Classes and object-oriented programming

This lab covers

- [Defining classes]
- [Using instance variables and [@property]]
- [Defining methods]
- [Defining class variables and methods]
- [Inheriting from other classes]
- [Making variables and methods private]
- [Inheriting from multiple classes]

In this lab, I discuss Python classes, which can be used to hold both data and code. Although most programmers are probably familiar with classes or objects in other languages, I make no particular assumptions about knowledge of a specific language or paradigm. In addition, this chapter is a description only of the constructs available in Python; it's not an exposition on object-oriented programming (OOP) itself.

Defining classes

A *class* in Python is effectively a data type. All the data types built into Python are classes, and Python gives you powerful tools to manipulate every aspect of a class's behavior. You define a class with the [class] statement:

```
class MyClass:
    body
```

[body] is a list of Python statements---typically, variable assignments and function definitions. No assignments or function definitions are required. The body can be just a single [pass] statement.

By convention, class identifiers are in CapCase---that is, the first letter of each component word is capitalized, to make the identifiers stand out. After you define the class, you can create a new object of the class type (an instance of the class) by calling the class name as a function:

```
instance = MyClass()
```

Using a class instance as a structure or record

Class instances can be used as structures or records. Unlike C structures or Java classes, the data fields of an instance don't need to be declared ahead of time; they can be created on the fly. The following short example defines a class called [Circle], creates a [Circle] instance, assigns a value to the [radius] field of the circle, and then uses that field to calculate the circumference of the circle:

```
>>> class Circle:
...     pass
...
>>> my_circle = Circle()
>>> my_circle.radius = 5
>>> print(2 * 3.14 * my_circle.radius)
31.4
```

As in Java and many other languages, the fields of an instance/structure are accessed and assigned to by using dot notation.

You can initialize fields of an instance automatically by including an [__init__] initialization method in the class body. This function is run every time an instance of the class is created, with that new instance as its first argument, [self]. The [__init__] method is similar to a constructor in Java, but it doesn't really *construct* anything; it *initializes* fields of the class. Also unlike those in Java and C++, Python classes may only have one [__init__] method. This example creates circles with a radius of [1] by default:

```
class Circle:
    def __init__(self):                        1
        self.radius = 1
my_circle = Circle()                           2
print(2 * 3.14 * my_circle.radius)             3
6.28
my_circle.radius = 5                           4
print(2 * 3.14 * my_circle.radius)             5
31.400000000000002
```

By convention, [self] is always the name of the first argument of [__init__]. [self] is set to the newly created circle instance when [__init__] is run ***1***. Next, the code uses the class definition. You first create a [Circle] instance object ***2***. The next line makes use of the fact that the radius field is already initialized ***3***. You can also overwrite the radius field ***4***; as a result, the last line prints a different result from the previous [print] statement ***5***.

Python also has something more like a constructor: the [__new__] method, which is what is called on object creation and returns an uninitialized object. Unless you're subclassing an immutable type, like [str] or [int], or using a metaclass to modify the object creation process, it's rare to override the existing [__new__] method.

You can do a great deal more by using true OOP, and if you're not familiar with it, I urge you to read up on it. Python's OOP constructs are the subject of the remainder of this lab.

Instance variables

Instance variables are the most basic feature of OOP. Take a look at the [Circle] class again:

```
class Circle:
    def __init__(self):
        self.radius = 1
```

[radius] is an *instance variable* of [Circle] instances. That is, each instance of the [Circle] class has its own copy of [radius], and the value stored in that copy may be different from the values stored in the [radius] variable in other instances. In Python, you can create instance variables as necessary by assigning to a field of a class instance:

```
instance.variable = value
```

If the variable doesn't already exist, it's created automatically, which is how [__init__] creates the [radius] variable.

All uses of instance variables, both assignment and access, require *explicit mention* of the containing instance---that is, [instance.variable]. A reference to [variable] by itself is a reference not to an instance variable, but to a local variable in the executing method. This is different from C++ and Java, where instance variables are referred to in the same manner as local method function variables. I rather like Python's requirement for explicit mention of the containing instance because it clearly distinguishes instance variables from local function variables.

Try this: Instance Variables

What code would you use to create a [Rectangle] class?

Methods

A *method* is a function associated with a particular class. You've already seen the special [__init__] method, which is called on a new instance when that instance is created. In the following example, you define another method, [area], for the [Circle] class; this method can be used to calculate and return the area for any [Circle] instance. Like most user-defined methods, [area] is called with a *method invocation syntax* that resembles instance variable access:

```
>>> class Circle:
...     def __init__(self):
...         self.radius = 1
...     def area(self):
...         return self.radius * self.radius * 3.14159
...
>>> c = Circle()
>>> c.radius = 3
>>> print(c.area())
28.27431
```

Method invocation syntax consists of an instance, followed by a period, followed by the method to be invoked on the instance. When a method is called in this way, it's a *bound* method invocation. However, a method *can* also be invoked as an *unbound* method by accessing it through its containing class. This practice is less convenient and is almost never done, because when a method is invoked in this manner, its first argument must be an instance of the class in which that method is defined and is less clear:

```
>>> print(Circle.area(c))
28.27431
```

Like [__init__], the [area] method is defined as a function within the body of the class definition. The first argument of any method is the instance it was invoked by or on, named [self] by convention. In many languages the instance, often called [this], is implicit and is never explicitly passed, but Python's design philosophy prefers to make things explicit.

Methods can be invoked with arguments if the method definitions accept those arguments. This version of [Circle] adds an argument to the [__init__] method so that you can create circles of a given radius without needing to set the radius after a circle is created:

```
class Circle:
    def __init__(self, radius):
        self.radius = radius
    def area(self):
        return self.radius * self.radius * 3.14159
```

Note the two uses of [radius] here. [self.radius] is the instance variable called [radius]. [radius] by itself is the local function parameter called [radius]. The two aren't the same! In practice, you'd probably call the local function parameter something like [r] or [rad] to avoid any possibility of confusion.

Using this definition of [Circle], you can create circles of any radius with one call on the [Circle] class. The following creates a [Circle] of radius 5:

```
c = Circle(5)
```

All the standard Python function features---default argument values, extra arguments, keyword arguments, and so forth---can be used with methods. You could have defined the first line of [__init__] to be

```
def __init__(self, radius=1):
```

Then calls to [circle] would work with or without an extra argument; [Circle()] would return a circle of radius 1, and [Circle(3)] would return a circle of radius 3.

There's nothing magical about method invocation in Python, which can be considered to be shorthand for normal function invocation. Given a method invocation [instance.method(arg1, arg2, . . .)], Python transforms it into a normal function call by using the following rules:

1. [Look for the method name in the instance namespace. If a method has been changed or added for this instance, it's invoked in preference over methods in the class or superclass. This lookup is the same sort of lookup discussed in [section 15.4.1] later in this lab.]
2. [If the method isn't found in the instance namespace, look up the class type [class] of [instance], and look for the method there. In the previous examples, [class] is [Circle]---the type of the instance [c].]
3. [If the method still isn't found, look for the method in the superclasses.]
4. [When the method has been found, make a direct call to it as a normal Python function, using the [instance] as the first argument of the function and shifting all the other arguments in the method invocation one space over to the right. So [instance.method(arg1, arg2, . . .)] becomes [class.method (instance, arg1, arg2, . . .)].]

Try this: Instance variables and Methods

Update the code for a [Rectangle] class so that you can set the dimensions when an instance is created, just as for the [Circle] class above. Also, add an [area()] method.

Class variables

A class variable is created by an assignment in the *class* body, not in the [__init__] function. After it has been created, it can be seen by all instances of the class. You can use a class variable to make a value for [pi] accessible to all instances of the [Circle] class:

```
class Circle:
    pi = 3.14159
    def __init__(self, radius):
        self.radius = radius
    def area(self):
        return self.radius * self.radius * Circle.pi
```

With the definition entered, you can type

```
>>> Circle.pi
3.14159
>>> Circle.pi = 4
>>> Circle.pi
4
>>> Circle.pi = 3.14159
>>> Circle.pi
3.14159
```

This example is exactly how you'd expect a class variable to act; it's associated with and contained in the class that defines it. Notice in this example that you're accessing [Circle.pi] before any circle instances have been created. Obviously, [Circle.pi] exists independently of any specific instances of the [Circle] class.

You can also access a class variable from a method of a class, through the class name. You do so in the definition of [Circle.area], where the [area] function makes specific reference to [Circle.pi]. In operation, this has the desired effect; the correct value for [pi] is obtained from the class and used in the calculation:

```
>>> c = Circle(3)
>>> c.area()
28.27431
```

You may object to hardcoding the name of a class inside that class's methods. You can avoid doing so through use of the special [__class__] attribute, available to all Python class instances. This attribute returns the class of which the instance is a member, for example:

```
>>> Circle
<class '__main__.Circle'>
>>> c.__class__
<class '__main__.Circle'>
```

The class named [Circle] is represented internally by an abstract data structure, and that data structure is exactly what is obtained from the [__class__] attribute of [c], an instance of the [Circle] class. This example lets you obtain the value of [Circle.pi] from [c] without ever explicitly referring to the [Circle] class name:

```
>>> c.__class__.pi
3.14159
```

You could use this code internally in the [area] method to get rid of the explicit reference to the [Circle] class; replace [Circle.pi] with [self.__class__.pi].

An oddity with class variables

There's a bit of an oddity with class variables that can trip you up if you aren't aware of it. When Python is looking up an instance variable, if it can't find an instance variable of that name, it tries to find and return the value in a class variable of the same name. Only if it can't find an appropriate class variable will Python signal an error. Class variables make it efficient to implement default values for instance variables; just create a class variable with the same name and appropriate default value, and avoid the time and memory overhead of initializing that instance variable every time a class instance is created. But this also makes it easy to inadvertently refer to an instance variable rather than a class variable without signaling an error. In this section, I look at how class variables operate in conjunction with the previous example.

First, you can refer to the variable [c.pi], even though [c] doesn't have an associated instance variable named [pi]. Python first tries to look for such an instance variable; when it can't find an instance variable, Python looks for and finds a class variable [pi] in [Circle]:

```
>>> c = Circle(3)
>>> c.pi
3.14159
```

This result may or may not be what you want. This technique is convenient but can be prone to error, so be careful.

Now, what happens if you attempt to use [c.pi] as a true class variable by changing it from one instance with the intention that all instances should see the change? Again, you use the earlier definition for [Circle]:

```
>>> c1 = Circle(1)
>>> c2 = Circle(2)
>>> c1.pi = 3.14
>>> c1.pi
3.14
>>> c2.pi
3.14159
>>> Circle.pi
3.14159
```

This example doesn't work as it would for a true class variable; [c1] now has its own copy of [pi], distinct from the [Circle.pi] accessed by [c2]. This happens because the assignment to [c1.pi] *creates* an instance variable in [c1]; it doesn't affect the class variable [Circle.pi] in any way. Subsequent lookups of [c1.pi] return the value in that instance variable, whereas subsequent lookups of [c2.pi] look for an instance variable [pi] in [c2], fail to find it, and resort to returning the value of the class variable [Circle.pi]. If you want to change the value of a class variable, access it through the class name, not through the instance variable [self].

Static methods and class methods

Python classes can also have methods that correspond explicitly to static methods in a language such as Java. In addition, Python has *class* methods, which are a bit more advanced.

Static methods

Just as in Java, you can invoke static methods even though no instance of that class has been created, although you *can* call them by using a class instance. To create a static method, use the [@staticmethod] decorator, as shown here.

Listing 15.1. File circle.py

```
"""circle module: contains the Circle class."""
class Circle:
    """Circle class"""
    all_circles = []
    pi = 3.14159
    def __init__(self, r=1):
        """Create a Circle with the given radius"""
        self.radius = r
        self.__class__.all_circles.append(self)
    def area(self):
        """determine the area of the Circle"""
        return self.__class__.pi * self.radius * self.radius

    @staticmethod
    def total_area():
        """Static method to total the areas of all Circles """
        total = 0
        for c in Circle.all_circles:
            total = total + c.area()
        return total
```

Now interactively type the following:

```
>>> import circle
>>> c1 = circle.Circle(1)
>>> c2 = circle.Circle(2)
>>> circle.Circle.total_area()
15.70795
>>> c2.radius = 3
>>> circle.Circle.total_area()
31.415899999999997
```

Also notice that documentation strings are used. In a real module, you'd probably put in more informative strings, indicating in the class docstring what methods are available and including usage information in the method docstrings:

```
>>> circle.__doc__
'circle module: contains the Circle class.'
>>> circle.Circle.__doc__
'Circle class'
>>> circle.Circle.area.__doc__
'determine the area of the Circle'
```

Class methods

Class methods are similar to static methods in that they can be invoked before an object of the class has been instantiated or by using an instance of the class. But class methods are implicitly passed the class they belong to as their first parameter, so you can code them more simply, as here.

Listing 15.2. File circle_cm.py

```
"""circle_cm module: contains the Circle class."""
class Circle:
    """Circle class"""
    all_circles = []
    pi = 3.14159
    def __init__(self, r=1):
        """Create a Circle with the given radius"""
        self.radius = r
        self.__class__.all_circles.append(self)
    def area(self):
        """determine the area of the Circle"""
        return self.__class__.pi * self.radius * self.radius

    @classmethod
    def total_area(cls):
        total = 0
        for c in cls.all_circles:
            total = total + c.area()
        return total
>>> import circle_cm
>>> c1 = circle_cm.Circle(1)
>>> c2 = circle_cm.Circle(2)
>>> circle_cm.Circle.total_area()
15.70795
>>> c2.radius = 3
>>> circle_cm.Circle.total_area()
31.415899999999997
```

The [@classmethod] decorator is used before the method [def] ***2***. The class parameter is traditionally [cls] ***3***. You can use [cls] instead of [self.__class__] ***4***.

By using a class method instead of a static method, you don't have to hardcode the class name into [total_area]. As a result, any subclasses of [Circle] can still call [total_area] and refer to their own members, not those in [Circle].

Try this: Class methods

Write a class method similar to [total_area()] that returns the total circumference of all circles.

Inheritance

Inheritance in Python is easier and more flexible than inheritance in compiled languages such as Java and C++ because the dynamic nature of Python doesn't force as many restrictions on the language.

To see how inheritance is used in Python, start with the [Circle] class discussed earlier in this lab, and generalize. You might want to define an additional class for squares:

```
class Square:
    def __init__(self, side=1):
        self.side = side
```

Now, if you want to use these classes in a drawing program, they must define some sense of where on the drawing surface each instance is. You can do so by defining an [x] coordinate and a [y] coordinate in each instance:

```
class Square:
    def __init__(self, side=1, x=0, y=0):
        self.side = side
        self.x = x
        self.y = y
class Circle:
    def __init__(self, radius=1, x=0, y=0):
        self.radius = radius
        self.x = x
        self.y = y
```

This approach works but results in a good deal of repetitive code as you expand the number of shape classes, because you presumably want each shape to have this concept of position. No doubt you know where I'm going here; this situation is a standard one for using inheritance in an object-oriented language. Instead of defining the [x] and [y] variables in each shape class, you can abstract them out into a general [Shape] class and have each class defining a specific shape inherit from that general class. In Python, that technique looks like this:

```
class Shape:
    def __init__(self, x, y):
        self.x = x
        self.y = y
class Square(Shape):
    def __init__(self, side=1, x=0, y=0):
        super().__init__(x, y)
        self.side = side
class Circle(Shape):
    def __init__(self, r=1, x=0, y=0):
        super().__init__(x, y)
        self.radius = r
```

There are (generally) two requirements in using an inherited class in Python, both of which you can see in the bolded code in the [Circle] and [Square] classes. The first requirement is defining the inheritance hierarchy, which you do by giving the classes inherited from, in parentheses, immediately after the name of the class being defined with the [class] keyword. In the previous code, [Circle] and [Square] both inherit from [Shape]. The second and more subtle element is the necessity to explicitly call the [__init__] method of inherited classes. Python doesn't automatically do this for you, but you can use the [super] function to have Python figure out which inherited class to use. This task is accomplished in the example code by the [super().__init__(x,y)] lines. This code calls the [Shape] initialization function with the instance being initialized and the appropriate arguments. Otherwise, in the example, instances of [Circle] and [Square] wouldn't have their [x] and [y] instance variables set.

Instead of using [super], you could call [Shape]'s [__init__] by explicitly naming the inherited class using [Shape.__init__(self, x, y)], which would also call the [Shape] initialization function with the instance being initialized. This technique wouldn't be as flexible in the long run because it hardcodes the inherited class's name, which could be a problem later if the design and the inheritance hierarchy change. On the other hand, the use of [super] can be tricky in more complex cases. Because the two methods don't exactly mix well, clearly document whichever approach you use in your code.

Inheritance also comes into effect when you attempt to use a method that isn't defined in the base classes but is defined in the superclass. To see this effect, define another method in the [Shape] class called [move], which moves a shape by a given displacement. This method modifies the [x] and [y] coordinates of the shape by an amount determined by arguments to the method. The definition for [Shape] now becomes

```
class Shape:
    def __init__(self, x, y):
        self.x = x
        self.y = y
    def move(self, delta_x, delta_y):
        self.x = self.x + delta_x
        self.y = self.y + delta_y
```

If you enter this definition for [Shape] and the previous definitions for [Circle] and [Square], you can engage in the following interactive session:

```
>>> c = Circle(1)
>>> c.move(3, 4)
>>> c.x
3
>>> c.y
4
```

If you try this code in an interactive session, be sure to reenter the [Circle] class after the redefinition of the [Shape] class.

The [Circle] class in the example didn't define a [move] method immediately within itself, but because it inherits from a class that implements [move], all instances of [Circle] can make use of [move]. In more traditional OOP terms, you could say that all Python methods are virtual---that is, if a method doesn't exist in the current class, the list of superclasses is searched for the method, and the first one found is used.

Try this: Inheritance

Rewrite the code for a [Rectangle] class to inherit from [Shape]. Because squares and rectangles are related, would it make sense to inherit one from the other? If so, which would be the base class, and which would inherit?

How would you write the code to add an [area()] method for the [Square] class? Should the [area] method be moved into the base [Shape] class and inherited by circle, square, and rectangle? If so, what issues would result?

Inheritance with class and instance variables

Inheritance allows an instance to inherit attributes of the class. Instance variables are associated with object instances, and only one instance variable of a given name exists for a given instance.

Consider the following example. Using these class definitions,

```
class P:
    z = "Hello"
    def set_p(self):
```

```
        self.x = "Class P"
    def print_p(self):
         print(self.x)
class C(P):
    def set_c(self):
        self.x = "Class C"
    def print_c(self):
        print(self.x)
```

execute the following code:

```
>>> c = C()
>>> c.set_p()
>>> c.print_p()
Class P
>>> c.print_c()
Class P
>>> c.set_c()
>>> c.print_c()
Class C
>>> c.print_p()
Class C
```

The object [c] in this example is an instance of class [C]. [C] inherits from [P] but [c] doesn't inherit from some invisible instance of class [P]. It inherits methods and class variables directly from [P]. Because there is only one instance ([c]), any reference to the instance variable [x] in a method invocation on [c] must refer to [c.x]. This is true regardless of which class defines the method being invoked on [c]. As you can see, when they're invoked on [c], both [set_p] and [print_p], defined in class [P], and refer to the same variable, which is referred to by [set_c] and [print_c] when they're invoked on [c].

In general, this behavior is what is desired for instance variables, because it makes sense that references to instance variables of the same name should refer to the same variable. Occasionally, somewhat different behavior is desired, which you can achieve by using private variables (see [section 15.9]).

Class variables are inherited, but you should take care to avoid name clashes and be aware of a generalization of the behavior you saw in the subsection on class variables. In the example, a class variable [z] is defined for the superclass [P] and can be accessed in three ways: through the instance [c], through the derived class [C], or directly through the superclass [P]:

```
>>> c.z; C.z; P.z
'Hello'
'Hello'
'Hello'
```

But if you try setting the class variable [z] through the class [C], a new class variable is created for the class [C]. This result has no effect on [P]'s class variable itself (as accessed through [P]). But future accesses through the class [C] or its instance [c] will see this new variable rather than the original:

```
>>> C.z = "Bonjour"
>>> c.z; C.z; P.z
'Bonjour'
'Bonjour'
'Hello'
```

Similarly, if you try setting [z] through the instance [c], a new instance variable is created, and you end up with three different variables:

```
>>> c.z = "Ciao"
>>> c.z; C.z; P.z
'Ciao'
'Bonjour'
'Hello'
```

Recap: Basics of Python classes

The points I've discussed so far are the basics of using classes and objects in Python. Before I go any farther, I'll bring the basics together in a single example. In this section, you create a couple of classes with the features discussed earlier, and then you see how those features behave.

First, create a base class:

```
class Shape:
    def __init__(self, x, y):
        self.x = x
        self.y = y
    def move(self, delta_x, delta_y):
        self.x = self.x + delta_x
        self.y = self.y + delta_y
```

Next, create a subclass that inherits from the base class [Shape]:

```
class Circle(Shape):
    pi = 3.14159
    all_circles = []
    def __init__(self, r=1, x=0, y=0):
        super().__init__(x, y)
        self.radius = r
        all_circles.append(self)
    @classmethod
    def total_area(cls):
        area = 0
        for circle in cls.all_circles:
                 area += cls.circle_area(circle.radius)
        return area
    @staticmethod
    def circle_area(radius):
        return Circle.pi * radius * radius
```

Now you can create some instances of the [Circle] class and put them through their paces. Because [Circle]'s [__init__] method has default parameters, you can create a [Circle] without giving any parameters:

```
>>> c1 = Circle()
>>> c1.radius, c1.x, c1.y
(1, 0, 0)
```

If you do give parameters, they are used to set the instance's values:

```
>>> c2 = Circle(2, 1, 1)
>>> c2.radius, c2.x, c2.y
(2, 1, 1)
```

If you call the [move()] method, Python doesn't find a [move()] in the [Circle] class, so it moves up the inheritance hierarchy and uses [Shape]'s [move()] method:

```
>>> c2.move(2, 2)
>>> c2.radius, c2.x, c2.y
(2, 3, 3)
```

Also, because part of what the [__init__] method does is add each instance to a list that is a class variable, you get the [Circle] instances:

```
>>> Circle.all_circles
[<__main__.Circle object at 0x7fa88835e9e8>, <__main__.Circle object at
     0x7fa88835eb00>]
>>> [c1, c2]
[<__main__.Circle object at 0x7fa88835e9e8>, <__main__.Circle object at
     0x7fa88835eb00>]
```

You can also call the [Circle] class's [total_area()] class method, either through the class itself or through an instance:

```
>>> Circle.total_area()
15.70795
>>> c2.total_area()
15.70795
```

Finally, you can call the static method [circle_area()], again either via the class itself or an instance. As a static method, [circle_area] doesn't get passed the instance or the class, and it behaves more like an independent function that's inside the class's namespace. In fact, quite often, static methods are used to bundle utility functions with a class:

```
>>> Circle.circle_area(c1.radius)
3.14159
>>> c1.circle_area(c1.radius)
3.14159
```

These examples show the basic behavior of classes in Python. Now that you've got the basics of classes down, you can move on to more advanced topics.

Private variables and private methods

A *private variable* or *private method* is one that can't be seen outside the methods of the class in which it's defined. Private variables and methods are useful for two reasons: They enhance security and reliability by selectively denying access to important or delicate parts of an object's implementation, and they prevent name clashes that can arise from the use of inheritance. A class may define a private variable and inherit from a class that defines a private variable of the same name, but this doesn't cause a problem, because the fact that the variables are private ensures that separate copies of them are kept. Private variables make it easier to read code, because they explicitly indicate what's used only internally in a class. Anything else is the class's interface.

Most languages that define private variables do so through the use of the keyword "private" or something similar. The convention in Python is simpler, and it also makes it easier to immediately see what is private and what isn't. Any method or instance variable whose name begins---but doesn't end---with a *double underscore* ([__]) is private; anything else isn't private.

As an example, consider the following class definition:

```
class Mine:
    def __init__(self):
        self.x = 2
        self.__y = 3
    def print_y(self):
        print(self.__y)
```

Using this definition, create an instance of the class:

```
>>> m = Mine()
```

[x] isn't a private variable, so it's directly accessible:

```
>>> print(m.x)
2
```

[__y] is a private variable. Trying to access it directly raises an error:

```
>>> print(m.__y)
Traceback (innermost last):
  File "<stdin>", line 1, in ?
AttributeError: 'Mine' object has no attribute '__y'
```

The [print_y] method isn't private, and because it's in the [Mine] class, it can access [__y] and print it:

```
>>> m.print_y()
3
```

Finally, you should note that the mechanism used to provide privacy *mangles* the name of private variables and private methods when the code is compiled to bytecode. What specifically happens is that [_classname] is prepended to the variable name:

```
>>> dir(m)
['_Mine__y', 'x', ...]
```

The purpose is to prevent any accidental accesses. If someone wanted to, he could deliberately simulate the mangling and access the value. But performing the mangling in this easily readable form makes debugging easy.

Try this: Private instance variables

Modify the [Rectangle] class's code to make the dimension variables private. What restriction will this modification impose on using the class?

Using @property for more flexible instance variables

Python allows you as the programmer to access instance variables directly, without the extra machinery of the getter and setter methods often used in Java and other object-oriented languages. This lack of getters and setters makes writing Python classes cleaner and easier, but in some situations, using getter and setter methods can be handy. Suppose that you want a value before you put it into an instance variable or where it would be handy to figure out an attribute's value on the fly. In both cases, getter and setter methods would do the job, but at the cost of losing Python's easy instance-variable access.

The answer is to use a property. A *property* combines the ability to pass access to an instance variable through methods like getters and setters and the straightforward access to instance variables through dot notation.

To create a property, you use the property decorator with a method that has the property's name:

```
class Temperature:
    def __init__(self):
        self._temp_fahr = 0
    @property
    def temp(self):
        return (self._temp_fahr - 32) * 5 / 9
```

Without a setter, such a property is read-only. To change the property, you need to add a setter:

```
    @temp.setter
    def temp(self, new_temp):
        self._temp_fahr = new_temp * 9 / 5 + 32
```

Now you can use standard dot notation to both get and set the property [temp]. Notice that the name of the method remains the same, but the decorator changes to the property name ([temp], in this case), plus [.setter] indicates that a setter for the [temp] property is being defined:

```
>>> t = Temperature()
>>> t._temp_fahr
0
>>> t.temp
-17.77777777777778

>>> t.temp = 34        1
>>> t._temp_fahr
93.2

>>> t.temp             2
34.0
```

The [0] in [_temp_fahr] is converted to centigrade before it's returned ***1***. The [34] is converted back to Fahrenheit by the setter ***2***.

One big advantage of Python's ability to add properties is that you can do initial development with plain-old instance variables and then seamlessly change to properties whenever and wherever you need to without changing any client code. The access is still the same, using dot notation.

Try this: Properties

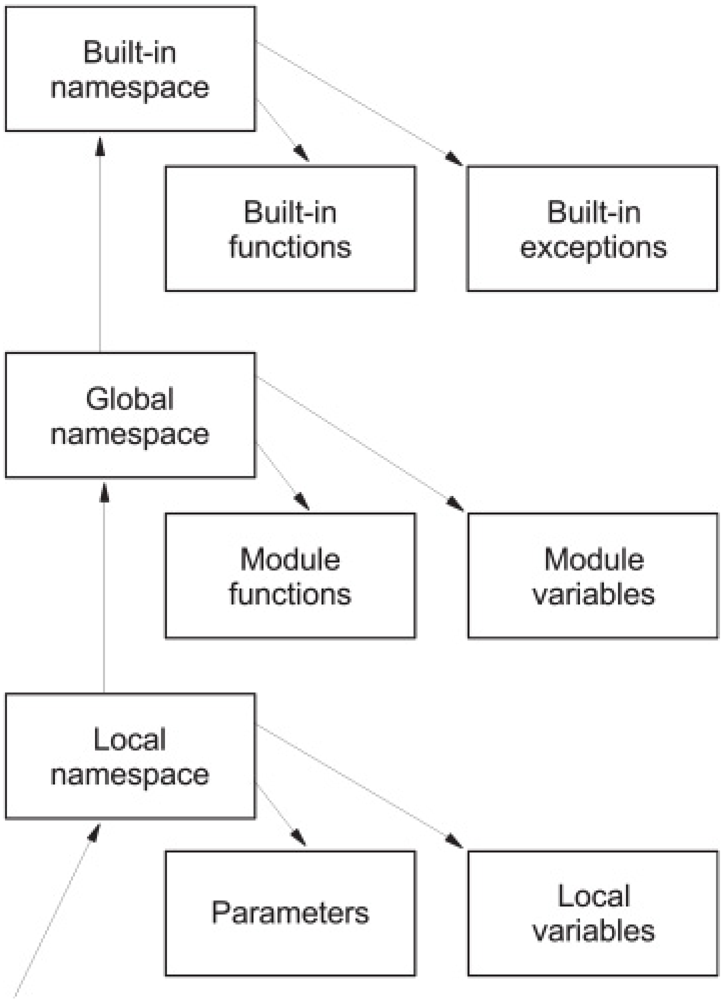
Update the dimensions of the [Rectangle] class to be properties with getters and setters that don't allow negative sizes.

Scoping rules and namespaces for class instances

Now you have all the pieces to put together a picture of the scoping rules and namespaces for a class instance.

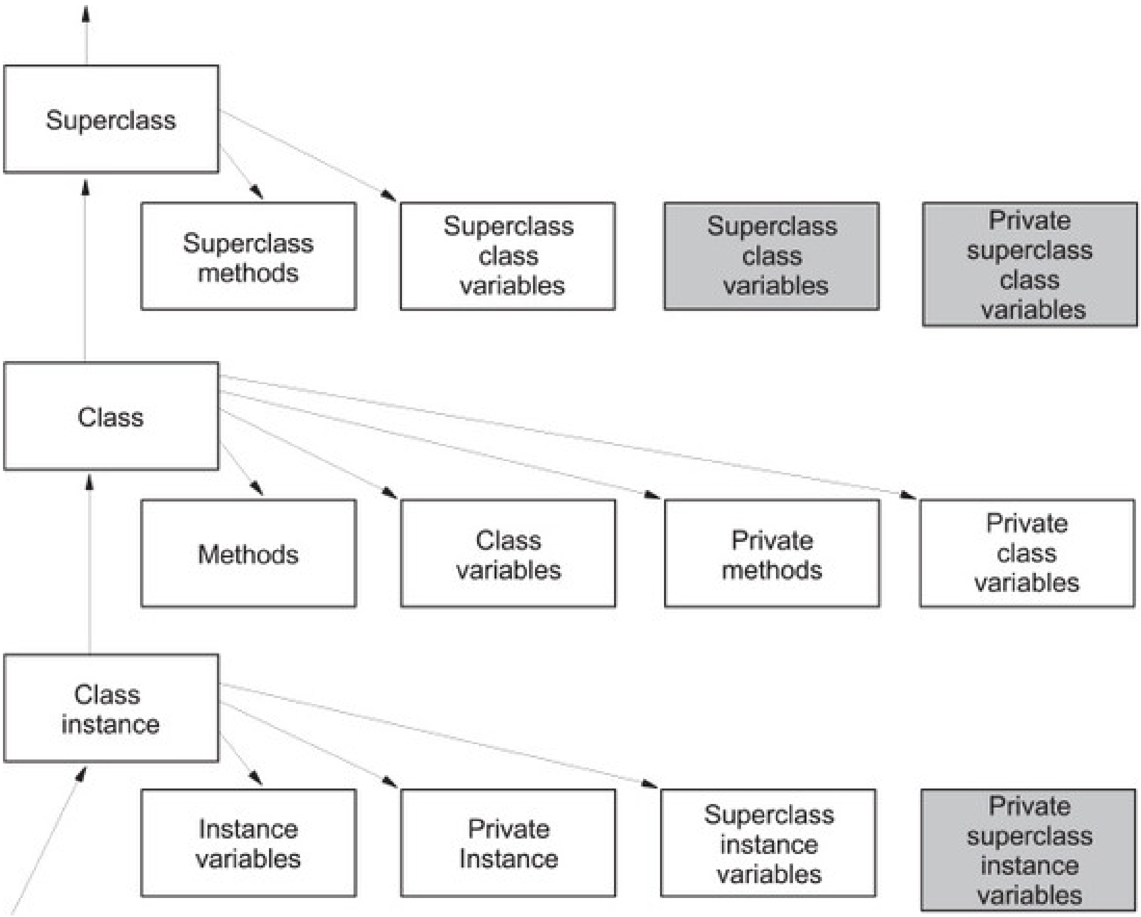
When you're in a method of a class, you have direct access to the *local namespace* (parameters and variables declared in the method), the *global namespace* (functions and variables declared at the module level), and the *built-in namespace* (built-in functions and built-in exceptions). These three namespaces are searched in the following order: local, global, and built-in (see [figure 15.1]).

Figure 15.1. Direct namespaces



You also have access through the [self] variable to the *instance's namespace* (instance variables, private instance variables, and superclass instance variables), its *class's namespace* (methods, class variables, private methods, and private class variables), and its *superclass's namespace* (superclass methods and superclass class variables). These three namespaces are searched in the order instance, class, and then superclass (see [figure 15.2]).

Figure 15.2. [self] variable namespaces



Private superclass instance variables, private superclass methods, and private superclass class variables can't be accessed by using [self]. A class is able to hide these names from its children.

The module in [listing 15.3] puts these two examples together to concretely demonstrate what can be accessed from within a method.

Listing 15.3. File cs.py

```
"""cs module: class scope demonstration module."""
mv ="module variable: mv"
def mf():
    return "module function (can be used like a class method in " \
           "other languages): mf()"
class SC:
    scv = "superclass class variable: self.scv"
    __pscv = "private superclass class variable: no access"
    def __init__(self):
        self.siv = "superclass instance variable: self.siv " \
                   "(but use SC.siv for assignment)"
        self.__psiv = "private superclass instance variable: " \
                       "no access"
    def sm(self):
        return "superclass method: self.sm()"
    def __spm(self):
```

```
        return "superclass private method: no access"
class C(SC):
    cv = "class variable: self.cv (but use C.cv for assignment)"
    __pcv = "class private variable: self.__pcv (but use C.__pcv " \
            "for assignment)"
    def __init__(self):
        SC.__init__(self)
        self.__piv = "private instance variable: self.__piv"
    def m2(self):
        return "method: self.m2()"
    def __pm(self):
        return "private method: self.__pm()"
    def m(self, p="parameter: p"):
        lv = "local variable: lv"
        self.iv = "instance variable: self.xi"
        print("Access local, global and built-in " \
              "namespaces directly")
        print("local namespace:", list(locals().keys()))
        print(p)

        print(lv)
        print("global namespace:", list(globals().keys()))

        print(mv)

        print(mf())
        print("Access instance, class, and superclass namespaces " \


              "through 'self'")
        print("Instance namespace:",dir(self))

        print(self.iv)

        print(self.__piv)

        print(self.siv)
        print("Class namespace:",dir(C))
        print(self.cv)

        print(self.m2())

        print(self.__pcv)

        print(self.__pm())
        print("Superclass namespace:",dir(SC))
        print(self.sm())

        print(self.scv)
```

This output is considerable, so we'll look at it in pieces.

In the first part, class [C']s method [m]'s local namespace contains the parameters [self] (which is the instance variable) and [p] along with the local variable [lv] (all of which can be accessed directly):

```
>>> import cs
>>> c = cs.C()
>>> c.m()
Access local, global and built-in namespaces directly
local namespace: ['lv', 'p', 'self']
parameter: p
local variable: lv
```

Next, method [m]'s global namespace contains the module variable [mv] and the module function [mf] (which, as described in a previous section, you can use to provide a class method functionality). There are also the classes defined in the module (the class [C] and the superclass [SC]). All these classes can be directly accessed:

```
global namespace: ['C', 'mf', '__builtins__', '__file__', '__package__',
     'mv', 'SC', '__name__', '__doc__']
module variable: mv
module function (can be used like a class method in other languages): mf()
```

Instance [C]'s namespace contains instance variable [iv] and the superclass's instance variable [siv] (which, as described in a previous section, is no different from the regular instance variable). It also has the mangled name of private instance variable [__piv] (which you can access through [self]) and the mangled name of the superclass's private instance variable [__psiv] (which you can't access):

```
Access instance, class, and superclass namespaces through 'self'
Instance namespace: ['_C__pcv', '_C__piv', '_C__pm', '_SC__pscv',
     '_SC__psiv', '_SC__spm', '__class__', '__delattr__', '__dict__',
     '__doc__', '__eq__', '__format__', '__ge__', '__getattribute__',
     '__gt__', '__hash__', '__init__', '__le__', '__lt__', '__module__',
     '__ne__', '__new__', '__reduce__', '__reduce_ex__', '__repr__',
     '__setattr__', '__sizeof__', '__str__', '__subclasshook__',
     '__weakref__', 'cv', 'iv', 'm', 'm2', 'scv', 'siv', 'sm']
instance variable: self.xi
private instance variable: self.__piv
superclass instance variable: self.siv (but use SC.siv for assignment)
```

Class [C]'s namespace contains the class variable [cv] and the mangled name of the private class variable [__pcv]. Both can be accessed through [self], but to assign to them, you need to use class [C]. Class [C] also has the class's two methods [m] and [m2], along with the mangled name of the private method [__pm] (which can be accessed through [self]):

```
Class namespace: ['_C__pcv', '_C__pm', '_SC__pscv', '_SC__spm', '__class__',
     '__delattr__', '__dict__', '__doc__', '__eq__', '__format__', '__ge__',
     '__getattribute__', '__gt__', '__hash__', '__init__', '__le__',
     '__lt__', '__module__', '__ne__', '__new__', '__reduce__',
     '__reduce_ex__', '__repr__', '__setattr__', '__sizeof__', '__str__',
     '__subclasshook__', '__weakref__', 'cv', 'm', 'm2', 'scv', 'sm']
class variable: self.cv (but use C.cv for assignment)
method: self.m2()
class private variable: self.__pcv (but use C.__pcv for assignment)
private method: self.__pm()
```

Finally, superclass [SC]'s namespace contains superclass class variable [scv] (which can be accessed through [self], but to assign to it, you need to use the superclass [SC]) and superclass method [sm]. It also contains the mangled names of private superclass method [__spm] and private superclass class variable [__pscv], neither of which can be accessed through [self]:

```
Superclass namespace: ['_SC__pscv', '_SC__spm', '__class__', '__delattr__',
     '__dict__', '__doc__', '__eq__', '__format__', '__ge__',
     '__getattribute__', '__gt__', '__hash__', '__init__', '__le__',
     '__lt__', '__module__', '__ne__', '__new__', '__reduce__',
     '__reduce_ex__', '__repr__', '__setattr__', '__sizeof__', '__str__',
     '__subclasshook__', '__weakref__', 'scv', 'sm']
superclass method: self.sm()
superclass class variable: self.scv
```

This example is a rather full one to decipher at first. You can use it as a reference or a base for your own exploration. As with most other concepts in Python, you can build a solid understanding of what's going on by playing around with a few simplified examples.

Destructors and memory management

You've already seen class initializers (the [__init__] methods). A destructor can be defined for a class as well. But unlike in C++, creating and calling a destructor isn't necessary to ensure that the memory used by your instance is freed. Python provides automatic memory management through a reference-counting mechanism. That is, it keeps track of the number of references to your instance; when this number reaches zero, the memory used by your instance is reclaimed, and any Python objects referenced by your instance have their reference counts decremented by one. *You almost never need to define a destructor*.

You may occasionally encounter a situation in which you need to deallocate an external resource explicitly when an object is removed. In such a situation, the best practice is to use a context manager, as discussed in [chapter 14]. As mentioned there, you can use the [contextlib] module from the standard library to create a custom context manager for your situation.

Multiple inheritance

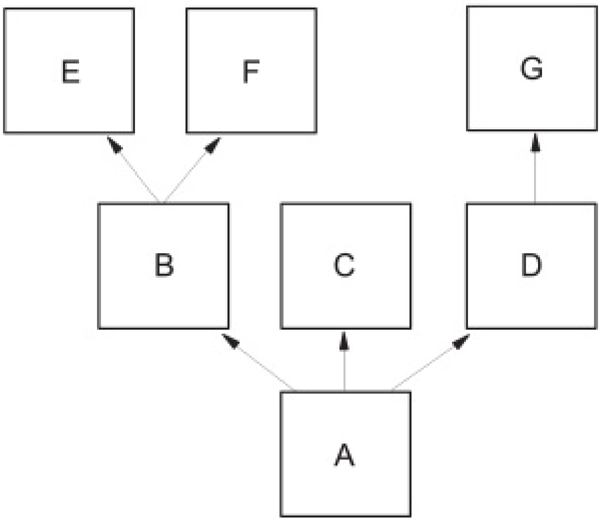
Compiled languages place severe restrictions on the use of *multiple inheritance*---the ability of objects to inherit data and behavior from more than one parent class. The rules for using multiple inheritance in C++, for example, are so complex that many people avoid using it. In Java, multiple inheritance is disallowed, although Java does have the interface mechanism.

Python places no such restrictions on multiple inheritance. A class can inherit from any number of parent classes in the same way that it can inherit from a single parent class. In the simplest case, none of the involved classes, including those inherited indirectly through a parent class, contains instance variables or methods of the same name. In such a case, the inheriting class behaves like a synthesis of its own definitions and all of its ancestors' definitions. Suppose that class [A] inherits from classes [B], [C], and [D]; class [B] inherits from classes [E] and [F]; and class [D] inherits from class [G] (see [figure 15.3]). Also suppose that none of these classes shares method names. In this case, an instance of class [A] can be used as though it were an instance of any of the classes [B]--[G], as well as [A]; an instance of class [B] can be used as though it were an instance of class [E] or [F] as well as class [B]; and an instance of class [D] can be used as though it were an instance of class [G] as well as class [D]. In terms of code, the class definitions look like this:

```
class E:
        . . .
class F:
        . . .
```

```
class G:
        . . .
class D(G):
        . . .
class C:
        . . .
class B(E, F):
        . . .
class A(B, C, D):
        . . .
```

Figure 15.3. Inheritance hierarchy



The situation is more complex when some of the classes share method names, because Python must decide which of the identical names is the correct one. Suppose that you want to resolve a method invocation [a.f()] on an instance [a] of class [A], where [f] isn't defined in [A] but is defined in all of [F], [C], and [G]. Which of the various methods will be invoked?

The answer lies in the order in which Python searches base classes when looking for a method not defined in the original class on which the method was invoked. In the simplest cases, Python looks through the base classes of the original class in left-to-right order, but it always looks through all of the ancestor classes of a base class before looking in the next base class. In attempting to execute [a.f()], the search goes something like this:

1. [Python first looks in the class of the invoking object, class [A].]
2. [Because [A] doesn't define a method [f], Python starts looking in the base classes of [A]. The first base class of [A] is [B], so Python starts looking in [B].]
3. [Because [B] doesn't define a method [f], Python continues its search of [B] by looking in the base classes of [B]. It starts by looking in the first base class of [B], class [E].]
4. [[E] doesn't define a method [f] and also has no base classes, so there's no more searching to be done in [E]. Python goes back to class [B] and looks in the next base class of [B], class [F].]

Class [F] does contain a method [f], and because it was the first method found with the given name, it's the method used. The methods called [f] in classes [C] and [G] are ignored.

Using internal logic like this isn't likely to lead to the most readable or maintainable of programs, of course. And with more complex hierarchies, other factors come into play to make sure that no class is searched twice and to support cooperative calls to [super].

But this hierarchy is probably more complex than you'd expect to see in practice. If you stick to the more standard uses of multiple inheritance, as in the creation of mixin or addin classes, you can easily keep things readable and avoid name clashes.

Lab 15: HTML classes

In this lab, you create classes to represent an HTML document. To keep things simple, assume that each element can contain only text and one subelement. So the [<html>] element contains only a [<body>] element, and the [<body>] element contains (optional) text and a [<p>] element that contains only text.

The key feature to implement is the [__str__()] method, which in turn calls its subelement's [__str__()] method, so that the entire document is returned when the [str()] function is called on an [<html>] element. You can assume that any text comes before the subelement.

Here's example output from using the classes:

```
para = p(text="this is some body text")
doc_body = body(text="This is the body", subelement=para)
doc = html(subelement=doc_body)
print(doc)

<html>
<body>
This is the body
<p>
this is some body text
</p>
</body>
</html>
```

Summary

- [Defining a class in effect creates a new data type.]
- [[__init__] is used to initialize data when a new instance of a class is created, but it isn't a constructor.]
- [The [self] parameter refers to the current instance of the class and is passed as the first parameter to methods of a class.]
- [Static methods can be called without creating an instance of the class, so they don't receive a [self] parameter.]
- [Class methods are passed a [cls] parameter, which is a reference to the class, instead of [self].]
- [All Python methods are virtual. That is, if a method isn't overridden in the subclass or private to the superclass, it's accessible by all subclasses.]
- [Class variables are inherited from superclasses unless they begin with two underscores [(__)], in which case they're private and can't be seen by subclasses. Methods can be made private in the same way.]
- [Properties let you have attributes with defined getter and setter methods, but they still behave like plain instance attributes.]
- [Python allows multiple inheritance, which is often used with mixin classes.]