Python in Neurocomputation - A Brief Introduction

Mike Hull

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Python in Neurocomputation - A Brief Introduction

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► High-level, general purpose programming language

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- ► High-level, general purpose programming language
- ▶ In development since 1989. Currently Version 2.6

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- Used by . . .
 - Google google-mail, google-groups & google-maps
 - Yahoo! discussion boards

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- High-level, general purpose programming language
- ▶ In development since 1989. Currently Version 2.6
- Opensource Strong User Community
- ▶ Used by ...
 - ► Google google-mail, google-groups & google-maps
 - Yahoo! discussion boards
- Popular as an interface to software: GIMP, Blender, Maya, SPSS, neuron

Design Philosophy

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- Design Philosophy
 - 'remarkable power with very clear syntax'

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- Design Philosophy
 - 'remarkable power with very clear syntax'
 - 'to describe something as clever is NOT considered a compliment in the Python culture'

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- Design Philosophy
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- Learning Curve

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- ► Learning Curve
- Scalability

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- Scalability
- Cross Platform

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- Scalability
- Cross Platform
- Standard Library databasing, cryptography, networking, graphics, . . .

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- Standard Library databasing, cryptography, networking, graphics, . . .
- Extensibility

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- Extensibility
- ► Rapid Development

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- ► Learning Curve
- Scalability
- Cross Platform
- Standard Library databasing, cryptography, networking, graphics, . . .
- Extensibility
- Rapid Development
- ...Programming Python is Fun!!

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How does Python look?

```
#Example 1
height = 12.5
weight = 23.8
area = height * weight
print area
>> 297.5
#Example 2
a = 'Xenopus'
b = 'laevis'
print 'Lets study ' + a + ' ' + b + '.'
>> Lets study Xenopus laevis.
```

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- Integer
- ► Float

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Basic Data Types

- ▶ Integer
- ► Float
- String

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- Integer
- Float
- String
- Lists

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- ▶ Integer
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- String
- Lists
- Dictionary

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- Integer
- ► Float
- String
- Lists
- Dictionary
- ▶ Tuples

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Libraries Examples

- Integer
- ► Float
- String
- Lists
- Dictionary
- Tuples
- ▶ None True False

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► Integer, Float >>> (50-5*6)/4

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► Integer, Float >>> (50-5*6)/4 5 Python in Neurocomputation - A Brief Introduction

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Basic Data Types

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String

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Basic Data Types

► Integer, Float

String

```
>>> 'Hello, ' + 'plymouth'
```

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► Integer, Float

```
>>> (50-5*6)/4
5
>>> 3 * 3.75 / 1.5
7.5
```

String

```
>>> 'Hello, ' + 'plymouth'
'Hello, plymouth'
```

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```
>>> (50-5*6)/4
5
>>> 3 * 3.75 / 1.5
7.5
```

String

```
>>> 'Hello, ' + 'plymouth'
'Hello, plymouth'
>>> a = 'Bristol has hills'
>>> a[0]
```

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```
>>> (50-5*6)/4
5
>>> 3 * 3.75 / 1.5
```

String

```
>>> 'Hello, ' + 'plymouth'
'Hello, plymouth'
>>> a = 'Bristol has hills'
>>> a[0]
'B'
```

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```
>>> (50-5*6)/4
5
>>> 3 * 3.75 / 1.5
```

String

```
>>> 'Hello, ' + 'plymouth'
'Hello, plymouth'
>>> a = 'Bristol has hills'
>>> a[0]
'B'
>>> a[1]
```

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Integer, Float

```
>>> (50-5*6)/4
5
>>> 3 * 3.75 / 1.5
```

String

```
>>> 'Hello, ' + 'plymouth'
'Hello, plymouth'
>>> a = 'Bristol has hills'
>>> a[0]
'B'
>>> a[1]
'r'
```

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Integer, Float

```
>>> (50-5*6)/4
5
>>> 3 * 3.75 / 1.5
```

String

```
>>> 'Hello, ' + 'plymouth'
'Hello, plymouth'
>>> a = 'Bristol has hills'
>>> a[0]
'B'
>>> a[1]
'r'
>>> len(a)
```

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Integer, Float

```
>>> (50-5*6)/4
5
>>> 3 * 3.75 / 1.5
```

String

```
>>> 'Hello, ' + 'plymouth'
'Hello, plymouth'
>>> a = 'Bristol has hills'
>>> a[0]
'B'
>>> a[1]
'r'
>>> len(a)
18
```

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>>>

print 'Item: ', x, ', Doubled: ', x*2,

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```
>>> 1 = [2,3,5,7,11,13]
>>> 1[0]
2
>>> len(1)
6
>>> for x in 1:
       print 'Item: ', x, ', Doubled: ', x*2,
>>>
Item: 2, Doubled: 4
Item: 3, Doubled: 6
Item: 5, Doubled: 10
Item: 7, Doubled: 14
Item: 11, Doubled: 22
Item: 13, Doubled: 26
```

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4 D > 4 A > 4 B > 4 B > B 9 Q Q

```
>>> 1 = [2,3,5,7,11,13]
>>> 1[0]
2
>>> len(1)
6
>>> for x in 1:
       print 'Item: ', x, ', Doubled: ', x*2,
>>>
Item: 2, Doubled: 4
Item: 3, Doubled: 6
Item: 5, Doubled: 10
Item: 7, Doubled: 14
Item: 11, Doubled: 22
Item: 13, Doubled: 26
```

>>> 1 = ['neuron', 'axon', 'dendrite', 4.6, 16]

▶ Dictionaries map a key to a value

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▶ Dictionaries map a key to a value

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▶ Dictionaries map a key to a value

```
>>> channel_density = {
                  'soma': 1.0,
                  'dendrite': 0.8,
                  'axon':0.7,
                  'axonhillock': 1.7,
```

>>> channel_density['axon']

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▶ Dictionaries map a key to a value

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Dictionaries map a key to a value

>>> channel_density['axonhillock']

```
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```

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Dictionaries map a key to a value

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>>> regions = channel_density.keys()

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```
>>> regions = channel_density.keys()
>>> regions
```

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```
>>> regions = channel_density.keys()
>>> regions
>>> ['axon','dendrite','soma','axonhillock']
```

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```
>>> regions = channel_density.keys()
>>> regions
>>> ['axon','dendrite','soma','axonhillock']
>>> for location in residence.keys():
        print location + ' has channel density '. channel density[location]
```

axon has channel density 1.0 dendrite has channel density 0.8 soma has channel density 1.0 axonhillock has a channel density 1.7

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Example 1

► Load SWC File and calculate the surface area of the neuron

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Example 1

- ► Load SWC File and calculate the surface area of the neuron
- ► SWC File Format

 ID TYPE XPOS, YPOS, ZPOS, RAD, PARENT_ID

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Example 1

- ▶ Load SWC File and calculate the surface area of the neuron
- SWC File Format

```
ID TYPE XPOS, YPOS, ZPOS, RAD, PARENT_ID
54 2 0.00 -3.00 -3.00 0.15 -1
55 51 0.50 -5.00 -4.00 0.50 54
56 51 0.00 -7.00 -7.00 0.15 55
```

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Background

- Load SWC File and calculate the surface area of the neuron
- SWC File Format

ID TYPE XPOS, YPOS, ZPOS, RAD, PARENT_ID 54 2 0.00 -3.00 -3.00 0.15 -1 55 51 0.50 -5.00 -4.00 0.50 54 56 51 0.00 -7.00 -7.00 0.15 55

▶ Surface Area of cylinder: $A = (R + r) \times \pi \times length$

Background

► For each line in the file (without a parent_id -1):

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- ► For each line in the file (without a parent_id -1):
 - Find the position and radius of the parent.

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- ► For each line in the file (without a parent_id -1):
 - ▶ Find the position and radius of the parent.
 - ► Find the length of the segment by subtracting this lines position for the parents (via Pythagorus)

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- ► For each line in the file (without a parent_id -1):
 - Find the position and radius of the parent.
 - Find the length of the segment by subtracting this lines position for the parents (via Pythagorus)
 - Calculate the surface area of this segment using length and radii

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- ► For each line in the file (without a parent_id -1):
 - Find the position and radius of the parent.
 - Find the length of the segment by subtracting this lines position for the parents (via Pythagorus)
 - Calculate the surface area of this segment using length and radii
- Add up the surface area of all lines.

Python Algorithm

Read all the lines in the file & create a dictionary with the data,

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Python Algorithm

▶ Read all the lines in the file & create a dictionary with the data, Map id's to a list containing the data on the line: $id \mapsto [x, y, z, r, parent_id]$

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Read all the lines in the file & create a dictionary with the data, Map id's to a list containing the data on the line: $id \mapsto [x, y, z, r, parent_id]$ $54 \mapsto [0.00, -3.00, -3.00, 0.15, -1]$

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Read all the lines in the file & create a dictionary with the data, Map id's to a list containing the data on the line:

 $id \mapsto [x, y, z, r, parent_id]$

 $54 \mapsto [0.00, -3.00, -3.00, 0.15, -1]$

 $55 \mapsto [0.00, -5.00, -4.00, 0.50, 54]$

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▶ Read all the lines in the file & create a dictionary with the data,

Map id's to a list containing the data on the line:

 $id \mapsto [x, y, z, r, parent_id]$

 $54 \mapsto [0.00, -3.00, -3.00, 0.15, -1]$

 $55 \mapsto [0.00, -5.00, -4.00, 0.50, 54]$

 $56 \mapsto [0.00, -7.00, -7.00, 0.15, 55]$

Read all the lines in the file & create a dictionary with the data.

Map id's to a list containing the data on the line:

 $id \mapsto [x, y, z, r, parent_id]$

 $54 \mapsto [0.00, -3.00, -3.00, 0.15, -1]$

 $55 \mapsto [0.00, -5.00, -4.00, 0.50, 54]$

 $56 \mapsto [0.00, -7.00, -7.00, 0.15, 55]$

Iterate over every id in the dictionary (without a parent_id of -1):

Read all the lines in the file & create a dictionary with the data.

Map id's to a list containing the data on the line:

 $id \mapsto [x, y, z, r, parent_id]$ $54 \mapsto [0.00, -3.00, -3.00, 0.15, -1]$ $55 \mapsto [0.00, -5.00, -4.00, 0.50, 54]$ $56 \mapsto [0.00, -7.00, -7.00, 0.15, 55]$

Iterate over every id in the dictionary (without a parent_id of -1): Lookup the data($[x, y, z, r, parent_id]$) for that id in the dictionary

Read all the lines in the file & create a dictionary with the data.

Map id's to a list containing the data on the line:

 $id \mapsto [x, y, z, r, parent_id]$ $54 \mapsto [0.00, -3.00, -3.00, 0.15, -1]$

 $55 \mapsto [0.00, -5.00, -4.00, 0.50, 54]$

 $56 \mapsto [0.00, -7.00, -7.00, 0.15, 55]$

Iterate over every id in the dictionary (without a parent_id of -1):

Lookup the data($[x, y, z, r, parent_id]$) for that id in the dictionary

Lookup the parent_data using parent_id (again using the dictionary)

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Read all the lines in the file & create a dictionary with the data,

Map id's to a list containing the data on the line:

 $id \mapsto [x, y, z, r, parent_id]$

 $54 \mapsto [0.00, -3.00, -3.00, 0.15, -1]$

 $55 \mapsto [0.00, -5.00, -4.00, 0.50, 54]$

 $56 \mapsto [0.00, -7.00, -7.00, 0.15, 55]$

▶ Iterate over every id in the dictionary (without a parent_id of -1):

Lookup the data($[x, y, z, r, parent_id]$) for that id in the dictionary

Lookup the parent_data using parent_id (again using the dictionary)

Calculate the length of the segment

Read all the lines in the file & create a dictionary with the data.

Map id's to a list containing the data on the line:

 $id \mapsto [x, y, z, r, parent_id]$

 $54 \mapsto [0.00, -3.00, -3.00, 0.15, -1]$

 $55 \mapsto [0.00, -5.00, -4.00, 0.50, 54]$

 $56 \mapsto [0.00, -7.00, -7.00, 0.15, 55]$

Iterate over every id in the dictionary (without a parent_id of -1):

Lookup the data($[x, y, z, r, parent_id]$) for that id in the dictionary

Lookup the parent_data using parent_id (again using the dictionary)

Calculate the length of the segment

Calculate the surface of the segment

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Read all the lines in the file & create a dictionary with the data,

Map id's to a list containing the data on the line:

 $id \mapsto [x, y, z, r, parent_id]$

 $54 \mapsto [0.00, -3.00, -3.00, 0.15, -1]$

 $55 \mapsto [0.00, -5.00, -4.00, 0.50, 54]$

 $56 \mapsto [0.00, -7.00, -7.00, 0.15, 55]$

▶ Iterate over every id in the dictionary (without a parent_id of -1):

Lookup the data($[x, y, z, r, parent_id]$) for that id in the dictionary

Lookup the parent_data using parent_id (again using the dictionary)

Calculate the length of the segment Calculate the surface of the segment

Add up the surface area of all id's.

Reading the File I

Program

```
swcFile = open( "myNeuron.swc")
for line in swcFile.readlines():
    print line,
```

Output

```
'54 2 0.00 -3.00 -3.00 0.15 -1'
'55 51 0.50 -5.00 -4.00 0.50 54'
'56 51 0.00 -7.00 -7.00 0.15 55'
...
'77 2 8.00 -8.00 -27.00 0.15 76'
```

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Reading the File II

Program

```
swcFile = open( "myNeuron.swc")
for line in swcFile.readlines():
    lineSplit = line.split()
    print lineSplit
```

Output

```
['54', '2', '0.00', '-3.00', '-3.00', '0.15', '-1']
['55', '51', '0.50', '-5.00', '-4.00', '0.50', '54']
['56', '51', '0.00', '-7.00', '-7.00', '0.15', '55']
...
['77', '2', '8.00', '-8.00', '-27.00', '0.15', '76']
```

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```
swcFile = open( "myNeuron.swc")
for line in swcFile.readlines():
    lineSplit = line.split()

id = int( lineSplit[0] )
    x = float( lineSplit[2] )
    y = float( lineSplit[3] )
    z = float( lineSplit[4] )
    r = float( lineSplit[5] )
    parent_id = int( lineSplit[6] )

print 'ID: %d (%f,%f,%f) R:%f Parent:%d' % (id,x,y,z,r,parent_id)
```

Output

```
ID: 54 (0.00,-3.00,-3.00) R:0.15 Parent:-1]
ID: 55,(0.50,-5.00,-4.00) R:0.50 Parent:54]
ID: 56,(0.00,-7.00,-7.00) R:0.15 Parent:55]
...
ID: 77,(8.00,-8.00,-27.00) R:0.15 Parent:76]
```

Building the Dictionary Program

```
idDict = {}
swcFile = open( "myNeuron.swc")
for line in swcFile.readlines():
    lineSplit = line.split()
    id = int( lineSplit[0] )
    x = float( lineSplit[2] )
    y = float( lineSplit[3] )
    z = float( lineSplit[4] )
    r = float( lineSplit[5] )
    parent_id = int( lineSplit[6] )
    idDict[id] = [x,y,z,r,parent_id]
print idDict
```

Output

```
{ 54 : [0.00,-3.00,-3.00,0.15,-1], 55: [0.50,-5.00,-4.00,0.50,54], 56: [0.00,-7.00,-7.00,0.15,55], ... 77: [8.00,-8.00,-27.00,0.15,76] }
```

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```
from math import pi,sqrt
def calcLength(x1,v1,z1, x2,v2,z2):
    y = y1-y2
   y = y1-y2
    z = z1-z2
    return sart( x*x + v*v + z*z )
total area = 0
for id. swcData in idDict.iteritems():
    #Shorthand for:x = swcData[0], v = swcData[1] ...
    x,y,z,rad,parent_id = swcData
    if parent id == -1:
        print "ID: %d - Root node - nothing to do" %id
    else:
        parent swc data = idDictionary[ parent id ]
        p_x,p_y,p_z,p_rad,p_parent_id = parent_swc_data
        1 = calcLength(x,y,z, p_x,p_y,p_z)
        sa = (rad + p_rad) * pi * 1
        print "ID: %d - Length %f, SA: %f" % (id,1,sa)
        total area = total area + sa
print 'Total Area:', total area
ID: 55 - Root node - nothing to do"
ID: 56 - Length 3.64, SA: 7.43
ID: 57 - Length 1.50, SA: 3.06
ID: 77 - Length 2.24, SA: 2.11
```

Total Area: 98.78

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Simplfied Program

```
from math import pi,sqrt
from numpy import array
from scipy.linalg import norm
swcFile = open("mvNeuron.swc")
for line in swcFile.readlines():
    lineSplit = line.split()
    id = int( lineSplit[0] )
    xyz = array( [float(lineSplit[2]), float(lineSplit[3]), float(lineSplit[4]) ] )
    r = float( lineSplit[5] )
    parent_id = int( lineSplit[6] )
    idDict[id] = [xyz,r,parent_id]
segmentAreas = {}
for id, (xyz,rad,parent_id) in idDict.iteritems():
    if parent id == -1: continue
    p_xyz,p_rad,p_parent_id = idDictionary[ parent_id ]
    segmentAreas[id] = (rad + p_rad) * pi * norm(p_xyz-xyz)
print 'Total Area:', sum( segmentAreas.values() )
```

Notes

Total: 17 Lines of code!

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numpy, scipy & matplotlib

 numpy contains basic array and matrix manipulation functions Python in Neurocomputation - A Brief Introduction

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numpy, scipy & matplotlib

- numpy contains basic array and matrix manipulation functions
- scipy contains higher-level toolboxes
 - signal-processing, statistics,
 - optimisation, fft, image-processing

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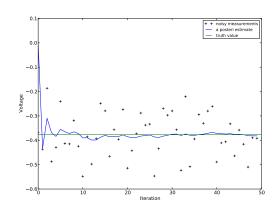
- numpy contains basic array and matrix manipulation functions
- scipy contains higher-level toolboxes
 - signal-processing, statistics,
 - optimisation, fft, image-processing
- matplotlib/pylab provide plotting functionality
 - Emulated matlab interfaces.
 - High-quality output
 - Most imaginable plots Polar, 3D, Map-Overlays, Shapes, Densities, [see gallery]
 - Flexible. Extensible architecture

Examples

```
import numpy, pylab
# intial parameters
n_{-iter} = 50
sz = (n_iter,) # size of array
x = -0.37727 \# truth value (typo in example at top of p. 13 calls this z)
z = numpy.random.normal(x, 0.1, size=sz) \# observations (normal about x, s=0.1)
Q = 1e-5 \# process variance
# allocate space for arrays
xhat=numpy.zeros(sz) # a posteri estimate of x
P=numpy, zeros(sz)
                        # a posteri error estimate
xhatminus=numpy.zeros(sz) # a priori estimate of x
Pminus=numpy.zeros(sz) # a priori error estimate
K=numpy.zeros(sz)
                      # gain or blending factor
R = 0.1**2 # estimate of measurement variance, change to see effect
# intial guesses
xhat[0] = 0.0
P[0] = 1.0
for k in range(1.n_iter):
    # time update
    xhatminus[k] = xhat[k-1]
    Pminus[k] = P[k-1]+Q
    # measurement update
    K[k] = Pminus[k]/(Pminus[k]+R)
    xhat[k] = xhatminus[k]+K[k]*(z[k]-xhatminus[k])
    P[k] = (1-K[k]) * Pminus[k]
```

Kalman Filter Example - Plotting

```
from pylab import *
figure()
plot(z,'k+',label='noisy measurements')
plot(xhat,'b-',label='a posteri estimate')
axhline(x,color='g',label='truth value')
legend()
xlabel('Iteration')
ylabel('Voltage')
```



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