

Python in Neurocomputation - A Brief Introduction

Mike Hull

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- ▶ High-level, general purpose programming language

What is Python?

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

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What is Python?

- ▶ High-level, general purpose programming language
- ▶ In development since 1989. Currently Version 2.6
- ▶ Opensource - Strong User Community

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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

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- ▶ 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

Why is Python Popular?

► Design Philosophy

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Why is Python Popular?

- ▶ 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
 - ▶ 'remarkable power with very clear syntax'
 - ▶ 'to describe something as clever is *NOT* considered a compliment in the Python culture'
- ▶ Learning Curve

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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'
- ▶ Learning Curve
- ▶ Scalability

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- ▶ Learning Curve
- ▶ Scalability
- ▶ Cross Platform

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

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

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- ▶ Standard Library - databasing, cryptography, networking, graphics, ...
- ▶ 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
species = 'Xenopus'
other = 'laevis'
print 'Lets study ' + species + ' ' + other + ' .'
>> Lets study Xenopus laevis.
```

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► Integer, Float

```
>>> (50-5*6)/4
```

Basic Data Types

► Integer, Float

```
>>> (50-5*6)/4  
5
```

Basic Data Types

► Integer, Float

```
>>> (50-5*6)/4
```

```
5
```

```
>>> 3 * 3.75 / 1.5
```

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Basic Data Types

► Integer, Float

```
>>> (50-5*6)/4
```

```
5
```

```
>>> 3 * 3.75 / 1.5
```

```
7.5
```

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```
>>> 3 * 3.75 / 1.5
```

```
7.5
```

► String

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```
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```

```
>>> 3 * 3.75 / 1.5
```

```
7.5
```

► String

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

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```
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```
5
```

```
>>> 3 * 3.75 / 1.5
```

```
7.5
```

► String

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

```
'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'
>>> a = 'Bristol has hills'
>>> a[0]
```

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► Integer, Float

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

► String

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

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

► 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
7.5
```

► 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
7.5
```

► 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
7.5
```

► String

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

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Lists

```
>>> l = [2,3,5,7,11,13]
```

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Lists

```
>>> l = [2,3,5,7,11,13]
```

```
>>> l[0]
```

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Lists

```
>>> l = [2,3,5,7,11,13]
```

```
>>> l[0]
```

```
2
```

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Lists

```
>>> l = [2,3,5,7,11,13]
```

```
>>> l[0]
```

```
2
```

```
>>> len(l)
```

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```
>>> l = [2,3,5,7,11,13]
```

```
>>> l[0]
```

```
2
```

```
>>> len(l)
```

```
6
```

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```
>>> l = [2,3,5,7,11,13]
```

```
>>> l[0]
```

```
2
```

```
>>> len(l)
```

```
6
```

```
>>> for x in l:
```

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

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```
>>> l = [2,3,5,7,11,13]
>>> l[0]
2
>>> len(l)
6
>>> for x in l:
>>>     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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```
>>> l = [2,3,5,7,11,13]
>>> l[0]
2
>>> len(l)
6
>>> for x in l:
>>>     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
>>> l = ['neuron', 'axon', 'dendrite', 4.6, 16]
```

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Dictionaries

- Dictionaries map a *key* to a *value*

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Dictionaries

- Dictionaries map a *key* to a *value*

```
>>> residence = { 'Mike': 'Edinburgh',  
                  'Roman': 'Plymouth',  
                  'Debbie': 'Bristol',  
                  'Azad': 'Plymouth',  
                  'Edgar': 'Bristol' }
```

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► Dictionaries map a *key* to a *value*

```
>>> residence = { 'Mike': 'Edinburgh',  
                  'Roman': 'Plymouth',  
                  'Debbie': 'Bristol',  
                  'Azad': 'Plymouth',  
                  'Edgar': 'Bristol' }
```

```
>>> residence['Edgar']
```

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► Dictionaries map a *key* to a *value*

```
>>> residence = { 'Mike': 'Edinburgh',  
                  'Roman': 'Plymouth',  
                  'Debbie': 'Bristol',  
                  'Azad': 'Plymouth',  
                  'Edgar': 'Bristol' }
```

```
>>> residence['Edgar']  
'Bristol'
```

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► Dictionaries map a *key* to a *value*

```
>>> residence = { 'Mike': 'Edinburgh',  
                  'Roman': 'Plymouth',  
                  'Debbie': 'Bristol',  
                  'Azad': 'Plymouth',  
                  'Edgar': 'Bristol' }
```

```
>>> residence['Edgar']  
'Bristol'
```

```
>>> residence['Azad']
```

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► Dictionaries map a *key* to a *value*

```
>>> residence = { 'Mike': 'Edinburgh',  
                  'Roman': 'Plymouth',  
                  'Debbie': 'Bristol',  
                  'Azad': 'Plymouth',  
                  'Edgar': 'Bristol' }
```

```
>>> residence['Edgar']  
'Bristol'
```

```
>>> residence['Azad']  
'Plymouth'
```

Dictionary Iteration

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```
>>> people = residence.keys()
```

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```
>>> people = residence.keys()
>>> people
```

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```
>>> people = residence.keys()
>>> people
>>> ['Debbie', 'Edgar', 'Azad', 'Mike', 'Roman']
```

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```
>>> people = residence.keys()
>>> people
>>> ['Debbie', 'Edgar', 'Azad', 'Mike', 'Roman']
>>> for name in residence.keys():
    print name + ' lives in ' + residence[name]
```

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```
>>> people = residence.keys()
>>> people
>>> ['Debbie', 'Edgar', 'Azad', 'Mike', 'Roman']
>>> for name in residence.keys():
    print name + ' lives in ' + residence[name]
```

```
Debbie lives in Bristol
Edgar lives in Bristol
Azad lives in Plymouth
Mike lives in Edinburgh
Roman lives in Plymouth
```

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

Example 1

- ▶ Load SWC File and calculate the surface area of the neuron
- ▶ SWC File Format
ID TYPE XPOS, YPOS, ZPOS, RAD, PARENT_ID

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
```

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

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

Human Algorithm

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- 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 line's 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 line's position for the parents (via Pythagoras)
 - ▶ 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 line's position for the parents (via Pythagoras)
 - ▶ Calculate the surface area of this segment using length and radii
- ▶ Add up the surface area of all lines.

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- ▶ 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:
 $id \mapsto [x, y, z, r, \text{parent_id}]$

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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:

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

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

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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:

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

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

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

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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:

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

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

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

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

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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):

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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

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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)

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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

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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

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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.

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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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Extracting the data

Program

```
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] }
```

Calculating the Surface Areas

```
from math import pi,sqrt
def calcLength(x1,y1,z1, x2,y2,z2):
    x = x1-x2
    y = y1-y2
    z = z1-z2
    return sqrt( x*x + y*y + z*z )

total_area = 0
for id, swcData in idDict.iteritems():
    #Shorthand for:x = swcData[0], y = 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

        l = calcLength(x,y,z, p_x,p_y,p_z)
        sa = (rad + p_rad) * pi * l
        print "ID: %d - Length %f, SA: %f" % (id,l,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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Simplified Program

```
from math import pi,sqrt
from numpy import array
from scipy.linalg import norm

swcFile = open("myNeuron.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

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- ▶ numpy contains basic matrix manipulation functions

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

numpy, scipy & matplotlib

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- ▶ numpy contains basic 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

Kalman Filter Example - Calculation

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```
import numpy, pylab

# initial 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

# initial 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]
```

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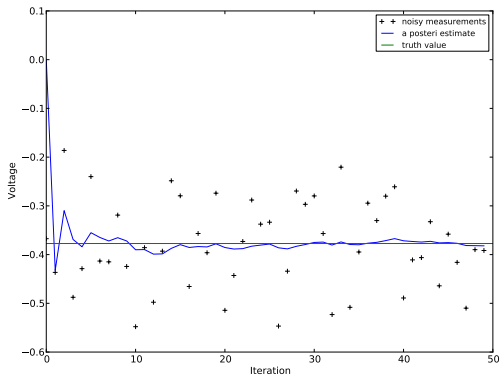
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Kalman Filter Example - Plotting

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



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Any Questions. . .

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