STATS 701
Data Analysis using Python

Lecture 7: Classes

Classes are programmer-defined types

Sometimes we use a collection of variables to represent a specific object

- **Example:** we used a tuple of tuples to represent a matrix
- **Example:** representing state of a board game
  - List of players, piece positions, etc.
- **Example:** representing a statistical model
  - Want to support methods for estimation, data generation, etc.

Important point: these data structures quickly become very complicated, and we want a way to encapsulate them. This is a core motivation (but hardly the only one) for **object-oriented programming**.

Classes encapsulate data types

Example: I want to represent a point in 2-dimensional space $\mathbb{R}^2$

Option 1: just represent a point by a 2-tuple

Option 2: make a point **class**, so that we have a whole new data type

Additional good reasons for this will become apparent shortly!

```python
class Point:
    '''Represents a 2-d point.'''
```

```python
print(Point)
```

```
<class '__main__.Point'>
```

Class header declares a new class, called `Point`.

Docstring provides explanation of what the class represents, and a bit about what it does. This is an ideal place to document your class.

Credit: Running example adapted from A. B. Downey, *Think Python*

Classes encapsulate data types

Note: By convention, class names are written in **CamelCase**.

Example: I want to represent a point in 2-dimensional space $\mathbb{R}^2$

Option 1: just represent a point by a 2-tuple

Option 2: make a point **class**, so that we have a whole new data type

Additional good reasons for this will become apparent shortly!

```python
class Point:
    '''Represents a 2-d point.'''
```

```python
print(Point)
```

Class definition creates a **class object**, `Point`.

```
<class '__main__.Point'>
```

Credit: Running example adapted from A. B. Downey, *Think Python*

Creating an object: Instantiation

```python
class Point:
    '''Represents a 2-d point.'''

p = Point()
p
```

```
<__main__.Point at 0x10669b940>
```

This defines a class `Point`, and from here on we can create new variables of type `Point`.

Creating an object: Instantiation

```python
class Point:
    '''Represents a 2-d point.'''

p = Point()
p
```

```
<__main__.Point at 0x10669b940>
```

Creating a new object is called **instantiation**. Here we are creating an **instance** `p` of the class `Point`.

Indeed, `p` is of type `Point`.

Note: An **instance** is an individual object from a given class.
In general, the terms **object** and **instance** are interchangeable: an object is an instantiation of a class.

Assigning Attributes

This dot notation should look familiar. Here, we are assigning values to **attributes** `x` and `y` of the object `p`. This both creates the attributes, and assigns their values.

```
p = Point()
p.x = 3.0
p.y = 4.0
(p.x,p.y)
```

Once the attributes are created, we can access them, again with dot notation.

```
(3.0, 4.0)
```

```
p.goat
```

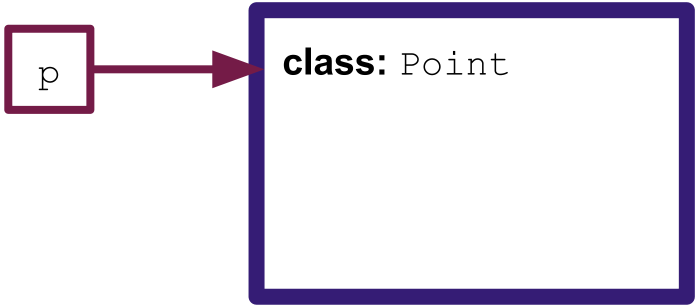
Attempting to access an attribute that an object doesn't have is an error.

```
---------------------------------------------------------------------------
AttributeError                            Traceback (most recent call last)
<ipython-input-5-f74ee22f01ba> in <module>()
----> 1 p.goat

AttributeError: 'Point' object has no attribute 'goat'
```

Thinking about Attributes: Object Diagrams

```python
class Point:
    '''Represents a 2-d point.'''

p = Point()
p.x = 3.0
p.y = 4.0
```

At this point, `p` is just an object with no attributes.

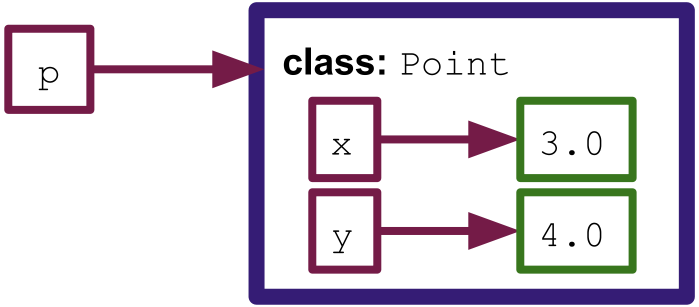


Thinking about Attributes: Object Diagrams

```python
class Point:
    '''Represents a 2-d point.'''

p = Point()
p.x = 3.0
p.y = 4.0
```

After these two lines, `p` has attributes `x` and `y`.



Thinking about Attributes: Object Diagrams

```
class Point:
    '''Represents a 2-d point.'''

p = Point()
p.x = 3.0
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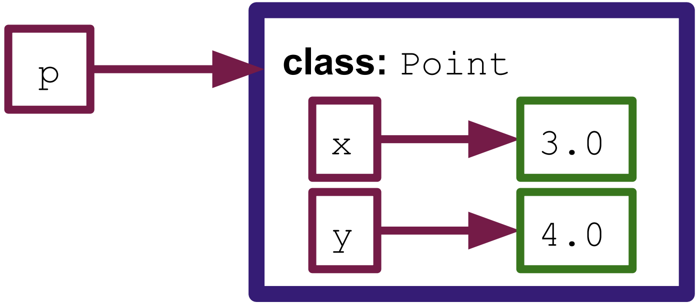
After these two lines, `p` has attributes `x` and `y`.



So dot notation `p.x`, essentially says, look inside the object `p` and find the attribute `x`.

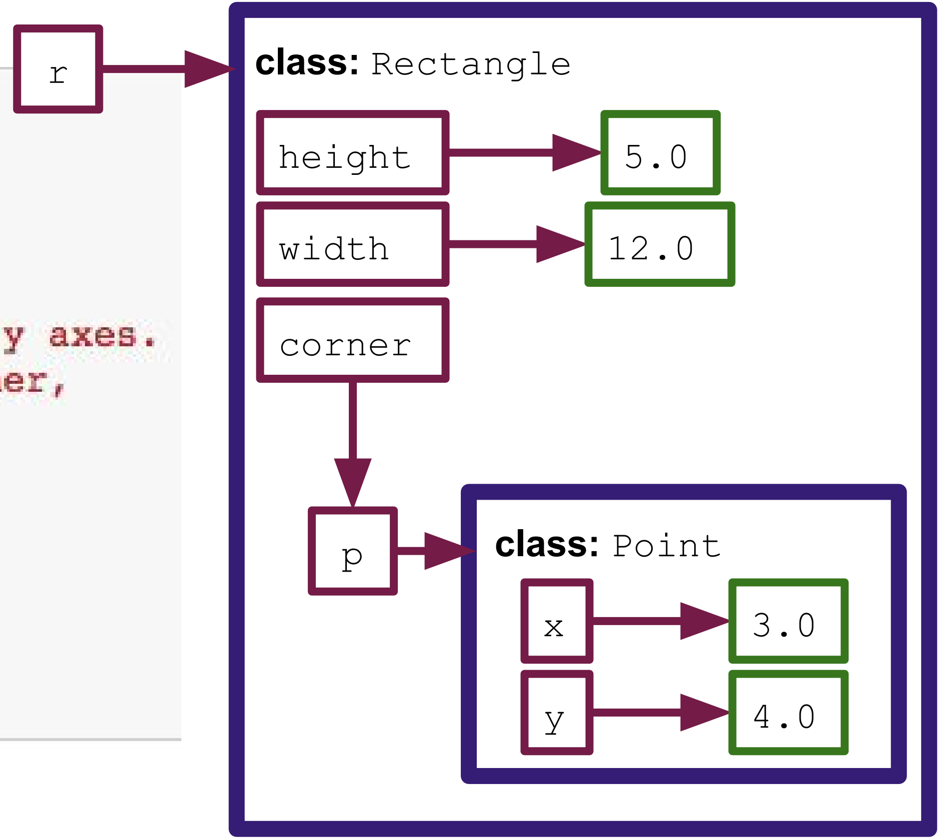
Nesting Objects

Objects can have other objects as their attributes.
We often call the attribute object **embedded**.

```
class Point:
    '''Represents a 2-d point.'''

class Rectangle:
    '''Represents a rectangle whose
    sides are parallel to the x and y axes.
    Specified by its upper-left corner,
    height, and width.'''

p = Point(); p.x = 3.0; p.y = 4.0
r = Rectangle()
r.corner = p
r.height = 5.0
r.width = 12.0
```



Nesting Objects

```
p1 = Point(); p1.x = 3.0; p1.y = 4.0
r1 = Rectangle()
r1.corner = p1
r1.height = 5.0
r1.width = 12.0

r2 = Rectangle()
r2.corner = Point()
r2.corner.x = 3.0
r2.corner.y = 4.0
r2.height = 5.0
r2.width = 12.0
```

Both of these blocks of code create equivalent `Rectangle` objects.

Note here that instead of creating a point and then embedding it, we embed a `Point` object and *then* populate its attributes.

Objects are mutable

```
p1 = Point(); p1.x = 3.0; p1.y = 4.0
r1 = Rectangle()
r1.corner = p1
r1.height = 5.0; r1.width = 12.0
r1.height = 2*r1.height

def shift_rectangle(rec, dx, dy):
    rec.corner.x = rec.corner.x + dx
    rec.corner.y = rec.corner.y + dx

shift_rectangle(r1, 2, 3)
(r1.corner.x, r1.corner.y)
```

```
(5.0, 6.0)
```

If my `Rectangle` object were immutable, this line would be an error, because I'm making an assignment.

Since objects are mutable, I can change attributes of an object inside a function and those changes remain in the object in the `__main__` namespace.

Returning Objects

```
def double_sides(r):
    rdouble = Rectangle()
    rdouble.corner = r.corner
    rdouble.height = 2*r.height
    rdouble.width = 2*r.width
    return(rdouble)

p1 = Point(); p1.x = 3.0; p1.y = 4.0
r1 = Rectangle()
r1.corner = p1
r1.height = 5.0
r1.width = 12.0

r2 = double_sides(r1)
r2.height, r2.width
```

```
(10.0, 24.0)
```

Functions can return objects. Note that this function is implicitly assuming that `rdouble` has the attributes `corner`, `height` and `width`. We will see how to do this soon.

The function creates a *new* Rectangle and returns it. Note that it doesn't change the attributes of its argument.

Copying and Aliasing

Recall that aliasing is when two or more variables have the same referent

i.e., when two variables are identical

Aliasing can often cause unexpected problems

Solution: make **copy** of object; variables equivalent, but not identical

```
p1 = Point(); p1.x = 3.0; p1.y = 4.0
import copy
p2 = copy.copy(p1)
p1 is p2
```

```
False
```

The `copy` module provides functions for copying objects. P2 is a copy of p1, so they should **not** be identical...

```
p1 == p2
```

```
False
```

...but they **should** be equivalent.

Copying and Aliasing

Documentation for the `copy` module:
https://docs.python.org/3/library/copy.html

Recall that aliasing is when two or more variables have the same referent

i.e., when two variables are identical

Aliasing can often cause unexpected problems

Solution: make **copy** of object; variables equivalent, but not identical

```
p1 = Point(); p1.x = 3.0; p1.y = 4.0
import copy
p2 = copy.copy(p1)
p1 is p2
```

```
False
```

The
cop
they

```
p1 == p2
```

```
False
```

...bu

Hey, those were supposed to be equivalent! What's up with that? **Answer:** by default, for programmer-defined types, `==` and `is` are the same. It's up to you, the programmer, to tell Python how to tell if two objects are equivalent, by defining a method `object.__eq__`. We'll come back to this.

Copying and Aliasing

```
p1 = Point(); p1.x = 3.0; p1.y = 4.0
r1 = Rectangle()
r1.corner = p1
r1.height = 5.0; r1.width = 12.0
r2 = copy.copy(r1)

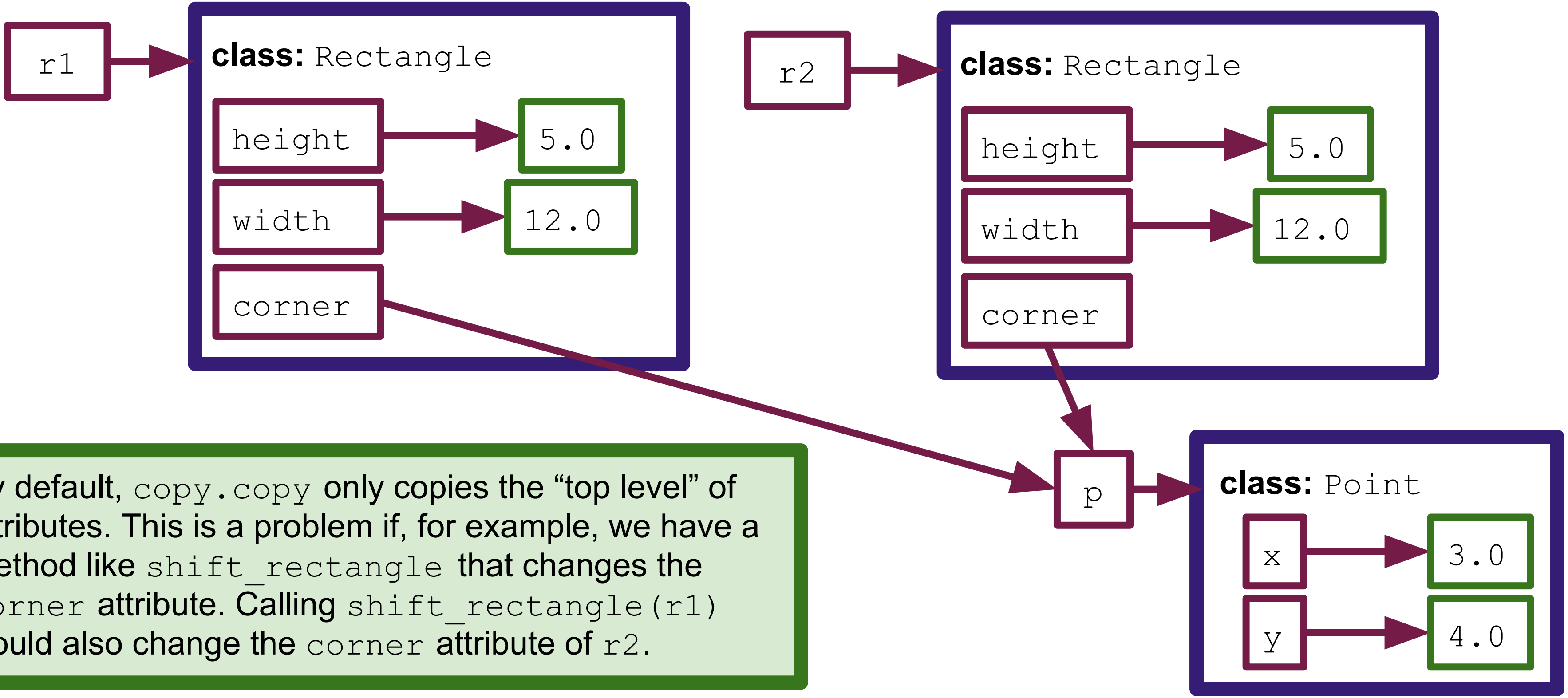
r1.corner is r2.corner
```

```
True
```

Here we construct a Rectangle, and then copy it. Expected behavior is that mutable attributes should **not** be identical, and yet...

...evidently our copied objects still have attributes that are identical.

Copying and Aliasing



By default, `copy.copy` only copies the “top level” of attributes. This is a problem if, for example, we have a method like `shift_rectangle` that changes the `corner` attribute. Calling `shift_rectangle(r1)` would also change the `corner` attribute of `r2`.

Copying and Aliasing

```
p1 = Point(); p1.x = 3.0; p1.y = 4.0
r1 = Rectangle()
r1.corner = p1
r1.height = 5.0; r1.width = 12.0
r2 = copy.deepcopy(r1)

r1.corner is r2.corner
```

```
False
```

`copy.deepcopy` is a recursive version of `copy.copy`. So it recursively makes copies of all attributes, and their attributes and so on.

We often refer to `copy.copy` as a **shallow copy** in contrast to `copy.deepcopy`.

Now when we test for identity we get the expected behavior. Python has created a copy of `r1.corner`.

`copy.deepcopy` documentation explains how the copying operation is carried out: https://docs.python.org/3/library/copy.html#copy.deepcopy

Pure functions vs modifiers

A **pure function** is a function that returns an object

...and **does not** modify any of its arguments

A **modifier** is a function that changes attributes of one or more of its arguments

```
def double_sides(r):
    rdouble = Rectangle()
    rdouble.corner = r.corner
    rdouble.height = 2*r.height
    rdouble.width = 2*r.width
    return(rdouble)

def shift_rectangle(rec, dx, dy):
    rec.corner.x = rec.corner.x + dx
    rec.corner.y = rec.corner.y + dx
```

`double_sides` is a **pure function**. It creates a new object and returns it, without changing the attributes of its argument.

`shift_rectangle` changes the attributes of its argument `rec`, so it is a **modifier**. We say that `rec` has **side effects**, in that it causes changes outside its scope.

https://en.wikipedia.org/wiki/Side_effect_(computer_science)

Pure functions vs modifiers

Why should one prefer one over the other?

Pure functions

- Are often easier to debug and verify (i.e., check correctness)
  - https://en.wikipedia.org/wiki/Formal_verification
- Common in **functional programming**

Modifiers

- Often faster and more efficient
- Common in **object-oriented programming**

Modifiers vs Methods

A modifier is a **function** that changes attributes of its arguments

A **method** is *like* a function, but it is provided by an object.

Define a class representing a 24-hour time.

```
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''

    def print_time(self):
        print("%.2d:%.2d:%.2d" % (self.hours, self.mins, self.secs))

t = Time()
t.hours=12; t.mins=34; t.secs=56
t.print_time()
```

```
12:34:56
```

Class supports a **method** called `print_time`, which prints a string representation of the time.

Every method must include `self` as its first argument. The idea is that the object is, in some sense, the object on which the method is being called.

More on Methods

```python
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''

    def print_time(self):
        print("%.2d:%.2d:%.2d" % (self.hours, self.mins, self.secs))

    def time_to_int(self):
        return(self.secs + 60*self.mins + 3600*self.hours)

def int_to_time(seconds):
    '''Convert a number of seconds to a Time object.'''
    t = Time()
    (minutes, t.secs) = divmod(seconds,60)
    (hrs, t.mins) = divmod(minutes,60)
    t.hours = hrs % 24 #military time!
    return t

t = int_to_time(1337)
t.time_to_int()
```

```
1337
```

`int_to_time` is a pure function that creates and returns a new `Time` object.

`Time.time_to_int` is a method, but it is still a pure function in that it has no side effects.

More on Modifiers

```python
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''

    def increment_pure(self, seconds):
        '''Return new Time object representing this time
        incremented by the given number of seconds.'''
        t = Time()
        t = int_to_time(self.time_to_int() + seconds)
        return t

    def increment_modifier(self, seconds):
        '''Increment this time by the given
        number of seconds.'''
        (mins, self.secs) = divmod(self.secs+seconds, 60)
        (hours, self.mins) = divmod(self.mins+mins, 60)
        self.hours = (self.hours + hours)%24

t1 = int_to_time(1234)
t1.increment_modifier(1111)
t1.time_to_int()
```

```
2345
```

I cropped out `time_to_int` and `print_time` for space.

Two different versions of the same operation. One is a pure function (pure method?), that does not change attributes of the caller. The second method is a modifier.

The modifier method does indeed change the attributes of the caller.

More on Modifiers

```python
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''
    def time_to_int(self):
        return(self.secs + 60*self.mins + 3600*self.hours)
    def print_time(self):
        print("%.2d:%.2d:%.2d" % (self.hours, self.mins, self.secs))

    def increment_pure(self, seconds):
        '''Return new Time object representing this time
        incremented by the given number of seconds.'''
        t = Time()
        t = int_to_time(self.time_to_int() + seconds)
        return t

t1.increment_pure(100, 200)
```

Here's an error you may encounter. How the heck did `increment_pure` get 3 arguments?!

```
---------------------------------------------------------------------------
TypeError                                 Traceback (most recent call last)
<ipython-input-55-1d8fb5e5c628> in <module>()
     14         return t
     15
---> 16 t1.increment_pure(100, 200)

TypeError: increment_pure() takes 2 positional arguments but 3 were given
```

Answer: the caller is considered an argument (because of `self`)!

Readings (this lecture)

Required:

Downey Chapters 15,16

Python documentation on classes (only through section 9.3):

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

Python documentation on copy module

https://docs.python.org/3/library/copy.html

Recommended:

D. Phillips (2015). *Python 3 Object-oriented Programming*, *Second Edition*. Packt Publishing.

M. Weisfeld (2009). *The Object-Oriented Thought Process, Third Edition*. Addison-Wesley.

Readings (next lecture)

Required:

Downey Chapters 17 and 18

Recommended:

Python documentation on operators

https://docs.python.org/3/reference/datamodel.html#specialnames

Coding style guides

https://google.github.io/styleguide/pyguide.html

https://www.python.org/dev/peps/pep-0008/