

Python's Very Basics

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Outline

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- 2 First Things
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- 6 Files and Modules
- 7 NumPy
- 8 Matplotlib and Pyplot

Preliminaries

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Python Sources

- These notes for a short, self-contained introduction
- Many other basic sources; some examples:
 - J. Guttag's book, *Introduction to Computation and Programming Using Python* (MIT Press, 2013): chapters 1–5 and 7
 - Assumes Python as the first programming language (C programmers can read the above chapters fast)
 - Plus an introduction to data structures and algorithm analysis
 - The [Python tutorial](#)
 - [Google's minicourse](#)
 - A fast and good introduction to strings, lists, dicts and files that assumes some programming knowledge
 - Plus a good set of exercises on them

More Advanced Sources

- For more experienced programmers: *Python Cookbook* (O'Reilly 2005)
- For Machine Learning/Data Science: W. McKinney's book, *Python for Data Analysis* (O'Reilly 2012)
 - Main goal: joint introduction to Python and data analysis
 - Good Python essentials summary in Appendix
- And all the documents in python.org as well as many web references (some below)
- As well as searches in stackoverflow
- As well as ...

But Also ...

- Is Python an easy language? Well, the basics yes, but ...
- From Quora: Joshua Engel, on learning Java
 - Learning Java, the language, is the work of an afternoon for a C programmer.
 - Learning Java, the programming environment, with eighty gazillion libraries and dozens of important frameworks, is the work of a dozen lifetimes.
- Perhaps true also for the Python ecosystem?

Working with Python

- Simplest initial mode: probably to work on a Jupyter notebook (more on them below)
 - Integrates a Python shell and an editor
 - Quite good for small programs; not so for larger ones
- Afterwards: for simple projects, combine a text editor with a Python shell in a edit(+copy)+execute+refine loop
 - Linux has a native shell but IPython is much better
 - One edits the program/module outside the shell, which can reload it automatically, and execute/check it
- For larger projects a Python IDE (of course!)

Python Installation

- Best option: install Continuum's Anaconda
 - Either the full Anaconda suite or the much simpler Miniconda
- Miniconda provides the standard library plus a set of common packages
 - We can add further packages with `conda install xxx`, which handles package dependencies
 - `pip install xxx` is another option but watch out for package inconsistencies
 - Install the latest Python 3.X (Python 2.7 will not be supported after 2019)
- To start the IPython/Jupyter tools, open the Anaconda command prompt and
 - Type `ipython` for the plain text IPython shell
 - Type `jupyter qtconsole` for the GUI version of the IPython shell
 - Type `jupyter notebook` for the Jupyter Notebook environments

Jupyter Notebooks

- Browser based interface to develop and document code
- Reasonable tool for beginner's Python programming
- Excellent tool for program– or work–flow documentation
- Cells for code, documentation, figures
- In code cells we can
 - Edit sentences or functions
 - Execute them with `Ctrl+Intro`
 - Debug, re–edit and re–execute until OK

Jupyter Notebooks II

- Text cells:
 - We mark them as Markdown cells with `Esc+m`
 - We can format text with Markdown syntax
 - They also admit formulas with LaTeX notation
- We can display figures from the Matplotlib module after executing the “magic” command `%matplotlib inline`
- Notebooks can be saved as such, as Python scripts, as plain html files or even converted to LaTeX using `nbconvert` (and then, say, to pdf)
- More in [The Jupyter notebook](#)

Jupyter Qt Console I

- GUI interface with inline figures, multiline editing, syntax highlighting ...
- Can have several tabs opened with different kernels
- Tab completion suggests possible command completions (and also object attributes or function's help)
- Opens with `jupyter qtconsole` in an Anaconda shell
- Easiest use: edit a piece of code with an outside editor, copy-paste it and run it with Enter
- Alternatively, edit a `.py` script with a (non Windows) text editor and run it with magic command `%run`
- Much better: write code as functions in a `.py` module and automatically reload it with the `%reload` command

Jupyter Qt Console II

- Magic commands begin with `%`
 - Run modules: `%run module.py`
 - Load scripts for shell editing: `%load module.py` (OK for small files)
 - OS commands: `%pwd`, `%cd`, ...
 - `%quickref` gives a simple IPython cheat sheet
 - `%lsmagic`, `%magic` list available magic functions
- `%alias` prints a list of aliases to common Unix commands
- More in:
A Qt Console for IPython

Import and Reload

- Simple way to start programming:
 - Write code adding functions in a `.py` module
 - Import the module into the shell (i.e. let the interpreter know about its functions)
 - Test functions and repeat cycle until OK
- Python 2.X: import module `module.py` with `import module as mod` and reload with `reload(mod)`
- Python 3.X: `import imp` and reload with `imp.reload(mod)`
- Much better: autoreload option in IPython:

```
%load_ext autoreload      #cargar extension autoreload
%autoreload 2             #reload all
```

- Automatically reloads `mod` after editing
 - But watch out for syntactic errors: the module is not imported and the previous version used
- More in [A Qt Console for IPython](#)

First Things

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Objects

- In Python everything is an object
 - If `o` is an object, typing `o.` + `tab` lists its methods
 - Also `dir(o)`
- Two general data types:
 - Scalar (atomic??): `int`, `float`, `bool`, `str`
 - Containers: contain scalars and other containers
- Type checking:
 - Implicit type assignment and runtime checking
 - Explicit type checking with `isinstance(object, type)` or `type(object) is b`
- Special “value” `None` : absence of value
- Type casting possible

Variables and Expressions

- Variables: **names** of objects (no synonyms of memory positions, as in C)
 - `a = 3` is **not an assignment** but a **binding** of `a` with the object `3`
- Python has a number of reserved words:
`and, print, while, class, lambda, ...`
 - They correspond to types, operators or built in functions
- Often leading and trailing single `_` and double `__` are used for special meanings
 - Good discussion in [The Meaning of Underscores in Python](#)
- Expressions often work as in C
 - `+=, -=, *=` : OK
 - `++, --` do not exist
 - `a // b` : integer division (also `a/b` in Python 2.X if `a, b` integers)
 - `1 / 2 = 0` in Python 2.X, `0.5` in Python 3.X
 - `a**b` : power

Variable Bindings

- Recall that variables in Python are in fact **names**
- At first sight more or less as in C, but there are clear cut differences
- There are not assignments but **bindings** between names and objects
 - Variable names **are not** synonyms of memory addresses where the variable values are stored
- Scope of bindings: (usually) the block in which the name appears
- Global variables: defined elsewhere and identified as `global name`
- Same use (and same problems) as in C

Scope Rules

- Python follows the LEGB scope Rule
- **L, Local**: names assigned in any way within a function and not declared global in that function
- **E, Enclosing function locals**: names in the local scope of any and all enclosing functions, from inner to outer
- **G, Global** (module): names assigned at the top-level of a module file, or declared global within the file
- **B, Built-in** (Python): names preassigned in the built-in names module

Variables and Bindings Examples

- Sometimes things may not behave as expected:

```
a = []; b = a; a.append(1); b.append(2)
print (a); print (b)
```

```
a = 10; b = a; a+=1
print (a, b)
```

- Swapping variables is also much different than in C:

```
a, b = b, a
print (a, b)
```

Bindings and Identities

- The `id` function returns the **identity** of an object:
 - An (long) integer which is guaranteed to be unique and constant for this object during its lifetime
 - But not an actual address
- Two names binding to the same object (usually) result in the same id:

```
a = 'aaa'; b='aaa'
print (id(a), id(b))
```

- But two names binding to the same integer beyond 256 will have different ids
- Using two different names for a mutable object means that changing one changes the other, but recall ...

```
a = []; b = a; a.append(1); b.append(2); print (id(a), id(b))
a = 10; b = a; print (id(a), id(b))
a+=1; print (id(a), id(b))
```

- Names can be destroyed using `del (name)` (kind of `free` in C)
- Nice discussion on [Python Objects](#)

Flow Control

- Code blocks are identified by their **indentation**:
 - Recommendation in [PEP 0008 – Style Guide for Python Code](#): 4 white spaces, no tabs
 - Results in highly structured code
 - But watch out for silly errors
- Selection: `if condition:/elif condition:/else:`
- Iterations through `while` and `for`; no `do while` construction
- While iteration:

```
while condition:  
    code block
```

- For iteration:

```
for var in sequence:  
    code block
```

- `sequence` has to be an **iterable** object such as strings (and lists, tuples, files, ...)

Loop Control Statements

- `break` : the loop terminates and execution goes to the statement immediately following the loop
- `continue` : the remainder of the loop body is skipped and execution goes to checking the loop's condition
- `pass` : used when a statement is required but do not want any command or code to executed
 - For instance, to leave temporarily an empty code block

More on `for`

- Try always to iterate over existing iterables and avoid C thinking over Python loops:

```
#do this only if needed
for i in range(1000000):
    print i

#never do this!!
for i in list(range(1000000)):
    print i
```

- `range(N)` defers the creation of the list element until it is needed
- The `while` and `for` equivalence is no longer straightforward
- More on iterables, `iterators` and `generators` later on

Strings

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Strings

- Alphanumerical characters between `'` or `"`: `a = 'aaa'`
- First **immutable** object: their individual elements cannot be changed
- Standard operators overload on strings:

```
str1+str2, int_*str_, str1 < str2
```

- `len(string)` returns its number of characters
- String elements accessible by indices: `a[0]`, `a[-1]`, `a[-2]`
- **Slicing** is used for substring access:

```
a[1:3], 'abc'[1:3], a[: -1]
```

- `sss[F:L]` extracts values of indices `F` to `L-1`
- **Extended slicing:** `sss[F:L:s]` extracts values of indices `F` to `L-1` by step `s`
 - `s[: : -1]` inverts the `s` array

String Methods

- String methods: very useful tools for string handling
- `s.lower()`, `s.upper()` : returns lowercase or uppercase versions of `s`
- `s.isalpha()`, `s.isdigit()` : tests if all the chars in `s` are of the corresponding type
- `s.find(string)` : searches for `string` and returns the first index where it begins or -1 if not found
- `s.replace(sOld, sNew)` : returns a string with `sOld` replaced by `sNew`
 - `s.replace(' ', '')` trims all blank space in `s`

String Methods II

- `s.split(delim)` : returns a list of substrings separated by the given delimiter
 - `s.split()` splits `s` over any sequence of white space characters
- The `separator.join(sequence)` construct uses Python's `join` function to put together the `sequence` list of strings separated by the string `separator`

```
s = 'XYZ'.join( ['a', 'b', 'c', 'd'] )
```

- `join` is the “inverse” of `split` :
 - `s.split('XYZ')` splits `s` in its substrings delimited by `XYZ`

More on Strings

- Multiple line string literals possible ending each line with a backslash \
 - We can also put in multiple lines Python expressions inside parenthesis
 - We can also use \ to span expressions on multiple lines
- **Raw strings:** literals preceded by `r`, as in `r'abc\edf\ghj'` that are not processed: `r'a\nb'` prints as `a\nb`
- Everything Unicode in Python 3.X
- The `string` library contains several useful string constants:
 - `string.ascii_letters` : the concatenation of the `ascii_lowercase` and `ascii_uppercase` constants
 - `string.digits` , `string.hexdigits` , `string.octdigits`
 - `string.punctuation`
 - `string.whitespace`

String Examples

- `s = 'abc'; s+s; 10*s, len(10*s)`
- `(3*s)[1:6]; (3*s)[: -1]; (3*s)[: : -1]`
- `(3*s).replace('a', 'A')`
- `s = ';'.join(['a', 'b', 'c', 'd']); s.split(';')`
- `s = '1 2 3 4 5'; s.split(' '); s.split()`
- `import string; string.digits; string.whitespace`

Printing (Old Style)

- Python's `print` can be made to work like C's `printf()` using the `%` format operator
- To do so one defines a string to be printed where
 - Inside the string `%d`, `%f`, `%g`, `%s` ... are used to define formats
 - At the right `%` precedes a tuple with the values to be printed
- Example:

```
a=3, b=3.1416, c='abcdefgh'
text = "int: %d float: %f string: %s" % (a, b, c)
print (text)
```

- Format delimiters of the form `%[flags][width][.precision]type` can be used to define the number of characters `width` and of decimal digits `precision`
 - Typical flag: `0` for 0-padded numerical values

Pythonic Printing: `format` Method

- Apply the `format` method to a string mixing text and formatting code
- The format contains one or more format codes (fields to be replaced) embedded in constant text
- The format codes are surrounded by `{ }`
- Inside `{ }` one has a positional parameter plus `:` plus a format string

```
"Second argument: {1:3d}, first one: {0:7.2f}".format(47.42,11)
```

```
"Art: {a:5d}, Price: {p:8.2f}".format(a=453, p=59.058)
```

```
"various precisions: {0:6.2f} or {0:6.3f}".format(1.4148)
```

- More in [Python3 Tutorial: Formatted Output - Python Course](#)

Basic Console Input/Output

- `input([prompt])` prints the optional string `prompt` on the shell console and returns a string after `Enter` with the newline stripped

```
num = input("Enter a 3 to continue .....\\n")
      Enter a 3 to continue .....      3+Enter

print(4*num, 4*int(num))
      3333 12
```

- `eval(expression)` processes the string `expression`

```
x = 1
eval('x+1')
      2
```

- `input` and `eval` can be used jointly to process console inputs

```
num = eval(input('enter an int: '))
      enter an int:      3+Enter

print(4*num, 4*int(num))
      3333 12
```


Functions

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Functions

- Definition

```
def name(parameters):  
    function body
```

- Function call: expression with value the returned value or `None`
- Call by value or by reference? In fact none of them
 - In C the terms value or reference correspond to variables as synonyms of memory addresses
 - In Python immutable objects are called by value and mutable by reference (but watch out!)
- Python uses **call by object** or **call by object reference**: if you pass a mutable object into a function/method:
 - It gets a reference to that same object and can be mutated with effects in the outside scope
 - But if it is rebound in the method, the outer scope will know nothing about it and no further outside changes are made

Python's Memory Model

- In C we have the **heap** and the **stack**
- In Python we have (global) **objects** and **frames**
- Frames are essentially dynamic blocks of pointers to objects
- There is a global frame for global objects (data, functions and so on)
- When called, each function creates its own dynamic frame (with its local variables)
- Good (recursive) visualization of frame and object evolution in the [Python Tutor](#) web page

An Example

- Bisection search for square root (from Guttag, p. 28):
- The following Python code yields approximate values to \sqrt{x} for a given $x \geq 1.0$ with precision `eps`:

```
def bisect_sqrt(x, eps):  
    '''... docstring ...'''  
    if x < 1:  
        print("error: input %f < 1." % x); return None  
    left = 1.; right = x; sqr = (left+right)/2  
    while abs (sqr**2 - x) > eps:  
        if sqr**2 < x:  
            left = sqr  
        else:  
            right = sqr  
        sqr = (left+right)/2  
    return sqr
```

- Exercise: change things to get a function `cube_root(x, eps)` that approximates the cubic root of $x \geq 1$

Calling Functions

- When a function is called
 - ① The function's frame and **namespace** are created
 - ② If needed, parameter expressions are evaluated and parameter names are bound to their results
 - ③ The function body is executed (and more names are added to the name space) until a return is reached
 - ④ The return value is bound according to the function call expression and the namespace is (usually) destroyed
- Multiple returned values are possible (well, actually tuples)
- Values are bound to parameters either positionally or through the formal parameter names
- This is exploited using default values

Argument Default Values I

- Argument order may be changed if we use default values

```
def printName(firstN, lastN, reverse):  
    #function's body: exercise  
  
#callable as:  
printN('Jose', 'Dorrnsoro', False)  
printN(lastN='Dorrnsoro', firstN='Jose', reverse=False)
```

- Default values are defined in the form `arg=value`

```
def printName(firstN, lastN, reverse=False):  
    #...  
  
#callable as:  
printN('Jose', 'Dorrnsoro')  
printN('Jose', 'Dorrnsoro', True)
```

Argument Default Values II

- In more detail: when a function is called,
 - The **positional arguments** are actually packed up into a **tuple** (`args`)
 - The **keyword arguments** are packed up into a **dict** (`kwargs`) with the variable names as keys
- Tuples are ordered and immutable, so we cannot move positional arguments around
- Dicts are not ordered and their objects are accessed through their keys; thus we can move `kwargs` around
- But cannot use a non keyword argument after a keyword one:

```
printN('Dorrnsoro', firstN='Jose', False) #error
```

- More on tuples and dicts below

Docstrings

- Given by a string contained between two triple quotes (`'''docstring '''` , `"""docstring """`) right after the `def` sentence
- Standard content:
 - A one line description of the function.
 - A full description after an empty line
 - A description of its parameters, returns and their types
- Standard parameter formst: reStructured text (reST) / Sphinx, which can be used to generate documentation automatically
 - Other frequent options: Google and Numpy formats
- More on [Stack Abuse: Python Docstrings](#)

Docstring Use

- Example

```
def bisect_sqrt(x, eps):  
    """Computes a square root of x by the bisection method.  
  
    Returns an approximation to the square root of x up to a  
        precision eps  
  
    Args:  
        x (float): the number whose square root we want  
        eps (float): the precision wanted  
  
    Returns:  
        sqr (float): the approximate square root  
    """  
    left= 1.; right = x; sqr = (left+right)/2  
    ...
```

- `help(bisect_sqrt)` in shell displays arguments and docstring
- `bisect_sqrt(` in shell opens window with help
- `pydoc -w my_module` writes a file `my_module.html` with (among others) the docstring info
 - Watch out: it executes the file (and prints all garbage comments inside!!)

Functions as Function Arguments

- In Python functions are **first class objects**: they can be used as any other object (say, a float or a list)
- They can appear in expressions
- They can be list objects
- They can be function arguments:

```
def square(n):  
    return n**2  
  
def listFuncValues(n, f):  
    l_func_vals =[f(i) for i in range(n)] #list comprehension  
    return l_func_vals
```

Functions Inside Functions

- Functions can be defined inside other functions
- The outside function names are seen by the inside function

```
def f_outside(x):  
    def f_inside():  
        def f_inside2():  
            return x*y  
        return x+f_inside2()  
    y = x*x  
    return 2*f_inside()
```

- Allows easy (and messy?) way to pass “local global” variables to subsidiary functions

Euclid Meets Python

- Python tries to build a kind of programming culture: [PEP 0008 – Style Guide for Python Code](#), [The Elements of Python Style](#)
- The [Zen of Python](#) contains short design guiding principles
- Pythonic code follows this one:
There should be one — and preferably only one — obvious way to do it
- An example (?): Euclid's algorithm

```
def mcd(x, y):  
    while(y):  
        x, y = y, x % y  
    return x
```

- By the way: in Python (almost) everything is `True` except 0 and “empty” things: `[]`, `""`, `set()`

True or False?

- But `and` and `or` have some quirks
 - `x and y` returns `y` if `x` is true, and `x` if not
 - `x or y` returns `x` if true, and `y` if not
 - Apply `bool()` to get `True`, `False`
- Examples:

```
10 and [] , [] or 0.
```

- Sometimes quite useful: assume we want their first character when two strings coincide

```
c = 'abc'; s = 'efg'  
c == s and s[0]
```

```
c = 'abc'; s = 'abc'  
c == s and s[0]
```

- To simplify things (?) Python has the functions `all()`, `any()`
 - `all(xx)` returns `True` if there are no `False` elements in iterable `xx`
 - `any(xx)` returns `True` if there is at least a `True` element
- To have some fun, check `all([])`, `any([])`

Structured Types

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Structured Types

- Python has five structured types: strings, tuples, lists, dicts and sets
- Recall that **strings** are ordered sequences of chars, each accessible through an index
- They are immutable
- They have a large and very useful set of methods
- Strings can be concatenated, indexed and sliced, and we can find their length through `len`
- `str(object)` transforms `object` into a string with results depending on what the object is
- More generally `type(object)` transforms when possible `object` into a another of type `type` with results depending on how the object is defined/programmed

Tuples

- **Tuples:** ordered sequences of values possibly of different types accessible through an index
- Examples

```
a = ('a', 1, 'b', 2); b = 'a', 1, 'b', 2  
a == b
```

- **Empty tuple:** `tup = ()`; one element tuple: `tup = ('a',)`
- Tuples are **immutable**: their individual elements cannot be changed
- Tuples can be concatenated, indexed and sliced, and we can find their length through `len`
- Apparent multiple returns in functions are actually handled as tuples
- Tuples are the immutable cousins of lists

Lists

- **List:** ordered sequences of values possibly of different types, each accessible through an index
- Perhaps the most used structured type in Python
- Lists can be concatenated (+), indexed and sliced
- Empty list: `l = []`
- `len(l)` returns the number of objects
- Implemented as dynamic arrays
 - Adding or removing items at the end is fast
 - Not so in other positions
 - Efficient use as stacks (but not so for queues)

List Methods

- Some list methods: `l.append(object)`, `l.count(object)`, `l.sort()`, `l.reverse()`, `l.remove(object)`, `l.insert(index, object)`, `l.pop(index)`
- Some of them such as `sort()`, `reverse()` are in place and return `None`
 - `sorted(l)` returns a sorted version of `l`
- `l.index(object)` returns the index where `object` is or raises an exception
 - To just check whether `elem` is in `l`, simply use `if elem in l:`
- The function `tuple` changes (freezes) a list into a tuple
- The function `list` changes (thaws) a tuple into a list
- List **comprehension** is an efficient way to generate particular lists

```
oddN = [2*n+1 for n in range(10)]
```

 - Also works for dicts and sets

Lists as Function Arguments I

- Python allows to use lists to pass arguments to a function
 - Thus you can build a list `L` with the arguments of a (long) call
 - And pass it to the function as `*L`
- Example:

```
def some_f(arg0int, arg1float, arg2string, arg3tuple):  
    print (str(arg0int)+str(arg1float)+  
          arg2string+str(arg3tuple))  
  
#callable as:  
l = [1, 3.14, 'abcd', ('a', 'b', 'c', 'd')]  
some_f(*l)
```

Lists as Function Arguments II

- Putting `*args` (or `*xxx`) as the last item the argument list of a function `fff` allows `fff` to accept an arbitrary number of positional arguments

```
def my_sum(*args):  
    return sum(args)  
  
my_sum(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)  
l = [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]  
my_sum(*l)
```

- Putting `**kwargs` as the same effect with a list of keyword arguments passed as `keyword:value`
- More on this later on and also in [Control Flow](#) section of The Python Tutorial

Iterators

- Iterators are objects that support two methods:
 - `__iter__` that returns the iterator object itself; used in `for` and `in` statements
 - `__next__` or `next()` that returns the next value from the iterator or raises the `StopIteration` exception if there are no more items to return
- They are usually built as `new = iter(old)` where `old` must be another iterator or a sequence (e.g. a list)

```
l = [1, 2, 3]
iter_l = iter(l)
next(iter_l)
for o in iter_l:
    print(o)
```

- The application of `next` exhaust the iterator

Generators

- Generators are “lazy” iterators created using a function with a `yield` keyword

```
def counter(low, high):  
    while low <= high:  
        yield low  
        low += 1
```

```
counter(1, 5)
```

```
for l in counter(1,5):  
    print(l)
```

- The function remembers its state in its last execution and starts from it in a new call
- Generators are lazy in the sense that values are generated just when they are needed
- Generators can be created with a variant of list comprehension replacing `[]` with `()`

```
def counter(low, high):  
    return (yield(x) for x in range(low, high+1))
```

filter, map and reduce

- `filter(function, sequence)` returns a sequence (i.e., list, tuple) with the items from `sequence` for which `function(item)` is true

```
par = lambda x: x % 2 == 0
list(filter(par, (1, 4, 9, 16, 25)))
```

- `map(function, sequence)` calls `function(item)` for each item in `sequence` and returns a list with the values

```
cube = lambda x: x**3
list(map(cube, filter(par, range(1, 11))))
```

- `reduce(function, sequence)`
 - Calls the **binary** function `function` on the first two items of the `sequence`, then on the result and the next item, and so on
 - Returns the single value finally computed

```
from functools import reduce
prod = lambda a, b: a*b
fact = lambda n: reduce(prod, range(1, n+1))
fact(5)
```

- `zip` joins several lists of the same length in a single list of tuples made of the elements on each list

```
l_1 = range(10)
l_2 = [i*i for i in l_1]

for a, b in zip(l_1, l_2):
    print(a*b)

for l in zip(l_1, l_2):
    print(l[0]*l[1])
```

- `enumerate` allows to iterate on a list and its indices:

```
l_2 = [i*i for i in l_1]

for i, sq in enumerate(l_2):
    print("el cuadrado de %2d es %4d" % (i, sq))
```


Dictionaries

- **dict**: built in implementation of ADT dictionary
- Can be seen as unordered lists with elements of the form
key:value
 - Elements are **accessed by key values** and not indices
- Empty dict: `d = { }`
- Adding elements: `d.update({ 'a':'alpha' })` , `d['a']='alpha'`
- The `keys()` method returns a list with the (unordered) key values
- The `values()` method returns a list with the `dict` values
- The `items()` method returns a list of key–value tuples
- We can iterate on the keys of a dict `d`: `for k in d:`
- The statement `k in d` returns `True` if the key `k` is in the dict `d`

args and kwargs Revisited

- We can define functions with an arbitrary number of positional and keyword arguments using `*args` and `**kwargs`
- In the following definition

```
def do_something(*args, **kwargs):  
    # whatever ...
```

Python assumes that `do_something` will get a first set with a variable number of arguments and then a set with a variable number of keyword arguments

- If we call it as

```
do_something(pa1, pa2, pa3, kw1=kwa1, kw2=kwa2)
```

the tuple `(pa1, pa2, pa3)` and the dict `{'kw1':kwa1, 'kw2':kwa2}` are passed to the function's body

- Typical uses:
 - Writing higher order functions that pass arbitrary values to inside functions
 - Understanding others' code

Gather and Scatter

- Python functions can take a variable number of arguments
- **Parameter names** `*args` and `**kwargs` are used to define functions which can receive a variable number of positional or keyword arguments
- When called, the positional arguments are **gathered** into a tuple and the keyword arguments into a dict that the function's body knows how to process
- The complement of gather are the **scatter** operators `*`, `**`
 - A single scatter `*` splits a list or tuple arguments into multiple arguments
 - A double scatter `**` splits a single dict argument into multiple keyword arguments

```
def do_something(*args, **kwargs):  
    for arg in args:  
        print(arg)  
    for key in kwargs:  
        print(key, '=', kwargs[key])  
  
do_something(1, 2, 3, a=11, b=22)  
do_something(*(1, 2, 3), **{'a':11, 'b':22})
```

More on dicts

- To be searched efficiently, dicts are under the hood hash tables
 - If not, dict searches might require to examine the entire dict, with an $O(N)$ cost, with N the number of items in the dict
- Pairs `key:value` are placed in buckets determined by `hash(key)`, with the number of pairs in a bucket being small
 - This guarantees $O(1)$ search costs
- To be eligible for a key, an object must support the `__hash__` and `__cmp__` or `__eq__` methods
 - Tuples can be dict keys, as they are immutable
 - But lists cannot, as they are mutable and cannot be hashed

Sets

- **set**: collection of different elements
- Initialization: `s = set()`
- Some methods:
 - `add, pop` : adds an object, removes and returns an object
 - `remove, clear` : removes an object, removes all objects
 - Membership: `in, not in`
 - `union, intersection, difference, symmetric_difference`
 - `issubset, issuperset`
- `len(s)` : number of objects in `s`
- `set(iterable)` : builds a set with the **unique** objects in the iterable

Removing Duplicates

- A usual task is to remove duplicate elements in a list
- Doing it a la C:

```
l_1 = [1, 2, 3, 1, 2, 3]
l_2 = []

for item in l_1:
    if item not in l_2:
        l_2.append(item)

print(l_2)
```

- The Pythonic way:

```
l_1 = [1, 2, 3, 1, 2, 3]
l_2 = list( set(l_1) )

print(l_2)
```

Files and Modules

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Working with Files

- Files are used through a **file handle**:

```
fName = open('file', 'w')
```

- A handle can be opened also with 'r', 'a'
- Once the handle fName is defined, we can then use

```
fName.read(size) # to read the next size bytes
fName.read() # to return a string with the entire file
fName.readline() # to return a string with the next line
# to return string list with each of the file lines:
fName.readlines()
fName.write(string)
#to write the strings in the list S as file lines:
fName.writelines(S)
fName.close()
```

- In Python a file is a sequence of lines; thus we can loop through a file

```
fName = open('file', 'r')
for line in fName:
    print line[:-1] #-1 avoids an extra line break
```


seek and tell

- The `seek(offset)` method resets the file's current position at `offset`
- Positions are computed in terms of bytes since the file begins
 - Essentially the number of the file's ANSI characters, including `'\n'`

`#examplefile.txt: file with 5 lines with five characters`

```
f = open('examplefile.txt', 'r'); c = 0
```

```
for l in f:  
    c += len(l)  
    print(c)
```

```
f.seek(19)  
for l in f:  
    print(l[:-1])
```

- `f.seek(0)` rewinds the file `f`
- The `tell()` method returns the file's current position

```
f.seek(0); chunk = 20  
while len(f.read(chunk)) == chunk:  
    print( f.tell() )  
print ( "file has %d characters" % f.tell() )
```

Modules

- **Files** *.py containing statements, function definitions, global variables, etc.
- The `import` statement binds a module within the scope where the import occurs
`import myModule as mm`
- If the file `myModule.py` has been changed after its import, it has to be reloaded to update the previous binds:
`reload(mm)`
 - `reload` performs syntactical checking
 - Automatic reload with the `autoreload` extension
- Module functions are used through object (dot) notation:
`mm.funcName(...)`

Using Modules

- Example (from Guttag, p. 52):

```
#module circle.py
pi = 3.1416

def area(radius):
    return pi*(radius**2)

#using circle.py
import circle #or reload(circle)
pi = 2
print pi
print circle.pi
print circle.area(1)
```

Module Variables

- Python modules can be run by `python module.py [arg_1, ...]` or by `module.py [arg_1, ...]` if the first line in `module.py` is the Python shebang `#!/usr/bin/env python`
- When the Python interpreter reads a source file, it defines some special variables and executes its (executable) code
 - If `xxx.py` is directly run from the Python interpreter, the special `__name__` variable is set to `'__main__'`
 - If `xxx.py` is being imported from another module, `__name__` is set to `'xxx'`
- Usually the following elements appear in a module to be run as a standalone program:

```
def main(.. args ..):  
    #main's body  
  
if __name__ == "__main__":  
    main(...args...)  
else:  
    #lo que sea
```

Important Modules

- There are Python modules for almost everything: see for instance [UsefulModules](#)
- Modules that are often imported are
 - `sys`, `os` for OS-related tasks (see next)
 - `math` for standard math operations
 - `matplotlib` for plotting (to be seen later on)
 - `numpy` for linear algebra (to be seen later on), `scipy` for scientific computing
 - `pandas` for index-field computing with tables (to be seen later on)
 - `sklearn` for machine learning (to be seen later on)
 - `statsmodels` for statistics

The `os` and `sys` Modules

- `os` provides interfaces to operating system dependent functionality
 - `os.chdir(path)` changes the interpreter's active directory
 - `os.system(command)` execute the command in the string command in a subshell
- `sys` provides access to some interpreter variables and to functions that interact strongly with the interpreter.
- `sys.path` is a list of strings that specifies the search path for modules; add new dirs using `.append()`
- `sys.argv` is a list containing command-line arguments
 - Thus `len(sys.argv)` gives the number of command-line arguments
 - `sys.argv[0]` is the script name

The `pickle` and `gzip` Modules

- `pickle` provides methods to **serialize** Python data structures, i.e., to transform them into a format that can be stored in a file
- `pickle.dump(obj, file, protocol=None)` pickles the object `obj` and saves it into an open file
- `pickle.load(file)` reads a pickled object representation from the open file
- The `pickle` methods can be used with files compressed with methods from the `gzip` module
- `gzip.open(filename, mode='rb', compresslevel=9)` opens a gzip-compressed file and returns a file object
 - The `mode` can be any combination of `r`, `w`, `a` and `b`, `t`

Redirecting Data Streams

- `sys.stdout` contains the current stdout stream

```
stdout = sys.stdout
f = open('out.log', 'w')
sys.stdout = f
print("something ...")
sys.stdout = stdout
f.close()
print("something ...")
os.listdir('.')
```

- The file methods apply to the standard data streams:

```
sys.stdout.write("Hello world!\n")

sys.stdout.write("Enter value\n")
sys.stdin.readline()[:-1]
```


Passing Command Line Arguments

- The following gives a basic way of passing command line arguments to a module `myMod`

```
$ python myMod.py arg1 arg2 arg3
```

provided we define `main` more or less as follows:

```
def main(args):  
    if len(args) != 3:  
        print "incorrect number of arguments ..."  
  
    var1 = int(args[0])  
    var2 = float(args[1])  
    var3 = str(args[2])  
  
if __name__ == '__main__':  
    main(sys.argv[1:])
```

- More complete parsing of command line arguments can be done with the `argparse` module

NumPy

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The NumPy Library

- NumPy (Numerical Python): package for basic scientific computing and data analysis
- Importing: `import numpy as np`
- Using: `xxx = np.yyy(zzz)`
- (Bad) Alternative: `from numpy import *`
 - Then we can write `xxx = yyy(zzz)`
 - And end up with insidious problems
 - Better not to use this to avoid potential naming conflicts
- Array: basic NumPy data structure

NumPy Arrays

- Can have elements of any type
- Building arrays:

```
d = np.array([ [1,2,3], [4,5,6] ], dtype=float)
```

- First array methods:

`xx.shape, xx.size`: dimensions of the array `xx` and overall size

`xx.astype(type)`: type change

- Have to distinguish arrays from lists (or dicts or tuples):

```
d1 = [ [1,2,3], [4,5,6] ] #list of lists
d1.shape #error
d = np.array(d1)
d.shape # (2,3)
d.dtype # int
```

- But many basic things are done in just the same way

Working With Arrays

- Array creation functions

```
d = np.zeros( tuple )  
d = np.ones( tuple ) #also: np.empty, np.eye  
i_vals = np.arange(10, dtype=int)
```

- Or simply append things on a list and convert it: `a_1 = np.array(l)`
- NumPy data types
intX, uintX: signed and unsigned X=8,16,32,64-bit integer types
floatX: X=16,32,64,128-bit floating point types
- Also `complex`, `boolean`, `str`, `unicode`, ...
- Special float values: `numpy.inf`, `numpy.nan` (not a number)
 - Warning: cannot use equality to test NaN

Working With Arrays II

- We can clip elements in arrays: `clip(a, aMin, aMax)`
- Arrays can be reshaped as long as the overall size remains constant

```
v0 = np.random.rand(365*24)
v1 = v0.reshape(365, 24)
```

```
v0.shape
v1.shape
v1.flatten().shape
```

- Arrays can be stacked along different axes

```
x0 = np.random.normal(-1., 1., 1000); x0.shape
x = x0.reshape(1000, 1); x.shape
y = np.random.normal( 1., 1., 1000).reshape(1000, 1)
```

```
z = np.hstack((x, y)); z.shape
v = np.vstack((x, y)); v.shape
```

```
p = np.concatenate((x, y), axis=1)
q = np.concatenate((x, y), axis=0)
```

Array Input and Output

- `np.loadtxt` loads text matrices/tables into arrays

```
#csv file in array.txt  
arr = np.loadtxt('array.txt', dtype='str', delimiter=',')
```

- Default values for `dtype` and `delimiter` are `float` and `whitespace` respectively
- `np.savetxt` writes an array to a delimited text file

```
x = y = z = np.arange(0.0,5.0,1.0)  
np.savetxt('xyz.tex', (x,y,z), delimiter='&')
```

- `np.load`: loads arrays in binary uncompressed/compressed formats `.npy`, `.npz`
- `np.save`, `np.savez`: save arrays in formats `.npy`, `.npz`

```
np.save('xyz.npy', (x,y,z))  
np.savez('xyz.npz', (x,y,z))  
%ls xyz*
```

Index Handling in NumPy

- Conditions on array values can be captured as boolean arrays:

```
x = np.random.normal(0., 1., 100)

ind_pos = x >= 0.; ind_neg = x < 0.
num_pos = ind_pos.sum() #; num_neg = ind_neg.sum();

np.logical_and(ind_pos, ind_neg)
np.logical_or(ind_pos, ind_neg)
```

- And also as index values (returning tuples):

```
ind_values_pos = np.nonzero(ind_pos)
ind_values_neg = np.nonzero(ind_neg)
```

- The condition complying elements can also be selected:

```
x = np.random.normal(0., 1., 100)
np.select([x**2 >= 1.], [x])
```

- **Alternatively** `np.where` returns arrays of indices of condition complying elements

```
np.where(x**2 >= 1)
```


Array Operations and Ufuncs

- Basic array operations: usually elementwise
 - Arithmetic operations overload when working with equal size arrays: `arrC = arrA + arrB`
 - Scalar operations work (more or less) as expected:
`1/arr , arr**0.5`
- Unary and binary **universal functions**: also perform elementwise operations
- Unary: `np.sqrt(arr)`, `np.exp(arr)`, ...
- Also logs, trigonometric functions, `ceil`, `floor`, ...
- Binary: `add`, ..., `divide`, `max`, `min`, `mod`, ...
- More in [Universal functions \(ufunc\)](#)

Mathematical and Statistical Methods

- More or less all to be expected: `sum`, `mean`, `std`, `var`, `min`, `max`, ...
- Most can be called either as methods or as functions:

```
x.mean(); np.mean(x)
```

- Can take an axis as argument, indicating along which axis the operation is to be done

```
x = np.random.rand(10); y = np.random.rand(10)
z = np.array([x,y])
np.shape(z)
z.mean(axis=0)
z.mean(1)
```

- If no axis passed, the function is computed over the **flattened** array
- More in [Mathematical functions](#) and [Statistics](#)

Histograms

- Histograms:

```
hist, binEdges = np.histogram(a, bins=10, range=None, density=False)
```

- Computes an histogram from `a` with a default of 10 bins and automatic ranges `(a.min(), a.max())`

- If `bins` is a sequence, it defines the bin edges, allowing for non-uniform bins
- If a range tuple is provided, values of `a` outside that range are ignored
- If `density=False` the histogram will contain the number of samples in each bin
- If `density=True` the histogram will contain the normalized number of samples in each bin

- Returns

- An array `hist` with the values of the histogram
- A float array `bin_edges` with the `length(hist)+1` bin edges

Linear Algebra in NumPy

- The submodule `numpy.linalg` contains the most used linear algebra functions
- `dot`: general matrix multiplication
 - Infix version operator:
- `diag`: returns the diagonal of a square matrix as a 1D array, or converts a 1D array into a square matrix with zeros on the off-diagonal
- `trace`, `det`, `inv`; `T`: transpose
- `eig`: compute the eigenvalues and eigenvectors of a square matrix
- `solve`: solve the linear system $Ax = b$ for x , where A is a square matrix

And Much, Much More ...

- The submodule `numpy.random` contains a lot of very useful random tools
- And there is also `numpy.polynomial`, all sorts of math functions, set functionality, ...
- Support for sparse matrices
- Support for **masked** arrays: automatic handling of exceptional values
- One can define and work with **structured** arrays that store and handle general structured values
- Has 24 built in data-types but more can be defined
- Details in [Numpy manual contents](#)

- Numerical and scientific modules on top of NumPy
 - Integration and Interpolation
 - Linear Algebra and Sparse Eigenvalue Problems
 - Optimization
 - Fourier Transforms and Signal Processing
 - Statistics
 - And more
- SciPy stack: NumPy + Pandas + SciPy + Matplotlib + Simpy + IPython

matplotlib.pyplot

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The `matplotlib` Library

- `matplotlib` is a 2D plotting library to generate plots, histograms, power spectra, bar charts, error charts, scatterplots, etc
- Resources available:
 - [Gallery](#): with first simple examples and source code
 - [Matplotlib Examples](#) with more sophisticated examples
 - [Plotting commands summary](#)
- The `pyplot` submodule combines standard plotting with functions to plot histograms, autocorrelation functions, error bars, ...
- Import: `import matplotlib.pyplot as plt`
- Online plot is possible in IPython's qtconsole or notebooks with magic command `%matplotlib inline`

Basic plotting

- Basic plot: `plt.plot(x, y, str)`
 - `x`, `y` are arrays or sequences
 - If any is two dimensional, columns are plotted individually
- The string `str` controls color and style with many options available
 - `'b-'`: solid blue line (solid line is the default)
 - `'g--'`: dashed green line
 - `'r-.'`: red dash-dot line
 - `'y:'`: yellow dotted line
- There can be several array-sequence groups:

```
plt.plot(x1, y1, 'g:', x2, y2, 'g-')
```

Basic pyplot commands

- **Title:** `plt.title(str)`
- **Axis labels:** `plt.xlabel('variable %d' % v)` puts the value of the `int v`
- **Axis limits:** `plt.xlim(xmin, xmax)`, `plt.ylim(ymin, ymax)`
- **Legends:** `plt.legend(handles, labels, loc)` assigns the strings in `labels` to the lines in `handles` and draws them in a position according to `loc`
 - `loc` values: 0—best, 1—upper right, ...
 - `handles` and `labels` can be handled implicitly if defined elsewhere:

```
_ = plt.hist(var[indP].values, bins=11, alpha=0.5, label='P')
_ = plt.hist(var[indN].values, bins=11, alpha=0.5, label='N',
             color='r')
plt.legend(loc='best')
```

- `plt.show()`, `plot.close()` displays and closes a plot

Basic pyplot commands II

- Bar plots: `plt.bar(left, height, width=0.8, ...)` makes a bar plot with rectangles with left sides `left`, heights `height` and widths `width`
- Histogram plots: `plt.hist(x, bins, range, ...)` works similarly to `np.histogram` with analogous first arguments
 - Returns arrays `hist`, `bin_edges` as `np.histogram`
- Saving plots:

`plt.savefig(fname, dpi=None, orientation='portrait', format=None)`

- `format` is one of the file extensions supported:
`pdf`, `png`, `ps`, `eps`, ...
- Can be inferred from the extension in `fname`

figure and subplot

- `plt.figure(num=None, figsize=None, dpi=None, ...)` creates a figure referenced as `num` with width and height in inches determined by the tuple in `figsize`
 - Basic use: `plt.figure(figsize=(XX, YY))`
- `subplot` is used to create a subplot within a figure and to refer to that particular subplot
- Typical use: `subplot(nrows, ncols, plot_number)`
 - The figure is notionally split in a grid with `nrows * ncols` subaxes
 - `plot_number` identifies the current plot in that grid starting from 1
 - If `nrows, ncols, plot_number` are ≤ 10 , a 3-digit version can be used: `subplot(311)`
- `plt.plot` implicitly creates a `subplot(111)`
- More sophisticated subplot location can be obtained using `plt.axes()`

An Example

```
d = { 'x': np.random.rand(100), 'y': np.random.rand(100) }

plt.figure( figsize = (12, 5) )
plt.subplot(1, 2, 1)
plt.title("Hist %s" % 'x')
plt.xlabel("%s" % 'x')
plt.ylabel("abs. frequencies")
_ = plt.hist(d['x'])

plt.subplot(1, 2, 2)
plt.title("%s vs %s" % ('x', 'y') )
plt.xlabel("Values")
plt.ylabel("abs. frequencies")
_ = plt.hist(d['x'], bins=11, alpha=0.5, label='x')
_ = plt.hist(d['y'], bins=11, alpha=0.5, label='y', color='r')
plt.legend(loc='best')
plt.show()
```