<http://simeonfranklin.com/blog/2012/jul/1/python-decorators-in-12-steps/>

**Understanding Python Decorators in 12 Easy Steps!**

## 1. Functions

Functions in Python are created with the *def* keyword and take a name and an optional list of parameters. They can return values with the return keyword. Let’s make and call the simplest possible function:

*>>>* ***def******foo****():*

*...* ***return*** *1*

*>>>* ***foo****()*

*1*

The body of the function (as with all multi-line statements in Python) is mandatory and indicated by indentation. We can call functions by appending parentheses to the function name.

## 2. Scope

In Python functions create a new scope, which means functions have their own namespace. This means Python looks first in the namespace of the function to find variable names when it encounters them in the function body. Python includes a couple of functions that let us look at our namespaces. Let’s write a simple function to investigate the difference between local and global scope.

*>>> a\_string = "This is a global variable"*

*>>>* ***def******foo****():*

*...* ***print******locals****()*

*>>>* ***print******globals****() # doctest: +ELLIPSIS*

*{..., 'a\_string': 'This is a global variable'}*

*>>>* ***foo****() # 2*

*{}*

The builtin globals function returns a dictionary containing all the variable names Python knows about. (For the sake of clarity I’ve omitted in the output a few variables Python automatically creates.) At point #2 I called my function *foo()* which prints the contents of the local namespace inside the function. As we can see the function *foo()* has its own separate namespace which is currently empty.

## 3. Variable resolution rules

This doesn’t mean that we can’t access global variables inside our function. Python’s scope rule is that variable creation always creates a new local variable but variable access (including modification) looks in the local scope and then searches all the enclosing scopes to find a match. So if we modify our function *foo()* to print our global variable things work as we would expect:

>>> a\_string = "This is a global variable"

>>> **def** **foo**():

... **print** a\_string *# 1*

>>> **foo**()

This is a global variable

At point #1 Python looks for a local variable in our function and not finding one, looks for a global variable of the same name.

On the other hand if we try to assign to the global variable inside our function it doesn’t do what we want:

>>> a\_string = "This is a global variable"

>>> **def** **foo**():

... a\_string = "test" *# 1*

... **print** **locals**()

>>> **foo**()

{'a\_string': 'test'}

>>> a\_string *# 2*

*'This is a global variable'*

As we can see, global variables can be accessed (even changed if they are mutable data types) but not (by default) assigned to. At point #1 inside our function we are actually creating a new local variable that "shadows" the global variable with the same name. We can see this be by printing the local namespace inside our function foo and notice it now has an entry. We can also see back out in the global namespace at point #2 that when we check the value of the variable *a\_string* it hasn’t been changed at all.

## 4. Variable lifetime

It’s also important to note that not only do variables live inside a namespace, they also have lifetimes. Consider

>>> **def** **foo**():

... x = 1

>>> **foo**()

>>> **print** x *# 1*

**Traceback** (most recent call last):

...

NameError: name 'x' **is** **not** defined

The namespace created for our function foo is created from scratch each time the function is called and it is destroyed when the function ends.

## 5. Function arguments and parameters

Python allows us to pass arguments to functions. The parameter names become local variables in our function.

*>>>* ***def******foo****(x):*

*...* ***print******locals****()*

*>>>* ***foo****(1)*

*{'x': 1}*

Python has a variety of ways to define function parameters and pass arguments to them. Function parameters can be either **positional** parameters that are **mandatory** or **named, default value** parameters that are **optional**.

>>> **def** **foo**(x, y=0): *# 1*

... **return** x - y

>>> **foo**(3, 1) *# 2*

2

>>> **foo**(3) *# 3*

3

>>> **foo**() *# 4*

**Traceback** (most recent call last):

...

TypeError: **foo**() takes at least 1 **argument** (0 given)

>>> **foo**(y=1, x=3) *# 5*

2

At point #1 we are defining a function that has a single positional parameter x and a single named parameter y. As we see at point #2 we can call this function passing arguments normally - the values are passed to the parameters of foo by position even though one is defined in the function definition as a named parameter. We can also call the function without passing any arguments at all for the named parameter as you can see at point #3 - Python uses the default value of 0 we declared if it doesn’t receive a value for the named parameter y. Of course we can’t leave out values for the first (mandatory, positional) parameter - point #4 demonstrates that this results in an exception.

Python supports named arguments at function call time. Look at point #5 - here we are calling a function with two named arguments even though it was **defined** with one named and one positional parameter. Since we have names for our parameters the order we pass them in doesn’t matter.

To describe a pretty simple concept: function parameters can have names or positions.

## 6. Nested functions

Python allows the creation of nested functions. This means we can declare functions inside of functions and all the scoping and lifetime rules still apply normally.

*>>>* ***def******outer****():*

*... x = 1*

*...* ***def******inner****():*

*...* ***print*** *x # 1*

*...* ***inner****() # 2*

*...*

*>>>* ***outer****()*

*1*

Consider what happens at point #1 - Python looks for a local variable named x, failing it then looks in the enclosing scope which is another function! The variable x is a local variable to our function outer but as before our function inner has access to the enclosing scope (read and modify access at least). At point #2 we call our inner function. It’s important to remember that inner is also just a variable name that follows Python’s variable lookup rules - Python looks in the scope of outer first and finds a local variable named inner.

## 7. Functions are first class objects in Python

This is simply the observation that in Python, functions are objects like everything else. Ah, function containing variable, you’re not so special!

>>> **issubclass**(int, object) *# all objects in Python inherit from a common baseclass*

True

>>> **def** **foo**():

... **pass**

>>> foo.\_\_class\_\_ *# 1*

<type 'function'>

>>> **issubclass**(foo.\_\_class\_\_, object)

True

You may never have thought of your functions as having attributes - but functions are objects in Python, just like everything else. (If you find that confusing wait till you hear that classes are objects in Python, just like everything else!) Perhaps this is making the point in an academic way - functions are just regular values like any other kind of value in Python. That means you can pass functions to functions as arguments or return functions from functions as return values! If you’ve never thought of this sort of thing consider the following perfectly legal Python:

>>> **def** **add**(x, y):

... **return** x + y

>>> **def** **sub**(x, y):

... **return** x - y

>>> **def** **apply**(func, x, y): *# 1*

... **return** **func**(x, y) *# 2*

>>> **apply**(add, 2, 1) *# 3*

3

>>> **apply**(sub, 2, 1)

1

This example might not seem too strange too you - add and sub are normal Python functions that receive two values and return a calculated value. At point #1 you can see that the variable intended to receive a function is just a normal variable like any other. At point #2 we are calling the function passed into apply - parentheses in Python are the call operator and call the value the variable name contains. And at point #3 you can see that passing functions as values doesn’t have any special syntax in Python - function names are just variable labels like any other variable.

You might have seen this sort of behavior before - Python uses functions as arguments for frequently used operations like customizing the sorted builtin by providing a function to the key parameter. But what about returning functions as values? Consider:

>>> **def** **outer**():

... **def** **inner**():

... **print** "Inside inner"

... **return** inner *# 1*

...

>>> foo = **outer**() *#2*

>>> foo *# doctest:+ELLIPSIS*

<function inner at 0x...>

>>> **foo**()

Inside inner

This may seem a little more bizarre. At point #1 I return the variable inner which happens to be a function label. There’s no special syntax here - our function is returning the inner function which otherwise couldn’t be called. Remember variable lifetime? The function inner is freshly redefined each time the function outer is called but if inner wasn’t returned from the function it would simply cease to exist when it went out of scope.

At point #2 we can catch the return value which is our function inner and store it in a new variable foo. We can see that if we evaluate foo it really does contain our function inner and we can call it by using the call operator (parentheses, remember?) This may look a little weird, but nothing to hard to understand so far, right? Hold on, because things are about to take a turn for the weird!

## 8. Closures

Let’s not start with a definition, let’s start with another code sample. What if we tweaked our last example slightly:

>>> **def** **outer**():

... x = 1

... **def** **inner**():

... **print** x *# 1*

... **return** inner

>>> foo = **outer**()

>>> foo.func\_closure *# doctest: +ELLIPSIS*

(<cell at 0x...: int object at 0x...>,)

From our last example we can see that inner is a function returned by outer, stored in a variable named fooand we could call it with foo(). But will it run? Let’s consider scoping rules first.

Everything works according to Python’s scoping rules - x is a local variable in our function outer. Wheninner prints x at point #1 Python looks for a local variable to inner and not finding it looks in the enclosing scope which is the function outer, finding it there.

But what about things from the point of view of variable lifetime? Our variable x is local to the functionouter which means it only exists while the function outer is running. We aren’t able to call inner till after the return of outer so according to our model of how Python works, x shouldn’t exist anymore by the time we call inner and perhaps a runtime error of some kind should occur.

It turns out that, against our expectations, our returned inner function does work. Python supports a feature called **function closures** which means that inner functions defined in non-global scope remember what their enclosing namespaces looked like **at definition time**. This can be seen by looking at thefunc\_closure attribute of our inner function which contains the variables in the enclosing scopes.

Remember - the function inner is being newly defined each time the function outer is called. Right now the value of x doesn’t change so each inner function we get back does the same thing as another innerfunction - but what if we tweaked it a little bit?

>>> **def** **outer**(x):

... **def** **inner**():

... **print** x *# 1*

... **return** inner

>>> print1 = **outer**(1)

>>> print2 = **outer**(2)

>>> **print1**()

1

>>> **print2**()

2

From this example you can see that **closures** - the fact that functions remember their enclosing scope - can be used to build custom functions that have, essentially, a hard coded argument. We aren’t passing the numbers 1 or 2 to our inner function but are building custom versions of our inner function that "remembers" what number it should print.

This alone is a powerful technique - you might even think of it as similar to object oriented techniques in some ways: outer is a constructor for inner with x acting like a private member variable. And the uses are numerous - if you are familiar with the key parameter in Python’s sorted function you have probably written a lambda function to sort a list of lists by the second item instead of the first. You might now be able to write an itemgetter function that accepts the index to retrieve and returns a function that could suitably be passed to the key parameter.

But let’s not do anything so mundane with closures! Instead let’s stretch one more time and write a decorator!

## 9. Decorators!

A decorator is just a callable that takes a function as an argument and returns a replacement function. We’ll start simply and work our way up to useful decorators.

>>> **def** **outer**(some\_func):

... **def** **inner**():

... **print** "before some\_func"

... ret = **some\_func**() *# 1*

... **return** ret + 1

... **return** inner

>>> **def** **foo**():

... **return** 1

>>> decorated = **outer**(foo) *# 2*

>>> **decorated**()

before some\_func

2

Look carefully through our decorator example. We defined a function named outer that has a single parameter some\_func. Inside outer we define an nested function named inner. The inner function will print a string then call some\_func, catching its return value at point #1. The value of some\_func might be different each time outer is called, but whatever function it is we’ll call it. Finally inner returns the return value ofsome\_func() + 1 - and we can see that when we call our returned function stored in decorated at point #2 we get the results of the print and also a return value of 2 instead of the original return value 1 we would expect to get by calling foo.

We could say that the variable decorated is a decorated version of foo - it’s foo plus something. In fact if we wrote a useful decorator we might want to replace foo with the decorated version altogether so we always got our "plus something" version of foo. We can do that without learning any new syntax simply by re-assigning the variable that contains our function:

>>> foo = **outer**(foo)

>>> foo *# doctest: +ELLIPSIS*

<function inner at 0x...>

Now any calls to foo() won’t get the original foo, they’ll get our decorated version! Got the idea? Let’s write a more useful decorator.

Imagine we have a library that gives us coordinate objects. Perhaps they are primarily made up of x and ycoordinate pairs. Sadly the coordinate objects don’t support mathematical operators and we can’t modify the source so we can’t add this support ourselves. We’re going to be doing a bunch of math, however, so we want to make add and sub functions that take two coordinate objects and do the appropriate mathematical thing. These functions would be easy to write (I’ll provide a sample Coordinate class for the sake of illustration)

>>> **class** **Coordinate**(object):

... **def** **\_\_init\_\_**(self, x, y):

... self.x = x

... self.y = y

... **def** **\_\_repr\_\_**(self):

... **return** "Coord: " + **str**(self.\_\_dict\_\_)

>>> **def** **add**(a, b):

... **return** **Coordinate**(a.x + b.x, a.y + b.y)

>>> **def** **sub**(a, b):

... **return** **Coordinate**(a.x - b.x, a.y - b.y)

>>> one = **Coordinate**(100, 200)

>>> two = **Coordinate**(300, 200)

>>> **add**(one, two)

Coord: {'y': 400, 'x': 400}

But what if our add and subtract functions had to also have some bounds checking behavior? Perhaps you can only sum or subtract based on positive coordinates and any result should be limited to positive coordinates as well. So currently

>>> one = **Coordinate**(100, 200)

>>> two = **Coordinate**(300, 200)

>>> three = **Coordinate**(-100, -100)

>>> **sub**(one, two)

Coord: {'y': 0, 'x': -200}

>>> **add**(one, three)

Coord: {'y': 100, 'x': 0}

but we’d rather have have the difference of one and two be {x: 0, y: 0} and the sum of one and three be {x: 100, y: 200} without modifying one, two, or three. Instead of adding bounds checking to the input arguments of each function and the return value of each function let’s write a bounds checking decorator!

>>> **def** **wrapper**(func):

... **def** **checker**(a, b): *# 1*

... **if** a.x < 0 **or** a.y < 0:

... a = **Coordinate**(a.x **if** a.x > 0 **else** 0, a.y **if** a.y > 0 **else** 0)

... **if** b.x < 0 **or** b.y < 0:

... b = **Coordinate**(b.x **if** b.x > 0 **else** 0, b.y **if** b.y > 0 **else** 0)

... ret = **func**(a, b)

... **if** ret.x < 0 **or** ret.y < 0:

... ret = **Coordinate**(ret.x **if** ret.x > 0 **else** 0, ret.y **if** ret.y > 0 **else** 0)

... **return** ret

... **return** checker

>>> add = **wrapper**(add)

>>> sub = **wrapper**(sub)

>>> **sub**(one, two)

Coord: {'y': 0, 'x': 0}

>>> **add**(one, three)

Coord: {'y': 200, 'x': 100}

This decorator works just as before - returns a modified version of a function but in this case it does something useful by checking and normalizing the input parameters and the return value, substituting 0 for any negative x or y values.

It’s a matter of opinion as to whether doing it this makes our code cleaner: isolating the bounds checking in its own function and applying it to all the functions we care to by wrapping them with a decorator. The alternative would be a function call on each input argument and on the resulting output before returning inside each math function and it is undeniable that using the decorator is at least less repetitious in terms of the amount of code needed to apply bounds checking to a function. In fact - if its our own functions we’re decorating we could make the decorator application a little more obvious.

## 10. The @ symbol applies a decorator to a function

Python 2.4 provided support to wrap a function in a decorator by pre-pending the function definition with a decorator name and the @ symbol. In the code samples above we decorated our function by replacing the variable containing the function with a wrapped version.

>>> add = **wrapper**(add)

This pattern can be used at any time, to wrap any function. But if we are defining a function we can "decorate" it with the @ symbol like:

>>> @wrapper

... **def** **add**(a, b):

... **return** **Coordinate**(a.x + b.x, a.y + b.y)

It’s important to recognize that this is no different than simply replacing the original variable add with the return from the wrapper function - Python just adds some syntactic sugar to make what is going on very explicit.

Again - using decorators is easy! Even if writing useful decorators like staticmethod or classmethod would be difficult, using them is just a matter of prepending your function with @decoratorname!

## 11. \*args and \*\*kwargs

We’ve written a useful decorator but it’s hard coded to work only on a particular kind of function - one which takes two arguments. Our inner function checker accepts two arguments and passes the arguments on to the function captured in the closure. What if we wanted a decorator that did something for any possible function? Let’s write a decorator that increments a counter for every function call of every decorated function without changing any of it’s decorated functions. This means it would have to accept the calling signature of any of the functions that it decorates and also call the functions it decorates passing on whatever arguments were passed to it.

It just so happens that Python has syntactic support for just this feature. Be sure to read the [Python Tutorial](http://docs.python.org/tutorial/controlflow.html#arbitrary-argument-lists) for more details but the \* operator used when defining a function means that any extra positional arguments passed to the function end up in the variable prefaced with a \*. So:

>>> **def** **one**(\*args):

... **print** args *# 1*

>>> **one**()

()

>>> **one**(1, 2, 3)

(1, 2, 3)

>>> **def** **two**(x, y, \*args): *# 2*

... **print** x, y, args

>>> **two**('a', 'b', 'c')

a **b** ('c',)

The first function one simply prints whatever (if any) positional arguments are passed to it. As you can see at point #1 we simply refer to the variable args inside the function - \*args is only used in the function definition to indicate that positional arguments should be stored in the variable args. Python also allows us to specify some variables and catch any additional parameters in args as we can see at point #2.

The \* operator can also be used when calling functions and here it means the analogous thing. A variable prefaced by \* when **calling** a function means that the variable contents should be extracted and used as positional arguments. Again by example:

>>> **def** **add**(x, y):

... **return** x + y

>>> lst = [1,2]

>>> **add**(lst[0], lst[1]) *# 1*

3

>>> **add**(\*lst) *# 2*

3

The code at point #1 does exactly the same thing as the code at point #2 - Python is doing automatically for us at point #2 what we could do manually for ourselves. This isn’t too bad - \*args means either extract positional variables from an iterable if calling a function or when defining a function accept any extra positional variables.

Things get only slightly more complicated when we introduce \*\* which does for dictionaries & key/value pairs exactly what \* does for iterables and positional parameters. Simple, right?

>>> **def** **foo**(\*\*kwargs):

... **print** kwargs

>>> **foo**()

{}

>>> **foo**(x=1, y=2)

{'y': 2, 'x': 1}

When we define a function we can use \*\*kwargs to indicate that all uncaptured keyword arguments should be stored in a dictionary called kwargs. As before neither the name args nor kwargs is part of Python syntax but it is convention to use these variable names when declaring functions. Just like \* we can use \*\* when calling a function as well as when defining it.

>>> dct = {'x': 1, 'y': 2}

>>> **def** **bar**(x, y):

... **return** x + y

>>> **bar**(\*\*dct)

3

## 12. More generic decorators

Given our new power we can write a decorator that "logs" the arguements to functions. We’ll just print to stdout for simplicity sake:

>>> **def** **logger**(func):

... **def** **inner**(\*args, \*\*kwargs): *#1*

... **print** "Arguments were: %s, %s" % (args, kwargs)

... **return** **func**(\*args, \*\*kwargs) *#2*

... **return** inner

Notice our inner function takes any arbitrary number and type of parameters at point #1 and passes them along as arguments to the wrapped function at point #2. This allows us to wrap or decorate any function, no matter it's signature.

>>> @logger

... **def** **foo1**(x, y=1):

... **return** x \* y

>>> @logger

... **def** **foo2**():

... **return** 2

>>> **foo1**(5, 4)

Arguments were: (5, 4), {}

20

>>> **foo1**(1)

Arguments were: (1,), {}

1

>>> **foo2**()

Arguments were: (), {}

2

Calling our functions results in a "logging" output line as well as the expected return value of each function.

## More about decorators

If you followed the last example you understand decorators! Congratulations - Go forth and use your new powers for good!

You might also consider a little further study: [Bruce Eckel has an excellent essay on decorators](http://www.artima.com/weblogs/viewpost.jsp?thread=240808) and implements them in Python with objects instead of functions. You might find the OOP code easier to read than our purely functional version. Bruce also has a follow-up essay on [providing arguments to decorators](http://www.artima.com/weblogs/viewpost.jsp?thread=240845)that may also easier to implement with objects than with functions. Finally - you might also investigate the builtin [functools](http://docs.python.org/dev/library/functools.html) wraps function which (confusingly) is a decorator that can be used in our decorators to modify the signature of our replacement functions so they look more like the decorated function.

[1] I also recently read an essay on explaining [decorators](http://pythonconquerstheuniverse.wordpress.com/2012/04/29/python-decorators/) that set me thinking…

[2] "global" is a big fat lie in Python which is a wonderful thing, but a discussion for another time…

**Update:** Thanks to Nick I've updated my terminology throughout to be clear that "parameters" are the named variables in function signatures while "arguments" are the values passed to functions.

**Update:** I've fixed several typos in the article. Thanks Gregory!