301AA - Advanced Programming

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AP-2017-27*: More on Python*

We have seen:

- Basic and Sequence Datatypes
- Dictionaries
- Control Structures
- List Comprehension
- Function definition
- Positional and keyword arguments of functions

Next topics

- Namespaces and Scopes
- Object Oriented programming in Python
- Inheritance
- Iterators and generators
- Functions as objects
- Higher-order functions
- Importing modules

Namespaces and Scopes

- A ***namespace*** is a mapping from names to objects: typically implemented as a dictionary. Examples:
  - **builtins**: pre-defined functions, exception names,…
    - Created at intepreter's start-up
  - global names of a module
    - Created when the module definition is read
    - Note: names created in interpreter are in module __main__
  - local names of a function invocation
    - Created when function is called, deleted when it completes
  - and also names of a class, names of an object…
- Name ***x*** of a module ***m*** is an *attribute of* ***m***, accessible with ***m.x***. If writable, it can be deleted with ***del***.

Namespaces and Scopes (2)

- A **scope** is a textual region of a Python program where a namespace is **directly accessible**, i.e. reference to a name attempts to find the name in the namespace.
- Scopes are determined statically, but are used dynamically.
- During execution at least three namespaces are directly accessible, searched in the following order:
  - the scope containing the local names
  - the scopes of any enclosing functions, containing non-local, but also non-global names
  - the next-to-last scope containing the current module's global names
  - the outermost scope is the namespace containing built-in names
- Assignments to names go in the local scope
- Non-local variables can be accessed using nonlocal or global

Example of scoping rules

```
def scope_test():
    def do_local():
        spam = "local spam"

    def do_nonlocal():
        nonlocal spam
        spam = "nonlocal spam"

    def do_global():
        global spam
        spam = "global spam"

    spam = "test spam"
    do_local()
    print("After local assignment:", spam)
    do_nonlocal()
    print("After nonlocal assignment:", spam)
    do_global()
    print("After global assignment:", spam)

scope_test()
print("In global scope:", spam)
```

```
After local assignment: test spam
After nonlocal assignment: nonlocal spam
After global assignment: nonlocal spam
In global scope: global spam
```

OOP in Python

- Typical ingredients of the Object Oriented Paradigm:
  - **Encapsulation**: dividing the code into a public **interface**, and a private **implementation** of that interface;
  - **Inheritance**: the ability to create **subclasses** that contain specializations of their parent classes.
  - **Polymorphism**: The ability to **override** methods of a Class by extending it with a subclass (inheritance) with a more specific implementation (**inclusion polymorphism**)

From https://docs.python.org/3/tutorial/classes.html:

- *"Python classes provide all the standard features of Object Oriented Programming: the class inheritance mechanism allows multiple base classes, a derived class can override any methods of its base class or classes, and a method can call the method of a base class with the same name. Objects can contain arbitrary amounts and kinds of data. As is true for modules, classes partake of the dynamic nature of Python: they are created at runtime, and can be modified further after creation."*

Defining a class

- A class is a blueprint for a new data type with specific internal ***attributes*** (like a struct in C) and internal operations (***methods***).
- To declare a class in Python the syntax is the following:

```
class className:
    statements
    statements
```

- **`statements`** are assigments or function definitions
- A new namespace is created, where all names introduced in the statements will go
- When the class definition is left, a ***class object*** is created, bound to **className**, on which two operations are defined: *attribute reference* and *class instantiation.*
- Syntax of class instantiation is **className()** , unless a constructor is defined

Accessing instance attributes

- Class **Points** declares a collection of objects (*instances*) with two *instance attributes.*

prova.py – /Users/thezed/Desktop/prova.py

```
class Point:
    x = 0
    y = 0

#Main:
p1 = Point() #we create an instance of the Class point.
p1.x = 2 #We modify the first attribute X
p1.y = -5 #We modify the second attribute Y
print "Punto P1 X:", p1.x, " Y:", p1.y
```

Ln: 9 Col: 38

- The first statement `p1=Point()` is the call to the ***implicit constructor*** of the class.
- **p1** is an ***instance*** (object of class Point)
- Instance attributes can be declared directly inside class or in **constructors** (more common), as we will see later.

Adding instance attributes

- Python objects are dynamic. You can add instance attributes any time!

prova.py – /Users/thezed/Desktop/prova.py

```python
class Point:
    x=0
    y=0

#Main:
p1=Point()
p1.x=2
p1.y=-5
p1.z=10 #I have added a new attribute to the object!
print "Point P1 with coordinates X: ", p1.x, " Y: ", p1.y, " Z: ", p1.z
```

Ln: 11 Col: 0

- The instance attribute **z** has been added to the object **p1** (**and only to that instance of class Point**).

Instance methods

- A class can define a set of ***instance methods***, which are just functions:

```
def methodname(self, parameter₁, ..., parameterₙ):
        statements
```

- **Self must be** the first parameter to any instance method. It represents the ***implicit parameter*** (**`this`** in Java)
- A method ***must*** access the object's attributes through the **`self`** reference
- The **self** parameter must not be passed when the method is called. It is bound to the target object. Syntax:

```
obj.methodname(arg₁, ..., argₙ):
```

- But it can be passed explicitly. Alternative syntax:

```
Class. methodname(obj, arg₁, ..., argₙ):
```

Instance methods (2)

- Example: class **Point** with three instance methods

prova.py – /Users/thezed/Desktop/prova.py

```python
from math import sqrt

class Point:
    #Attributes:
    x = 0
    y = 0

    #Methods:
    def set_location(self, x, y):
        self.x = x
        self.y = y

    def distance_from_origin(self):
        return sqrt(self.x * self.x + self.y * self.y)

    def distance(self, other):
        dx = self.x - other.x
        dy = self.y - other.y
        return sqrt(dx * dx + dy * dy)

#Main:
P1=Point()
P1.set_location(2, 3)
P2=Point()
P2.set_location(5, 10)
print "Distanza dall'origine di P1: ", P1.distance_from_origin()
print "Distanza tra i due punti P1-P2: ", P1.distance(P2)
```

Ln: 13 Col: 0

Untitled

```python
P1=Point()
Point.set_location(P1, 5, 10)
P1.set_location(5, 10)
```

Equivalent calling syntax

Ln: 3 Col: 22

Constructors

- A constructor is a ***special instance method*** of a class with name **`__init__`**. Syntax:

```
def __init__(self, parameter1, ..., parametern):
        statements
```

- Invocation: **`obj = className(arg1, …, argn)`**

- Returns an object of the class. Parameter **`self`** is bound to the new object.

- Note: at most ONE constructor (**no overloading in Python**!)

prova.py – /Users/thezed/Desktop/prova.py

```
class point:
    x=0
    y=0

    #Constructor:
    def __init__(self, x=0, y=0):
        self.x = x
        self.y = y


#Main:
p1=point()
print "Point P1 with coordinates X: ", p1.x, " Y: ", p1.y
```

Ln: 12 Col: 9

Defining attributes in constructor

- In this version, the instance attribute are not defined in the class but in the constructor.

prova.py – /Users/thezed/Desktop/prova.py

```python
from math import sqrt

class Point:
    #Costruttore:
    def __init__(self, x, y):
        self.x = x #Attribute x is created in the constructor!
        self.y = y #Attribute y is created in the constructor!

    #Metodi di utilità:
    def distance_from_origin(self):
        return sqrt(self.x * self.x + self.y * self.y)

    def distance(self, other):
        dx = self.x - other.x
        dy = self.y - other.y
        return sqrt(dx * dx + dy * dy)

    def translate(self, dx, dy):
        self.x += dx
        self.y += dy

    #Metodo di stampa:
    def __str__(self):
        return "(" + str(self.x) + ", " + str(self.y) + ")"
```

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String representation

- It is often useful to have a textual representation of an object with the values of its attributes. This is possible with the following instance method:

```
def __str__(self) :
        return <string>
```

- This is equivalent to Java's **toString** (converts object to a string) and it is invoked automatically when **str** or **print** is called.

prova.py – /Users/thezed/Desktop/prova.py

```
class point:
    x=0
    y=0

    #Constructor:
    def __init__(self, x=0, y=0):
        self.x = x
        self.y = y
    #Print:
    def __str__(self):
        return "(" + str(self.x) + ", " + str(self.y) + ")"


#Main:
p1=point()
print "Point P1", p1
```

Ln: 8 Col: 18

Other special methods

- **Method overloading**: you can define special instance methods so that Python's built-in operators can be used with your class.

Binary Operators

Operator	Class Method
-	`__sub__(self, other)`
+	`__add__(self, other)`
*	`__mul__(self, other)`
/	`__truediv__(self, other)`

Operator	Class Method
==	`__eq__(self, other)`
!=	`__ne__(self, other)`
<	`__lt__(self, other)`
>	`__gt__(self, other)`
<=	`__le__(self, other)`
>=	`__ge__(self, other)`

Unary Operators

-	`__neg__(self)`
+	`__pos__(self)`

- Similar to C++

Special methods (2)

- Example: special method summing two points componentwise, overloading +.

prova.py - /Users/thezed/Desktop/prova.py

```
class Point:
    #Constructor:
    def __init__(self, x=0, y=0):
        self.x=x
        self.y=y
    #Methods:
    def getX(self):
        return self.x
    def getY(self):
        return self.y
    def setX(self, new):
        self.x=new
    def setY(self, new):
        self.y=new
    def __str__(self):
        return "(" + str(self.x) + ", " + str(self.y) + ")"
    def __add__(self, other):
        return Point(self.getX() + other.getX(), self.getY() + other.getY())

#Main:
p1=Point(2,-5)
p2=Point(4, 3)
p3=p1+p2
print "Punto P3: ", p3
```

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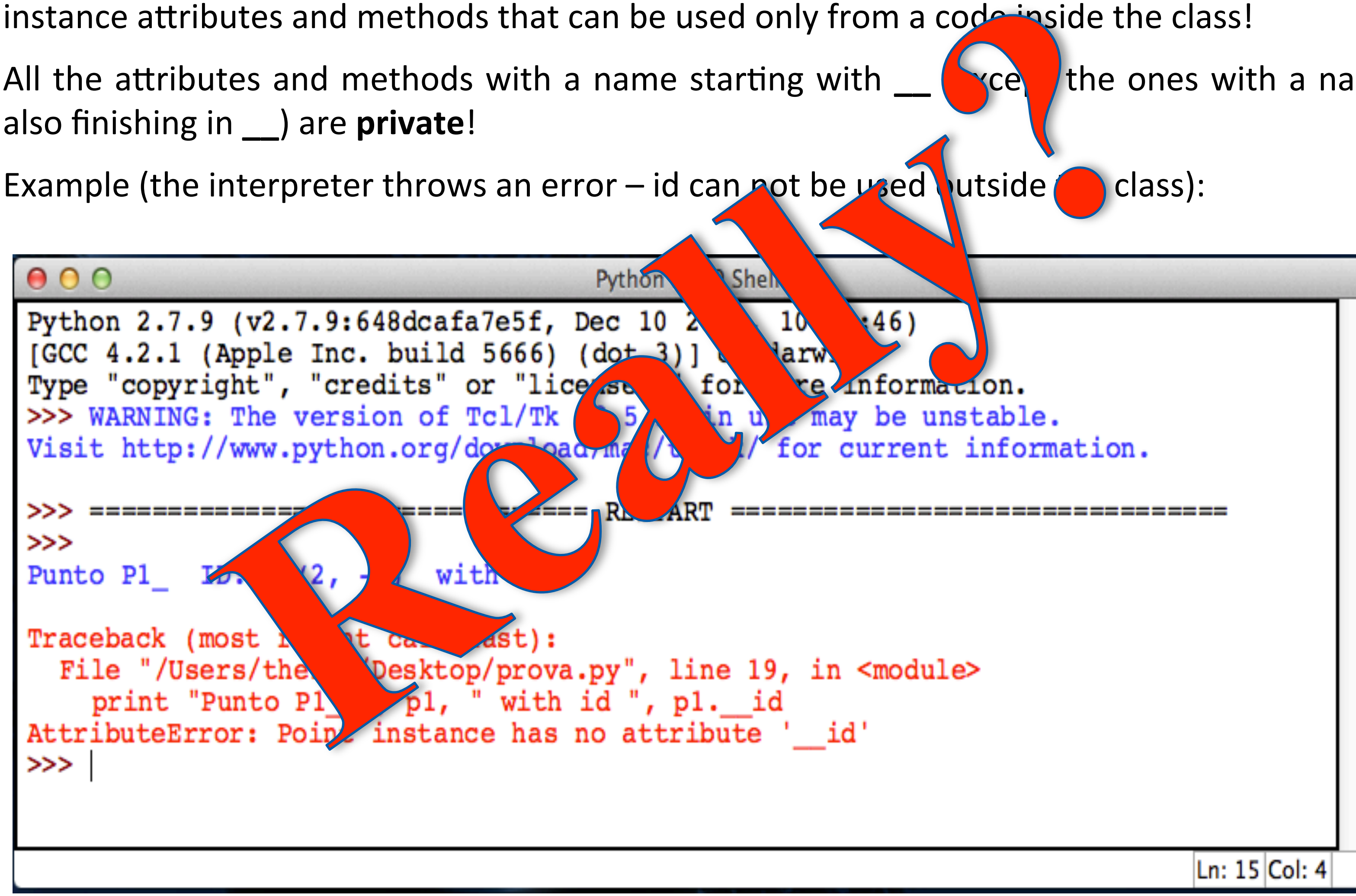
Private attributes and methods

- Actually in Python is possible to declare **private** instance attributes and methods, i.e. instance attributes and methods that can be used only from a code inside the class!
- All the attributes and methods with a name starting with __ (except the ones with a name also finishing in __) are **private**!
- Example (the interpreter throws an error – id can not be used outside the class):



Encapsulation (and "name mangling")

- **Private** instance variables (not accessible except from inside an object) **don’t exist in Python.**

- **Convention:** a **name prefixed with underscore** (e.g. `_spam`) is treated as ***non-public part of the API*** (function, method or data member).
  It should be considered an implementation detail and subject to change without notice.

Name mangling ("storpiatura")

- Sometimes class-private members are needed to avoid clashes with names defined by subclasses. Limited support for such a mechanism, called *name mangling.*

- Any **name with at least two leading underscores and at most one trailing underscore** like e.g. `__spam` is textually replaced with `_classname__spam`, where `classname` is the current class name.

Example for name mangling

- Name mangling is helpful for letting subclasses override methods without breaking intraclass method calls.

```
class Mapping:
    def __init__(self, iterable):
        self.items_list = []
        self.__update(iterable)

    def update(self, iterable):
        for item in iterable:
            self.items_list.append(item)

    __update = update # private copy of update() method

class MappingSubclass(Mapping):

    def update(self, keys, values):
        # provides new signature for update()
        # but does not break __init__()
        for item in zip(keys, values):
            self.items_list.append(item)
```

Class attributes

- Python classes can define "**Instance attributes**", associated with each object, and also "**class attributes**" associated with the class (similar to **static variables** in Java).
- Their usage is as follows:
  - Outside the class they are used by referring to the class name: "**`classname.attribute`**";
  - Inside an instance method they are referred as "**`self.__class__.attribute`**" or "**`classname.attribute`**".
- **Example**: we have a class "**Node**" with an instance attribute "**name**". We want to keep tracking on how many times this class is instantiated. We use a class attribute "**count**".

prova.py - /Users/thezed/Desktop/prova.py

```python
class Node:
    count = 0 #Static attribute
    name = "" #Instance attribute
    def __init__(self, name):
        self.name = name
        self.__class__.count = self.__class__.count + 1

#Main:
n1 = Node("Nodo1")
print n1.name, " ", Node.count
n2 = Node("Nodo2")
print n2.name, " ", Node.count
n3 = Node("Nodo3")
print n3.name, " ", Node.count
```

Python 2.7.6 Shell

```
Python 2.7.6 (default, Nov 18 2013, 15:12:51)
[GCC 4.2.1 Compatible Apple LLVM 5.0 (clang-500.2.79)] on darwin
Type "copyright", "credits" or "license()" for more information.
>>> ================================ RESTART ================================
>>>
Nodo1    1
Nodo2    2
Nodo3    3
>>>
```

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Class vs. instance attributes

- Note that the syntax for introducing an instance attribute or a class attribute is identical. The difference is in the way they are conventionally used.
  - One can mix-up the two concepts, accessing the same attribute in both ways
  - Better to define instance attributes in constructors
- Everything is handled using namespaces:
  - Each class introduces a new namespace
  - Each object introduces a new namespace, nested in the one of its class
- Inspect in the interpreter what happens when the following class is defined. Use **dir** and **__dict__**

```
class point:
   x = 0
   def __init__(self, y):
      self.y = y
```

Static and Class methods

- Sometimes we need to process data associated with classes instead of instances.
- Example: keeping track of instances created or instances currently in memory. This data are associated to class.
- It is worth noting that simple functions written outside the class can suffice for this purpose!
- However, the code is not well associated with class, cannot be inherited and the name of the method is not localized.
- Hence, Python offers us static and class methods.

Static methods

- **Static methods** are simple functions with no **`self`** argument, preceded by the **@staticmethod** annotation (which is a **decorator**, see later…)
- They are defined inside a class but they cannot access instance attributes and methods (they cannot access the variable *sender* in the example)
- They can be called through both the class and any instance of that class!

prova.py – /Users/thezed/Desktop/prova.py

```python
class Spam:
    numInstances = 0 #class attribute
    def __init__(self, sender):
        Spam.numInstances = Spam.numInstances + 1
        self.sender = sender #sender is an instance attribute

    @staticmethod
    def getInstances():
        return Spam.numInstances


#Main:
first = Spam("Marco Rossi")
second = Spam("Pinco Pallino")
print "Numero di instanze create di Spam: ", first.getInstances()
print "Numero di instanze create di Spam: ", first.getInstances()
print "Numero di instanze create di Spam: ", Spam.getInstances()
```

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- **<u>Benefits of static methods</u>**: they allow subclasses to customize the static methods with inheritance. Classes can inherit static methods without redefining them. The output of the program is "**2**" for all the print statements.

Class methods

- Similar to static methods but they have a first parameter which is the class name.
- Definition must be preceded by the **@classmethod** decorator
- Can be invoked on the class or on an instance.

Untitled

```
class Spam:
    numInstances = 0; #class attribute
    def __init__(self, sender):
        Spam.numInstances = Spam.numInstances + 1
        self.sender = sender #sender is an instance attribute

    @classmethod
    def getInstances(cls):
        return cls.numInstances

#Main:
first = Spam("Marco Rossi")
second = Spam("Pinco Pallino")
print "Numero di istanze di Spam: ", first.getInstances()
print "Numero di istanze di Spam: ", second.getInstances()
print "Numero di istanze di Spam: ", Spam.getInstances()
```

Ln: 15 Col: 24

(Multiple) Inheritance, in one slide

- A class can be defined as a *derived class*

```
class derived(baseClass):
        statements
        statements
```

- No need of additional mechanisms: when leaving the definition, the class object remembers the **baseClass**, and uses it as the next non-local scope to resolve names
- All instance methods are automatically virtual
- Python supports **multiple inheritance**

```
class derived(base1,..., basen):
        statements
        statements
```

- ***Diamond problem*** solved by an algorithm that linearizes the set of all (directly or indirectly) inherited classes: the **Method resolution order** (**MRO**)
- https://www.python.org/download/releases/2.3/mro/

What are iterators?

- An ***iterator*** is an object which allows a programmer to traverse through all the elements of a collection (***iterable*** object), regardless of its specific implementation. In Python they are used implicitly by the **FOR** loop construct.

- Python iterator objects required to support two methods:
  - **`__iter__`** returns the iterator object itself. This is used in **FOR** and **IN** statements.
  - **`next`** method returns the next value from the iterator. If there is no more items to return then it should raise **`StopIteration`** exception.

- Remember that an iterator object can be used only once. It means after it raises **`StopIteration`** once, it will keep raising the same exception.

- Example:

```
for element in [1, 2, 3]:
        print element
```

```
>>> lista= [1,2,3]
>>> it = iter(lista)
>>> it
<listiterator object at 0x00A1DB50>
>>> it.next()
1
>>> it.next()
2
>>> it.next()
3
>>> it.next() -> raises StopIteration
```

Iterator objects

- This example shows how to create a class which is an iterator. The iterator can be used in a FOR loop!

prova.py – /Users/thezed/Desktop/prova.py

```python
class Counter():
    def __init__(self, low, high):
        self.current = low
        self.high = high

    def __iter__(self):
        #Returns itself as an iterator object
        return self

    def next(self):
        #Returns the next value till current is lower than high
        if self.current > self.high:
            raise StopIteration
        else:
            self.current = self.current + 1
            return self.current - 1

#Main:
c = Counter(5, 10)
for i in c:
    print i
```

```python
#Main:
c = Counter(5, 10)
iterator = iter(c)
while True:
    try:
        x = iterator.next()
        print x,
    except StopIteration as e:
        break
```

Ln: 21 Col: 11

- Output: **5 6 7 8 9 10**! Similar to ***range*** but slightly different…

Generators

- **Generators** are a simple and powerful tool for creating iterators.
- They are written like **regular functions** but use the **`yield`** statement whenever they want to return data.
- Each time the **`next()`** is called, the generator resumes where it left-off (it remembers all the data values and which statement was last executed).
- An example shows that generators can be trivially easy to create.
- ***Anything that can be done with generators can also be done with class based iterators as described in the previous section (not vice-versa).***
- What makes generators so compact is that the **`__iter__()`** and **`next()`** methods are created automatically.
- Another key feature is that the local variables and execution state are **automatically saved** between calls.
- This made the function easier to write and much more clear than an approach using class variables like **`self.index`** and **`self.data`**.

Generators (2)

- In addition to automatic method creation and saving program state, when generators terminate, they automatically raise **`StopIteration`**.
- In combination, these features make it easy to create iterators with no more effort than writing a regular function.

prova.py – /Users/thezed/Desktop/prova.py

```python
#A generator that yields items:
def genum(n, p):
    if p <= 0:
        raise StopIteration
    num = 0
    while num < n:
        yield num
        num += p

#Main:
for i in genum(10, 2):
    print i
```

Ln: 13 Col: 0

- The output is: **0 2 4 6 8!**

Back to functions - Recap

- All functions return some value (possibly **None**)
- Function call creates a new namespace
- Parameters are passed by object reference
- Functions can have optional keyword arguments
- Functions can take a variable number of args and kwargs

Function documentation

- The comment after the functions header is bound to the **__doc__** special attribute

```
def my_function():
    """Summary line: do nothing, but document it.
    Description: No, really, it doesn't do anything.
    """
    pass


print(my_function.__doc__)
# Summary line: Do nothing, but document it.
#
#     Description: No, really, it doesn't do anything.
```

Functions are objects

- As everything in Python, also functions are object, of class **function**

```
def echo(arg): return arg
type(echo)          # <class 'function'>
hex(id(echo))       # 0x1003c2bf8
print(echo)         # <function echo at 0x1003c2bf8>
foo = echo
hex(id(foo))        # '0x1003c2bf8'
print(foo)          # <function echo at 0x1003c2bf8>
isinstance(echo, object)        # => True
```

Lambdas (anonymous functions)

- They exists! But very limited…

```
lambda arguments: expression
```

- The body can only be a single expression

Higher-order functions

- Functions can be passed as argument and returned as result
- Main combinators (map, filter) predefined: allow standard functional programmin style in Python
- Heavy use of iterators, which support laziness

Map

```
>>> print(map.__doc__)  % documentation
map(func, *iterables) --> map object
Make an iterator that computes the function using
arguments from each of the iterables.  Stops when the
shortest iterable is exhausted.
map
```

```
>>> map(lambda x:x+1, range(4))      % lazyness: returns
<map object at 0x10195b278>          % an iterator
>>> list(map(lambda x:x+1, range(4)))
[1, 2, 3, 4]
>>> list(map(lambda x, y : x+y, range(4), range(10)))
[0, 2, 4, 6]      % map of a binary function
>>> z = 5         % variable capture
>>> list(map(lambda x : x+z, range(4)))
[5, 6, 7, 8]
```

`Import` and Modules

- **Programs will often use classes & functions defined in another file**
- **A Python module is a single file with the same name (plus the *.py* extension)**
- **Modules can contain many classes and functions**
- **Access using *import***

Where does Python look for module files?

- **The list of directories where Python looks: sys.path**
- **When Python starts up, this variable is initialized from the PYTHONPATH environment variable**
- **To add a directory of your own to this list, append it to this list.**

```
sys.path.append('/my/new/path')
```

  - **Oops! Operating system dependent….**

Defining Modules

- **Modules** are files containing definitions and statements. A module defines a new namespace.
- Modules can be organized hierarchically in **packages**

```
# File fibo.py - Fibonacci numbers module
def fib(n):    # write Fibonacci series up to n
    a, b = 0, 1
    while b < n:
        print(b, end=' ')
        a, b = b, a+b
    print()

def fib2(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
```

Importing a module

```
>>> import fibo    # imports module from local file
'fibo.py'
>>> fibo.fib(6)    # dot notation
[1, 1, 2, 3, 5]
>>> fibo.__name__ # special attribute __name__
'fibo'
>>> fibo.fib.__module__    # special attribute __module__
'fibo'
```

```
>>> from fibo import fib, fib2
      # or from fibo import *
>>> fib(500)
>>> fib.__module__          # special attribute __module__
'fibo'
>>> fibo.__name__ # NameError: name 'fibo' is not defined
```

Executing a module as a script

- A module can be invoked as a script from the shell as

```
> python fibo.py 60
```

- Executed with __name__ set to "__main__".

```
# File fibo.py - Fibonacci numbers module
def fib(n):    # write Fibonacci series up to n
    ...
def fib2(n):   # return Fibonacci series up to n
    ...
if __name__ == "__main__": # added code
    import sys
    fib(int(sys.argv[1]))
```

```
> python fibo.py 60
1 1 2 3 5 8 13 21 34
>
```

The `dir()` Function

- The built-in function **dir()** returns a sorted list of strings containing all names defined in a module

```
>>> import sys
>>> dir(sys)           # Prints names defined in sys
['__displayhook__', '__doc__', '__excepthook__', '__loader__',
'__name__', '__package__', '__stderr__', '__stdin__',
      ...
>>> dir() # Prints names defined currently
      ...
>>> import builtins
>>> dir(builtins) #Prints built-in functions and variables
```