

Image Processing with Python

An introduction to the use of
Python, NumPy, SciPy and matplotlib
for image processing tasks

In preparation for the exercises of the Master course module
Image Processing 1
at winter semester 2013/14

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Outline

- Introduction
- Presenting the Python programming language
- Image processing with NumPy and SciPy
- Visualization with matplotlib and the spyder IDE
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Prerequisites (Software)

- Python (we use version 2.X *with X>5*)
 - <http://www.python.org>
- NumPy and SciPy (with PIL: <http://www.pythonware.com/products/pil>)
 - <http://www.scipy.org>
- matplotlib
 - <http://matplotlib.org>
- spyder IDE
 - <http://code.google.com/p/spyderlib>

Installing Python and packages

- **Linux**

- All of the prerequisites should be installable by means of the package manager of the distribution of your choice.

- **Mac OS X**

- Install the MacPorts package manager (<http://www.macports.org>) and use this to get all necessary packages.

- **Windows**

- Python-(x,y) (<http://code.google.com/p/pythonxy>) contains all necessary packages in binary form and an installer.

Goals for today...

- Draw interest to another programming language, namely: *Python*
- Motivation of an interactive Workflow („Spielwiese“)
- „Easy access“ into practical image processing tasks using *NumPy, SciPy, matplotlib and spyder*
- Finally: Give you the ability to solve the exercises of this course

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Introducing Python

The following introduction is based on the official „Python-Tutorial“

<http://docs.python.org/tutorial/index.html>



Python

„Python is an easy to learn, powerful programming language. [...] Python’s elegant syntax and dynamic typing, together with its interpreted nature, make it an ideal language for scripting and rapid application development in many areas on most platforms.“

„By the way, the language is named after the BBC show “Monty Python’s Flying Circus” and has nothing to do with reptiles.“

The Python Tutorial, Sep. 2010

Why another language?

Why Python?

- Interactive: no code/compile/test-cycle!
- A lot of currently needed and easy accessible functionality compared with traditional scripting languages!
- Platform independent and freely available!
- Large user base and good documentation!
- Forces compactness and readability of programs by syntax!
- Some say: can be learned in 10 minutes...

Getting in touch with Python (2.X)

- All of this tutorial will use the interactive mode:
 - Start the interpreter: `python`
 - Or, an advanced interpreter: `ipython`

1. Example:

```
> python
Python 2.7 (#1, Feb 28 2010, 00:02:06)
Type "help", "copyright", "credits" or "license" for more information.
>>> the_world_is_flat = True
>>> if the_world_is_flat:
...     print "Be careful not to fall off!"
...
Be careful not to fall off!
```

Data types – numbers (1)

- Python supports integer, floating point and complex valued numbers by default:

```
>>> 2+2
4
>>> # This is a comment
... 2+2
4
>>> # Integer division returns the floor:
... 7/3
2
>>> 7.0 / 2 # but this works...
3.5
>>> 1.0j * 1.0j
(-1+0j)
```

Data types – numbers (2)

- Assignments and conversions:

```
>>> a=3.0+4.0j
>>> float(a)
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
TypeError: can't convert complex to float; use abs(z)
>>> a.real
3.0
>>> a.imag
4.0
>>> abs(a) # sqrt(a.real**2 + a.imag**2)
5.0
```

Special variables

- Example: last result „_“ (only in interactive mode):

```
>>> tax = 12.5 / 100
>>> price = 100.50
>>> price * tax
12.5625
>>> price + _
113.0625
>>> round(_, 2)
113.06
```

- Many more in ipython!

Data types – strings

- Sequences of chars (like e.g. in C), but immutable!

```
>>> word = 'Help' + 'A'
>>> word
'HelpA'
>>> '<' + word*5 + '>'
'<HelpAHelpAHelpAHelpAHelpA>'
>>> 'str' 'ing'          # <- This is ok
'string'
>>> word[4]
'A'
>>> word[0:2]
'He'
>>> word[2:]          # Everything except the first two characters
'lpA'
```

Data types – lists

- Lists may contain different types of entries at once!
- First element has index: 0, last element: length-1.

```
>>> a = ['spam', 'eggs', 100, 1234]
```

```
>>> a
```

```
['spam', 'eggs', 100, 1234]
```

```
>>> a[0]
```

```
'spam'
```

```
>>> a[-2]
```

```
100
```

```
>>> a[1:-1]
```

```
['eggs', 100]
```

```
>>> a[:2] + ['bacon', 2*2]
```

```
['spam', 'eggs', 'bacon', 4]
```

The first program (1)

- Counting Fibonacci series

```
>>> # Fibonacci series:
... # the sum of two elements defines the next
... a, b = 0, 1
>>> while b < 10:
...     print b
...     a, b = b, a+b
...
1
1
2
3
5
8
```

The first program (2)

- Counting Fibonacci series (with a colon after the print)

```
>>> # Fibonacci series:
... # the sum of two elements defines the next
... a, b = 0, 1
>>> while b < 10:
...     print b,
...     a, b = b, a+b
...
1 1 2 3 5 8 13 21 34 55 89 144 233 377 610 987
```

Conditionals – if

- Divide cases in if/then/else manner:

```
>>> x = int(raw_input("Please enter an integer: "))
Please enter an integer: 42
>>> if x < 0:
...     x = 0
...     print 'Negative changed to zero'
... elif x == 0:
...     print 'Zero'
... elif x == 1:
...     print 'Single'
... else:
...     print 'More'
...
More
```

Control flow – for (1)

- Python's for-loop:

```
>>> # Measure the length of some strings:
... a = ['two', 'three', 'four']
>>> for x in a:
...     print x, len(x)
...
two 3
three 5
four 4
```

- is indeed a for-each-loop!

Control flow – for (2)

- What about a counting for loop?
- Quite easy to get:

```
>>> a = ['Mary', 'had', 'a', 'little', 'lamb']
>>> for i in range(len(a)):
...     print i, a[i]
...
0 Mary
1 had
2 a
3 little
4 lamb
```

Defining functions (1)

- Functions are one of the most important way to abstract from problems and to design programs:

```
>>> def fib(n):      # write Fibonacci series up to n
...     """Print a Fibonacci series up to n."""
...     a, b = 0, 1
...     while a < n:
...         print a,
...         a, b = b, a+b
...
>>> # Now call the function we just defined:
... fib(2000)
0 1 1 2 3 5 8 13 21 34 55 89 144 233 377 610 987 1597
```

Defining functions (2)

- Functions are (themselves) just Python symbols!

```
>>> fib
<function fib at 10042ed0>
>>> f = fib
>>> f(100)
0 1 1 2 3 5 8 13 21 34 55 89
```

- No explicit return value needed (default: “None”)

```
>>> fib(0)
>>> print fib(0)
None
```

Defining functions (3)

- Fibonacci series with a list of numbers as return value:

```
>>> def fib2(n): # return Fibonacci series up to n
...     """Return a list containing the Fibonacci series up to n."""
...     result = []
...     a, b = 0, 1
...     while a < n:
...         result.append(a)    # see below
...         a, b = b, a+b
...     return result
...
>>> f100 = fib2(100)    # call it
>>> f100                # write the result
[0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89]
```

Function argument definitions (1)

- Named default arguments:

```
def ask_ok(prompt, retries=4, complaint='Yes or no, please!'):
    while True:
        ok = raw_input(prompt)
        if ok in ('y', 'ye', 'yes'):
            return True
        if ok in ('n', 'no', 'nop', 'nope'):
            return False
        retries = retries - 1
        if retries < 0:
            raise IOError('refuse user')
    print complaint
```

Function argument definitions (2)

- Calling strategy in more detail:

```
def parrot(voltage, state='a stiff', action='vroom', type='Norwegian Blue'):  
    print "-- This parrot wouldn't", action,  
    print "if you put", voltage, "volts through it."  
    print "-- Lovely plumage, the", type  
    print "-- It's", state, "!"
```

```
parrot(1000)
```

```
parrot(action = 'VOOOOOM', voltage = 1000000)
```

```
parrot('a thousand', state = 'pushing up the daisies')
```

```
parrot('a million', 'bereft of life', 'jump')
```


Excuse: lambda abstraction

- If you want, you can go functional with Python, e.g. using the provided lambda abstractor:

```
>>> f = lambda x, y: x**2 + 2*x*y + y**2
```

```
>>> f(1,5)
```

```
36
```

```
>>> (lambda x: x*2)(3)
```

```
6
```

Modules

- If you have saved this as „fibonacci.py“:

```
# Fibonacci numbers module
def fib(n): # return Fibonacci series up to n
    result = []
    a, b = 0, 1
    while b < n:
        result.append(b)
        a, b = b, a+b
    return result
```

...you have already written your first Python module.
Call it using:

```
>>> import fibo
>>> fibo.fib(100)
[1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89]
```

Summary of Python

- You'll learn Python the best:
 - ... by means of practical use of the language!
 - ... especially not by listening to lectures!
- Python has a lot more to offer!
E.g.: A class system, error handling, IO, GUI, Networking
- The slides shown before should have shown that:
 - Getting in touch is quite easy!
 - The learning rate is comparably steep!
 - You get early and valuable experiences of achievements!
- All this makes Python so popular!!

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Image processing with NumPy and SciPy

Unfortunately, it is not possible to give a complete introduction in either NumPy or SciPy.

The image processing introduction is based on:

http://scipy-lectures.github.io/advanced/image_processing

More material regarding NumPy can e.g. be found at:

<http://numpy.scipy.org>

A good beginner's tutorial is provided at:

http://www.scipy.org/Tentative_NumPy_Tutorial



Images as *efficient* arrays?!

- In many programming environments, like e.g. MatLab, images are represented as random access arrays
- However, Python's built-in array is often neither flexible nor powerful enough for image processing
- Thus: use NumPy arrays for image representation.
- Idea of a first (very basic) workflow:
 - Load images using `scipy.misc` (via PIL)
 - Process the images using NumPy and Scipy
 - Save the images using `scipy.misc` (via PIL)

NumPy at a glance

- *„NumPy is the fundamental package needed for scientific computing with Python. It contains among other things: a powerful N-dimensional array object [...]“*
 - NumPy Homepage, 2010
- May have required a whole course on its own...
- Still growing scientific user community (SciPy/NumPy)
- Reliable algorithms
- Quite fast, compared to commercial software implementations

Loading and saving images

- Load an image into a NumPy array (requires PIL)

```
>>> import numpy as np
>>> from scipy import misc
>>> img = misc.imread('lena.png')
```

- Saving a NumPy array as an image (requires PIL)

```
...
>>> img = misc.imread('lena.png')
>>> misc.imsave('lena_copy.png', img)
```

- Attention: Usually only 2d- and 3d-arrays with datatype „uint8“ (0 – 255) can be saved as images.
A type conversion may be necessary before saving!

„Hello Image“

- First example: Load, “view” and save an image:

```
...
>>> img = misc.imread('lena.png') #or: img = misc.lena()
>>> img
array([[162, 162, 162, ..., 170, 155, 128],
       ...,
       [ 44,  44,  55, ..., 104, 105, 108]])
>>> misc.imsave(img, 'lena_copy.png')
```



NumPy image representation (1)

- Gray-value images:

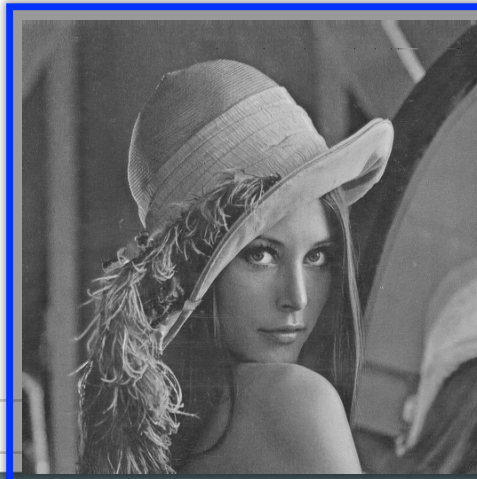
```
...  
>>> img  
array([[162, 162, 162, ..., 170, 155, 128],  
       [162, 162, 162, ..., 170, 155, 128],  
       [162, 162, 162, ..., 170, 155, 128],  
       ...,  
       [ 43,  43,  50, ..., 104, 100,  98],  
       [ 44,  44,  55, ..., 104, 105, 108],  
       [ 44,  44,  55, ..., 104, 105, 108]])
```



NumPy image representation (2)

- RGB-value images:

```
...  
>>> img_rgb  
array([[[[121, 112, 131], ..., [139, 144, 90]],  
       [[ 89,  82, 100], ..., [146, 153, 99]],  
       [[ 73,  66,  84], ..., [144, 153, 98]],  
       ...,  
       [[ 87, 106,  76], ..., [119, 158, 95]],  
       [[ 85, 101,  72], ..., [120, 156, 94]],  
       [[ 85, 101,  74], ..., [118, 154, 92]]], dtype=uint8)
```



NumPy slicing and index tricks

- Extract channels using slicing

```
>>> img_rgb[:, :, 0]          # <-- red channel
>>> img_rgb[..., 0]          # same as above, fix inner-most dim. to 0

>>> img_rgb[..., 1]          # <-- green channel

>>> img_rgb[..., 2]          # <-- blue channel
>>> img_rgb[..., -1]         # same as above, since blue is the last ch.
```

- Extract sub-images using index ranges:

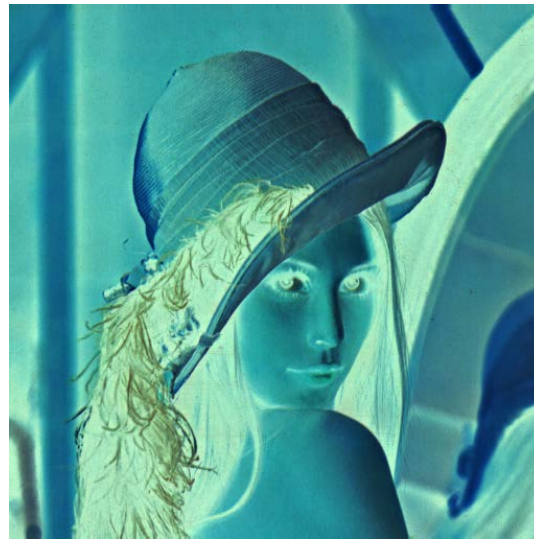
```
>>> img_rgb[100:200, 100:200, 0] # <-- red channel, size 100x100 px
>>> img[100:200, 100:200] # <-- 100x100 px of gray-scale image
```

- **Attention:** NumPy often creates views and does not copy your data, when using index tricks!
→ Compare to Call-By-Reference Semantics

Basic Image Processing (1)

- Example: Invert an image (create the negative):

```
...  
>>> img_invert = 255 - img  
>>> img_rgb_invert = 255 - img_rgb # <-- works for rgb too!
```



Basic Image Processing (2)

- Example: Threshold an image:

```
...  
>>> threshold = 100  
>>> mask = img < threshold  
>>> masked_img = img.copy()  
>>> masked_img[mask] = 0
```



Summary: Image Processing with SciPy and NumPy

- Many image processing algorithms already „onboard“, like e.g. filters and Fourier transformation in `scipy.ndimage` package
- Enables you to fast process images due to highly sophisticated C-implementation
- Contains a lot of numerical operations
- Time and memory efficient due to referential workflow

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Visualization with matplotlib

“matplotlib is a python 2D plotting library which produces publication quality figures in a variety of hardcopy formats and interactive environments across platforms. matplotlib can be used in python scripts, the python and ipython shell...”

<http://matplotlib.org>, October 2013

This introduction is based on the matplotlib image tutorial:

http://matplotlib.org/users/image_tutorial.html

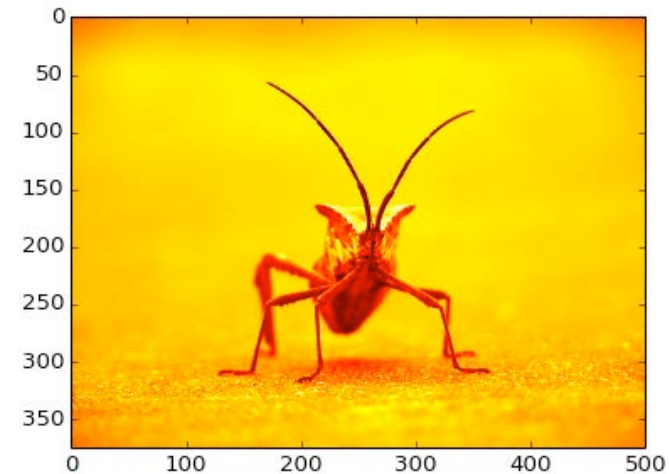
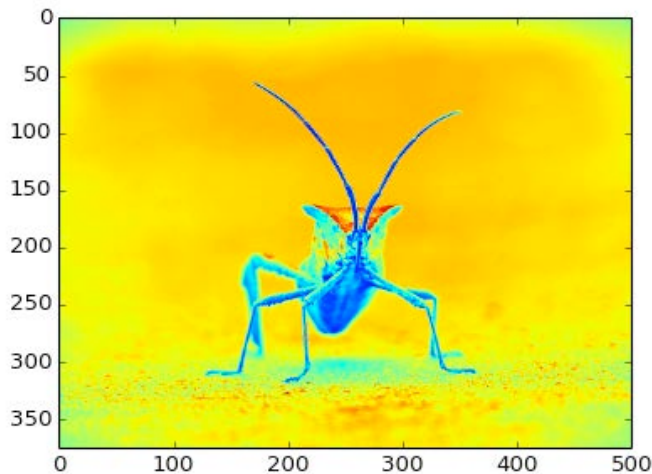
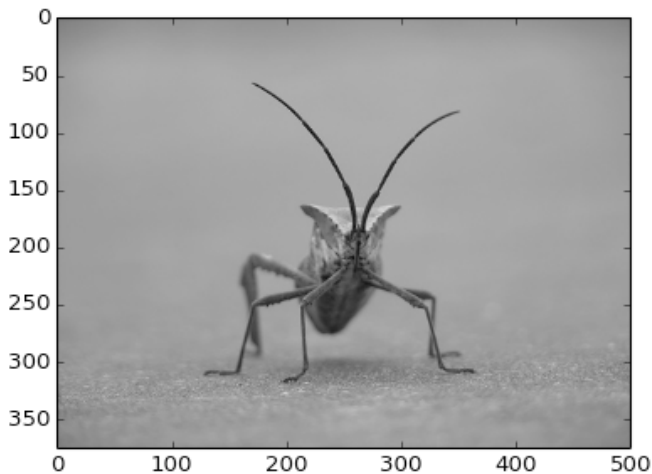


Showing images interactively

- Use matplotlib to show an image figure:

```
>>> import matplotlib.pyplot as plt
>>> from scipy import misc
>>> img = misc.imread('stinkbug.png') # <-- stored as a gray rgb image
>>> lum_img = img[...,0]

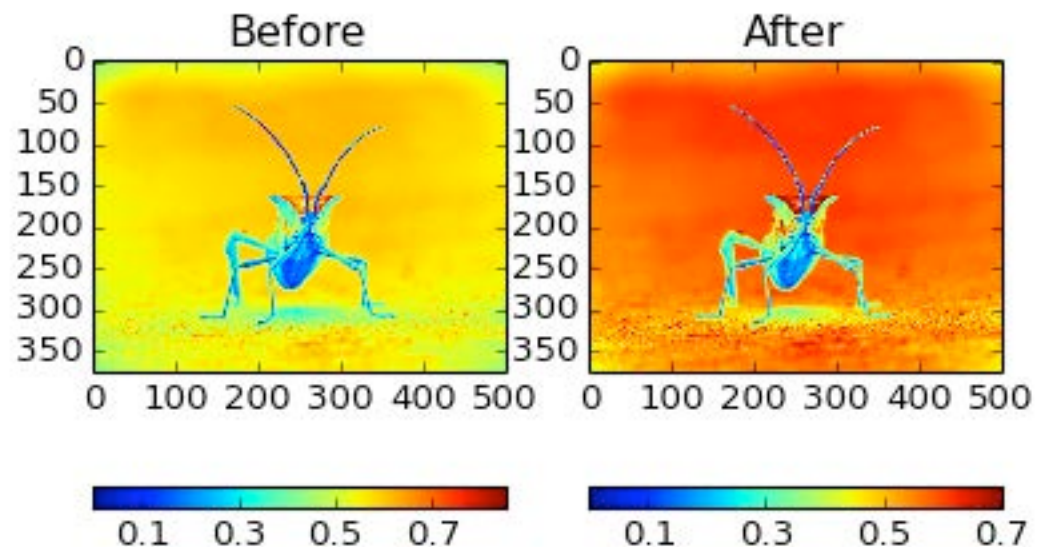
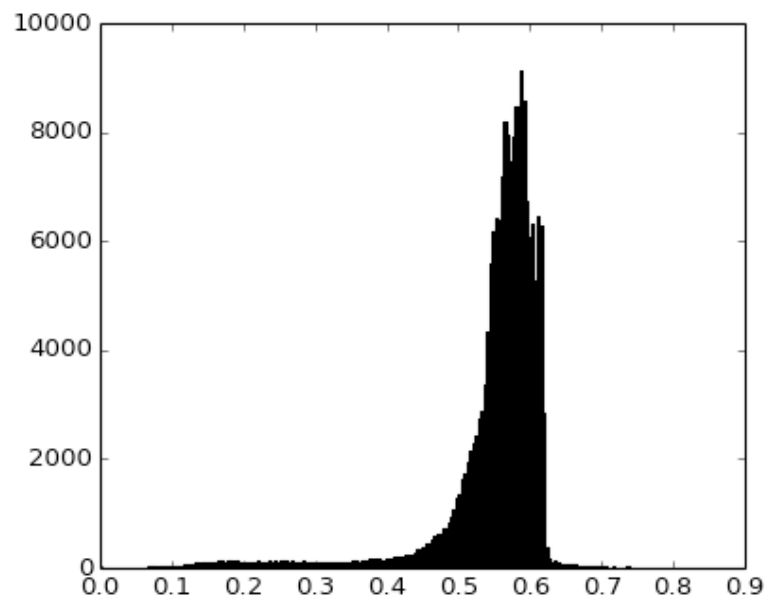
>>> img_plot = plt.imshow(img)
>>> img_plot.show()
>>> img_lum_plot = plt.imshow(lum_img)
>>> img_lum_plot.show()
>>> img_lum_plot.set_cmap(gray) # also try hot, spectral etc.
```



Show with enhanced contrast

- Use matplotlib to inspect the histogram:

```
...  
>>> plt.hist(lum_img.flatten(), 256, range=(0.0,1.0), fc='k', ec='k')  
>>> plt.show()  
  
>>> imgplot.set_clim(0.0,0.7)
```



Visualization issue: Interpolation

- When zooming in, it may be necessary to interpolate the images pixels.
- By default, bilinear interpolation is used. It might be better to use „nearest neighbor“ interpolation to see the pixels:

```
...  
>>> img_plot.set_interpolation('nearest')
```

- Or, for more accuracy, you may want to try bicubic interpolation:

```
...  
>>> img_plot.set_interpolation('bicubic')
```


Working with the spyder IDE

„spyder (previously known as Pydee) is a powerful interactive development environment for the Python language with advanced editing, interactive testing, debugging and introspection features.[...]

spyder lets you easily work with the best tools of the Python scientific stack in a simple yet powerful environment.[...]“

<http://code.google.com/p/spyderlib>, October 2013

The screenshots of this introduction have been taken from the spyder homepage.



spyder²

Light, intuitive, simple, powerful

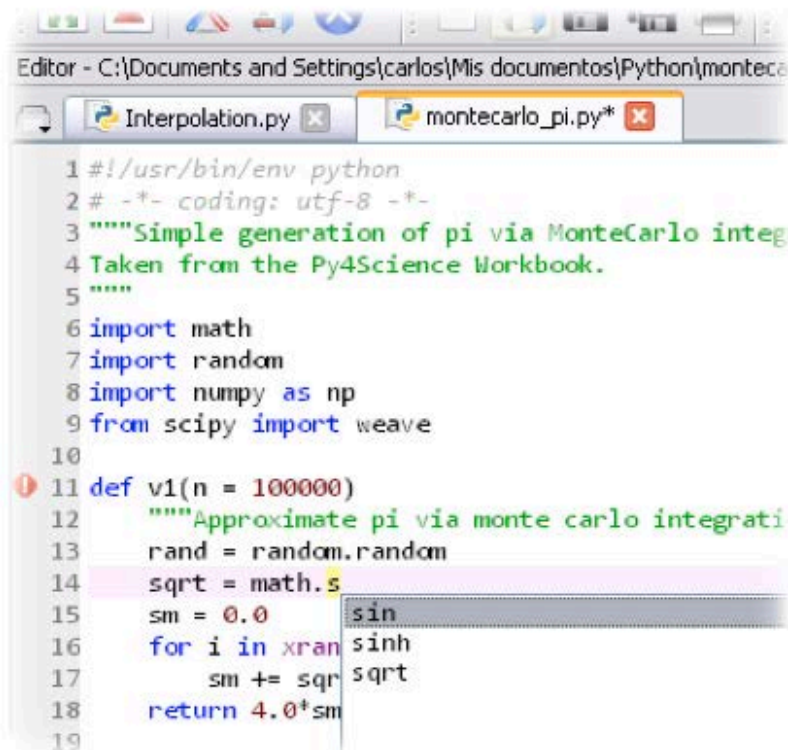
The spyder IDE

The image shows the Spyder IDE interface. The main window is titled "Spyder" and contains several panes:

- Editor:** Displays a Python script named `montecarlo_pi.py`. The script includes a docstring, imports for `math`, `random`, `numpy`, and `scipy`, and two functions: `v1` (approximate pi via Monte Carlo integration) and `v2` (implement v1 using `weave` for C call).
- Object inspector:** Shows the `numpy.mean` function signature: `mean(a, axis=None, dtype=None, out=None)`. It provides a description: "Function of numpy.core.fromnumeric module. Compute the arithmetic mean along the specified axis. Returns the average of the array elements. The average is taken over the flattened array by default, otherwise over the specified axis. float64 intermediate and return values are used for integer inputs." It also lists parameters: `a` (array_like) and `axis` (int, optional).
- Console:** Shows the output of the IPython shell. The first command is `In [2]: sin([1,2,3])`, resulting in `Out[2]: array([0.84147098, 0.90929743, 0.14112001])`. The second command is `In [3]:`.

The status bar at the bottom indicates: Permissions: RW | End-of-lines: LF | Encoding: UTF-8 | Line: 1 | Column: 1

spyder - the editor



```
Editor - C:\Documents and Settings\carlos\Mis documentos\Python\monteca
Interpolation.py x montecarlo_pi.py* x
1 #!/usr/bin/env python
2 # -*- coding: utf-8 -*-
3 """Simple generation of pi via MonteCarlo integ
4 Taken from the Py4Science Workbook.
5 """
6 import math
7 import random
8 import numpy as np
9 from scipy import weave
10
11 def v1(n = 100000)
12     """Approximate pi via monte carlo integrati
13     rand = random.random
14     sqrt = math.s
15     sm = 0.0
16     for i in xrange
17         sm += sqr
18     return 4.0*sm
19
```

A powerful editor is a central piece of any good IDE. Spyder's editor has:

- Syntax coloring for Python, C/C++ and Fortran files
- Powerful dynamic code introspection features (powered by [rope](#)):
 - Code completion and calltips
 - Go to an object definition with a mouse click
- Class and function browser.
- Occurrence highlighting.
- To-do lists (TODO, FIXME, XXX).
- Get errors and warnings on the fly (provided by [pyflakes](#))
- Breakpoints and conditional breakpoints to use with the python debugger (pdb).

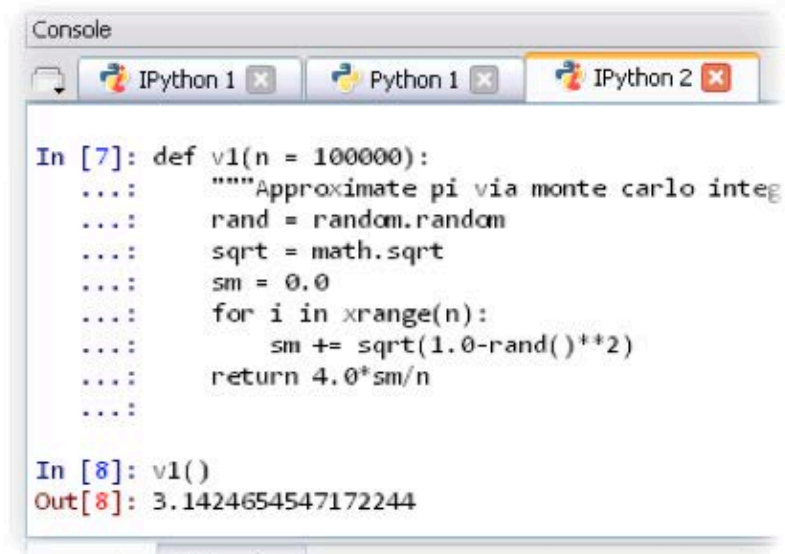
[Learn More](#)

spyder - the console

To easily interact with your code as you progress, Spyder lets you

- Open as many Python and Ipython consoles as you want
- Run a whole script or any portion of it from the [Editor](#)
- Have code completion and automatic link to documentation through the [Object Inspector](#)
- Execute all consoles in a separate process so they don't block the application

[Learn More](#)



```
Console
IPython 1 x Python 1 x IPython 2 x

In [7]: def v1(n = 100000):
...:     """Approximate pi via monte carlo integ
...:     rand = random.random
...:     sqrt = math.sqrt
...:     sm = 0.0
...:     for i in xrange(n):
...:         sm += sqrt(1.0-rand())**2)
...:     return 4.0*sm/n
...:

In [8]: v1()
Out[8]: 3.1424654547172244
```

spyder - the variable explorer

Name	Type	Size	Value
nest	int	1	-1
pi	float	1	3.1415926535897931
s	float	1	3.0
t	float64	(100,)	array([0.11505883, 0.590396 ...])
tckp	list	3	<list @ 0x65A18C8>
u	float64	(100,)	
x	float64	(100,)	
xnew	float64	(400,)	

With the Variable Explorer you can browse and analyze all the results your code is producing, and also

- Edit variables with Spyder's [Array Editor](#), which has support for a lot of data types (numbers, strings, lists, arrays, dictionaries)
- Have multiple Array Editors open at once, thus allowing to compare variable contents
- Import/Export data from/to a lot of file types (text files, numpy files, Matlab files)
- Generate 2D plots of list and arrays
- View local variables while you're debugging

[Learn More](#)

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Summary (1)

- The Python programming language
 - Readable, meaningful syntax (remember the tabs!)
 - Highly functional, full of functionality
 - Steep learning experience and fast results
 - Perfectly practicable for interactive work
 - Can be extended easily
 - Large global community

Summary (2)

- NumPy and SciPy
 - Efficient Array implementation
 - Loading and saving of images (transparently via PIL)
 - Adds (nature) scientific stuff to Python
 - Contains basic image processing functionality
 - Highly active and widely recommended packages

Summary (3)

- matplotlib
 - Plots everything...
 - Works well with NumPy arrays
- spyder
 - Nice IDE
 - Integrates Scientific work flow (a bit like MatLab)
- Everything is there and freely available: Time to start with the excercises!

Thank you for your attention!

Time for questions, discussions etc.