Python for Scientific Computing in Economics

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Before We Start

Installed Anaconda?

- Free from http://continuum.io/downloads
- Make it your default Python distribution

Installed Anaconda a while ago?

- In a terminal type conda update anaconda

Need a temporary solution?

- https://try.jupyter.org/

Topics

- Getting started
  - Scientific computing background
  - Intro to Python
  - How to run Python code
- Scientific programming
  - The scientific libraries
  - Graphics
- Learning Python
  - Basic syntax, data types
- Exercise

Scientific Programming Environments

Low level languages:

- C, C++
- Fortran

High level languages

- Matlab
- Julia
- Python
- R, etc.

Low level languages require more details from the user

```c
/* Creates a linear array.  */
void linspace(double *ls, double a, double b, int n)
{
    double step = (b - a) / (n - 1);
    int i;
    for (i = 0; i < n; i++)
    {
        ls[i] = a;
        a += step;
    }
}
```

High level languages require less information

```
function linspace!(ls, a, b)
    n = length(ls)
    step = (b - a) / (n - 1)
    for i in 1:n
        ls[i] = a
        a += step
    end
    return ls
end
```

High level languages tend to be convenient for the user

```
>>> a, b = 1, 4
>>> a + b
5
>>> a, b = 'foo', 'bar'
>>> a + b
'foobar'
```

But harder to convert into optimized machine code

Although **big** steps forward in recent years

- Julia, Python + Numba

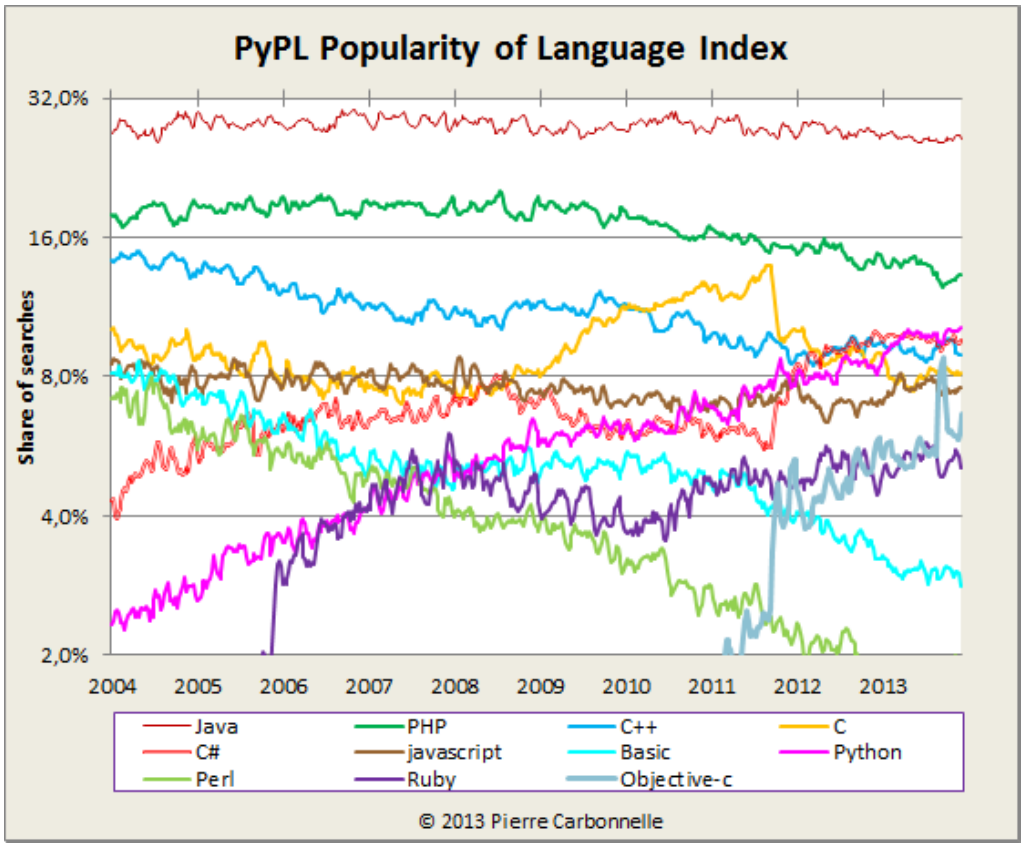
What's Python?

A high level, general purpose programming language

Used extensively by

- Tech firms (YouTube, Dropbox, Reddit, etc., etc.)
- Hedge funds and finance industry
- Gov't agencies (NASA, CERN, etc.)
- Academia

Free and open source


PyPL Popularity of Language Index
32,0%
16,0%
8,0%
4,0%
2,0%
Share of searches
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Java
PHP
C++
C
C#
javascript
Basic
Python
Perl
Ruby
Objective-c
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Python is noted for

- Elegant, modern design
- Clean syntax, readability
- High productivity

Often used to teach first courses in comp sci and programming

- MIT, Udacity, edX, etc.

Scientific Programming

Rapid adoption by the scientific community

- Artifical intelligence
- engineering
- computational biology
- chemistry
- physics, etc., etc.

Major Scientific Libraries

NumPy

- basic data types
- simple array processing operations

SciPy

- built on top of NumPy
- provides additional functionality

Matplotlib

- 2D and 3D figures

NumPy Example: Mean and standard dev of an array

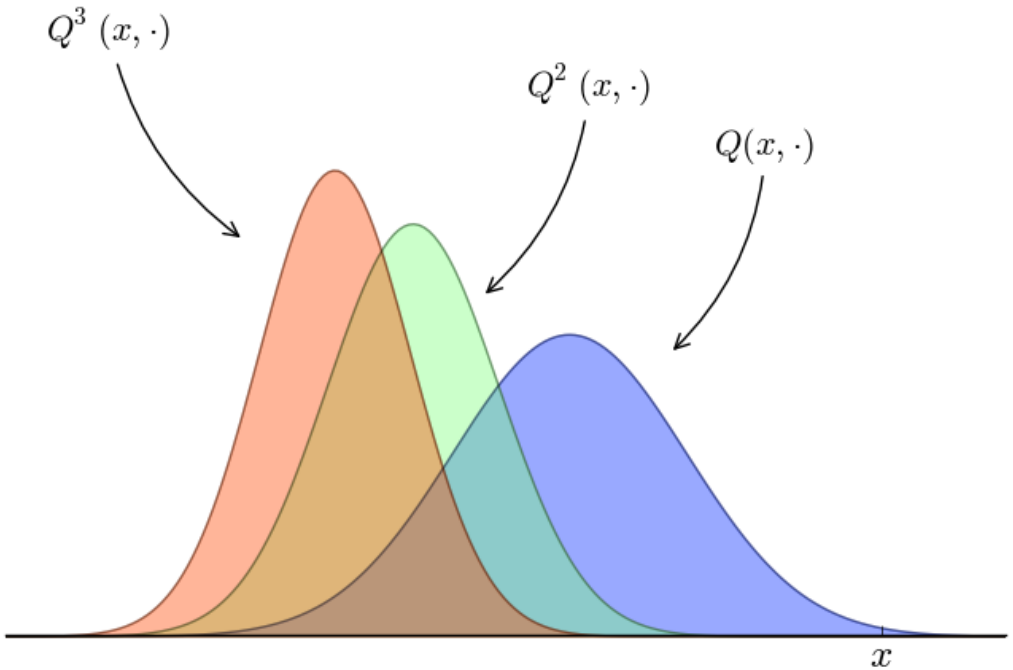
```
>>> import numpy as np
>>> a = np.random.randn(10000)
>>> a.mean()
0.0020109779347995344
>>> a.std()
1.0095758844793006
```

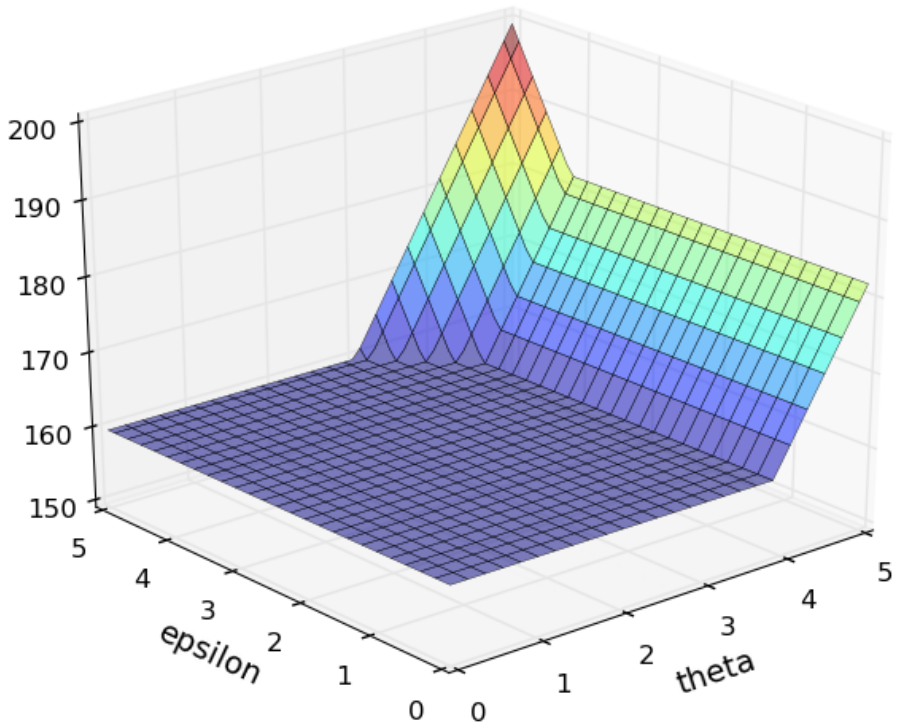
SciPy Example: Calculate

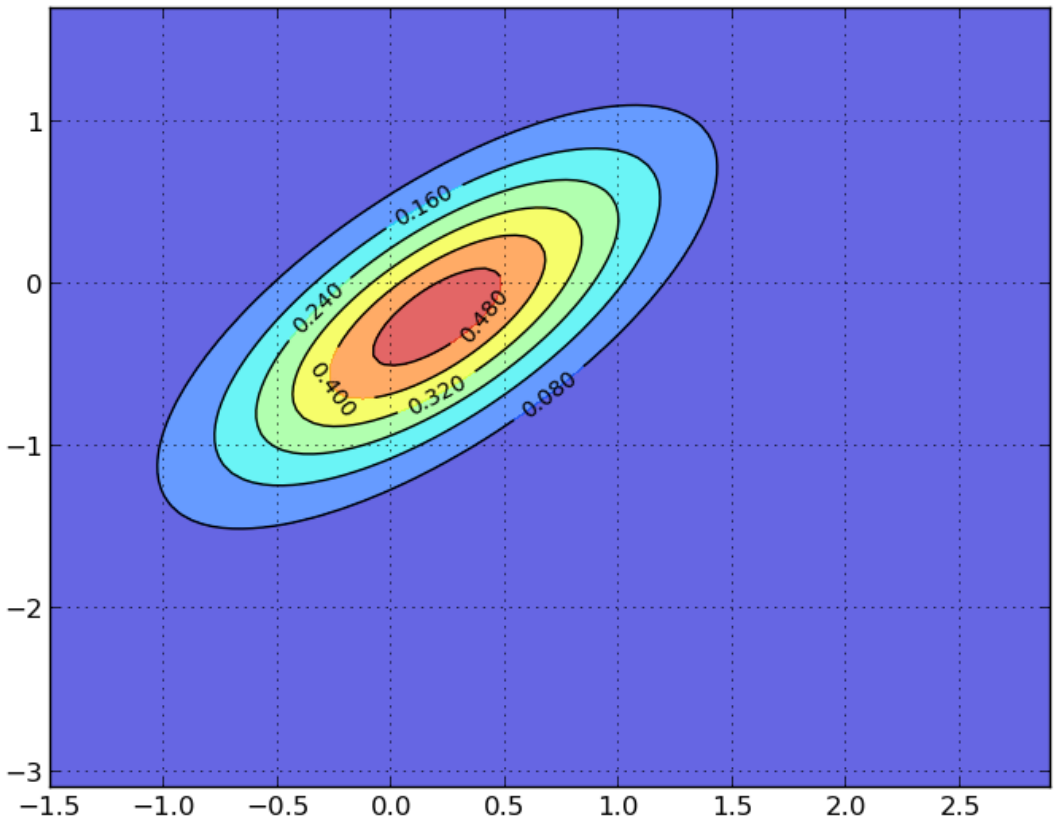
$$\int_{-2}^{2} \phi(z)dz \quad \text{where} \quad \phi \sim N(0,1)$$

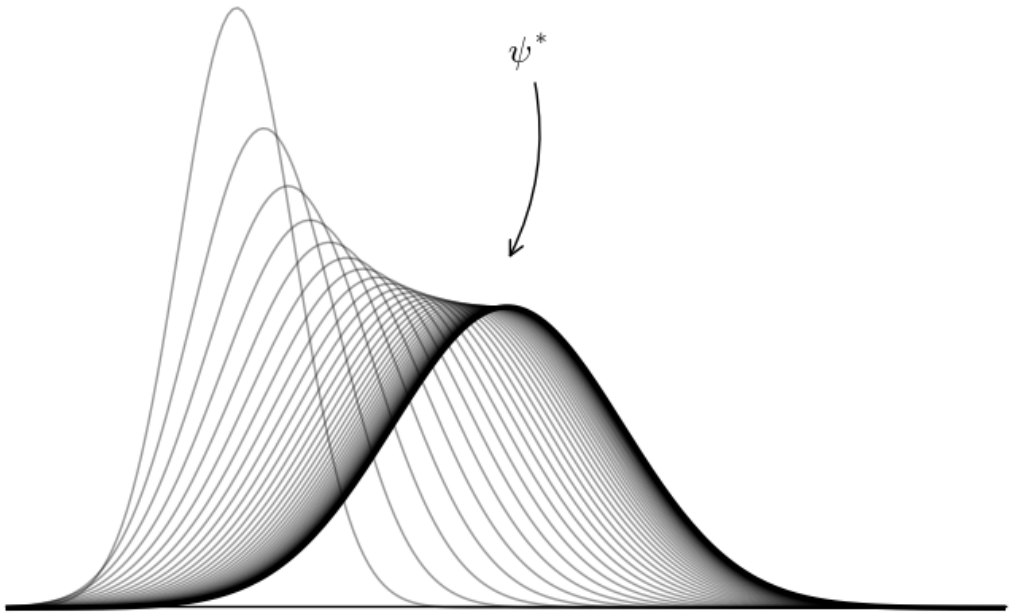
```
>>> from scipy.stats import norm
>>> from scipy.integrate import quad
>>> phi = norm()
>>> value, error = quad(phi.pdf, -2, 2)
>>> value
0.9544997361036417
```

Matplotlib examples




200
190
180
170
160
150
5
4
3
2
1
0
epsilon
0
1
2
3
4
5
theta


0.160
0.240
0.480
0.400
0.320
0.080
1
0
−1
−2
−3
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5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Other Scientific Libraries

Pandas

- statistics and data analysis

SymPy

- symbolic manipulations à la Mathematica

Still more:

- **statsmodels** — statistics / econometrics
- **scikit-learn** — machine learning in Python

The QuantEcon Libraries

Code for

- Markov chains
- Dynamic programming
- LQ control
- etc

Both Python and Julia versions

See http://quantecon.org/

Other Scientific Tools

Also tools for

- working with graphs (as in networks)
- parallel processing, GPUs
- manipulating large data sets
- interfacing C / C++ / Fortran
- cloud computing
- database interaction
- bindings to other languages, like R and Julia
- etc.

Why I Prefer Python to Matlab

1. Open source
   - no license hassles
   - can read / edit source code
2. General purpose
   - meets all my coding needs
3. Very well designed language
4. Other awesomeness
   - Fast loops through Numba
   - Jupyter, etc

How About Julia?

- Specialized to scientific computing
- Open source
- Fast

Why I personally use Python more than Julia

1. General purpose
2. Python has copied some goodies from Julia (Numba)
3. Language design fits my brain
4. Julia is still a bit unstable

Interacting with Python

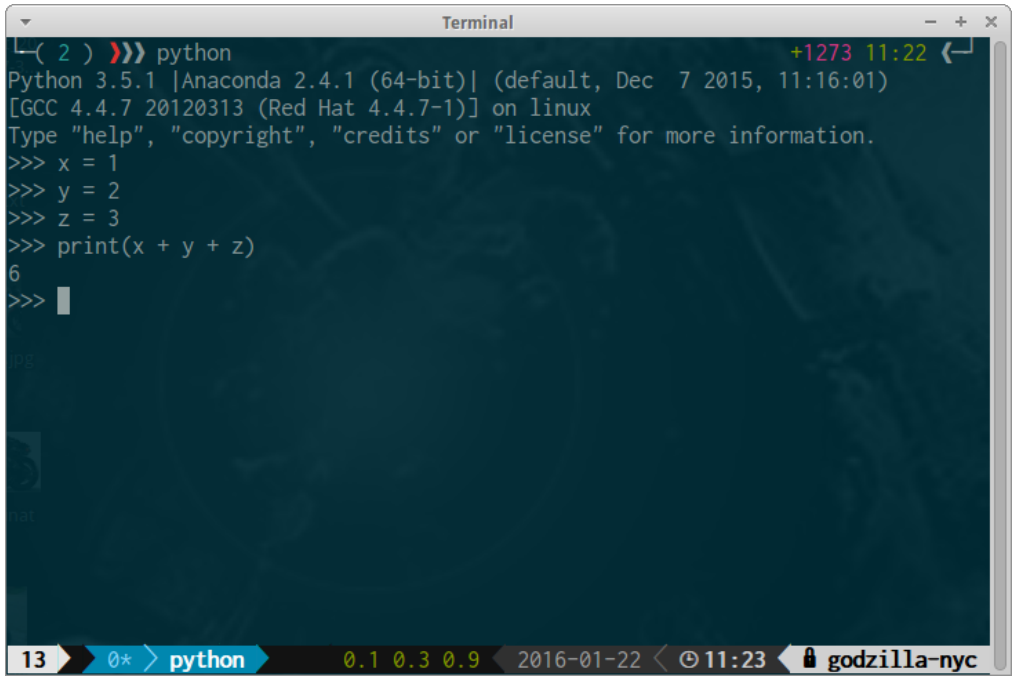
Here we'll interact with Python using **Jupyter notebooks**

- A browser based front end to Python, Julia, R, etc.
- Stores output as well as input
- Allows for rich text, graphics, etc.
- Easy to run remotely on servers / in cloud

But before then let's quickly review other options

One (not very good) option is the plain **Python REPL**

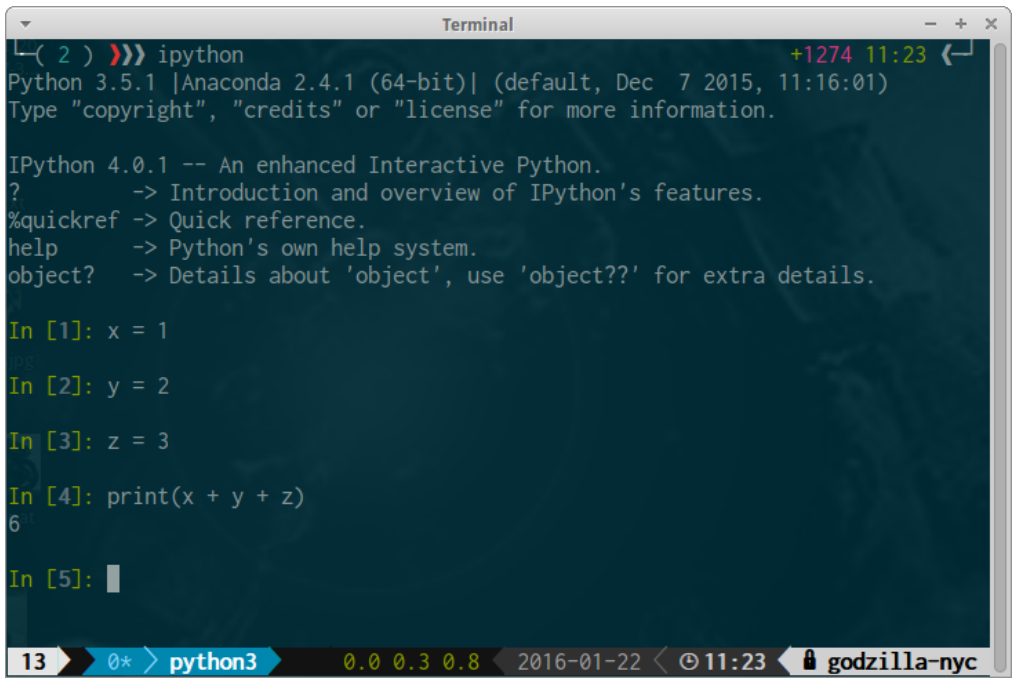
- REPL = read, eval, print loop



Open up a terminal (cmd for Windows) and type python

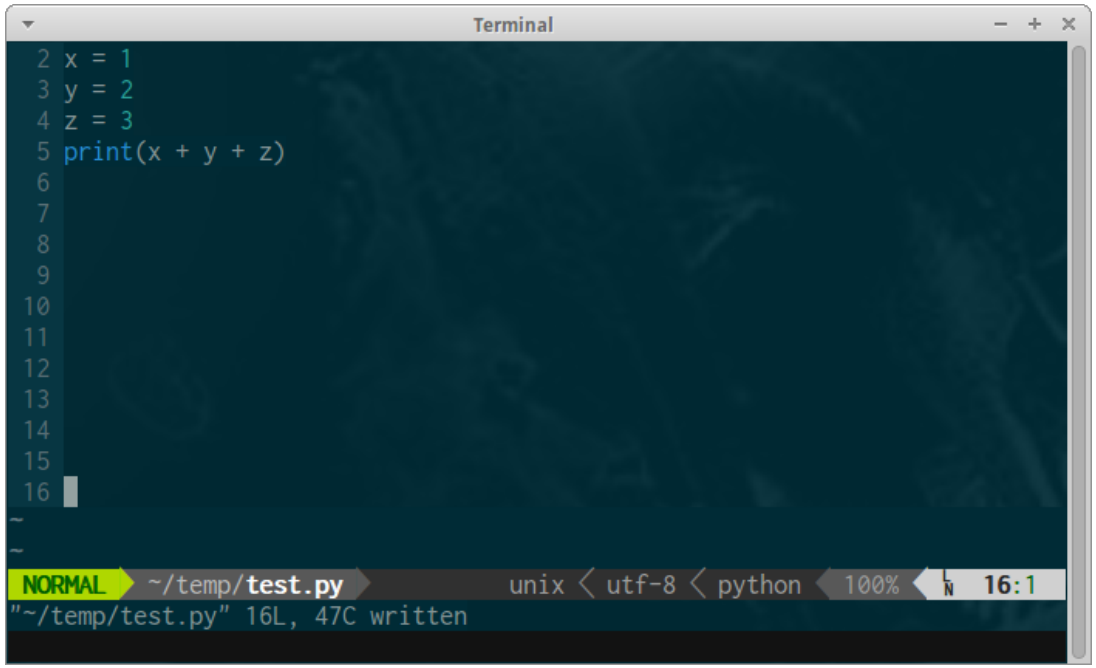
IPython

A nicer Python REPL with support for shell commands, etc.

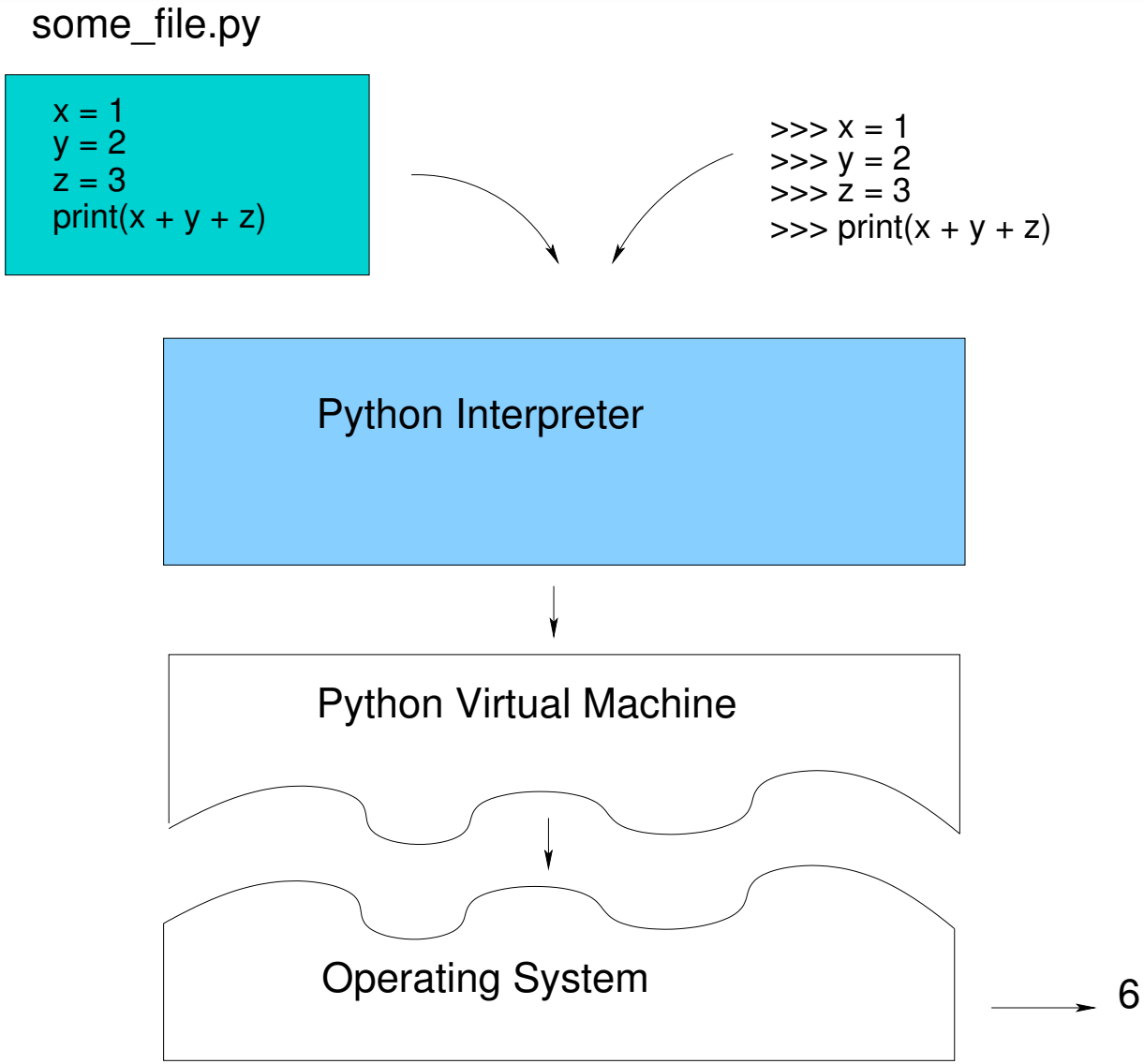


Open up a terminal (cmd for Windows) and type ipython

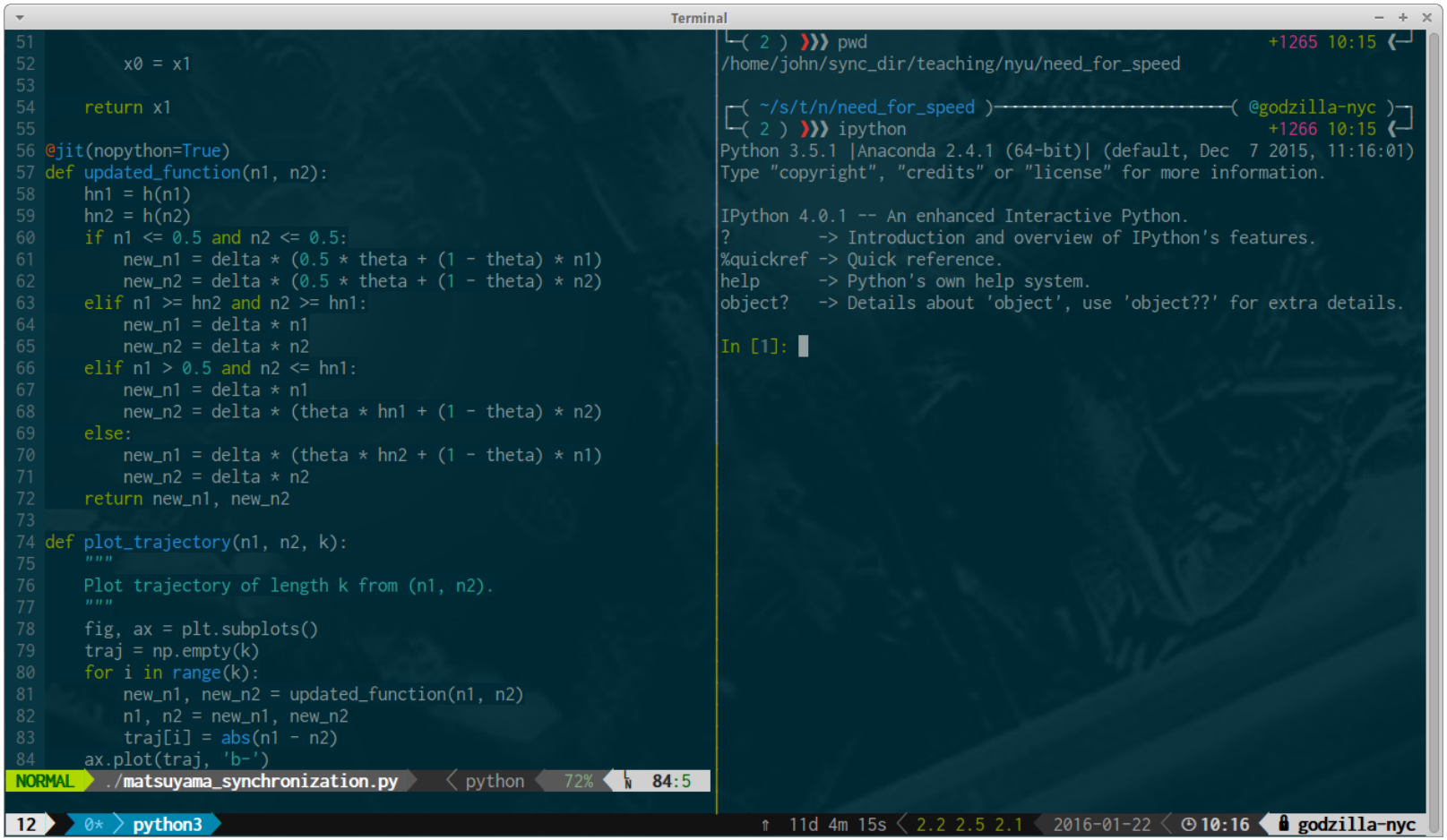
Sometimes it's better to write all the commands in a **text file**



. . . and then run it through the interpreter

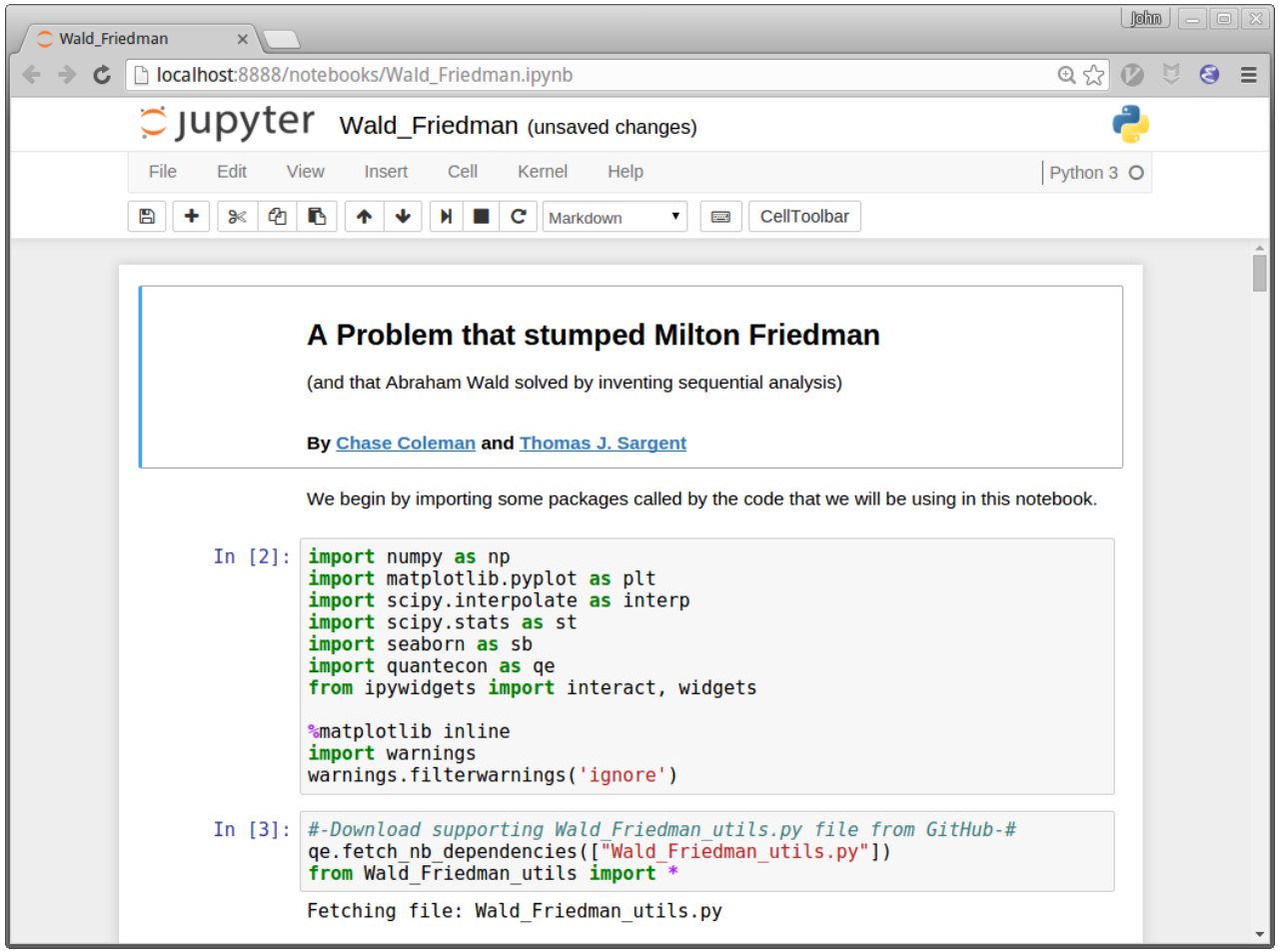

some_file.py
x = 1
y = 2
z = 3
print(x + y + z)
>>> x = 1
>>> y = 2
>>> z = 3
>>> print(x + y + z)
Python Interpreter
Python Virtual Machine
Operating System
6

Here's a text editor (vim) on one side and IPython on the other



(Linux terminal, running through tmux)

Jupyter Notebooks



To show

- Editing modes, execution
- Markdown
- Inline figures
- Language agnostic

- Ref: quant-econ.net/py/getting_started.html

An Easy Python Program

Next step: write and pick apart small Python program

Notes

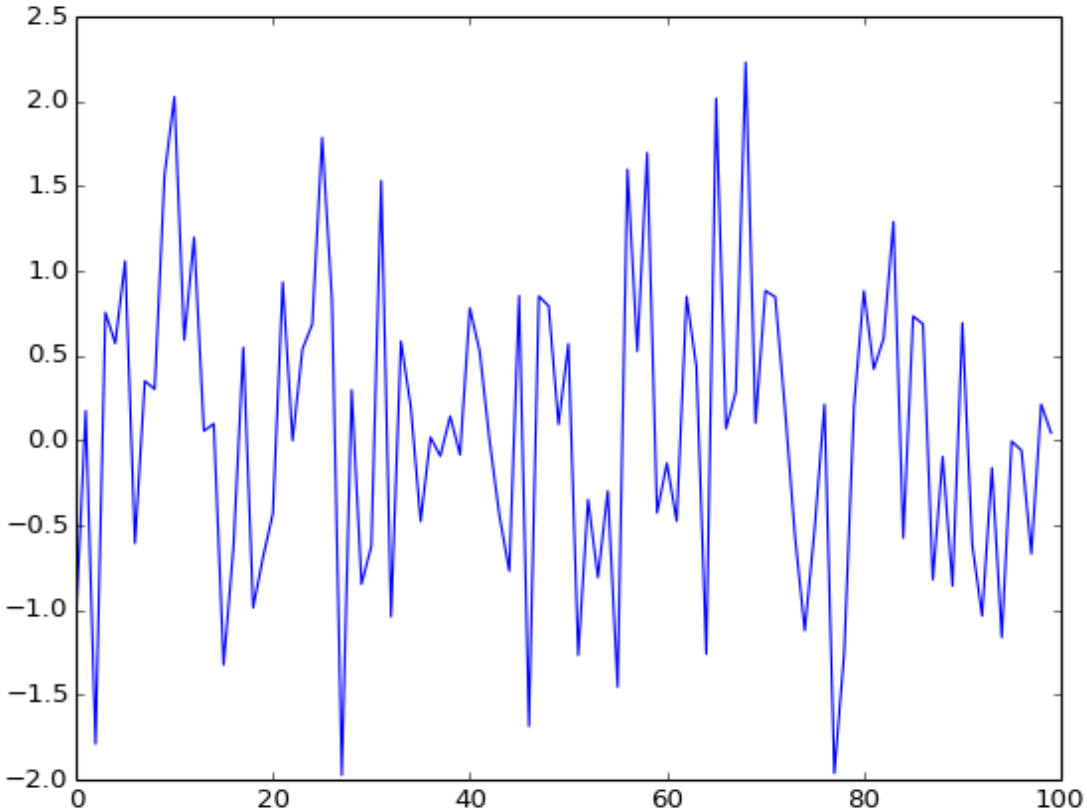
1. Source = quant-econ.net/python_by_example.html
2. Like all first programs, to some extent contrived
3. We focus as much as possible on pure Python

Example: Plotting a White Noise Process

Suppose we want to simulate and plot

$$\epsilon_0, \epsilon_1, \ldots, \epsilon_T \quad \text{where} \quad \{\epsilon_t\} \overset{\text{IID}}{\sim} N(0,1)$$

In other words, we want to generate figures like this



A first pass (from quant-econ.net/py/python_by_example.html)

```
1 from random import normalvariate
2 import matplotlib.pyplot as plt
3 ts_length = 100
4 epsilon_values = []   # An empty list
5 for i in range(ts_length):
6     e = normalvariate(0, 1)
7     epsilon_values.append(e)
8 plt.plot(epsilon_values, 'b-')
9 plt.show()
```

Import Statements

First, consider the lines

```
1 from random import normalvariate
2 import matplotlib.pyplot as plt
```

Here matplotlib and random are two separate **modules**

- module = file containing Python code

Importing a module causes Python to

- run the code in those files
- set up a matching "namespace" to store variables

```
>>> import random
>>> random.normalvariate(0, 1)
-0.12451500570438317
>>> random.uniform(-1, 1)
0.35121616197003336
```

You can also just import the names directly, like so

```
>>> from random import normalvariate, uniform
>>> normalvariate(0, 1)
-0.38430990243287594
>>> uniform(-1, 1)
0.5492316853602877
```

Lists

Statement epsilon_values = [] creates an empty list

Lists: a Python data structure used to group objects

```
>>> x = [10, 'foo', False]
>>> type(x)
<type 'list'>
```

Note that different types of objects can be combined in a single list

Adding a value to a list: list_name.append(some_value)

```
>>> x
[10, 'foo', False]
>>> x.append(2.5)
>>> x
[10, 'foo', False, 2.5]
```

- append() is an example of a **method**
- method = a function "attached to" an object

Another example of a list method:

```
>>> x
[10, 'foo', False, 2.5]
>>> x.pop()
2.5
>>> x
[10, 'foo', False]
```

An example of a string method:

```
>>> s = 'foobar'
>>> s.upper()
'FOOBAR'
```

As in C, Java, etc., lists in Python are zero based

```
>>> x
[10, 'foo', False]
>>> x[0]
10
>>> x[1]
'foo'
```

The range() function creates a sequential list of integers

```
>>> range(4)
[0, 1, 2, 3]
>>> range(5)
[0, 1, 2, 3, 4]
```

Note: range(n) gives indices of list x when len(x) equals n

The for Loop

Consider again these lines from test_program_1.py

```
5  for i in range(ts_length):
6      e = normalvariate(0, 1)
7      epsilon_values.append(e)
8  plt.plot(epsilon_values, 'b-')
```

Lines 6–7 are the **code block** of the for loop

Reduced indentation signals lower limit of the code block

Comments on Indentation

In Python **all** code blocks are delimited by indentation

This is a **good** thing (more consistency, less clutter)

But tricky at first, so please remember

- Line before start of code block always ends in a colon
- All lines in a code block must have same indentation
- The Python standard is 4 spaces—please use it
- Tabs and spaces are different

Using the Scientific Libraries

In fact the scientific libraries will do all this more efficiently

For example, try

```
>>> from numpy.random import randn
>>> epsilon_values = randn(3)
>>> epsilon_values
array([-0.15591709, -0.67383208, -0.45932047])
```

Exercise

Simulate and plot the correlated time series

$$x_{t+1} = \alpha\, x_t + \epsilon_{t+1} \quad \text{where} \quad x_0 = 0 \quad \text{and} \quad t = 0, \ldots, T$$

Here $\{\epsilon_t\} \overset{\text{IID}}{\sim} N(0,1)$

In your solution, restrict your import statements to

```
from random import normalvariate
import matplotlib.pyplot as plt
```

Set $T = 200$ and $\alpha = 0.9$

Solution

```
import matplotlib.pyplot as plt
from random import normalvariate

alpha = 0.9
ts_length = 200
x = 0

x_values = []
for i in range(ts_length):
    x_values.append(x)
    x = alpha * x + normalvariate(0, 1)
plt.plot(x_values, 'b-')
plt.show()
```

Further Resources

See http://quant-econ.net for

- Basic instructions
- Python lectures
- Julia lectures
- Code related to econ