Language Fundamentals

Logit Academy

DAY 1

Schedule

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	Day 1	Day 2	Day 3	Day 4	Day 5
Morning	Course Introduction	Introduction to Python	Matplotlib, Numpy	Statistics, Pandas	Introduction to SQL
Break					
Morning	Course Overview	Introduction to Python	Numpy	Pandas, Seaborn	SQLAlchemy
Lunch					
Afternoon	IPython, Slack	Exercises	Exercises	Exercises	Exercises
Break					
Afternoon	Introduction to Python	Exercises	Exercises	Exercises	Exercises

What Is Python?

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ONE LINER

Python is an interpreted programming language that is easy to learn, easy to use, and comprehensive in terms of data science tools (data munging, stats, machine learning, NLP, etc.) and programming styles (from exploratory analysis to repeatable science to software engineering for production deployment).

PYTHON HIGHLIGHTS

- Interpreted and interactive
- Automatic garbage collection
- Dynamic typing
- Object-oriented
- Free
- Portable / Cross-Platform
- Easy to Learn and Use
- “Batteries Included”

Python data analytics platform and environment

IPython

An enhanced
interactive Python shell

IPython

STANDARD PYTHON COMMANDS WITH NUMBERED In/Out

```
In [1]: a = 1

In [2]: a + 2
Out[2]: 3
```

TIMING YOUR CODE

```
# One of the most useful features of IPython is built-in timing.
# Use %timeit for one-line of code, and %%timeit for multiple lines.
In [3]: %%timeit
   ...: a = []
   ...: for value in xrange(10):
   ...:     a.append(value**2)
   ...:
100000 loops, best of 3: 1.88 us per loop

In [4]: %timeit a = [value**2 for value in xrange(10)]
1000000 loops, best of 3: 1.46 us per loop
```

Function Info in IPython

HELP USING ?

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

In [5]: len?
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.
```

Function Info in IPython

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SHOW SOURCE CODE USING ??

```
In [6]: import numpy as np

In [7]: np.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.

Directory Navigation in IPython

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```
# Change directory (note Unix style forward slashes!)
In [8]: cd c:/python_class/Demos/speed_of_light
c:\python_class\Demos\speed_of_light
```

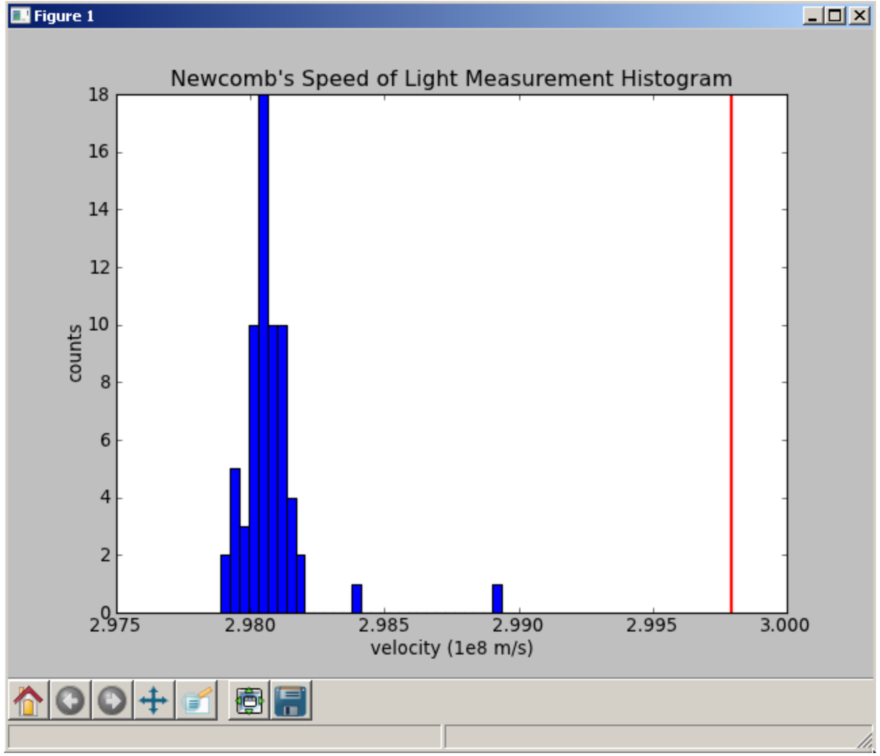
Tab completion helps you find and type directory and file names.

```
# List directory contents (Unix style, not "dir").
In [9]: ls
 Volume in drive C has no label.
 Volume Serial Number is 5417-593D
 Directory of c:\python_class\Demos\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 newcomb_histogram.dat
09/01/2008  02:48 PM           1,436 newcomb_histogram.py
09/01/2008  02:48 PM           1,232 newcomb_histogram2.py
               6 File(s)      2,874,278 bytes
               2 Dir(s) 11,997,437,952 bytes free
```

Running Scripts in IPython

```
# tab completion
In [10]: %run newcomb_hi
newcomb_histogram.dat  newcomb_histogram.py

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



IPython History

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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.

Reading Simple Tracebacks

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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.

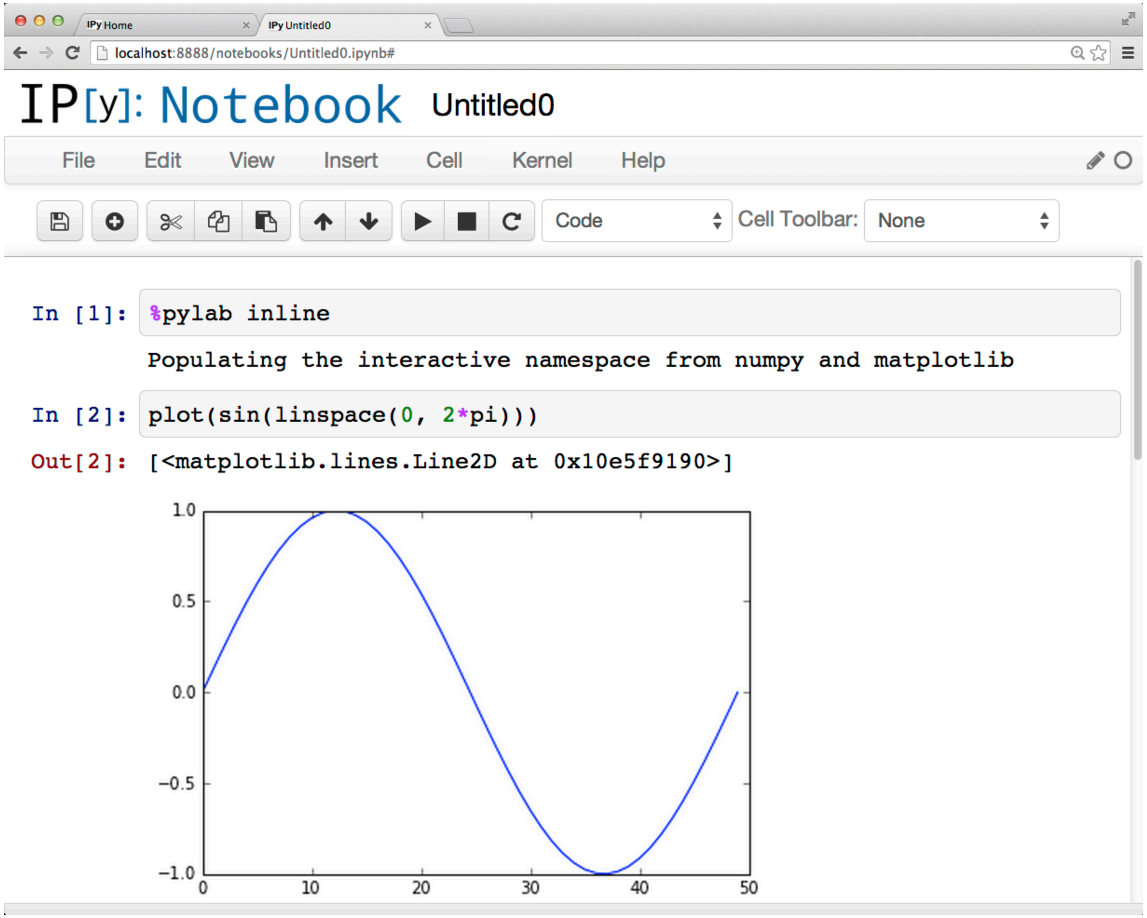
ERROR TRYING TO ADD A NON-EXISTENT VARIABLE

```
# 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
```

IPython Notebook: Share your results

One `.ipynb` file with:

- code
- results
- inline figures
- formatted text (including equations)
- titles
- etc



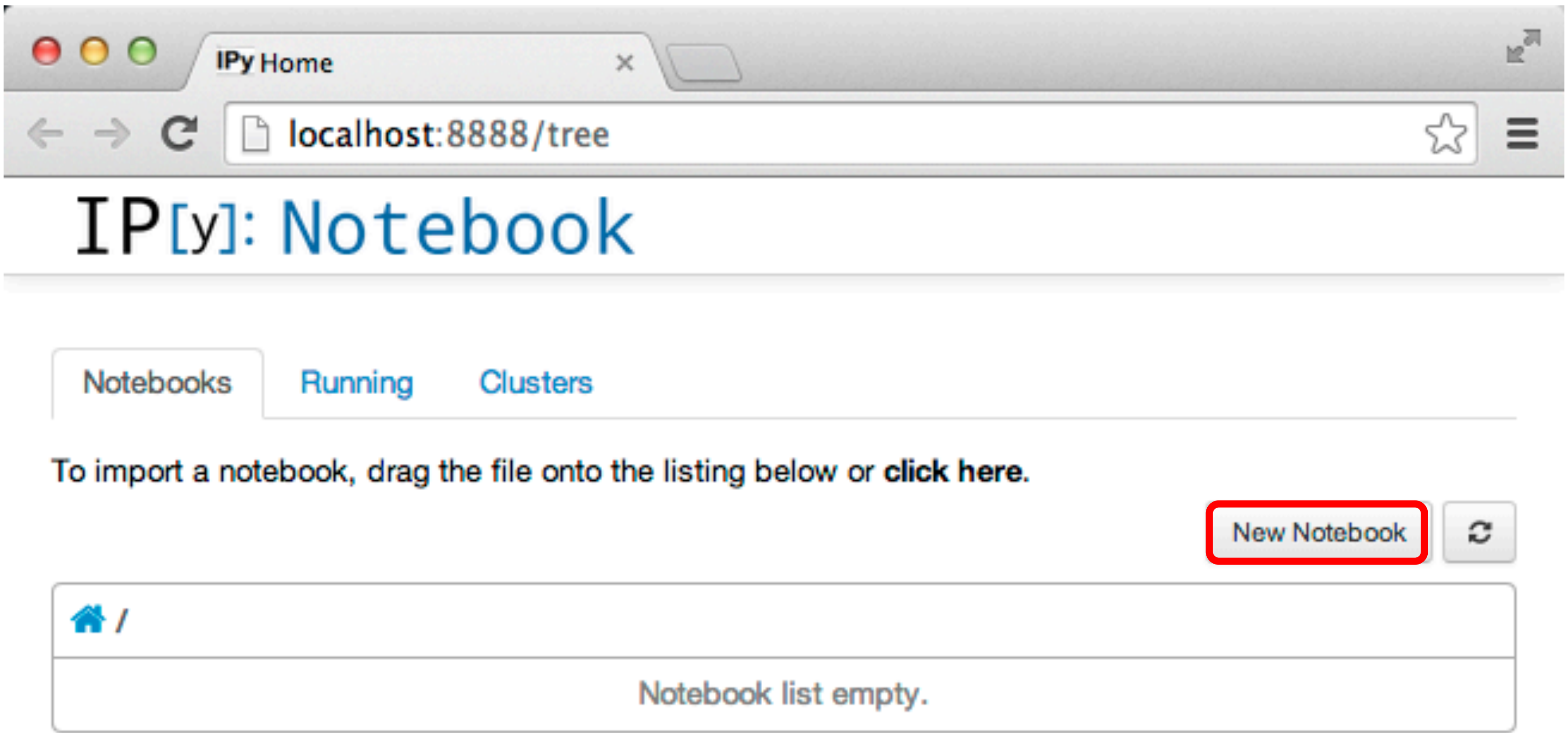
Easy to share results:

- results inline with code
- code is executable

Creating a notebook from terminal

From a terminal/command prompt, start a notebook server that is viewed in your default web browser:

```
$ ipython notebook
```



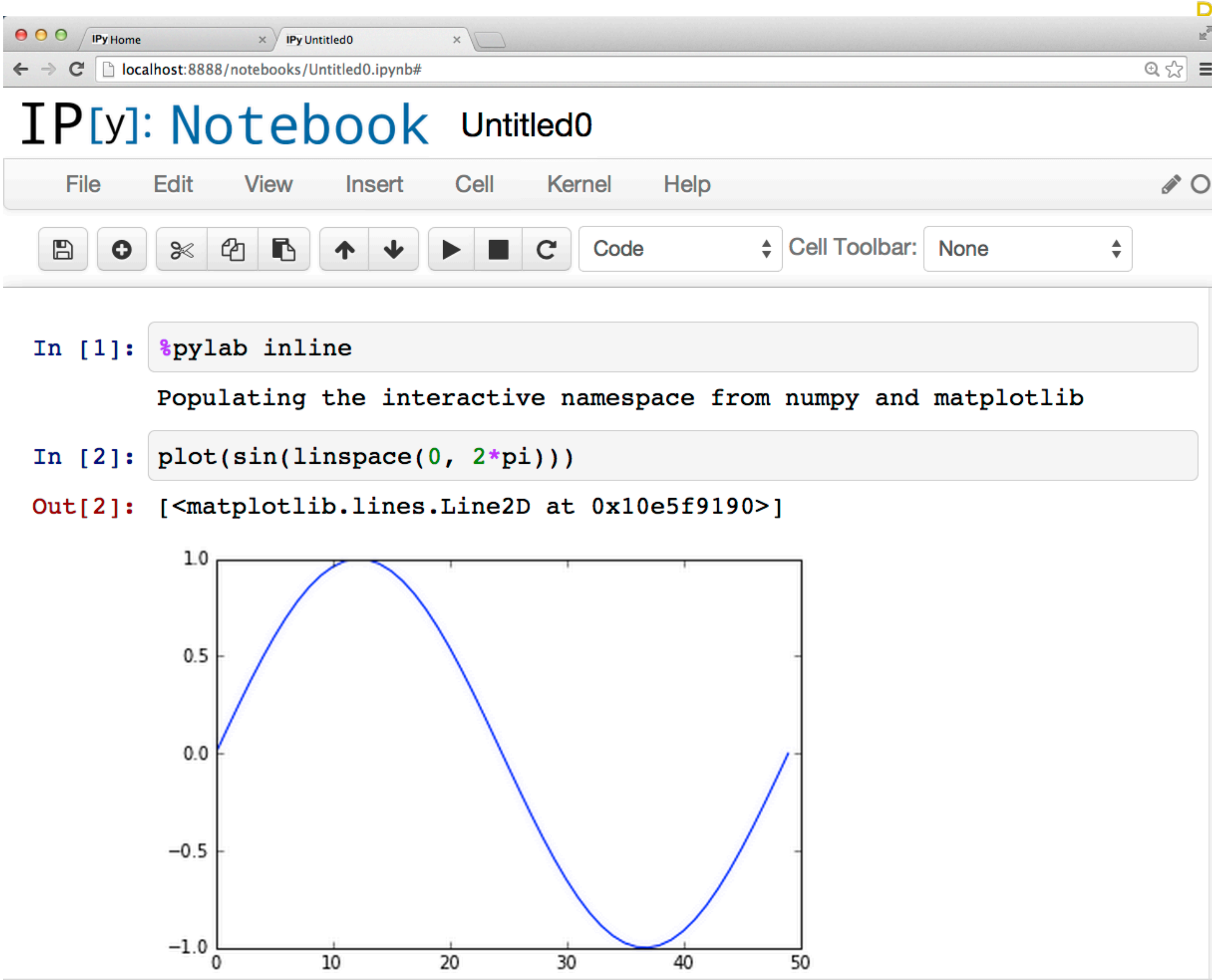
IPython notebook features

1. Cells can group multiple commands. Execute cells with SHIFT-ENTER.
2. Make a cell a “Markdown” cell to create titles, control the font, ...
3. Cells can be deleted, moved around, inserted AND executed in random order.
4. Insert images, webpages, LaTeX formulas, YouTube videos, ... using `IPython.display` objects or functions:

```
In [2]: from IPython.display import Latex
        Latex("$\int_{a}^{b} f(x)\ dx$")
```

Out[2]: $\int_{a}^{b} f(x)\ dx$

Inline figures in the notebook



Introduction to Python
Software Craftsmanship

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

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

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"

Software Carpentry

Greg Wilson et. al., "Best Practices for Scientific Computing". http://arxiv.org/abs/1210.0530

An 11-page paper giving recommendations for improving productivity and software reliability for those developing scientific software.

Coding Modes

Python developers code in two modes:

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: Read the code and understand without having to think

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...>
```

Primary Naming Consideration

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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
```

Using *extremely* short names

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LOOP INDICES I, J, and K

```
# This is ok.
for i in xrange(10):
    scores[i] = 0

# But this is better.
events = xrange(10)
for event in events:
    decathalon_scores[event] = 0
```

Using *extremely* short names

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INDUSTRY STANDARD VARIABLES IN "SMALL" CONTEXT

```
# Quick, what does each variable stand for?
y  = a * sin(w*t + phi)
```

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
```

Bad Code Comments

REPEATING THE CODE

Comments that just repeat what's in the 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
```

Better Code Comments

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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)
```

Comments in production Python code

PERCENTAGE OF PYTHON SOURCE LINES THAT ARE COMMENT LINES

Project	Comments
numpy	40.4%
scipy	37.2%
pandas	20.5%
matplotlib	27.8%
ipython	32.1%
traits	39.2%
chaco	27.4%

* As determined by `cloc`: http://cloc.sourceforge.net on `master` versions as of 2014-12-17.

Python Coding Standard

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The Python Coding Standard is defined in Python Enhancement Proposal 8* (PEP-8).

* http://www.python.org/dev/peps/pep-0008/

Testing Code

Test Driven Development

Overarching Concept:

Write tests as you write your code

Test Driven Development

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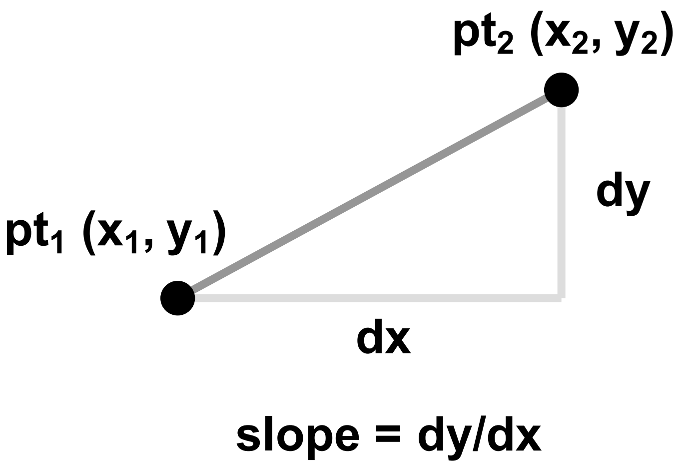
TEST

```
# 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
```

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)

Discovering tests: nosetests

FROM THE TERMINAL

```
$ ls fancy_package/
fancy_math.py  fancy_physics.py tests/

$ ls fancy_package/tests/
test_fancy_math.py test_fancy_physics.py

$ nosetests -v
test_fancy_math_solution.test_slope_float ... ok
Integer division has the potential to break the slope function. ...
ok
Test for infinite slope function. ... ok
----------------------------------------------------------------------
Ran 3 tests in 0.095s

OK
```

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 slope

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)
```

Timing and Profiling Code

Ways to time execution

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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

Timing in Python

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USE TIME PACKAGE

```python
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 operations/function call
>>> import numpy as np
>>> a = np.arange(1000)
>>> %timeit a**2
100000 loops, best of 3: 3.26 µs
per loop
>>> %timeit a**2.1
10000 loops, best of 3: 66.7 µs
per loop
>>> %timeit a*a
100000 loops, best of 3: 2.29 µs
per loop
```

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 **`runctx()`**) function. This counts and times function calls, and generates a profiling dataset.
2. 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.

These 2 steps can be executed automatically using the IPython **`%run -p`** magic command.

Automatic method

The most convenient way to profile a script execution at the function level is to use the -p option of %run from within IPython:

```
>>> %run -p solve-sudoku.py  easy-sudoku.txt

5752950 function calls (3568633 primitive calls) in 4.022 seconds

   Ordered by: internal time

   ncalls        tottime  percall  cumtime  percall filename:lineno(function)
1006113/52612    2.336    0.000    3.762    0.000 solve-sudoku.py:94(eliminate)
964245/255618    0.542    0.000    3.218    0.000 solve-sudoku.py:102(<genexpr>)
206977/14262     0.247    0.000    3.850    0.000 {all}
  2575327        0.242    0.000    0.242    0.000 {len}
151887/12264     0.186    0.000    3.850    0.000 solve-sudoku.py:87(assign)
   457535        0.175    0.000    0.175    0.000 {method 'replace' of 'str' objects}
246847/64876     0.149    0.000    3.812    0.000 solve-sudoku.py:89(<genexpr>)
    75832        0.054    0.000    0.072    0.000 solve-sudoku.py:158(<genexpr>)
     1633        0.020    0.000    0.092    0.000 {min}
      366        0.014    0.000    2.199    0.006 solve-sudoku.py:129(initialize)
    41810        0.013    0.000    0.016    0.000 solve-sudoku.py:117(<genexpr>)
 4496/793        0.008    0.000    1.781    0.002 solve-sudoku.py:159(<genexpr>)
[…]
```

time in *this* function only

time in this function

+ all called functions

Controlled method

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}
```

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.

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.

line_profiler example

http_search.py

```
import re

PATTERN = r"https?:\/\/[\w\-_]+(\.[\w\-_]+)+([\w\-
\.,@?^=%&amp;:/~\+#]*[\w\-\@?^=%&amp;/~\+#])?"

@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.

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                                           @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
```

line_profiler example

http_search2.py

```
import re

PATTERN = r"https?:\/\/[\w\-_]+(\.[\w\-_]+)+([\w\-
\.,@?^=%&amp;:/~\+#]*[\w\-\@?^=%&amp;/~\+#])?"

@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
```

`pdb`
The Python debugger

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 and syntax highlighting.

Starting pdb

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- Run the script from the command line under debugger control
  `C:\> python -m pdb script.py [arg ...]`

- Call a function from the **pdb** module in an IPython session:

  `>>> 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

- Hard-code a breakpoint inside a script or a module:
  `import pdb; pdb.set_trace()`

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.

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
```

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]
```

Example session

DEBUGGING FROM ORIGIN OF EXCEPTION

```
ipdb> l
  6         """
  7         num_items = len( item_list )
  8         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 ) :

ipdb> item_list
['0']
ipdb> half
2
ipdb> c

In [4]:
```

Print the source code around the line which raised the exception

Print the contents of the list

Print the value of the index ah-ha!

Return to ipython

Example session

DATA SCIENCE

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( l ))
(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!

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.

DAY 2

Introduction to Python

Data types

Outline

- Data types:
  - Numerical types: int, long, float, complex
  - Booleans
  - Strings
  - Lists and tuples
  - Dictionaries and sets
  - Things to know about efficiency

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 = 1234567890123456789O
>>> a
1234567890123456789OL
>>> 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 64-bit architectures are:

`integer` **8 byte (4 byte on Windows)**
`long integer` **Any precision**
`float` **8 byte, like C's double**
`complex` **16 byte**

The NumPy library, which we will see later, supports a larger number of numeric types.

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
```

IN-PLACE OPERATIONS

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

Logical expressions, `bool` data type

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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
```

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'
```

Multi-line Strings

TRIPLE QUOTES

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

NEW LINE CHARACTER

```
# Including a newline character
>>> a = "hello\nworld"
>>> print a
hello
world
```

A few string methods and functions

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REPLACING TEXT

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

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'
```

STRINGS TO NUMBERS

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

String Formatting

The `format()` method replaces any ***replacement fields*** in the string with the values given as arguments.

Optional *Optional*

Replacement field format: `{<name>:<format_spec>}`

```
# If 'name' is an integer, it refers to the argument position.
>>> '{0} is greater than {1}'.format(100, 50)
'100 is greater than 50'

# If 'name' is text, it refers to a keyword argument.
>>> '{last}, {first}'.format(first='Ellen', last='Ripley')
'Ripley, Ellen'
```

String Formatting – Format spec

The optional format specification is used to control how the values are displayed. (See Appendix for details.)

```
# 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]

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

# Alignment with fill character.
>>> template = '[{0:*<10s}]  [{0:*>10s}]  [{0:*^10s}]'
>>> print template.format('PYTHON')
[PYTHON****]  [****PYTHON]  [**PYTHON**]
```

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'.

String Formatting with %

DATA SCIENCE

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).

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]
```

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 Matlab and Fortran programmers!***

More on list objects

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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
```

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
```

Common methods for lists

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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(key)

By default, sort the elements in ascending order. If a key function is given, apply it to each element to determine the value for sorting.

Slicing

DATA SCIENCE

`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]
```

OMITTING 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]
```

Lists 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]
```

Mutable vs. Immutable

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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]
```

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'
```

Tuple – Immutable Sequence

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TUPLE CREATION

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

PARENTHESES ARE OPTIONAL

```
>>> 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.

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
```

Tuple (un)packing

(UN)PACKING TUPLES

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

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

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

WHY IS IT USEFUL?

We will see later on that this feature is very common in Python code, e.g.:

```
# Returning multiple values
def monomials(x):
    return 1, x, x**2
a0, a1, a2 = monomials(3)

# Iterating over tuples
friends = [('Guido', 28),
           ('Mario', 51),
           ('Antonio', 30)]
for (name, age) in friends:
   txt = "{} is {} years old"
   print txt.format(name, age)
```

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'] = 'Ralf'
>>> record['last'] = 'Emmerson'
>>> record['born'] = 1803
>>> print record
{'first': 'Ralf', 'born': 1803, 'last': 'Emmerson'}
# Create another dictionary with initial entries.
>>> new_record = {'first': 'Ralph', 'middle':'Waldo'}
# Now update the first dictionary with values from the new one.
>>> record.update(new_record)
>>> print record
{'first': 'Ralph', 'middle': 'Waldo', 'last':'Emmerson',
'born': 1803}
```

Accessing and deleting keys and values

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ACCESS USING INDEX NOTATION

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

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)
1803
>>> record.get('home', 'TBD')
'TBD'
>>> record['home']
KeyError: ...
```

REMOVE AN ENTRY WITH DEL

```
>>> del record['middle']
>>> record
{'born': 1803, 'first':
'Ralph', 'last': 'Emmerson'}
```

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)
1803
>>> record
{'first': 'Ralph', 'last':
'Emmerson'}
>>> record.pop('born', 0)
0
```

Dictionaries in action

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

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

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

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

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

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

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

# Add some horses.
>>> cargo['horses'] = 5
>>> cargo['horses']
5
```

Common methods for dictionaries

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some_dict.clear( )

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

some_dict.copy( )

Create a copy of the dictionary

x in some_dict

Test whether the dictionary contains the key x.

some_dict.keys( )

Return a list of all the keys in the dictionary.

some_dict.values( )

Return a list of all the values in the dictionary.

some_dict.items( )

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

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/REMOVE ELEMENTS

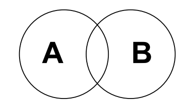
```
>>> t.add(5)
>>> t
set([1, 2, 3, 5])
>>> t.update([5,6,7])
>>> t
set([1, 2, 3, 5, 6, 7])
```

REMOVE ELEMENTS

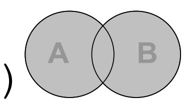
```
>>> t.remove(1)
set([2, 3, 5, 6, 7])
```

SET OPERATIONS

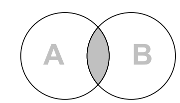
```
>>> a = set([1,2,3,4])
>>> b = set([3,4,5,6])
```



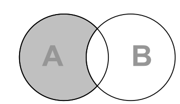

```
>>> a.union(b)
set([1, 2, 3, 4, 5, 6])
```



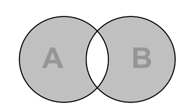

```
>>> a.intersection(b)
set([3, 4])
```




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




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



Selecting a data type

Selecting the appropriate data type is important

	insert	remove	find	ordered
list	linear	linear	linear	✓
set	constant	constant	constant	✗
dict	constant	constant	constant	✗

Typical usages for each data type:

- Lists: Represent ordered collections of items, stacks, and queues [1]
- Sets: Represent collections of unique, unordered items
- Dicts: Represent registries, caches, mappings in general

[1] Also see the `deque` module for an efficient queue implementation

Introduction to Python

Control statements

Outline

- If statements
- While loops
- For loops
  - List comprehensions
  - Looping patterns

If statements

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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 'Foo!'
...     print 'x > 0'
... elif x == 0:
...     print 'x is 0'
... else:
...     print 'x is negative'
... < hit return >
Foo!
x > 0
```

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):
      ...
```

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.

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
```

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 SEQUENCE

```
>>> animals=('dogs','cats')
>>> accum = ''
>>> for animal in animals:
...     accum += animal + ' '
... < hit return >
>>> print accum
dogs cats
```

List Comprehension

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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.

Looping Patterns

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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
```

Looping over a dictionary

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```
>>> 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
```

Introduction to Python

Organizing code

Outline

- Functions
- Modules
- Packages

Functions

Functions are reusable snippets of code.

- Definition
- Positional and keyword arguments

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.*

A colon (**:**) terminates the function signature.

```
def add(x, y):
    """Add two numbers"""
    return x + y
```

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

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.

Our new function in action

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

```
# 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
```

Function Calling Conventions

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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
```

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}
```

Function Calling Conventions

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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)
```

Expanding Function Arguments

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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}
```

Evolution of a script

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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
...
```

To A Function

Evolves to a function…

ONE MEGA-FUNCTION

```
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
    ...
```

Evolution Stops

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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 very minimal re-use.

Evolution to a library

DATA SCIENCE

Long term benefits come from continuing to "**refactor**" this 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)
```

“One Idea Per Function” Benefits

Smaller, less complex snippets of code

- are easier for others (and you) to read in the future,
- have more potential for reuse,
- make it easier to modify behavior (decoupling!), and
- are easier to test.

Don’t Repeat Yourself

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)
```

DON’T REPEAT YOURSELF

```
# 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)
```

Modules

Modules and packages

Modules and packages are Python’s “libraries”, i.e. a collection of constants, functions, and classes.

Importing a module

BASIC IMPORTS

```
# The most basic import
>>> import numpy
>>> numpy.pi
3.141592653589793
# Use an 'alias'
>>> import numpy as np
>>> np.pi
3.141592653589793
```

IMPORTING SPECIFIC SYMBOLS

```
# Select specific names to
# bring into the local
# namespace.
>>> from numpy import add, pi
>>> pi
3.141592653589793
>>> add(2, 3)
5
```

IMPORTING *EVERYTHING*

```
# Pull *everything* into the
# local namespace.
>>> from numpy import *
>>> pi
3.141592653589793
>>> add(3, 4.5)
7.5
```

MODULES ARE .PY FILES

Modules are just .py files.

```
# my_tools.py
def greetings():
    return "Hello everyone"
```

```
>>> import my_tools
>>> my_tools.greetings()
'Hello everyone'
```

Modules

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

EX.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()
```

Packages

PACKAGES

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

Example:

```
>>> from email.utils import parseaddr
>>> from email import utils
>>> utils.parseaddr('John Doe <jdoe@company.com>')
('John Doe', 'jdoe@company.com')
```

`utils` is a *module* in the *package* **`email`** .

PACKAGES ARE DIRECTORIES

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

The file `__init__.py` indicates that foo is a package. It often is an empty file.

Setting up PYTHONPATH

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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
```

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
```

Common Directory Structure

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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.

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

httplib, 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

urllib2 – open and read from URLs

and many more… To see the content of one:

>>> dir(module_name**)**

Selections from the Python Standard Library

datetime – Dates and Times

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```
>>> 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.
```

datetime – Dates and Times

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```
>>> 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]

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>)
>>>
```

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.

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')
```

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

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)
```

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

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.

DAY 3

Core libraries for data processing

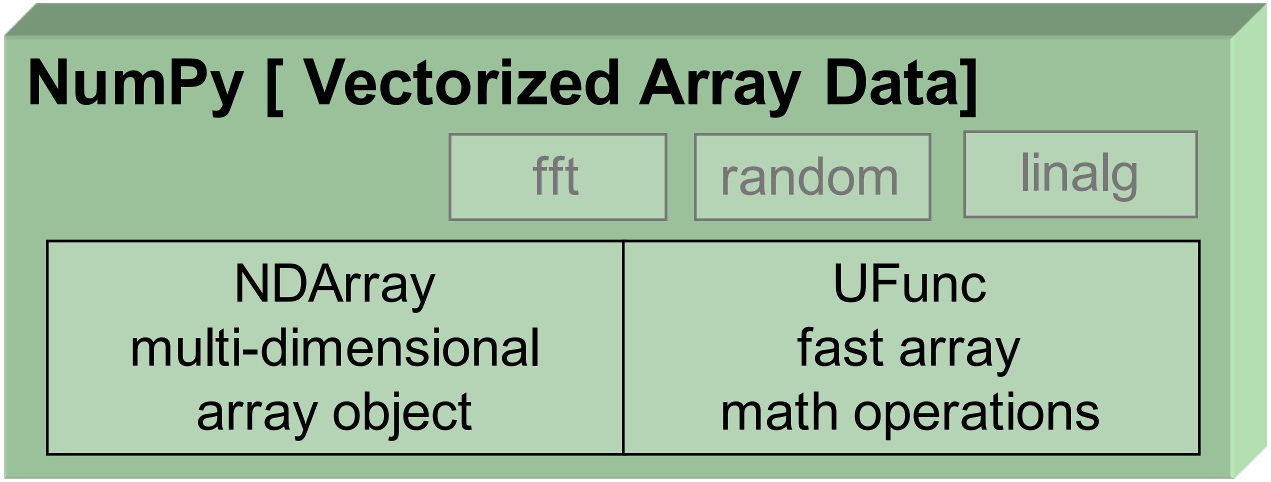
Outline

- NumPy
- matplotlib
- SciPy
- Pandas

NumPy

The standard numerical library for Python

NumPy: array and array functions



NumPy arrays

- The array data structure
- Defining arrays
- Indexing and slicing
- Creating arrays
- Array calculations
- Advanced NumPy

Getting Started

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IMPORT NUMPY

```
In [1]: from numpy import *
In [2]: __version__
Out[2]: 1.8.1
        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

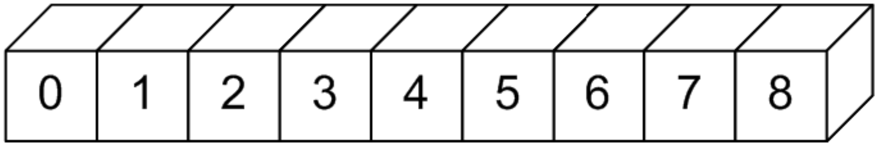
```
C:\> ipython --pylab
In [1]: array([1,2,3])
Out[1]: array([1, 2, 3])
```

IPython has a 'pylab' mode where it imports all of NumPy and Matplotlib, 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.

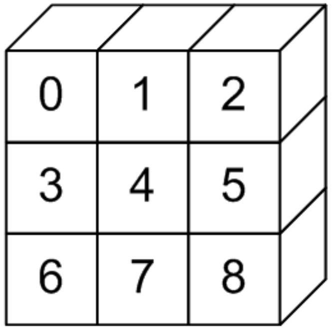
The array data structure

Array Data Structure

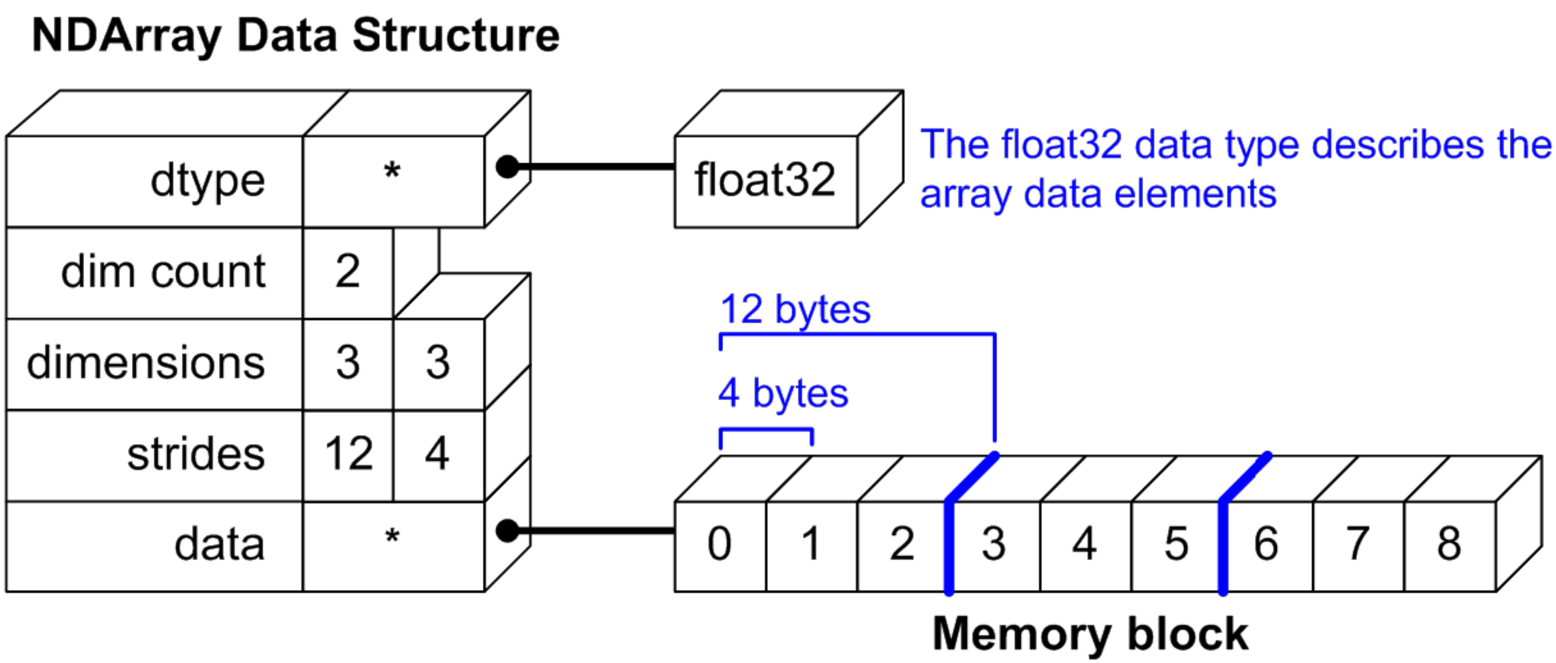


Memory block

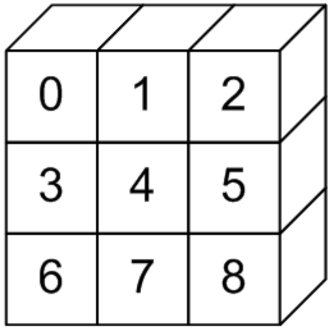
Python View:



Array Data Structure



Python View:



Operations on the array structure

Operations that only affect the array structure, not the data, can be executed without copying memory.

Transpose

TRANSPOSE

```
>>> a = array([[0,1,2],
...            [3,4,5]])
>>> a.shape
(2,3)
# Transpose swaps the order
# of axes.
>>> a.T
array([[0, 3],
       [1, 4],
       [2, 5]])
>>> a.T.shape
(3,2)
```

TRANSPOSE RETURNS VIEWS

```
# 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)
```

Reshaping Arrays

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RESHAPE

```
>>> a = array([[0,1,2],
...            [3,4,5]])

# Return a new array with a
# different shape (a view
# where possible)
>>> 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
```

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]])
```

Flattening Arrays

FLATTEN (SAFE)

`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                    no change
array([[0,  1],
       [2,  3]])
```

RAVEL (EFFICIENT)

`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.

```
# 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                    changed!
array([[10,  1],
       [ 2,  3]])
```

Matplotlib Basics

http://matplotlib.org/

DATA SCIENCE

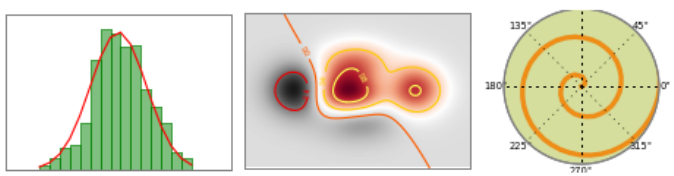
matplotlib

home | search | examples | gallery | docs » modules | index

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 Workshop *MLOSS* and one presented at ChiPy.

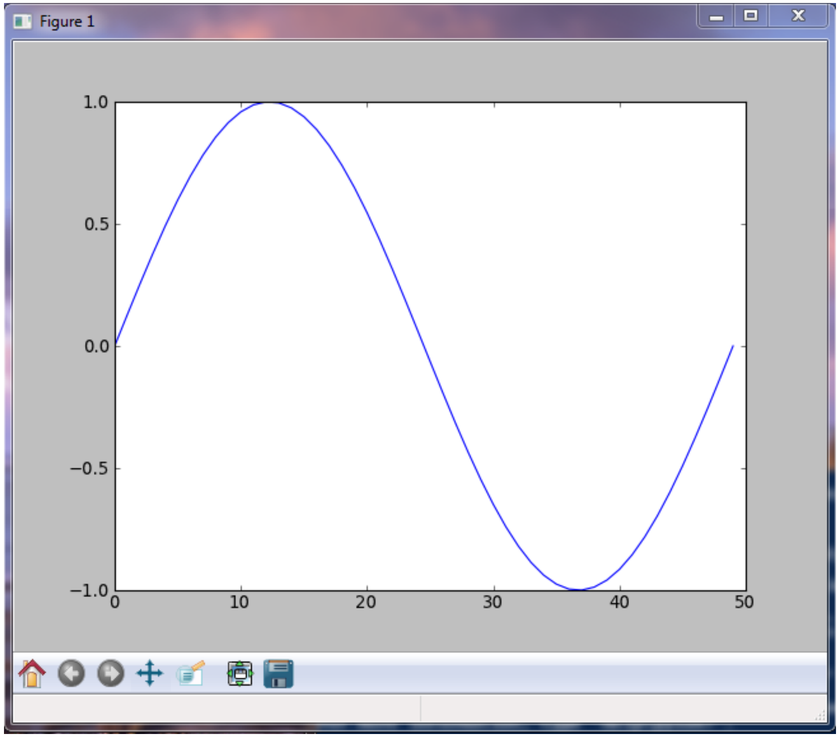
Toolkits

There are several matplotlib addon toolkits, including the projection and mapping toolkit

Line Plots

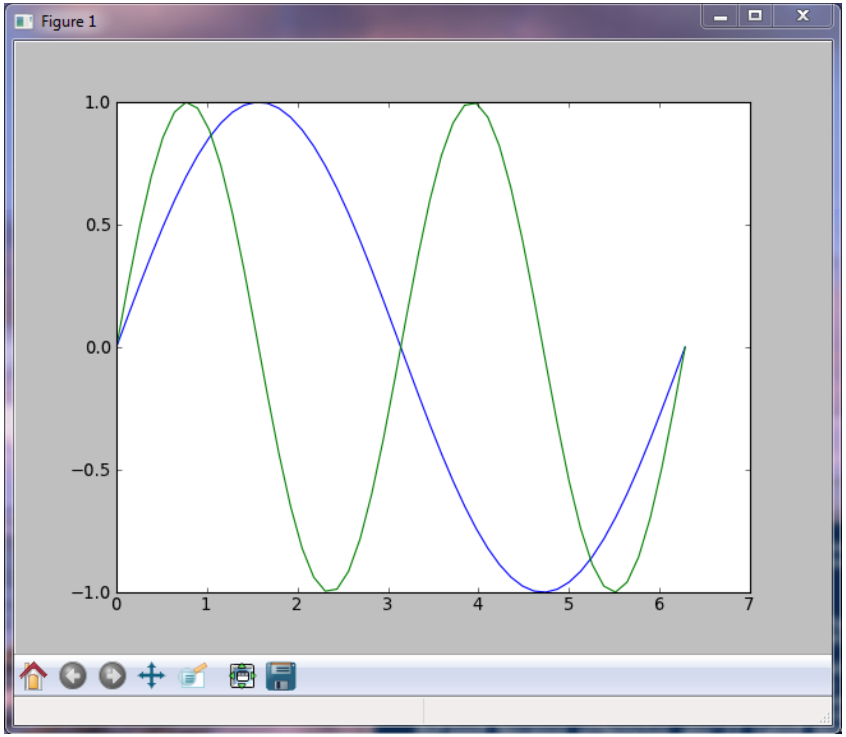
PLOT AGAINST INDICES

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

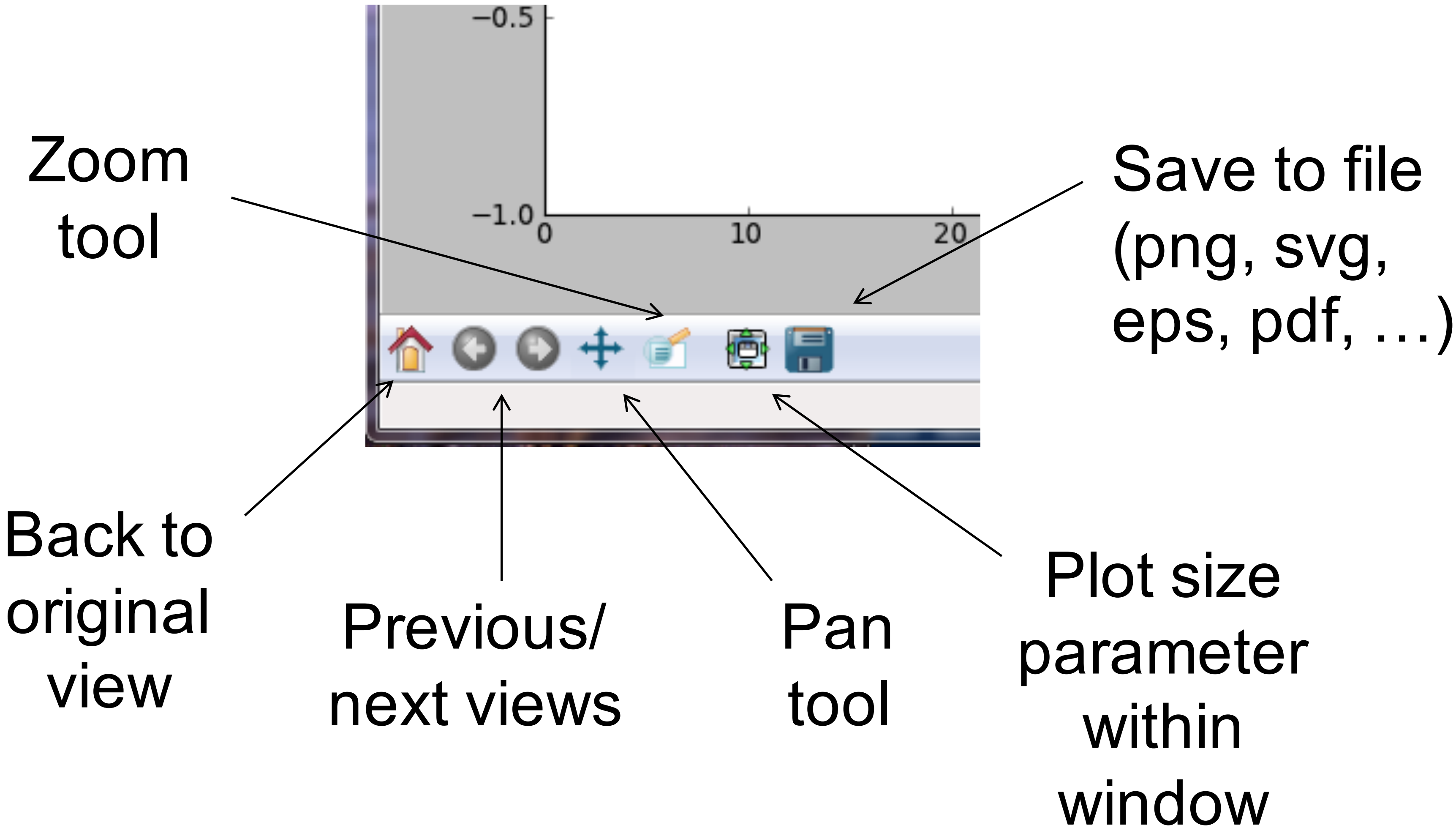


MULTIPLE DATA SETS

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



Matplotlib Menu Bar



Line Plots

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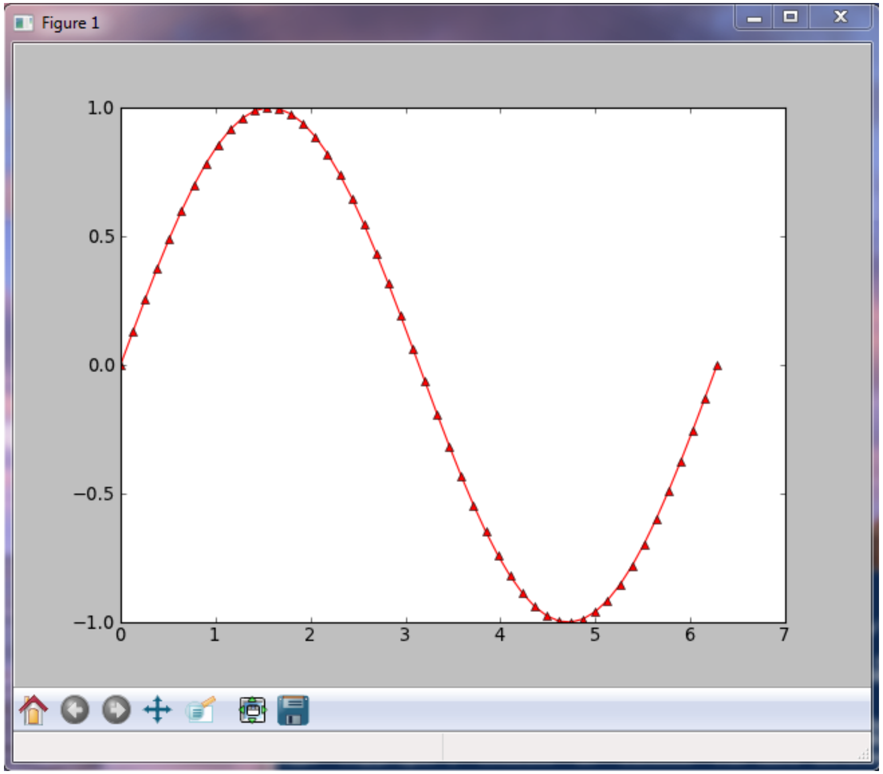
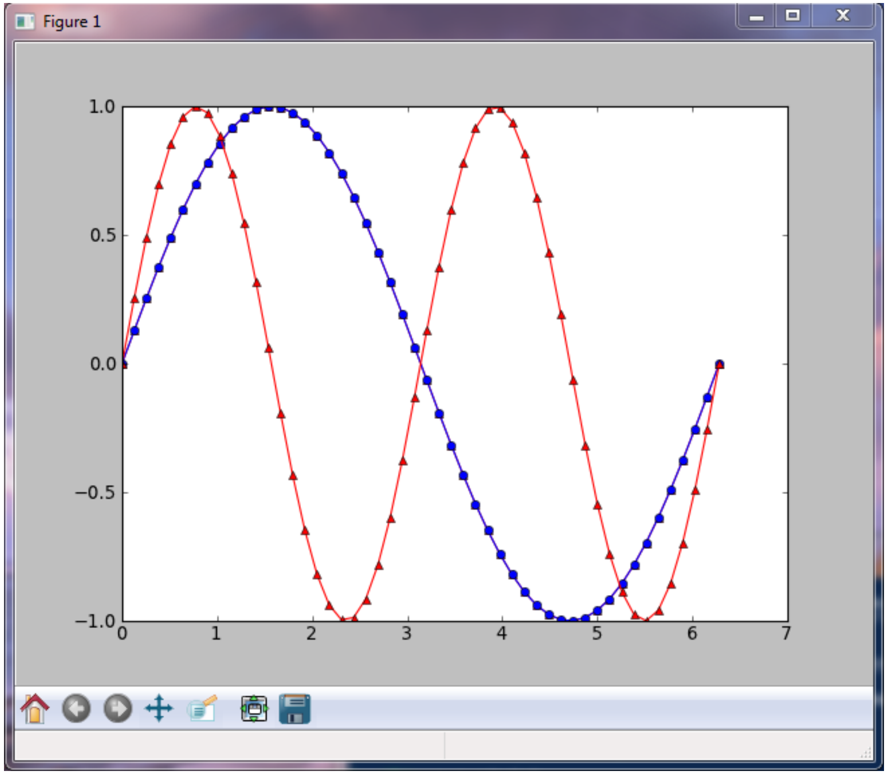
LINE FORMATTING

```
# red, dot-dash, triangles
>>> plot(x, sin(x), 'r-^')
```



MULTIPLE PLOT GROUPS

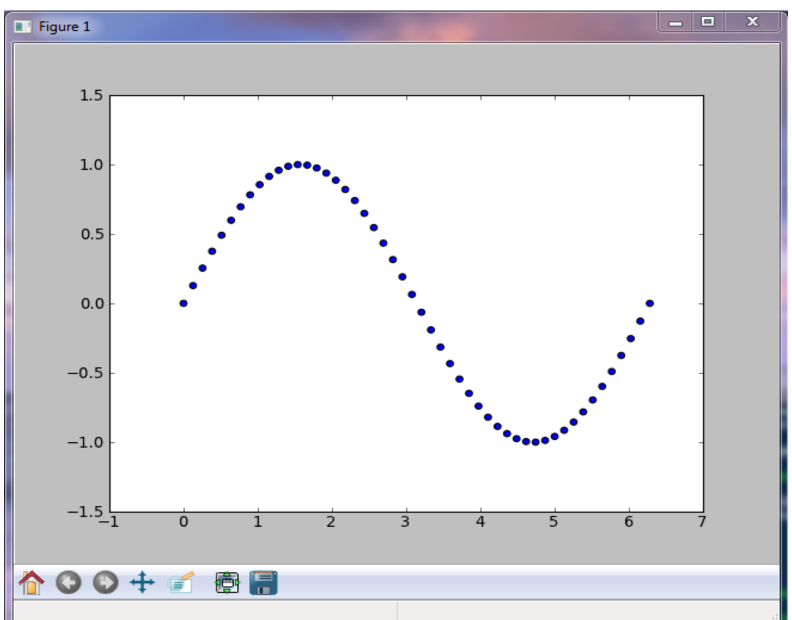
```
>>> plot(x, sin(x), 'b-o',
...         x, sin(2*x), 'r-^')
```



Scatter Plots

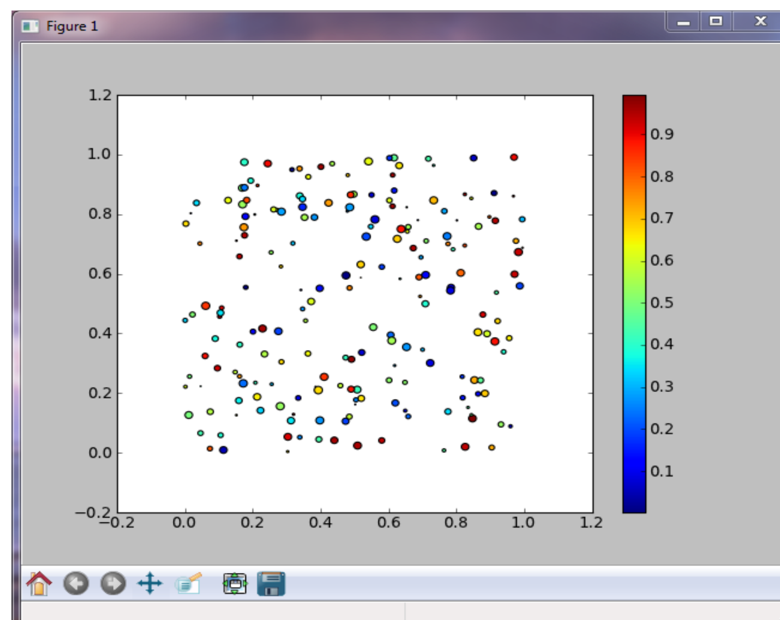
SIMPLE SCATTER PLOT

```
>>> 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()
```

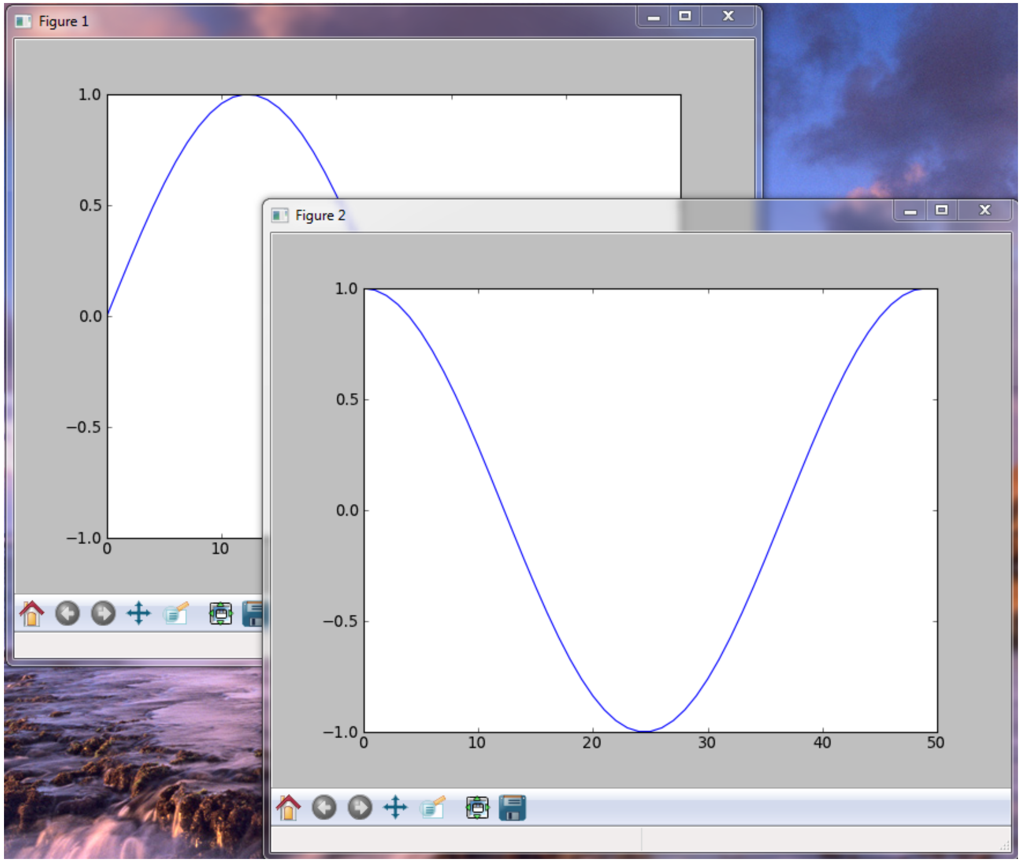


Multiple Figures

```
>>> 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)
```



Multiple Plots Using `subplot`

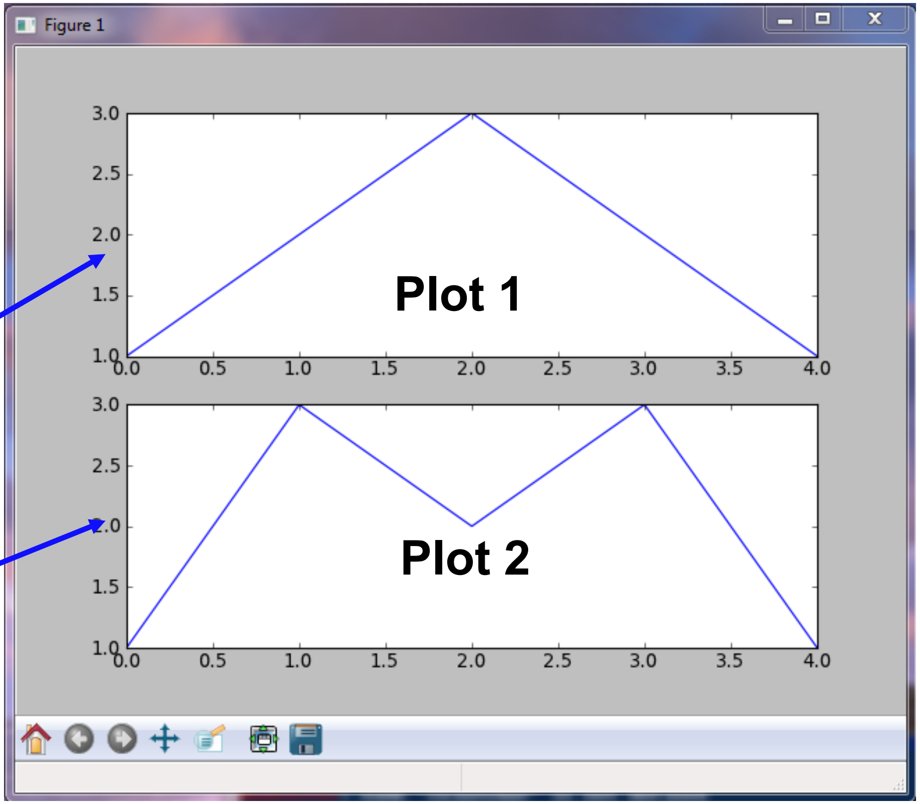
```
>>> x = array([1,2,3,2,1])
>>> y = array([1,3,2,3,1])

# To divide the plotting area
```

columns

```
>>> subplot(2, 1, 1)
>>> plot(x)
```

rows   active plot



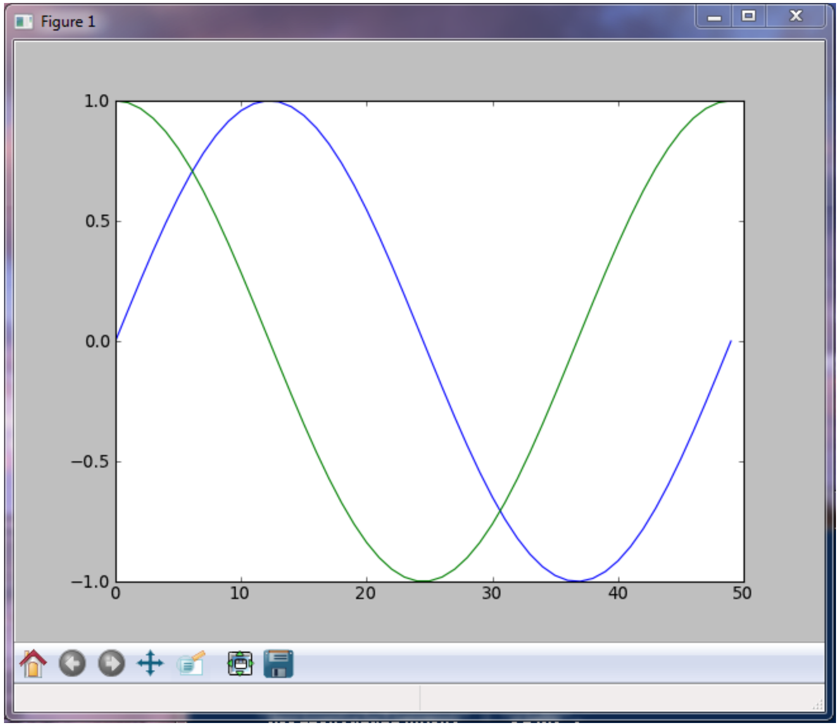

```
# Now activate a new plot
# area.
>>> subplot(2, 1, 2)
>>> plot(y)
```

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

Adding Lines to a Plot

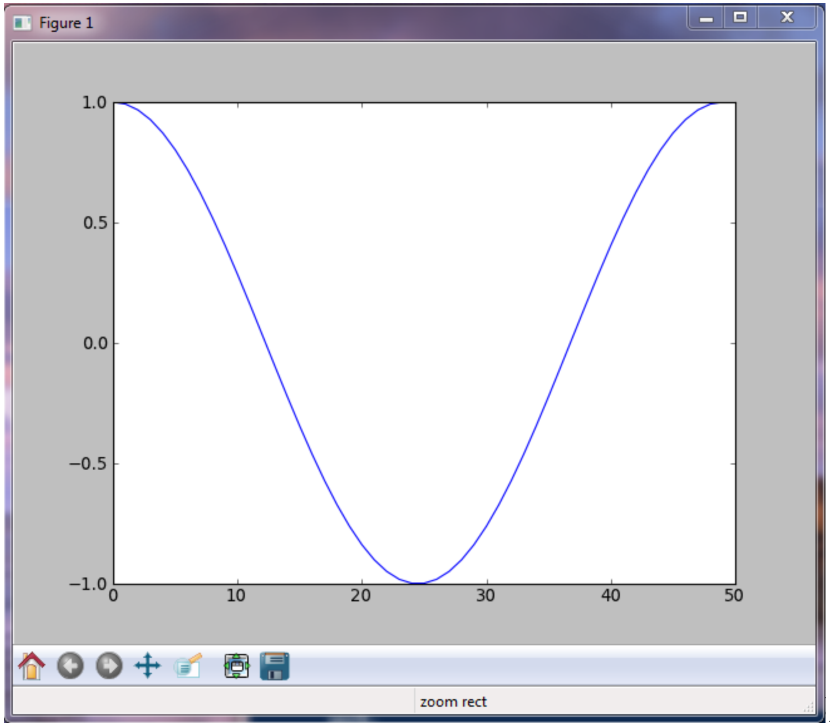
MULTIPLE PLOTS

```
# 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

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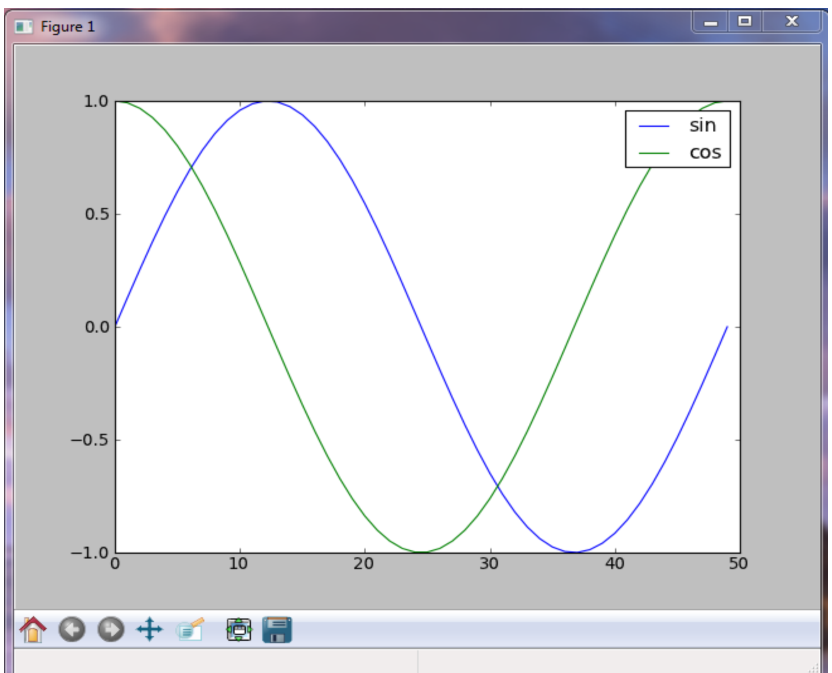
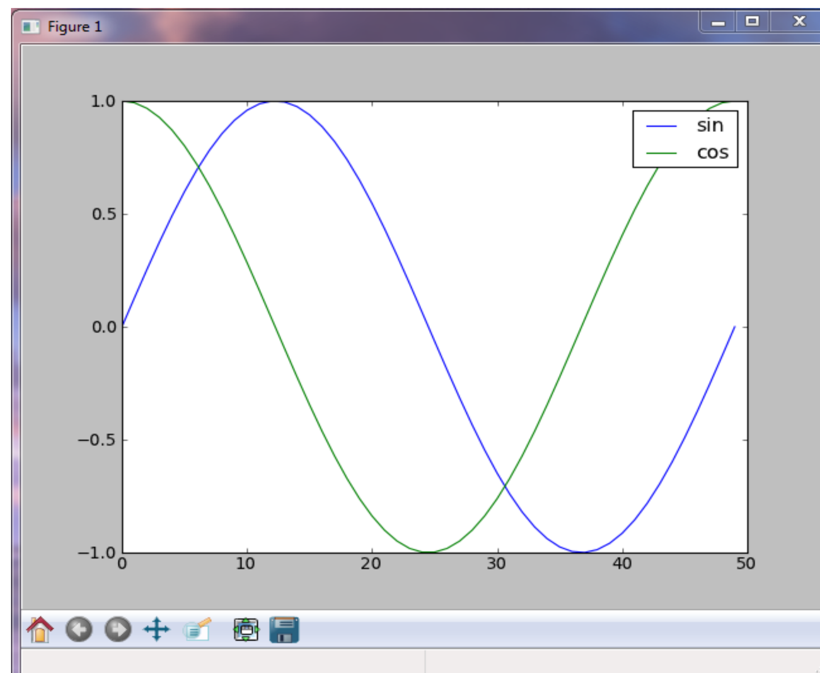
LEGEND LABELS WITH PLOT

```
# Add labels in plot command.
>>> plot(sin(x), label='sin')
>>> plot(cos(x), label='cos')
>>> legend()
```



LABELING WITH LEGEND

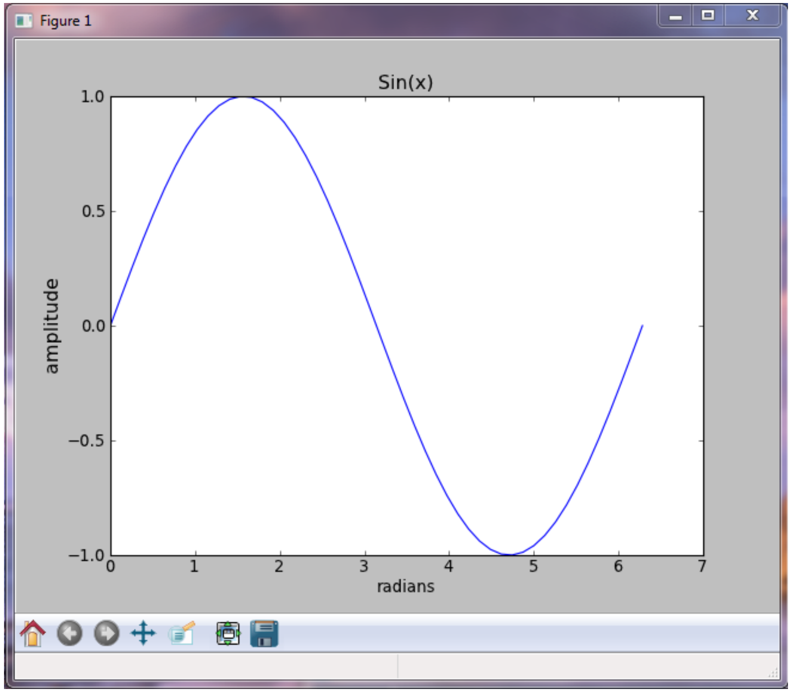
```
# Or as a list in legend().
>>> plot(sin(x))
>>> plot(cos(x))
>>> legend(['sin', 'cos'])
```



Titles and Grid

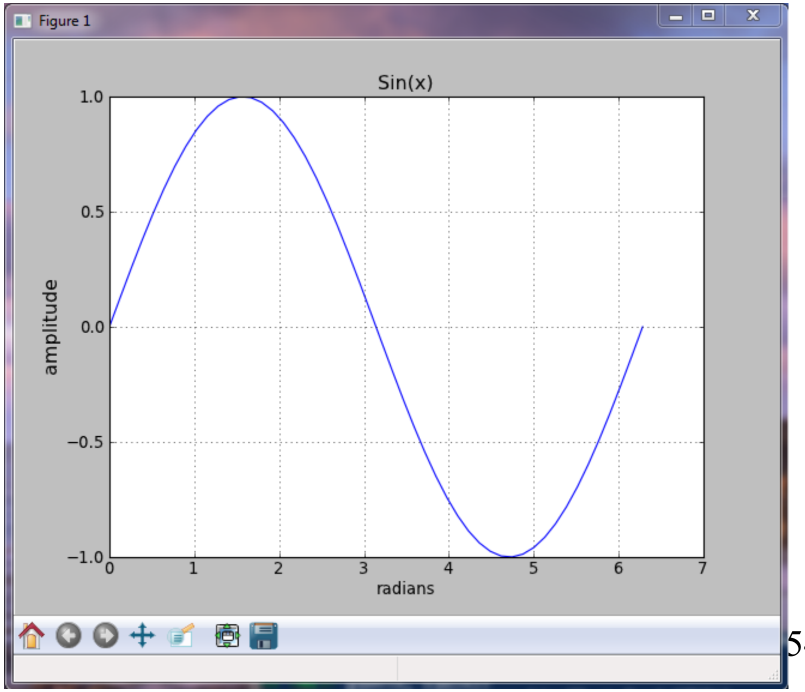
TITLES AND AXIS LABELS

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



PLOT GRID

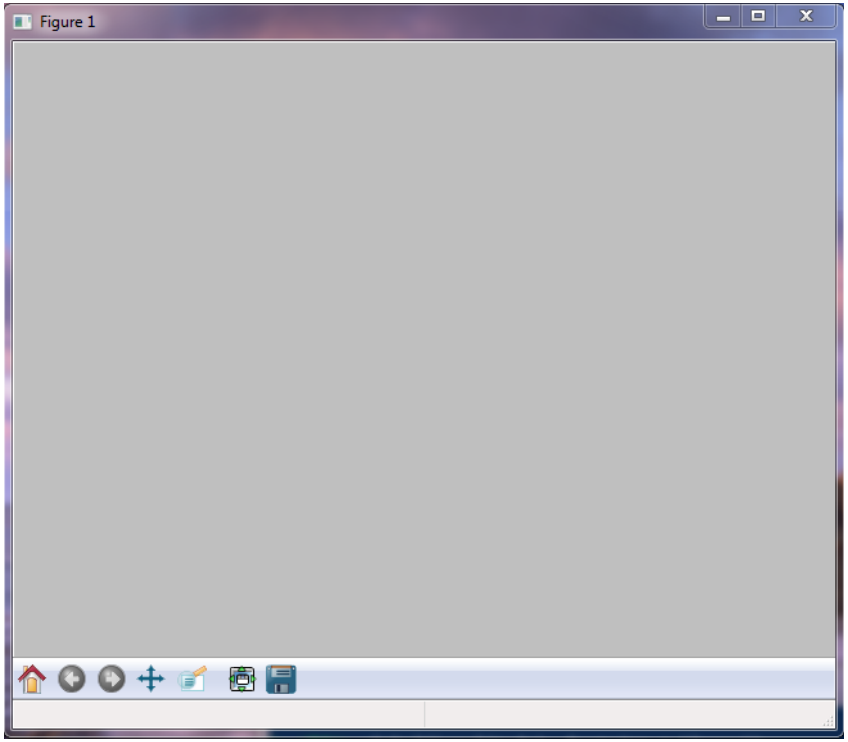
```
# Display gridlines in plot
>>> grid()
```



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')
```

Display Images (or plot surface)

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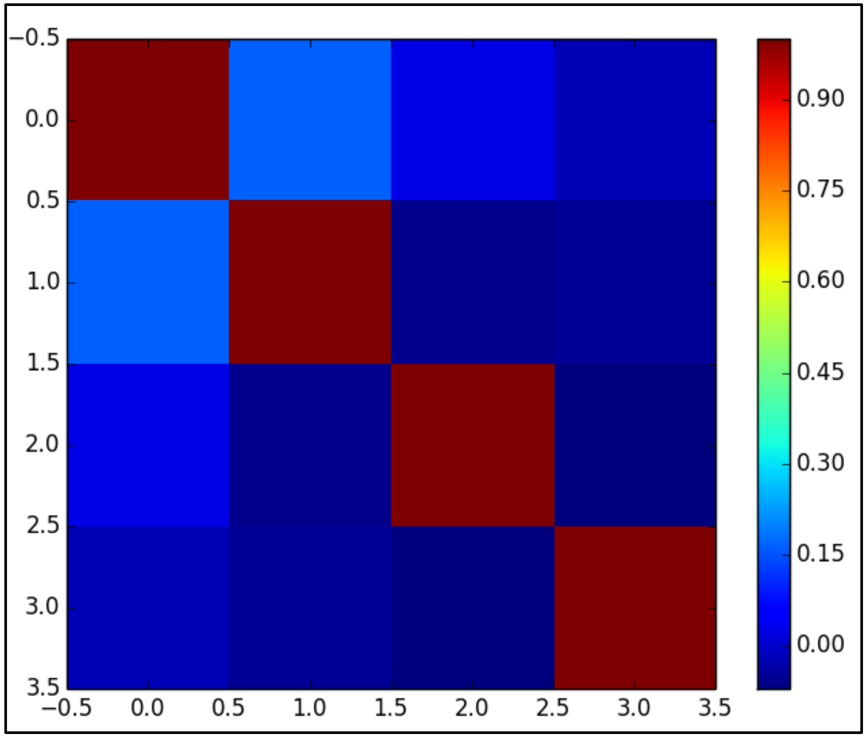
IMAGE PLOTS

```
>>> # Create some data
>>> e1 = rand(100)
>>> e2 = rand(100)*2
>>> e3 = rand(100)*10
>>> e4 = rand(100)*100
>>> corrmatrix = \
...   corrcoef([e1, e2, e3, e4])

>>> # Plot corr matrix as image
>>> imshow(corrmatrix,
... interpolation='nearest')
>>> colorbar()
```



Plotting from Scripts

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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

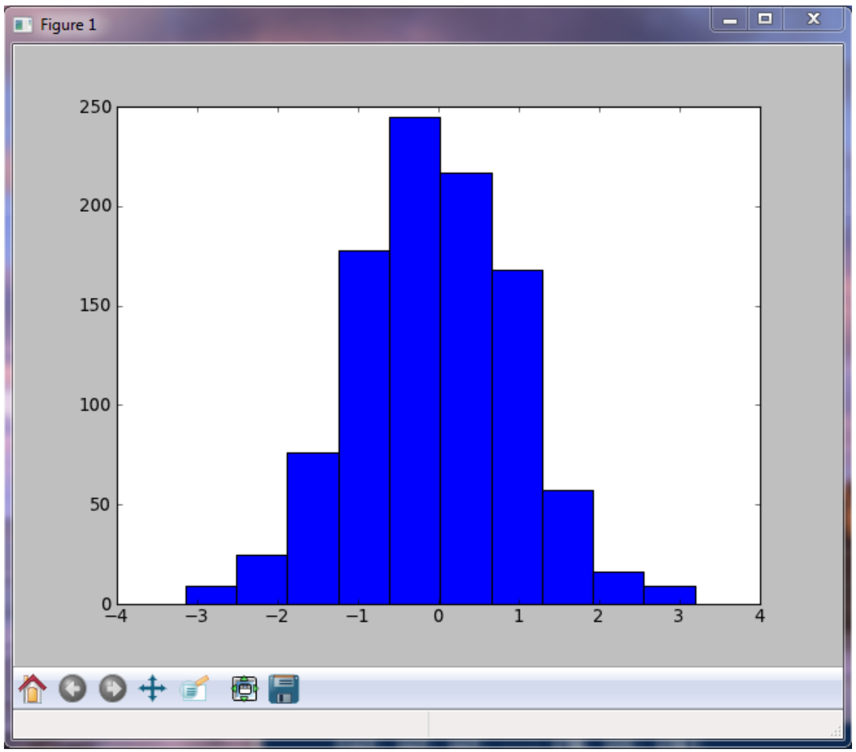
```
# script.py
# In a script, you must call
# the show() command to display
# plots. Call it at the end of
# all your plot commands for
# best performance.
figure()
plot(sin(x))
figure()
plot(cos(x))

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

Histograms

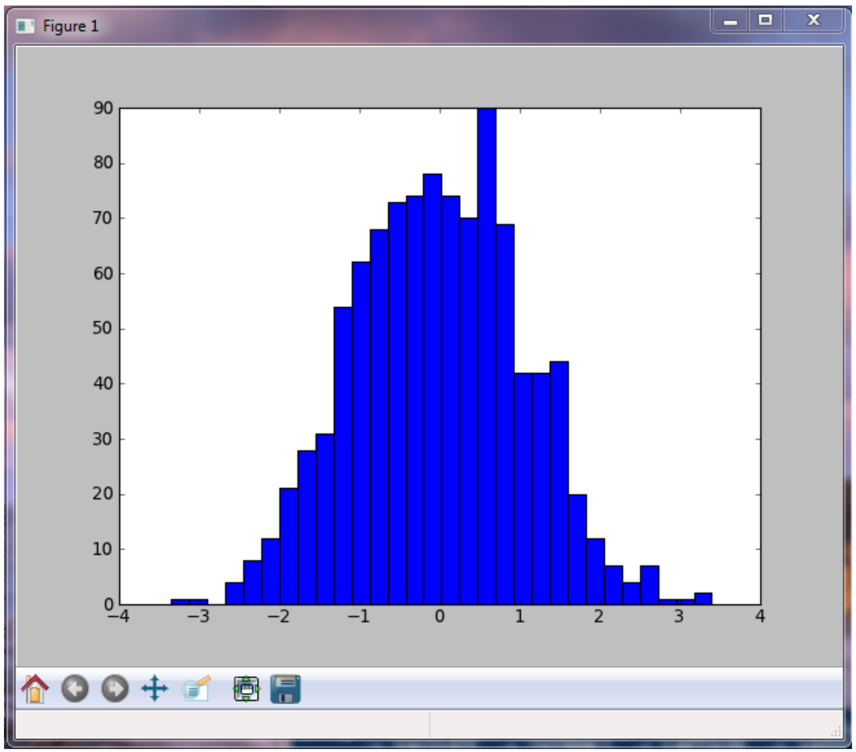
HISTOGRAM

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



HISTOGRAM 2

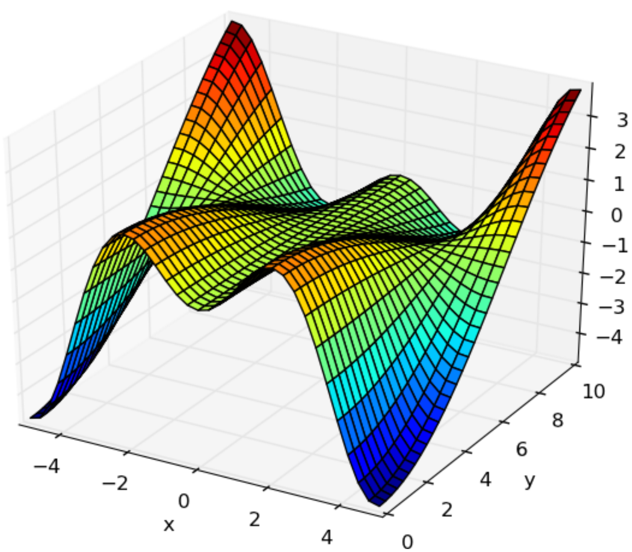
```
# change the number of bins
>>> hist(randn(1000), 30)
```



3D Plots with Matplotlib

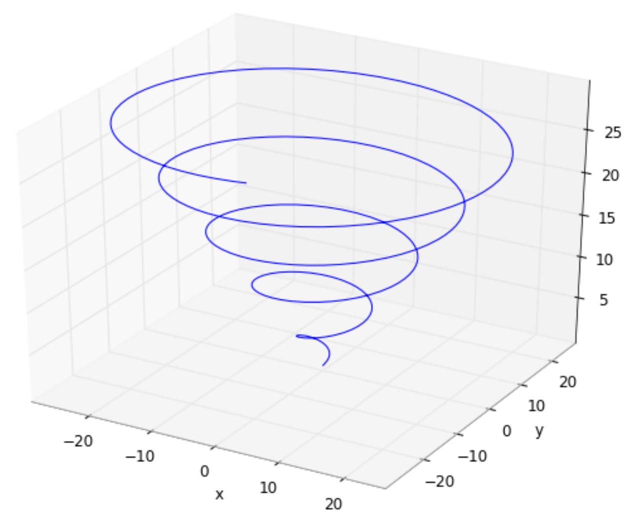
SURFACE PLOT

```
>>> 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’)
```



Numpy (continued)

Introducing NumPy Arrays

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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')
```

NUMBER OF DIMENSIONS

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

ARRAY SHAPE

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

BYTES PER ELEMENT

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

BYTES OF MEMORY USED

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

Array Operations

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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)
```

Setting Array Elements

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ARRAY INDEXING

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

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])
```

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])
```

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])
```

OMITTING 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])
```

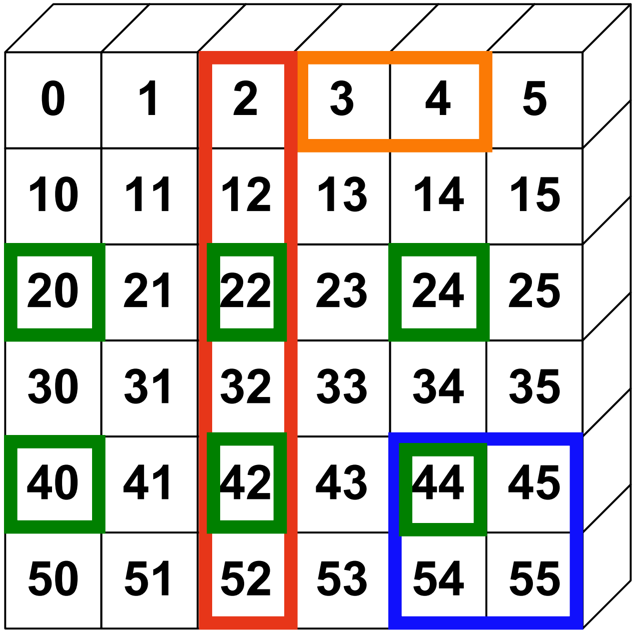
Array Slicing

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]])
```



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))

# 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])
```

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])
```

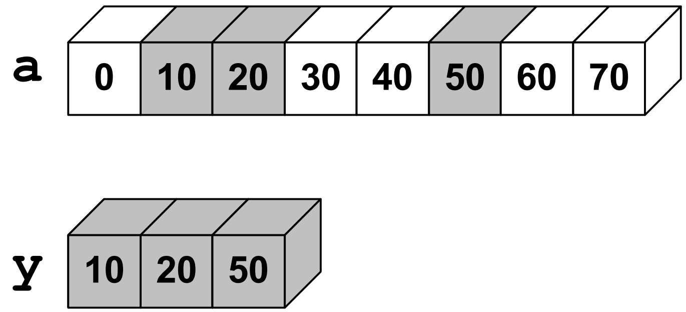
Fancy Indexing

INDEXING BY POSITION

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


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

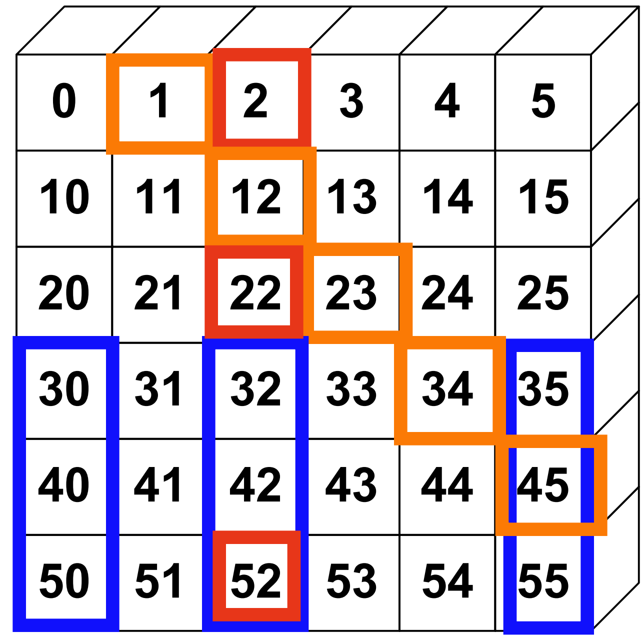
INDEXING WITH BOOLEANS

```
# 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]
```



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])
```

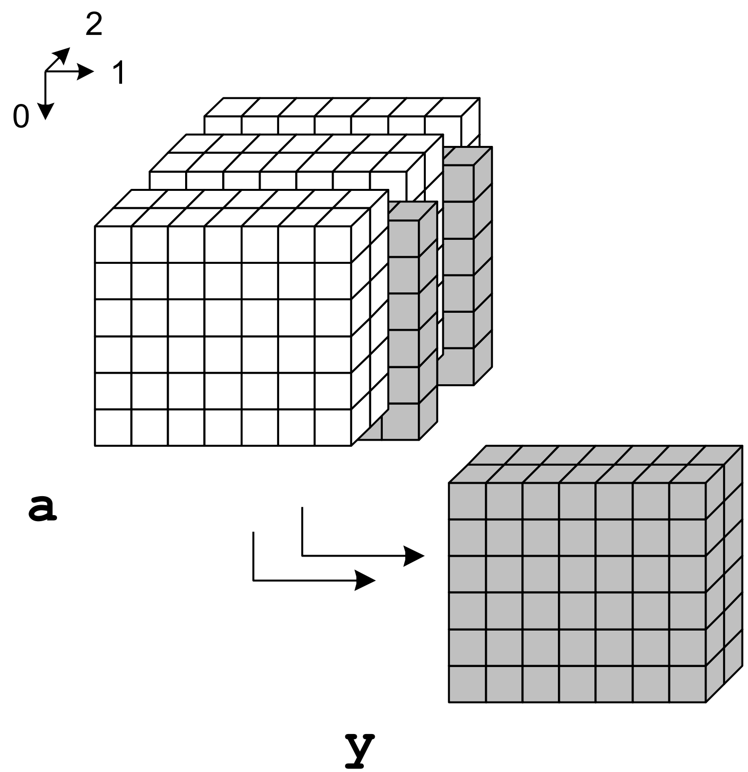


Unlike slicing, fancy indexing creates copies instead of a view into original array.

3D Example

MULTIDIMENSIONAL

```
# retrieve two slices from a
# 3D cube via indexing
>>> y = a[:,:,[2,-2]]
```



Creating arrays

Array Constructor Examples

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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 Creation Functions

ARANGE

```
arange(start=None,stop,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.])
```

Array Creation Functions (cont.)

DATA SCIENCE

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.])
```

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.])
```

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
```

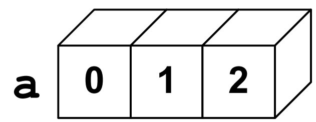
```
# loadtxt() automatically generates
# an array from the txt file
arr = loadtxt('Data.txt', skiprows=1,
    dtype=int, delimiter=",",
    usecols = (0,1,2,4),
    comments = "%")

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

Indexing with newaxis

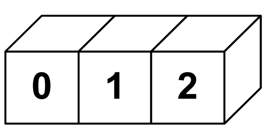
`newaxis` is a special index that inserts a new axis in the array at the specified location.

Each **`newaxis`** increases the array's dimensionality by 1.



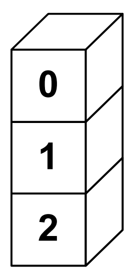
1 X 3

```
>>> shape(a)
(3,)
>>> y = a[newaxis,:]
>>> shape(y)
(1, 3)
```



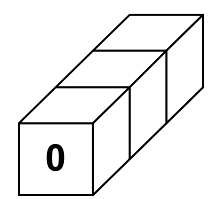
3 X 1

```
>>> y = a[:,newaxis]
>>> shape(y)
(3, 1)
```



1 X 1 X 3

```
> y = a[newaxis,newaxis,:]
> shape(y)
(1, 1, 3)
```



“Flattening” Arrays

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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]])
```

no change

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]])
```

changed!

“(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                    changed!
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]])
```

Reshaping Arrays

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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
```

Type Casting

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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.])
```

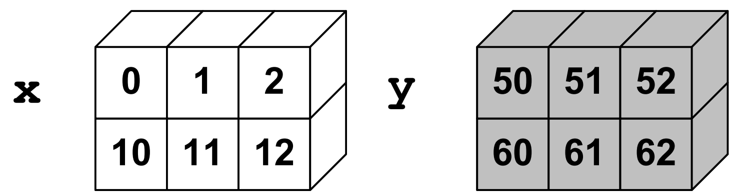
NumPy dtypes

Type	Available NumPy types	Code	Comments
Boolean	`bool`	`b`	Elements are 1 byte in size.
Integer	`int8, int16, int32, int64, int128, int`	`i`	int defaults to the size of long in C for the platform.
Unsigned Integer	`uint8, uint16, uint32, uint64, uint128, uint`	`u`	uint defaults to the size of unsigned long in C for the platform.
Float	`float16, float32, float64, float, longfloat`	`f`	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`	`c`	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`	`S` or `a, U`	For example, dtype='S4' would be used for an array of 4-character strings.
DateTime	`datetime64, timedelta64`	None	Allow operations between dates and/or times. New in 1.7.
Object	`object`	`O`	Represent items in array as Python objects.
Records	`void`	`V`	Used for arbitrary data structures.

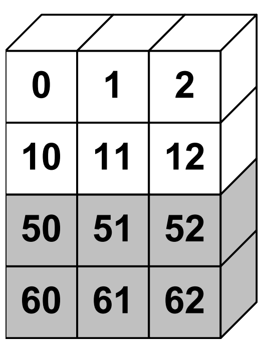
Concatenate

`concatenate((a0,a1,…,aN),axis=0)`

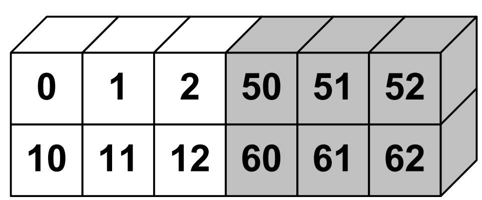
The input arrays **`(a0,a1,…,aN)`** are concatenated along the given **`axis`**. They must have the same shape along every axis *except* the one given.



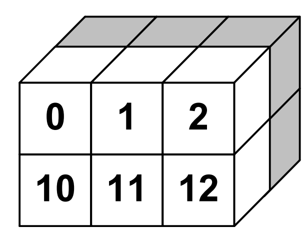

```
>>> concatenate((x,y))
```




```
>>> concatenate((x,y),1)
```

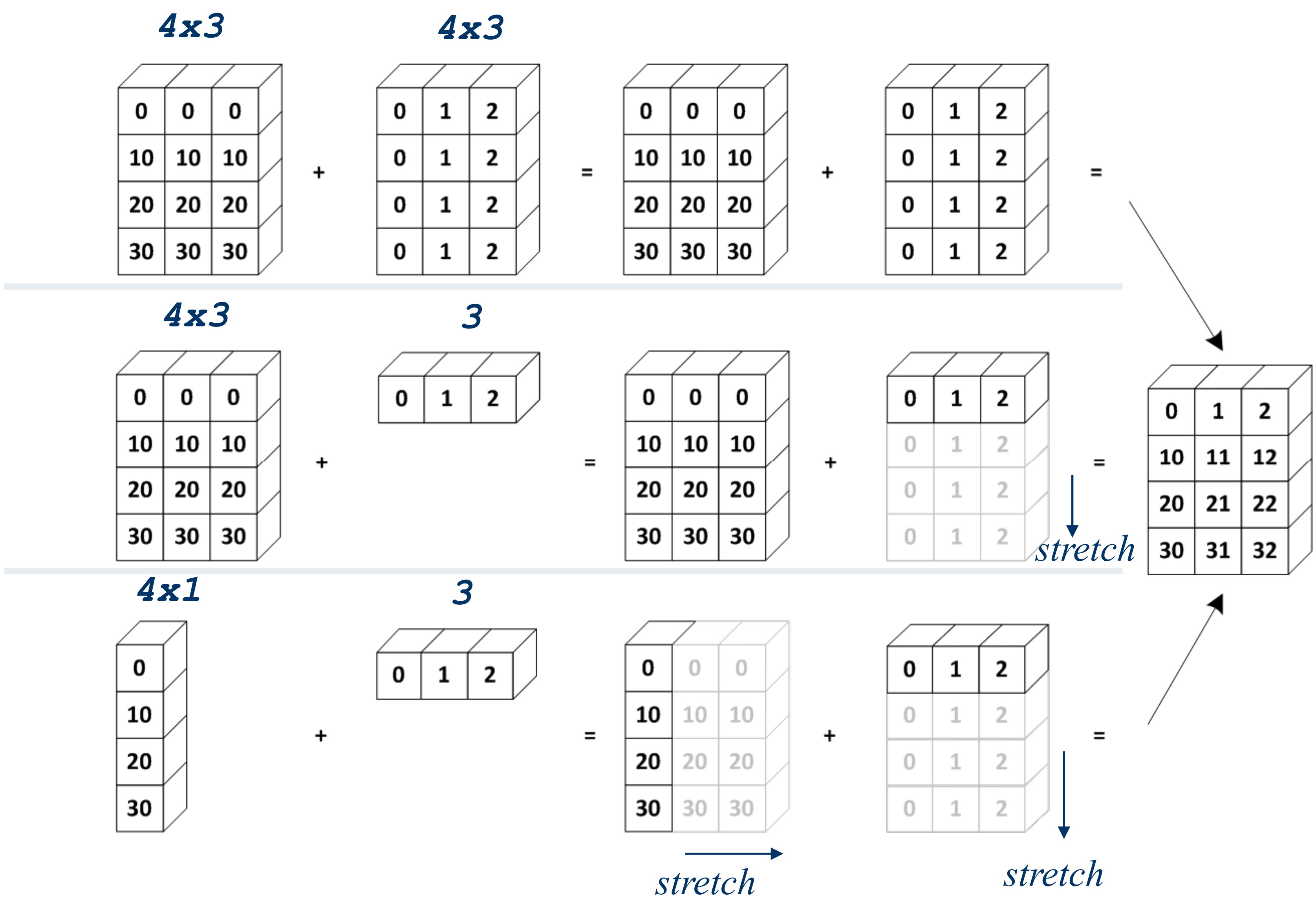



```
>>> array((x,y))
```



See also vstack(), hstack() and dstack() respectively.

Array Broadcasting



Array calculation methods

Array Calculation Methods

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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])

# as a function
>>> prod(a, axis=0)
array([ 4, 10, 18])
```

Min/Max

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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
# as a function
>>> amax(a, axis=0)
3.0
```

ARGMIN

```
# Find index of minimum value.
>>> a.argmin(axis=0)
2
# as a function
>>> argmin(a, axis=0)
2
```

ARGMAX

```
# Find index of maximum value.
>>> a.argmax(axis=0)
1
# as a function
>>> argmax(a, axis=0)
1
```

Statistics Array Methods

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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])
```

Trig and math Functions

TRIGONOMETRIC

```
sin(x)           sinh(x)
cos(x)           cosh(x)
arccos(x)        arccosh(x)

arctan(x)        arctanh(x)
arcsin(x)        arcsinh(x)
arctan2(x,y)
```

OTHERS

```
exp(x)           log(x)
log10(x)         sqrt(x)
absolute(x)      conjugate(x)
negative(x)      ceil(x)
floor(x)         fabs(x)
hypot(x,y)       fmod(x,y)
maximum(x,y)     minimum(x,y)
```

VECTOR OPERATIONS

```
dot(x,y)         vdot(x,y)
inner(x,y)       outer(x,y)
cross(x,y)       kron(x,y)
tensordot(x,y[,axis])
```

hypot(x,y)

Element by element distance calculation using $\sqrt{x^2 + y^2}$

Other array functions

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DATA SCIENCE

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		squeeze
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	nansum
prod	diag	nanmax
cumprod	select	nanargmax
diff	extract	nanargmin
angle	insert	nanmin

Vectorizing Functions

SCALAR SINC FUNCTION

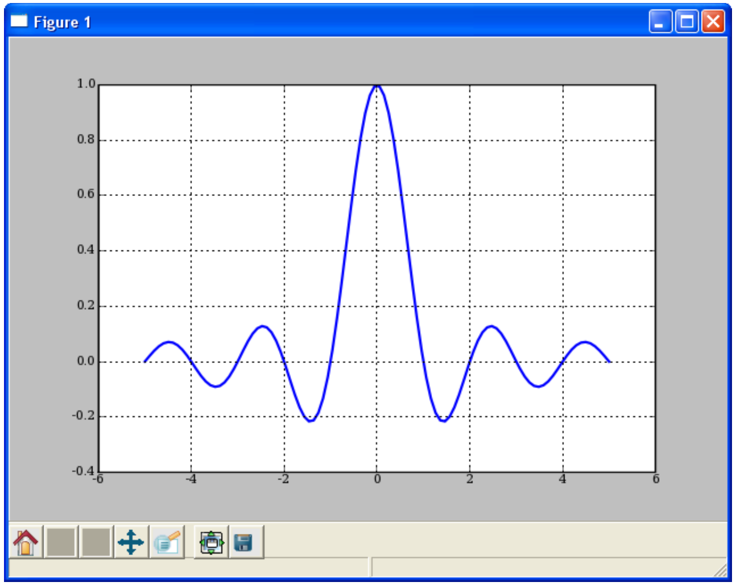
```
# special.sinc already available
# This is just for show.
def sinc(x):
    if x == 0.0:
        return 1.0
    else:
        w = pi*x
        return sin(w) / w
```

```
# 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))
```



"Advanced" NumPy

Advanced NumPy overview

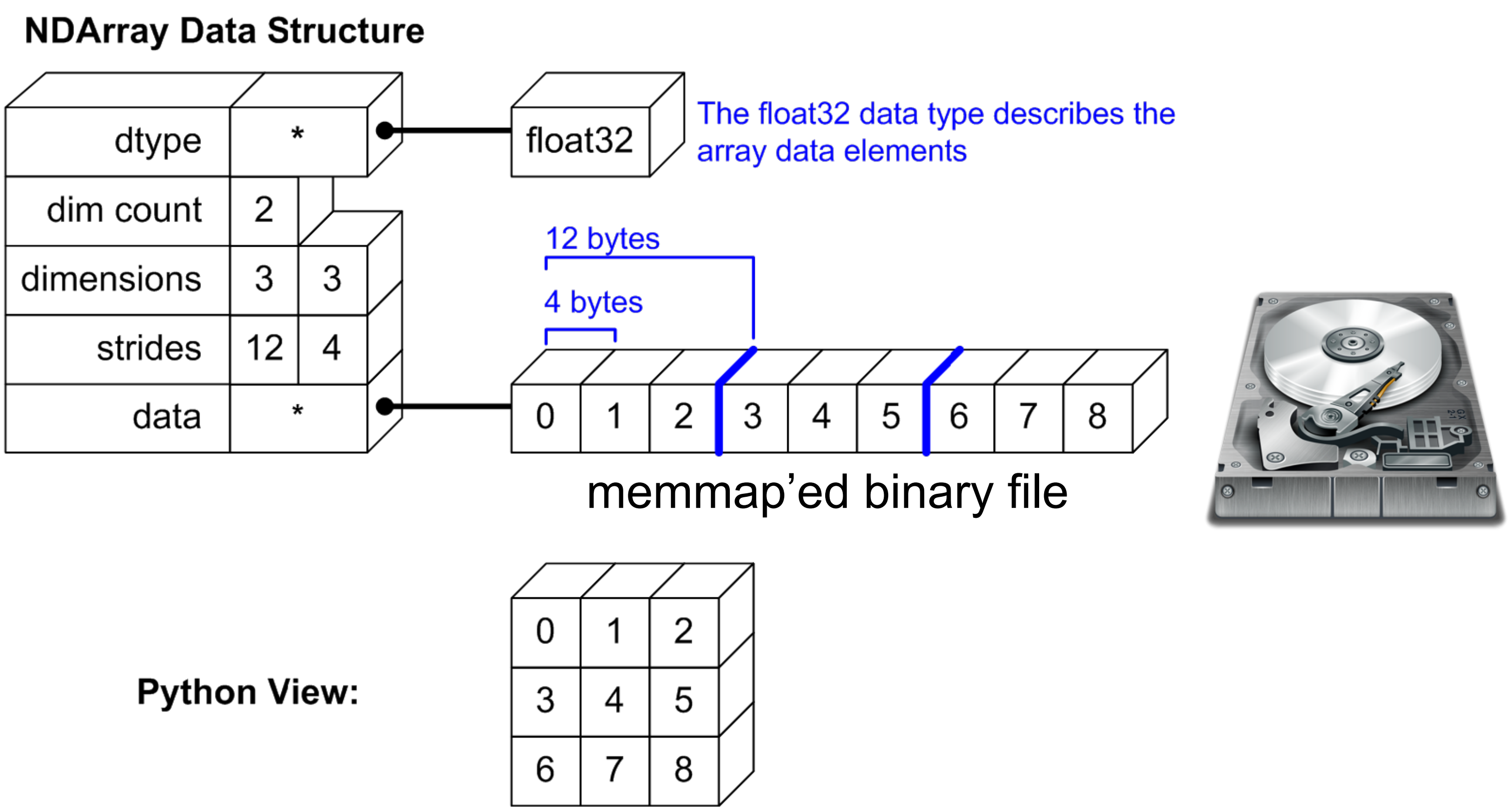
NumPy is the low-level core of most Python Data Science libraries.

There are a couple of advanced NumPy topics that it's worth being aware of:

- structured arrays
- memmap’ed arrays

memmap'ed arrays

The array data can come from any buffer-like storage, including memmap'ed files. Users can use the array object transparently, and the OS creates memory pages as needed.



Memory Mapped Arrays

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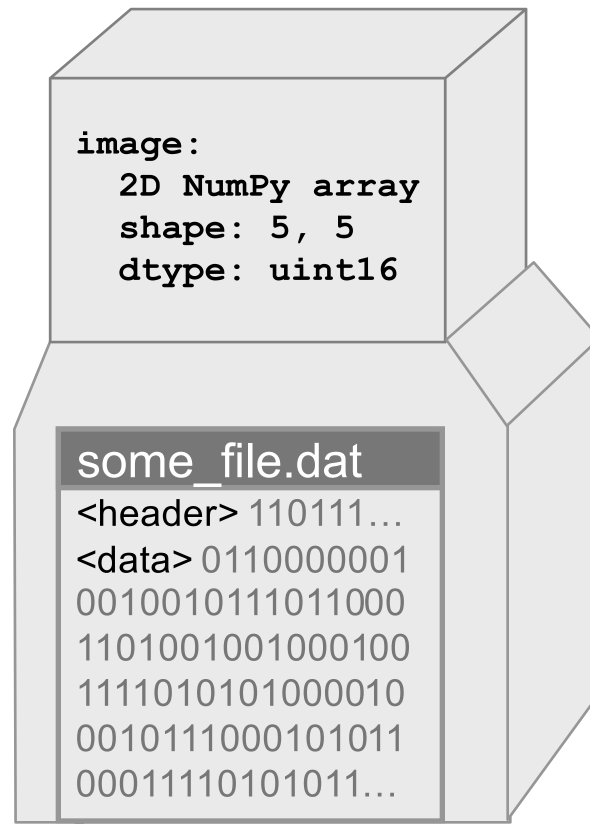
- Methods for Creating:
  - **memmap**: subclass of ndarray that manages the memory mapping details.
  - **frombuffer**: Create an array from a memory mapped buffer object.
  - **ndarray constructor**: Use the `buffer` keyword to pass in a memory mapped buffer.
- Limitations:
  - Files must be < 2GB 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).

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
```



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**': Open an existing file as an array for reading.

'**c**' or '**copyonwrite**': "Copy on write" arrays are "writable" as Python arrays, but they *never* modify the underlying file.

'**r+**' or '**readwrite**': Create a read/write array from an existing file. The file will have "write through" behavior where changes to the array are written to the underlying file. Use the **`flush()`** method to ensure the array is synchronized with the file.

'**w+**' or '**write**': Create the file or overwrite if it exists. The array is filled with zeros and has "write through" behavior similar to 'r+'.

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)
```

Structured arrays

Structured arrays allow interpreting the array elements as fields of multiple types. Combined with memmaps, it increases the opportunities for creating disk-backed arrays from binary files.

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)
```

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)]
```

Nested Datatype

logit DATA SCIENCE

nested.dat

Time	Size	Position				Gain	Samples (2048) ...			
		Az	El	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	–339
1172581077650	4108	0.567244	–0.148407	1	4	40	1537	–2633	–4945	–367
1172581077702	4108	0.558511	0.148407	1	4	40	1105	3701	6129	423

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)
```