Python

A. Svyatkovskiy, based on the original course by C. Rowley and R. Lupton

3 October 2016

Outline

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The Butterfly

machine code, assembly

"native"
C, C++, Fortran

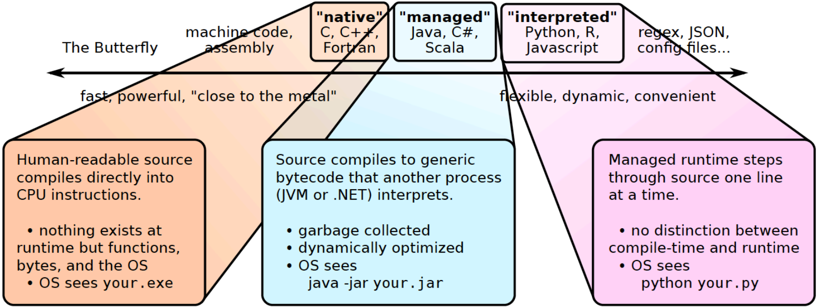
"managed"
Java, C#, Scala

"interpreted"
Python, R, Javascript

regex, JSON, config files...

fast, powerful, "close to the metal"

flexible, dynamic, convenient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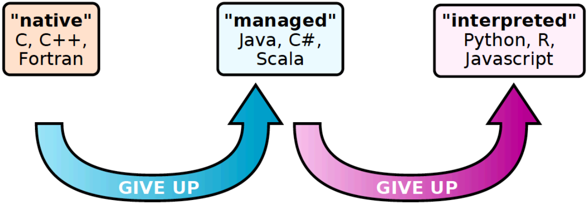
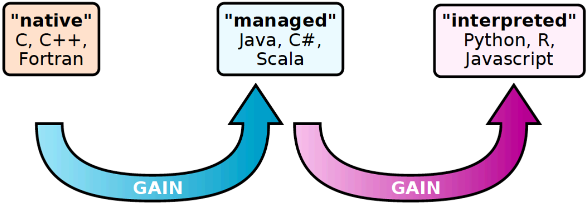
Human-readable source compiles directly into CPU instructions.
• nothing exists at runtime but functions, bytes, and the OS
• OS sees your.exe
Source compiles to generic bytecode that another process (JVM or .NET) interprets.
• garbage collected
• dynamically optimized
• OS sees java -jar your.jar
Managed runtime steps through source one line at a time.
• no distinction between compile-time and runtime
• OS sees python your.py



- memory management
- byte-level control
- some speed

- compilation step
- type safety
- some more speed



- high-level abstractions
- hardware portability
- easier debugging

- simplicity, flexibility
- rapid prototyping of incomplete ideas

Python

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- Object oriented
- Rich libraries
- Dynamic typing

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Hello World

Let us write "Hello world" in python:

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Or interactively:

```
$ python
>>> print "Hello world"
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On nobel.princeton.edu you can use python 2.7 and jupyter 4.1.1 by saying module load anaconda (maybe in your **.bashrc** file). If you find other Princeton machines where this doesn't work please let CSES know.

Primitive types

- None
- bool (True , False)
- int
- long (arbitrary precision)
- float

Lists and Tuples

Python supports two separate-but-almost-equal list types:

- list

```
>>> li = [100, 101, 102, 103]
>>> li[0]
100
>>> x = li[1:3]
>>> x
[101, 102]                                    # not [100, 101, 102]
```

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>>> li[-1] = 666
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Useful list methods: append , insert , pop , reverse , sort , index

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Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: 'tuple' object does not support item assignment
```

Strings

Python strings can be delimited with ", ', """, or '''

```
>>> s = "Hello world"
>>> s2 = 'Goodbye, sweet life'
>>> s3 = """I really like
to split greetings over multiple lines"""
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Dictionaries

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>>> di.update({"rhl" : "Robert"}}
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You can use dictionaries in conjunction with `%` formatting:

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>>> addressBook = {}
>>> addressBook["Alexey"] = ["alexeys", "Svyatkovskiy"]
>>> addressBook["Robert"] = ["rhl", "Lupton"]
>>> print addressBook["Alexey"][0]
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>>> print addressBook["Robert"]["email"]
rhl
```

You can't use a `list` as a key in a `dict` (as you might modify the list later), but you *can* use a `tuple` as it's immutable.

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Control structures

Python has the standard control structures: if-elif-else , for , while and logicals and , or , not == , < , . . .

```
if x == 1:
    print "One"
elif x == 2 or x == 3:
    print "Two or Three"
else:
    print "Something else"
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Another issue is mixing tabs and spaces; it's probably better to instruct your editor to insert spaces even when you hit the tab key to avoid the problem.

for and while loops

```
for r in ("Arrow", "Birdland", "Matinee"):
   print r
```

for and while loops

```
for r in ("Arrow", "Birdland", "Matinee"):
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n = 10
for i in range(n):
    for j in range(i, n):
        print i, j
```

(note that range(n) counts from 0 to n-1, not up to n).

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(note that `range(n)` counts from `0` to `n-1`, not up to `n`).

```
i = 0
while True:
    i += 10
    if i == 100:
        break
    print i
```

for and while loops

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for r in ("Arrow", "Birdland", "Matinee"):
    print r

n = 10
for i in range(n):
    for j in range(i, n):
        print i, j
```

(note that range(n) counts from 0 to n-1 , not up to n).

```
i = 0
while True:
    i += 10
    if i == 100:
        break
    print i
```

continue is also available.

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That comma is essential. It isn't really the loop's fault, it's just that a string is treated as a list of characters.

Functions

```
def simple_squares(n):
    squares = []
    for number in range(n):
        squares.append(number*number)
        # Now, squares should have [1,4,9,16,25]
    print "List of squares: ", squares
```

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This mans that if you modify a list or dictionary passed to a function it'll be modified in the calling routine too; you may need to make a copy:

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li = li[:]
di = di.copy()
```

It'd be nice if `list` also supported `copy` , the closest is `list(xxx)` . You can always use `import copy; copy.copy(xxx)` (but it's slower).

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li = li[:]
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```

It'd be nice if list also supported copy , the closest is list(xxx) . You can always use import copy; copy.copy(xxx) (but it's slower). This is a *shallow copy*, but copy.deepcopy is also available.

Lambda Functions

Python supports anonymous functions using a construct called "lambda". Sometimes you need to pass a function as an argument, or you want to do a short but complex operation multiple times. Following lambda is completely identical to the function defined on the previous slide:

```
def simple_squares_lambda(n):
    squares = map(lambda x: x*x, range(n))
    print "List of squares calculated in a Pythonic way with lambda: ",
```

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    squares = map(lambda x: x*x, range(n))
    print "List of squares calculated in a Pythonic way with lambda: ",
```

Lambda functions are typically used in functional programming languages like Scala and in frameworks like Spark.

Functional programming

map, *filter*, *reduce* functions facilitate a functional approach to programming in Python:

```
def functional_python(n):
    squares = map(lambda x: x*x, filter(lambda x: x < 4, range(n)))
    return squares
```

Hello World

A better **hello.py** script is

```
$ cat hello.py
#!/usr/bin/env python
def greet(who="world")
    print "Hello %s" % (who)

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

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

The advantage is that I can say either

```
$ python hello.py
Hello world
```

or

```
>>> import hello
>>> hello.greet("class")
Hello class
```

(__name__ is "__main__" when run from the shell, and "hello" when imported).

Default arguments

You can also specify default values for arguments (as well as variable numbers of arguments):

```
def my_range(n, end=None, dn=1):
    """Return a list of numbers
Details ...
"""
    if end is None:
        i, end = 0, n
    else:
        i = n

    out = []
    while i < end:
        out.append(i)
        i += dn

    return out
```

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    else:
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    out = []
    while i < end:
        out.append(i)
        i += dn

    return out
```

```
>>> my_range(3)
(0, 1, 2)
>>> my_range(2, 4)
(2, 3)
>>> my_range(2, 10, 2)
(2, 4, 6, 8)
>>> my_range(10, dn=2)
(0, 2, 4, 6, 8)
```

List comprehensions

```
>>> print [10 + x for x in range(5)]
[10, 11, 12, 13, 14]
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If you write instead

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>>> r = (10 + x for x in range(5))
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you get a *generator* instead:

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<generator object <genexpr> at 0x1005cde10>
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>>> print r
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>>> print [x for x in r]
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>>> print list(r)
[10, 11, 12, 13, 14]
```

See the next slide for an explanation.

Dictionary comprehensions

A dictionary comprehension takes the form *key: value for (key, value) in iterable*. This syntax was introduced in Python 3 and backported to Python 2.7. Main use case is given two lists to create a dictionary where the item at each position in the first list becomes a key and the item at the corresponding position in the second list becomes the value:

```
>>> seasons = ['Fall','Winter','Spring','Summer']
>>> {k[:2]: v for (k, v) in zip(seasons, range(len(seasons)))}
{'Fa': 0, 'Sp': 2, 'Su': 3, 'Wi': 1}
```

Generators and iterators

Consider

```
def fibonacci(n):
    prev = 0
    cur = 1
    for j in range(n):
        yield cur
        (cur, prev) = (cur + prev, cur)
```

Generators and iterators

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```
>>> [x for x in fibonacci(10)]
[1, 1, 2, 3, 5, 8, 13, 21, 34, 55]
```

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[1, 1, 2, 3, 5, 8, 13, 21, 34, 55]
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fibonacci returns a *generator* which has a method next . The first call to next calls fibonacci and returns the value of the yield statement. When you call next again it miraculously resumes just after the yield and continues until it reaches yield again; when it returns (either explicitly or implicitly) a StopIteration exception is raised:

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`fibonacci` returns a *generator* which has a method `next`. The first call to `next` calls `fibonacci` and returns the value of the `yield` statement. When you call `next` again it miraculously resumes just after the `yield` and continues until it reaches `yield` again; when it `returns` (either explicitly or implicitly) a `StopIteration` exception is raised:

```
>>> f = fibonacci(1)
>>> f.next()
1
>>> f.next()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
StopIteration
```

Exceptions

Don't do this at home:

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>>> my_range(0, 10, -2)
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>>> ^C^C
>>> import pdb;  pdb.pm()
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> <stdin>(13)my_range()
(Pdb) p i
-5184308
(Pdb)
```

We're counting down to $-\infty$

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```

We're counting down to $-\infty$

```
def my_range(n, end=None, dn=1):
    ...
    if end > n and dn <= 0:
        raise RuntimeError("Increment is negative: %g" % (dn))
```

Catching exceptions

An exception need not be fatal:

```
try:
   my_range(0, 10, -2)
except RuntimeError, e:
   print "Caught exception:", e
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There are also more complicated and powerful forms of this try except pattern.

Classes

Python is an Object Oriented language. In **people.py** I wrote:

```
class Person(object):
    """Describe a person"""

    def __init__(self, email=None, surname=None):
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Note that `self` plays the part of C++'s `this`, but you have to explicitly write it out. All member functions expect `self` as their first argument. Let's use our new `class`

```
>>> import people
>>> addressBook = {}
>>> addressBook["Clancy"] = people.Person("cwrowley", "Rowley")
>>> addressBook["Robert"] = people.Person(surname="Lupton")
>>> print addressBook["Clancy"].email
cwrowley
```

Special Methods

Let’s take a look at Clancy:

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That's annoying. The solution is to add a method `__str__` to `Person`:

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class Person(object):
    ...
    def __str__(self):
        return "(%s, %s)" % (self.email, self.surname)
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After a `reload` and after rebuilding `addressBook` with our new version of `Person` , we get:

```
>>> print addressBook["Clancy"]
(cwrowley, Rowley)
```

Dynamic typing

Let's return to another old friend[1], `max`

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def max(a, b):
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>>> print max("a", "b")
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>>> print max(["a", "b"], ["a", "c"])
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```

The comparison is consistent-but-undefined. If we want to sort by the email address:

```
def __cmp__(self, rhs):
    return cmp(self.email, rhs.email)
```

and now max works as expected.

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Outline

Libraries

The Official Library

`http://docs.python.org/2/library/index.html`

Python has *many* libraries. I'll skim the surface of four

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Python has *many* libraries. I'll skim the surface of four

- `re` Regular expressions
- `argparse` Argument parsing
- `matplotlib` Plotting
- `numpy` Array operations

you can install `matplotlib` and `numpy` (and more) using anaconda; `re` and `argparse` are part of python's standard library.

Regular Expressions, re

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The object returned by re.search contains matched substrings:

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```

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```

Python's re module provides two searching methods. I've been using search , but there is also match . I recommend that you never use match (because re.match(r"RE", ...) == re.search(r"

Command Line Parsing

One of the uses of python is to write utilities run from the command line. In C you'd use `getopt`, in C++ `getopt` or `boost::program_options`.

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One of the uses of python is to write utilities run from the command line. In C you'd use `getopt`, in C++ `getopt` or `boost::program_options`. In python you have (sigh) three options:

- `getopt` Deprecated since python 2.3
- `optparse` Deprecated in python 2.7
- `argparse` The new kid on the block; only in python 2.7 (and 3.?), but back-ported to 2.6.

Your best choice in new code

argparse

```
#!/usr/bin/env python
import argparse

parser = argparse.ArgumentParser(description='Say hello')

parser.add_argument('who', metavar='who', type=str, nargs='*',
                   help='List of people to greet',
                   default=["world"])
parser.add_argument("-w", "--who",
                  dest="speaker", help="name of speaker",
                  default="Robert")
parser.add_argument("-s", "--silent", action='store_true', default=False
                  help="Refuse to say anything")

args = parser.parse_args()

if args.silent:
    print "I plead the fifth"
else:
    print "%s says \"Hello %s\"" % (args.speaker, " ".join(args.who))
```

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```

```
$ hello.py
Robert says "Hello world"
$ hello.py -s TAs and the class
I plead the fifth
$ hello.py --who Clancy TAs and the class
Clancy says "Hello TAs and the class"
```

Plotting, matplotlib

While there are a number of plotting packages available for python, the most popular seems to be matplotlib ; a list of other options may be found at `https://wiki.python.org/moin/NumericAndScientific/Plotting`.
We'll only discuss matplotlib here.

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There's quite a nice tutorial from the EuroScipy 2012 conference at

`http://webloria.loria.fr/~rougier/teaching/matplotlib`

Using matplotlib from the python prompt

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This is what we recommend.

Using matplotlib from the python prompt

Using matplotlib from a python shell is a little tricky (see `http://matplotlib.org/users/shell.html`) for a discussion. One way to get interactive plotting is to use ipython -pylab (or ipython --pylab in newer releases). See `http://ipython.org/ipython-doc/stable/interactive/reference.html#plotting-with-matplotlib`. This is what we recommend.

If you insist on purity, you can use Qt4Agg by setting values in **$HOME/.matplotlib/matplotlibrc**:

```
backend       : Qt4Agg
interactive   : True
```

Using Qt4Agg requires that your version of python was built with Qt support (comes with Anaconda).

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```

Using Qt4Agg requires that your version of python was built with Qt support (comes with Anaconda).
matplotlib can use other backends (*e.g.* WXAgg) if you have the proper package installed (in this case wxPython)
The interactive: True means that matplotlib should *not* enter its wait-for-the-user interactive loop.

Plotting using matplotlib

There are two-and-a-half ways to use matplotlib

Plotting using `matplotlib`

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- Interactive:
  - uses `matplotlib.pyplot` package (or `matplotlib.pylab`)
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  - looks very similar to matlab
- Object-oriented (more *pythonic*), using pyplot.figure and axes
- Using the low-level objects directly:
  - Renderers which provide an abstract interface to drawing primitives (*e.g.* draw_path)
  - Backend objects which take care of how to actually draw the object (*e.g.* Qt4Agg to use Qt)
  - A FigureCanvas to draw on
  - An Artist that knows how to use *renderers* to draw on *canvases*.

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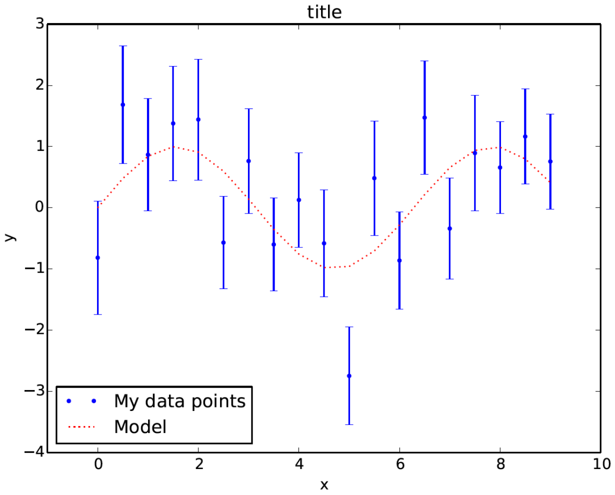
  - A FigureCanvas to draw on
  - An Artist that knows how to use *renderers* to draw on *canvases*.

If you need fine control over your plots you need to know the classes and their methods, but you may not need to go far down that path.

Interactive plotting with matplotlib.pylab

For interactive use, probably the most convenient is to use pylab , which looks a lot like Matlab:

plot_sin.pdf



Using matplotlib.pyplot

Format characters

The format string is of the form CM (ColourMarker)

b	blue	-	solid line	.	point
g	green	--	dashed line	,	pixel
r	red	:	dotted line	o	circle
c	cyan	-.	dot-dash line	v	triangle (down)
m	magenta			^	triangle (up)
y	yellow			<	triangle (left)
k	black			>	triangle (right)
w	white				

There are more colours, but it's better to use the color keyword. For markers, it's really better to use the marker and linestyle (abbreviation: ls) keywords

Semi-*OO* plotting with matplotlib

Jupyter (a.k.a. iPython) notebooks

We can run these commands in the browser with a command like:

```
$ jupyter notebook --no-browser src/notebooks/sin.ipynb
```

This provides a nice way of documenting your work.

See http://jupyter.readthedocs.io/en/latest/install.html

Multi-panel plots

Once again, I need a `figure`, and then the command to select the third sub-window out of a `2x2` set is

```
figure.add_subplot(2, 2, 3)
```

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so I could say

```
axes = figure.add_subplot(2, 2, 1)
# make a plot
axes = figure.add_subplot(2, 2, 2)
# make another plot
axes = figure.add_subplot(2, 2, 3)
# keep plotting
axes = figure.add_subplot(2, 2, 4)
# plot plot plot
```

But I'm lazy and I don't like duplicating `2, 2`

Multi-panel plots

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```
figure.add_subplot(2, 2, 3)
```

so I could say

```
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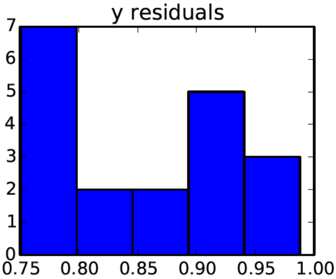
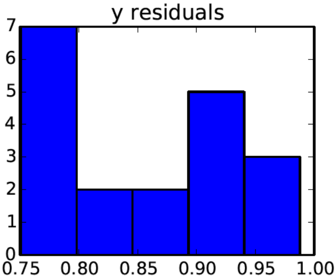
# make another plot
axes = figure.add_subplot(2, 2, 3)
# keep plotting
axes = figure.add_subplot(2, 2, 4)
# plot plot plot
```

But I'm lazy and I don't like duplicating `2, 2`
Instead, I'll use a generator:

Panel I: Histogram

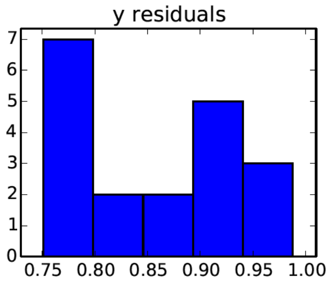

y residuals
7
6
5
4
3
2
1
0
0.75
0.80
0.85
0.90
0.95
1.00



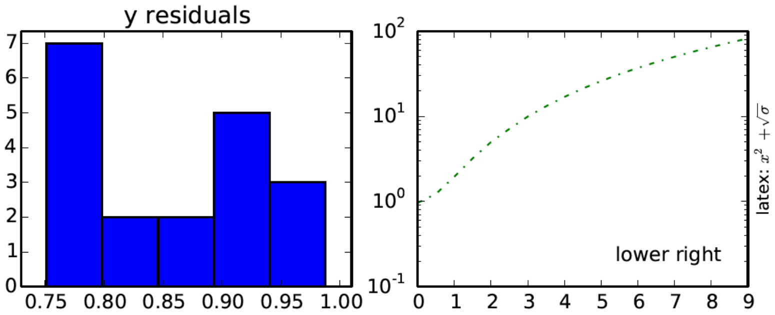
Hmm. Not a good choice for the axis limits.

Panel I: Histogram

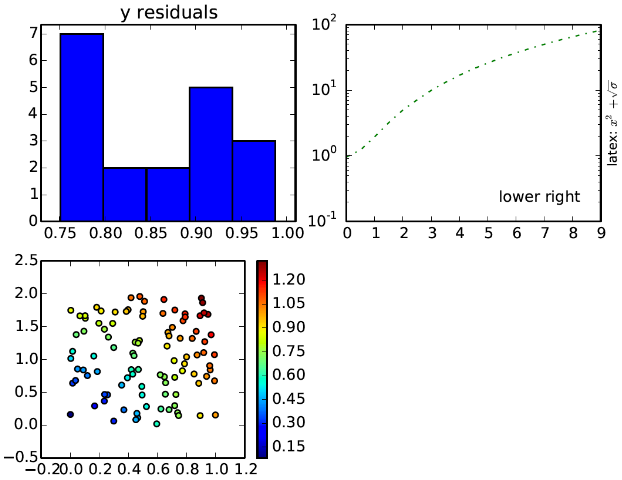
Let's fix those limits:


y residuals
7
6
5
4
3
2
1
0
0.75
0.80
0.85
0.90
0.95
1.00

Panel II: Log-linear

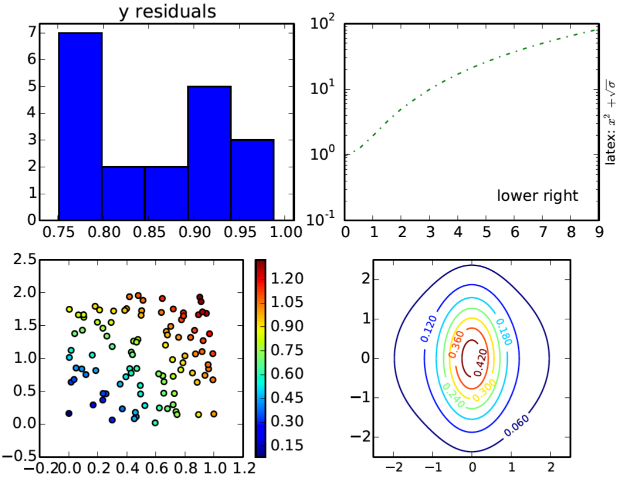

y residuals
7
6
5
4
3
2
1
0
0.75 0.80 0.85 0.90 0.95 1.00
10^2
10^1
10^0
10^{-1}
0 1 2 3 4 5 6 7 8 9
lower right
latex: $x^2 + \sqrt{\sigma}$

Panel III: Scatter Plot


y residuals
7
6
5
4
3
2
1
0
0.75 0.80 0.85 0.90 0.95 1.00
10^2
10^1
10^0
10^{-1}
0 1 2 3 4 5 6 7 8 9
lower right
latex: $x^2 + \sqrt{\sigma}$
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15

Panel IV: Contours

plot_multi.pdf



Non-interactive plotting

What if you just want to make a plot, and not worry about interactive and Qt ? One way is to use a canvas :

Array operations, numpy

While the array library, numpy , is not part of the python standard library it is widely available.

NumPy home (but it's easier to get it from *anaconda*)

`http://numpy.scipy.org`

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import numpy as np
```

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```
import numpy as np

x = np.linspace(0.0, 9.0, 19)
model = np.sin(x)
```

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```
import numpy as np

x = np.linspace(0.0, 9.0, 19)
model = np.sin(x)

yerr = np.abs(y - model)
zs = np.sqrt(xs**2 + ys**2/4.0)
```

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zs = np.sqrt(xs**2 + ys**2/4.0)

np.random.seed(666)
xs = np.random.random(100)
y = np.random.normal(loc=model, scale=0.2)
```

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zs = np.sqrt(xs**2 + ys**2/4.0)

np.random.seed(666)
xs = np.random.random(100)
y = np.random.normal(loc=model, scale=0.2)

axis = np.linspace(-2.0, 2.0, 100)
X, Y = np.meshgrid(axis, axis)
```

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np.random.seed(666)
xs = np.random.random(100)
y = np.random.normal(loc=model, scale=0.2)

axis = np.linspace(-2.0, 2.0, 100)
X, Y = np.meshgrid(axis, axis)
```

The import numpy as np is common enough that it's what the numpy documentation assumes.

numpy Arrays

numpy Arrays

```
>>> x = np.linspace(0.0, 5.0, 11); print x
[ 0.   0.5  1.   1.5  2.   2.5  3.   3.5  4.   4.5  5. ]
```

numpy Arrays

```
>>> x = np.linspace(0.0, 5.0, 11); print x
[ 0.   0.5  1.   1.5  2.   2.5  3.   3.5  4.   4.5  5. ]
```

We could have used arange (analogous to python's range):

```
>>> print np.arange(0.0, 5.1, 0.5)
[ 0.   0.5  1.   1.5  2.   2.5  3.   3.5  4.   4.5  5. ]
```

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>>> x = np.linspace(0.0, 5.0, 11); print x
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```
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[ 0.   0.5  1.   1.5  2.   2.5  3.   3.5  4.   4.5  5. ]
```

There's also

```
>>> print np.zeros(4), np.ones(4), np.empty(4, dtype='i')
[0.  0.  0.  0.] [1.  1.  1.  1.] [9 0 18402543 1]
```

numpy Arrays

```
>>> x = np.linspace(0.0, 5.0, 11); print x
[ 0.   0.5  1.   1.5  2.   2.5  3.   3.5  4.   4.5  5. ]
```

We could have used arange (analogous to python's range):

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>>> print np.arange(0.0, 5.1, 0.5)
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```

There's also

```
>>> print np.zeros(4), np.ones(4), np.empty(4, dtype='i')
[0.  0.  0.  0.] [1.  1.  1.  1.] [9 0 18402543 1]
```

```
>>> x = np.arange(5); print np.multiply.outer(x, x)
[[ 0  0  0  0  0]
 [ 0  1  2  3  4]
 [ 0  2  4  6  8]
 [ 0  3  6  9 12]
 [ 0  4  8 12 16]]
```

numpy Mathematical functions

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```
>>> x = np.arange(5)
>>> y = np.sin(x); print y
[ 0.          0.84147098  0.90929743  0.14112001 -0.7568025 ]
```

There are lots of other mathematical builtins (sin , cos , tan , arcsin , arctan2 , abs , sqrt , . . .)

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```

There are lots of other mathematical builtins (sin , cos , tan , arcsin , arctan2 , abs , sqrt , . . .)

```
>>> print zip(x, y)
[(0, 0.0), (1, 0.8414709848078965), (2, 0.90929742682568171),
 (3, 0.14112000805986721), (4, -0.7568024953079282)]
```

numpy Mathematical functions

```
>>> x = np.arange(5)
>>> y = np.sin(x); print y
[ 0.          0.84147098  0.90929743  0.14112001 -0.7568025 ]
```

There are lots of other mathematical builtins (sin , cos , tan , arcsin , arctan2 , abs , sqrt , . . .)

```
>>> print zip(x, y)
[(0, 0.0), (1, 0.8414709848078965), (2, 0.9092974268256817),
 (3, 0.1411200080598672), (4, -0.7568024953079282)]
```

```
>>> print "\n".join(("%d %6.3f" % z for z in zip(x, y)))
0  0.000
1  0.841
2  0.909
3  0.141
4 -0.757
```

(OK, so that's a python, not numpy , trick)

numpy Random Numbers

numpy Random Numbers

```
>>> np.random.seed(666)
>>> np.random.random(10)
array([ 0.70043712,  0.84418664,  0.67651434,  0.72785806,  0.95145796,
        0.0127032 ,  0.4135877 ,  0.04881279,  0.09992856,  0.50806631])
```

(*n.b.* I didn't say `print`, so I got the `repr` not the `str` value of the result)

numpy Random Numbers

```
>>> np.random.seed(666)
>>> np.random.random(10)
array([ 0.70043712,  0.84418664,  0.67651434,  0.72785806,  0.95145796,
        0.0127032 ,  0.4135877 ,  0.04881279,  0.09992856,  0.50806631])
```

(*n.b.* I didn't say print , so I got the repr not the str value of the result)

```
>>> print np.random.normal(loc=np.arange(5), scale=0.2)
[-0.2177586   0.88484585  1.66341985  3.04583705  3.64867496]
>>> print np.random.normal(np.arange(5), 0.2)
[ 0.16892652  1.05544397  2.17058031  3.03891992  4.26212754]
```

The two calls are identical, but the random numbers are (of course) different.

numpy in n-D

numpy in n-D

```
>>> axis = np.linspace(-2.0, 2.0, 5)
>>> X, Y = np.meshgrid(axis, axis)
>>> print X
[[-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]]
>>> print Y
[[-2. -2. -2. -2. -2.]
 [-1. -1. -1. -1. -1.]
 [ 0.  0.  0.  0.  0.]
 [ 1.  1.  1.  1.  1.]
 [ 2.  2.  2.  2.  2.]]
```

numpy in n-D

```
>>> axis = np.linspace(-2.0, 2.0, 5)
>>> X, Y = np.meshgrid(axis, axis)
>>> print X
[[-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]]
>>> print Y
[[-2. -2. -2. -2. -2.]
 [-1. -1. -1. -1. -1.]
 [ 0.  0.  0.  0.  0.]
 [ 1.  1.  1.  1.  1.]
 [ 2.  2.  2.  2.  2.]]

>>> print np.cos(X)*np.sin(Y)
[[ 0.37840125 -0.4912955  -0.90929743 -0.4912955   0.37840125]
 [ 0.35017549 -0.45464871 -0.84147098 -0.45464871  0.35017549]
 [-0.          0.          0.          0.         -0.        ]
 [-0.35017549  0.45464871  0.84147098  0.45464871 -0.35017549]
 [-0.37840125  0.4912955   0.90929743  0.4912955  -0.37840125]]
```

numpy in n-D

```
>>> axis = np.linspace(-2.0, 2.0, 5)
>>> X, Y = np.meshgrid(axis, axis)
>>> print X
[[-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]
 [-2. -1.  0.  1.  2.]]
>>> print Y
[[-2. -2. -2. -2. -2.]
 [-1. -1. -1. -1. -1.]
 [ 0.  0.  0.  0.  0.]
 [ 1.  1.  1.  1.  1.]
 [ 2.  2.  2.  2.  2.]]

>>> print np.cos(X)*np.sin(Y)
[[ 0.37840125 -0.4912955  -0.90929743 -0.4912955   0.37840125]
 [ 0.35017549 -0.45464871 -0.84147098 -0.45464871  0.35017549]
 [-0.          0.          0.          0.         -0.        ]
 [-0.35017549  0.45464871  0.84147098  0.45464871 -0.35017549]
 [-0.37840125  0.4912955   0.90929743  0.4912955  -0.37840125]]

>>> print np.fft.fft(X)*np.sin(Y)
[[-0.00000000+0.j          2.27324357-3.12885135j  2.27324357-0.73862161
   2.27324357+0.73862161j  2.27324357+3.12885135j]
 [-0.00000000+0.j          2.10367746-2.89546363j  2.10367746-0.68352624
   2.10367746+0.68352624j  2.10367746+2.89546363j]
 [ 0.00000000+0.j         -0.00000000+0.j         -0.00000000+0.j
   0.00000000-0.j          0.00000000-0.j         ]
...
```

numpy indexing with Boolean arrays

You aren't restricted to using scalars as array indexes:

```
>>> x = np.arange(-4, 5); print x
[-4 -3 -2 -1  0  1  2  3  4]
>>> i = x**2 > 4
>>> print i
[ True  True False False False False False  True  True]
>>> print x[i]
[-4 -3  3  4]
```

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```
>>> x = np.arange(-4, 5); print x
[-4 -3 -2 -1  0  1  2  3  4]
>>> i = x**2 > 4
>>> print i
[ True  True False False False False False  True  True]
>>> print x[i]
[-4 -3  3  4]

>>> x[i] = 10 + np.abs(x[i])
>>> print x
[14 13 -2 -1  0  1  2 13 14]
```

numpy indexing with Boolean arrays

You aren't restricted to using scalars as array indexes:

```
>>> x = np.arange(-4, 5); print x
[-4 -3 -2 -1  0  1  2  3  4]
>>> i = x**2 > 4
>>> print i
[ True  True False False False False False  True  True]
>>> print x[i]
[-4 -3  3  4]

>>> x[i] = 10 + np.abs(x[i])
>>> print x
[14 13 -2 -1  0  1  2 13 14]

>>> I = np.array([2, 7])
>>> print x[I]
[-2 13]
```

numpy Linear Algebra

numpy Linear Algebra

```
>>> n = 3; i = np.arange(n); M = np.zeros((n,n))
>>> M[(i,i)] = i + 1; print M
[[ 1.  0.  0.]
 [ 0.  2.  0.]
 [ 0.  0.  3.]]
>>> np.linalg.inv(M)
array([[ 1.        ,  0.        ,  0.        ],
       [ 0.        ,  0.5       ,  0.        ],
       [ 0.        ,  0.        ,  0.33333333]])
```

numpy Linear Algebra

```
>>> n = 3; i = np.arange(n); M = np.zeros((n,n))
>>> M[(i,i)] = i + 1; print M
[[ 1.  0.  0.]
 [ 0.  2.  0.]
 [ 0.  0.  3.]]
>>> np.linalg.inv(M)
array([[ 1.        ,  0.        ,  0.        ],
       [ 0.        ,  0.5       ,  0.        ],
       [ 0.        ,  0.        ,  0.33333333]])

>>> M = np.matrix(M)
>>> U, s, Vt = np.linalg.svd(M)
>>> U * np.diag(s) * Vt                    # should == M
matrix([[ 1.,  0.,  0.],
        [ 0.,  2.,  0.],
        [ 0.,  0.,  3.]])
```

numpy Linear Algebra

```
>>> n = 3; i = np.arange(n); M = np.zeros((n,n))
>>> M[(i,i)] = i + 1; print M
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 [ 0.  2.  0.]
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Uh oh; that's an element-by-element product.

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```

Uh oh; that's an element-by-element product. An `array` is not a `matrix`; you have to say

```
>>> U.dot(np.diag(s)).dot(Vt)
```

numpy Linear Algebra

Beware: vectors are treated differently from matrices. The vector x is the same as the vector x.T :

```
>>> x = np.array((1, 2))
>>> x
array([1, 2])
>>> x.T
array([1, 2])
>>> np.dot(x, x.T)
5
>>> np.dot(x.T, x)
5
```

numpy Linear Algebra

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```

If you want to distinguish between row vectors and column vectors, need to use a $1 \times n$ or $n \times 1$ matrix:

```
>>> x.resize(1,2)
>>> x
array([[1, 2]])
>>> x.T
array([[1],
       [2]])
>>> np.dot(x, x.T)
array([[5]])
>>> np.dot(x.T, x)
array([[1, 2],
       [2, 4]])
```

numpy Linear Algebra

If you use a matrix , you don't need to use dot :

```
>>> v = np.matrix((1, 2))
>>> v * v.T
matrix([[5]])
>>> v.T * v
matrix([[1, 2],
        [2, 4]])
```

numpy Linear Algebra

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A future version of python will support U @ np.diag(s) @ Vt with @ meaning, "matrix multiply".

numpy Linear Algebra

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>>> v.T * v
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        [2, 4]])
```

A future version of python will support `U @ np.diag(s) @ Vt` with `@` meaning, "matrix multiply". This does not remove the confusion between vectors and matrices, however: it is merely a shorthand for `U.dot(np.diag(s)).dot(Vt)`.

Other numpy capabilities

numpy has lots of libraries:

- FFTs
- Linear algebra
- Statistics
- *etc.*

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I used the statistics package in analyzing the course questionnaire:

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cov = np.corrcoef(data, rowvar=False)
for i in range(len(cov[0])):
   print "%6.3f" np.mean(data[:, i]), \
         " ".join(["%6.3f" % x for x in cov[i]])
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```

The scipy package adds many more:

- N-dimensional image convolution
- Interpolation
- Sparse linear algebra (*e.g.* 3M x 5k least-squares problems)
- Optimization
- *etc.*

Outline

1. Programming Languages
2. Intro to Python
3. Libraries
4. Beyond Libraries

Embedding C/C++/Fortran in python

One extremely powerful technique is to wrap your own code in python, a topic that we'll cover later in the course. To whet your appetite, here's some analysis code that I wrote four years ago last week: