21. Even more OOP

21.1. MyTime

As another example of a user-defined type, we'll define a class called `MyTime` that records the time of day. We'll provide an `__init__` method to ensure that every instance is created with appropriate attributes and initialization. The class definition looks like this:

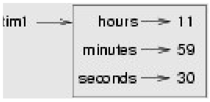
```
class MyTime:

    def __init__(self, hrs=0, mins=0, secs=0):
        """ Create a MyTime object initialized to hrs, mins, secs """
        self.hours = hrs
        self.minutes = mins
        self.seconds = secs
```

We can instantiate a new `MyTime` object:

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

The state diagram for the object looks like this:



We'll leave it as an exercise for the readers to add a `__str__` method so that MyTime objects can print themselves decently.

21.2. Pure functions

In the next few sections, we'll write two versions of a function called `add_time`, which calculates the sum of two `MyTime` objects. They will demonstrate two kinds of functions: pure functions and modifiers.

The following is a rough version of `add_time`:

```
def add_time(t1, t2):
    h = t1.hours + t2.hours
    m = t1.minutes + t2.minutes
    s = t1.seconds + t2.seconds
    sum_t = MyTime(h, m, s)
    return sum_t
```

The function creates a new `MyTime` object and returns a reference to the new object. This is called a **pure function** because it does not modify any of the objects passed to it as parameters and it has no side effects, such as updating global variables, displaying a value, or getting user input.

Here is an example of how to use this function. We'll create two `MyTime` objects: `current_time`, which contains the current time; and `bread_time`, which contains the amount of time it takes for a breadmaker to make bread. Then we'll use `add_time` to figure out when the bread will be done.

```
>>> 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
```

The output of this program is `12:49:30`, which is correct. On the other hand, there are cases where the result is not correct. Can you think of one?

The problem is that this function does not deal with cases where the number of seconds or minutes adds up to more than sixty. When that happens, we have to carry the extra seconds into the minutes column or the extra minutes into the hours column.

Here's a better version of the function:

```
def add_time(t1, t2):

    h = t1.hours + t2.hours
    m = t1.minutes + t2.minutes
    s = t1.seconds + t2.seconds

    if s >= 60:
        s -= 60
        m += 1

    if m >= 60:
        m -= 60
        h += 1

    sum_t = MyTime(h, m, s)
    return sum_t
```

This function is starting to get bigger, and still doesn't work for all possible cases. Later we will suggest an alternative approach that yields better code.

21.3. Modifiers

There are times when it is 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 makes are visible to the caller. Functions that work this way are called **modifiers**.

`increment`, which adds a given number of seconds to a `MyTime` object, would be written most naturally as a modifier. A rough draft of the function looks like this:

```
def increment(t, secs):
    t.seconds += secs

    if t.seconds >= 60:
        t.seconds -= 60
        t.minutes += 1

    if t.minutes >= 60:
        t.minutes -= 60
        t.hours += 1
```

The first line performs the basic operation; the remainder deals with the special cases we saw before.

Is this function correct? What happens if the parameter `seconds` is much greater than sixty? In that case, it is not enough to carry once; we have to keep doing it until `seconds` is less than sixty. One solution is to replace the `if` statements with `while` statements:

```
def increment(t, seconds):
    t.seconds += seconds

    while t.seconds >= 60:
        t.seconds -= 60
        t.minutes += 1

    while t.minutes >= 60:
        t.minutes -= 60
        t.hours += 1
```

This function is now correct when seconds is not negative, and when hours does not exceed 23, but it is not a particularly good solution.

21.4. Converting `increment` to a method

Once again, OOP programmers would prefer to put functions that work with `MyTime` objects into the `MyTime` class, so let's convert `increment` to a method. To save space, we will leave out previously defined methods, but you should keep them in your version:

```
class MyTime:
    # Previous method definitions here...

    def increment(self, seconds):
        self.seconds += seconds

        while self.seconds >= 60:
            self.seconds -= 60
            self.minutes += 1

        while self.minutes >= 60:
            self.minutes -= 60
            self.hours += 1
```

The transformation is purely mechanical — we move the definition into the class definition and (optionally) change the name of the first parameter to `self`, to fit with Python style conventions.

Now we can invoke `increment` using the syntax for invoking a method.

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

Again, the object on which the method is invoked gets assigned to the first parameter, `self`. The second parameter, `seconds` gets the value `500`.

21.5. An "Aha!" insight

Often a high-level insight into the problem can make the programming much easier.

In this case, the insight is that a `MyTime` object is really a three-digit number in base 60! The `second` component is the ones column, the `minute` component is the sixties column, and the `hour` component is the thirty-six hundreds column.

When we wrote `add_time` and `increment`, we were effectively doing addition in base 60, which is why we had to carry from one column to the next.

This observation suggests another approach to the whole problem — we can convert a `MyTime` object into a single number and take advantage of the fact that the computer knows how to do arithmetic with numbers. The following method is added to the `MyTime` class to convert any instance into a corresponding number of seconds:

```
class MyTime:
    # ...

    def to_seconds(self):
        """ Return the number of seconds represented
            by this instance
        """
        return self.hours * 3600 + self.minutes * 60 + self.seconds
```

Now, all we need is a way to convert from an integer back to a `MyTime` object. Supposing we have `tsecs` seconds, some integer division and mod operators can do this for us:

```python
hrs = tsecs // 3600
leftoversecs = tsecs % 3600
mins = leftoversecs // 60
secs = leftoversecs % 60
```

You might have to think a bit to convince yourself that this technique to convert from one base to another is correct.

In OOP we're really trying to wrap together the data and the operations that apply to it. So we'd like to have this logic inside the `MyTime` class. A good solution is to rewrite the class initializer so that it can cope with initial values of seconds or minutes that are outside the **normalized** values. (A normalized time would be something like 3 hours 12 minutes and 20 seconds. The same time, but unnormalized could be 2 hours 70 minutes and 140 seconds.)

Let's rewrite a more powerful initializer for `MyTime`:

```python
class MyTime:
    # ...

    def __init__(self, hrs=0, mins=0, secs=0):
        """ Create a new MyTime object initialized to hrs, mins, secs.
            The values of mins and secs may be outside the range 0-59,
            but the resulting MyTime object will be normalized.
        """

        # Calculate total seconds to represent
        totalsecs = hrs*3600 + mins*60 + secs
        self.hours = totalsecs // 3600        # Split in h, m, s
        leftoversecs = totalsecs % 3600
        self.minutes = leftoversecs // 60
        self.seconds = leftoversecs % 60
```

Now we can rewrite `add_time` like this:

```python
def add_time(t1, t2):
    secs = t1.to_seconds() + t2.to_seconds()
    return MyTime(0, 0, secs)
```

This version is much shorter than the original, and it is much easier to demonstrate or reason that it is correct.

21.6. Generalization

In some ways, converting from base 60 to base 10 and back is harder than just dealing with times. Base conversion is more abstract; our intuition for dealing with times is better.

But if we have the insight to treat times as base 60 numbers and make the investment of writing the conversions, we get a program that is shorter, easier to read and debug, and more reliable.

It is also easier to add features later. For example, imagine subtracting two `MyTime` objects to find the duration between them. The naive approach would be to implement subtraction with borrowing. Using the conversion functions would be easier and more likely to be correct.

Ironically, sometimes making a problem harder (or more general) makes the programming easier, because there are fewer special cases and fewer opportunities for error.

Specialization versus Generalization

Computer Scientists are generally fond of specializing their types, while mathematicians often take the opposite approach, and generalize everything.

What do we mean by this?

If we ask a mathematician to solve a problem involving weekdays, days of the century, playing cards, time, or dominoes, their most likely response is to observe that all these objects can be represented by integers. Playing cards, for example, can be numbered from 0 to 51. Days within the century can be numbered. Mathematicians will say *"These things are enumerable — the elements can be uniquely numbered (and we can reverse this numbering to get back to the original concept). So let's number them, and confine our thinking to integers. Luckily, we have powerful techniques and a good understanding of integers, and so our abstractions — the way we tackle and simplify these problems — is to try to reduce them to problems about integers."*

Computer Scientists tend to do the opposite. We will argue that there are many integer operations that are simply not meaningful for dominoes, or for days of the century. So we'll often define new specialized types, like `MyTime`, because we can restrict, control, and specialize the operations that are possible. Object-oriented programming is particularly popular because it gives us a good way to bundle methods and specialized data into a new type.

Both approaches are powerful problem-solving techniques. Often it may help to try to think about the problem from both points of view — *"What would happen if I tried to reduce everything to very few primitive types?"*, versus *"What would happen if this thing had its own specialized type?"*

21.7. Another example

The `after` function should compare two times, and tell us whether the first time is strictly after the second, e.g.

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

This is slightly more complicated because it operates on two `MyTime` objects, not just one. But we'd prefer to write it as a method anyway — in this case, a method on the first argument:

```
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
```

We invoke this method on one object and pass the other as an argument:

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

We can almost read the invocation like English: If the current time is after the done time, then...

The logic of the `if` statements deserve special attention here. Lines 11-18 will only be reached if the two hour fields are the same. Similarly, the test at line 16 is only executed if both times have the same hours and the same minutes.

Could we make this easier by using our "Aha!" insight and extra work from earlier, and reducing both times to integers? Yes, with spectacular results!

```
class MyTime:
    # Previous method definitions here...

```

```
    def after(self, time2):
        """ Return True if I am strictly greater than time2 """
        return self.to_seconds() > time2.to_seconds()
```

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.

21.8. Operator overloading

Some languages, including Python, make it possible to have different meanings for the same operator when applied to different types. For example, `+` in Python means quite different things for integers and for strings. This feature is called **operator overloading**.

It is especially useful when programmers can also overload the operators for their own user-defined types.

For example, to override the addition operator `+`, we can provide a method named `__add__`:

```
class MyTime:
    # Previously defined methods here...

    def __add__(self, other):
        return MyTime(0, 0, self.to_seconds() + other.to_seconds())
```

As usual, the first parameter is the object on which the method is invoked. The second parameter is conveniently named `other` to distinguish it from `self`. To add two `MyTime` objects, we create and return a new `MyTime` object that contains their sum.

Now, when we apply the `+` operator to `MyTime` objects, Python invokes the `__add__` method that we have written:

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

The expression `t1 + t2` is equivalent to `t1.__add__(t2)`, but obviously more elegant. As an exercise, add a method `__sub__(self, other)` that overloads the subtraction operator, and try it out.

For the next couple of exercises we'll go back to the `Point` class defined in our first chapter about objects, and overload some of its operators. Firstly, adding two points adds their respective (x, y) coordinates:

```
class Point:
    # Previously defined methods here...

    def __add__(self, other):
        return Point(self.x + other.x,  self.y + other.y)
```

There are several ways to override the behavior of the multiplication operator: by defining a method named `__mul__`, or `__rmul__`, or both.

If the left operand of `*` is a `Point`, Python invokes `__mul__`, which assumes that the other operand is also a `Point`. It computes the **dot product** of the two Points, defined according to the rules of linear algebra:

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

If the left operand of `*` is a primitive type and the right operand is a `Point`, Python invokes `__rmul__`, which performs **scalar multiplication**:

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

The result is a new `Point` whose coordinates are a multiple of the original coordinates. If `other` is a type that cannot be multiplied by a floating-point number, then `__rmul__` will yield an error.

This example demonstrates both kinds of multiplication:

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

What happens if we try to evaluate `p2 * 2`? 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:

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

Unfortunately, the error message is a bit opaque. This example demonstrates some of the difficulties of object-oriented programming. Sometimes it is hard enough just to figure out what code is running.

21.9. Polymorphism

Most of the methods we have written only work for a specific type. When we create a new object, we write methods that operate on that type.

But there are certain operations that we will want to apply to many types, such as the arithmetic operations in the previous sections. If many types support the same set of operations, we can write functions that work on any of those types.

For example, the `multadd` operation (which is common in linear algebra) takes three parameters; it multiplies the first two and then adds the third. We can write it in Python like this:

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

This function will work for any values of `x` and `y` that can be multiplied and for any value of `z` that can be added to the product.

We can invoke it with numeric values:

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

Or with `Point`s:

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

In the first case, the `Point` is multiplied by a scalar and then added to another `Point`. In the second case, the dot product yields a numeric value, so the third parameter also has to be a numeric value.

A function like this that can take arguments with different types is called **polymorphic**.

As another example, consider the function `front_and_back`, which prints a list twice, forward and backward:

```
def front_and_back(front):
    import copy
    back = copy.copy(front)
    back.reverse()
    print(str(front) + str(back))
```

Because the `reverse` method is a modifier, we make a copy of the list before reversing it. That way, this function doesn't modify the list it gets as a parameter.

Here's an example that applies `front_and_back` to a list:

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

Of course, we intended to apply this function to lists, so it is not surprising that it works. What would be surprising is if we could apply it to a `Point`.

To determine whether a function can be applied to a new type, we apply Python's fundamental rule of polymorphism, 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.* The operations in the `front_and_back` function include `copy`, `reverse`, and `print`.

Not all programming languages define polymorphism in this way. Look up *duck typing*, and see if you can figure out why it has this name.

`copy` works on any object, and we have already written a `__str__` method for `Point` objects, so all we need is a `reverse` method in the `Point` class:

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

Then we can pass `Point`s to `front_and_back`:

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

The most interesting polymorphism is the unintentional kind, where we discover that a function we have already written can be applied to a type for which we never planned.

21.10. Glossary

dot product

An operation defined in linear algebra that multiplies two `Point`s and yields a numeric value.

functional programming style

A style of program design in which the majority of functions are pure.

modifier

A function or method that changes one or more of the objects it receives as parameters. Most modifier functions are void (do not return a value).

normalized

Data is said to be normalized if it fits into some reduced range or set of rules. We usually normalize our angles to values in the range [0..360). We normalize minutes and seconds to be values in the range [0..60). And we'd be surprised if the local store advertised its cold drinks at "One dollar, two hundred and fifty cents".

operator overloading

Extending built-in operators (`+`, `-`, `*`, `>`, `<`, etc.) so that they do different things for different types of arguments. We've seen early in the book how `+` is overloaded for numbers and strings, and here we've shown how to further overload it for user-defined types.

polymorphic

A function that can operate on more than one type. Notice the subtle distinction: overloading has different functions (all with the same name) for different types, whereas a polymorphic function is a single function that can work for a range of types.

pure function

A function that does not modify any of the objects it receives as parameters. Most pure functions are fruitful rather than void.

scalar multiplication

An operation defined in linear algebra that multiplies each of the coordinates of a `Point` by a numeric value.

21.11. Exercises

1. Write a Boolean function `between` that takes two `MyTime` objects, `t1` and `t2`, as arguments, and returns `True` if the invoking object falls between the two times. Assume `t1 <= t2`, and make the test closed at the lower bound and open at the upper bound, i.e. return True if `t1 <= obj < t2`.
2. Turn the above function into a method in the `MyTime` class.
3. Overload the necessary operator(s) so that instead of having to write

```
if t1.after(t2): ...
```

   we can use the more convenient

```
if t1 > t2: ...
```

4. Rewrite `increment` as a method that uses our "Aha" insight.
5. Create some test cases for the `increment` method. Consider specifically the case where the number of seconds to add to the time is negative. Fix up `increment` so that it handles this case if it does not do so already. (You may assume that you will never subtract more seconds than are in the time object.)
6. Can physical time be negative, or must time always move in the forward direction? Some serious physicists think this is not such a dumb question. See what you can find on the Internet about this.