Warning: the HTML version of this document is generated from Latex and may contain translation errors. In particular, some mathematical expressions are not translated correctly.

Chapter 12

Classes and objects

12.1 User-defined compound types

Having used some of Python's built-in types, we are ready to create a user-defined type: the `Point`.

Consider the concept of a mathematical point. In two dimensions, a point is two numbers (coordinates) that are treated collectively as a single object. In mathematical notation, points are often written in parentheses with a comma separating the coordinates. For example, `(0, 0)` represents the origin, and `(x, y)` represents the point `x` units to the right and `y` units up from the origin.

A natural way to represent a point in Python is with two floating-point values. The question, then, is how to group these two values into a compound object. The quick and dirty solution is to use a list or tuple, and for some applications that might be the best choice.

An alternative is to define a new user-defined compound type, also called a **class**. This approach involves a bit more effort, but it has advantages that will be apparent soon.

A class definition looks like this:

```
class Point:
  pass
```

Class definitions can appear anywhere in a program, but they are usually near the beginning (after the `import` statements). The syntax rules for a class definition are the same as for other compound statements (see Section 4.4).

This definition creates a new class called `Point`. The **pass** statement has no effect; it is only necessary because a compound statement must have something in its body.

By creating the `Point` class, we created a new type, also called `Point`. The members of this type are called **instances** of the type or **objects**. Creating a new instance is called **instantiation**. To instantiate a `Point` object, we call a function named (you guessed it) `Point`:

```
blank = Point()
```

The variable `blank` is assigned a reference to a new `Point` object. A function like `Point` that creates new objects is called a **constructor**.

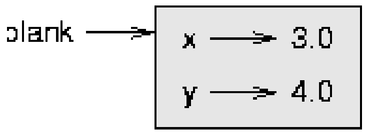
12.2 Attributes

We can add new data to an instance using dot notation:

```
>>> blank.x = 3.0
>>> blank.y = 4.0
```

This syntax is similar to the syntax for selecting a variable from a module, such as `math.pi` or `string.uppercase`. In this case, though, we are selecting a data item from an instance. These named items are called **attributes**.

The following state diagram shows the result of these assignments:



The variable `blank` refers to a Point object, which contains two attributes. Each attribute refers to a floating-point number.

We can read the value of an attribute using the same syntax:

```
>>> print blank.y
4.0
>>> x = blank.x
>>> print x
3.0
```

The expression `blank.x` means, "Go to the object `blank` refers to and get the value of `x`." In this case, we assign that value to a variable named `x`. There is no conflict between the variable `x` and the attribute `x`. The purpose of dot notation is to identify which variable you are referring to unambiguously.

You can use dot notation as part of any expression, so the following statements are legal:

```
print '(' + str(blank.x) + ', ' + str(blank.y) + ')'
distanceSquared = blank.x * blank.x + blank.y * blank.y
```

The first line outputs `(3.0, 4.0)`; the second line calculates the value 25.0.

You might be tempted to print the value of `blank` itself:

```
>>> print blank
<__main__.Point instance at 80f8e70>
```

The result indicates that `blank` is an instance of the `Point` class and it was defined in `__main__`. `80f8e70` is the unique identifier for this object, written in hexadecimal (base 16). This is probably not the most informative way to display a `Point` object. You will see how to change it shortly.

> *As an exercise, create and print a `Point` object, and then use `id`*

to print the object's unique identifier. Translate the hexadecimal form into decimal and confirm that they match.

12.3 Instances as arguments

You can pass an instance as an argument in the usual way. For example:

```
def printPoint(p):
  print '(' + str(p.x) + ', ' + str(p.y) + ')'
```

`printPoint` takes a point as an argument and displays it in the standard format. If you call `printPoint(blank)`, the output is `(3.0, 4.0)`.

As an exercise, rewrite the `distance` function from [Section 5.2](#) so that it takes two `Point`s as arguments instead of four numbers.

12.4 Sameness

The meaning of the word "same" seems perfectly clear until you give it some thought, and then you realize there is more to it than you expected.

For example, if you say, "Chris and I have the same car," you mean that his car and yours are the same make and model, but that they are two different cars. If you say, "Chris and I have the same mother," you mean that his mother and yours are the same person. [* Note](#) So the idea of "sameness" is different depending on the context.

When you talk about objects, there is a similar ambiguity. For example, if two `Point`s are the same, does that mean they contain the same data (coordinates) or that they are actually the same object?

To find out if two references refer to the same object, use the `is` operator. For example:

```
>>> p1 = Point()
>>> p1.x = 3
>>> p1.y = 4
>>> p2 = Point()
>>> p2.x = 3
>>> p2.y = 4
>>> p1 is p2
False
```

Even though `p1` and `p2` contain the same coordinates, they are not the same object. If we assign `p1` to `p2`, then the two variables are aliases of the same object:

```
>>> p2 = p1
>>> p1 is p2
True
```

This type of equality is called **shallow equality** because it compares only the references, not the contents of the objects.

To compare the contents of the objects — **deep equality** — we can write a function called `samePoint`:

```
def samePoint(p1, p2) :
  return (p1.x == p2.x) and (p1.y == p2.y)
```

Now if we create two different objects that contain the same data, we can use `samePoint` to find out if they represent the same point.

```
>>> p1 = Point()
>>> p1.x = 3
>>> p1.y = 4
>>> p2 = Point()
>>> p2.x = 3
>>> p2.y = 4
>>> samePoint(p1, p2)
True
```

Of course, if the two variables refer to the same object, they have both shallow and deep equality.

12.5 Rectangles

Let's say that we want a class to represent a rectangle. The question is, what information do we have to provide in order to specify a rectangle? To keep things simple, assume that the rectangle is oriented either vertically or horizontally, never at an angle.

There are a few possibilities: we could specify the center of the rectangle (two coordinates) and its size (width and height); or we could specify one of the corners and the size; or we could specify two opposing corners. A conventional choice is to specify the upper-left corner of the rectangle and the size.

Again, we'll define a new class:

```
class Rectangle:
  pass
```

And instantiate it:

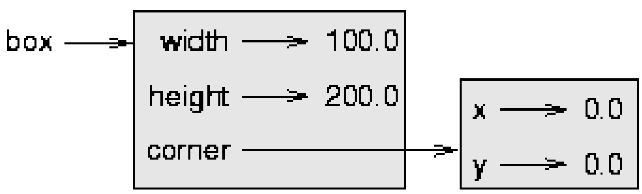
```
box = Rectangle()
box.width = 100.0
box.height = 200.0
```

This code creates a new `Rectangle` object with two floating-point attributes. To specify the upper-left corner, we can embed an object within an object!

```
box.corner = Point()
box.corner.x = 0.0
box.corner.y = 0.0
```

The dot operator composes. The expression `box.corner.x` means, "Go to the object `box` refers to and select the attribute named `corner`; then go to that object and select the attribute named `x`."

The figure shows the state of this object:



12.6 Instances as return values

Functions can return instances. For example, `findCenter` takes a `Rectangle` as an argument and returns a `Point` that contains the coordinates of the center of the `Rectangle`:

```
def findCenter(box):
  p = Point()
  p.x = box.corner.x + box.width/2.0
  p.y = box.corner.y - box.height/2.0
  return p
```

To call this function, pass `box` as an argument and assign the result to a variable:

```
>>> center = findCenter(box)
>>> printPoint(center)
(50.0, -100.0)
```

12.7 Objects are mutable

We can change the state of an object by making an assignment to one of its attributes. For example, to change the size of a rectangle without changing its position, we could modify the values of `width` and `height`:

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

We could encapsulate this code in a method and generalize it to grow the rectangle by any amount:

```
def growRect(box, dwidth, dheight) :
  box.width = box.width + dwidth
  box.height = box.height + dheight
```

The variables `dwidth` and `dheight` indicate how much the rectangle should grow in each direction. Invoking this method has the effect of modifying the `Rectangle` that is passed as an argument.

For example, we could create a new `Rectangle` named `bob` and pass it to `growRect`:

```
>>> bob = Rectangle()
>>> bob.width = 100.0
>>> bob.height = 200.0
>>> bob.corner = Point()
>>> bob.corner.x = 0.0
>>> bob.corner.y = 0.0
>>> growRect(bob, 50, 100)
```

While `growRect` is running, the parameter `box` is an alias for `bob`. Any changes made to `box` also affect `bob`.

> *As an exercise, write a function named `moveRect` that takes a `Rectangle` and two parameters named `dx` and `dy`. It should change the location of the rectangle by adding `dx` to the `x` coordinate of `corner` and adding `dy` to the `y` coordinate of `corner`.*

12.8 Copying

Aliasing can make a program difficult to read because changes made in one place might have unexpected effects in another place. It is hard to keep track of all the variables that might refer to a given object.

Copying an object is often an alternative to aliasing. The `copy` module contains a function called `copy` that can duplicate any object:

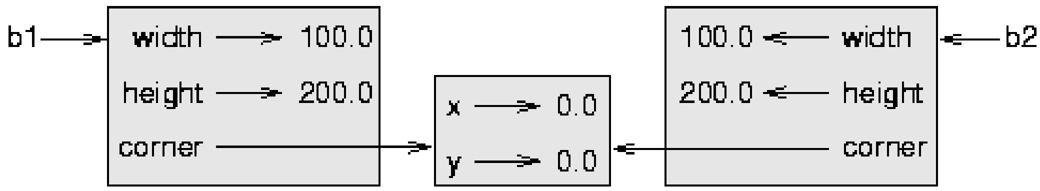
```
>>> import copy
>>> p1 = Point()
>>> p1.x = 3
>>> p1.y = 4
>>> p2 = copy.copy(p1)
>>> p1 == p2
False
>>> samePoint(p1, p2)
True
```

Once we import the `copy` module, we can use the `copy` method to make a new `Point`. `p1` and `p2` are not the same point, but they contain the same data.

To copy a simple object like a `Point`, which doesn't contain any embedded objects, `copy` is sufficient. This is called **shallow copying**.

For something like a `Rectangle`, which contains a reference to a `Point`, `copy` doesn't do quite the right thing. It copies the reference to the `Point` object, so both the old `Rectangle` and the new one refer to a single `Point`.

If we create a box, `b1`, in the usual way and then make a copy, `b2`, using `copy`, the resulting state diagram looks like this:



This is almost certainly not what we want. In this case, invoking `growRect` on one of the `Rectangles` would not affect the other, but invoking `moveRect` on either would affect both! This behavior is confusing and error-prone.

Fortunately, the `copy` module contains a method named `deepcopy` that copies not only the object but also any embedded objects. You will not be surprised to learn that this operation is called a **deep copy**.

```
>>> b2 = copy.deepcopy(b1)
```

Now `b1` and `b2` are completely separate objects.

We can use `deepcopy` to rewrite `growRect` so that instead of modifying an existing `Rectangle`, it creates a new `Rectangle` that has the same location as the old one but new dimensions:

```
def growRect(box, dwidth, dheight) :
  import copy
  newBox = copy.deepcopy(box)
  newBox.width = newBox.width + dwidth
  newBox.height = newBox.height + dheight
  return newBox
```

An an exercise, rewrite `moveRect` so that it creates and returns a new `Rectangle` instead of modifying the old one.

12.9 Glossary

class
: A user-defined compound type. A class can also be thought of as a template for the objects that are instances of it.

instantiate
: To create an instance of a class.

instance
: An object that belongs to a class.

object
: A compound data type that is often used to model a thing or concept in the real world.

constructor
: A method used to create new objects.

attribute
: One of the named data items that makes up an instance.

shallow equality
: Equality of references, or two references that point to the same object.

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; implemented by the `copy` function in the `copy` module.

deep copy
: To copy the contents of an object as well as any embedded objects, and any objects embedded in them, and so on; implemented by the `deepcopy` function in the `copy` module.

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