiguous. Use a.any() or a.all()
```

```
# Also, you cannot currently use the "short version" of
# comparison with NumPy arrays.
>>> 2<a<4
Traceback (most recent call last):
ValueError: The truth value of an array with more than one
element is ambiguous. Use a.any() or a.all()
```

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Universal Function Methods

The mathematical, comparative, logical, and bitwise operators *op* that take two arguments (binary operators) have special methods that operate on arrays:

```
op.reduce(a, axis=0)
op.accumulate(a, axis=0)
op.outer(a,b)
op.reduceat(a, indices)
```

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op.reduce()

op.reduce(a) applies *op* to all the elements in a 1-D array *a* reducing it to a single value.

For example:

$$\begin{aligned} y &= \text{add.reduce}(a) \\ &= \sum_{n=0}^{N-1} a[n] \\ &= a[0] + a[1] + \dots + a[N-1] \end{aligned}$$

ADD EXAMPLE

```
>>> a = array([1,2,3,4])
>>> add.reduce(a)
10
```

STRING LIST EXAMPLE

```
>>> a = array(['ab','cd','ef'],
...           dtype=object)
>>> add.reduce(a)
'abcdef'
```

LOGICAL OP EXAMPLES

```
>>> a = array([1,1,0,1])
>>> logical_and.reduce(a)
False
>>> logical_or.reduce(a)
True
```

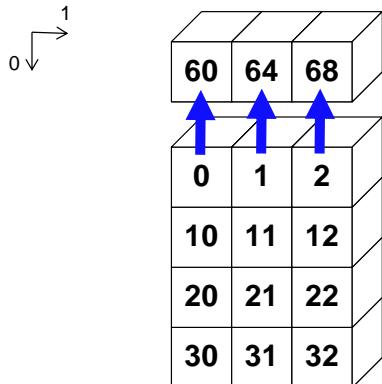
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op.reduce()

For multidimensional arrays, `op.reduce(a, axis)` applies `op` to the elements of `a` along the specified `axis`. The resulting array has dimensionality one less than `a`. The default value for `axis` is 0.

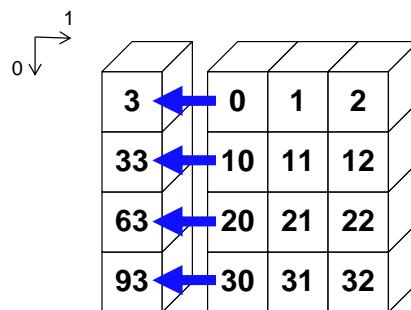
SUM COLUMNS BY DEFAULT

```
>>> add.reduce(a)
array([60, 64, 68])
```



SUMMING UP EACH ROW

```
>>> add.reduce(a, 1)
array([ 3, 33, 63, 93])
```



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op.accumulate()

`op.accumulate(a)` creates a new array containing the intermediate results of the `reduce` operation at each element in `a`.

For example:

$$y = \text{add.accumulate}(a) \\ = \left[\sum_{n=0}^0 a[n], \sum_{n=0}^1 a[n], \dots, \sum_{n=0}^{N-1} a[n] \right]$$

ADD EXAMPLE

```
>>> a = array([1,2,3,4])
>>> add.accumulate(a)
array([ 1, 3, 6, 10])
```

STRING LIST EXAMPLE

```
>>> a = array(['ab','cd','ef'],
...           dtype=object)
>>> add.accumulate(a)
array([ab, abcd, abcdef],
      dtype=object)
```

LOGICAL OP EXAMPLES

```
>>> a = array([1,1,0])
>>> logical_and.accumulate(a)
array([True, True, False])
>>> logical_or.accumulate(a)
array([True, True, True])
```

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op.reduceat()

`op.reduceat(a, indices)`

applies `op` to ranges in the 1-D array `a` defined by the values in `indices`. The resulting array has the same length as `indices`.

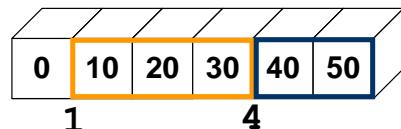
For example:

`y = add.reduceat(a, indices)`

$$y[i] = \sum_{n=indices[i]}^{indices[i+1]} a[n]$$

EXAMPLE

```
>>> a = array([0,10,20,30,
...             40,50])
>>> indices = array([1,4])
>>> add.reduceat(a,indices)
array([60, 90])
```

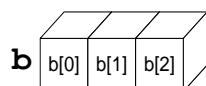
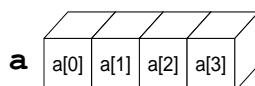


For multidimensional arrays, `reduceat()` is always applied along the *last axis* (sum of rows for 2-D arrays). This is different from the default for `reduce()` and `accumulate()`.

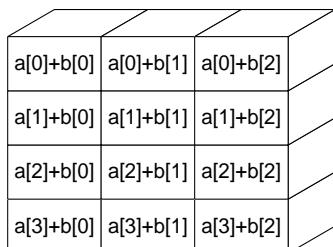
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op.outer()

`op.outer(a,b)` forms all possible combinations of elements between `a` and `b` using `op`. The shape of the resulting array results from concatenating the shapes of `a` and `b`. (Order matters.)



`>>> add.outer(a,b)`



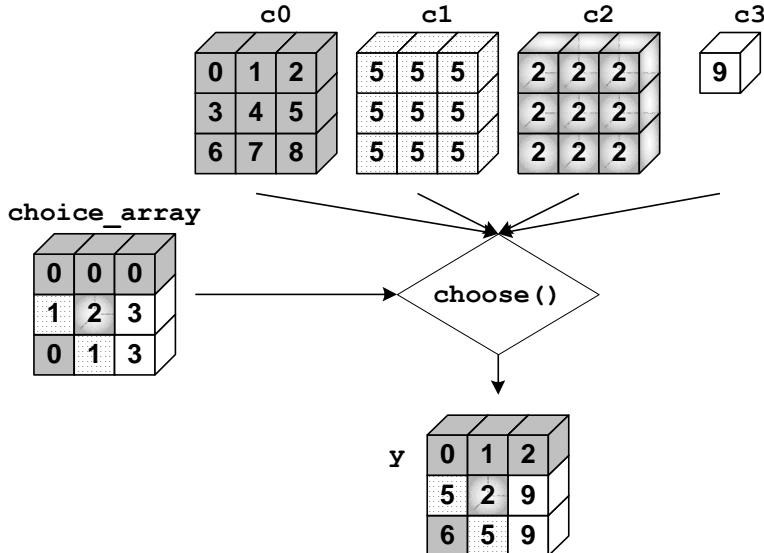
`>>> add.outer(b,a)`



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Array Functions – choose ()

```
>>> y = choose(choice_array, (c0,c1,c2,c3))
```



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Example - choose ()

CLIP LOWER VALUES TO 10

```
>>> a
array([[ 0,  1,  2],
       [10, 11, 12],
       [20, 21, 22]])

>>> a < 10
array([[True, True, True],
       [False, False, False],
       [False, False, False]],
      dtype=bool)

>>> choose(a<10,(a,10))
array([[10, 10, 10],
       [10, 11, 12],
       [20, 21, 22]])
```

CLIP LOWER AND UPPER VALUES

```
>>> lt = a < 10
>>> gt = a > 15
>>> choice = lt + 2 * gt
>>> choice
array([[1, 1, 1],
       [0, 0, 0],
       [2, 2, 2]])

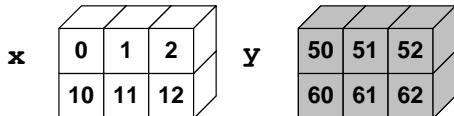
>>> choose(choice,(a,10,15))
array([[10, 10, 10],
       [10, 11, 12],
       [15, 15, 15]])
```

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Array Functions – `concatenate()`

`concatenate((a0,a1,...,aN),axis=0)`

The input arrays (a_0, a_1, \dots, a_N) are concatenated along the given `axis`. They must have the same shape along every axis *except* the one given.



```
>>> concatenate((x,y))    >>> concatenate((x,y),1)    >>> array((x,y))
```

| |
|----------|
| 0 1 2 |
| 10 11 12 |
| 50 51 52 |
| 60 61 62 |

| |
|----------|
| 0 1 2 |
| 10 11 12 |
| 50 51 52 |
| 60 61 62 |

| |
|----------|
| 0 1 2 |
| 10 11 12 |



See also `vstack()`, `hstack()` and `dstack()` respectively.

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Array Broadcasting

NumPy arrays of different dimensionality can be combined in the same expression. Arrays with smaller dimension are **broadcasted** to match the larger arrays, *without copying data*. Broadcasting has **two rules**.

RULE 1: PREPEND ONES TO SMALLER ARRAYS' SHAPE

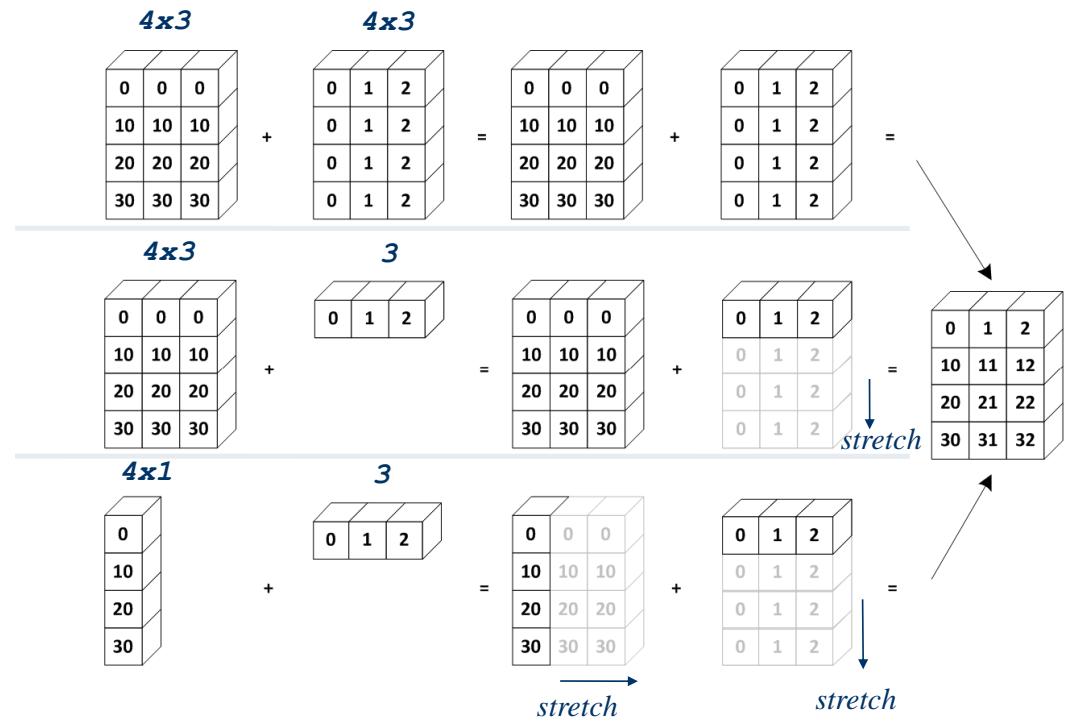
```
In [3]: a = ones((3, 5)) # a.shape == (3, 5)
In [4]: b = ones((5,)) # b.shape == (5,)
In [5]: b.reshape(1, 5) # result is a (1,5)-shaped array.
In [6]: b[newaxis, :] # equivalent, more concise.
```

RULE 2: DIMENSIONS OF SIZE 1 ARE REPEATED WITHOUT COPYING

```
In [7]: c = a + b # c.shape == (3, 5)
           is logically equivalent to...
In [8]: tmp_b = b.reshape(1, 5)
In [9]: tmp_b_repeat = tmp_b.repeat(3, axis=0)
In [10]: c = a + tmp_b_repeat
# But broadcasting makes no copies of "b"s data!
```

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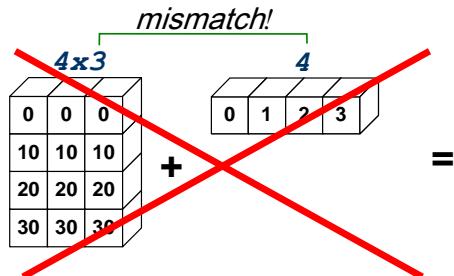
Array Broadcasting



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Broadcasting Rules

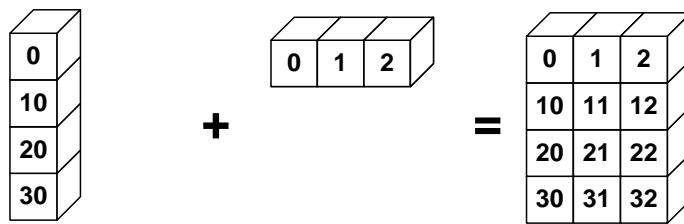
The *trailing axes* of either arrays must be 1 or both must have the same size for broadcasting to occur. Otherwise, a `"ValueError: shape mismatch: objects cannot be broadcast to a single shape"` exception is thrown.



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Broadcasting in Action

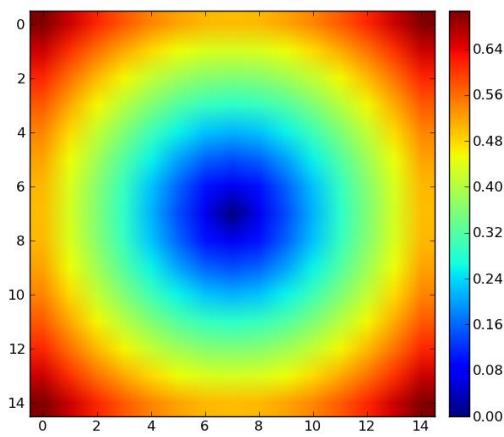
```
>>> a = array((0,10,20,30))
>>> b = array((0,1,2))
>>> y = a[:, newaxis] + b
```



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Application: distance from center

```
In [1]: a = linspace(0, 1, 15) - 0.5
In [2]: b = a[:, newaxis] # b.shape == (15, 1)
In [3]: dist2 = a**2 + b**2 # broadcasting sum.
In [4]: dist = sqrt(dist2)
In [5]: imshow(dist); colorbar()
```



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Broadcasting's usefulness

Broadcasting can often be used to replace needless data replication inside a NumPy array expression.

`np.meshgrid()` – use `newaxis` appropriately in broadcasting expressions.

`np.repeat()` – broadcasting makes repeating an array along a dimension of size 1 unnecessary.

MESHGRID: COPIES DATA

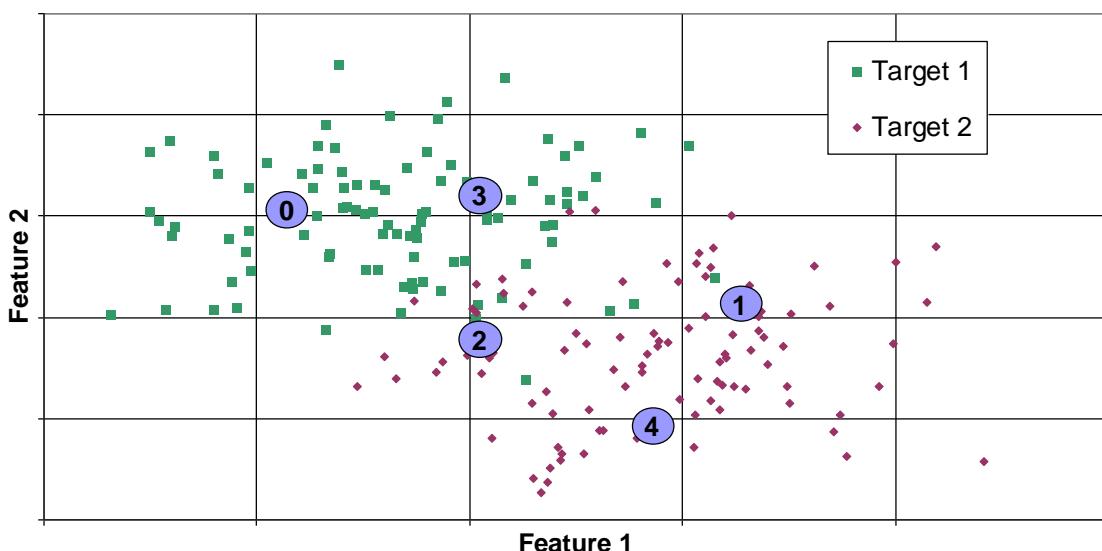
```
In [3]: x, y = \
    meshgrid([1,2],[3,4,5])
In [4]: z = x + y
```

BROADCASTING: NO COPIES

```
In [5]: x = array([1,2])
In [6]: y = array([3,4,5])
In [7]: z = \
    x[newaxis,:] + y[:,newaxis]
```

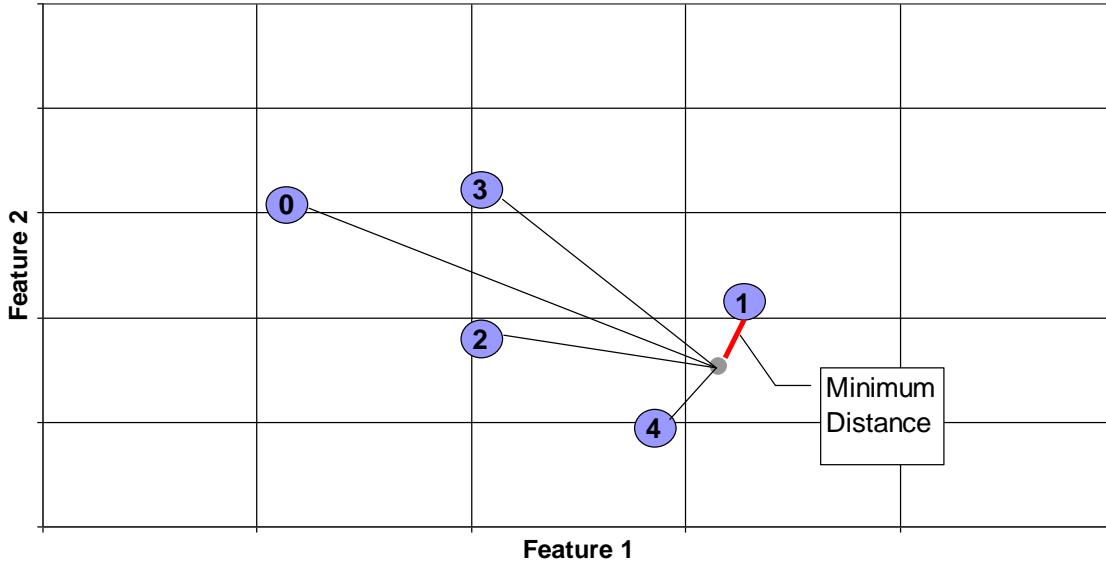
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Vector Quantization Example



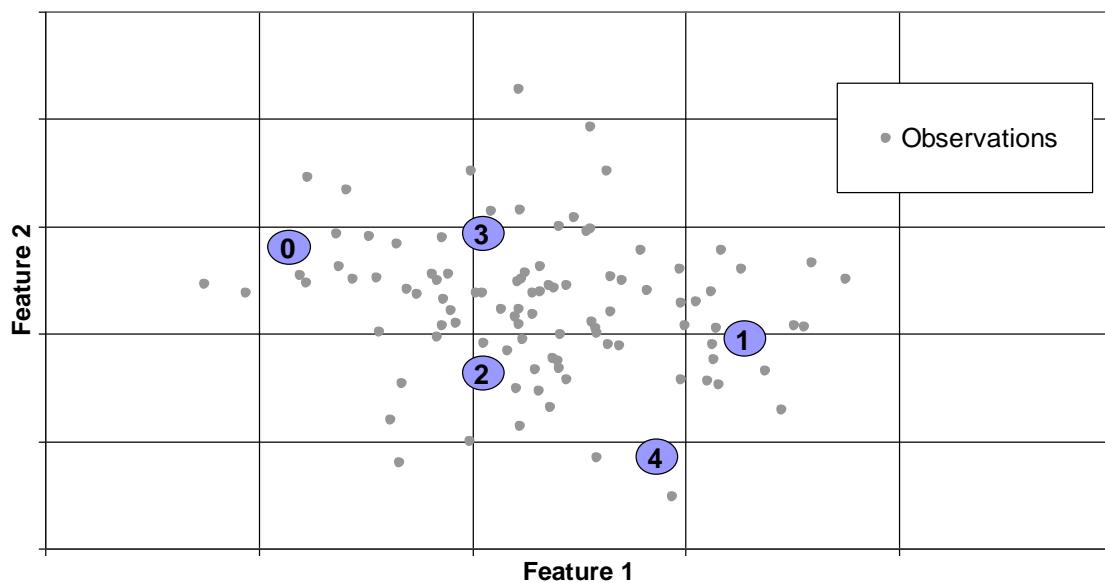
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Vector Quantization Example



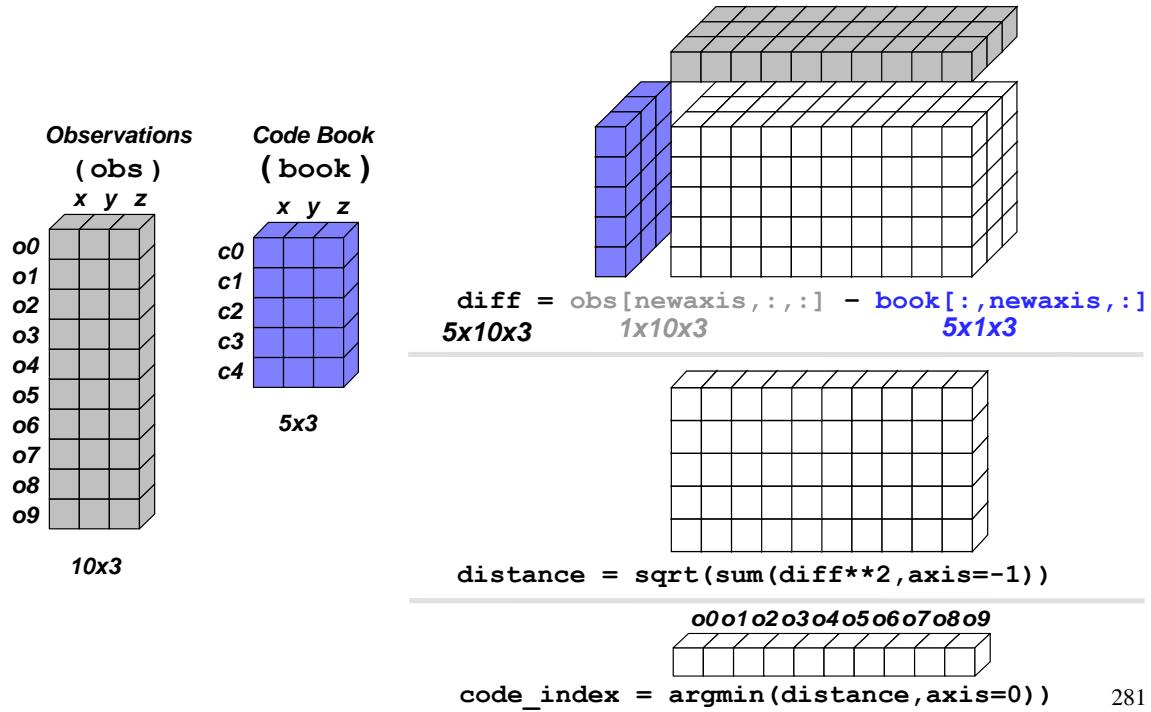
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Vector Quantization Example



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Vector Quantization Example



VQ Speed Comparisons

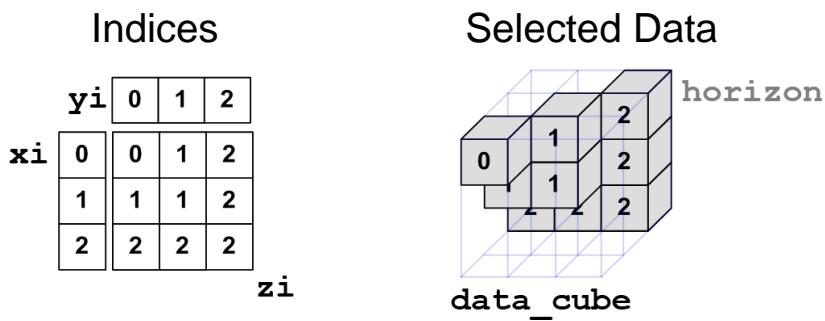
| Method | Run Time (sec) | Speed Up |
|--------------------|----------------|----------|
| Matlab 5.3 | 1.611 | - |
| Python VQ1, double | 2.245 | 0.71 |
| Python VQ1, float | 1.138 | 1.42 |
| Python VQ2, double | 1.637 | 0.98 |
| Python VQ2, float | 0.954 | 1.69 |
| C, double | 0.066 | 24.40 |
| C, float | 0.064 | 24.40 |

- 4000 observations with 16 features categorized into 40 codes on Pentium III 500 MHz.
- VQ1 uses the technique described on the previous slide verbatim.
- VQ2 applies broadcasting on an observation by observation basis. This turned out to be much more efficient because it is less memory intensive.

Broadcasting Indices

Broadcasting can also be used to slice elements from different “depths” in a 3-D (or any other shape) array. This is a *very* powerful feature of indexing.

```
>>> xi,yi = ogrid[:3,:3]
>>> zi = array([[0, 1, 2],
   [1, 1, 2],
   [2, 2, 2]])
>>> horizon = data_cube[xi,yi,zi]
```



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“Structured” Arrays

```
# "Data structure" (dtype) that describes the fields and
# type of the items in each array element.
>>> particle_dtype = dtype([('mass','float32'), ('velocity', 'float32')])
# This must be a list of tuples.
>>> particles = array([(1,1), (1,2), (2,1), (1,3)],
                      dtype=particle_dtype)
>>> print particles
[(1.0, 1.0) (1.0, 2.0) (2.0, 1.0) (1.0, 3.0)]
# Retrieve the mass for all particles through indexing.
>>> print particles['mass']
[ 1.  1.  2.  1.]
# Retrieve particle 0 through indexing.
>>> particles[0]
(1.0, 1.0)
# Sort particles in place, with velocity as the primary field and
# mass as the secondary field.
>>> particles.sort(order=('velocity','mass'))
>>> print particles
[(1.0, 1.0) (2.0, 1.0) (1.0, 2.0) (1.0, 3.0)]

# See demo/multitype_array/particle.py.
```

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“Structured” Arrays

Elements of an array can be any fixed-size data structure!

```
name char[10]
age int
weight double
```

| Brad | Jane | John | Fred |
|-------|--------|----------|-------|
| 33 | 25 | 47 | 54 |
| 135.0 | 105.0 | 225.0 | 140.0 |
| Henry | George | Brian | Amy |
| 29 | 61 | 32 | 27 |
| 154.0 | 202.0 | 137.0 | 187.0 |
| Ron | Susan | Jennifer | Jill |
| 19 | 33 | 18 | 54 |
| 188.0 | 135.0 | 88.0 | 145.0 |

EXAMPLE

```
>>> from numpy import dtype, empty
# structured data format
>>> fmt = dtype([('name', 'S10'),
                  ('age', int),
                  ('weight', float)
                 ])
>>> a = empty((3,4), dtype=fmt)
>>> a.itemsize
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>>> a['name'] = [['Brad', ... , 'Jill']]
>>> a['age'] = [[33, ... , 54]]
>>> a['weight'] = [[135, ... , 145]]
>>> print a
[[('Brad', 33, 135.0)
 ...
 ('Jill', 54, 145.0)]]
```

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Nested Datatype

nested.dat

| Time | Size | Position | | | | Gain | Samples (2048) ... | | | | |
|---------------|------|----------|-----------|------|----|------|--------------------|-------|-------|------|--|
| | | Az | EI | Type | ID | | | | | | |
| 1172581077060 | 4108 | 0.715594 | -0.148407 | 1 | 4 | 40 | 561 | 1467 | 997 | -30 | |
| 1172581077091 | 4108 | 0.706876 | -0.148407 | 1 | 4 | 40 | 7 | 591 | 423 | | |
| 1172581077123 | 4108 | 0.698157 | -0.148407 | 1 | 4 | 40 | 49 | -367 | -565 | -35 | |
| 1172581077153 | 4108 | 0.689423 | -0.148407 | 1 | 4 | 40 | -55 | -953 | -1151 | -30 | |
| 1172581077184 | 4108 | 0.680683 | -0.148407 | 1 | 4 | 40 | -719 | -1149 | -491 | 38 | |
| 1172581077215 | 4108 | 0.671956 | -0.148407 | 1 | 4 | 40 | -1503 | -683 | 661 | 149 | |
| 1172581077245 | 4108 | 0.663232 | -0.148407 | 1 | 4 | 40 | -2731 | -281 | 2327 | 291 | |
| 1172581077276 | 4108 | 0.654511 | -0.148407 | 1 | 4 | 40 | -3493 | -159 | 3277 | 380 | |
| 1172581077306 | 4108 | 0.645787 | -0.148407 | 1 | 4 | 40 | -3255 | -247 | 3145 | 385 | |
| 1172581077339 | 4108 | 0.637058 | -0.148407 | 1 | 4 | 40 | -2303 | -101 | 2079 | 247 | |
| 1172581077370 | 4108 | 0.628321 | -0.148407 | 1 | 4 | 40 | -1495 | -553 | 571 | 107 | |
| 1172581077402 | 4108 | 0.619599 | -0.148407 | 1 | 4 | 40 | -955 | -1491 | -1207 | -25 | |
| 1172581077432 | 4108 | 0.61087 | -0.148407 | 1 | 4 | 40 | -875 | -3009 | -2987 | -93 | |
| 1172581077463 | 4108 | 0.602148 | -0.148407 | 1 | 4 | 40 | -491 | -3681 | -4193 | -175 | |
| 1172581077497 | 4108 | 0.593438 | -0.148407 | 1 | 4 | 40 | 167 | -3501 | -4573 | -250 | |
| 1172581077547 | 4108 | 0.584696 | -0.148407 | 1 | 4 | 40 | 1007 | -2613 | -4463 | -303 | |
| 1172581077599 | 4108 | 0.575972 | -0.148407 | 1 | 4 | 40 | 1261 | -2155 | -4299 | -338 | |
| 1172581077650 | 4108 | 0.567244 | -0.148407 | 1 | 4 | 40 | 1537 | -2633 | -4945 | -367 | |
| 1172581077700 | 4108 | 0.558544 | -0.148407 | 1 | 4 | 40 | 1105 | -2701 | -5100 | -400 | |

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Nested Datatype (cont'd)

The data file can be extracted with the following code:

```
>>> dt = dtype([('time', uint64),
...             ('size', uint32),
...             ('position', [('az', float32),
...                         ('el', float32),
...                         ('region_type', uint8),
...                         ('region_ID', uint16)]),
...             ('gain', uint8),
...             ('samples', int16, 2048)])
```



```
>>> data = loadtxt('nested.dat', dtype=dt, skiprows = 2)
>>> data['position']['az']
array([ 0.71559399,  0.70687598,  0.69815701,  0.68942302,
       0.68068302, ...], dtype=float32)
```

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Memory Mapped Arrays

- Methods for Creating:
 - **memmap**: subclass of ndarray that manages the memory mapping details.
 - **frombuffer**: Create an array from a memory mapped buffer object.
 - **ndarray constructor**: Use the `buffer` keyword to pass in a memory mapped buffer.
- Limitations:
 - Files must be < 2GB on Python 2.4 and before.
 - Files must be < 2GB on 32-bit machines.
 - Python 2.5 and higher on 64 bit machines is theoretically "limited" to 17.2 *billion* GB (17 Exabytes).

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Memory Mapped Example

```
# Create a "memory mapped" array where
# the array data is stored in a file on
# disk instead of in main memory.
>>> from numpy import memmap
>>> image = memmap('some_file.dat',
                     dtype='uint16',
                     mode='r+',
                     shape=(5,5),
                     offset=header_size)

# Standard array methods work.
>>> mean_value = image.mean()

# Standard math operations work.
# The resulting scaled_image *is*
# stored in main memory. It is a
# standard numpy array.
>>> scaled_image = image * .5
```

image:
2D NumPy array
shape: 5, 5
dtype: uint16

some_file.dat
<header> 110111...
<data> 0110000001
0010010111011000
1101001001000100
1111010101000010
0010111000101011
00011110101011...

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memmap

The `memmap` subclass of `array` handles opening and closing files as well as synchronizing memory with the underlying file system.

```
memmap(filename, dtype='uint8', mode='r+',  
       offset=0, shape=None, order=0)
```

filename Name of the underlying file. For all modes, except for 'w+', the file must already exist and contain at least the number of bytes used by the array.

dtype The numpy data type used for the array. This can be a "structured" dtype as well as the standard simple data types.

offset Byte offset within the file to the memory used as data within the array.

mode <see next slide>

shape Tuple specifying the dimensions and size of each dimension in the array. `shape=(5,10)` would create a 2D array with 5 rows and 10 columns.

order 'C' for row major memory ordering (standard in the C programming language) and 'F' for column major memory ordering (standard in Fortran).

memmap -- mode

The mode setting for memmap arrays is used to set the access flag when opening the specified file using the standard `mmap` module.

```
memmap(filename, dtype=uint8, mode='r+' ,
        offset=0, shape=None, order=0)
```

mode A string indicating how the underlying file should be opened.

'**r**' or '**readonly**

'**c**' or '**copyonwritenever modify the underlying file.**

'**r+**' or '**readwriteflush() method to ensure the array is synchronized with the file.**

'**w+**' or '**write**

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memmap -- write through behavior

```
# Create a memory mapped "write through" file, overwriting it if it exists.
In [66]: q=memmap('new_file.dat',mode='w+',shape=(2,5))
In [67]: q
memmap([[0, 0, 0, 0, 0],
         [0, 0, 0, 0, 0]], dtype=uint8)

# Print out the contents of the underlying file. Note: It
# doesn't print because 0 isn't a printable ascii character.
In [68]: !cat new_file.dat

# Now write the ascii value for 'A' (65) into our array.
In [69]: q[:] = ord('A')
In [70]: q
memmap([[65, 65, 65, 65, 65],
         [65, 65, 65, 65, 65]], dtype=uint8)

# Ensure the OS has written the data to the file, and examine
# the underlying file. It is full of 'A's as we hope.
In [71]: q.flush()
In [72]: !cat new_file.dat
AAAAAAAAAA
```

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memmap -- copy on write behavior

```
# Create a copy-on-write memory map where the underlying file is never
# modified. The file must already exist.

# This is a memory efficient way of working with data on disk as arrays but
# ensuring you never modify it.

In [73]: q=memmap('new_file.dat',mode='c',shape=(2,5))

In [74]: q
memmap([[65, 65, 65, 65, 65],
         [65, 65, 65, 65, 65]], dtype=uint8)

# Set values in array to something new.

In [75]: q[1] = ord('B')

In [76]: q
memmap([[65, 65, 65, 65, 65],
         [66, 66, 66, 66, 66]], dtype=uint8)

# Even after calling flush(), the underlying file is not updated.

In [77]: q.flush()

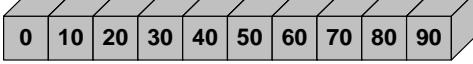
In [78]: !cat new_file.dat
AAAAAA
```

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Using Offsets

```
# Create a memory mapped array with 10 elements.

In [1]: q=memmap('new_file.dat',mode='w+', dtype=uint8, shape=(10,))
In [2]: q[:] = arange(0,100,10)
memmap([ 0, 10, 20, 30, 40, 50, 60, 70, 80, 90], dtype=uint8)

      new_file.dat  
```

Now, create a new memory mapped array (read only) with an offset into
the previously created file.

```
In [3]: q=memmap('new_file.dat',mode='r', dtype=uint8, shape=6, offset=4)
In [4]: q
memmap([40, 50, 60, 70, 80, 90], dtype=uint8)

      new_file.dat  
```

The number of bytes required by the array must be equal or less than
the number of bytes available in the file.

```
In [3]: q=memmap('new_file.dat',mode='r', dtype=uint8, shape=7, offset=4)
ValueError: mmap length is greater than file size
```

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Working with file headers

File Format:

| | | |
|--------|-------------------------------|--------------|
| header | rows (int32) | cols (int32) |
| data | 64 bit floating point data... | |

```
# Create a dtype to represent the header.
header_dtype = dtype([('rows', int32), ('cols', int32)])

# Create a memory mapped array using this dtype. Note the shape is empty.
header = memmap(file_name, mode='r', dtype=header_dtype, shape=())

# Read the row and column sizes from using this structured array.
rows = header['rows']
cols = header['cols']

# Create a memory map to the data segment, using rows, cols for shape
# information and the header size to determine the correct offset.
data = memmap(file_name, mode='r+', dtype=float64,
              shape=(rows, cols), offset=header.dtype.itemsize)      295
```

memory maps with ndarray

File Format:

| | | |
|--------|-------------------------------|--------------|
| header | rows (int32) | cols (int32) |
| data | 64 bit floating point data... | |

```
# mmap is a standard Python module for working with memory maps.
import mmap
import numpy

# Create a dtype to represent the header.
header_dtype = numpy.dtype([('rows', int32), ('cols', int32)])

# Open a file for read/write access in binary mode.
file = open(file_name, 'r+b')

# Create a read-only memory map from the opened file with the
# correct size to read the header of the file.
mm = mmap.mmap(file.fileno(), header_dtype.itemsize,
                access=mmap.ACCESS_READ)
< continued >                                              296
```

memory maps with ndarray

File Format:

| | | |
|--------|-------------------------------|--------------|
| header | rows (int32) | cols (int32) |
| data | 64 bit floating point data... | |

```
# Create a new array using the ndarray constructor.
# The first argument is the shape, and we pass in the data type and the
# memory buffer to use (mm) as keyword arguments.
header = numpy.ndarray((), dtype=header_dtype, buffer=mm)

rows = header['rows']
cols = header['cols']

# Create a writable memory map to use for the data array.  The size of the
# memory map in bytes is the size of a float64 (8) * rows * columns.
mm = mmap.mmap(file.fileno(), 8*rows*cols, access=mmap.ACCESS_WRITE)

# Create our data array using this new memory map.  Start the arrays
# data at the memory location directly after the header using offset.
data = numpy.ndarray((rows, cols), dtype=float64, buffer=mm,
                     offset=header_dtype.itemsize)
```

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Structured Arrays

| char[12] | int64 | float32 |
|-------------|---------|---------|
| Name | Time | Value |
| MSFT_profit | 10 | 6.20 |
| GOOG_profit | 12 | -1.08 |
| MSFT_profit | 18 | 8.40 |
| INTC_profit | 25 | -0.20 |
| : | : | : |
| GOOG_profit | 1000325 | 3.20 |
| GOOG_profit | 1000350 | 4.50 |
| INTC_profit | 1000385 | -1.05 |
| MSFT_profit | 1000390 | 5.60 |

Disk

| | | | | | | | | | | | | |
|-------------|----|------|-------------|----|-------|-------|-------------|---------|-------|-------------|---------|------|
| MSFT_profit | 10 | 6.20 | GOOG_profit | 12 | -1.08 | • • • | INTC_profit | 1000385 | -1.05 | MSFT_profit | 1000390 | 5.60 |
|-------------|----|------|-------------|----|-------|-------|-------------|---------|-------|-------------|---------|------|

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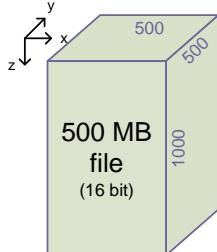
Elements of array can be any fixed-size data structure!

Example

```
>>> import numpy as np
>>> fmt = np.dtype([('name', 'S12'),
                   ('time', np.int64),
                   ('value', np.float32)])
>>> vals = [('MSFT_profit', 10, 6.20),
            ('GOOG_profit', 12, -1.08),
            ('INTC_profit', 1000385, -1.05),
            ('MSFT_profit', 1000390, 5.60)]

>>> arr = np.array(vals, dtype=fmt)
# or
>>> arr = np.fromfile('db.dat', dtype=fmt)
# or
>>> arr = np.memmap('db.dat', dtype=fmt,
                    mode='c')
```

Memmap Timings (3D arrays)



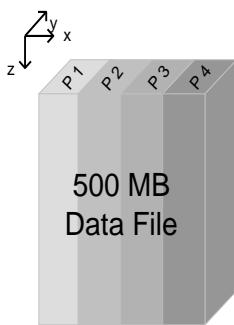
| Operations (500x500x1000) | Linux | | OS X | |
|------------------------------|--------------|------------------|--------------|------------------|
| | In Memory | Memory Mapped | In Memory | Memory Mapped |
| read | 2103 ms | 11.0 ms | 3505.00 | 27.00 |
| x slice | 1.8 ms | 4.8 ms | 1.80 | 8.30 |
| y slice | 2.8 ms | 4.6 ms | 4.40 | 7.40 |
| z slice | 9.2 ms | 13.8 ms | 10.40 | 18.70 |
| downsample 4x4 | 0.02 ms | 125 ms | 0.02 | 198.70 |

All times in milliseconds (ms).

Linux: Ubuntu 4.10, Dell Precision 690, Dual Quad Core Zeon X5355 2.6 GHz, 8 GB Memory
OS X: OS X 10.5, MacBook Pro Laptop, 2.6 GHz Core Duo, 4 GB Memory

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Parallel FFT On Memory Mapped File



| Processors | Time (seconds) | Speed Up |
|------------|-------------------|----------|
| 1 | 11.75 | 1.0 |
| 2 | 6.06 | 1.9 |
| 4 | 3.36 | 3.5 |
| 8 | 2.50 | 4.7 |

```

1  from numpy import ceil
2  from ipython1.kernel import client
3  from geoio import vtio
4
5  # Execute an fft on a sub-section of a seismic cube.
6  code = \
7  """"
8  from numpy import fft
9  from geoio import vtio
10
11 seismic, params = vtio.read(file_name,rescale=False)
12 start, end = id*size, (id+1) * size
13 local_seismic = vtio.unclip(seismic[start:end,:,:])
14 spectrum = fft.fft(local_seismic, axis=-1)
15 """
16
17 def equal_size_split(ary, cluster):
18     # Return the number of rows each worker should work
19     return int(ceil(float(len(ary))/len(cluster)))
20
21 # Run parallel code on each of the remote processors
22 file_name = "500_500_1000.vt"
23 cluster = client.MultiEngineClient(('127.0.0.1',10105))
24 seismic, params = vtio.read(file_name,rescale=False)
25 cluster['size'] = equal_size_split(seismic, cluster)
26 cluster['file_name'] = file_name
27 cluster.execute(code)

```

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Controlling Output Format

```
set_printoptions(precision=None, threshold=None,
                 edgeitems=None, linewidth=None,
                 suppress=None)
```

precision The number of digits of precision to use for floating point output. The default is 8.

threshold Array length where NumPy starts truncating the output and prints only the beginning and end of the array. The default is 1000.

edgeitems Number of array elements to print at beginning and end of array when threshold is exceeded. The default is 3.

linewidth Characters to print per line of output. The default is 75.

suppress Indicates whether NumPy suppresses printing small floating point values in scientific notation. The default is **False**.

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Controlling Output Formats

PRECISION

```
>>> a = arange(1e6)
>>> a
array([ 0.00000000e+00, 1.00000000e+00, 2.00000000e+00, ...,
       9.99997000e+05, 9.99998000e+05, 9.99999000e+05])
>>> set_printoptions(precision=3)
>>> a
array([ 0.000e+00, 1.000e+00, 2.000e+00, ...,
       1.000e+06, 1.000e+06, 1.000e+06])
```

SUPPRESSING SMALL NUMBERS

```
>>> set_printoptions(precision=8)
>>> a = array((1, 2, 3, 1e-15))
>>> a
array([ 1.00000000e+00, 2.00000000e+00, 3.00000000e+00,
       1.00000000e-15])
>>> set_printoptions(suppress=True)
>>> a
array([ 1., 2., 3., 0.])
```

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Controlling Error Handling

```
seterr(all=None, divide=None, over=None,
       under=None, invalid=None)
```

Set the error handling flags in ufunc operations on a per thread basis. Each of the keyword arguments can be set to ‘ignore’, ‘warn’, ‘print’, ‘log’, ‘raise’, or ‘call’.

| | |
|----------------|--|
| all | All error types to the specified value |
| divide | Divide-by-zero errors |
| over | Overflow errors |
| under | Underflow errors |
| invalid | Invalid floating point errors |

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Controlling Error Handling

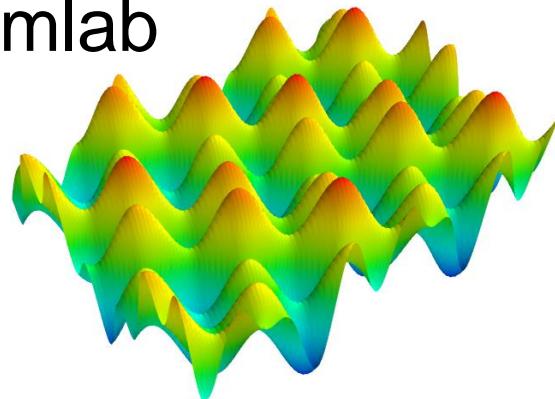
```
>>> a = array((1,2,3))
>>> a/0.
Warning: divide by zero encountered in divide
array([ 1.#INF0000e+000,  1.#INF0000e+000,  1.#INF0000e+000])

# Ignore division-by-zero. Also, save old values so that
# we can restore them.
>>> old_err = seterr(divide='ignore')
>>> a/0.
array([ 1.#INF0000e+000,  1.#INF0000e+000,  1.#INF0000e+000])

# Restore original error handling mode.
>>> old_err
{'divide': 'print', 'invalid': 'print', 'over': 'print',
 'under': 'ignore'}
>>> seterr(**old_err)
>>> a/0.
Warning: divide by zero encountered in divide
array([ 1.#INF0000e+000,  1.#INF0000e+000,  1.#INF0000e+000])
```

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Interactive 3D Visualization with Mayavi-mlab

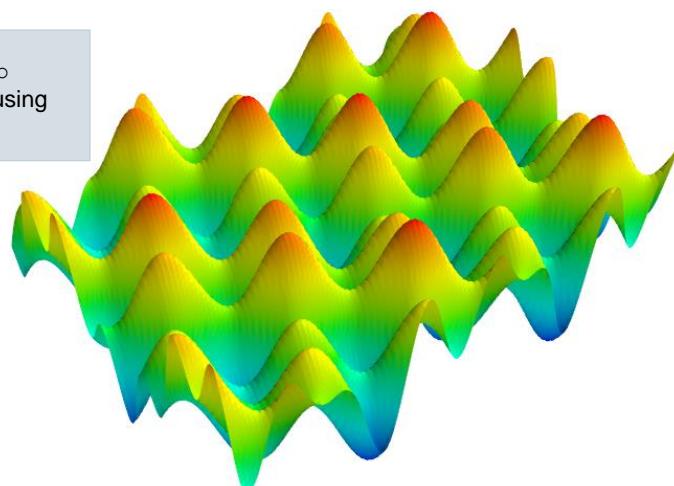


3D Visualization with Mayavi

```
C:\ ipython --pylab  
  
>>> from mayavi import mlab
```



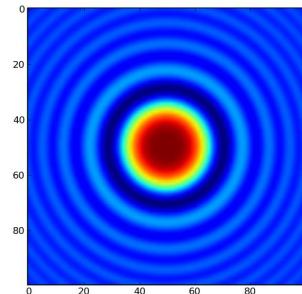
matplotlib also has an `mlab` namespace. Be sure you are using the one from `mayavi`



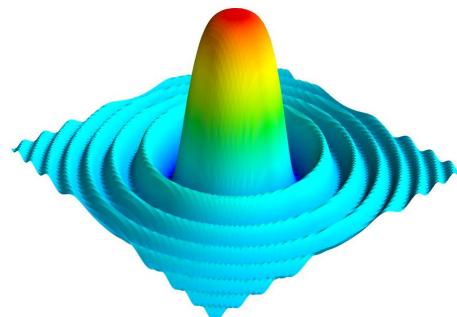
Interactive Example

```
# create arrays
>>> x, y = mgrid[-5:5:100j,-5:5:100j]
>>> r = x**2 + y**2
>>> z = sin(r)/r

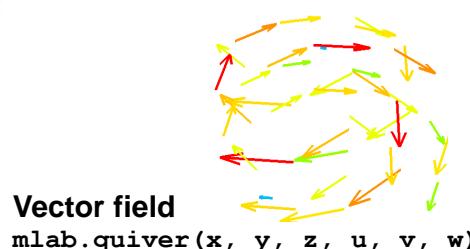
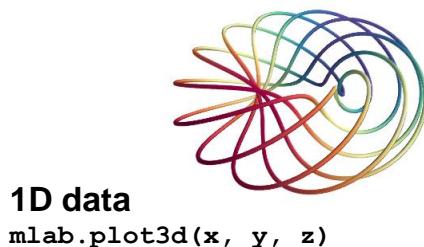
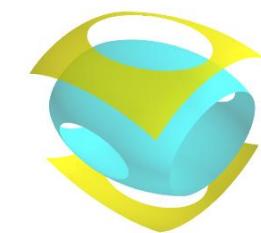
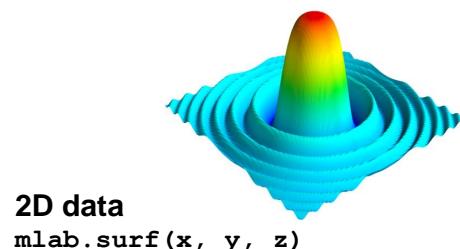
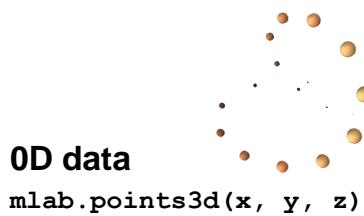
# plot with pylab
>>> imshow(z)
```



```
# plot with mayavi
>>> from mayavi import mlab
>>> mlab.surf(x,y,5*z)
```



Some Plotting Commands



Points in 3D

scaling applied

```
mlab.points3d(x, y, z, color=(1.0,0.0,1.0), mode='sphere', scale_factor=0.1)
```

x.shape == y.shape == z.shape

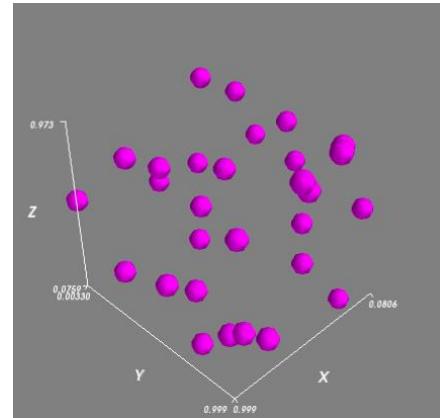
color = (R, G, B)

0.0 <= R, G, B <= 1.0

default is (1.0, 1.0, 1.0)

mode = 'sphere', 'cone', 'cube', 'arrow', 'cylinder', 'point',
 '2darrows', '2dcircle', '2dcross', '2ddash', '2ddiamond',
 '2dhooked_arrow', '2dsquare', '2dthick_arrow',
 '2dthick_cross', '2dtriangle', '2dvertex'

```
from numpy.random import rand
x,y,z = rand(30),rand(30),rand(30)
mlab.axes()
```



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Lines in 3D

```
mlab.plot3d(x, y, z, color=(0.0,1.0,1.0), tube_radius=0.03)
```

1-d arrays giving end-points of connected line-segments

len(x) == len(y) == len(z)

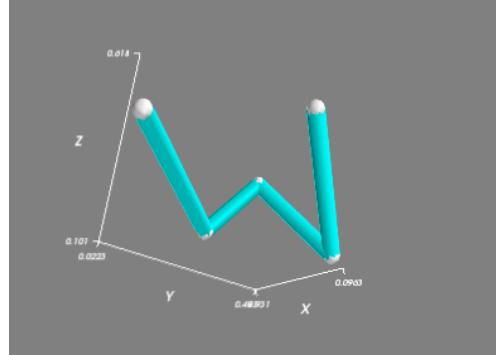
color = (R, G, B)

0.0 <= R, G, B <= 1.0

default is (1.0, 1.0, 1.0)

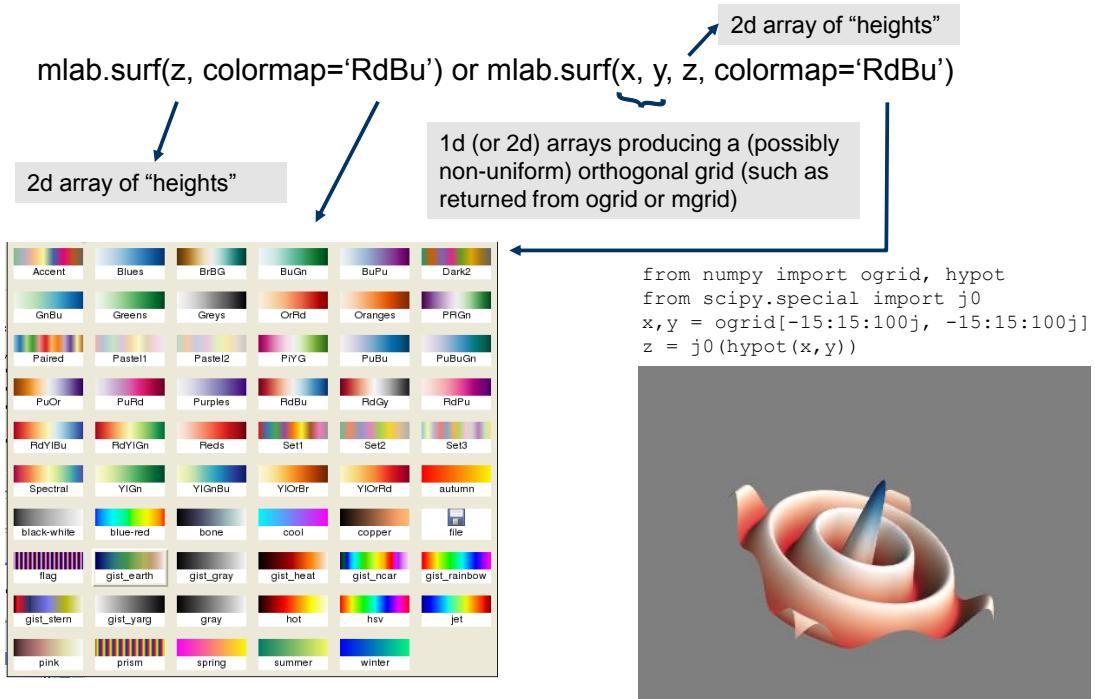
A float giving the radius of the tubes representing the lines.
 default is 0.025

```
from numpy.random import rand
x,y,z = rand(5), rand(5), rand(5)
mlab.points3d(x,y,z,scale_factor=0.06)
mlab.axes()
```



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Surfaces in 3D



Volumes in 3D

mlab.contour3d(data, contours=6, colormap='Dark2')

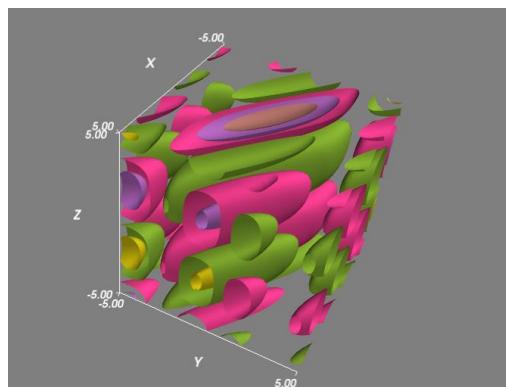
3d array of volume data

Integer number of contours or
List of specific contours



from numpy import ogrid, tanh, cos
from scipy.special import j0
x,y,z = ogrid[-5:5:64j, -5:5:64j, -5:5:64j]
data = cos(0.5*y)*j0(x+y*1.3)*sin(0.8*z)

mlab.axes(ranges=[-5,5]*3)



Vector Fields in 3D – quiver3d

`mlab.quiver3d(u, v, w) or mlab.quiver3d(x, y, z, u, v, w)`

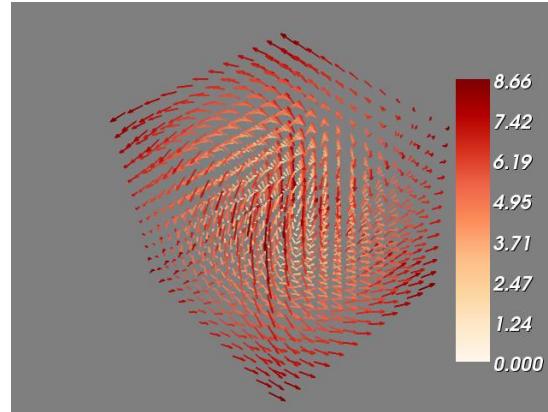
3-d arrays each representing a component of a 3-d vector field. All must be the same shape.

1, 2, or 3-d arrays of the same shape as u, v, and w providing real locations of the vectors.

1, 2, or 3-d arrays of the same shape as x, y, and z representing components of the vectors.

any colormap argument will color glyphs according to magnitude of vector.

```
from numpy import mgrid
x,y,z = mgrid[-5:5:12j, -5:5:12j, -5:5:12j]
u,v,w = -z, y, x
mlab.quiver3d(u,v,w, colormap='OrRd')
```



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Vector Fields in 3D – flow

`mlab.flow(u, v, w, linetype='tube', seedtype='sphere', colormap='PuRd')`

3-d arrays representing vector field. Can also be called with `x, y, z, u, v, w` where x, y, and z are all 3-d arrays.

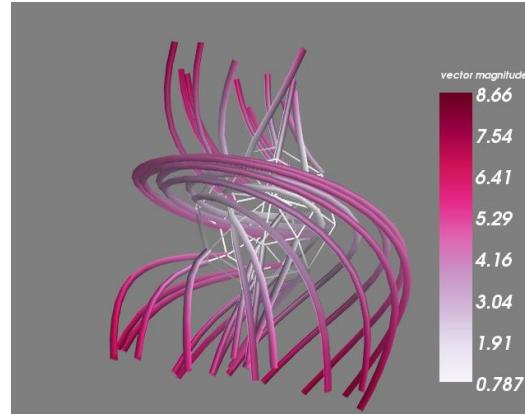
`linetype= 'line', 'ribbon', or 'tube'`

`seedtype = 'sphere', 'plane', 'line', or 'point'`

streamlines are calculated from seedpoints spaced throughout the specified seed widget. The seed widget is shown and can be interacted with to compute new streamlines.

any colormap argument will color according to magnitude of vector.

```
from numpy import mgrid
x,y,z = mgrid[-5:5:12j, -5:5:12j, -5:5:12j]
u,v,w = -z, y, x
```

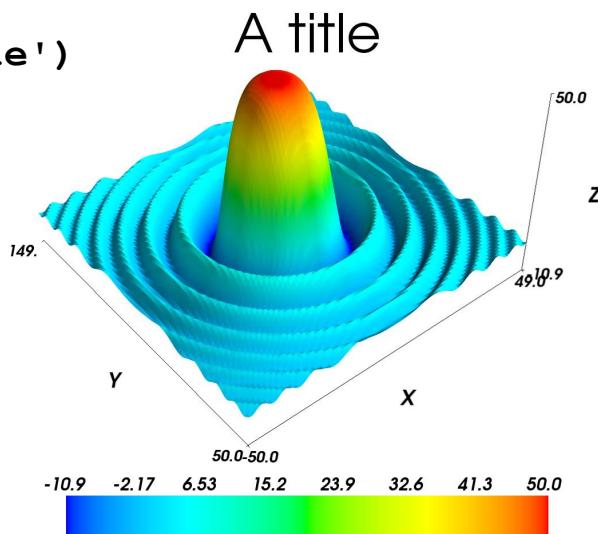


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Figure Decorations

```
>>> mlab.title('A title')
>>> mlab.axes()
>>> mlab.colorbar()
>>> zlabel('Depth')

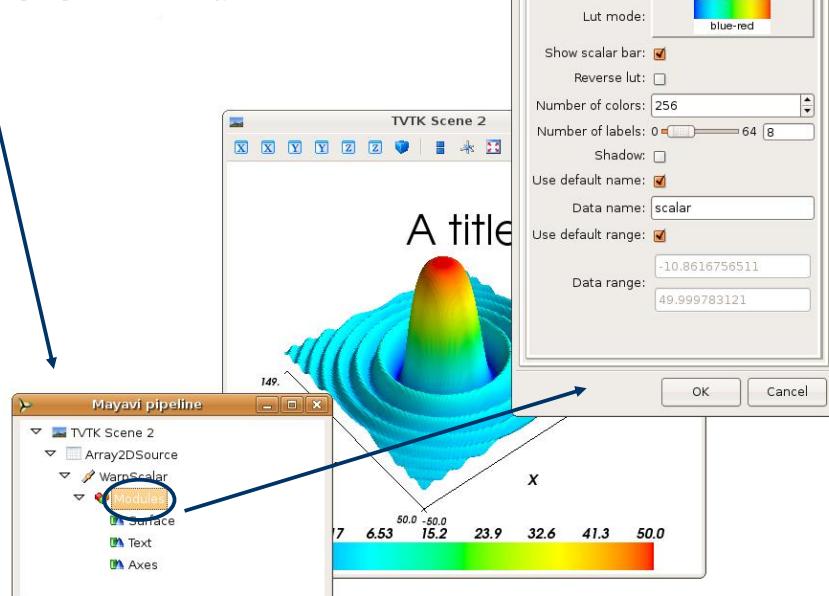
>>> mlab.clf()
>>> mlab.figure()
>>> mlab.gcf()
```



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Graphical User Interface

`mlab.show_pipeline()`

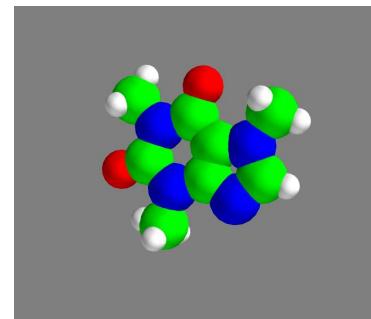


Examples and Demos

```
>>> mlab.test_<TAB>
mlab.test_points3d()
mlab.test_plot3d()
mlab.test_surf()
mlab.test_contour3d()
mlab.test_quiver3d()
```

```
mlab.test_molecule()
mlab.test_flow()
mlab.test_mesh()
```

Use ?? in IPython to look at the source code of these examples.



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Scientific Analysis with SciPy

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Overview

- Available at www.scipy.org
- Open source BSD style license
- 38 contributors to the project in 2011

CURRENT PACKAGES

- Special Functions (scipy.special)
- Signal Processing (scipy.signal)
- Image Processing (scipy.ndimage)
- Fourier Transforms (scipy.fftpack)
- Optimization (scipy.optimize)
- Numerical Integration (scipy.integrate)
- Linear Algebra (scipy.linalg)
- Input/Output (scipy.io)
- Statistics (scipy.stats)
- Fast Execution (scipy.weave)
- Clustering Algorithms (scipy.cluster)
- Sparse Matrices (scipy.sparse)
- Interpolation (scipy.interpolate)
- ...and more.

Note: “import scipy” does NOT import all these packages. Must be imported individually 319

Statistics

scipy.stats — CONTINUOUS DISTRIBUTIONS

over 80
continuous
distributions!

METHODS

pdf entropy

cdf nnlf

rvs moment

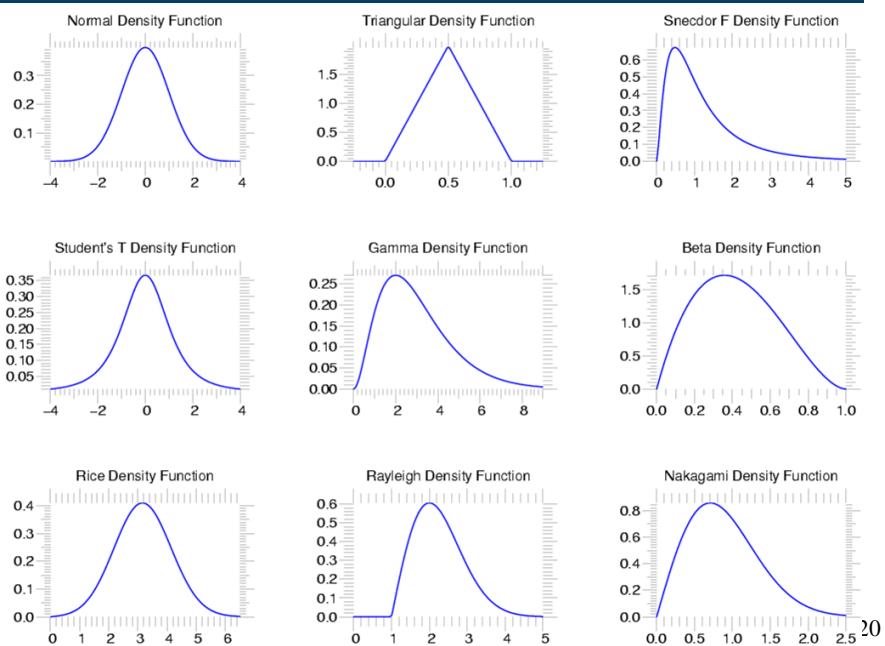
ppf freeze

stats

fit

sf

isf



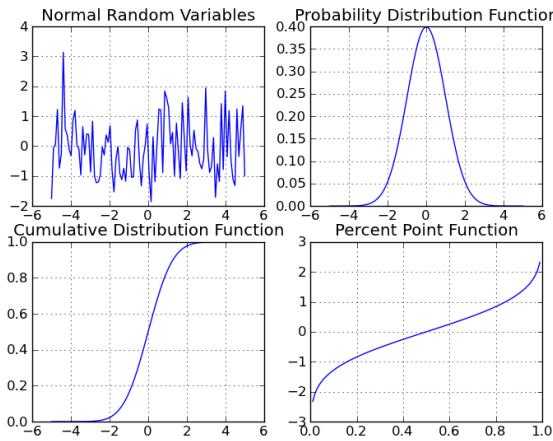
Using stats objects

DISTRIBUTIONS

```
>>> from scipy.stats import norm
# Sample normal dist. 100 times.
>>> samp = norm.rvs(size=100)

>>> x = linspace(-5, 5, 100)
# Calculate probability dist.
>>> pdf = norm.pdf(x)
# Calculate cumulative dist.
>>> cdf = norm.cdf(x)

>>> x = linspace(0, 1, 100)
# Calculate Percent Point Function
>>> ppf = norm.ppf(x)
```

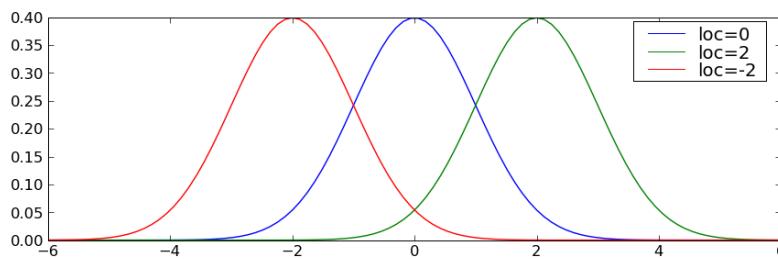


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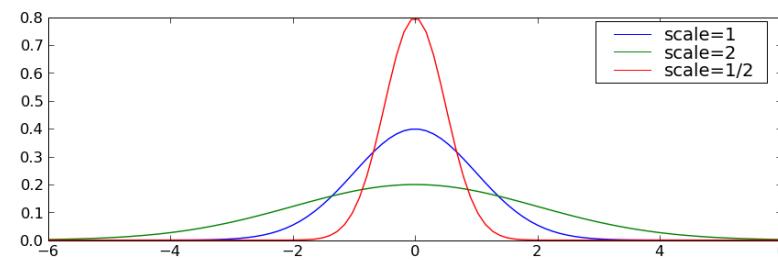
Distribution objects

Every distribution can be modified by `loc` and `scale` keywords
 (many distributions also have required `shape` arguments to select from a family)

LOCATION (`loc`) --- shift left (<0) or right (>0) the distribution



SCALE (`scale`) --- stretch (>1) or compress (<1) the distribution



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Example distributions

NORM (norm) – $N(\mu, \sigma)$

Only location and scale arguments:

| | | |
|----------|--------------------|----------|
| location | mean | μ |
| scale | standard deviation | σ |

LOG NORMAL (lognorm)

$\log(S)$ is $N(\mu, \sigma)$

S is lognormal
one shape parameter!

| | |
|----------|--------------------------------|
| location | offset from zero (rarely used) |
| scale | e^μ |
| shape | σ |

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Setting location and Scale

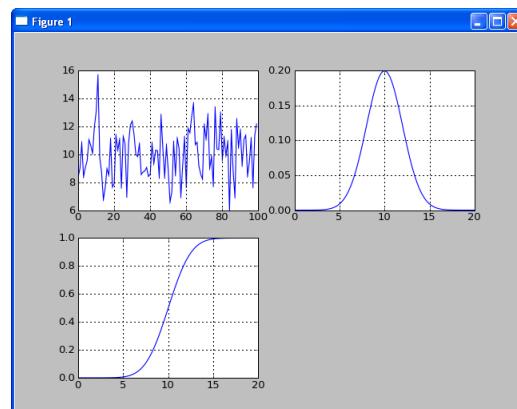
NORMAL DISTRIBUTION

```
>>> from scipy.stats import norm
# Normal dist with mean=10 and std=2
>>> dist = norm(loc=10, scale=2)

>>> x = linspace(-5, 15, 100)
# Calculate probability dist.
>>> pdf = dist.pdf(x)
# Calculate cumulative dist.
>>> cdf = dist.cdf(x)

# Get 100 random samples from dist.
>>> samp = dist.rvs(size=100)

# Estimate parameters from data
>>> mu, sigma = norm.fit(samp)
>>> print "%4.2f, %4.2f" % (mu, sigma)
10.07, 1.95
```



.fit returns best
shape + (loc, scale)
that explains the data

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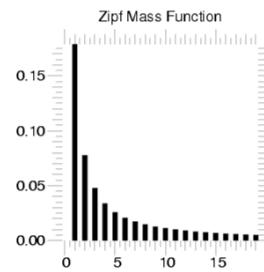
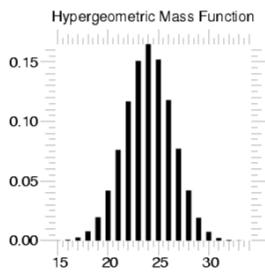
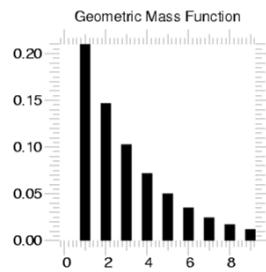
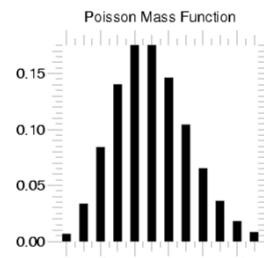
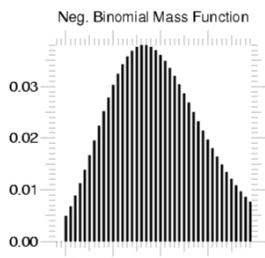
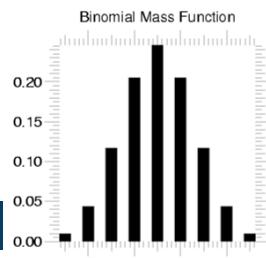
Statistics

scipy.stats — Discrete Distributions

10 standard
discrete
distributions
(plus any
finite RV)

METHODS

pmf moment
cdf entropy
rvs freeze
ppf
stats
sf
isf



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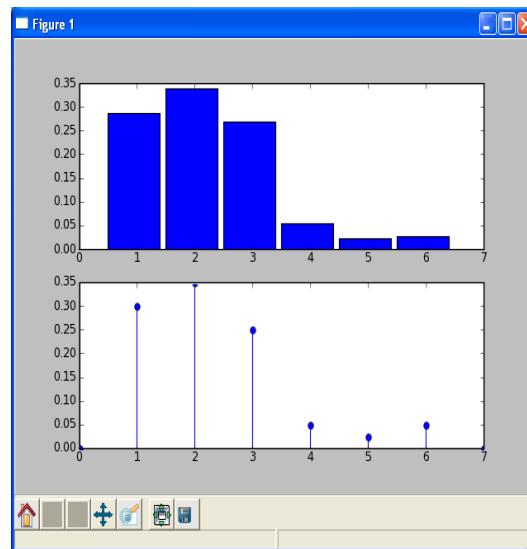
Using stats objects

CREATING NEW DISCRETE DISTRIBUTIONS

```
# Create loaded dice.
>>> from scipy.stats import rv_discrete
>>> xk = [1, 2, 3, 4, 5, 6]
>>> pk = [0.3, 0.35, 0.25, 0.05,
          0.025, 0.025]
>>> new = rv_discrete(name='loaded',
                      values=(xk,pk))

# Calculate histogram
>>> samples = new.rvs(size=1000)
>>> bins = linspace(0.5, 6.5, 7)
>>> subplot(211)
>>> hist(samples, bins=bins, normed=True)

# Calculate pmf
>>> x = range(0, 8)
>>> subplot(212)
>>> stem(x,new.pmf(x))
```



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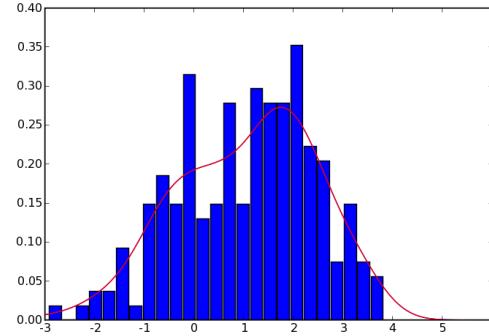
Statistics

CONTINUOUS DISTRIBUTION ESTIMATION USING GAUSSIAN KERNELS

```
# Sample two normal distributions
# and create a bimodal distribution
>>> rvl = stats.norm()
>>> rv2 = stats.norm(2.0, 0.8)
>>> samples = hstack([rv1.rvs(size=100),
                      rv2.rvs(size=100)])

# Use a Gaussian kernel density to
# estimate the PDF for the samples.
>>> from scipy.stats.kde import gaussian_kde
>>> approximate_pdf = gaussian_kde(samples)
>>> x = linspace(-3, 6, 200)

# Compare the histogram of the samples to
# the PDF approximation.
>>> hist(samples, bins=25, normed=True)
>>> plot(x, approximate_pdf(x), 'r')
```



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Linear Algebra

scipy.linalg — FAST LINEAR ALGEBRA

- Uses optimized BLAS and MKL if available — very fast
- Low-level access to BLAS and LAPACK routines in modules `linalg.blas`, and `linalg.lapack` (FORTRAN order)
- High level matrix routines
 - Linear Algebra Basics: `inv`, `pinv`, `solve`, `det`, `norm`, `lstsq`, ...
 - Decompositions: `eig`, `lu`, `svd`, `orth`, `cholesky`, `qr`, `schur`, ...
 - Matrix Functions: `expm`, `logm`, `sqrtm`, `cosm`, `coshm`, `funm` (general matrix functions)

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Solving $A^*X = B$

SOLVE Ax=b

```
>>> from scipy import linalg
>>> a = array([[1.0, 3.0, 2.0],
...             [4.0, 0.0, 1.0],
...             [2.0, 2.0, 2.0]])
>>> b = array([2.0, 1.0, 0.0])
>>> x = linalg.solve(a, b)

>>> x
array([ 1.5,  3.5, -5. ])

# Check:
>>> dot(a, x)
array([ 2.,  1.,  0.])
```

LEAST SQUARES Ax=b

```
# Over-specified problem:
>>> a = array([[1.0, 4.0],
...             [3.0, 0.0],
...             [2.0, 1.0]])
>>> b = array([2.0, 1.0, 0.0])
>>> x, res, rnk, svals =
...     linalg.lstsq(a, b)

# Least squares solution:
>>> x
array([ 0.1832,  0.4059])
# Sum of squared residuals:
>>> res
0.83663366336633671
# Effective rank of `a`:
>>> rnk
2
# Singular values of `a`:
>>> svals
array([ 4.6567,  3.0521])
```

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LU FACTORIZATION

To solve many equations $AX=B$ for different matrices B , factor $A=L^*U$, L is lower triangular (L) and U is upper-triangular

```
>>> from scipy import linalg
>>> a = array([[1,3,5],
...             [2,5,1],
...             [2,3,6]])
# time consuming factorization
>>> lu, piv = linalg.lu_factor(a)

# fast solve for 1 or more
# right hand sides.
>>> b = array([10,8,3])
>>> linalg.lu_solve((lu, piv), b)
array([-7.82608696,  4.56521739,
       0.82608696])

# check
>>> dot(a, _)
array([ 10.,   8.,   3.])
```

QR FACTORIZATION

To solve $Ax=b$, factor $A=QR$, where Q is orthogonal and R is upper triangular.

```
>>> a = array([[12, -51,    4],
...             [ 6, 167, -68],
...             [-4,  24, -41]])
>>> q, r = linalg.qr(a)
>>> q
array([[-0.8571,  0.3943,  0.3314],
       [-0.4286, -0.9029, -0.0343],
       [ 0.2857, -0.1714,
       0.9429]])
>>> r
array([[ -14.,   -21.,    14.],
       [  0.,   -175.,    70.],
       [  -0.,     0.,   -35.]])
```

See the `qr` docstring for more advanced options (e.g. pivoting for rank-revealing QR decomposition).

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Eigenvalues, eigenvectors

EIGENVALUES AND VECTORS

```
>>> a = array([[1,3,5],
...             [2,5,1],
...             [2,3,6]])
# compute eigenvalues/vectors
>>> vals, vecs = linalg.eig(a)
# print eigenvalues
>>> vals
array([ 9.39895873+0.j,
       -0.73379338+0.j,
       3.33483465+0.j])
# eigenvectors are in columns
# print first eigenvector
>>> vecs[:,0]
array([-0.57028326,
       -0.41979215,
       -0.70608183])
# norm of vector should be 1.0
>>> linalg.norm(vecs[:,0])
1.0
```

SCHUR DECOMPOSITION

Factor $A = ZTZ^{-1}$, where Z is unitary and T is upper triangular.

```
>>> t, z = linalg.schur(a)
>>> t
array(
[[ 156.137,   64.737,   85.651],
 [ 0.        ,  16.06,   15.814],
 [ 0.        ,   0.        , -34.197]])
>>> z
array([[ 0.328, -0.94,   0.098],
       [-0.937, -0.337, -0.093],
       [-0.121,  0.061,  0.991]])
# Diagonals in t are eigenvalues:
>>> linalg.eigvals(a)
array([ 156.137+0.j,   16.060+0.j,
       -34.197+0.j])
```

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Linear Algebra

SINGULAR VALUE DECOMPOSITION

Factor $A = U S V^*$, where U and V are unitary, and S is diagonal. This generalizes diagonalization.

```
>>> a = array([[2, 1],
...             [2, 0]])
>>> u, s, vt = linalg.svd(a)
>>> u
array([[ -0.75 , -0.662],
       [-0.662,  0.75 ]])
# s holds the singular values.
>>> s
array([ 2.921,  0.685])
>>> vt
array([[ -0.966, -0.257],
       [ 0.257, -0.966]])
# Use to inverse A
>>> inv_a = dot(vt.T,
...               dot(diag(1/s), u.T))
>>> dot(a, inv_a)
array([[ 1.0, -4.44089210e-16],
       [-2.22044605e-16,  1.0]])
```

```
# Nonsquare example:
underspecified
# set of equations
>>> a = array([[2, 1, -4],
...             [2, 3,  1]])
>>> u, s, vt = linalg.svd(a)
>>> u
array([[ -0.938, -0.347],
       [-0.347,  0.938]])
>>> s
array([ 4.702,  3.59 ])
>>> vt
array([[ -0.546, -0.421,  0.724],
       [ 0.329,  0.687,  0.648],
       [ 0.77 , -0.592,  0.237]])
```

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Inverse, and determinants

MATRIX INVERSION

```
# Square matrix
>>> from scipy import linalg
>>> a = array([[2, 1, -4],
...             [2, 3, 1]])
>>> a_inv = linalg.inv(a)
>>> a_inv
array([[ 0.,  0.5],
       [ 1., -1.]])
# Check
>>> dot(a, a_inv)
array([[ 1.,  0.],
       [ 0.,  1.]])
# Alternatively (slower)
>>> linalg.solve(a, identity(2))
array([[ 0.,  0.5],
       [ 1., -1.]])
```

```
# Non-square mat: Pseudo-inverse
# with least-square method
>>> b = array([[2, 1, -4],
...             [2, 3, 1]])
>>> linalg.pinv(b)
array([[ 0.07719298,
        0.12631579,
        0.01754386,
        0.21052632],
       [-0.20701754,
        0.11578947]])
```

MATRIX DETERMINANT

```
>>> linalg.det(a)
-2.0
# If LU decomposition available:
>>> lu, _ = linalg.lu_factor(a)
>>> np.prod(lu.diagonal())
-2.0
```

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Matrix Objects

STRING CONSTRUCTION

```
>>> from numpy import mat
>>> a = mat('1,3,5;2,5,1;2,3,6')
>>> a
matrix([[1, 3, 5],
       [2, 5, 1],
       [2, 3, 6]])
```

TRANSPOSE ATTRIBUTE

```
>>> a.T
matrix([[1, 2, 2],
       [3, 5, 3],
       [5, 1, 6]])
```

INVERTED ATTRIBUTE

```
>>> a.I
matrix([[-1.1739,  0.1304,   0.956],
       [ 0.4347,  0.1739,  -0.391],
       [ 0.1739, -0.130,   0.0434]
      ])
```

DIAGONAL

```
>>> a.diagonal()
matrix([[1, 5, 6]])
>>> a.diagonal(-1)
matrix([[2, 3]])
```

SOLVE

```
>>> b = mat('10;8;3')
>>> a.I*b
matrix([[-7.82608696],
       [ 4.56521739],
       [ 0.82608696]])
```

```
>>> from scipy import linalg
>>> linalg.solve(a,b)
matrix([[-7.82608696],
       [ 4.56521739],
       [ 0.82608696]])
```

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Interpolation

scipy.interpolate — General purpose Interpolation

• 1D Interpolating Class

- Constructs callable function from data points and desired spline interpolation order.
- Function takes vector of inputs and returns interpolated value using the spline.

• Radial basis functions

- Simple but effective N-dimensional interpolation
- Works with scattered data

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1D Spline Interpolation

```
>>> from scipy.interpolate import interp1d

interp1d(x, y, kind='linear', axis=-1, copy=True,
bounds_error=True, fill_value=numpy.nan)

Returns a function that uses interpolation to find the
value of new points.
```

- **x** - 1d array of increasing real values which cannot contain duplicates
- **y** - Nd array of real values whose length along the interpolation axis must be len(x)
- **kind** - kind of interpolation (e.g. 'linear', 'nearest', 'quadratic', 'cubic'). Can also be an integer n>1 which returns interpolating spline (with minimum sum-of-squares discontinuity in nth derivative).
- **axis** - axis of y along which to interpolate
- **copy** - make internal copies of x and y
- **bounds_error** - raise error for out-of-bounds
- **fill_value** - if bounds_error is False, then use this value to fill in out-of-bounds.

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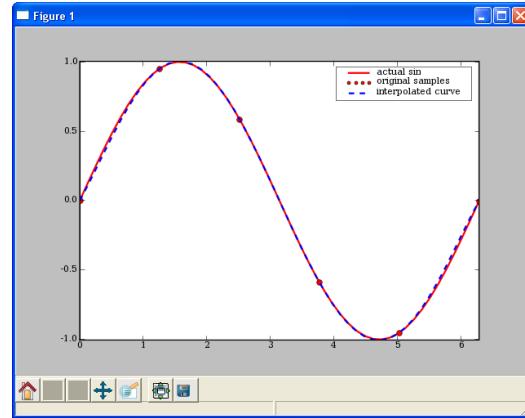
1D Spline Interpolation

```
# demo/interpolate/spline.py
from scipy.interpolate import interp1d
from pylab import plot, axis, legend
from numpy import linspace

# sample values
x = linspace(0,2*pi,6)
y = sin(x)

# Create a spline class for interpolation.
# kind='nearest' -> zeroth order hold.
# kind='linear' -> linear interpolation
# kind=n -> use an nth order spline
spline_fit = interp1d(x,y,kind=5)
xx = linspace(0,2*pi, 50)
yy = spline_fit(xx)

# display the results.
plot(xx, sin(xx), 'r-', x, y, 'ro', xx, yy, 'b--', linewidth=2)
axis('tight')
legend(['actual sin', 'original samples', 'interpolated curve'])
```



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Radial Basis Functions

```
>>> from scipy.interpolate import Rbf

func = Rbf(x, y, ..., function='multiquadric',
epsilon=None, smooth=0, norm=euclidean_norm)

    Returns a function that uses interpolation to find the
    value of new points.

• x - array of real values
• y - array of real values the same shape as x
• ... - additional array arguments can be provided for N-d
  interpolation
• function - basis function used to interpolate; one of
  'multiquadric', 'inverse multiquadric', 'gaussian',
  'linear', 'cubic', 'quintic', 'thin-plate'
• epsilon - adjustable constant for 'gaussian' or
  'multiquadratics' functions. Defaults to approximate
  average distance between nodes.
• smooth - Greater than zero increases smoothness of
  approximation. Default of 0 is interpolation.
• norm - function (vectorized) that returns the distance
  between two points
```

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Radial Basis Functions

The function is approximated by a sum of radial functions with certain weights n_j :

$$f(\mathbf{x}) = \sum_j h(||\mathbf{x} - \mathbf{x}_j||)n_j \quad f(\mathbf{x}_i) = \sum_j h(||\mathbf{x}_i - \mathbf{x}_j||)n_j$$

Typical radial functions:

$$h_{\text{multiquadric}}(r) = \sqrt{\frac{r^2}{\epsilon^2} + 1}$$

$$h_{\text{inverse multiquadric}}(r) = \frac{1}{\sqrt{\frac{r^2}{\epsilon^2} + 1}}$$

$$h_{\text{gaussian}}(r) = \exp\left(-\frac{r^2}{\epsilon^2}\right)$$

$$h_{\text{linear}}(r) = r$$

$$h_{\text{cubic}}(r) = r^3$$

$$h_{\text{quintic}}(r) = r^5$$

$$h_{\text{thin-plate}}(r) = r^2 + \log(r)$$

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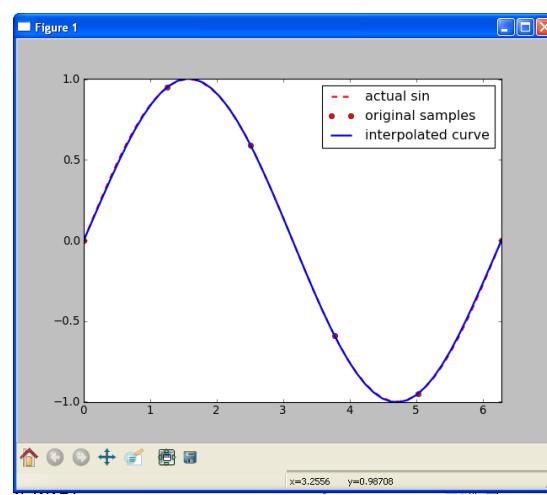
1D RBF Interpolation

```
# demo/interpolate/spline.py
from scipy.interpolate import Rbf
from pylab import plot, axis, legend
from numpy import linspace

# sample values
x = linspace(0,2*pi,6)
y = sin(x)

# Create a new function
fit = Rbf(x,y, function='gaussian')
xx = linspace(0,2*pi, 50)
yy = fit(xx)

# display the results.
plot(xx, sin(xx), 'r--', x, y, 'ro', xx, yy, 'b-', linewidth=2)
axis('tight')
legend(['actual sin', 'original samples', 'interpolated curve'])
```

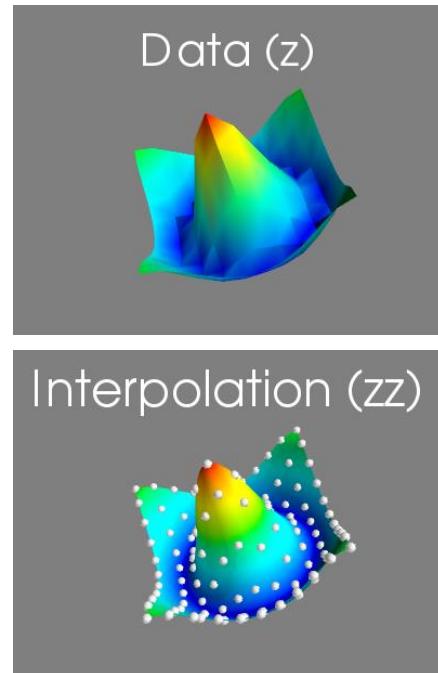


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2D RBF Interpolation

EXAMPLE

```
>>> from scipy.interpolate import \
...     Rbf
>>> from numpy import hypot, mgrid
>>> from scipy.special import j0
>>> x, y = mgrid[-5:6,-5:6]
>>> z = j0(hypot(x,y))
>>> newfunc = Rbf(x, y, z)
>>> xx, yy = mgrid[-5:5:100j,
...                  -5:5:100j]
# xx and yy are both 2-d
# result is evaluated
# element-by-element
>>> zz = newfunc(xx, yy)
>>> from mayavi import mlab
>>> mlab.surf(x, y, z*5)
>>> mlab.figure()
>>> mlab.surf(xx, yy, zz*5)
>>> mlab.points3d(x,y,z*5,
...                 scale_factor=0.5)
```



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Optimization

scipy.optimize — Minimization and Root Finding

Univariate Function Minimization

`minimize_scalar` – minimize a scalar-valued function of a single variable:
available methods include brent, bounded, golden

Multivariate Function Minimization (constrained and unconstrained)

`minimize` – minimize scalar-valued function of one or more variables: available
methods include BFGS, Nelder-Mead simplex, Newton conjugate gradient, COBYLA,
SLSQP, anneal, brute

Least Squares Fitting

`leastsq` – wrapper to the Fortran leastsq function from MINPACK

Curve Fitting

`curve_fit` – powerful, general, tool to fit functional parameters.

Root Finding

`brentq`, `brenth`, `ridder`, `bisect`, `newton` – find root of a scalar function

`fixed_point` – find the fixed point of a function

`root` – multidimensional root-finding: methods include hybr and lm for small problems
and krylov, broyden2, and anderson for large problems.

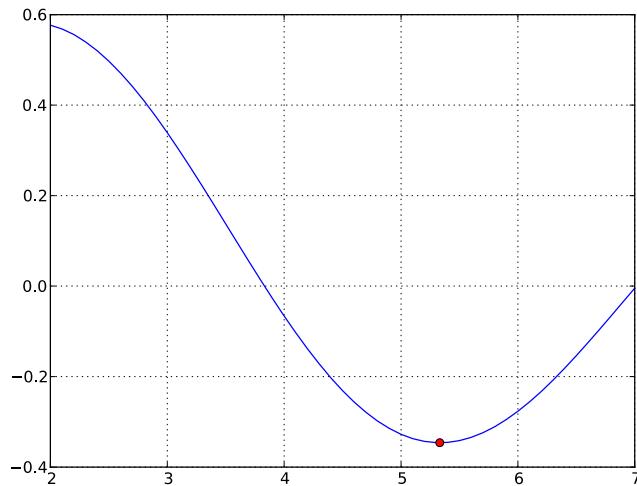
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Optimization: 1-D Minimization

EXAMPLE: MINIMIZE BESSEL FUNCTION

```
# minimize 1st order Bessel
# function between 4 and 7
>>> from scipy.special import j1
>>> from scipy.optimize import \
...     minimize_scalar

>>> x = np.linspace(2, 7, 200)
>>> j1x = j1(x)
>>> plot(x, j1x)
>>> result = minimize_scalar(j1,
...     method="bounded",
...     bounds=[4, 7])
>>> j1_min = j1(result.x)
>>> plot(result.x, j1_min,'ro')
```



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Result Object

Output of `minimize`, `minimize_scalar`, and `root` is a `Result` object with attributes:

- `x` : solution to the optimization
- `success` : True/False – did the optimization succeed?
- `status` : integer termination status
- `message` : termination status message
- `fun, jac, hess` : values of the function, Jacobian, Hessian, (if available) at the optimized value
- `nfev, njev, nhev` : number of evaluations of the function, Jacobian, or Hessian (if available)
- ... : other attributes are added by specific methods

Note: older legacy functions (`fmin`, `fmin_bgfs`, `fminbound`, `fsolve`, etc.) do not have a unified API and are replaced by the above.

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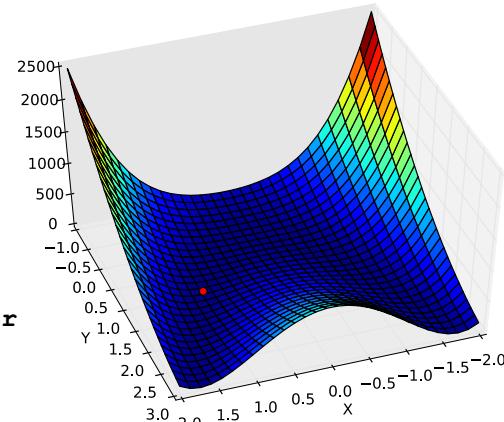
Optimization: Using Derivatives

minimize: WITHOUT DERIVATIVE

```
>>> from scipy.optimize import rosen
>>> x0 = [1.3, 1.6, -0.5, -1.8, 0.8]
>>> result = minimize(rosen, x0)
>>> print result.x
[ 1.  1.  1.  1.  1.]
>>> print result.nfev
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```

Rosenbrock function

$$f(\mathbf{x}) = \sum_{i=1}^{N-1} 100 \left(x_i - x_{i-1}^2 \right)^2 + (1 - x_{i-1})^2.$$



minimize: USING DERIVATIVE

```
>>> from scipy.optimize import rosen_der
>>> result = minimize(rosen, x0,
...                   jac=rosen_der)
>>> print result.x
[ 1.  1.  1.  1.  1.]
>>> print result.nfev, result.njev
66 66
```

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Optimization: Solving Nonlinear Equations

ROOT

SYSTEM OF EQUATIONS

```
>>> def equations(x,a,b,c):
...     x0, x1, x2 = x
...     eqs = \
...         [3 * x0 - cos(x1*x2) + a,           3x0 - cos(x1x2) + a = 0
...          x0**2 - 81*(x1+0.1)**2 + sin(x2) + b,   x0^2 - 81(x1 + 0.1)^2 + sin(x2) + b = 0
...          exp(-x0*x1) + 20*x2 + c]           e^-x0x1 + 20x2 + c = 0
...     return eqs

>>> from scipy.optimize import root
# coefficients
>>> a = -0.5 ; b = 1.06
>>> c = (10 * pi - 3.0) / 3
# Optimization start location.
>>> initial_guess = [0.1, 0.1, -0.1]
# Solve the system of non-linear equations.
>>> result = root(equations, initial_guess, args=(a, b, c))
>>> print "root:", result.x
root: [ 0.5   0.    -0.52]
>>> print "solution at root:", result.fun
solution at root: [ 0.  -0.   0.]
```

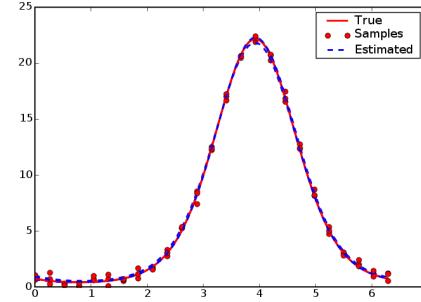
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Optimization: Data Fitting

NONLINEAR LEAST SQUARES CURVE FITTING

```
>>> from scipy.optimize import curve_fit
>>> from scipy.stats import norm
# Define the function to fit.
>>> def function(x, a, b, f, phi):
...     result = a * exp(-b * sin(f * x + phi))
...     return result

# Create a noisy data set.
>>> actual_params = [3, 2, 1, pi/4]
>>> x = linspace(0,2*pi,25)
>>> exact = function(x, *actual_params)
>>> noisy = exact + 0.3*norm.rvs(size=len(x))
# Use curve_fit to estimate the function parameters from the noisy data.
>>> initial_guess = [1,1,1,1]
>>> estimated_params, err_est = curve_fit(function, x, noisy, p0=initial_guess)
>>> estimated_params
array([3.1705, 1.9501, 1.0206, 0.7034])
# err_est is an estimate of the covariance matrix of the estimates
# (i.e. how good of a fit is it)
>>> err_est.diagonal()
array([ 0.0572,  0.006362,  0.0005834,  0.008979])
```



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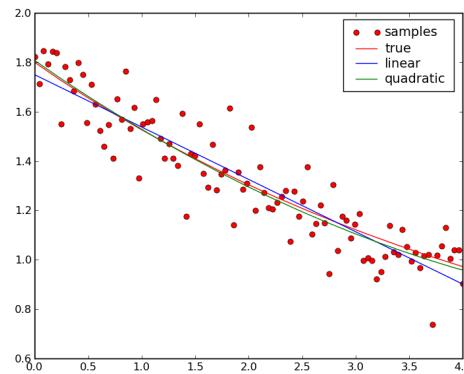
Fitting Polynomials (NumPy)

POLYFIT(X, Y, DEGREE)

```
>>> from numpy import polyfit, poly1d
>>> from scipy.stats import norm
# Create clean data.
>>> x = linspace(0, 4.0, 100)
>>> y = 1.5 * exp(-0.2 * x) + 0.3
# Add a bit of noise.
>>> noise = 0.1 * norm.rvs(size=100)
>>> noisy_y = y + noise

# Fit noisy data with a linear model.
>>> linear_coef = polyfit(x, noisy_y, 1)
>>> linear_poly = poly1d(linear_coef)
>>> linear_y = linear_poly(x)

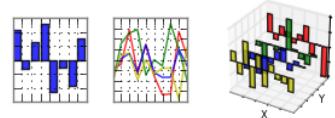
# Fit noisy data with a quadratic model.
>>> quad_coef = polyfit(x, noisy_y, 2)
>>> quad_poly = poly1d(quad_coef)
>>> quad_y = quad_poly(x)
```



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Data Analysis with pandas

$y_{it} = \beta' x_{it} + \mu_i + \epsilon_{it}$



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Pandas

Pandas (version 0.12.0, Jul 2013) is a library to make analysis of structured datasets easy.

Author: Wes McKinney, <http://pandas.pydata.org/>

License: BSD

GOALS

- New array-based data-structures with axis labeling + nice representation in ipython,
- Date/time management built-in, including timezones,
- Data alignment, data merging, data aggregation (group by), missing data management,
- Statistical tools (describe, moving stats, covariance, correlation, panel regression),
- Easy visualization (line plot, bar chart, boxplot, scatter plot matrix, ...) with Matplotlib.

RELATED PROJECTS

- Built on top of: NumPy, pytables, matplotlib.
- Replaces scikits.timeseries. Is now an optional dependency of statsmodels.
- Offers similar features to larry, datarray (labeled arrays).

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New Data Structures

PANDAs = PANel DAta = multi-dimensional data in stats & econometrics.

Data-structures:

- A Series is a 1D data-structure that derives from np.ndarray.
- A DataFrame is a 2D data-structure that can be viewed as a dictionary of series. It is NOT a subclass of an numpy array.
- A Panel is a 3D data-structure that can be viewed as a dict of DataFrames.

| | Rk | Fst N | Lst N | DoB | Gend | Grade | offset |
|---------|----|-------|-------|------|------|-------|--------|
| TAMU UT | 4 | John | Doe | 1981 | M | 4.18 | -1.18 |
| 1 | 2 | Jill | Ford | 1975 | F | 5.26 | 1.26 |
| 2 | 5 | Chris | Jones | NaN | M | 3.91 | 0.91 |
| 3 | 6 | Dave | Smith | 1965 | M | 1.23 | NaN |
| 4 | 1 | Ellen | Frank | 1973 | F | 5.52 | 0.52 |
| 5 | 3 | Frank | Hart | 1976 | M | 4.71 | -0.71 |
| 6 | | | | | | | |

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Creating (Time)Series

FROM LIST AND DICT

```
# Data and corresponding indices can
# be stored in lists.
>>> index = ['a', 'b', 'c', 'd']
>>> Series(range(4), index=index,
           name='first series')
a    0
b    1
c    2
d    3
Name: first series
# data + indices in a dict
>>> d = {'a':0,'b':1,'c':2,'d':1}
>>> s = Series(d, name='first series')
>>> print s.name
'first series'
>>> s.name = ''
>>> print s.index
Index([a, b, c, d], dtype=object)
>>> print s.values, type(s.values)
array([0, 1, 2, 1], dtype=int64)
numpy.ndarray
>>> s.dtype
dtype('int64')
```

FROM A NUMPY ARRAY

```
>>> from numpy.random import randn
>>> Series(randn(4), index=index)
a   -1.062984
b   -0.961625
c   -0.720323
d    1.100681
```

ACCESS ELEMENTS

```
# Access elements like an array
>>> s[2]
2
>>> s[:2]
a    0
b    1
# Access elements like a dictionary
>>> print s['c'], 'c' in s
2 True
# Slicing works on indices!
>>> s['a':'c']
a    0
b    1
c    2
```



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Creating DataFrames

FROM A DICT OF SERIES

```
# DF from a dict of series: keys are
# column names.
>>> s2=Series(randn(3), name='B',
             index=index[1:])
>>> d = {'A':s, 'B':s2}
>>> df = DataFrame(d)
      A          B
a  0       NaN
b  1 -0.961625
c  2 -0.720323
d  1  1.100681
>>> df.index, df.columns
Index([a, b, c, d], dtype=object)
Index([A, B], dtype=object)
>>> df.shape, df.dtypes
(4,2)
A           int64
B        float64
>>> df.values
array([[ 0.          ,         nan],
       [ 1.          , -0.96162549],
       [ 2.          , -0.72032263],
       [ 1.          ,  1.100680533]])
```

FROM A NUMPY ARRAY

```
>>> DataFrame(randn(4,4), index=index,
              columns=['A','B','C','D'])
      A          B          C          D
a  0.28164 -0.36826  0.04011  1.25030
b -0.71049 -1.23956 -0.08504 -0.08336
c -1.29446  0.70709  1.39642  0.49035
d  0.74632 -0.03512 -0.69237  0.81488
# List(series) interpreted as an array
>>> df2 = concat([s,s2], axis=1,
                 keys=['A', 'B'])
```

ACCESS OR ADD ELEMENTS

```
>>> col1 = df['A']
>>> col2 = df.B
>>> df['flag'] = df['B'] > 0
>>> df.ix['c']
A          2
B     -0.7203226
flag      False
Name: c
>>> df.ix[['c','B']]
-0.7203226322119064
```

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Creating Panels

FROM A DICT OF DATAFRAMES

```
# Panel from a dict of dataframes:
# keys used for third 'items' axis.
>>> df2=df.ix[::-2,:]
>>> data = {'item1': df,'item2': df2}
>>> wp = Panel(data)

>>> wp.items, wp.major_axis,
wp.minor_axis
Index([item1, item2], dtype=object)
Index([a, b, c, d], dtype=object)
Index([A, B, flag], dtype=object)
>>> wp.shape
(2, 4, 3)
>>> wp.values
array([[[0, nan, False],
       [1, -0.96162549, False],
       [2, -0.72032263, False],
       [1, 1.100680533, True]],
      [[0.0, nan, False],
       [nan, nan, nan],
       [2.0, -0.72032263, False],
       [nan, nan, nan]]],
      dtype=object)
```

FROM A NUMPY ARRAY

```
>>> items = ['foo','bar','baz','biz']
>>> Panel(randn(4,4,4), items=items)
<class 'pandas.core.panel.Panel'>
Dimensions: 4 (items) x 4 (major) x 4 (minor)
Items: foo to biz
Major axis: 0 to 3
Minor axis: 0 to 3
```

ACCESS OR ADD ELEMENTS

```
>>> df1 = wp['item1']
      A          B   flag
a  0       NaN  False
b  1 -0.9616255  False
c  2 -0.7203226  False
d  1  1.100681   True
>>> df2 = wp.item2
>>> del wp['item1']
>>> wp.ix['item2','c','A']
2.0
```

Pandas IO

READING FUNCTIONS

| Format | Method, Function, Class |
|-----------|-----------------------------|
| txt, csv | read_table, read_csv |
| clipboard | read_clipboard |
| pickle | read_pickle |
| HDF5 | read_hdf, HDFStore |
| Excel | read_excel, ExcelFile |
| R | pandas.rpy.common.load_data |

WRITING FUNCTIONS

| Format | Method, Function, Class |
|----------|-------------------------|
| txt, csv | to_string, to_csv |
| html | to_html |
| pickle | to_pickle |
| HDF5 | to_hdf, HDFStore |
| Excel | to_excel, ExcelWriter |

EXAMPLES

```
# Pickle is supported
>>> df.to_pickle('foo.pickle')
>>> read_pickle('foo.pickle')

# To load a table from an ascii file
df = read_table('foo.txt', sep=',',
                 header=1, skiprows=2, index_col=0,
                 names=['Paris', 'NY', 'Tokyo',
                        'London'], parse_dates=True,
                 na_values = [-9999])

# Long term storage: HDF5
>>> st = HDFStore('foo.h5')
>>> st['data1'] = df
>>> st['ser1'] = s
>>> s2 = st['ser1']
>>> st.close()
```

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Indexes and data alignment

RE-INDEXING

```
# reindex shuffles the existing index
>>> s.reindex(['c', 'b', 'a', 'e'])
c    2
b    1
a    0
e    NaN
# The index attr can be overwritten
>>> s.index = ['p', 'q', 'r', 's']
# 'rename' modifies index label
>>> s.rename(lambda a: a.upper())
P    0
Q    1
R    2
S    3
# Sort by values
>>> s.values[:] = [5, 3, 0, 2]
>>> s.order()
r    0
s    2
q    3
p    5
# Explicit alignment of BOTH series
>>> s, s2 = s.align(s2)
```

ALIGNMENT FROM OPERATIONS

```
# Operations automatically align on
# the index (different from ndarray)
>>> s[1:] + s[:-2]
a    NaN
b      1
c      2
d    NaN
e    NaN

# Sort a DF by a (list of) column(s)
>>> df.sort('A')
      A          B   flags
a  0      NaN  False
b  1 -0.961625  False
d  1  1.100681   True
c  2 -0.720323  False
```

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More on indexing

INDEX TO/FROM A COLUMN

```
# Any dataframe column can become the
# index
>>> df
      A          B
a  0      NaN
b  1 -0.961625
c  2 -0.720323
d  3  1.100681
>>> df2 = df.set_index('A')
      B
A
0      NaN
1 -0.961625
2 -0.720323
3  1.100681
# The opposite operation converts the
# index to a column
>>> df2.reset_index()
      A          B
0  0      NaN
1  1 -0.961625
2  2 -0.720323
3  3  1.100681
```

REDUNDANT INDEXES

```
# Although dangerous, it is possible
# to have redundant indices
>>> index = ['a', 'b', 'c', 'c']
>>> s=Series(range(4), index=index)
a  0
b  1
c  2
c  3
>>> s['c']
c  2
c  3
>>> type(s['c'])
pandas.core.series.Series
```

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Multi-indexed pandas

MULTI-INDEXING SERIES

```
>>> ind1=['bar', 'bar', 'baz', 'baz']
>>> ind2=['one', 'two', 'one', 'two']
>>> ind = [ind1,ind2]
>>> s = Series(randn(4), index=ind)
bar one    0.03
      two    0.80
baz one    0.56
      two   -2.08
>>> s.index
MultiIndex
[('bar', 'one') ('bar', 'two') ('baz',
'one') ('baz', 'two')]
>>> s['bar']
one    0.03
two    0.80
>>> s.reindex([('baz', 'two'),
              ('bar', 'one')])
baz two   -2.08
bar one    0.03
```

MULTI-INDEXING DATAFRAMES

```
>>> df = DataFrame(randn(4,2),
                  index=ind)
          0         1
bar one  0.24  0.81
      two -0.96  0.49
baz one  1.23  0.29
      two -0.97  1.18
>>> df.ix['bar']
          0         1
one    0.24  0.81
two   -0.96  0.49
>>> df.ix['bar', 'one']
0    0.24
1    0.81
Name: one
# Partial slicing works!
>>> df.ix[('bar','two'):('baz','two')]
          0         1
bar two -0.96  0.49
baz one  1.23  0.29
      two -0.97  1.18
```

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Multi-indexed pandas II

MANIPULATING INDEXES

```
# By default each index is identified
# by a level 0 (outer), 1 (inner)

>>> s.swaplevel(0,1)
one    bar      0.03
two    bar      0.80
one    baz      0.56
two    baz     -2.08

# reorder_levels generalizes that
>>> s.reorder_levels([1,0])
(...)

>>> s.index.names=['first','second']
>>> s
first  second
bar    one      0.03
       two      0.80
baz    one      0.56
       two     -2.08
```

SLICING

```
>>> df.index.names=['first','second']
>>> df.xs("one", level="second")
          0      1
first
bar    0.24  0.81
baz    1.23  0.29
```

SORTING

```
>>> s.sortlevel(level='second')
bar    one      0.03
baz    one      0.56
bar    two      0.80
baz    two     -2.08
```

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Computation with pandas

SERIES

```
# Series are subclasses of ndarrays:
# computations are element by element
>>> i = ['a', 'b', 'c', 'd']
>>> s = Series(range(4), index=i)
>>> s + 1
a    1
b    2
c    3
d    4

# All Numpy operators can be applied
>>> s2 = np.exp(s)
>>> s = s.astype(np.float32)
# including fancy indexing with masks
>>> s[s > 1.5] = 1.5
```

DATAFRAMES

```
>>> df
   A      B  flags
a  0    NaN  False
b  1   -0.9  False
c  2   -0.7  False
d  1    1.1   True
```

```
# Dataframe computations are applied
# columns by columns
>>> df2 = df + 1
# Adding a series or re-scaling
>>> row = df.ix[1]
>>> df - row
      A      B  flag
a  -1    NaN  False
b   0      0  False
c   1    0.2  False
d   0    2.0  True

# This would have been equivalent
>>> rescaled = df.sub(row, axis=0)
# Adding another dataframe can be done
# with a filler.
>>> df1.add(df2, fill_value=0)
# 'apply' a custom function to columns
>>> f = lambda x: x.max() - x.min()
>>> df.apply(f, axis = 0)
A      2
B      2
C    True
```

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Statistical Analysis

DESCRIPTIVE STATS

```
# Descriptive stats available:
# count, sum, mean, median, min, max,
# abs, prod, std, var, skew, kurt,
# quantile, cumsum, cumprod, cummax
# Stats on DF are column per column
>>> print df.mean(), df.mean(axis=1)
A      1.000000    a   -0.354328
B     -0.227542    b    0.500000
flag   0.250000    c    0.426559
                 d   1.033560
# Stats func accept a level as kw arg
# applicable for multi-index pandas
>>> df.describe()
          A            B
count  4.000000  3.000000
mean   1.000000 -0.227542
std    0.816497  1.162964
min    0.000000 -1.062984
25%    0.750000 -0.891653
50%    1.000000 -0.720323
75%    1.250000  0.190179
max    2.000000  1.100681
>>> pandas.rolling_<TAB>
```

CORRELATIONS & REGRESSION

```
>>> cov = df.cov()
>>> ts.corr(ts2, method='kendall')
0.066666666666666693
>>> ols(y = ts2, x = ts)
Formula: Y ~ <x> + <intercept>
Number of Observations: 20
Number of Degrees of Freedom: 2
R-squared: 0.9936
Adj R-squared: 0.9932
Rmse: 0.0582
F-stat(1,18): 2772.7496, p-value: 0.0
Degrees of Freedom: model 1, resid 18
(...)
```



For more stats, see `statsmodels`.

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Dealing with missing data

FIND & REMOVE/REPLACE NaN

```
# A boolean mask with 'null' values:
# None, np.NaN, np.inf, -np.inf
>>> np.all(isnull(s) | s.notnull())
True
# Replace missing values manually
>>> s[isnull(s)] = 0.
# Automatic version with forward fill
>>> s.fillna(method='ffill')
# Inverse operation
>>> s[s == -9999] = np.nan
# Remove all entries w/ missing values
>>> df.dropna(how='all')
# Interpolation also removes NaN
>>> s.interpolate()
```

SPARSE DATASETS

```
# If mostly missing data, convert to
# SparseSeries, SparseDataFrame, ...
# Only stores non-null values & loc
>>> print len(s), s.count(), s.nbytes
1000, 10, 8000
```

```
>>> sp_s = s.to_sparse()
>>> print sp_s nbytes
80
```

MERGING DATASETS

```
# Combining overlapping datasets with
# a priority
>>> df1 = DataFrame({
    'A' : [1.,nan,3.,5.,nan],
    'B' : [nan,2.,3.,nan,6.])
>>> df2 = DataFrame({
    'A' : [5.,2.,4.,nan,3.,7.],
    'B' : [nan,nan,3.,4.,6.,8.])
>>> df1.combine_first(df2)
      A    B
0    1  NaN
1    2    2
2    3    3
3    5    4
4    3    6
5    7    8
# More custom merging to be
# implemented using combine and a
# custom function
```

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Pivot tables and reshaping

PIVOTING

```
# Repeating columns can be viewed as
# an additional axis
>>> df

      date variable     value
0 2000-01-03        A  0.469112
1 2000-01-04        A -0.282863
2 2000-01-05        A -1.509059
3 2000-01-03        B -1.135632
4 2000-01-04        B  1.212112
5 2000-01-05        B -0.173215
>>> df.pivot(index='date',
             columns='variable', values='value')

variable      A      B
date
2000-01-03  0.469112 -1.135632
2000-01-04 -0.282863  1.212112
2000-01-05 -1.509059 -0.173215
```

(UN-)STACKING

```
# Stacking a DF creates a
# series with multiple indexes made
# from the column names.
>>> s

      a   b
one  1   2
two  3   4
>>> stacked = s.stack()

one  a    1
      b    2
two  a    3
      b    4
# Opposite operation unstacks the
# last level by default. If more cplx
# DF, can specify a level to unstack
>>> stacked.unstack()

      a   b
one  1   2
two  3   4
>>> stacked.unstack(level=0)

      one   two
      a    1    3
      b    2    4
```

365

Pivot tables and reshaping II

PIVOT_TABLE

```
# Another way to reshape a DF and
# aggregate at the same time
>>> df

      A   B   C   D
0  foo  one small  1
1  foo  one large  2
2  foo  one large  2
3  foo  two small  3
4  foo  two small  3
5  bar  one large  4
6  bar  one small  5
7  bar  two small  6
8  bar  two large  7

>>> table= df.pivot_table(values='D',
                           rows=['A', 'B'], cols=['C'],
                           aggfunc=np.sum)

>>> table

      small  large
foo  one    1    4
      two    6    NaN
bar  one    5    4
      two    6    7
```

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Data aggregation

Aggregation in a dataset is done in 3 steps: Split > Apply > Combine

SPLIT WITH groupby

```
# Group data by one column's value
>>> gps = df.groupby('flags')

# gps = iterator of tuples with
# group name and sub part of df

>>> gps.groups
{False: ['a', 'b', 'c'], True: ['d']}

# groupby can also take a custom
# function that acts on index labels

>>> df = df.reset_index()

>>> myfunc = lambda x: x%2 == 0

>>> gps2 = df.groupby(myfunc)

# Series can also be grouped by

>>> df['A'].groupby(myfunc)

# which is identical to

>>> gps2['A']
```

APPLY WITH aggregate()

```
# Values in groups can be aggregated
>>> gps.sum()
      A      B
flags
False  3 -1.6
True   1  1.1

# Version more flexible but slower
>>> gps.aggregate(np.sum)
# agg is even more flexible
>>> gps.agg([np.mean, np.std])
>>> gps.agg({'A':'sum', 'B':'std'})
      A          B
flags
False  3  0.141421
True   1      NaN
```

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Data aggregation II

APPLY WITH transform()

```
# Values in groups can be
# transformed (length conserved)
>>> f = lambda x: x - x.mean()
>>> gps.transform(f)
      A      B
a     -1    NaN
b      0  -0.1
c      1   0.1
d      0   0.0
```

APPLY WITH apply()

```
# Computations from values in
# groups can be turned into a DF
# of calcs
>>> desc = lambda x: x.describe()
```

```
>>> gps['A'].apply(desc).unstack()
```

| | count | mean | std | min | 25% | 50% | 75% | max |
|-------|-------|------|-----|-----|-----|-----|-----|-----|
| flags | | | | | | | | |
| False | 3 | 1 | 1 | 0 | 0.5 | 1 | 1.5 | 2 |
| True | 1 | 1 | NaN | 1 | 1.0 | 1 | 1.0 | 1 |

```
>>> def f(group):
    return DataFrame({'original':group,
                      'demeaned': group - group.mean()})
>>> gps['A'].apply(f)
```

| | demeaned | original |
|-------|----------|----------|
| index | | |
| a | -1 | 0 |
| b | 0 | 1 |
| c | 1 | 2 |
| d | 0 | 1 |

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Dealing with date & time

CREATING DATE/TIME INDEXES

```
# The index can be a list of
# dates+times locations that can be
# automatically generated
>>> date_range('1/1/2000', periods=4)
<class
'pandas.tseries.index.DatetimeIndex'>
[2000-01-01 00:00:00, ..., 2000-01-04
00:00:00]
Length: 4, Freq: D, Timezone: None
# Specify frequency: us,ms,S,T,H,D,B,
# W,M,3min, 2h20min, 2W,...
>>> r=date_range('1/1/2000', periods=72,
                 freq='H')
>>> i=date_range('1/1/2000', periods=4,
                  freq=datetools.YearEnd())
>>> i=date_range('1/1/2000', periods=4,
                  freq='3min')
>>> ts=Series(range(4), index=i)
2000-01-01 00:00:00    0
2000-01-01 00:03:00    1
2000-01-01 00:06:00    2
2000-01-01 00:09:00    3
Freq: 3T
```

UP-/DOWN-SAMPLING

```
>>> ts.resample('T')
2000-01-01 00:00:00    0
2000-01-01 00:01:00    NaN
2000-01-01 00:02:00    NaN
2000-01-01 00:03:00    1
2000-01-01 00:04:00    NaN
2000-01-01 00:05:00    NaN
2000-01-01 00:06:00    2
2000-01-01 00:07:00    NaN
2000-01-01 00:08:00    NaN
2000-01-01 00:09:00    3
Freq: T
# Group hourly data into daily
>>> ts2 = Series(randn(72), index=r)
>>> ts2.resample('D', how='mean',
                 closed='left', label='left')
01-Jan-2000    0.397501
02-Jan-2000    0.186568
03-Jan-2000    0.327240
Freq: D
>>> my_avg = lambda x: x[1:-1].mean()
>>> ts3=ts2.resample('D', how=my_avg)
```

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Dealing with date & time II

RANGES OF PERIODS

```
# The index can be a list of
# dates/times intervals
>>> PeriodIndex(['2011-1', '2011-2',
                 '2011-3', '2011-4'], freq='M')
<class 'tseries.period.PeriodIndex'>
freq: M
[Jan-2011, ..., Apr-2011]
length: 4
# They can be automatically generated
>>> pr = period_range('1/1/2000',
                      periods=4, freq='M')
freq: M
[Jan-2000, ..., Apr-2000]
length: 4
>>> ps=Series(range(4), index=pr)
2000-01    0
2000-02    1
2000-03    2
2000-04    3
Freq: M, dtype: int64
```

CONVERT TIMESTAMP<->PERIOD

```
>>> ts = ps.to_timestamp(how='end')
2000-01-31    0
2000-02-29    1
2000-03-31    2
2000-04-30    3
Freq: M
>>> all(ts.to_period() == ps)
True
```

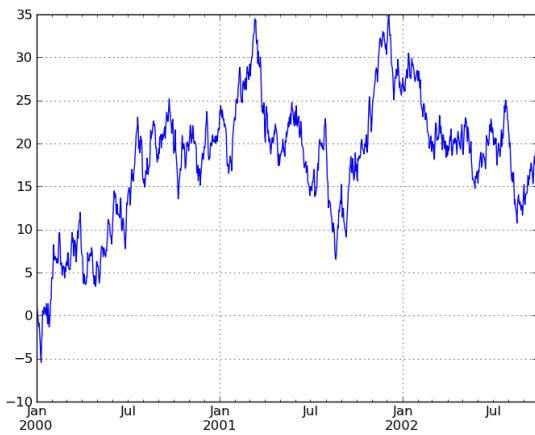
TIMEZONES

```
# Timestamps/pandas can be tz aware
>>> ts_utc = ts.tz_localize('UTC')
>>>
ts_us=ts_utc.tz_convert('US/Eastern')
2012-01-30 19:00:00-05:00 -0.425792
2012-02-28 19:00:00-05:00  0.788903
2012-03-30 20:00:00-04:00  0.009502
2012-04-29 20:00:00-04:00  1.775263
2012-05-30 20:00:00-04:00 -1.656727
Freq: M
>>> ts.index == ts_us.index
True
```

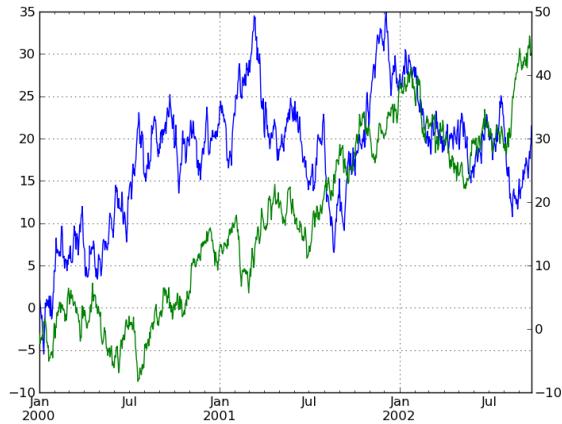
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Visualizing (Time)series

```
>>> ts.plot()
```



```
>>> ts2.plot(secondary_y=True, style='g')
```



See also

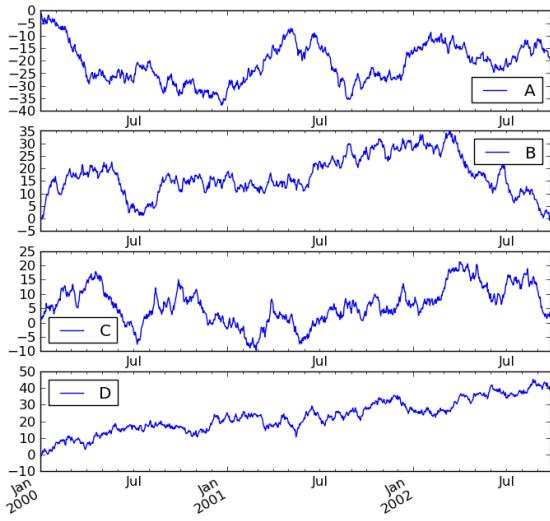
`tools.plotting.lag_plot,`
`tools.plotting.autocorrelation_plot` 371

Visualizing DataFrames

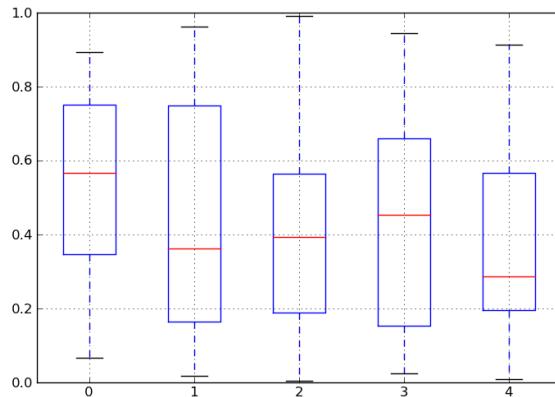
```
>>> plt.figure()  

>>> df.plot(subplots=True)  

>>> plt.legend(loc='best')
```



```
>>> df.boxplot()
```



See also:

`plot with kind='bar', 'barh', 'kde' keywd`
`hist method`
`tools.plotting.scatter_matrix,`
`andrews_curves, lag_plot`

Software Craftsmanship in Python

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Software Engineering Quotes

Programs should be written for people to read, and only incidentally for machines to execute.

Structure and Interpretation of Computer Programs
Harold Abelson and Gerald Sussman

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Software Engineering Quotes

You need to have empathy not just for your users, but for your readers. It's in your interest, because you'll be one of them. Many a hacker has written a program only to find on returning to it six months later that he has no idea how it works.

Hackers and Painters

Paul Graham

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Software Engineering Quotes

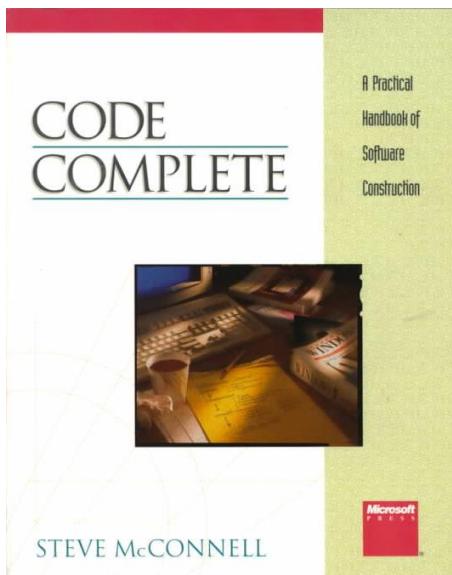
Debugging is twice as hard as writing the code in the first place. Therefore, if you write the code as cleverly as possible, you are, by definition, not smart enough to debug it.

Brian Kernighan

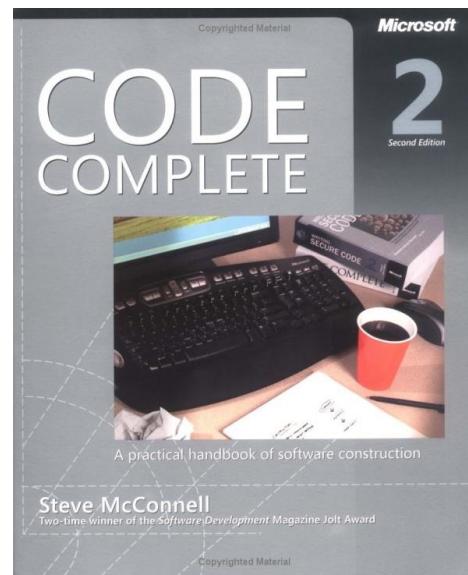
co-author of “The C Programming Language”

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Useful References

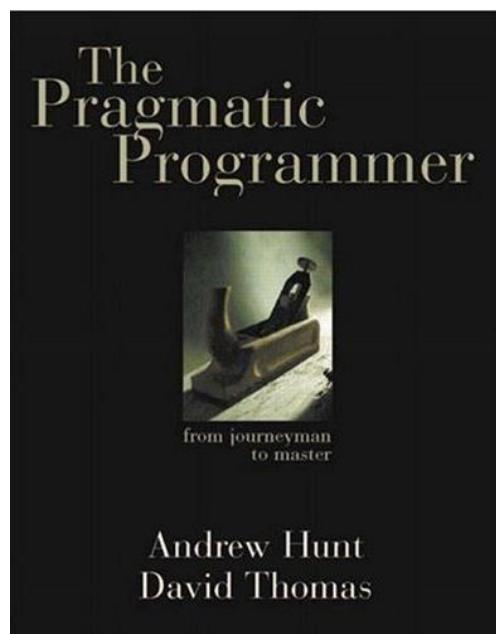


or



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Useful References



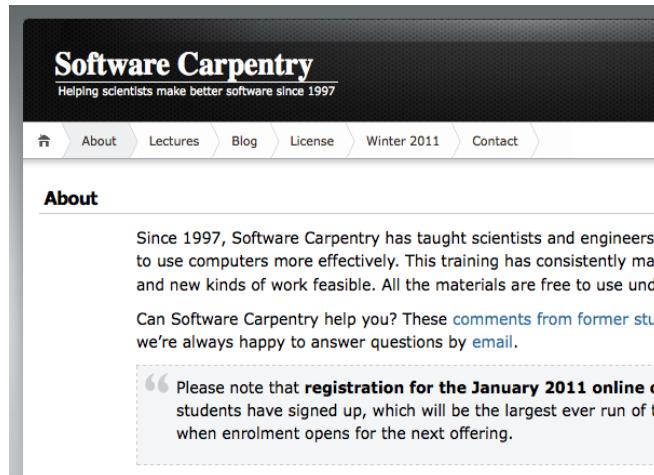
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Software Carpentry

Software Carpentry

<http://software-carpentry.org>

A Python-based course
on software design and
engineering for
scientists.



Coding Modes

The mode (context) you're in changes
the way you code.

Interactive Mode: Quick Iteration

Interactive Prompt and exploratory development.

Production Mode: Building for the Ages

Creating code that will be re-used by you or
others.

Naming Variables

Goal: Clarity for future readers of
the code

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Typical Scientific Naming Convention

STRAIGHT FROM FFTPACK

```
SUBROUTINE CFFTB1 (N,C,CH,WA,IFAC)
  DIMENSION      CH(*)      ,C(*)      ,WA(*)      ,IFAC(*)
  NF = IFAC(2)
  NA = 0
  L1 = 1
  IW = 1
  DO 116 K1=1,NF
    IP = IFAC(K1+2)
    L2 = IP*L1
    IDO = N/L2
    IDOT = IDO+IDO
    IDL1 = IDOT*L1
    IF (IP .NE. 4) GO TO 103
    IX2 = IW+IDOT
    IX3 = IX2+IDOT
    IF (NA .NE. 0) GO TO 101
    CALL PASSB4 (IDOT,L1,C,CH,WA(IW),WA(IX2),WA(IX3))
    GO TO 102
<and on and on for 368 lines...>
```

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Primary Naming Consideration

Priority 1: A variable name should fully and accurately describe the entity and variable it represents.

POOR NAME CHOICES

```
# Update Cash Balance after stock trade.
c1 = n * ip
c2 = c1 + compute_tc(ins, n)
b -= c2
```

DESCRIPTIVE NAME CHOICES

```
# Update Cash Balance after stock trade.
instrument_cost = instrument_quantity * instrument_price
trade_cost = instrument_cost + transaction_cost(instrument_name,
                                                instrument_quantity)
cash_balance -= trade_cost
```

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Descriptive Name Choices

| Entity Represented | Variable Name |
|---|---|
| The number of trading days in the current month | number_of_trading_days_in_current_month, NumberOfTradingDaysPerMonth, trading_days_in_current_month |
| Length of a moving average window | length_of_moving_average_window, lengthOfMovingAverageWindow |
| Risk Free Interest Rate | risk_free_interest_rate risk_free_rate RiskFreeRate |

These names are descriptive without much room for ambiguity, and they are trivially decoded.

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But the Names are Looooong...

Yes they are... Here are examples from the VTK library, a 3D visualization tool set with 1800+ classes. (www.vtk.org)

| | | |
|--|---|--|
| 3 vtk3DSImporter vtk3DWidget A vtkAbstractArray vtkAbstractMapper vtkAbstractMapper3D vtkAbstractParticleWriter vtkAbstractPicker vtkAbstractPropPicker vtkAbstractTransform vtkAbstractVolumeMapper vtkAbstractWidget ActionFunction vtkActor vtkActor2D vtkActor2DCollection vtkActorCollection vtkAdjacentVertexIterator vtkAffineRepresentation vtkAffineRepresentation2D vtkAffineWidget vtkAlgorithm vtkAlgorithmOutput vtkAmoebaMinimizer vtkAMRBox vtkAngleRepresentation vtkAngleRepresentation2D vtkAngleWidget vtkAnimationCue vtkAnimationCue::AnimationCueInfo vtkAnimationScene vtkAnnotatedCubeActor vtkAppendCompositeDataLeaves vtkAppendFilter vtkAppendPolyData vtkAppendSelection vtkApproximatingSubdivisionFilter | vtkHyperOctreeCutter vtkHyperOctreeDepth vtkHyperOctreeDualGridContourFilter vtkHyperOctreeFractalSource vtkHyperOctreeLightWeightCursor vtkHyperOctreeLimiter vtkHyperOctreePointsGrabber vtkHyperOctreeSampleFunction vtkHyperOctreeSurfaceFilter vtkHyperOctreeToUniformGridFilter vtkHyperStreamline I vtkIconGlyphFilter vtkIdentColoredPainter vtkIdentityTransform vtkIDFilter vtkIDList vtkIDListCollection vtkIDTypeArray vtkImage2DIslandPixel vtkImageAccumulate vtkImageActor vtkImageActorPointPlacer vtkImageAlgorithm vtkImageAnisotropicDiffusion2D vtkImageAnisotropicDiffusion3D vtkImageAppend vtkImageAppendComponents vtkImageBlend vtkImageButterworthHighPass vtkImageButterworthLowPass vtkImageCacheFilter vtkImageCanvasSource2D vtkImageCast vtkImageChangeInformation vtkImageCheckerboard vtkImageCityBlockDistance vtkImageClip | vtkPostgreSQLQuery vtkPostScriptWriter vtkOutlineCornerFilter vtkOutlineFilter vtkPOVExporter vtkPPolyDataNormals vtkPProbeFilter vtkPrimitivePainter vtkPriorityQueue vtkPriorityQueue::Item vtkProbeFilter vtkProbeSelectedLocations vtkProcessGroup vtkProcessIdScalars vtkProcessObject vtkProcessStatistics vtkProcrustesAlignmentFilter vtkProgrammableAttributeDataFilter vtkProgrammableDataObjectSource vtkProgrammableFilter vtkProgrammableGlyphFilter vtkProgrammableSource vtkProjectedTerrainPath vtkProjectedTetrahedralMapper vtkProjectedTexture vtkProp vtkProp3D vtkProp3DCollection vtkPropAssembly vtkPropCollection vtkProperty vtkProperty2D property_traits< vtkGraphEdgeMap > (boost) property_traits< vtkGraphIndexMap > (boost) property_traits< vtkIntArray * > (boost) vtkPropPicker vtkPruneTreeFilter vtkPSphereSource |
|--|---|--|

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The Downside to Long Names

DETAILED NAMES AND OBFUSCATED EQUATIONS

```
# Long names can make simple formulas difficult to read,
# reducing clarity.
historic_daily_percent_price_change_per_day = \
    (historic_daily_adjusted_close_price[1:] - \
     historic_daily_adjusted_close_price[:-1]) \
    / historic_daily_adjusted_close_price[:-1]
```

SHORTER NAMES IMPROVE EQUATION READABILITY

```
# Variable table:
# adj_close - Daily adjusted closing price for an instrument.
# change_percentage - Daily percent change in adjusted closing price.
change_percentage = (adj_close[1:] - adj_close[:-1]) / adj_close[:-1]
```

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Optimal Name Lengths

Studies on debugging COBOL indicate*
 10-16 character names is optimal length.
 8-20 characters is almost as good.

| TOO LONG | TOO SHORT | JUST_RIGHT |
|--|----------------------------|---|
| <code>risk_free_interest_rate</code> | <code>r, rfir, rate</code> | <code>risk_free_rate,</code> <code>rsk_fr_rate</code> |
| <code>length_of_moving_average_window</code> | <code>N, nw</code> | <code>win_len, window_length,</code> <code>Nwindow, mov_avg_win_len</code> |

* Gorla, N., A. C. Benander, and B. A. Benander. 1990. "Debugging Effort Estimation Using Software Metrics." IEEE Transactions on Software Engineering SE-16, no. 2 (February): 223-231

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Strategies for Shortening Names

Use Standard Abbreviations

```
administrator_information -> admin_info
```

Truncate consistently after 2nd or 3rd letter of each word

```
display_window -> dis_win
```

Remove Non-leading Vowels

```
risk_free_interest_rate -> rsk_fr_intrst_rt
```

Use only significant words in variable

```
start_of_next_paragraph -> next_paragraph_start
```

Remove useless suffixes

```
checking_account -> check_account
```

Iterate until variables are between 8 and 20 characters.

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Using *extremely* short names

LOOP INDICES I, J, and K

```
# This is ok.  
for i in range(10):  
    scores[i] = 0  
  
# But this is better.  
for event in range(10):  
    decathlon_scores[event] = 0
```

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Using *extremely* short names

INDUSTRY STANDARD VARIABLES IN “SMALL” CONTEXT

```
# Quick, what does each variable stand for?  
y = a * sin(w*t + phi)
```

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Using *extremely* short names

INDUSTRY STANDARD VARIABLES IN “SMALL” CONTEXT

```
def sin_wave(t, a=1, w=2*pi, phi=0):
    """
    Return a sin wave form for time t.

    Inputs
    -----
    t: time in seconds
    a: amplitude scale factor
    w: frequency in radians/second
    phi: phase shift in radians

    Returns
    -----
    y: sin wave output
    """
    y = a * sin(w*t + phi)
    return y
```

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Domain vs. Computing Names

Variable names should relate to the problem space, not generic programming terminology.

```
# Not so good... Algorithm-centric names
sum = 0
for record in record_list:
    sum += will_retire(record.name)

# Better. Domain specific names.
gold_watch_order = 0
for employee in employee_list:
    gold_watch_order += will_retire(employee.name)
```

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Qualified Names

Use the “most important” part of the name as the first word for “grouped” variables. Usually, this is a noun.

MOST IMPORTANT WORD FIRST

```
# The _avg suffix on the price
# variable indicates it is an
# average price.

price_avg = mean(prices)
price_std = std(prices)

volume_avg = mean(volumes)
volume_std = std(volumes)
```

ADJECTIVE FIRST AS IN ENGLISH

```
# But... Placing avg as a prefix
# read more like english
# (adjective first). So,
# arguments can be made for this
# approach as well.

avg_price = mean(prices)
avg_volume = mean(volumes)

std_price = std(prices)
std_volume = std(volumes)
```

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Qualified Names

Both prefixes and suffixes are found in “real” code, and are quite readable.

Stick with one approach for a given variable group.

EXAMPLE WITH MIXED PREFIX AND SUFFIX VARIABLES

```
# Find the total profit made from group of trades.
profit_total = 0.0
current_trade_index = 0
while current_trade_index < last_trade_index:
    current_trade = trades[current_trade_index]
    profit, open_positions = update_positions(current_trade,
                                                open_positions)
    profit_total += profit
    current_trade_index += 1
```

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Global “Constants”

GLOBALS

```
# "Constant" Global variables
# are often capitalized.
>>> from enthought.kiva import \
...     constants
>>> constants.ITALIC
2
# But not always.
# [This is a global type.]
>>> import numpy
>>> numpy.float32
<type 'numpy.float32'>
```

ENUMERATED TYPE PREFIX

```
# Type prefixes (like JOIN) often
# indicate a group of enumerated
# constants.
>>> constants.JOIN_BEVEL
1
>>> constants.JOIN_MITER
2
```

CONSTANTS IN MODULES

The prefix used to differentiate constants in other languages are often removed and put in a single module in Python.

```
# wxPython is a GUI library
# wrapped around the C++
# wxWidgets library.
>>> import wx

# In C++, the constant is
# wxALIGN_CENTER
>>> wx.ALIGN_CENTER
2304
```

 Note that these global values are not truly constants as they are writable variables.

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Boolean Variables

GENERIC NAMES

```
# Try not to use generic names
# as they don't provide much
# information
flag = True
status = True
```

STANDARD NAMES

```
# These common names are more
# informative.
done = True
found = True
success = True
valid = True
error = True
ok = True

# Using the prefix is_ can
# help identify booleans.
is_done = True
```

POSITIVE VALUES

```
# Positive values are easy to
# interpret
if found:
    employee_of_month = employee

# Negative Booleans take more
# mental gymnastics to read
if not not_found:
    employee_of_month = employee
```

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Naming Containers

When naming lists (or sequences) of elements, use the plural of the word, or a suffix that indicates it is a container.

VARIABLE SUFFIX FOR CONTAINERS

```
# Using the _list suffix is descriptive and is more
# easily differentiated from a single item.
for name in name_list:
    print name
```

PLURAL VARIABLE NAME FOR CONTAINERS

```
# Using the plural version of the variable is also a common paradigm.
for name in names:
    print name

# For long variables names, the singular and plural approach isn't
# as good. It is too hard to differentiate between the two.
close_price = {}
for equity_symbol in equity_symbols:
    close_price[equity_symbol] = lookup_daily_close(equity_symbol)

# And this is obviously problematic...
for moose in moose:
    moose.bellow()
```

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Naming Variables Review

Priority 1: A variable's name should fully and accurately describe the entity and variable it represents.

Names should refer to the real-world problem rather than to computer programming terms.

A name should be long enough so that you don't have to puzzle out its meaning.

Short names are OK for industry standard names, indices, and in “small” contexts.

Computed-value qualifiers should be at the end of the name.

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Documenting Code

399

Documentation Layers

| |
|--|
| Application Documentation End User Manuals, Domain specific Tutorials, etc. |
| Developer Documentation Architecture Description, Concepts, Developer Tutorials |
| API Documentation Doc-strings for functions, classes, and modules |
| Inline Code Comments Describe intent of code or algorithm design |
| Self Documenting Code Variable and Function Names, Good Design, Clear Layout |

SELF DOCUMENTING CODE

```
# Snippet out of a draw() method for drawing
# "bulls eye" cross hairs at the mouse position
# on a plot.

plot = self.component
if plot is None:
    return

# sx, sy: mouse position in screen space.
sx, sy = plot.map_screen(self.current_position)

if plot.orientation == "h" and sx is not None:
    self._draw_vertical_line(gc, sx)
elif sy is not None:
    self._draw_horizontal_line(gc, sy)

if self.show_marker:
    self._draw_marker(gc, sx, sy)
```

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Documentation Layers

| |
|--|
| Application Documentation |
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INLINE CODE COMMENTS

```
# Code snippet out of a Enthought Envisage
# library written by Martin Chilvers.

def unregister_services(self):
    """ Unregister any service offered by the
        plugin.
    """

    # Services must be unregistered in reverse
    # order that they were registered in.
    service_ids = self._service_ids[:]
    service_ids.reverse()

    app = self.application
    for service_id in service_ids:
        app.unregister_service(service_id)

    # Reset services in case the plugin is
    # started again.
    self._service_ids = []
```

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Documentation Layers

| |
|--|
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API DOCUMENTATION [FROM NUMPY]

```
def interp(x, xp, fp, left=None, right=None):
    """
    One-dimensional linear interpolation.

    Returns the one-dimensional piecewise
    linear interpolant to a function with
    given values at discrete data-points.

    Parameters
    ----------
    x : array_like
        The x-coordinates of the
        interpolated values.
    xp : 1-D sequence of floats
        The x-coordinates of the data
        points, must be increasing.
    <snip>
    Returns
    -------
    y : {float, ndarray}
        Interpolated values, same shape as `x`.
    <snip>
    """

```

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Documentation Layers

| |
|--|
| Application Documentation |
| End User Manuals, Domain specific Tutorials, etc. |
| Developer Documentation |
| Architecture Description, Concepts, Developer Tutorials |
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DEVELOPER DOCUMENTATION

Provides a high level explanation of concepts and use of a library.

Guide to NumPy

Travis E. Oliphant, PhD
Dec 7, 2006

Contents

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Documentation Layers

| |
|--|
| Application Documentation |
| End User Manuals, Domain specific Tutorials, etc. |
| Developer Documentation |
| Architecture Description, Concepts, Developer Tutorials |
| API Documentation |
| Doc-strings for functions, classes, and modules |
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| Self Documenting Code |
| Variable and Function Names, Good Design, Clear Layout |

APPLICATION DOCUMENTATION

THE ARTIST'S GUIDE TO GIMP EFFECTS

CREATIVE TECHNIQUES FOR PHOTOGRAPHERS, ARTISTS, AND DESIGNERS

michael j. hammel



404

Documentation Layers

| | |
|----------------------------------|--|
| Application Documentation | End User Manuals, Domain specific Tutorials, etc. |
| Developer Documentation | Architecture Description, Concepts, Developer Tutorials |
| API Documentation | Doc-strings for functions, classes, and modules |
| Inline Code Comments | Describe intent of code or algorithm design |
| Self Documenting Code | Variable and Function Names, Good Design, Clear Layout |

OUR FOCUS

- **Writing useful inline code comments**
- **Creating function, class, and module level documentation.**

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Bad Code Comments

REPEATING THE CODE

Comments that just parrot code are pretty much useless.

```
# Check if the printer is ready.
if printer_status == 'ready':
    document.print()
```

INCORRECT COMMENTS

This comment is not even accurate. It likely got out of sync with the code when the bank implemented a minimum balance policy and the comment wasn't updated.

```
# Flag withdrawals that cause
# customer balance to become
# negative.
new_balance = balance - withdrawal
if new_balance < min_allowed_balance:
    success = False
```

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Better Code Comments

SUMMARY COMMENTS

Summarizing a few lines with a description of the code's intent is useful.

```
# Solve the dense linear system
# ZI=V for the currents I, given
# the impedance matrix Z and the
# driving voltage V.
lu_matrix, pivot = lu_factor(Z)
I = lu_solve((lu_matrix, pivot), V)
```

FIXME COMMENTS

Flag design decisions and trade-offs that others should be aware of when editing code in the future.

```
# FIXME: Sales tax hard coded to
# 8.25%. This should be passed in
# or looked up with a function
# call.
price_total = price * (1.0825)
```

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Function Docstring Format

TYPICAL DOCUMENTATION FORMAT – FOO.PY

```
""" Short docstring for the module goes here.

A longer description for the module goes it here. It
is typically multiple lines long.
"""

class Foo(object):
    """ Short docstring for Foo class.

    Longer docstring describing the Foo class.
    """

    def some_method(self):
        """ Short description for some_method.

        Longer description for some_method...
        """

        pass

    def bar():
        """ Short docstring for bar function.

        And, not surprisingly, the long description for the function.
        """

        pass
```



See the `foo.py` example in
the `demo/docstrings`
directory.

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Command line help

IPYTHON HELP PRINTS DOCSTRINGS

```
In [12]: import foo
In [13]: foo?
Type:           module
Base Class:     <type 'module'>
String Form:    <module 'foo' from 'foo.py'>
Namespace:      Interactive
File:           c:\temp\foo.py
Docstring:
    Short docstring for the module goes here.
```

A longer description for the module goes here. It is typically multiple lines long.

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Styles of Documentation

SIMPLE IS AS SIMPLE DOES

Use simple docstrings for simple functions.

```
# from the Python standard library: locale.py

def str(val):
    """Convert float to integer, taking the locale into account."""
    return format("%.12g", val)
```

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Styles of Documentation

FORMAL DOCUMENTATION SPECIFICATION

```
def interp(x, xp, fp, left=None, right=None):
    """
    One-dimensional linear interpolation.

    Returns the one-dimensional piecewise linear
    interpolant to a function with given values
    at discrete data-points.

    Notes
    =====
    Does not check that the x-coordinate sequence
    C{xp} is increasing. If C{xp} is not increasing,
    the results are nonsense. A simple check for
    increasingness is::

        np.all(np.diff(xp) > 0)

    Examples
    =======
    >>> xp = [1, 2, 3]
    >>> fp = [3, 2, 0]
    >>> np.interp(2.5, xp, fp)
    1.0
    >>> np.interp([0, 1, 1.5, 2.72, 3.14], xp, fp)
    array([ 3.,  3.,  2.5,  0.56,  0.])
    >>> UNDEF = -99.0
    >>> np.interp(3.14, xp, fp, right=UNDEF)
    -99.0
```

`@param x : array_like.`
 `The x-coordinates of the interpolated values.`

`@param xp : 1-D sequence of floats.`
 `The x-coordinates of the data points, must be`
 `increasing.`

`@param fp : 1-D sequence of floats.`
 `The y-coordinates of the data points, same length`
 `as C{xp}.`

`@param left : float, optional.`
 `Value to return for C{x < xp[0]}, default is`
 `C{fp[0]}.`

`@param right : float, optional.`
 `Value to return for C{x > xp[-1]}, defaults is`
 `C{fp[-1]}.`

`@return: float or ndarray.`
 `The interpolated values, same shape as C{x}.`

`@raise ValueError: if C{xp} and C{fp} have different`
 `lengths`

"""

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Formal Specifications

BENEFITS

- Formalism helps developers know what to document.
 - Uniform look to documentation.
 - Tools like Sphinx and Epydoc can generate nice HTML and PDF docs automatically.
- 

DRAWBACKS

- Can add (significant) overhead for creating new functions.
- Overhead can inhibit developers from re-factoring and creating new functions when they should.

numpy.interp

`numpy.interp(x, xp, fp, left=None, right=None)`
One-dimensional linear interpolation.
>Returns the one-dimensional piecewise linear interpolant to a function with given values at discrete data-points.

Parameters: `x` : array_like
The x-coordinates of the interpolated values.
`xp` : 1-D sequence of floats
The x-coordinates of the data points, must be increasing.
`fp` : 1-D sequence of floats
The y-coordinates of the data points, same length as `xp`.
`left` : float, optional
Value to return for `x`, default is `fp[0]`.
`right` : float, optional
Value to return for `x > xp[-1]`, defaults is `fp[-1]`.

Returns: `y` (float, ndarray)
The interpolated values, same shape as `x`.

Raises: `ValueError`:
If `xp` and `fp` have different length

Notes

Does not check that the x-coordinate sequence `xp` is increasing. If `xp` is not increasing, the results are nonsense. A simple check for increasingness is:

```
np.all(np.diff(xp) > 0)
```

Examples

```
>>> xp = [1, 2, 3]
>>> fp = [3, 2, 0]
>>> np.interp(2.5, xp, fp)
1.0
>>> np.interp([0, 1, 1.5, 2.72, 3.14], xp, fp)
array([ 3.,  3.,  2.5,  0.56,  0.])
>>> UNDEF = -99.0
>>> np.interp(3.14, xp, fp, right=UNDEF)
-99.0
```

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Restructured Text Docstring Format

<http://epydoc.sourceforge.net/othermarkup.html#restructuredtext>
<http://docutils.sourceforge.net/docs/user/rst/quickstart.html>

```
_docformat_ = "restructuredtext"

def interp(x, xp, fp, left=None, right=None):
    """
    One-dimensional linear interpolation.

    Returns the one-dimensional piecewise linear
    interpolant to a function with given values at
    discrete data-points.

    :Parameters:
        x : array_like.
            The x-coordinates of the interpolated
            values.

        xp : 1-D sequence of floats.
            The x-coordinates of the data points, must
            be increasing.

        fp : 1-D sequence of floats.
            The y-coordinates of the data points, same
            length as C{xp}.

        left : float, optional.
            Value to return for C{x < xp[0]}, default
            is C{fp[0]}.

        right : float, optional.
            Value to return for C{x > xp[-1]}, defaults
            is C{fp[-1]}.

    :return: float or ndarray.
            The interpolated values, same shape as C{x}.

    :raises ValueError: if C{xp} and C{fp} have different
            lengths

    Notes
    =====
    Does not check that the x-coordinate sequence C{xp} is
    increasing. If C{xp} is not increasing, the results
    are nonsense. A simple check for increasingness is::

        np.all(np.diff(xp) > 0)

    Examples
    ======
    >>> xp = [1, 2, 3]
    >>> fp = [3, 2, 0]
    >>> np.interp(2.5, xp, fp)
    1.0
    >>> np.interp([0, 1, 1.5, 2.72, 3.14], xp, fp)
    array([ 3.,  3.,  2.5,  0.56,  0.])
    >>> UNDEF = -99.0
    >>> np.interp(3.14, xp, fp, right=UNDEF)
    -99.0
    """

```

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Tips for Restructured Text

EXAMPLE CODE

Precede by '::' and a blank line.

```
""" Decorator to turn a code-
block inside of a function
into a string::

    @func2str
    def code():
        c = a + b
        d = a - b
"""

Result:
```

Decorator to turn a code-block inside of a function into a string.

```
@func2str
def code():
    c = a + b
    d = a - b
```

PARAMETER DESCRIPTIONS

Parameter lists are “definition lists”, so every item must have a separate description line.

```
x_ctrl : float
    X-value of the control point.
y_ctrl : float
    Y-value of the control point.
```

Not this (“unexpected indentation” error):

```
x_ctrl : float
y_ctrl : float
    The control point.
```

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Tips for Restructured Text

MIXING LIST SYNTAX

This example looks nice in the source file, but it is mixing syntax for bullet lists and definition lists. It gets an indentation error.

- **object:** The value is treated as a normal Python object and is not modified.
- **file:** The value is a file, and supports various types of conversions.

This can be made into valid ReST as a bullet list or as a definition list.

BULLET LISTS

- **object:** The value is treated as a normal Python object and is not modified.
- **file:** The value is a file, and supports various types of conversions.

OBJECT LISTS

object

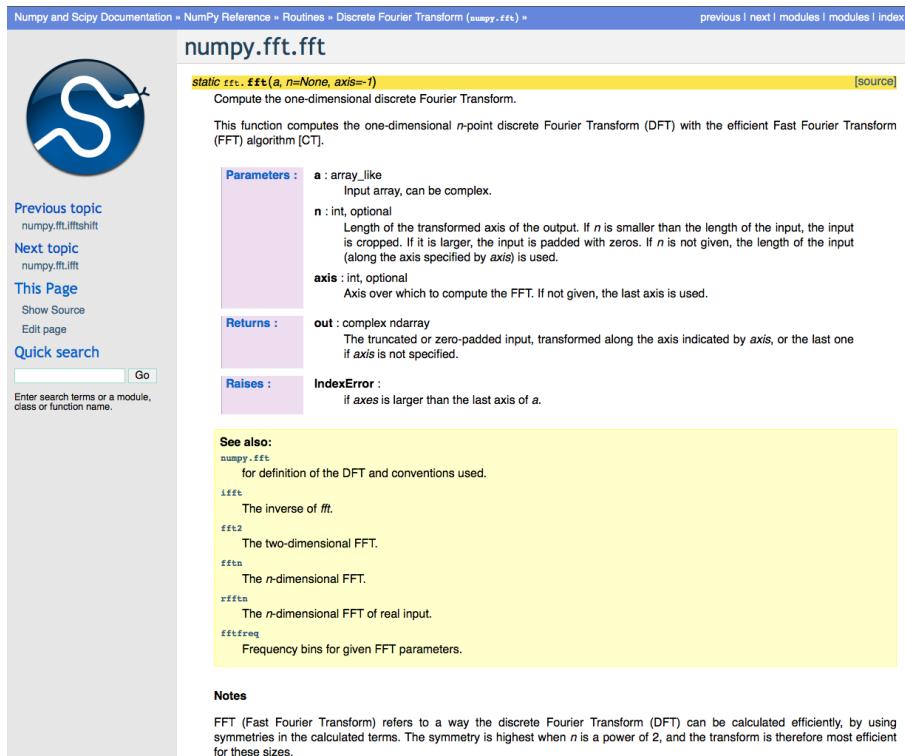
The value is treated as a normal Python object and is not modified.

file

The value is a file, and supports various types of conversions.

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Result with Sphinx



Numpy and Scipy Documentation » NumPy Reference » Routines » Discrete Fourier Transform ([numpy.fft](#)) »

[previous](#) | [next](#) | [modules](#) | [modules](#) | [index](#)

numpy.fft.fft

static `fft(a, n=None, axis=-1)` [source]

Compute the one-dimensional discrete Fourier Transform.

This function computes the one-dimensional n -point discrete Fourier Transform (DFT) with the efficient Fast Fourier Transform (FFT) algorithm (CT).

Parameters :

- a :** array_like
Input array, can be complex.
- n :** int, optional
Length of the transformed axis of the output. If n is smaller than the length of the input, the input is cropped. If it is larger, the input is padded with zeros. If n is not given, the length of the input (along the axis specified by `axis`) is used.
- axis :** int, optional
Axis over which to compute the FFT. If not given, the last axis is used.

Returns :

- out :** complex ndarray
The truncated or zero-padded input, transformed along the axis indicated by `axis`, or the last one if `axis` is not specified.

Raises :

- IndexError :**
if `axes` is larger than the last axis of `a`.

See also:

- `numpy.fft`
for definition of the DFT and conventions used.
- `ifft`
The inverse of `fft`.
- `fft2`
The two-dimensional FFT.
- `fftn`
The n -dimensional FFT.
- `rfftn`
The n -dimensional FFT of real input.
- `fftfreq`
Frequency bins for given FFT parameters.

Notes

FFT (Fast Fourier Transform) refers to a way the discrete Fourier Transform (DFT) can be calculated efficiently, by using symmetries in the calculated terms. The symmetry is highest when n is a power of 2, and the transform is therefore most efficient for these sizes.

420

Line Count Metrics for Documentation

PORTION OF CODE THAT SHOULD BE COMMENTS

Number for several Python projects using cloc: <http://cloc.sourceforge.net/>

| Language | files | blank | comment | code |
|--------------------|-------|-------|----------------|--------|
| C | 81 | 22565 | 41042 | 120573 |
| Python | 424 | 24915 | 54760 | 83183 |
| C/C++ Header | 93 | 3064 | 3082 | 10007 |
| Cython | 6 | 940 | 2422 | 1523 |
| C++ | 8 | 52 | 116 | 643 |
| make | 9 | 100 | 74 | 457 |
| HTML | 5 | 47 | 15 | 403 |
| CSS | 3 | 134 | ~39 % Comments | |
| Fortran 77 | 22 | 11 | ~~ | ~~ |
| Fortran 90 | 15 | 56 | 20 | 200 |
| sed | 1 | 0 | 12 | 140 |
| Bourne Shell | 7 | 22 | 23 | 92 |
| Bourne Again Shell | 1 | 13 | 12 | 87 |
| SUM: | 675 | 51919 | 101689 | 217975 |

Result: SciPy: 32%, NumPy: 39%, ETS: 38%

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Coding Standards

Foolish Consistencies...

A foolish consistency is the hobgoblin of little minds, adored by little statesmen and philosophers and divines. With consistency a great soul has simply nothing to do. He may as well concern himself with his shadow on the wall. Out upon your guarded lips! Sew them up with packthread, do. Else if you would be a man speak what you think to-day in words as hard as cannon balls, and to-morrow speak what to-morrow thinks in hard words again, though it contradict every thing you said to-day. Ah, then, exclaim the aged ladies, you shall be sure to be misunderstood! Misunderstood! It is a right fool's word. Is it so bad then to be misunderstood? Pythagoras was misunderstood, and Socrates, and Jesus, and Luther, and Copernicus, and Galileo, and Newton, and every pure and wise spirit that ever took flesh. To be great is to be misunderstood.

From the essay “Self Reliance,” by Ralph Waldo Emerson

*Quoted in “PEP 8: Style Guide for Python,”
by Guido Von Rossum and Barry Warsaw*

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Foolish Consistencies...

True. But this statement is too often used to get rid of good consistencies.

Show your creativity and personal style in your algorithms, not your code layout. Code consistencies make sharing and debugging much more efficient.

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Foolish Consistencies...

Ralph doesn't differentiate between good and foolish consistencies, but Guido does. From the Python Coding Standard*:

[There are] two good reasons to break a particular [coding standard] rule:

- (1) When applying the rule would make the code less readable, even for someone who is used to reading code that follows the rules.
[editorial addition: Think about others, not you.]
- (2) To be consistent with surrounding code that also breaks it (maybe for historic reasons) -- although this is also an opportunity to clean up someone else's mess (in true XP style).

* <http://www.python.org/dev/peps/pep-0008/>

Python Coding Standard

The Python Coding Standard is defined in Python Enhancement Proposal 8* (PEP-8).

* <http://www.python.org/dev/peps/pep-0008/>

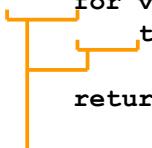
Indentation and Spaces

INDENTATION

Always use 4 spaces to indent code blocks.

```
def sum(a):
    total = 0
    for value in a:
        total += a
    return total
```

4 spaces each



TABS OR SPACES?

Never mix tabs and spaces in a file.

The “Tab Nanny” tool shipped with Python can check this.

```
# mixed.py
# This file contains tabs and spaces
def foo(a):
    print 'tabs'
    print 'spaces'

C:>c:\python25\lib\tabnanny.py mixed.py
mixed.py 5 "           print 'spaces'\n"
```



Most editors (emacs, vim, etc.) have a python mode that will insert 4 spaces when you type <tab>.

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Line Lengths and Wrapping

80 CHARACTER LINES

Limit line lengths to 80 characters.

Emacs and many other editors wrap at 80 characters by default.

```
# Use '\' at the end of lines to continue on the next line.
from numpy import array, sin, cos, allclose, zeros, ones,
                  uint32, float32

# Code enclosed in () or [] or {} does not need the '\'.
if (instrument_volume > VOLUME_THRESHOLD and
    instrument_price < PRICE_THRESHOLD):
    <do something>

# Align function arguments with beginning of function args.
a, b = some_long_function_call_name(with_long_var1,
                                      and_long_var2)
```

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Line Spacing

TOP LEVEL FUNCTIONS/CLASSES

```
# Separate top level functions
# and classes with two blank
# lines.

def add(a, b):
    total = a + b
    return total

class Person(object):
    def __init__(self, first, last):
        self.first = first
        self.last = last

class City(object):
    pass
    def __init__(self, name, state):
        self.name = name
        self.state = state
```

CLASS METHODS

```
# Separate class methods by a
# single line

class Person(object):

    def __init__(self, first, last):
        self.name = name

    def full_name(self):
        return self.first + \
            self.last

    def __repr__(self):
        string = "Person(%s)" % \
            self.full_name
```

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Line Spacing

GROUPING FUNCTIONS

```
# Extra blank lines may be used
# (sparingly) to separate groups
# of related functions.

#-----
# Math functions
#-----

def add(a, b):
    total = a + b
    return total

def subtract(a, b):
    difference = a - b
    return difference

#-----
# Name functions
#-----

def full_name(first, last):
    full = first + last
    return full
```

ONE LINER FUNCTIONS

```
# Lines can be omitted between
# one-liner implementations (such
# as dummy functions).

def stub1():
    pass
def stub2():
    pass
def stub3():
    pass
```

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Line Spacing

FUNCTION BODIES

```
# Use blank lines (sparingly) in
# functions to indicate logical
# sections.

def blend_color_channel(c1, c2, alpha):

    # Validation
    if not 0 <= alpha <= 1.0:
        raise ValueError, "bad alpha"

    # Channel blending algorithm.
    new_c = c1 * alpha + \
            c2 * (1 - alpha) extra space

return new_c
```

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Imports

SEPARATE LINES

```
# Imports should usually be on
# separate lines.

# Like this.
import os
import sys

# NOT like this.
import os, sys
```

IMPORT FROM A MODULE

```
# It is OK (and encouraged) to have
# have items imported from a module
# on the same line.
```

```
from numpy import array, float32
```

AVOID IMPORT *

```
# Do not use import * except at
# the command prompt.
```

```
# Only at the command prompt...
from numpy import *
```

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Imports

LOCATION IN FILE

```
# Imports should happen at the top
# of a file so that others can
# quickly see the dependencies for
# a module.

# foo.py
import os
import sys

def some_function():
    pass
...
```

LOCAL IMPORTS

```
# It is OCCASIONALLY useful to break
# this rule to have "optional"
# dependencies in a module. Be
# careful about this.

#-----
# Statistical Functions
#-----
def mean(a):
    ...

def std(a):
    ...

#-----
# Statistical Plot Functions
#-----
def histogram_plot(a):
    from pylab import plot
    ...
```

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Imports

GROUPING IMPORTS

```
# PEP-8
# Group imports in the following
# order:
# 1. Standard library imports
# 2. Related 3rd party imports
# 3. Application specific imports

import os
import sys

import wx

import pricing_models
```

LOCAL IMPORTS

```
# At Enthought, we expand the number
# of groupings and label them.
# 1. Standard library imports
# 2. Math/science libraries
# 3. Related 3rd party imports
# 4. Enthought specific libraries
# 5. Application specific imports

# Standard Imports
import os
import sys

# Math Imports
from numpy import array

# 3rd Party Imports
import wx

# Enthought Imports
from enthought.traits.api import Int

# Application Imports
import pricing_models
```

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Absolute Imports

USE ABSOLUTE IMPORTS

Example directory structure for Python libraries.

```
C:/  
    python_library/  
        package/  
            __init__.py  
            some_module.py  
            another_module.py  
        tests/  
            test_some_module.py  
            test_another_module.py
```

```
# PEP-8  
# Relative imports of intra-package  
# imports are highly discouraged.  
# Use absolute package path for  
# all imports.
```

```
# File: another_module.py  
  
# Recommended  
from package.some_module import func  
  
# Discouraged  
from some_module import func  
  
...
```

435

Avoid Extraneous White Space

INSIDE (), [], OR {}

```
# Yes  
spam(ham[1], {eggs: 2})
```

```
# No  
spam( ham[ 1 ], { eggs: 2 } )
```

BEFORE COMMAS AND COLONS

```
# Yes  
if x == 4:  
    print x, y
```

```
# No  
If x == 4 :  
    print x , y
```

FUNCTION CALLS

```
# Yes  
spam(1)
```

```
# No  
spam (1)
```

SLICING AND INDEXING

```
# Yes  
dict['key'] = list[index]
```

```
# No  
dict ['key'] = list [index]
```

AROUND ASSIGNMENT

```
# PEP-8 encourages the first
```

```
# Yes  
# No extra space  
x = 1  
y = 2  
long_variable = 3
```

```
# No  
# Align '=' character  
x           = 1  
y           = 2  
long_variable = 3
```

436

Whitespace

AROUND BINARY OPERATORS

```
# Binary operators are surrounded by
# a space on either side.
```

```
# Yes
if a > 1:
    b = 2 * (a + 1)
```

```
# No
if a> 1:
    b= 2 * (a+1)
```

FUNCTION ARGUMENTS

```
# Don't put spaces around '=' in
# keyword arguments.
```

```
# Yes
def quad(x, a=0, b=1, c=0):
    y = a * x**2 + b * x + c
    return y
```

```
# No
def quad(x, a = 0, b = 1, c = 0):
    y = a * x**2 + b * x + c
    return y
```

437

Compound Statements

COMPOUND STATEMENTS

```
# Compound statements are discouraged
```

```
# Yes
if foo == 'blah':
    do_something()
func1()
func2()
func3()
```

```
# No
if foo == 'blah': do_something()
func1(); func2(); func3();
```

438

Naming Conventions

VARIABLES

```
# Use lower_case notation without
# capital letters for variables in
# your functions, methods, and scripts.

# Yes
lower_case = 3

# No
CamelCase = 3
mixedCase = 3
Mixed_Case = 3
```

GLOBAL VARIABLES

```
# Use UPPER_CASE notation for
# module level "constants" or
# "static" class variables.

# File: foo.py

# Globals
# Yes
UPPER_CASE = 3

# No
CamelCase = 3
mixedCase = 3
Mixed_Case = 3

def some_function(a):
    result = a * UPPER_CASE
    return result
```

439

Naming Conventions

FUNCTIONS AND METHODS

```
# function and methods should use
# lower_case names with underscores.
# Do not use the Java convention of
# mixedCase.

# Yes
def some_function(a):
    pass

# No
def SomeFunction(a):
    pass

def someFunction(a):
    pass
```

CLASSES

```
# Class names are CamelCase.
# If there is one class in a file and
# class is named FooBar, the file is
# named foo_bar.

# file: foo_bar.py

# Yes
class FooBar(object):

    def some_method(self):
        pass

# No
class foo_bar(object):

    def some_method(self):
        pass
```

440

Naming Conventions

PRIVATE CLASSES AND FUNCTIONS

```
# Names of 'private' classes, methods  
# and functions start with a single  
# underscore.  
  
def _private_function(a):  
    pass  
  
def _PrivateClass(object):  
    pass
```

441

Naming Packages and Modules

MODULE NAMES

```
# Module names should be lower case  
# with underscores.  
  
# Yes  
foo_bar.py  
  
# No  
FooBar.py
```

PACKAGE NAMES

```
# Package directories should be all  
# lower case alpha-numeric characters.  
# Avoid underscores unless absolutely  
# necessary.  
  
# Yes  
packagename  
  
# No  
PackageName  
package_name
```

442

Using Future

Python can turn on planned features for future versions of Python that are backward incompatible. Here are several commonly used future features:

```
from __future__ import division, absolute_import, with_statement
```

- **division**

In “old” Python, `1/2` would become `0` because it used “integer” division. In Python 3.0, `1/2` will be `0.50`.

- **with_statement**

Enable the `with` statement found in Python 2.5 and beyond.

- **absolute_import**

Distinguish between absolute and relative module imports.

`import foo` imports from the top level of the module namespace.

`import .foo` imports from the same package as this module.

443

Using Future

All `future_statements` must appear near the top of the module. The only lines that can appear before a `future_statement` are:

The module docstring (if any).

Comments.

Blank lines.

Other `future_statements`.

FUTURE EXAMPLE

```
""" This is a module docstring.
"""

# This is a comment, preceded by a blank line and followed by
# a future_statement.
from __future__ import with_statement

from math import sin
from __future__ import division # compile-time error!
# ERROR because it is preceded by a non-future_statement.
```

444

Common Directory Structure

PACKAGE/MODULE/TESTS LAYOUT

Example directory structure for Python libraries.

C:/

```
python_library/
    yourpackage/
        __init__.py
        some_module.py
        another_module.py
        tests/
            test_some_module.py
            test_another_module.py
```

The tests for module have
are named similarly (test_
prefix) but live “one level
below” in a tests directory.

445

Functions and Refactoring Code

446

Evolution of a script

Useful software often starts its life as a script.

EXPLORATORY SCRIPT

```
# Read data files into some structure.
for file in files:
    ...
# Check for errors in data.
if data > bad_value:
    raise ValueError
...
# Execute one or more algorithms on the data.
important_number = data * 2 + blah...
...
# Create a report about the results.
print important_number
...
```

448

To A Function

Evolves to a function...

ONE MEGA-FUNCTION TO BIND THEM ALL

```
def display_data_report(files):
    # Read data files into some structure.
    for file in files:
        ...
    # Check for errors in data.
    if data > bad_value:
        raise ValueError
    ...
    # Execute one or more algorithms on the data.
    important_number = data * 2 + blah
    ...
    # Create a report about the results.
    print important_number
    ...
```

449

Evolution Stops

And Stops...

There are some short term benefits to this.

MEGA-FUNCTION BENEFITS

- Easy (quick) to create from original script.
- Easy to read and modify during construction.
 - All the code is “in one place.”
 - Access to all variables at any time.
(Global namespaces are nice that way.)
- Achieves some re-use.

450

Evolution to a library

Long term benefits come from continuing to “refactor” function until there is “one idea per function.”

LOW LEVEL FUNCTION LIBRARY

```
def data_from_files(files):
    # Read data files into a structure.
    for file in files:
        ...

def check_for_errors(data):
    # Check for errors in data.
    if data > bad_value:
        raise ValueError
    ...

def calc_important_number(data):
    # Execute one or more algorithms.
    important_number = data * 2
    ...

def create_report(data, calc_data):
    # Create a report about results.
    print important_number
    ...
```

DRIVER FUNCTIONS

```
def display_data_report(files):
    """
    "Driver" function that calls
    the low level library functions.
    """

    data = data_from_files(files)
    check_for_errors(data)
    res = calc_important_number(data)
    create_report(data, res)
```

451

“One Idea Per Function” Benefits

- Smaller, less complex snippets of code that are easier for others (and you) to read code in the future.
- Builds up a set of re-usable functions.
- Easier for others to modify behavior without modifying original code.
- Better Potential for Testing.

452

Avoid Duplicate Code

DUPLICATED CODE

```
instrument1_prices = lookup_price(instrument1, start_date, stop_date)
instrument1_price_avg = mean(instrument1_prices)
print_summary(instrument1, instrument1_prices, instrument1_price_avg)

instrument2_prices = lookup_price(instrument2, start_date, stop_date)
instrument2_price_avg = mean(instrument2_prices)
print_summary(instrument2, instrument2_prices, instrument2_price_avg)
```

REFACTOR TO USE A FUNCTION

```
# refactor code so duplicated lines are in a function.
def summarize_price_info(instrument, start_date, stop_date):
    instrument_prices = lookup_price(instrument, start_date, stop_date)
    instrument_price_avg = mean(instrument_prices)
    print_summary(instrument, instrument_prices, instrument_price_avg)

# Now call the function for the two different instruments.
summarize_price_info(instrument1, start_date, stop_date)
summarize_price_info(instrument2, start_date, stop_date)
```

453

Simplify Complex Conditionals

COMPLEX CONDITIONAL

```
if (    isinstance(float, value)
    and sqrt(value**2+other_value**2) > 21
    and value < 5):
    do_something_important(value)
```

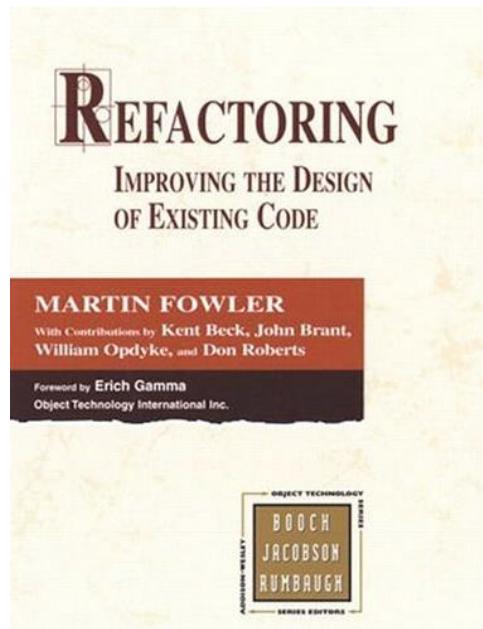
REFACTOR TO USE A FUNCTION

```
# Refactor code so the complex expression is in a function.
def is_important(value, other_value):
    important = isinstance(float, value) \
        and sqrt(value**2+other_value**2) > 21 \
        and value < 5
    return important

if is_important(value, other_value):
    do_something_important(value)
```

454

Useful Reference



455

Testing Code

456

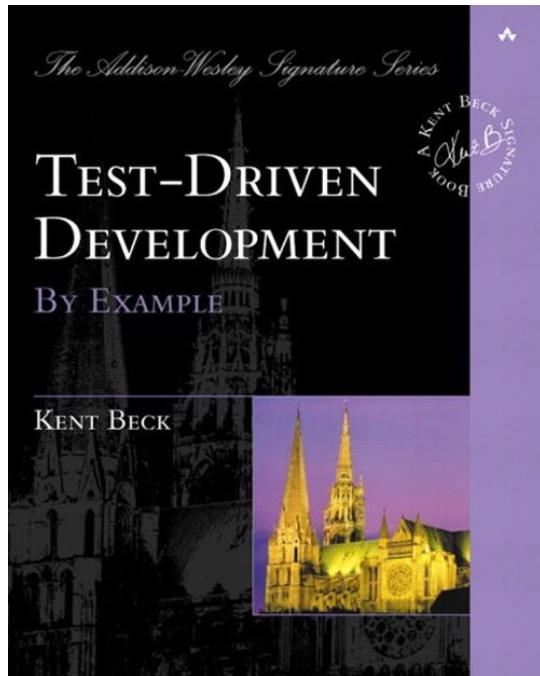
Test Driven Development

Overarching Concept:

Write Tests First.

458

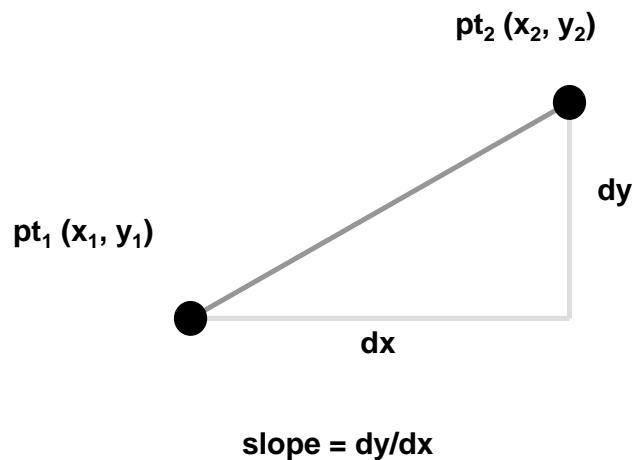
Useful Reference



459

Test Driven Development

PROBLEM DEFINITION



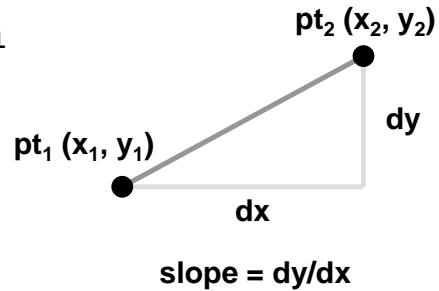
460

Test Driven Development

TEST

```
# test_fancy_math.py
from nose.tools import assert_almost_equal
from fancy_math import slope

def test_slope():
    pt1 = [0.0, 0.0]
    pt2 = [1.0, 2.0]
    s = slope(pt1, pt2)
    assert_almost_equal(s, 2)
```



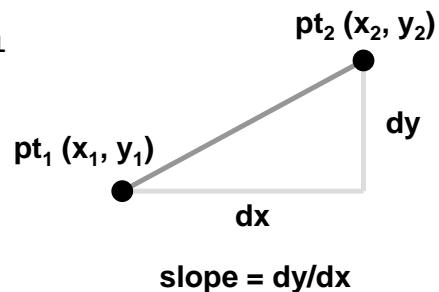
461

Test Driven Development

TEST

```
# test_fancy_math.py
from nose.tools import assert_almost_equal
from fancy_math import slope

def test_slope():
    pt1 = [0.0, 0.0]
    pt2 = [1.0, 2.0]
    s = slope(pt1, pt2)
    assert_almost_equal(s, 2)
```



FANCY_MATH

```
# Simplest function that passes, tests...
def slope(pt1, pt2):
    return 2
```

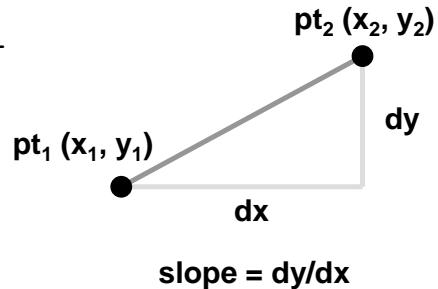
462

Test Driven Development

TEST

```
# test_fancy_math.py
from nose.tools import assert_almost_equal
from fancy_math import slope

def test_slope():
    pt1 = [0.0, 0.0]
    pt2 = [1.0, 2.0]
    s = slope(pt1, pt2)
    assert_almost_equal(s, 2)
```



FANCY_MATH

```
# Simplest function that passes, tests...
def slope(pt1, pt2):
    return 2
```

Smart Alec...

463

TDD Rationale

Build only the features you need.
(YAGNI Principle – you ain't gonna need it)

All the features are tested.

You are the first consumer of your API.
(Helps in design process)

464

Running NoseTests

FROM IPYTHON

```
In [27]: ls
Volume in drive W is Shared Folders
Volume Serial Number is 0000-0064

Directory of w:\...\slope

09/29/2008  11:41 PM    <DIR>          .
09/29/2008  11:30 PM    <DIR>          ..
09/29/2008  11:37 PM            123 fancy_math.py
09/29/2008  11:41 PM            195 test_fancy_math.py
2 File(s)
2 Dir(s)  48,067,092,480 bytes free

In [28]: !nosetests -v
test_fancy_math.test_slope ... ok

-----
Ran 1 test in 0.000s
```

OK 465

Using Unittest Framework

TESTS EMBEDDED IN CLASSES

```
# Test cases:
#   - each method is a unit test
#   - found by nosetests as well

from unittest import TestCase

from fancy_math import *

class TestModule(TestCase):

    def test_slope(self):
        pt1 = [0.0, 0.0]
        pt2 = [1.0, 2.0]
        s = slope(pt1, pt2)
        self.assertAlmostEqual(s, 2)
```

Doctests

TESTS EMBEDDED IN DOCSTRINGS

```
def factorial(n):
    """
    Return the product of all positive integers less than
    or equal to n.

    Example:
    >>> factorial(3)
    6
    >>> factorial(4)
    24
    """
    if n <= 1:
        result = 1
    else:
        result = n * factorial(n-1)
    return result

if __name__ == "__main__":
    import doctest
    doctest.testmod()
```

Optional

467

Monitoring execution

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The logging module

- Key part of good software craftsmanship
- Part of the standard library
- Structure of a logging system:
 1. Create a logger instance
 2. Add 1 or more handlers (console, file, http, ...)
 3. Set a level for these handlers or the logger
 4. [OPTIONAL] Control the formatting
 5. Add logger calls throughout the code

469

Simple Example

```
from logging import getLogger, FileHandler, StreamHandler

logger = getLogger() # Root logger
console_handler = StreamHandler()
logger.addHandler(console_handler)
file_handler = FileHandler("log.txt")
logger.addHandler(file_handler)

logger.debug("Debugging level message") # Hidden
logger.info("Informative level message") # Hidden
logger.warning("Warning level message")
Warning level message
logger.error("Error level message")
Error level message
```



More numerous

More critical

470

More complex example

```

from logging import getLogger, StreamHandler, DEBUG, INFO, WARNING, ERROR
from logging.handlers import RotatingFileHandler

logger = getLogger(__name__) # local file's logger
console_handler = logging.StreamHandler()
logger.addHandler(console_handler)
# File handler that is a rotating file
file_handler = RotatingFileHandler("log.txt", maxBytes=1024, backupCount=3)
formatter = logging.Formatter("%(levelname)s - %(asctime)s - %(name)s "
                             "- %(message)s")
file_handler.setFormatter(formatter)
logger.addHandler(file_handler)
logger.setLevel(DEBUG)      # highly sensitive logger

logger.debug("Debugging level message")
DEBUG - 2012-10-16 23:08:03,592 - package.analysis_module - Debugging level
message

```

471

Ways to time execution

Timing inside the code (**Good**)

- the time module from std lib

Timing in ipython (**Better**):

- %timeit “magic command”
- -t option of ‘run’ (optionally –N also)

Profiling the code (**Best**):

- cProfile or line_profiler package

472

Timing in python

USE TIME PACKAGE

```

import time
from numpy.random import randn
from numpy import linspace, pi, exp, sin
from scipy.optimize import leastsq

def func(x,A,a,f,phi):
    return A*exp(-a*sin(f*x+phi))

def errfunc(params, x, data):
    return func(x, *params) - data

start = time.time()
params0 = [1,1,1,1]
x = linspace(0,2*pi,25)
ptrue = [3,2,1,pi/4]
true = func(x, *ptrue)
noisy = true + 0.3*randn(len(x))
pmin,ierr = leastsq(errfunc, params0,
                     args=(x, noisy))
print "Total: %f s" %(time.time()-start)

```

USE IPYTHON TOOLS

```

# For a script
>>> run -t [-N10] test.py
IPython CPU timings (estimated):
  User : 1.10 s.
  System : 0.00 s.
Wall time: 1.11 s.

# For a function call
>>> import random as rand
>>> import numpy.random as \
nprand
>>> %timeit rand.randint(0,10)
100000 loops, best of 3: 2.02 us
per loop
>>> %timeit nprand.randint(10)
10000000 loops, best of 3: 178 ns
per loop

```

473

Timing and Profiling Code

Ways to time execution

Timing inside the code (**Good**)

- the time module from std lib

Timing in ipython (**Better**):

- %timeit “magic command”
- -t option of ‘run’ (optionally –N also)

Profiling the code (**Best**):

- cProfile or line_profiler package

475

Timing in python

USE TIME PACKAGE

```
import time
from numpy.random import randn
from numpy import linspace, pi, exp, sin
from scipy.optimize import leastsq

def func(x,A,a,f,phi):
    return A*exp(-a*sin(f*x+phi))

def errfunc(params, x, data):
    return func(x, *params) - data

start = time.time()
params0 = [1,1,1,1]
x = linspace(0,2*pi,25)
ptrue = [3,2,1,pi/4]
true = func(x, *ptrue)
noisy = true + 0.3*randn(len(x))
pmin,ierr = leastsq(errfunc, params0,
                     args=(x, noisy))
print "Total: %f s" %(time.time()-start)
```

USE IPYTHON TOOLS

```
# For a script
>>> run -t [-N10] test.py
IPython CPU timings (estimated):
  User      :      1.10 s.
  System   :      0.00 s.
Wall time:      1.11 s.

# For a function call
>>> import random as rand
>>> import numpy.random as \
nprand
>>> %timeit rand.randint(0,10)
100000 loops, best of 3: 2.02 us
per loop
>>> %timeit nprand.randint(10)
10000000 loops, best of 3: 178 ns
per loop
```

476

Profiling with cProfile

`cProfile` (and its pure python version, `profile`) are profiling tools in the standard library.

WORKFLOW

The `cProfile` workflow has two main steps:

1. Run the code to be profiled via the `cProfile`'s `run()` (or `runcode()`) function or using the `kernprof.py` script. This counts and times function calls, and generates a profiling dataset.
1. Process and display the profile data. In the simplest case (e.g. `cProfile.run('foo()')`), a predefined report is generated and printed. For finer control, you can save the raw data to a file and process it using the `pstats` module.

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Profiling with kernprof.py

From the command line (if the `line_profiler` package is installed):

```
$ kernprof.py datafit.py
Wrote profile results to datafit.py.prof

$ python -m pstats
Welcome to the profile statistics browser.

% read datafit.py.prof
datafit.py.prof% strip
datafit.py.prof% sort time
datafit.py.prof% stats 20
(...)

  ncalls  tottime  percall  cumtime  percall
filename:lineno(function)
      1    0.299    0.299    0.363    0.363  _core.py:4 (<module>)
      1    0.130    0.130    0.635    0.635  mpl.py:1 (<module>)
      1    0.115    0.115    0.482    0.482  __init__.py:14 (<module>)
     12    0.114    0.009    0.415    0.035  __init__.py:1 (<module>)
(...)
```

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Profiling from iPython

EXAMPLE

```
>>> import time
>>> def func(n):
...     if n < 0:
...         return
...     time.sleep(0.1*n)
...     func(n-1)
...     return
...
>>> import cProfile
>>> cProfile.run('func(3)')
    11 function calls (7 primitive calls) in 0.601 seconds

Ordered by: standard name

      ncalls  tottime  percall  cumtime  percall filename:lineno(function)
          5/1    0.000    0.000    0.601    0.601 <stdin>:1(func)
             1    0.000    0.000    0.601    0.601 <string>:1(<module>)
             1    0.000    0.000    0.000    0.000 {method 'disable' of ...
             4    0.600    0.150    0.600    0.150 {time.sleep}
```

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Profiling with cProfile

OUTPUT TABLE COLUMNS

- ncalls** The number of calls. Counts of the form N/M indicate N actual calls (including recursive calls), and M 'primitive' (nonrecursive) calls.
- tottime** The total time spent in the given function (and excluding time made in calls to sub-functions).
- percall** The quotient of **tottime** divided by **ncalls**.
- cumtime** The total time spent in this and all subfunctions (from invocation until exit). This figure is accurate even for recursive functions.
- percall** The quotient of **cumtime** divided by primitive calls.
- filename:lineno(function)** Provides the respective data of each function.

480

Profiling with cProfile

USE PSTATS TO CONTROL THE TABLE

```
# Save the raw profile data to a file.
>>> cProfile.run('func(3)', filename='func.prof')
# Use pstats.Stats to manipulate the data.
>>> import pstats
>>> stats = pstats.Stats('func.prof')
# Clean up the filenames.
>>> stats.strip_dirs()
<pstats.Stats instance at 0xdbda0>
# Sort by the cumulative time.
>>> stats.sort_stats('cumulative')
<pstats.Stats instance at 0xdbda0>
# Print the table.
>>> stats.print_stats()
```

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Profiling with cProfile

USE PSTATS TO CONTROL THE TABLE - CONTINUED

```
Wed May 4 14:56:13 2011      func.prof
```

```
11 function calls (7 primitive calls) in 0.600 seconds
```

```
Ordered by: cumulative time
```

| | ncalls | tottime | percall | cumtime | percall |
|--|---------------------------|---------|---------|---------|---------------------------------|
| | filename:lineno(function) | | | | |
| | 1 | 0.000 | 0.000 | 0.600 | 0.600 <string>:1(<module>) |
| | 5/1 | 0.000 | 0.000 | 0.600 | 0.600 <stdin>:1(func) |
| | 4 | 0.600 | 0.150 | 0.600 | 0.150 {time.sleep} |
| | 1 | 0.000 | 0.000 | 0.000 | 0.000 {method 'disable' of ...} |

```
<pstats.Stats instance at 0xdbda0>
```

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Profiling with cProfile

MORE OUTPUT CONTROL

Arguments to `Stats.sort_stats(...)`

| Valid Argument | Meaning |
|----------------|----------------------|
| 'calls' | call count |
| 'cumulative' | cumulative time |
| 'file' | file name |
| 'module' | file name |
| 'pcalls' | primitive call count |
| 'line' | line number |
| 'name' | function name |
| 'nfl' | name/file/line |
| 'stdname' | standard name |
| 'time' | internal time |

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Profiling with cProfile

MORE OUTPUT CONTROL

Arguments to `Stats.print_stats([restriction, ...])` allow to filter the output:

Each restriction is either:

- an *integer* to select the number of lines to output;
- a *decimal fraction* between 0.0 and 1.0 to select a percentage of lines; or
- a *regular expression* to match the filename.

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Profiling with cProfile

A FEW USEFUL OUTPUT CASES

```
# Find out what is taking the most time:  
>>> stats.sort_stats('cumulative').print_stats(10)  
  
# Find functions in which the program is spending the  
# the most time (not including calls to other functions):  
>>> stats.sort_stats('time').print_stats(10)  
  
# Check how often __init__ is called in all the modules  
# (sorted by name):  
>>> stats.sort_stats('file').print_stats('__init__')
```

485

Profiling with cProfile

MORE DOCUMENTATION

Python standard library documentation:

- <http://docs.python.org/library/profile.html>

Doug Hellman's "Python Module of the Week" blog:

- <http://blog.doughellmann.com/2008/08/pymotw-profile-cprofile-pstats.html>

486

line_profiler and kernprof

`line_profiler` and `kernprof` are profiling tools developed by Robert Kern.

- `line_profiler` is a module for doing line-by-line profiling of functions.
- `kernprof` is a convenient script for running either `line_profiler` or the standard library's `cProfile` module.

INSTALLATION

```
$ easy_install line_profiler
```

TYPICAL WORKFLOW

1. Decorate the functions to be profiled with `@profile`.
2. Run your script using `kernprof.py` with the `-l` option. For example,


```
$ kernprof.py -l script_to_profile.py
```
3. Run the `line_profiler` module to display the results. For example,


```
$ python -m line_profiler script_to_profile.py.lprof
```
4. Adjust your code, and repeat steps 2-4.
5. Remove the `@profile` decorators.

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line_profiler example

http_search.py

```
import re

PATTERN = r"https?:\/\/[^\w\-\_]+(\.\[^\w\-\_]+\)+([\w\-
\.,@?^=%&:/~\+\#]*[\w\-\@?^=%&:/~\+\#])?"
```

```
@profile
def scan_for_http(f):
    addresses = []
    for line in f:
        result = re.search(PATTERN, line)
        if result:
            addresses.append(result.group(0))
    return addresses

if __name__ == "__main__":
    import sys
    f = open(sys.argv[1], 'r')
    addresses = scan_for_http(f)
    for address in addresses:
        print address
```



See demo/profiling directory
for code.

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line_profiler example

Run kernprof.py and line_profiler

```
$ kernprof.py -l http_search.py sample.html
...
http://sphinx.pocoo.org/
Wrote profile results to http_search.py.lprof

$ python -m line_profiler http_search.py.lprof

Timer unit: 1e-06 s

File: http_search.py
Function: scan_for_http at line 6
Total time: 0.016079 s

Line #      Hits          Time  Per Hit   % Time  Line Contents
=====
6           1           3     3.0     0.0    @profile
7                           def scan_for_http(f):
8           1           3     3.0     0.0        addresses = []
9       1350      2080    1.5    12.9        for line in f:
10      1349      12417    9.2    77.2            result = re.search(PATTERN, line)
11      1349      1513    1.1     9.4            if result:
12         39          65    1.7     0.4                addresses.append(result.group(0))
13         1           1     1.0     0.0            return addresses
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```

line_profiler example

http_search2.py

```
import re

PATTERN = r"https?:\/\/[^\w\-\_]+(\.[^\w\-\_]+)+([\w\-
\.,@?^=%&:/~\+]*[\w\-\@?^=%&:/~\+])?"
```

```
@profile
def scan_for_http(f):
    addresses = []
    pat = re.compile(PATTERN)
    for line in f:
        result = pat.search(line)
        if result:
            addresses.append(result.group(0))
    return addresses

if __name__ == "__main__":
    import sys
    f = open(sys.argv[1], 'r')
    addresses = scan_for_http(f)
    for address in addresses:
        print address
```

line_profiler example

Run kernprof.py and line_profiler on the modified file

```
$ kernprof.py -l http_search2.py sample.html
...
Wrote profile results to http_search2.py.lprof
$ python -m line_profiler http_search2.py.lprof

Timer unit: 1e-06 s

File: http_search2.py
Function: scan_for_http at line 6
Total time: 0.00911 s

Line #      Hits         Time  Per Hit   % Time  Line Contents
=====
    6                               @profile
    7                               def scan_for_http(f):
    8           1             3     3.0     0.0     addresses = []
    9           1        3117  3117.0    34.2     pat = re.compile(PATTERN)
   10      1350       1995     1.5    21.9     for line in f:
   11      1349       2507     1.9    27.5     result = pat.search(line)
   12      1349       1415     1.0    15.5     if result:
   13       39          72     1.8     0.8     addresses.append(result.group(0))
   14           1          1     1.0     0.0     return addresses
```

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pdb
The Python debugger

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What is pdb?

pdb is part of the standard library

pdb, like Python, is interactive and interpreted,
allowing for the execution of arbitrary Python
code in the context of any stack frame

pdb can debug a “post-mortem” condition, and
can also be called under program control

ipdb (not in std lib) is similar but includes tab
completion

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Starting pdb

- Run the script from the **command line** under debugger control

```
C:\> python -m pdb script.py [arg ...]
```

- During an **iPython session**, here are some of the common pdb functions used for debugging :

```
>>> pdb.run( statement )
```

Execute the statement (given as a string) under debugger control

```
>>> pdb.runcall( function[, argument, ...] )
```

Call the function (not a string) with the given arguments under debugger control

```
>>> pdb.pm()
```

Start the debugger at the point of the last exception

- Inside **a script** or a module to hard-code a breakpoint

```
import pdb ; pdb.set_trace()
```

- Useful for hard-coding a breakpoint in a program even if code is not being debugged (analyzing a failed assertion, etc.)

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pdb commands

- *pdb* runs as an interactive session having a specific set of commands
- Some of the more common *pdb* commands:

(Pdb) h(help)[command]

One of the most important! Lists all the commands available, or help on a specific command

(Pdb) u(p) / d(own)

Pop up or push down the execution stack

(Pdb) b(reak)[[filename:]lineno | function[, condition]]

Set a breakpoint at a specific file/line or function and optionally if a specific condition is met. If no args are given, list all the breakpoints & their numbers

(Pdb) s(tep) / n(ext)

Execute the current line only. **step** will push into a function call and **next** will execute the function call and move to the next statement in the current function

(Pdb) a(rgs)

Print the args for the current function

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pdb commands

(Pdb) l(ist) [first[, last]]

List the source code at the point of execution. Args **first** and **last** set a range for the number of lines printed. No args prints 11 lines around the current line, if only **first**, prints 11 lines around that line.

(Pdb) j(ump) lineno

Jump to a line in the bottom-most frame only and execute from there. Not all jumps are possible!

(Pdb) p / pp [expression]

Print or “pretty print” **expression** in the context of the current frame

(Pdb) a(lias) [name [command]]

Create an alias for **command** named **name**, or list all aliases.

Here are two useful aliases (especially when placed in a .pdbrc file):

```
#print all instance variables (usage "pi classInst")
alias pi for k in %1.__dict__.keys(): print "%1.",k,"=",%1.__dict__[k]
#print instance variables in self
alias ps pi self
```

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iPython and pdb

```
# ipython can call pdb automatically upon error

In [1]: pdb
Automatic pdb calling has been turned ON
In [2]: import middle
In [3]: middle.run()

-----
IndexError                                     Traceback (most recent call last)
Z:\projects\Training\pdb\<console>

Z:\projects\Training\pdb\middle.py in run()
    31     """
    32     for i in range( 1, 11 ) :
    33         l = make_list( i )
--> 34         print "The middle item(s) in %s\n\tis/are %s\n" % (l, get_middle( l ))
    35

Z:\projects\Training\pdb\middle.py in get_middle(item_list)
    9
   10     if( num_items % 2 ) :
--> 11         return item_list[half]
   12
   13     return item_list[(half - 1):(half + 1)]

IndexError: list index out of range
> Z:\projects\training\pdb\middle.py(11) get_middle()
-> return item_list[half]
```

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Example session

DEBUGGING FROM ORIGIN OF EXCEPTION

```
ipdb> 1
      -----
      num_items = len( item_list )
      half = num_items * 2
      9
      10    if( num_items % 2 ) :
--> 11        return item_list[half]
      12
      13    return item_list[(half - 1):(half + 1)]
      14
      15
      16    def make_list( size=0 ) :
```

Print the source code around the line which raised the exception


```
ipdb> item_list
['0']
ipdb> half
2
ipdb> c
```

Print the contents of the list

Print the value of the index ah-ha!

In [4]:

Return to ipython



Test this with `middle.py` in Demos/pdb

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Example session

DEBUGGING MIDDLE.PY FROM THE START

```
>>> import pdb
>>> import middle
>>> pdb.runcall( middle.run )
> z:\projects\pgtraining\pdb\middle.py(32) run()
-> for i in range( 1, 11 ) :
(Pdb) s
> z:\projects\pgtraining\pdb\middle.py(33) run()
-> l = make_list( i )
(Pdb) n
> z:\projects\pgtraining\pdb\middle.py(34) run()
-> print "The middle item(s) in %s\n\tis/are %s\n" % (l, get_middle( 1 ))
(Pdb) s
--Call--
> z:\projects\pgtraining\pdb\middle.py(2) get_middle()
-> def get_middle( item_list ) :
(Pdb) s
...
> z:\projects\pgtraining\pdb\middle.py(11) get_middle()
-> return item_list[half]
(Pdb) item_list
['0']
(Pdb) half
2
```

We know make_list is ok, so skip over it with “next”

Continue to execute lines until we see something suspicious

Print the contents of the list

Print the value of the index ah-ha!

Debugging exercise

In Demos/ directory, file_sum.py contains a class which computes the sum of every number in a file.

file_sum.py has 2 bugs.

Once fixed, the script runs like this:

```
C:\> python file_sum.py dir.dat
The sum of all numbers in dir.dat is 4355
```

Other debugging tools

- ipdb (not in std lib) offers the same functionalities as pdb (set_trace allowing to march through execution) but allow more interactive exploration thanks to the tab completion like in ipython. BUT still only allow 1 line evaluations.
- To do more exploration at a given point in an application, IPython can be invoked, with its embed function:

```
from IPython import embed ; embed()
```

It starts a normal ipython session with the namespace populated from the namespace of your application at the break point. To exit. `ctrl-d`.

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Python and Other Languages: An Overview

Why use another language with Python?

- **Best of both worlds:** Tested and optimized legacy code + flexibility of Python
- **Python as glue:** Combine several components into one larger program
- **Speedup Python:** Speed up performance critical components with a faster language
- **Division of labor:** Let Fortran be an array processing DSL, let Python and its ecosystem handle automatic testing, file IO, text processing, data munging, GUI integration, HTTP serving, etc.

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External language toolkit

Wrapping legacy code and external libraries:

- Wrap with **hand-written extension module**
- **Cython** wrap C/C++ with custom interface
- **SWIG** Automatically wrap large C/C++ libraries
- **f2py** Automatically wrap Fortran libraries
- **ctypes** Easy to manually wrap external libraries

Speed up Python code:

- **Hand-written extension module**
- **Cython** Add type information to Python
- **Weave** Speed up NumPy array expressions
- Shedskin and others not covered here

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Wrapping and Levels of Granularity

Coarse-grained:

- Python communicates with external program via config files and command line interface using **subprocess**

Medium-grained:

- In external program, create a handful of functions that are designed to be wrapped with Python
- Wrap a select few pieces of external program and customize the interface

Fine-grained:

- Wrap *everything* using automatic tool like SWIG or f2py.
- Expose the entire library and its API to Python.

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Hand Wrapping C/C++

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The Wrapper Function

fact.h

```
#ifndef FACT_H
#define FACT_H
int fact(int n);
#endif
```

fact.c

```
#include "fact.h"
int fact(int n)
{
    if (n <=1) return 1;
    else return n*fact(n-1);
}
```

WRAPPER FUNCTION

```
static PyObject* wrap_fact(PyObject *self, PyObject *args)
{
    /* Python-C data conversion */
    int n, result;
    if (!PyArg_ParseTuple(args, "i", &n))
        return NULL;
    /* C Function Call */
    result = fact(n);
    /* C->Python data conversion */
    return Py_BuildValue("i", result);
}
```

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Complete Example

```
/* Must include Python.h before any standard headers! */
#include "Python.h"
#include "fact.h"

/* Define the wrapper functions exposed to Python (must be static) */
static PyObject* wrap_fact(PyObject *self, PyObject *args) {
    int n, result;
    /* Python->C Conversion */
    if (!PyArg_ParseTuple(args, "i", &n))
        return NULL;
    /* Call our function */
    result = fact(n);
    /* C->Python Conversion */
    return Py_BuildValue("i", result);
}
/* Method table declaring the names of functions exposed to Python */
static PyMethodDef ExampleMethods[] = {
    {"fact", wrap_fact, METH_VARARGS, "Calculate the factorial of n"},
    {NULL, NULL, 0, NULL}      /* Sentinel */
};
/* Module initialization function called at "import example" */
PyMODINIT_FUNC initexample(void) {
    (void) Py_InitModule("example", ExampleMethods); }
```

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Compiling/using your extension

BUILD DYNAMIC LIB BY HAND (EPD ON WINDOWS)

```
C:\...\> gcc -c fact.c fact_wrap.c -I. -Ic:\python27\include
C:\...\> gcc -shared fact.o fact_wrap.o -Lc:\python27\libs
                           -lpython27 -o example.pyd
```

BUILD BY HAND (UNIX)

```
~\...\> gcc -c -fPIC fact.c fact_wrap.c -I. -I/usr/include/python2.7
~\...\> gcc -shared fact.o fact_wrap.o -L/usr/lib/python2.7/config
                           -lpython2.7 -o example.so
```

USING THE MODULE IN PYTHON

```
In [1]: import example
In [2]: dir(example)
Out[2]: ['__doc__', '__file__', '__name__', '__package__', 'fact']
```



Note that the include and library directories are platform specific. Also, be sure to link against the appropriate version of Python (2.7 in these examples).

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Building using setup.py

SETUP.PY

```
# setup.py files are the Python equivalent of Make
from distutils.core import setup, Extension

ext = Extension(name='example', sources=['fact_wrap.c', 'fact.c'])

setup(name="example", ext_modules=[ext])
```

CALLING SETUP SCRIPTS

```
# Build and install the module.
$ setup.py build
$ setup.py install

# Or build the module "in-place" to ease testing.
$ setup.py build_ext --inplace --compiler=mingw32

* Blue text needed only on windows.
```

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More details

More details on the wrapping functions (C <-> Python) :
<http://docs.python.org/extending>

More details on writing a setup.py file to incorporate extension modules:

<http://docs.python.org/extending/building.html>

Using NumPy arrays in hand-wrapped C code:

<http://docs.scipy.org/doc/numpy/reference/c-api.html>

... and a simple example: demo/hand_wrap_ndarray/

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Cython

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What is Cython?

Cython is a Python-like language for writing extension modules. It allows one to mix Python with C or C++ and significantly lowers the barrier to speeding up Python code.

The **cython** command generates a C or C++ source file from a Cython source file; the C/C++ source is then compiled into a heavily optimized extension module.

Cython has built-in support for working with NumPy arrays and Python buffers, making numerical programming nearly as fast as C and (nearly) as easy as Python.

<http://www.cython.org/>

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A really simple example

PI.PYX

```
# Define a function. Include type information for the argument.
def multiply_by_pi(int num):
    return num * 3.14159265359
```

SETUP_PI.PY

```
# Cython has its own "extension builder" module that knows how
# to build cython files into python modules.
from distutils.core import setup
from distutils.extension import Extension
from Cython.Distutils import build_ext

ext = Extension("pi", sources=["pi.pyx"])

setup(ext_modules=[ext],
      cmdclass={'build_ext': build_ext})
```



See demo/cython for this example.
Build it using build.bat.

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A simple Cython example

CALLING MULTIPLY_BY_PI FROM PYTHON

```
$ python setup_pi.py build_ext --inplace -c mingw32

>>> import pi
>>> pi.multiply_by_pi()
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
TypeError: function takes exactly 1 argument (0 given)
>>> pi.multiply_by_pi("dsa")
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
TypeError: an integer is required
>>> pi.multiply_by_pi(3)
9.4247779607700011
```

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(some of) the generated code

C CODE GENERATED BY CYTHON

```
static PyObject *_pyx_f_2pi_multiply_by_pi(PyObject *__pyx_self,
PyObject *__pyx_args, PyObject *__pyx_kwds); /*proto*/
static PyObject *_pyx_f_2pi_multiply_by_pi(PyObject *__pyx_self,
PyObject *__pyx_args, PyObject *__pyx_kwds) {
    int __pyx_v_num;
    PyObject *__pyx_r;
    PyObject *__pyx_1 = 0;
    static char *__pyx_argnames[] = {"num",0};
    if (!PyArg_ParseTupleAndKeywords(__pyx_args, __pyx_kwds, "i",
__pyx_argnames,
&__pyx_v_num)) return 0;

    /* "C:\pi.pyx":2 */
    __pyx_1 = PyFloat_FromDouble((__pyx_v_num * 3.14159265359));
    if (!__pyx_1) {
        __pyx_filename = __pyx_f[0]; __pyx_lineno = 2; goto __pyx_L1;
    }
    __pyx_r = __pyx_1;
    __pyx_1 = 0;
```

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Def vs. CDef

DEF — PYTHON FUNCTIONS

```
# Python callable function.
def inc(int num, int offset):
    return num + offset

# Call inc for values in sequence.
def inc_seq(seq, offset):
    result = []
    for val in seq:
        res = inc(val, offset)
        result.append(res)
    return result
```

INC FROM PYTHON

```
# inc is callable from Python.
>>> inc.inc(1,3)
4
>>> a = range(4)
>>> inc.inc_seq(a, 3)
[3,4,5,6]
```

CDEF — C FUNCTIONS

```
# cdef becomes a C function call.
cdef int fast_inc(int num,
                  int offset):
    return num + offset

# fast_inc for a sequence
def fast_inc_seq(seq, offset):
    result = []
    for val in seq:
        res = fast_inc(val, offset)
        result.append(res)
    return result
```

FAST_INC FROM PYTHON

```
# fast_inc not callable in Python
>>> inc.fast_inc(1,3)
Traceback: ... no 'fast_inc'
# But fast_inc_seq is 2x faster
# for large arrays.
>>> inc.fast_inc_seq(a, 3)
[3,4,5,6]
```

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CPdef: combines def + cdef

CPDEF — C AND PYTHON FUNCTIONS

```
# cdef becomes a C function call.
cpdef fast_inc(int num, int offset):
    return num + offset

# Calls compiled version inside Cython file
def inc_seq(seq, offset):
    result = []
    for val in seq:
        res = fast_inc(val, offset)
        result.append(res)
    return result
```

FAST_INC FROM PYTHON

```
# fast_inc is now callable in Python via Python wrapper
>>> inc.fast_inc(1,3)
4
# No speed degradation here
>>> inc.inc_seq(a, 3)
[3,4,5,6]
```

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Functions from C Libraries

EXTERNAL C FUNCTIONS

```
# len_extern.pyx
# First, "include" the header file you need.
cdef extern from "string.h":
    # Describe the interface for the functions used.
    cdef extern int strlen(char *c)

def get_len(char *message):
    # strlen can now be used from Cython code (but not Python)...
    return strlen(message)
```

CALL FROM PYTHON

```
>>> import len_extern
>>> len_extern.strlen
Traceback (most recent call last):
AttributeError: 'module' object has no attribute 'strlen'
>>> len_extern.get_len("woohoo!")
7
```

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Structures from C Libraries

TIME_EXTERN.PYX

```
cdef extern from "time.h":
    # Describe the structure you are using.
    struct tm:
        ...
        int tm_mday # Day of the month: 1-31
        int tm_mon # Months *since* january: 0-11
        int tm_year # Years since 1900
        ...
    ctypedef long time_t
    tm* localtime(time_t *timer)
    time_t time(time_t *tloc)

def get_date():
    """ Return a tuple with the current day, month, and year."""
    cdef time_t t
    cdef tm* ts
    t = time(NULL)
    ts = localtime(&t)
    return ts.tm_mday, ts.tm_mon + 1, ts.tm_year
```

CALLING FROM PYTHON

```
>>> extern_time.get_date()
(8, 4, 2011)
```

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Classes

SHRUBBERY.PYX

```
cdef class Shrubbery:
    # Class level variables
    cdef int width, height

    def __init__(self, w, h):
        self.width = w
        self.height = h
    def describe(self):
        print "This shrubbery is",self.width,"by ",self.height," cubits."
```

CALLING FROM PYTHON

```
>>> import shrubbery
>>> x = shrubbery.Shrubbery(1, 2)
>>> x.describe()
This shrubbery is 1 by 2 cubits.
>>> print x.width
AttributeError: 'shrubbery.Shrubbery' object has no attribute 'width'521
```

Classes from C++ libraries

rectangle_extern.h

```
class Rectangle {
public:
    int x0, y0, x1, y1;
    Rectangle(int x0, int y0, int x1, int y1);
    ~Rectangle();
    int getLength();
    int getHeight();
    int getArea();
    void move(int dx, int dy);};
```



The implementation of the class and methods is done inside rectangle_extern.cpp.
See demo/cython for this example.

Classes from C++ libraries

rectangle.pyx

```
cdef extern from "rectangle_extern.h":
    cdef cppclass Rectangle:
        Rectangle(int, int, int, int)
        int x0, y0, x1, y1
        int getLength()
        int getHeight()
        int getArea()
        void move(int, int)

    cdef class PyRectangle:
        cdef Rectangle *thisptr      # hold a C++ instance which we're wrapping
        def __cinit__(self, int x0, int y0, int x1, int y1):
            self.thisptr = new Rectangle(x0, y0, x1, y1)
        def __dealloc__(self):
            del self.thisptr
        def getLength(self):
            return self.thisptr.getLength()
```

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Classes from C++ libraries

SETUP.PY

```
from distutils.core import setup
from Cython.Distutils import build_ext
from distutils.extension import Extension
setup(
    ext_modules=[Extension("rectangle", sources = ["rectangle.pyx",
                                                    "rectangle_extern.cpp"],
                           language = "c++")],
    cmdclass = {'build_ext': build_ext})
```

CALLING FROM PYTHON

```
In [1]: import rectangle
In [2]: r = rectangle.PyRectangle(1,1,2,2)  # calls __cinit__
In [3]: r.getLength()
Out[3]: 1
In [4]: r.getHeight()
AttributeError:rectangle.PyRectangle object has no attribute getHeight
In [5]: del r  # calls __dealloc__
```

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Using NumPy with Cython

```
#cython: boundscheck=False
# Import the numpy cython module shipped with Cython.
cimport numpy as np
ctypedef np.float64_t DOUBLE

def sum(np.ndarray[DOUBLE] ary):
    # How long is the array in the first dimension?
    cdef int n = ary.shape[0]
    # Define local variables used in calculations.
    cdef unsigned int i
    cdef double sum
    # Sum algorithm implementation.
    sum = 0.0
    for i in range(0, n):
        sum = sum + ary[i]
    return sum
```

```
C:\demo\cython>test_sum.py
elements: 1,000,000
python sum(approx sec, result): 7.030
numpy sum(sec, result): 0.047
cython sum(sec, result): 0.047
```

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Problem: Make This Fast!

```
def mandelbrot_escape(x, y, n):
    z_x = x
    z_y = y
    for i in range(n):
        z_x, z_y = z_x**2 - z_y**2 + x, 2*z_x*z_y + y
        if z_x**2 + z_y**2 >= 4.0:
            break
    else:
        i = -1
    return i

def generate_mandelbrot(xs, ys, n):
    d = empty(shape=(len(ys), len(xs)))
    for j in range(len(ys)):
        for i in range(len(xs)):
            d[j,i] = mandelbrot_escape(xs[i], ys[j], n)
    return d
```

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Step 1: Add Type Information

Type information can be added to function signatures:

```
def mandelbrot_escape(double x, double y, int n):  
    ...  
  
def generate_mandelbrot(xs, ys, int n):  
    ...
```

Variables can be declared to have a type using 'cdef':

```
def generate_mandelbrot(xs, ys, int n):  
    cdef int i,j  
    cdef int N = len(xs)  
    cdef int M = len(ys)  
    ...
```

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Step 2: Use Cython C Functions

In Cython you can declare functions to be C functions using 'cdef' instead of 'def':

```
cdef int mandelbrot_escape(float x, float y, int n):  
    ...
```

This makes the functions:

Generate actual C functions, so they are much faster.

Not visible to Python, but freely usable in your Cython module.

Arbitrary Python objects can still be passed in and out of C functions using the 'object' type.

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Solution 2: This is Fast!

```
cdef int mandelbrot_escape(double x, double y, int n):
    cdef double z_x = x
    cdef double z_y = y
    cdef int i
    for i in range(n):
        z_x, z_y = z_x**2 - z_y**2 + x, 2*z_x*z_y + y
        if z_x**2 + z_y**2 >= 4.0:
            break
    else:
        i = -1
    return i

def generate_mandelbrot(xs, ys, int n):
    cdef int i,j
    cdef int N = len(xs)
    cdef int M = len(ys)
    d = empty(dtype=int, shape=(N, M))
    for j in range(M):
        for i in range(N):
            d[j,i] = mandelbrot_escape(xs[i], ys[j], n)
    return d
```

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Step 3: Use NumPy in Cython

In our example, we are still using Python-level numpy calls to do our array indexing:

```
d[j,i] = mandelbrot_escape(xs[i], ys[j], n)
```

If we use the Cython interface to NumPy, we can declare our arrays to be C-level numpy extension types, and gain even more speed.

NumPy arrays are declared using a special buffer notation:

```
cimport numpy as np
...
cdef np.ndarray[int, ndim=2] my_array
```

You must declare both the type of the array, and the number of dimensions. All the standard numpy types are declared in the numpy cython declarations.

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Solution 3: This is *Really* Fast!

mandel.pyx

```
cimport numpy as np
...
def generate_mandelbrot(np.ndarray[double, ndim=1] xs,
                       np.ndarray[double, ndim=1] ys, int n):
    cdef int i,j
    cdef int N = len(xs)
    cdef int M = len(ys)
    cdef np.ndarray[int, ndim=2] d = empty(dtype=int, shape=(N, M))
    for j in range(M):
        for i in range(N):
            d[j,i] = mandelbrot_escape(xs[i], ys[j], n)
    return d
```

setup.py

```
...
import numpy
...
ext = Extension("mandel", ["mandel.pyx"],
                 include_dirs = [numpy.get_include()])
```

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Step 4: Parallelization using OpenMP

Cython supports native parallelism. To use this kind of parallelism, the Global Interpreter Lock (GIL) must be released. It currently supports OpenMP (more backends might be supported in the future).

- 1) Release the GIL before a block of code:

```
with nogil:
    # This block of code is executed after releasing the GIL
```

- 2) Declare that a cdef function can be called safely without the GIL:

```
cdef int mandelbrot_escape(double x, double y, int n) nogil:
    ...
```

- 3) Parallelize for-loops with prange:

```
from cython.parallel import prange
...
for j in prange(M):
    for i in prange(N):
        d[j,i] = mandelbrot_escape(xs[i], ys[j], n)
```

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Solution 4: Even faster!

mandel.pyx

```
from cython.parallel import prange
...
cdef int mandelbrot_escape(double x, double y, int n) nogil:
...
def generate_mandelbrot(np.ndarray[double, ndim=1] xs,
                       np.ndarray[double, ndim=1] ys, int n):
    """ Generate a mandelbrot set """
    cdef ...
    with nogil:
        for j in prange(M):
            for i in prange(N):
                d[j,i] = mandelbrot_escape(xs[i], ys[j], n)
    return d
```

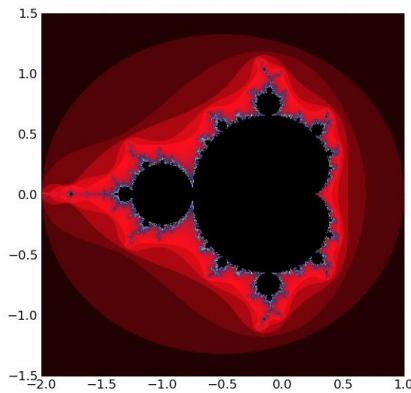
setup.py

```
ext = Extension("mandel", ["mandelbrot.pyx"],
                include_dirs = [numpy.get_include()],
                extra_compile_args=['-fopenmp'],
                extra_link_args=['-fopenmp'])
```

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Conclusion

| Solution | Time | Speed-up |
|------------------------------|----------|----------|
| Pure Python | 630.72 s | x 1 |
| Cython (Step 1) | 2.7776 s | x 227 |
| Cython (Step 2) | 1.9608 s | x 322 |
| Cython+Numpy (Step 3) | 0.4012 s | x 1572 |
| Cython+Numpy+prange (Step 4) | 0.2449 s | x 2575 |



Timing performed on a 2.3 GHz Intel Core i7 MacBook Pro with 8GB RAM using a 2000x2000 array and an escape time of n=100.

[July 20, 2012]

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