



## Lecture 11 – Classes & Objects II

<https://cw.fel.cvut.cz/wiki/courses/be5b33prg/start>

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OOP is about changing the perspective

- Syntax for a function call: **function\_name(variable)**  
**function** is the one who executes on the variable
- Syntax in OOP: **object\_name.function\_name()**  
**object** is the one who executes its method on given data / attribute



```
1 class Point:
2     """ Create a new Point, at coordinates x, y """
3
4     def __init__(self, x=0, y=0):
5         """ Create a new point at x, y """
6         self.x = x
7         self.y = y
8
9     def distance_from_origin(self):
10        """ Compute my distance from the origin """
11        return ((self.x ** 2) + (self.y ** 2)) ** 0.5
```

- Advantage of using a class (*e.g. Point*) rather than a tuple is that **class methods are sensible operations** for points, but may not be appropriate for other tuples (*e.g. calculate the distance from the origin*)
- Class allows to **group together sensible operations** as well as data to apply the methods on
- Each instance of the class has its **own state**
- Method **behaves like a function** but it is invoked on a specific instance



## @classmethod

- In the same way class attributes are defined, **which are shared between all instances of a class**, class methods are defined using @classmethod **decorator** for ordinary method
- Class method still has its **calling object as the first parameter**, but by convention it is **cls** instead of **self**
- If class method is called from an instance, **this parameter will contain the instance object**, but if it is called from the class **it will contain the class object**
- Naming the parameter **cls** serves as **reminder that it is not guaranteed to have any instance attributes**



## What are class methods good for?

- For tasks associated with a class utilizing constants and other class attributes **without the need to create any class instances**
- **EXAMPLE:** *when we write classes to group related constants together with functions which act on them – no need to instantiate these classes at all*



```
class Inst:

    def __init__(self, name):
        self.name = name

    def introduce(self):
        print("Hello, I am %s, and my name is " %(self, self.name))
```

```
myinst = Inst("Test Instance")
otherinst = Inst("An other instance")
myinst.introduce()
# outputs: Hello, I am <Inst object at x>, and my name is Test Instance
otherinst.introduce()
# outputs: Hello, I am <Inst object at y>, and my name is An other instance
```



```
class Cls:

    @classmethod
    def introduce(cls):
        print("Hello, I am %s!" %cls)
```

```
Cls.introduce() # same as Cls.introduce(Cls)
# outputs: Hello, I am <class 'Cls'>
```

Notice that again `Cls` is passed hiddenly, so we could also say `Cls.introduce(Inst)` and get output `"Hello, I am <class 'Inst'>`. This is particularly useful when we're inheriting a class from `Cls`:

```
class SubCls(Cls):
    pass

SubCls.introduce()
# outputs: Hello, I am <class 'SubCls'>
```



## @staticmethod

- Static method **does not have the calling object passed** into it as the first parameter
- Static method **does not have access to the rest of the class or instance**
- Static method is **most commonly called from class objects** (*like class methods*)



# RECAP: EXAMPLE – STATIC METHODS



9

```
1 class Person:
2     TITLES = ('Dr', 'Mr', 'Mrs', 'Ms')
3
4     def __init__(self, name, surname):
5         self.name = name
6         self.surname = surname
7
8     def fullname(self): # instance method
9         # instance object accessible through self
10        return "%s %s" % (self.name, self.surname)
11
12    @classmethod
13    def allowed_titles_starting_with(cls, startswith): # class method
14        # class or instance object accessible through cls
15        return [t for t in cls.TITLES if t.startswith(startswith)]
16
17    @staticmethod
18    def allowed_titles_ending_with(endswith): # static method
19        # no parameter for class or instance object
20        # we have to use Person directly
21        return [t for t in Person.TITLES if t.endswith(endswith)]
22
23
```

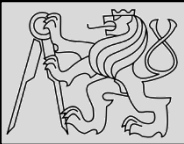
```
In[3]: jane = Person("Jane", "Smith")
In[4]: print(jane.fullname())
Jane Smith
In[5]: print(jane.allowed_titles_starting_with("M"))
['Mr', 'Mrs', 'Ms']
In[6]: print(Person.allowed_titles_starting_with("M"))
['Mr', 'Mrs', 'Ms']
In[7]: print(jane.allowed_titles_ending_with("s"))
['Mrs', 'Ms']
In[8]: print(Person.allowed_titles_ending_with("s"))
['Mrs', 'Ms']
```

SOURCE <http://python-textbok.readthedocs.io/en/1.0/Classes.html#> UNDER [CC BY-SA 4.0 licence](https://creativecommons.org/licenses/by-sa/4.0/) Revision 8e685e710775



```
1  class Rectangle:
2      """ A class to manufacture rectangle objects """
3
4      def __init__(self, posn, w, h):
5          """ Initialize rectangle at posn, with width w, height h """
6          self.corner = posn
7          self.width = w
8          self.height = h
9
10     def __str__(self):
11         return "({0}, {1}, {2})".
12             .format(self.corner, self.width, self.height)
13
```

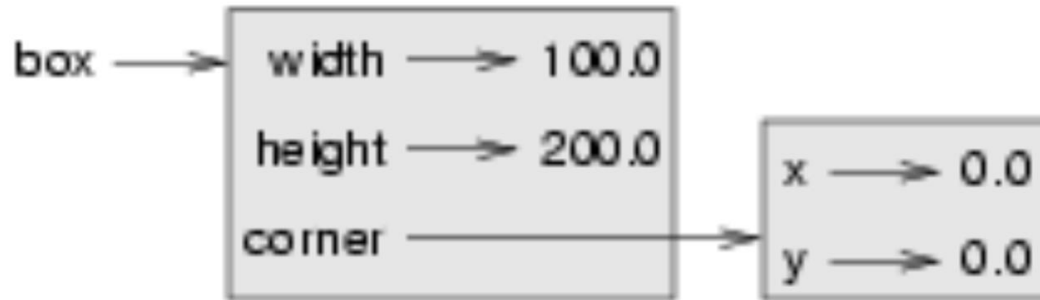
- Assume a **rectangle** that is oriented either vertically or horizontally, never at an angle;
- Specify the **upper-left corner** of the rectangle, and its **size**



```
1 class Rectangle:
2     """ A class to manufacture rectangle objects """
3
4     def __init__(self, posn, w, h):
5         """ Initialize rectangle at posn, with width w, height h """
6         self.corner = posn
7         self.width = w
8         self.height = h
9
10    def __str__(self):
11        return "({0}, {1}, {2})"
12            .format(self.corner, self.width, self.height)
13
14    box = Rectangle(Point(0, 0), 100, 200)
15    bomb = Rectangle(Point(100, 80), 5, 10)    # In my video game
16    print("box: ", box)
17    print("bomb: ", bomb)
```

```
box: ((0, 0), 100, 200)
bomb: ((100, 80), 5, 10)
```

- To specify the upper-left corner embed a **Point object** within the new **Rectangle object**
- Create two new Rectangle objects, and then print them



- The dot operator composes.
- The expression **box.corner.x** means:

*“Go to the object that box refers to and select its attribute named corner, then go to that object and select its attribute named x”*



```
1 class Rectangle:
2     # ...
3
4     def grow(self, delta_width, delta_height):
5         """ Grow (or shrink) this object by the deltas """
6         self.width += delta_width
7         self.height += delta_height
8
9     def move(self, dx, dy):
10        """ Move this object by the deltas """
11        self.corner.x += dx
12        self.corner.y += dy
```

```
>>> r = Rectangle(Point(10,5), 100, 50)
>>> print(r)
((10, 5), 100, 50)
>>> r.grow(25, -10)
>>> print(r)
((10, 5), 125, 40)
>>> r.move(-10, 10)
print(r)
((0, 15), 125, 40)
```

- Change the state of an object by making an assignment to one of its attributes

```
box.width += 50
box.height += 100
```

- Provide a method to encapsulate this inside the class
- Provide another method to *move the position of the rectangle elsewhere*



```
>>> p1 = Point(3, 4)
>>> p2 = Point(3, 4)
>>> p1 is p2
False
```

```
>>> p3 = p1
>>> p1 is p3
True
```

- *If two objects are the same, does it mean they contain the **same data** or that they are the **same object**?*
- The **is** operator was used in previous examples on the lists when explaining aliases: **it allows us to find out if two references refer to the same object**



- **Shallow copy**: is defined as constructing a new collection object and then **populating it with references** to the child objects found in the original, i.e. a shallow copy is **only one level deep**. The **copying process does not recurse** and therefore will not create copies of the child objects.
- **Deep copy**: is defined as **recursive copying process**, i.e. first constructing a new collection object and then recursively populating it with **copies of the child objects** found in the original. *Copying an object this way walks the whole object tree to create a fully independent clone of the original object and all of its children.*



```
1 def same_coordinates(p1, p2):  
2     return (p1.x == p2.x) and (p1.y == p2.y)
```

```
>>> p1 = Point(3, 4)  
>>> p2 = Point(3, 4)  
>>> same_coordinates(p1, p2)  
True
```

- **Shallow equality:** When **is** is **True**, this type of equality is *shallow equality* because it compares only the **references** and not the *contents* of the objects
- **Deep equality:** To compare the **contents** of the objects a function like *same\_coordinates* needs to be created
- **IMPORTANT:** **If two variables refer to the same object, they have both shallow and deep equality**



```
1 p = Point(4, 2)
2 s = Point(4, 2)
3 print("== on Points returns", p == s)
4 # By default, == on Point objects does a shallow equality test
5
6 a = [2,3]
7 b = [2,3]
8 print("== on lists returns", a == b)
9 # But by default, == does a deep equality test on lists
```

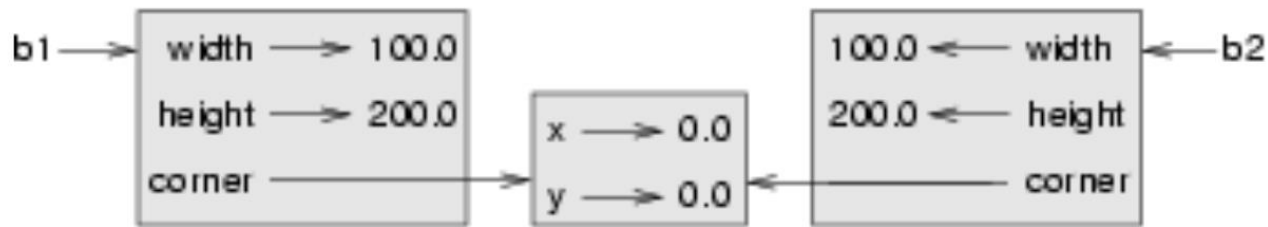
```
== on Points returns False
== on lists returns True
```

- Think about **shallow** & **deep** copy when designing classes!
- Even though the two lists (or tuples, etc.) are *distinct objects with different memory addresses*, for **lists** the **==** operator tests for **deep equality**, while in the case of **objects** (points) it makes a **shallow test**



```
>>> import copy
>>> p1 = Point(3, 4)
>>> p2 = copy.copy(p1)
>>> p1 is p2
False
>>> same_coordinates(p1, p2)
True
```

- Aliasing makes code difficult to read – *changes made in one place might have unexpected effects in another place*
- Copying object is an **alternative to aliasing**: the **copy module** contains a function `copy` that can duplicate any object
- **EXAMPLE**: *To copy objects import the copy module and use the copy function to make a new Point: p1 and p2 are **not the same point**, but they **contain the same data** (shallow copy)*



- Assume **Rectangle**, which contains a reference to a **Point**: copy **copies the reference** to the **Point** object, so both the old **Rectangle** and the new one **refer to the same Point**
- Invoking **grow** on one of the Rectangle objects would not affect the other,
- Invoking **move** on either would affect both since **shallow copy has created an alias to the Point that represents the corner**
- Copy module contains a function named **deepcopy** that copies not only the object but also any embedded objects

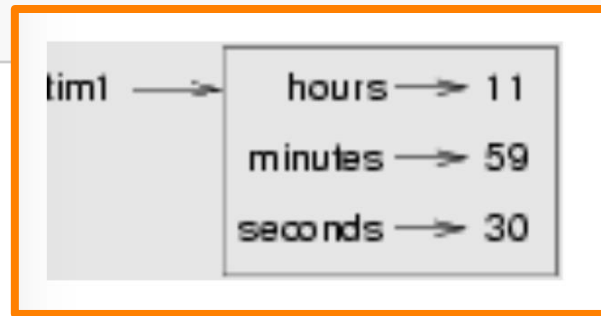


- **Deep copy**: To copy the contents of an object as well as any embedded objects, and any objects embedded in them, etc. (*implemented as `deepcopy` function in `copy` module*)
- **Deep equality**: Equality of values, or two references that point to objects that have the same value
- **Shallow copy**: To copy the contents of an object, including any references to embedded objects (one level copy). (*implemented by the `copy` function in the `copy` module*)
- **Shallow equality**: Equality of references, or two references that point to the same object



```
1 class MyTime:
2
3     def __init__(self, hrs=0, mins=0, secs=0):
4         """ Create a MyTime object initialized to hrs, mins, secs """
5         self.hours = hrs
6         self.minutes = mins
7         self.seconds = secs
```

```
1 tim1 = MyTime(11, 59, 30)
```



- **EXAMPLE:** User-defined type called **MyTime** that records the time of day
- Initializer using an **\_\_init\_\_** method to ensure that every instance is created with appropriate attributes



```
1 def add_time(t1, t2):
2     h = t1.hours + t2.hours
3     m = t1.minutes + t2.minutes
4     s = t1.seconds + t2.seconds
5     sum_t = MyTime(h, m, s)
6     return sum_t
```

```
>>> current_time = MyTime(9, 14, 30)
>>> bread_time = MyTime(3, 35, 0)
>>> done_time = add_time(current_time, bread_time)
>>> print(done_time)
12:49:30
```

**EXAMPLE:** *Create two **MyTime** objects*

- **current\_time**, which contains the current time
- **bread\_time**, which contains the amount of time it takes for a breadmaker to make bread
- use **add\_time** to figure out when the bread will be done

**PROBLEM: ??**



```
1 def add_time(t1, t2):
2     h = t1.hours + t2.hours
3     m = t1.minutes + t2.minutes
4     s = t1.seconds + t2.seconds
5     sum_t = MyTime(h, m, s)
6     return sum_t
```

```
>>> current_time = MyTime(9, 14, 30)
>>> bread_time = MyTime(3, 35, 0)
>>> done_time = add_time(current_time, bread_time)
>>> print(done_time)
12:49:30
```

**EXAMPLE:** *Create two **MyTime** objects:*

- **current\_time**, which contains the current time
- **bread\_time**, which contains the amount of time it takes for a breadmaker to make bread
- use **add\_time** to figure out when the bread will be done

**PROBLEM:** *We do not deal with cases where the number of seconds or minutes adds up to more than sixty!*



```
1 def add_time(t1, t2):
2     h = t1.hours + t2.hours
3     m = t1.minutes + t2.minutes
4     s = t1.seconds + t2.seconds
5     sum_t = MyTime(h, m, s)
6     return sum_t
```

```
>>> current_time = MyTime(9, 14, 30)
>>> bread_time = MyTime(3, 35, 0)
>>> done_time = add_time(current_time, bread_time)
>>> print(done_time)
12:49:30
```

- There can be two versions of a function **add\_time**, **pure** function or the **modifier**, which both calculate the sum of two MyTime objects
- Function that creates a new MyTime object and returns a reference to the new object is a **pure function** because **it does not modify** any of the objects passed to it as parameters and **it has no side effects**



```
1  def add_time(t1, t2):
2
3      h = t1.hours + t2.hours
4      m = t1.minutes + t2.minutes
5      s = t1.seconds + t2.seconds
6
7      if s >= 60:
8          s -= 60
9          m += 1
10
11     if m >= 60:
12         m -= 60
13         h += 1
14
15     sum_t = MyTime(h, m, s)
16     return sum_t
```

**PROBLEM:** *Do we now deal with cases where the number of seconds or minutes adds up to more than sixty?*



```
1 def increment(t, secs):
2     t.seconds += secs
3
4     if t.seconds >= 60:
5         t.seconds -= 60
6         t.minutes += 1
7
8     if t.minutes >= 60:
9         t.minutes -= 60
10        t.hours += 1
```

```
1 def increment(t, seconds):
2     t.seconds += seconds
3
4     while t.seconds >= 60:
5         t.seconds -= 60
6         t.minutes += 1
7
8     while t.minutes >= 60:
9         t.minutes -= 60
10        t.hours += 1
```

- It can be useful for a function to **modify** one or more of the objects it gets as parameters
- Usually, the **caller keeps a reference** to the objects it passes, so any changes the function are visible to the caller (*modifier*)
- Function **increment**, which adds a given number of seconds to a MyTime object, is a natural example of a **modifier**



```
1 class MyTime:
2     # Previous method definitions here...
3
4     def increment(self, seconds):
5         self.seconds += seconds
6
7         while self.seconds >= 60:
8             self.seconds -= 60
9             self.minutes += 1
10
11        while self.minutes >= 60:
12            self.minutes -= 60
13            self.hours += 1
```

```
1 current_time.increment(500)
```

- **SOLUTION:** Include functions that work with MyTime objects into the MyTime class, i.e. conversion of the function **increment** to a method
- This conversion means moving the definition into the class and changing the name of the first parameter to **self**



```
1 class MyTime:
2     # ...
3
4     def to_seconds(self):
5         """ Return the number of seconds represented
6             by this instance
7         """
8         return self.hours * 3600 + self.minutes * 60 + self.seconds
```

```
1 hrs = tsecs // 3600
2 leftoversecs = tsecs % 3600
3 mins = leftoversecs // 60
4 secs = leftoversecs % 60
```

- **INSIGHT:** **MyTime** object is actually a **three-digit number in base 60!**
- Another approach —convert the **MyTime** object into a single number instead, i.e. the method **to\_seconds** can be added to the **MyTime** class to convert any instance into corresponding number of seconds



```
1 class MyTime:
2     # ...
3
4     def __init__(self, hrs=0, mins=0, secs=0):
5         """ Create a new MyTime object initialized to hrs, mins, secs.
6             The values of mins and secs may be outside the range 0-59,
7             but the resulting MyTime object will be normalized.
8         """
9
10        # Calculate total seconds to represent
11        totalesecs = hrs*3600 + mins*60 + secs
12        self.hours = totalesecs // 3600          # Split in h, m, s
13        leftoversecs = totalesecs % 3600
14        self.minutes = leftoversecs // 60
15        self.seconds = leftoversecs % 60
```

- In OOP we wrap together the **data** and the **operations**
- Solution is to rewrite the class initializer so that it can cope with initial values of seconds or minutes that are **outside the range of the normalized values**  
(normalized time: 3 hours 12 minutes and 20 seconds; the same time but not normalized 2 hours 70 minutes and 140 seconds)



```
>>> t1 = MyTime(10, 55, 12)
>>> t2 = MyTime(10, 48, 22)
>>> after(t1, t2)           # Is t1 after t2?
True
```

- The function **after** can be defined to compare two times and specify whether **the first time is strictly after the second**
- This solution is a bit more complicated because it operates on **two MyTime objects** not just one



```
1 class MyTime:
2     # Previous method definitions here...
3
4     def after(self, time2):
5         """ Return True if I am strictly greater than time2 """
6         if self.hours > time2.hours:
7             return True
8         if self.hours < time2.hours:
9             return False
10
11        if self.minutes > time2.minutes:
12            return True
13        if self.minutes < time2.minutes:
14            return False
15        if self.seconds > time2.seconds:
16            return True
17
18        return False
```

```
1 if current_time.after(done_time):
2     print("The bread will be done before it starts!")
```

- **Lines 11-18** will only be reached if the two hour fields are the same.
- The test at **line 16** is only executed if both times have the same hours and the same minutes.



```
1 class MyTime:
2     # Previous method definitions here...
3
4     def after(self, time2):
5         """ Return True if I am strictly greater than time2 """
6         return self.to_seconds() > time2.to_seconds()
```

- The whole example can be made easier using the previously discovered insight of converting the time into single integer!
- This is a great way to code this:  
If we want to tell if the first time is after the second time, turn them both into integers and compare the integers.



```
1 class MyTime:
2     # Previously defined methods here...
3
4     def __add__(self, other):
5         return MyTime(0, 0, self.to_seconds() + other.to_seconds())
```

- **Operator overloading**: opens the possibility to have different meanings for the same operator when applied to different types
- **EXAMPLE**: the **+** in Python means quite different things for integers (**addition**) and for strings (**concatenation**)!
- To override the addition operator **+** provide a method named **\_\_add\_\_**



```
1 class MyTime:
2     # Previously defined methods here...
3
4     def __add__(self, other):
5         return MyTime(0, 0, self.to_seconds() + other.to_seconds())
```

```
>>> t1 = MyTime(1, 15, 42)
>>> t2 = MyTime(3, 50, 30)
>>> t3 = t1 + t2
>>> print(t3)
05:06:12
```

- **First parameter** is the **object on which the method is invoked**
- **Second parameter** is named **other** to distinguish it from **self**
- To add two MyTime objects create and return a **new MyTime object** that contains their sum
- The expression **t1 + t2** is equivalent to **t1.\_\_add\_\_(t2)**



```
1 class Point:  
2     # Previously defined methods here...  
3  
4     def __add__(self, other):  
5         return Point(self.x + other.x, self.y + other.y)
```

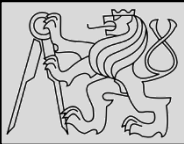
- **EXAMPLE:** *back to the Point class – adding two points adds their respective (x, y) coordinates*
- There are several ways to override the behavior of the **multiplication operator** by defining a method named **\_\_mul\_\_** or **\_\_rmul\_\_** or both



```
1 def __mul__(self, other):  
2     return self.x * other.x + self.y * other.y
```

```
1 def __rmul__(self, other):  
2     return Point(other * self.x, other * self.y)
```

- If the **left** operand of **\*** is a **Point**, Python invokes **\_\_mul\_\_**, which assumes that the other operand is also a Point (this computes the **dot product** of the two Points)
- If the **left** operand of **\*** is a **primitive type** and the right operand is a **Point**, Python invokes **\_\_rmul\_\_**, which performs *scalar multiplication*
- The result is always a new **Point** whose coordinates are a multiple of the original coordinates



```
>>> p1 = Point(3, 4)
>>> p2 = Point(5, 7)
>>> print(p1 * p2)
43
>>> print(2 * p2)
(10, 14)
```

**PROBLEM:** How is `p2 * 2` evaluated?



```
>>> p1 = Point(3, 4)
>>> p2 = Point(5, 7)
>>> print(p1 * p2)
43
>>> print(2 * p2)
(10, 14)
```

```
>>> print(p2 * 2)
AttributeError: 'int' object has no attribute 'x'
```

- **PROBLEM:** How is `p2 * 2` evaluated?
- Since the first parameter is a Point, Python invokes `__mul__` with 2 as the second argument
- Inside `__mul__`, the program tries to access the `x` coordinate of other, which **fails** because an **integer has no attributes**



```
1 def front_and_back(front):
2     import copy
3     back = copy.copy(front)
4     back.reverse()
5     print(str(front) + str(back))
```

```
>>> my_list = [1, 2, 3, 4]
>>> front_and_back(my_list)
[1, 2, 3, 4][4, 3, 2, 1]
```

- **EXAMPLE: *front\_and\_back*** – consider a function which prints a list twice: forward and backward
- The reverse method is a **modifier** therefore a copy needs to be made before applying it (this way we prevent to modify the list the function gets as a parameter!)
- Function that can take arguments with different types and handles them accordingly is called **polymorphic**



```
1 def multadd (x, y, z):  
2     return x * y + z
```

```
>>> multadd (3, 2, 1)  
7
```

```
>>> p1 = Point(3, 4)  
>>> p2 = Point(5, 7)  
>>> print(multadd (2, p1, p2))  
(11, 15)  
>>> print(multadd (p1, p2, 1))  
44
```

- **Polymorphism** == ability to process objects differently based on data type
- There are certain operations that can be applied to many types, such as the arithmetic operations ...
- **EXAMPLE:** *The **multadd** operation takes three parameters: multiplies the first two and then adds the third*



```
1 def multadd (x, y, z):  
2     return x * y + z
```

```
>>> multadd (3, 2, 1)  
7
```

```
>>> p1 = Point(3, 4)  
>>> p2 = Point(5, 7)  
>>> print(multadd (2, p1, p2))  
(11, 15)  
>>> print(multadd (p1, p2, 1))  
44
```

- **EXAMPLE:** *The **multadd** operation takes three parameters: multiplies the first two and then adds the third*
- **The first case:** the Point is multiplied by a scalar and then added to another Point
- **The second case:** the dot product yields a numeric value, so the third parameter also has to be a numeric value



```
1 def reverse(self):  
2     (self.x , self.y) = (self.y, self.x)
```

```
>>> p = Point(3, 4)  
>>> front_and_back(p)  
(3, 4)(4, 3)
```

- Python's fundamental rule of polymorphism is called the **duck typing rule**: *If all of the operations inside the function can be applied to the type, the function can be applied to the type.*
- Operations in the **front\_and\_back** : *copy, reverse, print*
- **EXAMPLE**: What about our Point class?  
The **copy** method works on any object; already written a **\_\_str\_\_** method for Point objects for the **str()** conversion, only the **reverse** method for the Point class is needed!



This lecture re-uses selected parts of the **OPEN BOOK PROJECT**  
**Learning with Python 3 (RLE)**

<http://openbookproject.net/thinkcs/python/english3e/index.html>  
available under [GNU Free Documentation License Version 1.3](#))

- Version date: October 2012
- by Peter Wentworth, Jeffrey Elkner, Allen B. Downey, and Chris Meyers (based on 2nd edition by Jeffrey Elkner, Allen B. Downey, and Chris Meyers)
- Source repository is at <https://code.launchpad.net/~thinkcspy-rle-team/thinkcspy/thinkcspy3-rle>
- For offline use, download a zip file of the html or a pdf version from <http://www.ict.ru.ac.za/Resources/cspw/thinkcspy3/>

This lecture re-uses selected parts of the **PYTHON TEXTBOOK**  
**Object-Oriented Programming in Python**

<http://python-textbok.readthedocs.io/en/1.0/Classes.html#>  
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