Short introduction to python

(based on last year's lecture by Marc Wiedermann)

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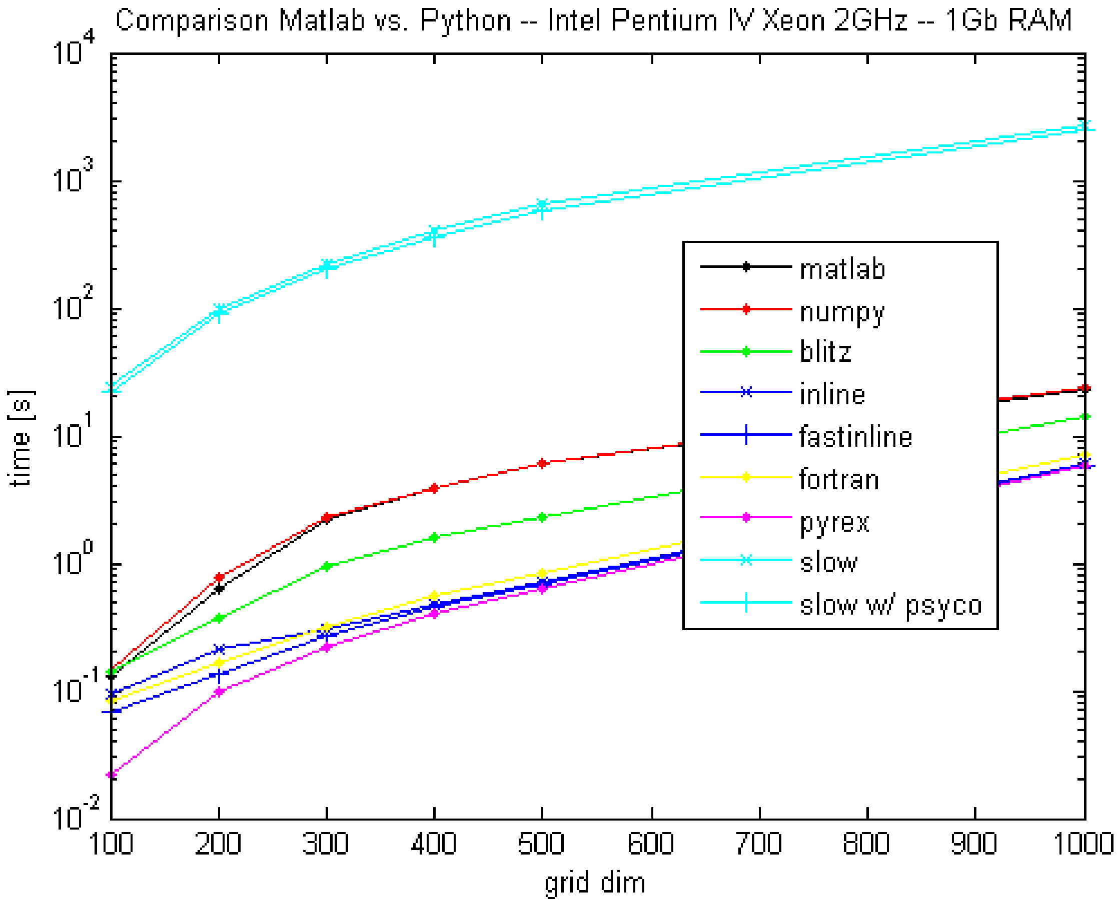
```
$ ipython
In [1]: print 'Hello World!'
Hello World
```

Why python?

- Similar syntax as matlab → easy to learn
- Interactive
- Easy to run in parallel
- Open source
- Expendable with numerous packages for different applications
- Intelligent coding makes it almost as fast as C



Important extensions

numpy
- Fast numerics and statistics

scipy
- Tailored to scientific applications (solving ODE, interpolation, integration,...)

matplotlib (pyplot)
- Plotting data

pyunicorn
- Advanced nonlinear statistical methods for time series analysis
- Some methods covered during the school are part of pyunicorn

basemap
- Plotting geoscientific data on maps

Running your code

<u>Two options (just like in matlab)</u>

1. Interactive console (ipython)
   - start by typing **`ipython`** in shell and get:

```
Python 2.7.6 (default, Jun 22 2015, 17:58:13)
Type "copyright", "credits" or "license" for more information.

IPython 1.2.1 -- An enhanced Interactive Python.
?         -> Introduction and overview of IPython's features.
%quickref -> Quick reference.
help      -> Python's own help system.
object?   -> Details about 'object', use 'object??' for extra details.

In [1]:
```

- Then just start coding!

2. Alternatively write a script, class or a whole package and run from shell with:

    `python nameofyourscript.py`

Importing and using packages

```
import numpy
print numpy.arange(10)

>>> [0 1 2 3 4 5 6 7 8 9]
```

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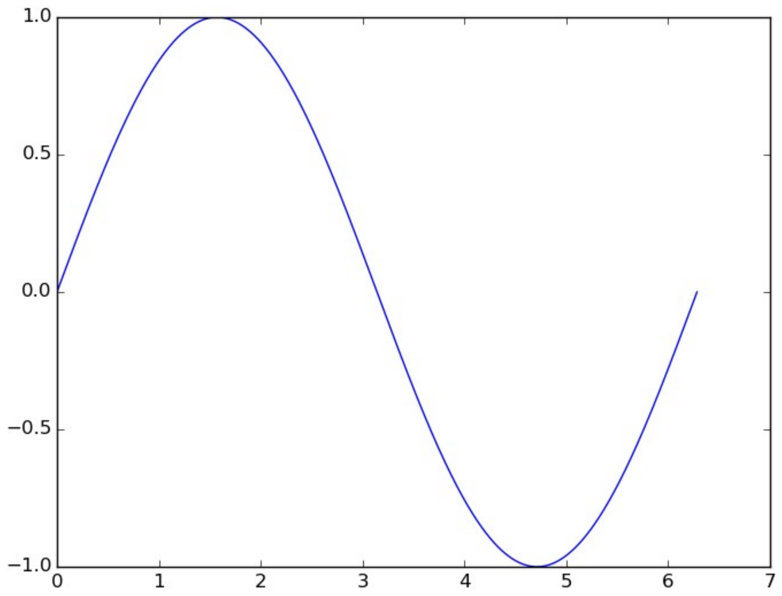
```

```
import numpy as np
from matplotlib import pyplot as plt
print np.arange(10)
x = np.linspace(0, 2*np.pi, 1000)
y = np.sin(x)
plt.plot(x, y)
plt.show()

>>> [0 1 2 3 4 5 6 7 8 9]
```



For loops

```
for i in range(10):
    print i,

>>> 0 1 2 3 4 5 6 7 8 9
```

For loops

```
for i in range(10):
    print i,

>>> 0 1 2 3 4 5 6 7 8 9


for name in ['marc', 'reik']:
    print name

>>> marc
>>> reik
```

For loops

```
for i in range(10):
    print i,

>>> 0 1 2 3 4 5 6 7 8 9
```

```
for name in ['marc', 'reik']:
    print name

>>> marc
>>> reik
```

```
for i in range(3):
    for j in range(2):
        print i*j

>>> 0 0 0 1 0 2
```

```
import numpy as np
i = np.arange(3)
for j in range(2):
    print i*j,

>>> [0 0 0] [1 0 2]
```

For loops

```
for i in range(10):
    print i,

>>> 0 1 2 3 4 5 6 7 8 9
```

```
for name in ['marc', 'reik']:
    print name

>>> marc
>>> reik
```

Always try to avoid nested for loops

Slow code:

```
for i in range(3):
    for j in range(2):
        print i*j

>>> 0 0 0 1 0 2
```

Fast code:

```
import numpy as np
i = np.arange(3)
for j in range(2):
    print i*j,

>>> [0 0 0] [1 0 2]
```

If-elif-else clauses and Logical comparison

```
for i in range(10):
    if i<5:
        print i, 'is small.'
```

```
>>> 0 is small.
>>> 1 is small.
>>> 2 is small.
>>> 3 is small.
>>> 4 is small.
```

If-elif-else clauses and Logical comparison

```
for i in range(10):
    if i<5:
        print i, 'is small.'
    elif i==5:
        print i, 'is 5.'



>>> 0 is small.
>>> 1 is small.
>>> 2 is small.
>>> 3 is small.
>>> 4 is small.
>>> 5 is 5.
```

If-elif-else clauses and Logical comparison

```
for i in range(10):
    if i<5:
        print i, 'is small.'
    elif i==5:
        print i, 'is 5.'
    else:
        print i, 'is large.'

>>> 0 is small.
>>> 1 is small.
>>> 2 is small.
>>> 3 is small.
>>> 4 is small.
>>> 5 is 5.
>>> 6 is large.
>>> 7 is large.
>>> 8 is large.
>>> 9 is large.
```

If-elif-else clauses and Logical comparison

```
for i in range(10):
    if i<5:
        print i, 'is small.'
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>>> 0 is small.
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>>> 3 is small.
>>> 4 is small.
>>> 5 is 5.
>>> 6 is large.
>>> 7 is large.
>>> 8 is large.
>>> 9 is large.
```

```
for animal in ['cat','fish','horse']:
    if animal is 'cat':
        print 'It is a', animal
    if animal is 'fish':
        print animal, 'has', len(animal),
        print 'letters'
    if animal is not 'horse':
        print 'It is not a horse'
    else:
        print 'It is a', animal
```

The length of any object can be computed with the len() statement.

More on numpy

- Make use of arrays instead on lists (huge performance gain)
- Computations can be performed on entire array instead of individual elements

<u>Standard python:</u>

```
a = range(10)
b = []
for i in range(len(a)):
   b.append(a[i] * 2)
print b

>>> [0, 2, 4, 6, 8, 10,
12, 14, 16, 18]
```

<u>Numpy:</u>

```
import numpy as np
a = np.arange(10)


b = a*2
print b

>>> [0, 2, 4, 6, 8, 10,
12, 14, 16, 18]
```

Lists can be converted to numpy array by typing:

`a = np.array(a)`

More on numpy – Functions

- Initialize empty array to fill it with data
  `np.zeros(100)` 1-dimensional array
  `np.zeros((100, 200))` 2-dimensional array

- Compute correlation between array of time series
  `np.corrcoef(time_series_array)`
  `np.corrcoef(time_series_a, time_series_b)`

- Initialize array of evenly spaced values
  `np.arange(n0, n1, stepsize)`
  `np.linspace(n0, n1, number_of_steps)`

- Standard deviation, mean and absolute values of a time series
  `np.mean(time_series)`
  `np.std(time_series)`
  `np.abs(time_series)`

- Loading .txt files
  `np.loadtxt(filename)`

More on numpy – Indexing

```
a = np.arange(6).reshape(2,3)

print a
>>> array([[0, 1, 2],
           [3, 4, 5]])

print a[0]
>>> [0, 1, 2]

print a[1, 1]
>>> 4

print a[:, 1]
>>> [1 4]
```

```
print a[:, :2]
>>> array([[0, 1],
           [3, 4]])

print a.T
>>> [[0 3]
     [1 4]
     [2 5]]
```

Always check
http://docs.scipy.org/doc/numpy/reference/routines.html
for help

Solving Odinary Differential Equations

http://beavotron.deviantart.com/art/Fox-and-Rabbit-92840871

Solving Ordinary Differential Equations

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- Described by the Lotka-Volterra model

$$\frac{\mathrm{d}x}{\mathrm{d}t} = \alpha x - \beta x y$$
$$\frac{\mathrm{d}y}{\mathrm{d}t} = \delta x y - \gamma y$$

Solving Odinary Differential Equations

```
from scipy.integrate import odeint
import numpy as np
import matplotlib.pyplot as plt

# Define the ODE
def LotkaVolterra(y,t,parameters):
    return [parameters[0]*y[0]-parameters[1]*y[0]*y[1],
            parameters[3]*y[0]*y[1]-parameters[2]*y[1]]

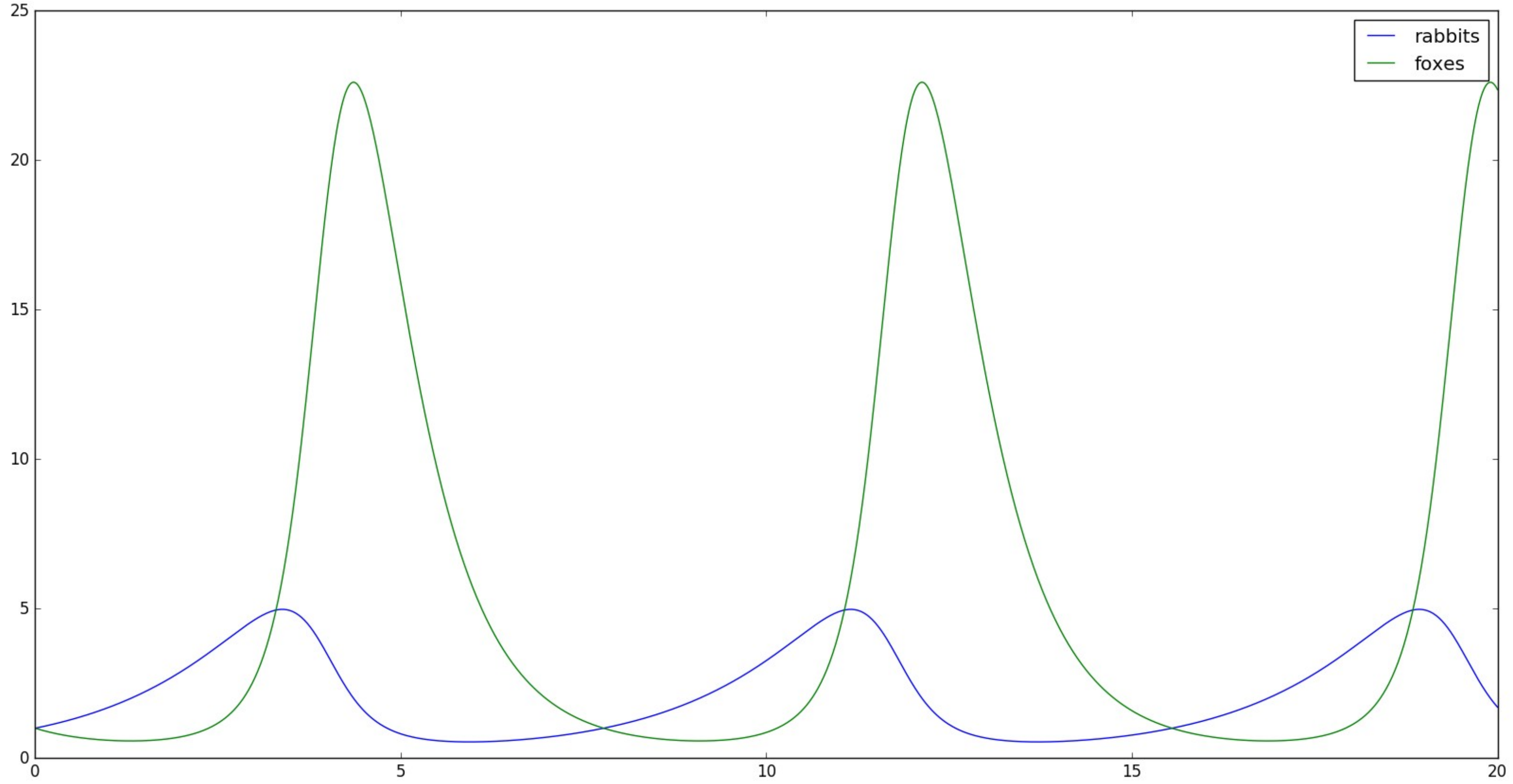
p = [0.6,0.1,1.5,0.75]  # parameter values
y0 = [1.0,1.0]      # initial conditions
t = np.linspace(0,20,1000)  # times for integration

res = odeint(LotkaVolterra,y0,t,args=(p,))   # solve the ODE

# plot the results
plt.plot(t,res[:,0],label="rabbits")
plt.plot(t,res[:,1],label="foxes")
plt.legend()
plt.show()
```

$$\frac{\mathrm{d}x}{\mathrm{d}t} = \alpha x - \beta x y$$
$$\frac{\mathrm{d}y}{\mathrm{d}t} = \delta x y - \gamma y$$

Solving Ordinary Differential Equations



Solving Stochastic Differential Equations

- In many real world applications there is stochastic noise
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- Thus we often need to work with Stochastic Differential Equations (SDE)
- In general we write:

$$\mathrm{d}X_t = a\left(X_t\right)\mathrm{d}t + b\left(X_t\right)\mathrm{d}W_t$$

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Wiener process

$$\mathrm{d}X_t = a\left(X_t\right)\mathrm{d}t + b\left(X_t\right)\mathrm{d}W_t$$

drift term

diffusion term

Solving Stochastic Differential Equations

$$\mathrm{d}X_t = a\left(X_t\right)\mathrm{d}t + b\left(X_t\right)\mathrm{d}W_t$$

Wiener process

drift term

diffusion term

- This SDE can numerically be solved using the Euler-Maruyama scheme (alternatives are the Milstein or Runge-Kutta methods)

1) discretization of time into N intervals of length Δt

2) solve for each time step as:

$$Y_n = Y_{n-1} + a\left(Y_{n-1}\right)\Delta t + b\left(Y_{n-1}\right)\Delta W$$

$$\mathcal{N}\left(0, \Delta t\right)$$

Solving Stochastic Differential Equations

Example: Ornstein-Uhlenbeck process

$$\mathrm{d}X_t = \Theta \cdot (\mu - X_t)\,\mathrm{d}t + \sigma \mathrm{d}W_t$$

Solving Stochastic Differential Equations

Example: Ornstein-Uhlenbeck process

$$\mathrm{d}X_t = \Theta \cdot (\mu - X_t)\,\mathrm{d}t + \sigma \mathrm{d}W_t$$

```
import numpy as np
import matplotlib.pyplot as plt

t_0 = 0      # define model parameters
t_end = 2
length = 1000
theta  = 1.1
mu     = 0.8
sigma  = 0.3

t = np.linspace(t_0,t_end,length)  # define time axis
dt = np.mean(np.diff(t))

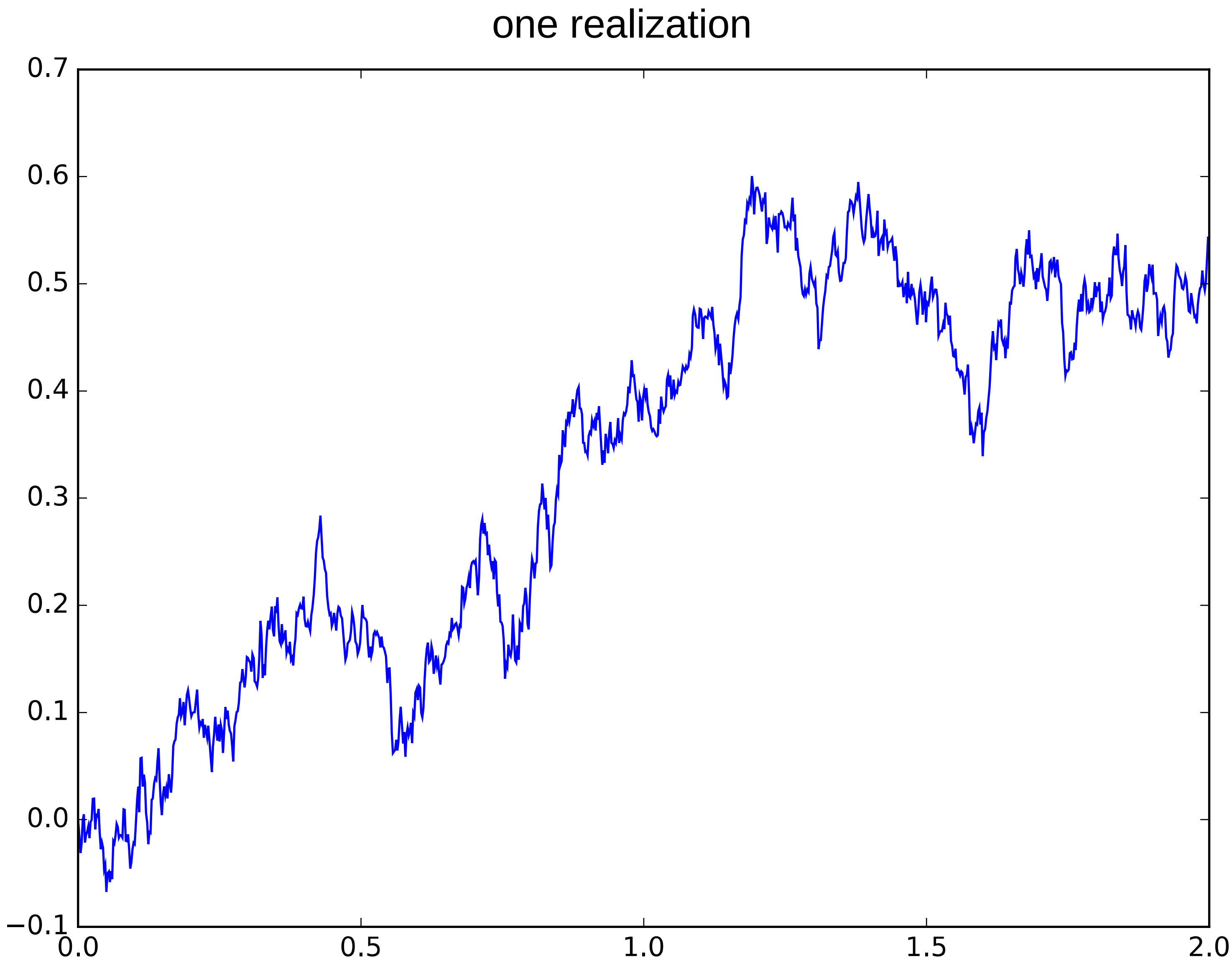
y = np.zeros(length)
y0 = np.random.normal(loc=0.0,scale=1.0)  # initial condition

drift = lambda y,t: theta*(mu-y)      # define drift term, google to learn about lambda
diffusion = lambda y,t: sigma            # define diffusion term
noise = np.random.normal(loc=0.0,scale=1.0,size=length)*np.sqrt(dt) #define noise process

# solve SDE
for i in xrange(1,length):
    y[i] = y[i-1] + drift(y[i-1],i*dt)*dt + diffusion(y[i-1],i*dt)*noise[i]

plt.plot(t,y)
plt.show()
```

Solving Stochastic Differential Equations



Solving Stochastic Differential Equations