The Pragmatic Programmers

Practical Programming

An Introduction to Computer Science Using Python

Jennifer Campbell
Paul Gries
Jason Montojo
Greg Wilson

Edited by Daniel H. Steinberg

What, no compiler, no sample payroll application? What kind of programming book is this? A great one, that's what. It launches from a "You don't know anything yet" premise into a fearless romp through the concepts and techniques of relevant programming technology. And what fun students will have with the images and graphics in the exercises!

➤ **Laura Wingerd**
Author, *Practical Perforce*

The debugging section is truly excellent. I know several practicing programmers who'd be rightfully offended by a suggestion to study the whole book but who could *really* do with brushing up on this section (and many others) once in a while.

➤ **Alex Martelli**
Author, *Python in a Nutshell*

This book succeeds in two different ways. It is both a science-focused CS1 text and a targeted Python reference. Even as it builds students' computational insights, it also empowers and encourages them to immediately apply their newfound programming skills in the lab or on projects of their own.

➤ **Zachary Dodds**
Associate professor of computer science, Harvey Mudd College

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CHAPTER 1

Introduction

Take a look at the pictures in Figure 1, *The Rainforest Retreats,* on page 2. The first one shows forest cover in the Amazon basin in 1975. The second one shows the same area 26 years later. Anyone can see that much of the rainforest has been destroyed, but how much is "much"?

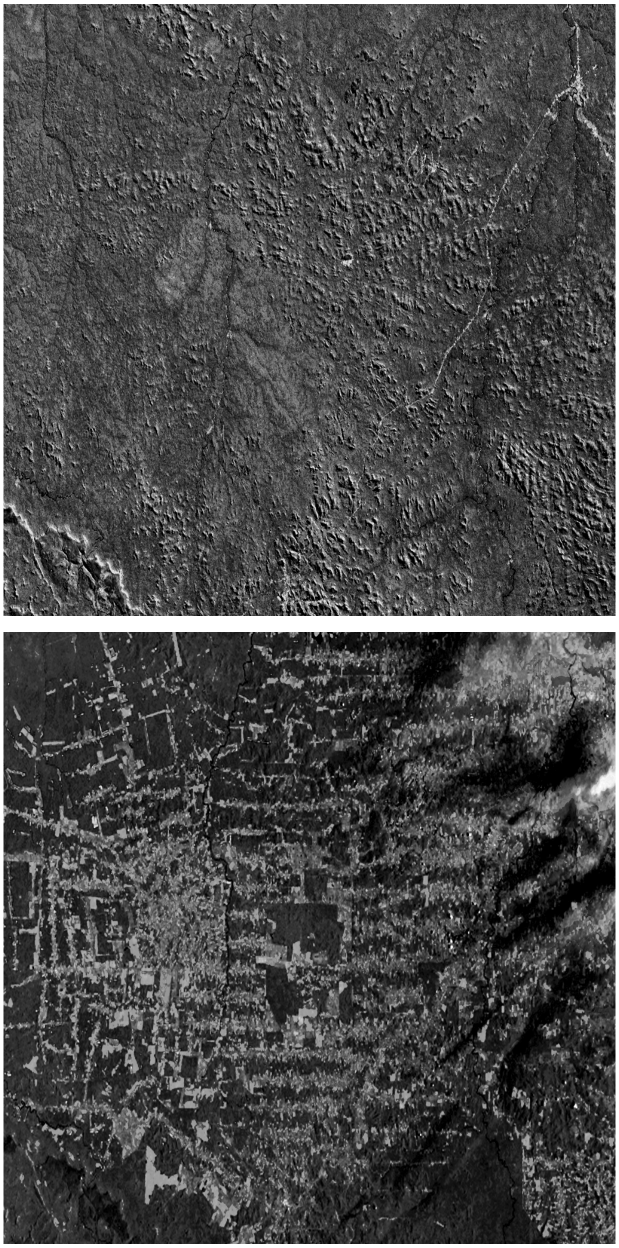
Now look at Figure 2, *Healthy blood cells---or are they?,* on page 3.

Are these blood cells healthy? Do any of them show signs of leukemia? It would take an expert doctor a few minutes to tell. Multiply those minutes by the number of people who need to be screened. There simply aren't enough human doctors in the world to check everyone.

This is where computers come in. Computer programs can measure the differences between two pictures and count the number of oddly shaped platelets in a blood sample. Geneticists use programs to analyze gene sequences; statisticians, to analyze the spread of diseases; geologists, to predict the effects of earthquakes; economists, to analyze fluctuations in the stock market; and climatologists, to study global warming. More and more scientists are writing programs to help them do their work. In turn, those programs are making entirely new kinds of science possible.

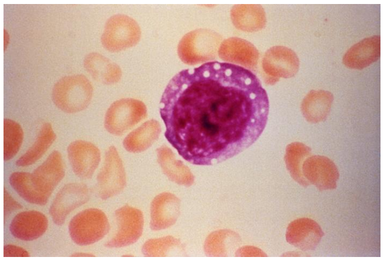
Of course, computers are good for a lot more than just science. We used computers to write this book; you have probably used one today to chat with friends, find out where your lectures are, or look for a restaurant that serves pizza *and* Chinese food. Every day, someone figures out how to make a computer do something that has never been done before. Together, those "somethings" are changing the world.

This book will teach you how to make computers do what *you* want them to do. You may be planning to be a doctor, linguist, or physicist rather than



(Photo credit: NASA/Goddard Space Flight Center Scientific Visualization Studio)

Figure 1—The Rainforest Retreats



(Photo credit: CDC)

Figure 2—Healthy blood cells—or are they?

a full-time programmer, but whatever you do, being able to program is as important as being able to write a letter or do basic arithmetic.

We begin in this chapter by explaining what programs and programming are. We then define a few terms and present a few boring-but-necessary bits of information for course instructors.

1.1 Programs and Programming

A *program* is a set of instructions. When you write down directions to your house for a friend, you are writing a program. Your friend "executes" that program by following each instruction in turn.

Every program is written in terms of a few basic operations that its reader already understands. For example, the set of operations that your friend can understand might include the following: "Turn left at Darwin Street," "Go forward three blocks," and "If you get to the gas station, turn around—you've gone too far."

Computers are similar but have a different set of operations. Some operations are mathematical, like "Add 10 to a number and take the square root," while others include "Read a line from the file named `data.txt`," "Make a pixel blue," or "Send email to the authors of this book."

The most important difference between a computer and an old-fashioned calculator is that you can "teach" a computer new operations by defining them in terms of old ones. For example, you can teach the computer that "Take the average" means "Add up the numbers in a set and divide by the set's size." You can then use the operations you have just defined to create still more operations, each layered on top of the ones that came before. It's a lot like creating life by putting atoms together to make proteins and then combining proteins to build cells and giraffes.

Defining new operations, and combining them to do useful things, is the heart and soul of programming. It is also a tremendously powerful way to think about other kinds of problems. As Prof. Jeannette Wing wrote *Computational Thinking* [Win06], computational thinking is about the following:

- *Conceptualizing, not programming.* Computer science is not computer programming. Thinking like a computer scientist means more than being able to program a computer. It requires thinking at multiple levels of abstraction.
- *A way that humans, not computers, think.* Computational thinking is a way humans solve problems; it is not trying to get humans to think like computers. Computers are dull and boring; humans are clever and imaginative. We humans make computers exciting. Equipped with computing devices, we use our cleverness to tackle problems we would not dare take on before the age of computing and build systems with functionality limited only by our imaginations.
- *For everyone, everywhere.* Computational thinking will be a reality when it is so integral to human endeavors it disappears as an explicit philosophy.

We hope that by the time you have finished reading this book, you will see the world in a slightly different way.

1.2 A Few Definitions

One of the pieces of terminology that causes confusion is what to call certain characters. The Python style guide (and several dictionaries) use these names, so this book does too:

()	Parentheses
[]	Brackets
{}	Braces

1.3 What to Install

For current installation instructions, please download the code from the book website and open `install/index.html` in a browser. The book URL is `http://pragprog.com/titles/gwpy/practical-programming`.

1.4 For Instructors

This book uses the Python programming language to introduce standard CS1 topics and a handful of useful applications. We chose Python for several reasons:

- *It is free and well documented.* In fact, Python is one of the largest and best-organized open source projects going.
- *It runs everywhere.* The reference implementation, written in C, is used on everything from cell phones to supercomputers, and it's supported by professional-quality installers for Windows, Mac OS X, and Linux.
- *It has a clean syntax.* Yes, every language makes this claim, but in the four years we have been using it at the University of Toronto, we have found that students make noticeably fewer "punctuation" mistakes with Python than with C-like languages.
- *It is relevant.* Thousands of companies use it every day; it is one of the three "official languages" at Google, and large portions of the game Civilization IV are written in Python. It is also widely used by academic research groups.
- *It is well supported by tools.* Legacy editors like Vi and Emacs all have Python editing modes, and several professional-quality IDEs are available. (We use a free-for-students version of one called Wing IDE.)

We use an "objects first, classes second" approach: students are shown how to *use* objects from the standard library early on but do not create their own classes until after they have learned about flow control and basic data structures. This compromise avoids the problem of explaining Java's `public static void main(String[] args)` to someone who has never programmed.

We have organized the book into two parts. The first covers fundamental programming ideas: elementary data types (numbers, strings, lists, sets, and dictionaries), modules, control flow, functions, testing, debugging, and algorithms. Depending on the audience, this material can be covered in nine or ten weeks.

The second part of the book consists of more or less independent chapters on more advanced topics that assume all the basic material has been covered. The first of these chapters shows students how to create their own classes and introduces encapsulation, inheritance, and polymorphism; courses for computer science majors will want to include this material. The other chapters cover application areas, such as 3D graphics, databases, GUI construction, and the basics of web programming; these will appeal to both computer science majors and students from the sciences and will allow the book to be used for both.

Lots of other good books on Python programming exist. Some are accessible to novices *Introduction to Computing and Programming in Python: A Multimedia Approach* [Guz04], *Python Programming: An Introduction to Computer Science* [Zel03], and others are for anyone with any previous programming experience *How to Think Like a Computer Scientist: Learning with Python* [DEM02], *Object-Oriented Programming in Python* [GL07], and *Learning Python* [LA03]. You may also want to take a look at *Python Education Special Interest Group (EDU-SIG)* [Pyt11], the special interest group for educators using Python.

1.5 Summary

In this book, we'll do the following:

- We will show you how to develop and use programs that solve real-world problems. Most of its examples will come from science and engineering, but the ideas can be applied to any domain.
- We start by teaching you the core features of a programming language called Python. These features are included in every modern programming language, so you can use what you learn no matter what you work on next.
- We will also teach you how to think methodically about programming. In particular, we will show you how to break complex problems into simple ones and how to combine the solutions to those simpler problems to create complete applications.
- Finally, we will introduce some tools that will help make your programming more productive, as well as some others that will help your applications cope with larger problems.

CHAPTER 2

Hello, Python

Programs are made up of commands that a computer can understand. These commands are called *statements*, which the computer *executes*. This chapter describes the simplest of Python's statements and shows how they can be used to do basic arithmetic. It isn't very exciting in its own right, but it's the basis of almost everything that follows.

2.1 The Big Picture

In order to understand what happens when you're programming, you need to have a basic understanding of how a program gets executed on a computer. The computer itself is assembled from pieces of hardware, including a *processor* that can execute instructions and do arithmetic, a place to store data such as a *hard drive*, and various other pieces such as computer monitor, a keyboard, a card for connecting to a network, and so on.

To deal with all these pieces, every computer runs some kind of *operating system*, such as Microsoft Windows, Linux, or Mac OS X. An operating system, or OS, is a program; what makes it special is that it's the only program on the computer that's allowed direct access to the hardware. When any other program on the computer wants to draw on the screen, find out what key was just pressed on the keyboard, or fetch data from the hard drive, it sends a request to the OS (see Figure 3, *Talking to the operating system*, on page 8).

This may seem a roundabout way of doing things, but it means that only the people writing the OS have to worry about the differences between one network card and another. Everyone else—everyone analyzing scientific data or creating 3D virtual chat rooms—only has to learn their way around the OS, and their programs will then run on thousands of different kinds of hardware.

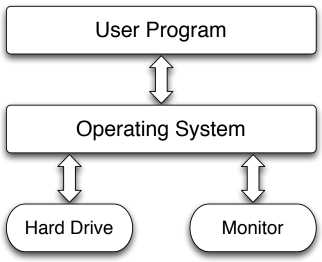


Figure 3—Talking to the operating system

Twenty-five years ago, that's how most programmers worked. Today, though, it's common to add another layer between the programmer and the computer's hardware. When you write a program in Python, Java, or Visual Basic, it doesn't run directly on top of the OS. Instead, another program, called an *interpreter* or *virtual machine*, takes your program and runs it for you, translating your commands into a language the OS understands. It's a lot easier, more secure, and more portable across operating systems than writing programs directly on top of the OS.

But an interpreter alone isn't enough; it needs some way to interact with the world. One way to do this is to run a text-oriented program called a *shell* that reads commands from the keyboard, does what they ask, and shows their output as text, all in one window. Shells exist for various programming languages as well as for interacting with the OS; we will be exploring Python in this chapter using a Python shell.

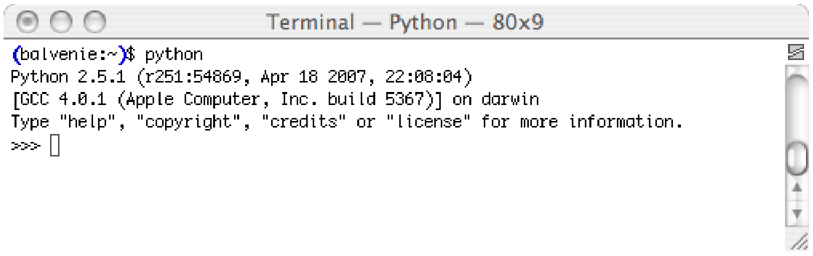
The more modern way to interact with Python is to use an *integrated development environment*, or IDE. This is a full-blown graphical interface with menus and windows, much like a web browser, word processor, or drawing program.

Our favorite IDE for student-sized programs is the free Wing 101, a "lite" version of the professional tool.[1]

Another fine IDE is IDLE, which comes bundled with Python. We prefer Wing 101 because it was designed specifically for beginning programmers, but IDLE is a capable development environment.

The Wing 101 interface is shown in Figure 5, *The Wing 101 interface*, on page 10. The top part is the editing pane where we will write Python pro-

1. See http://www.wingware.com for details.



```
(balvenie:~)$ python
Python 2.5.1 (r251:54869, Apr 18 2007, 22:08:04)
[GCC 4.0.1 (Apple Computer, Inc. build 5367)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> 
```

Figure 4—A Python shell

grams. You can run the code you type there by clicking the Run button on the toolbar. You can also save the contents of that pane into a .py file. The bottom half of the IDE, labeled as Python Shell, is where we will experiment with snippets of Python programs. We'll use the top pane more when we get to Chapter 4, *Modules*, on page 37; for now we'll stick to the shell.

The >>> part is called a *prompt*, because it prompts us to type something.

2.2 Expressions

As we learned at the beginning of the chapter, Python commands are called *statements*. One kind of statement is an *expression statement*, or *expression* for short. You're familiar with mathematical expressions like 3 + 4 and 2 - 3 / 5; each expression is built out of *values* like 2 and 3 / 5 and *operators* like + and -, which combine their *operands* in different ways.

Like any programming language, Python can *evaluate* basic mathematical expressions. For example, the following expression adds 4 and 13:

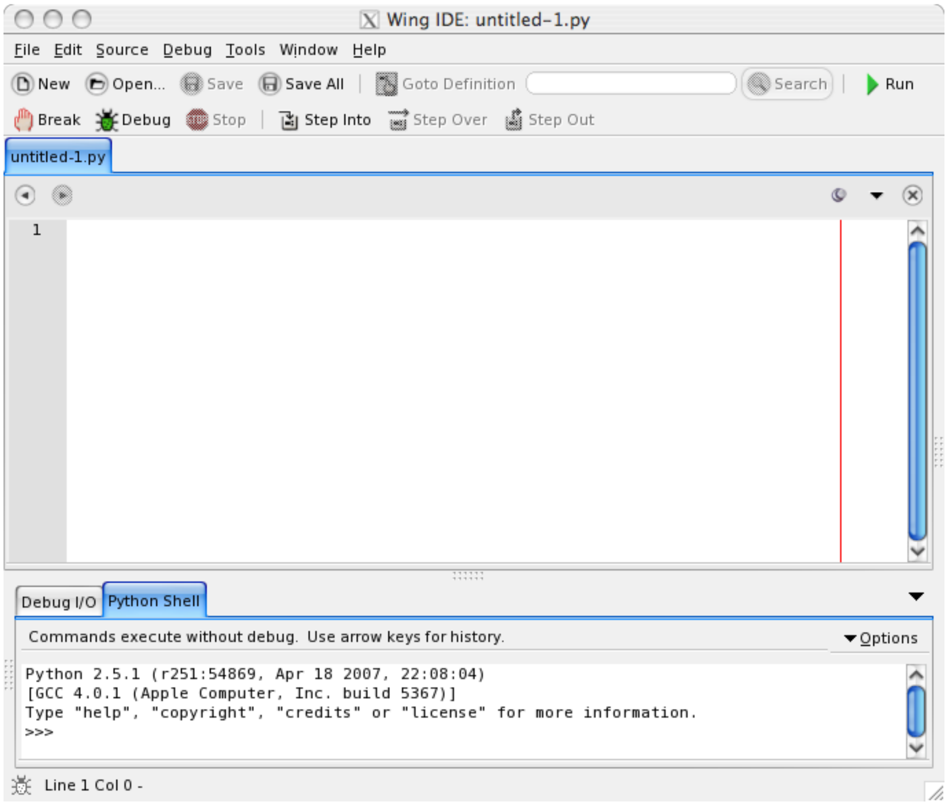
```
>>> 4 + 13
17
```

When an expression is evaluated, it produces a single result. In the previous expression, 4 + 13 produced the result 17.

Type int

It's not surprising that 4 + 13 is 17. However, computers do not always play by the rules you learned in primary school. For example, look at what happens when we divide 17 by 10:

```
>>> 17 / 10
1
```


Wing IDE: untitled-1.py
File Edit Source Debug Tools Window Help
New Open... Save Save All Goto Definition Search Run
Break Debug Stop Step Into Step Over Step Out
untitled-1.py
Debug I/O Python Shell
Options
Line 1 Col 0 -

Commands execute without debug. Use arrow keys for history.

```
Python 2.5.1 (r251:54869, Apr 18 2007, 22:08:04)
[GCC 4.0.1 (Apple Computer, Inc. build 5367)]
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

Figure 5—The Wing 101 interface

You would expect the result to be 1.7, but Python produces 1 instead. This is because every value in Python has a particular *type*, and the types of values determine how they behave when they're combined.

In Python, an expression involving values of a certain type produces a value of that same type. For example, 17 and 10 are integers—in Python, we say they are of type `int`. When we divide one by the other, the result is also an `int`.

Notice that Python doesn't round integer expressions. If it did, the result would have been 2. Instead, it takes the *floor* of the intermediate result. If you want the leftovers, you can use Python's modulo operator (%) to return the remainder:

```
>>> 17 % 10
7
```

Division in Python 3.0

In the latest version of Python (Python 3.0), 5 / 2 is 2.5 rather than 2. Python 3.0 is currently less widely used than its predecessors, so the examples in this book use the "classic" behavior.

Be careful about using % and / with negative operands. Since Python takes the floor of the result of an integer division, the result is one smaller than you might expect:

```
>>> -17 / 10
-2
```

When using modulo, the sign of the result matches the sign of the second operand:

```
>>> -17 % 10
3
>>> 17 % -10
-3
```

Type float

Python has another type called float to represent numbers with fractional parts. The word *float* is short for *floating point*, which refers to the decimal point that moves around between digits of the number.

An expression involving two floats produces a float:

```
>>> 17.0 / 10.0
1.7
```

When an expression's operands are an int and a float, Python automatically converts the int to a float. This is why the following two expressions both return the same answer as the earlier one:

```
>>> 17.0 / 10
1.7
>>> 17 / 10.0
1.7
```

If you want, you can omit the zero after the decimal point when writing a floating-point number:

```
>>> 17 / 10.
1.7
>>> 17. / 10
1.7
```

Operator	Symbol	Example	Result
-	Negation	-5	-5
*	Multiplication	8.5 * 3.5	29.75
/	Division	11 / 3	3
%	Remainder	8.5 % 3.5	1.5
+	Addition	11 + 3	14
-	Subtraction	5 - 19	-14
**	Exponentiation	2 ** 5	32

Table 1—Arithmetic operators

However, most people think this is bad style, since it makes your programs harder to read: it's very easy to miss a dot on the screen and see "17" instead of "17."

2.3 What *Is* a Type?

We've now seen two types of numbers, so we ought to explain exactly what we mean by a *type*. In computing, a type is a set of values, along with a set of operations that can be performed on those values. For example, the type int is the values ..., -3, -2, -1, 0, 1, 2, 3, ..., along with the operators +, -, *, /, and % (and a few others we haven't introduced yet). On the other hand, 84.2 is a member of the set of float values, but it is not in the set of int values.

Arithmetic was invented before Python, so the int and float types have exactly the same operators. We can see what happens when these are applied to various values in Table 1, *Arithmetic operators*, on page 12.

Finite Precision

Floating-point numbers are not exactly the fractions you learned in grade school. For example, take a look at Python's version of the fraction $\frac{1}{3}$ (remember to include a decimal point so that the result isn't truncated):

```
>>> 1.0 / 3.0
0.33333333333333331
```

What's that 1 doing at the end? Shouldn't it be a 3? The problem is that real computers have a finite amount of memory, which limits how much information they can store about any single number. The number 0.33333333333333331 turns out to be the closest value to $\frac{1}{3}$ that the computer can actually store.

More on Numeric Precision

Computers use the same amount of memory to store an integer regardless of that integer's value, which means that -22984, -1, and 100000000 all take up the same amount of room. Because of this, computers can store int values only in a certain range. A modern desktop or laptop machine, for example, can store the numbers only from -2147483648 to 2147483647. (We'll take a closer look in the exercises at where these bounds come from.)

Computers can store only *approximations* to real numbers for the same reason. For example, $^1/_4$ can be stored exactly, but as we've already seen, $^1/_3$ cannot. Using more memory won't solve the problem, though it will make the approximation closer to the real value, just as writing a larger number of 3s after the 0 in 0.333… doesn't make it exactly equal to $^1/_3$.

The difference between $^1/_3$ and 0.3333333333333331 may look tiny. But if we use that value in a calculation, then the error may get compounded. For example, if we add the float to itself, the result ends in …6662; that is a slightly worse approximation to $^2/_3$ than 0.666…. As we do more calculations, the rounding errors can get larger and larger, particularly if we're mixing very large and very small numbers. For example, suppose we add 10,000,000,000 and 0.00000000001. The result ought to have twenty zeroes between the first and last significant digit, but that's too many for the computer to store, so the result is just 10,000,000,000—it's as if the addition never took place. Adding lots of small numbers to a large one can therefore have no effect at all, which is *not* what a bank wants when it totals up the values of its customers' savings accounts.

It's important to be aware of the floating-point issue so that your programs don't bite you unexpectedly, but the solutions to this problem are beyond the scope of this text. In fact, *numerical analysis*, the study of algorithms to approximate continuous mathematics, is one of the largest subfields of computer science and mathematics.

Operator Precedence

Let's put our knowledge of ints and floats to use to convert Fahrenheit to Celsius. To do this, we subtract 32 from the temperature in Fahrenheit and then multiply by $^5/_9$:

```
>>> 212 - 32.0 * 5.0 / 9.0
194.22222222222223
```

Python claims the result is 194.22222222222223[2] degrees Celsius when in fact it should be 100. The problem is that * and / have higher *precedence* than -; in other words, when an expression contains a mix of operators, the

2. This is another floating-point approximation.

* and / are evaluated before - and +. This means that what we actually calculated was 212 - ((32.0 * 5.0) / 9.0).

We can alter the order of precedence by putting parentheses around parts of the expression, just as we did in Mrs. Singh's fourth-grade class:

```
>>> (212 - 32.0) * 5.0 / 9.0
100.0
```

The order of precedence for arithmetic operators is listed in Table 2, *Arithmetic operators by precedence*, on page 15. It's a good rule to parenthesize complicated expressions even when you don't need to, since it helps the eye read things like 1+1.7+3.2*4.4-16/3.

2.4 Variables and the Assignment Statement

Most handheld calculators[3] have one or more memory buttons. These store a value so that it can be used later. In Python, we can do this with a *variable*, which is just a name that has a value associated with it. Variables' names can use letters, digits, and the underscore symbol. For example, X, species5618, and degrees_celsius are all allowed, but 777 isn't (it would be confused with a number), and neither is no-way! (it contains punctuation).

You create a new variable simply by giving it a value:

```
>>> degrees_celsius = 26.0
```

This statement is called an *assignment statement*; we say that degrees_celsius is *assigned* the value 26.0. An assignment statement is executed as follows:

1. Evaluate the expression on the right of the = sign.
2. Store that value with the variable on the left of the = sign.

In the diagram below, we can see the *memory model* for the result of the assignment statement. It's pretty simple, but we will see more complicated memory models later.

$$\begin{tikzcd} \texttt{degrees\_celsius} \arrow[r] & 26.0 \end{tikzcd}$$

Once a variable has been created, we can use its value in other calculations. For example, we can calculate the difference between the temperature stored in degrees_celsius and the boiling point of water like this:

```
>>> 100 - degrees_celsius
74.0
```

3. And cell phones, and wristwatches, and...

Operator	Symbol
**	Exponentiation
-	Negation
*, /, %	Multiplication, division, and remainder
+, -	Addition and subtraction

Table 2—Arithmetic operators by precedence

Whenever the variable's name is used in an expression, Python uses the variable's value in the calculation. This means that we can create new variables from old ones:

```
>>> difference = 100 - degrees_celsius
```

Typing in the name of a variable on its own makes Python display its value:

```
>>> difference
74.0
```

What happened here is that we gave Python a very simple expression—one that had no operators at all—so Python evaluated it and showed us the result.

It's no more mysterious than asking Python what the value of 3 is:

```
>>> 3
3
```

Variables are called variables because their values can change as the program executes. For example, we can assign `difference` a new value:

```
>>> difference = 100 - 15.5
>>> difference
84.5
```

This does *not* change the results of any calculations done with that variable before its value was changed:

```
>>> difference = 20
>>> double = 2 * difference
>>> double
40
>>> difference = 5
>>> double
40
```

As the memory models illustrate in Figure 6, *Changing a variable's value,* on page 17, once a value is associated with double, it stays associated until the program explicitly overwrites it. Changes to other variables, like difference, have no effect.

We can even use a variable on both sides of an assignment statement:

```
>>> number = 3
>>> number
3
>>> number = 2 * number
>>> number
6
>>> number = number * number
>>> number
36
```

This wouldn't make much sense in mathematics—a number cannot be equal to twice its own value—but = in Python doesn't mean "equals to." Instead, it means "assign a value to."

When a statement like number = 2 * number is evaluated, Python does the following:

1. Gets the value currently associated with number
2. Multiplies it by 2 to create a new value
3. Assigns that value to number

Combined Operators

In the previous example, the variable number appeared on both sides of the assignment statement. This is so common that Python provides a shorthand notation for this operation:

```
>>> number = 100
>>> number -= 80
>>> number
20
```

Here is how a *combined operator* is evaluated:

1. Evaluate the expression to the right of the = sign.
2. Apply the operator attached to the = sign to the variable and the result of the expression.
3. Assign the result to the variable to the left of the = sign.

Note that the operator is applied *after* the expression on the right is evaluated:

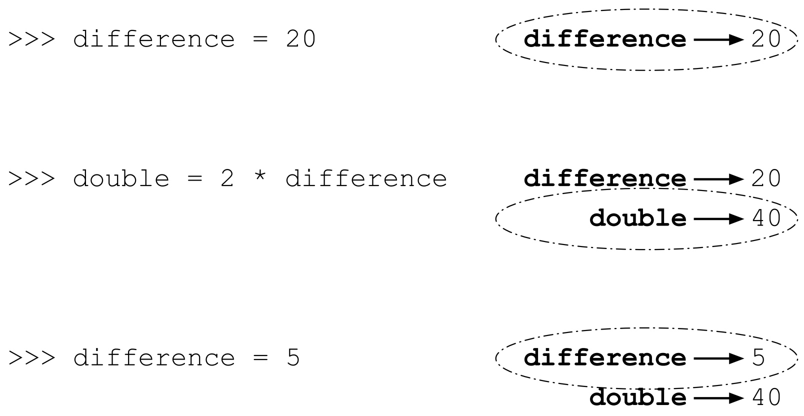


Figure 6—Changing a variable's value

```
>>> d = 2
>>> d *= 3 + 4
>>> d
14
```

All the operators in Table 2, *Arithmetic operators by precedence*, on page 15, have shorthand versions. For example, we can square a number by multiplying it by itself:

```
>>> number = 10
>>> number *= number
>>> number
100
```

which is equivalent to this:

```
>>> number = 10
>>> number = number * number
>>> number
100
```

2.5 When Things Go Wrong

We said earlier that variables are created by assigning them values. What happens if we try to use a variable that hasn't been created yet?

```
>>> 3 + something
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
NameError: name 'something' is not defined
```

This is pretty cryptic. In fact, Python's error messages are one of its few weaknesses from the point of view of novice programmers. The first two lines aren't much use right now, though they'll be indispensable when we start writing longer programs. The last line is the one that tells us what went wrong: the name something wasn't recognized.

Here's another error message you might sometimes see:

```
>>> 2 +
  File "<stdin>", line 1
    2 +
      ^
SyntaxError: invalid syntax
```

The rules governing what is and isn't legal in a programming language (or any other language) are called its *syntax*. What this message is telling us is that we violated Python's syntax rules—in this case, by asking it to add something to 2 but not telling it what to add.

2.6 Function Basics

Earlier in this chapter, we converted 212 degrees Fahrenheit to Celsius. A mathematician would write this as $f(t)={}^{5}\!/_{9}(t\text{-}32)$, where t is the temperature in Fahrenheit that we want to convert to Celsius. To find out what 80 degrees Fahrenheit is in Celsius, we replace t with 80, which gives us $f(80) = {}^{5}\!/_{9}$ (80-32), or 26 ${}^{2}\!/_{3}$.

We can write functions in Python, too. As in mathematics, they are used to define common formulas. Here is the conversion function in Python:

```
>>> def to_celsius(t):
...     return (t - 32.0) * 5.0 / 9.0
...
```

(Press enter to add a blank line so the Python interpreter knows you're done.) This has these major differences from its mathematical equivalent:

- A function definition is another kind of Python statement; it defines a new name whose value can be rather complicated but is still just a value.
- The *keyword* def is used to tell Python that we're defining a new function.
- We use a readable name like to_celsius for the function rather than something like f whose meaning will be hard to remember an hour later. (This isn't actually a requirement, but it's good style.)
- There is a colon instead of an equals sign.
- The actual formula for the function is defined on the next line. The line is indented four spaces and marked with the keyword return.

Python displays a triple-dot prompt automatically when you're in the middle of defining a new function; you do not type the dots any more than you type the greater-than signs in the usual >>> prompt. If you're using a smart editor, like the one in Wing 101, it will automatically indent the *body* of the function by the required amount. (This is another reason to use Wing 101 instead of a basic text editor like Notepad or Pico: it saves a lot of wear and tear on your spacebar and thumb.)

Here is what happens when we ask Python to evaluate to_celsius(80), to_celsius(78.8), and to_celsius(10.4):

```
>>> to_celsius(80)
26.666666666666668
>>> to_celsius(78.8)
26.0
>>> to_celsius(10.4)
-12.0
```

Each of these three statements is called a *function call*, because we're calling up the function to do some work for us. We have to define a function only once; we can call it any number of times.

The general form of a function definition is as follows:

```
def <code:bold>function_name</code:bold>(<code:bold>parameters</code:bold>):
    <code:bold>block</code:bold>
```

As we've already seen, the def keyword tells Python that we're defining a new function. The name of the function comes next, followed by zero or more *parameters* in parentheses and a colon. A *parameter* is a variable (like t in the function to_celsius) that is given a value when the function is called. For example, 80 was assigned to t in the function call to_celsius(80), and then 78.8 in to_celsius(78.8), and then 10.4 in to_celsius(10.4). Those actual values are called the *arguments* to the function.

What the function does is specified by the *block* of statements inside it. to_celsius's block consisted of just one statement, but as we'll see later, blocks making up more complicated functions may be many statements long.

to_celsius produces its value using a return statement, which has this general form:

```
return <code:bold>expression</code:bold>
```

and is executed as follows:

1. Evaluate the expression to the right of the keyword return.
2. Use that value as the result of the function.

It's important to be clear on the difference between a function *definition* and a function *call*. When a function is defined, Python records it but doesn't execute it. When the function is called, Python jumps to the first line of that function and starts running it (see Figure 7, *Function control flow*, on page 21). When the function is finished, Python returns to the place where the function was originally called.

Local Variables

Some computations are complex, and breaking them down into separate steps can lead to clearer code. Here, we break down the evaluation of the polynomial $ax^2 + bx + c$ into several steps:

```
>>> def polynomial(a, b, c, x):
...     first  = a * x * x
...     second = b * x
...     third  = c
...     return first + second + third
...
>>> polynomial(2, 3, 4, 0.5)
6.0
>>> polynomial(2, 3, 4, 1.5)
13.0
```

Variables like first, second, and third that are created within a function are called *local variables*. These variables exist only during function execution; when the function finishes executing, the variables no longer exist. This means that trying to access a local variable from outside the function is an error, just like trying to access a variable that has never been defined:

```
>>> polynomial(2, 3, 4, 1.3)
11.280000000000001
>>> first
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
NameError: name 'first' is not defined
>>> a
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
NameError: name 'a' is not defined
```

As you can see from this example, a function's parameters are also local variables. When a function is called, Python assigns the argument values given in the call to the function's parameters. As you might expect, if a

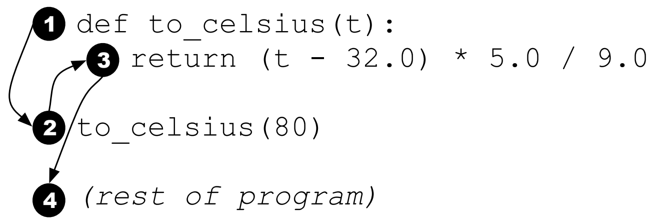


Figure 7—Function control flow

function is defined to take a certain number of parameters, it must be passed the same number of arguments:[4]

```
>>> polynomial(1, 2, 3)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: polynomial() takes exactly 4 arguments (3 given)
```

The *scope* of a variable is the area of the program that can access it. For example, the scope of a local variable runs from the line on which it is first defined to the end of the function.

2.7 Built-in Functions

Python comes with many *built-in functions* that perform common operations. One example is abs, which produces the absolute value of a number:

```
>>> abs(-9)
9
```

Another is round, which rounds a floating-point number to the nearest integer (represented as a float):

```
>>> round(3.8)
4.0
>>> round(3.3)
3.0
>>> round(3.5)
4.0
```

Just like user-defined functions, Python's built-in functions can take more than one argument. For example, we can calculate 2^4 using the power function pow:

```
>>> pow(2, 4)
16
```

4. We'll see later how to create functions that take any number of arguments.

Some of the most useful built-in functions are ones that convert from one type to another. The type names int and float can be used as if they were functions:

```
>>> int(34.6)
34
>>> float(21)
21.0
```

In this example, we see that when a floating-point number is converted to an integer, it is truncated—not rounded.

2.8 Style Notes

Psychologists have discovered that people can keep track of only a handful of things at any one time (*Forty Studies That Changed Psychology* [Hoc04]). Since programs can get quite complicated, it's important that you choose names for your variables that will help you remember what they're for. X1, X2, and blah won't remind you of anything when you come back to look at your program next week; use names like celsius, average, and final_result instead.

Other studies have shown that your brain automatically notices differences between things—in fact, there's no way to stop it from doing this. As a result, the more inconsistencies there are in a piece of text, the longer it takes to read. (JuSt thInK a bout how long It w o u l d tAKE you to rEa d this cHaPTer iF IT wAs fORmaTTeD like thIs.) It's therefore also important to use consistent names for variables. If you call something maximum in one place, don't call it max_val in another; if you use the name max_val, don't also use the name maxVal, and so on.

These rules are so important that many programming teams require members to follow a style guide for whatever language they're using, just as newspapers and book publishers specify how to capitalize headings and whether to use a comma before the last item in a list. If you search the Internet for *programming style guide*, you'll discover links to hundreds of examples.

You will also discover that lots of people have wasted many hours arguing over what the "best" style for code is. Some of your classmates may have strong opinions about this as well. If they do, ask them what data they have to back up their beliefs, in other words, whether they know of any field studies that prove that spaces after commas make programs easier to read than no spaces. If they can't cite any studies, pat them on the back and send them on their deluded way.

2.9 Summary

In this chapter, we learned the following:

- An operating system is a program that manages your computer's hardware on behalf of other programs. An interpreter or virtual machine is a program that sits on top of the operating system and runs your programs for you. Building layers like this is the best way we have found so far for constructing complicated systems.
- Programs are made up of statements. These can be simple expressions (which are evaluated immediately), assignment statements (which create new variables or change the values of existing variables), and function definitions (which teach Python how to do new things).
- Every value in Python has a specific type, which determines what operations can be applied to it. The two types used to represent numbers are `int` and `float`.
- Expressions are evaluated in a particular order. However, you can change that order by putting parentheses around subexpressions.
- Variables must be given values before they are used.
- When a function is called, the values of its arguments are assigned to its parameters, the statements inside the function are executed, and a value is returned. The values assigned to the function's parameters, and the values of any local variables created inside the function, are forgotten after the function returns.
- Python comes with predefined functions called *built-ins*.

2.10 Exercises

Here are some exercises for you to try on your own:

1. For each of the following expressions, what value will the expression give? Verify your answers by typing the expressions into Python.

   a. `9 - 3`

   b. `8 * 2.5`

   c. `9 / 2`

   d. `9 / -2`

   e. `9 % 2`

   f. `9 % -2`
   g. `-9 % 2`
   h. `9 / -2.0`
   i. `4 + 3 * 5`
   j. `(4 + 3) * 5`

2. Unary minus negates a number. Unary plus exists as well; for example, Python understands +5. If `x` has the value -17, what do you think `+x` should do? Should it leave the sign of the number alone? Should it act like absolute value, removing any negation? Use the Python shell to find out its behavior.

3. a. Create a new variable `temp`, and assign it the value 24.

   b. Convert the value in `temp` from Celsius to Fahrenheit by multiplying by 1.8 and adding 32; associate the resulting value with `temp`. What is `temp`'s new value?

4. a. Create a new variable `x`, and assign it the value 10.5.

   b. Create a new variable `y`, and assign it the value 4.

   c. Sum `x` and `y`, and associate the resulting value with `x`. What are `x` and `y`'s new values?

5. Write a bullet list description of what happens when Python evaluates the statement `x += x - x` when `x` has the value 3.

6. The function name `to_celsius` is problematic: it doesn't mention the original unit, and it isn't a verb phrase. (Many function names are verb phrases because functions actively do things.) We also assumed the original unit was Fahrenheit, but Kelvin is a temperature scale too, and there are many others (see Section 6.5, *Exercises*, on page 110 for a discussion of them).

   We could use a longer name such as `fahrenheit_to_celsius` or even `convert_fahrenheit_to_celsius`. We could abbreviate it as `fahr_to_cel`, make it much shorter and use `f2c`, or even just use `f`. Write a paragraph describing which name you think is best and why. Consider ease of remembering, ease of typing, and readability. Don't forget to consider people whose first language isn't English.

7. In the United States, a car's fuel efficiency is measured in miles per gallon. In the metric system, it is usually measured in liters per 100 kilometers.

    a. Write a function called `convert_mileage` that converts from miles per gallon to liters per 100 kilometers.

    b. Test that your functions returns the right values for 20 and 40 miles per gallon.

    c. How did you figure out what the right value was? How closely do the computer's results match the ones you expected?

8. Explain the difference between a parameter and an argument.

9. a. Define a function called `liters_needed` that takes a value representing a distance in kilometers and a value representing gas mileage for a vehicle and returns the amount of gas needed in liters to travel that distance. Your definition should call the function `convert_mileage` that you defined as part of a previous exercise.

    b. Verify that `liters_needed(150, 30)` returns 11.761938367442955 and `liters_needed(100, 30)` returns 7.84129224496197.

    c. When `liters_needed` is called with arguments 100 and 30, what is the value of the argument to `convert_mileage`?

    d. The function call `liters_needed(100, 30)` results in a call to `convert_mileage`. Which of those two functions finishes executing first?

10. We've seen built-in functions `abs`, `round`, `pow`, `int`, and `float`. Using these functions, write expressions that do the following:

    a. Calculate 3 to the power of 7.

    b. Convert 34.7 to an integer by truncating.

    c. Convert 34.7 to an integer by rounding.

    d. Take the absolute value of -86, then convert it to a floating-point number.

CHAPTER 3

Strings

Numbers are fundamental to computing—in fact, crunching numbers is what computers were invented to do—but there are many other kinds of data in the world as well, such as addresses, pictures, and music. Each of these can be represented as a data type, and knowing how to manipulate those data types is a big part of being able to program. This chapter introduces a non-numeric data type that represents text, such as the words in this sentence or the sequence of bases in a strand of DNA. Along the way, we will see how to make programs a little more interactive.

3.1 Strings

Computers may have been invented to do arithmetic, but these days, most of them spend a lot of their time processing text. From desktop chat programs to Google, computers create text, store it, search it, and move it from one place to another.

In Python, a piece of text is represented as a *string*, which is a sequence of *characters* (letters, numbers, and symbols). The simplest data type for storing sequences of characters is `str`; it can store characters from the Latin alphabet found on most North American keyboards. Another data type called `unicode` can store strings containing any characters at all, including Chinese ideograms, chemical symbols, and Klingon. We will use the simpler type, `str`, in our examples.

In Python, we indicate that a value is a string by putting either single or double quotes around it:

```
>>> 'Aristotle'
'Aristotle'
>>> "Isaac Newton"
'Isaac Newton'
```

The quotes must match:

```
>>> 'Charles Darwin"
  File "<stdin>", line 1
    'Charles Darwin"
                   ^
SyntaxError: EOL while scanning single-quoted string
```

We can join two strings together by putting them side by side:

```
>>> 'Albert' 'Einstein'
'AlbertEinstein'
```

Notice that the words Albert and Einstein run together. If we want a space between the words, then we can add a space either to the end of Albert or to the beginning of Einstein:

```
>>> 'Albert ' 'Einstein'
'Albert Einstein'
>>> 'Albert' ' Einstein'
'Albert Einstein'
```

It's almost always clearer to join strings with +. When + has two string operands, then it is referred to as the *concatenation operator*:

```
>>> 'Albert' + ' Einstein'
'Albert Einstein'
```

Since the + operator is used for both numeric addition and for string concatenation, we call this an *overloaded operator*. It performs different functions based on the type of operands that it is applied to.

The shortest string is the *empty string*, containing no characters at all.

As the following example shows, it's the textual equivalent of 0—adding it to another string has no effect:

```
>>> ''
''
>>> "Alan Turing" + ''
'Alan Turing'
>>> "" + 'Grace Hopper'
'Grace Hopper'
```

Here is an interesting question: can the + operator be applied to a string and numeric value? If so, what function would be applied, addition or concatenation? We'll give it a try:

```
>>> 'NH' + 3
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
```

```
TypeError: cannot concatenate 'str' and 'int' objects
>>> 9 + ' planets'
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
TypeError: unsupported operand type(s) for +: 'int' and 'str'
```

This is the second time Python has told us that we have a type error. The first time, in *Local Variables*, on page 20, the problem was not passing the right number of parameters to a function. Here, Python took exception to our attempts to add values of different data types, because it doesn't know which version of + we want: the one that adds numbers or the one that concatenates strings.

In this case, it's easy for a human being to see what the right answer is. But what about this example?

```
>>> '123' + 4
```

Should Python produce the string '1234' or the integer 127? The answer is that it shouldn't do either: if it guesses what we want, it'll be wrong at least some of the time, and we will have to try to track down the problem without an error message to guide us.[1]

If you want to put a number in the middle of a string, the easiest way is to convert it via the built-in str function and then do the concatenation:

```
>>> '12' + str(34) + '56'
'123456'
```

The fact that Python will not combine strings and numbers using + doesn't mean that other operators can't combine strings and integers. In particular, we can repeat a string using the * operator, like this:

```
>>> 'AT' * 5
'ATATATATAT'
>>> 4 * '-'
'----'
```

If the integer is less than or equals to zero, then this operator yields the empty string (a string containing no characters):

```
>>> 'GC' * 0
''
>>> 'TATATATA' * -3
''
```

1. If you still aren't convinced, consider this: in JavaScript (a language used for web programming), '7'+0 is the string '70', but '7'-0 is 7.

3.2 Escape Characters

Suppose you want to put a single quote inside a string. If you write it directly, Python will complain:

```
>>> 'that's not going to work'
  File "<stdin>", line 1
    'that's not going to work'
          ^
SyntaxError: invalid syntax
```

The problem is that when Python sees the second quote—the one that you think of as being part of the string—it thinks the string is over. It then doesn't know what to do with all the stuff that comes after the second quote.

One simple way to fix this is to use double quotes around the string:

```
>>> "that's better"
"that's better"
```

If you need to put a double quote in a string, you can use single quotes around the string. But what if you want to put both kinds of quote in one string? You could do this:

```
>>> 'She said, "That' + "'" + 's hard to read."'
```

Luckily, there's a better way. If you type the previous expression into Python, the result is as follows:

```
'She said, "That\'s hard to read."'
```

The combination of the backslash and the single quote is called an *escape sequence*. The name comes from the fact that we're "escaping" from Python's usual syntax rules for a moment. When Python sees a backslash inside a string, it means that the next character represents something special—in this case, a single quote, rather than the end of the string. The backslash is called an *escape character*, since it signals the start of an escape sequence.

As shown in Table 3, *Escape sequences*, on page 31, Python recognizes several escape sequences. In order to see how most are used, we will have to introduce two more ideas: multiline strings and printing.

3.3 Multiline Strings

If you create a string using single or double quotes, the whole string must fit onto a single line.

Here's what happens when you try to stretch a string across multiple lines:

Escape Sequence	Description
\n	End of line
\\	Backslash
\'	Single quote
\"	Double quote
\t	Tab

Table 3—Escape sequences

```
>>> 'one
Traceback (most recent call last):
  File "<string>", line 1, in <string>
Could not execute because an error occurred:
  EOL while scanning single-quoted string: <string>, line 1, pos 4:
  'one
```

EOL stands for "end of line," so in this error report, Python is saying that it reached the end of the line before it found the end of the string.

To span multiple lines, put three single quotes or three double quotes around the string instead of one of each. The string can then span as many lines as you want:

```
>>> '''one
... two
... three'''
'one\ntwo\nthree'
```

Notice that the string Python creates contains a \n sequence everywhere our input started a new line. In reality, each of the three major operating systems uses a different set of characters to indicate the end of a line. This set of characters is called a *newline*. On Linux, a newline is one '\n' character; on version 9 and earlier of Mac OS X, it is one '\r'; and on Windows, the ends of lines are marked with both characters as '\r\n'.

Python always uses a single \n to indicate a newline, even on operating systems like Windows that do things other ways. This is called *normalizing* the string; Python does this so that you can write exactly the same program no matter what kind of machine you're running on.

3.4 Print

So far, we have been able to display the value of only one variable or expression at a time. Real programs often want to display more information, such as the values of multiple variable values. This can be done using a print statement:

```
>>> print 1 + 1
2
>>> print "The Latin 'oryctolagus cuniculus' means 'domestic rabbit'."
The Latin 'oryctolagus cuniculus' means 'domestic rabbit'.
```

The first statement does what you'd expect from the numeric examples we've seen previously, but the second does something slightly different from previous string examples: it strips off the quotes around the string and shows us the string's contents, rather than its representation. This example makes the difference between the two even clearer:

```
>>> print 'In 1859, Charles Darwin revolutionized biology'
In 1859, Charles Darwin revolutionized biology
>>> print 'and our understanding of ourselves'
and our understanding of ourselves
>>> print 'by publishing "On the Origin of Species".'
by publishing "On the Origin of Species".
```

And the following example shows that when Python prints a string, it prints the values of any escape sequences in the string, rather than their backslashed representations:

```
>>> print 'one\ttwo\nthree\tfour'
one     two
three   four
```

This example shows how the tab character \t can be used to lay values out in columns. A print statement takes a comma-separated list of items to print and displays them on a line of their own. If no values are given, print simply displays a blank line. You can use any mix of types in the list; Python always inserts a single space between each value:

```
>>> area = 3.14159 * 5 * 5
>>> print "The area of the circle is", area, "sq cm."
The area of the circle is 78.539750 sq cm.
```

3.5 Formatted Printing

Sometimes, Python's default printing rules aren't what we want. In these cases, we can specify the exact format we want for our output by providing Python with a *format string*:

```
>>> print "The area of the circle is %f sq cm." % area
The area of the circle is 78.539750 sq cm.
```

In the previous statement, %f is a *conversion specifier*. It indicates where the value of the variable area is to be inserted. Other markers that we might use are %s, to insert a string value, and %d, to insert an integer. The letter following the % is called the *conversion type*.

The % between the string and the value being inserted is another overloaded operator. We used % earlier for modulo; here, it is the *string formatting* operator. It does *not* modify the string on its left side, any more than the + in 3 + 5 changes the value of 3. Instead, the string formatting operator returns a new string.

We can use the string formatting operator to lay out several values at once. Here, for example, we are laying out a float and an int at the same time:

```
>>> rabbits = 17
>>> cage = 10
>>> print "%f rabbits are in cage #%d." % (rabbits, cage)
17.000000 rabbits are in cage #10.
```

As we said earlier, print automatically puts a newline at the end of a string. This isn't necessarily what we want; for example, we might want to print several pieces of data separately and have them all appear on one line. To prevent the newline from being added, put a comma at the end of the print statement:

```
>>> print rabbits,
17>>>
```

3.6 User Input

In an earlier chapter, we explored some built-in functions. Another built-in function that you will find useful is raw_input, which reads a single line of text from the keyboard. The "raw" part means that it returns whatever the user enters as a string, even if it looks like a number:

```
>>> line = raw_input()
Galapagos Islands
>>> print line
Galapagos Islands
>>> line = raw_input()
123
>>> print line * 2
123123
```

If you are expecting the user to enter a number, you must use int or float to convert the string to the required type:

```
>>> value = raw_input()
123
>>> value = int(value)
>>> print value * 2
246
>>> value = float(raw_input())
Galapagos
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
ValueError: invalid literal for float(): Galapagos
```

Finally, raw_input can be given a string argument, which is used to prompt the user for input:

```
>>> name = raw_input("Please enter a name: ")
Please enter a name: Darwin
>>> print name
Darwin
```

3.7 Summary

In this chapter, we learned the following:

- Python uses the string type str to represent text as sequences of characters.
- Strings are usually created by placing pairs of single or double quotes around the text. Multiline strings can be created using matching pairs of triple quotes.
- Special characters like newline and tab are represented using escape sequences that begin with a backslash.
- Values can be displayed on the screen using a print statement and input can be provided by the user using raw_input.

3.8 Exercises

Here are some exercises for you to try on your own:

1. For each of the following expressions, what value will the expression give? Verify your answers by typing the expressions into the Python shell.

   a. 'Comp' 'Sci'

   b. 'Computer' + ' Science'

   c. 'H20' * 3

   d. 'C02' * 0

2. For each of the following phrases, express them as Python strings using the appropriate type of quotation marks (single, double or triple) and, if necessary, escape sequences:

   a. They'll hibernate during the winter.

   b. "Absolutely not," he said.

   c. "He said, 'Absolutely not,'" recalled Mel.

   d. hydrogen sulfide

   e. left\right

3. Rewrite the following string using single or double quotes instead of triple quotes:

```
'''A
B
C'''
```

4. Use the built-in function `len` to find the length of the empty string.

5. Given variables `x` and `y`, which refer to values 3 and 12.5 respectively, use `print` to display the following messages. When numbers appear in the messages, the variables `x` and `y` should be used in the `print` statement.

   a. The rabbit is 3.

   b. The rabbit is 3 years old.

   c. 12.5 is average.

   d. 12.5 * 3

   e. 12.5 * 3 is 37.5.

6. Section 3.5, *Formatted Printing*, on page 32, introduced the use of the `%` operator to format strings for output. Explain what formats you would use to get the following outputs:

   a. `"___" % 34.5 => "34.50"`

   b. `"___" % 34.5 => "3.45e+01"`

   c. `"___" % 8 => "0008"`

   d. `"___" % 8 => "8 "`

7. Use `raw_input` to prompt the user for a number and store the number entered as a `float` in a variable named `num`, and then print the contents of `num`.

8. If you enter two strings side by side in Python, it automatically concatenates them:

   ```
   >>> 'abc' 'def'
   'abcdef'
   ```

   If those same strings are stored in variables, though, putting them side by side is a syntax error:

   ```
   >>> left = 'abc'
   >>> right = 'def'
   >>> left right
     File "<stdin>", line 1
   left right
    ^
   SyntaxError: invalid syntax
   ```

   Why do you think Python doesn't let you do this?

9. Some people believe that multiplying a string by a negative number ought to produce an error, rather than an empty string. Explain why they might think this. If you agree, explain why; if you don't, explain why not.

CHAPTER 4

Modules

Mathematicians don't prove every theorem from scratch. Instead, they build their proofs on the truths their predecessors have already established. In the same way, it's vanishingly rare for someone to write all of a program herself; it's much more common—and productive—to make use of the millions of lines of code that other programmers have written before.

A *module* is a collection of functions that are grouped together in a single file. Functions in a module are usually related to each other in some way; for example, the math module contains mathematical functions such as cos (cosine) and sqrt (square root). This chapter shows you how to use some of the hundreds of modules that come with Python and how to create new modules of your own. You will also see how you can use Python to explore and view images.

4.1 Importing Modules

When you want to refer to someone else's work in a scientific paper, you have to cite it in your bibliography. When you want to use a function from a module, you have to *import* it. To tell Python that you want to use functions in the math module, for example, you use this import statement:

```
>>> import math
```

Once you have imported a module, you can use the built-in help function to see what it contains:[1]

```
>>> help(math)
Help on built-in module math:
```

1. When you do this interactively, Python displays only a screenful of information at a time. Press the spacebar when you see the "More" prompt to go to the next page.

```
NAME
    math

FILE
    (built-in)

DESCRIPTION
    This module is always available.  It provides access to the
    mathematical functions defined by the C standard.

FUNCTIONS
    acos(...)
        acos(x)

        Return the arc cosine (measured in radians) of x.

    asin(...)
        asin(x)

        Return the arc sine (measured in radians) of x.
...
```

Great—our program can now use all the standard mathematical functions. When we try to calculate a square root, though, we get an error telling us that Python is still unable to find the function sqrt:

```
>>> sqrt(9)
Traceback (most recent call last):
  File "<string>", line 1, in <string>
NameError: name 'sqrt' is not defined
```

The solution is to tell Python explicitly to look for the function in the math module by combining the module's name with the function's name using a dot:

```
>>> math.sqrt(9)
3.0
```

The reason we have to join the function's name with the module's name is that several modules might contain functions with the same name. For example, does the following call to floor refer to the function from the math module that rounds a number down or the function from the (completely fictional) building module that calculates a price given an area (see Figure 8, *How import works*, on page 39)?

```
>>> import math
>>> import building
>>> floor(22.7)
```

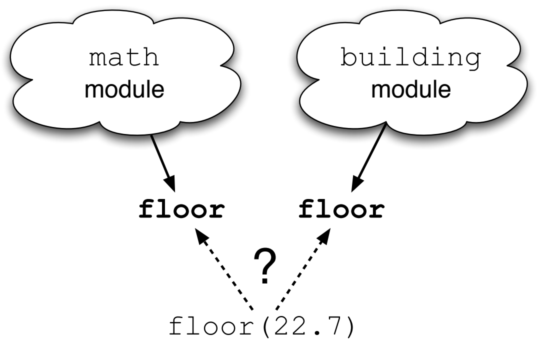


Figure 8—How import works

Once a module has been imported, it stays in memory until the program ends. There are ways to “unimport” a module (in other words, to erase it from memory) or to reimport a module that has changed while the program is running, but they are rarely used. In practice, it’s almost always simpler to stop the program and restart it.

Modules can contain more than just functions. The math module, for example, also defines some variables like pi. Once the module has been imported, you can use these variables like any others:

```
>>> math.pi
3.1415926535897931
>>> radius = 5
>>> print 'area is %6f' % (math.pi * radius ** 2)
area is 78.539816
```

You can even assign to variables imported from modules:

```
>>> import math
>>> math.pi = 3 # would turn circles into hexagons
>>> radius = 5
>>> print 'circumference is', 2 * math.pi * radius
circumference is 30
```

Don’t do this! Changing the value of π is not a good idea. In fact, it’s such a bad idea that many languages allow programmers to define unchangeable *constants* as well as variables. As the name suggests, the value of a constant cannot be changed after it has been defined: π is always 3.14159 and a little bit, while SECONDS_PER_DAY is always 86,400. The fact that Python doesn’t allow programmers to “freeze” values like this is one of the language’s few significant flaws.

Combining the module's name with the names of the things it contains is safe, but it isn't always convenient. For this reason, Python lets you specify exactly what you want to import from a module, like this:

```
>>> from math import sqrt, pi
>>> sqrt(9)
3.0
>>> radius = 5
>>> print 'circumference is %6f' % (2 * pi * radius)
circumference is 31.415927
```

This can lead to problems when different modules provide functions that have the same name. If you import a function called spell from a module called magic and then you import another function called spell from the module grammar, the second replaces the first. It's exactly like assigning one value to a variable, then another: the most recent assignment or import wins.

This is why it's usually *not* a good idea to use import *, which brings in everything from the module at once. It saves some typing:

```
>>> from math import *
>>> '%6f' % sqrt(8)
'2.828427'
```

but using it means that every time you add anything to a module, you run the risk of breaking every program that uses it.

The standard Python library contains several hundred modules to do everything from figuring out what day of the week it is to fetching data from a website. The full list is online at http://docs.python.org/modindex.html; although it's far too much to absorb in one sitting (or even one course), knowing how to use the library well is one of the things that distinguishes good programmers from poor ones.

4.2 Defining Your Own Modules

Section 2.1, *The Big Picture,* on page 7 explained that in order to save code for later use, you can put it in a file with a .py extension. You can then tell Python to run the code in that file, rather than typing commands in at the interactive prompt. What we didn't tell you then is that every Python file can be used as a module. The name of the module is the same as the name of the file, but without the .py extension.

For example, the following function is taken from Section 2.6, *Function Basics,* on page 18:

The __builtins__ Module

Python's built-in functions are actually in a module named _builtins_. The double underscores before and after the name signal that it's part of Python; we'll see this convention used again later for other things. You can see what's in the module using help(_builtins_), or if you just want a directory, you can use dir instead (which works on other modules as well):

```
>>> dir(__builtins__)
['ArithmeticError', 'AssertionError', 'AttributeError',
'BaseException', 'DeprecationWarning', 'EOFError', 'Ellipsis',
'EnvironmentError', 'Exception', 'False', 'FloatingPointError',
'FutureWarning', 'GeneratorExit', 'IOError', 'ImportError',
'ImportWarning', 'IndentationError', 'IndexError', 'KeyError',
'KeyboardInterrupt', 'LookupError', 'MemoryError', 'NameError',
'None', 'NotImplemented', 'NotImplementedError', 'OSError',
'OverflowError', 'PendingDeprecationWarning', 'ReferenceError',
'RuntimeError', 'RuntimeWarning', 'StandardError',
'StopIteration', 'SyntaxError', 'SyntaxWarning', 'SystemError',
'SystemExit', 'TabError', 'True', 'TypeError',
'UnboundLocalError', 'UnicodeDecodeError', 'UnicodeEncodeError',
'UnicodeError', 'UnicodeTranslateError', 'UnicodeWarning',
'UserWarning', 'ValueError', 'Warning', 'ZeroDivisionError', '_',
'__debug__', '__doc__', '__import__', '__name__', 'abs', 'all',
'any', 'apply', 'basestring', 'bool', 'buffer', 'callable',
'chr', 'classmethod', 'cmp', 'coerce', 'compile', 'complex',
'copyright', 'credits', 'delattr', 'dict', 'dir', 'divmod',
'enumerate', 'eval', 'execfile', 'exit', 'file', 'filter',
'float', 'frozenset', 'getattr', 'globals', 'hasattr', 'hash',
'help', 'hex', 'id', 'input', 'int', 'intern', 'isinstance',
'issubclass', 'iter', 'len', 'license', 'list', 'locals', 'long',
'map', 'max', 'min', 'object', 'oct', 'open', 'ord', 'pow',
'property', 'quit', 'range', 'raw_input', 'reduce', 'reload',
'repr', 'reversed', 'round', 'set', 'setattr', 'slice', 'sorted',
'staticmethod', 'str', 'sum', 'super', 'tuple', 'type', 'unichr',
'unicode', 'vars', 'xrange', 'zip']
```

As of Python 2.5, 32 of the 135 things in _builtins_ are used to signal errors of particular kinds, such as SyntaxError and ZeroDivisionError. There are also functions called copyright, which tells you who holds the copyright on Python, and license, which displays Python's rather complicated license. We'll meet some of this module's other members in later chapters.

Download modules/convert.py

```
def to_celsius(t):
    return (t - 32.0) * 5.0 / 9.0
```

Put this function definition in a file called temperature.py, and then add another function called above_freezing that returns True if its argument's value is above freezing (in Celsius), and False otherwise:

Download modules/freezing.py
```
def above_freezing(t):
    return t > 0
```

Congratulations—you have now created a module called temperature:

Download modules/temperature.py
```
def to_celsius(t):
    return (t - 32.0) * 5.0 / 9.0

def above_freezing(t):
    return t > 0
```

Now that you've created this file, you can now import it like any other module:

```
>>> import temperature
>>> temperature.above_freezing(temperature.to_celsius(33.3))
True
```

What Happens During Import

Let's try another experiment. Put the following in a file called experiment.py:

Download modules/experiment.py
```
print "The panda's scientific name is 'Ailuropoda melanoleuca'"
```

and then import it (or click Wing 101's Run button):

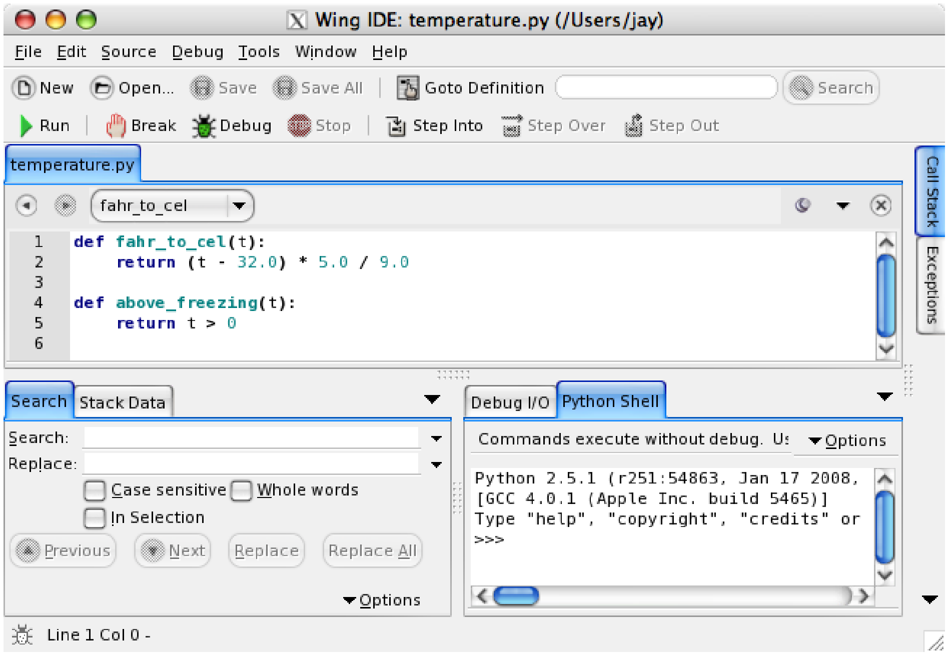
```
>>> import experiment
The panda's scientific name is 'Ailuropoda melanoleuca'
```

What this shows is that *Python executes modules as it imports them.* You can do anything in a module you would do in any other program, because as far as Python is concerned, it's just another bunch of statements to be run.

Let's try another experiment. Start a fresh Python session, and try importing the experiment module twice in a row:

```
>>> import experiment
The panda's scientific name is 'Ailuropoda melanoleuca'
>>> import experiment
>>>
```

Notice that the message wasn't printed the second time. That's because Python loads modules only the first time they are imported. Internally, Python keeps track of the modules it has already seen; when it is asked to load one that's already in that list, it just skips over it. This saves time and will be particularly important when you start writing modules that import other modules, which in turn import other modules—if Python didn't keep


Wing IDE: temperature.py (/Users/jay)
File Edit Source Debug Tools Window Help
New Open... Save Save All Goto Definition Search
Run Break Debug Stop Step Into Step Over Step Out
temperature.py
fahr_to_cel
Call Stack
Exceptions
Search Stack Data
Search:
Replace:
Case sensitive Whole words
In Selection
Previous Next Replace Replace All
Options
Debug I/O Python Shell
Commands execute without debug. U:
Options
Line 1 Col 0 -

```
def fahr_to_cel(t):
    return (t - 32.0) * 5.0 / 9.0

def above_freezing(t):
    return t > 0
```

```
Python 2.5.1 (r251:54863, Jan 17 2008,
[GCC 4.0.1 (Apple Inc. build 5465)]
Type "help", "copyright", "credits" or
>>>
```

Figure 9—The temperature module in Wing 101

track of what was already in memory, it could wind up loading commonly used modules like math dozens of times.

Using __main__

As we've now seen, every Python file can be run directly from the command line or IDE or can be imported and used by another program. It's sometimes useful to be able to tell inside a module which is happening, in other words, whether the module is the main program that the user asked to execute or whether some other module has that honor.

Python defines a special variable called __name__ in every module to help us figure this out. Suppose we put the following into echo.py:

Download modules/echo.py

```
print "echo: __name__ is", __name__
```

If we run this file, its output is as follows:

```
echo: __name__ is __main__
```

As promised, Python has created the variable __name__. Its value is "__main__", meaning, "This module is the main program."

But look at what happens when we import echo.py, instead of running it directly:

```
>>> import echo
echo: __name__ is echo
```

The same thing happens if we write a program that does nothing but import our echoing module:

Download modules/import_echo.py
```python
import echo
print "After import, __name__ is", __name__, "and echo.__name__ is", echo.__name__
```

which, when run from the command line, produces this:

```
echo: __name__ is echo
After import, __name__ is __main__ and echo.__name__ is echo
```

What's happening here is that when Python imports a module, it sets that module's __name__ variable to be the name of the module, rather than the special string "__main__". This means that a module can tell whether it is the main program:

Download modules/test_main.py
```python
if __name__ == "__main__":
    print "I am the main program"
else:
    print "Someone is importing me"
```

Try it. See what happens when you run it directly and when you import it.

Knowing whether a module is being imported or not turns out to allow a few handy programming tricks. One is to provide help on the command line whenever someone tries to run a module that's meant to be used as a library. For example, think about what happens when you run the following on the command line vs. importing it into another program:

Download modules/main_help.py
```python
'''
This module guesses whether something is a dinosaur or not.
'''

def is_dinosaur(name):
    '''
    Return True if the named creature is recognized as a dinosaur,
    and False otherwise.
    '''
    return name in ['Tyrannosaurus', 'Triceratops']
if __name__ == '__main__':
    help(__name__)
```

We will see other uses in the following sections and in later chapters.

Providing Help

Let's return to the temperature module for a moment and modify it to round temperatures off. We'll put the result in temp_round.py:

Download modules/temp_round.py
```
def to_celsius(t):
    return round((t - 32.0) * 5.0 / 9.0)

def above_freezing(t):
    return t > 0
```

What happens if we ask for help on the function to_celsius?

```
>>> import temp_round
>>> help(temp_round)
Help on module temp_round:

NAME
    temp_round

FILE
    /home/pybook/modules/temp_round.py

FUNCTIONS
    above_freezing(t)

    to_celsius(t)
```

That's not much use: we know the names of the functions and how many parameters they need, but not much else. To provide something more useful, we should add *docstrings* to the module and the functions it contains and save the result in temp_with_doc.py:

Download modules/temp_with_doc.py
```
'''Functions for working with temperatures.'''

def to_celsius(t):
    '''Convert Fahrenheit to Celsius.'''
    return round((t - 32.0) * 5.0 / 9.0)

def above_freezing(t):
    '''True if temperature in Celsius is above freezing, False otherwise.'''
    return t > 0
```

Asking for help on this module produces a much more useful result.

```
>>> import temp_with_doc
>>> help(temp_with_doc)
Help on module temp_with_doc:

NAME
    temp_with_doc - Functions for working with temperatures.

FILE
    /home/pybook/modules/temp_with_doc.py

FUNCTIONS
    above_freezing(t)
        True if temperature in Celsius is above freezing, False otherwise.

    to_celsius(t)
        Convert Fahrenheit to Celsius.
```

The term *docstring* is short for "documentation string." Docstrings are easy to create: if the first thing in a file or a function is a string that isn't assigned to anything, Python saves it so that help can print it later.

You might think that a module this small doesn't need much documentation. After all, it has only two functions, and their names are pretty descriptive of what they do. But writing documentation is more than a way to earn a few extra marks—it's essential to making software usable. Small programs have a way of turning into larger and more complicated ones. If you don't document as you go along and keep the documentation in the same file as the program itself, you will quickly lose track of what does what.

4.3 Objects and Methods

Numbers and strings may have been enough to keep programmers happy back in the twentieth century, but these days, people expect to work with images, sound, and video as well. A Python module called media provides functions for manipulating and viewing pictures; it isn't in the standard library, but it can be downloaded for free from http://packages.python.org/PyGraphics/. (One of the exercises discusses why it needs a separate download.)

In order to understand how media works, we first have to introduce two concepts that are fundamental to modern program design. And to do *that*, we have to back up and take another look at strings.

So far, we have seen two operators that work on strings: concatenation (+), which "adds" strings, and formatting (%), which gives you control over how values are displayed. There are dozens of other things we might want to do to strings, such as capitalize them, strip off any leading or trailing blanks, or find out whether one string is contained inside another. Having single-character operators such as + and - for all of these is impractical, because we would quickly run out of letters and have to start using two- and three-character combinations that would be impossible to remember.

We could put all the functions that work on strings in a module and ask users to load that module, but there's a simpler way to solve the problem. Python strings "own" a set of special functions called *methods*. These are called just like the functions inside a module. If we have a string like 'hogwarts', we can capitalize it by calling 'hogwarts'.capitalize(), which returns 'Hogwarts'. Similarly, if the variable villain has been assigned the string 'malfoy', the expression villain.capitalize() will return the string 'Malfoy'.

Every string we create automatically shares all the methods that belong to the string data type. The most commonly used ones are listed in Table 4, *Common string methods*, on page 48; you can find the complete list in Python's online documentation or type help(str) into the command prompt.

Using methods is almost the same as using functions, though a method almost always does something to or with the thing that owns it. For example, let's call the startswith method on the string 'species':

```
>>> 'species'.startswith('a')
False
>>> 'species'.startswith('s')
True
```

The method startswith takes a string argument and returns a bool to tell us whether the string whose method was called—the one on the left of the dot—starts with the string that is given as an argument. String also has an endswith method:

```
>>> 'species'.endswith('a')
False
>>> 'species'.endswith('s')
True
```

We can chain multiple method calls together in a single line by calling a method of the value returned by another method call. To show how this works, let's start by calling swapcase to change lowercase letters to uppercase and uppercase to lowercase:

```
>>> 'Computer Science'.swapcase()
'cOMPUTER sCIENCE'
```

Method	Description
capitalize()	Returns a copy of the string with the first letter capitalized
find(s)	Returns the index of the first occurrence of s in the string, or -1 if s is not in the string
find(s, beg)	Returns the index of the first occurrence of s after index beg in the string, or -1 if s is not in the string after index beg
find(s, beg, end)	Returns the index of the first occurrence of s between indices beg and end in the string, or -1 if s is not in the string between indices beg and end
islower()	Tests that all characters are lowercase
isupper()	Tests that all characters are uppercase
lower()	Returns a copy of the string with all characters converted to lowercase
replace(old, new)	Returns a copy of the string with all occurrences of the substring old replaced with new
split()	Returns the space-separated words as a list
split(del)	Returns the del-separated words as a list
strip()	Returns a copy of the string with leading and trailing whitespace removed
strip(s)	Returns a copy of the string with the characters in s removed
upper()	Returns a copy of the string with all characters converted to uppercase

Table 4—Common string methods

Since the result of this method is a string, we can immediately call the result's endswith method to check that the first call did the right thing to the last few letters of the original string.

```
>>> 'Computer Science'.swapcase().endswith('ENCE')
True
```

In Figure 10, *Chaining method calls*, on page 49, we can see what's going on when we do this. Note that Python automatically creates a temporary variable to hold the value of the swapcase method call long enough for it to call that value's endswith method.

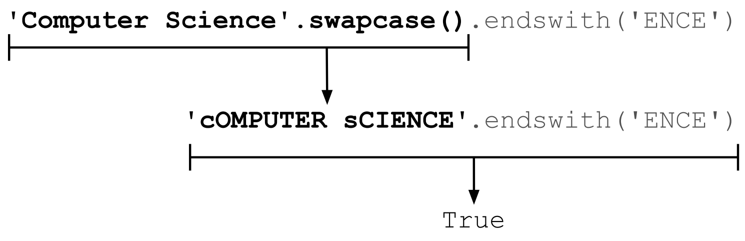

'Computer Science'.swapcase().endswith('ENCE')
'cOMPUTER sCIENCE'.endswith('ENCE')
True

Figure 10—Chaining method calls

Something that has methods is called an *object*. It turns out that *everything* in Python is an object, even the number zero:

```
>>> help(0)
Help on int object:

class int(object)
 |  int(x[, base]) -> integer
 |
 |  Convert a string or number to an integer, if possible.  A floating point
 |  argument will be truncated towards zero (this does not include a string
 |  representation of a floating point number!)  When converting a string, use
 |  the optional base.  It is an error to supply a base when converting a
 |  non-string. If the argument is outside the integer range a long object
 |  will be returned instead.
 |
 |  Methods defined here:
 |
 |  __abs__(...)
 |      x.__abs__() <==> abs(x)
 |
 |  __add__(...)
 |      x.__add__(y) <==> x+y
...
```

Most modern programming languages are structured this way: the "things" in the program are objects, and most of the code in the program consists of methods that use the data stored in those objects. Chapter 13, *Object-Oriented Programming*, on page 245 will show you how to create new kinds of objects; for now, let's take a look at the objects Python uses to store and manipulate images.

Images

Now that we have seen the basic features of modules, objects, and methods, let's look at how they can solve real-world problems. For our running example, we will write some programs that display and manipulate pictures and other images.

Suppose you have a file called pic207.jpg on your hard drive and want to display it on your screen. You could double-click to open it, but what does that actually *do*? To start to answer that question, type the following into a Python prompt:

```
>>> import media
>>> f = media.choose_file()
>>> pic = media.load_picture(f)
>>> media.show(pic)
```

Figure 11—Madeleine

When the file dialog box opens, navigate to pic207.jpg. The result should be the awesomely cute photo shown in Figure 11, *Madeleine*, on page 51. Here's what the commands shown earlier actually did:

1. Import the functions from the media module.
2. Call that module's choose_file function to open a file-choosing dialog box. This call returns a string that contains the path to the picture file.
3. Call the module's load_picture function to read the contents of the picture file into memory. This creates a Python object, which is assigned to the variable pic.
4. Call that module's show function, which launches another program to display the picture. Python has to launch another program because it can't print the picture out at the command line.

Double-clicking would definitely have been easier.

But let's see your mouse do this:

```
>>> pic.get_width()
500
>>> pic.get_height()
375
>>> pic.title
'modules/pic207.jpg'
```

The first two commands tell us how wide and high the picture is in pixels. The third tells us the path to the file containing the picture.

Now try this:

```
>>> media.crop_picture(pic, 150, 50, 450, 300)
>>> media.show(pic)
>>> media.save_as(pic, 'pic207cropped.jpg')
```

As you can guess from the name, crop crops the picture. The upper-left corner is (150, 50), and the lower-right corner is (450, 300); the resulting picture is shown in Figure 12, *Madeleine cropped*, on page 53.

The code also shows the new picture and then writes it to a new file. This file is saved in the *current working directory*, which by default is the directory in which the program is running. On our system this happens to be '/Users/pgries/'.

Now let's put Madeleine's name on her hat. To do that, we use picture's add_text function; the result is shown in Figure 13, *Madeleine named*, on page 53.

```
>>> media.add_text(pic, 115, 40, 'Madeleine', media.magenta)
>>> media.show(pic)
```

Function choose_file is useful for writing interactive programs, but when we know exactly which files we want or we want more than one file, it's often easier to skip that navigation step. As an example, let's open up all three pictures of Madeleine in a single program:

Download modules/show_madeleine.py

```
import media

pic1 = media.load_picture('pic207.jpg')
media.show(pic1)
pic2 = media.load_picture('pic207cropped.jpg')
media.show(pic2)
pic3 = media.load_picture('pic207named.jpg')
media.show(pic3)
```

Since we haven't specified what directory to find the files in, the program looks for them in the current working directory. If the program can't find them there, it reports an error.

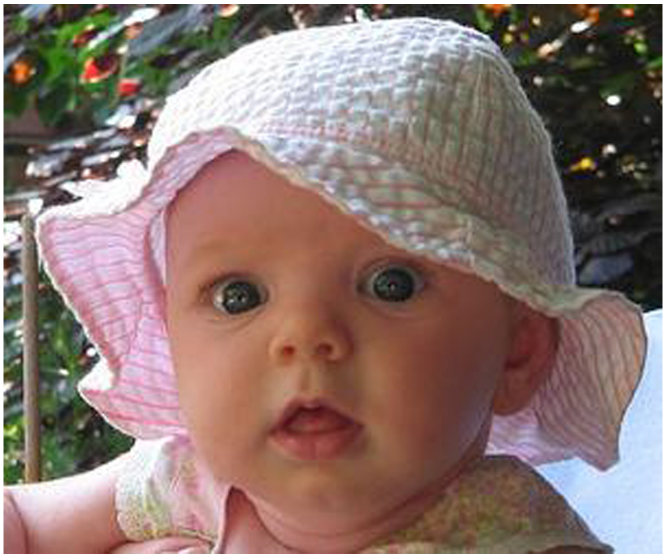


Figure 12—Madeleine cropped

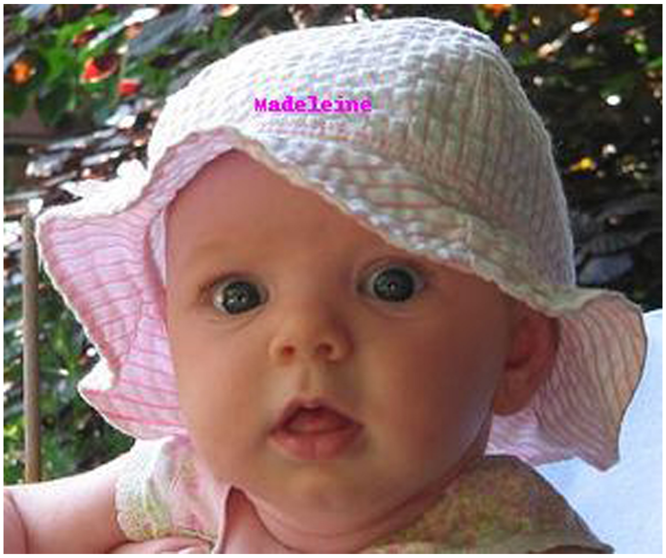


Figure 13—Madeleine named

Color	Value
black	Color(0, 0, 0)

Color	Value
white	Color(255, 255, 255)
red	Color(255, 0, 0)
green	Color(0, 255, 0)
blue	Color(0, 0, 255)
magenta	Color(255, 0, 255)
yellow	Color(255, 255, 0)
aqua	Color(0, 255, 255)
pink	Color(255, 192, 203)
purple	Color(128, 0, 128)

Table 5—Example color values

4.4 Pixels and Colors

Most people want to do a lot more to pictures than just display them and crop them. If you do a lot of digital photography, you may want to remove the "red-eye" caused by your camera flash. You might also want to convert pictures to black and white for printing, highlight certain objects, and so on.

To do these things, you must work with the individual *pixels* that make up the image. The media module represents pixels using the *RGB color model* discussed in *RGB and Hexadecimal*, on page 59. Module media provides a Color type and more than 100 predefined Color values. Several of them are listed in Table 5, *Example color values*, on page 53; black is represented as "no blue, no green, no red," white is the maximum possible amount of all three, and other colors lie somewhere in between.

The media module provides functions for getting and changing the colors in pixels (see Table 6, *Pixel-manipulation functions*, on page 55) and for manipulating colors themselves (see Table 7, *Color functions*, on page 56).

To see how these functions are used, let's go through all the pixels in Madeleine's cropped and named picture and make it look like it was taken at sunset. To do this, we're going to remove some of the blue and some of the green from each pixel, making the picture darker and redder.[2]

2. We're not actually adding any red, but reducing the amount of blue and green will fool the eye into thinking we have.

Function	Description
get_red(pixel)	Gets the red component of pixel
set_red(pixel, value)	Sets the red component of pixel to value
get_blue(pixel)	Gets the blue component of pixel
set_blue(pixel, value)	Sets the blue component of pixel to value
get_green(pixel)	Gets the green component of pixel
set_green(pixel, value)	Sets the green component of pixel to value
get_color(pixel)	Gets the color of pixel
set_color(pixel, color)	Sets the color of pixel to color

Table 6—Pixel-manipulation functions

Download modules/sunset.py

```
import media

pic = media.load_picture('pic207.jpg')
media.show(pic)
for p in media.get_pixels(pic):
    new_blue = int(0.7 * media.get_blue(p))
    new_green = int(0.7 * media.get_green(p))
    media.set_blue(p, new_blue)
    media.set_green(p, new_green)

media.show(pic)
```

Some things to note:

- Color values are integers, so we need to convert the result of multiplying the blue and green by 0.7 using the function int.
- The for loop does something to each pixel in the picture. We will talk about for loops in detail in Section 5.4, *Processing List Items*, on page 75, but just reading the code aloud will give you the idea that it associates each pixel in turn with the variable p, extracts the blue and green components, calculates new values for them, and then resets the values in the pixel.

Try this on a picture of your own, and see how convincing the result is.

4.5 Testing

Another use for modules in real-world Python programming is to make sure that programs don't just run but also produce the right answers. In science, for example, the programs you use to analyze experimental data must be

Function	Description
darken(color)	Returns a color slightly darker than color
lighten(color)	Returns a color slightly lighter than color
create_color(red, green, blue)	Returns color (red, green, blue)
distance(c1, c2)	Returns how far apart colors c1 and c2 are

Table 7—Color functions

at least as reliable as the lab equipment you used to collect that data, or there's no point running the experiment. The programs that run CAT scanners and other medical equipment must be even more reliable, since lives depend on them. As it happens, the tools used to make sure that these programs are behaving correctly can also be used by instructors to grade students' assignments and by students to check their programs before submitting them.

Checking that software is doing the right thing is called *quality assurance*, or QA. Over the last fifty years, programmers have learned that quality isn't some kind of magic pixie dust that you can sprinkle on a program after it has been written. Quality has to be designed in, and software must be tested and retested to check that it meets standards.

The good news is that putting effort into QA actually makes you more productive overall. The reason can be seen in Boehm's curve in Figure 14, *Boehm's curve*, on page 57. The later you find a bug, the more expensive it is to fix, so catching bugs early reduces overall effort.

Most good programmers today don't just test their software while writing it; they build their tests so that other people can rerun them months later and a dozen time zones away. This takes a little more time up front but makes programmers more productive overall, since every hour invested in preventing bugs saves two, three, or ten frustrating hours tracking bugs down.

One popular testing library for Python is called Nose, which can be downloaded for free at http://code.google.com/p/python-nose/ [3]. To show how it works, we will use it to test our temperature module. To start, create a new Python file called test_temperature.py. The name is important: when Nose runs,

3. We use Nose because it does not require any knowledge of object-oriented programming. Once you know about classes and objects, you should have a look at the unittest library that comes with Python.

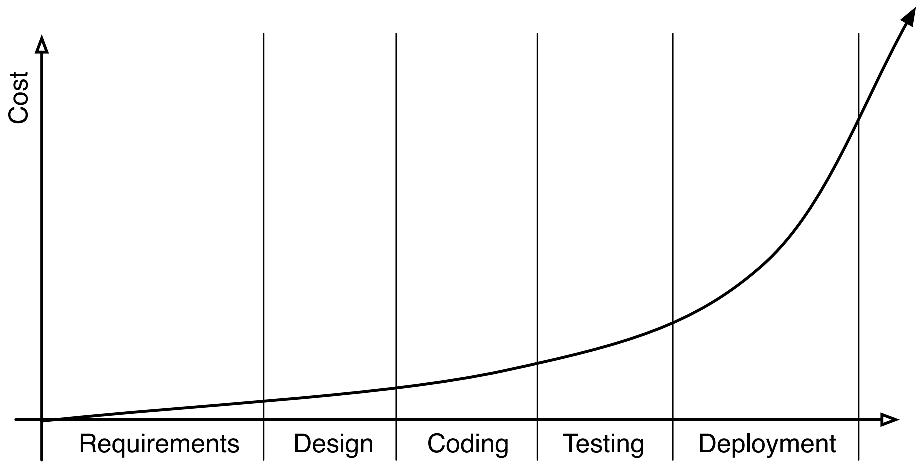


Figure 14—Boehm's curve

it automatically looks for files whose names start with the letters test_. The second part of the name is up to us—we could call it test_hagrid.py if we wanted to—but a sensible name will make it easier for other people to find things in our code.

Every Nose test module should contain the following:

- Statements to import Nose and the module to be tested
- Functions that actually test our module
- A function call to trigger execution of those test functions

Like the name of the test module, the names of the test functions must start with test_. Using the structure outlined earlier, our first sketch of a testing module looks like this:

Download modules/test_temperature.py

```
import nose
import temperature

def test_to_celsius():
    '''Test function for to_celsius'''
    pass # we'll fill this in later

def test_above_freezing():
    '''Test function for above_freezing.'''
    pass # we'll fill this in too

if __name__ == '__main__':
    nose.runmodule()
```

For now, each test function contains nothing except a docstring and a pass statement. As the name suggests, this does nothing—it's just a placeholder to remind ourselves that we need to come back and write some more code.

If you run the test module, the output starts with two dots to say that two tests have run successfully. (If a test fails, Nose prints an "F" instead to attract attention to the problem.) The summary after the dashed line tells us that Nose found and ran two tests, that it took less than a millisecond to do so, and that everything was OK:

```
..
----------------------------------------------------------------------
Ran 2 tests in 0.000s

OK
```

Two successful tests isn't surprising, since our functions don't actually test anything yet. The next step is to fill them in so that they actually do something useful. The goal of testing is to confirm that our code works properly; for to_celsius, this means that given a value in Fahrenheit, the function produces the corresponding value in Celsius.

It's clearly not practical to try every possible value—after all, there are a lot of real numbers. Instead, we select a few representative values and make sure the function does the right thing for them.

For example, let's make sure that the round-off version of to_celsius from *Providing Help*, on page 45 returns the right result for two reference values: 32 Fahrenheit (0 Celsius) and 212 Fahrenheit (100 Celsius). Just to be on the safe side, we should also check a value that doesn't translate so neatly. For example, 100 Fahrenheit is 37.777... Celsius, so our function should return 38 (since it's rounding off).

We can execute each test by comparing the *actual value* returned by the function with the *expected value* that it's supposed to return. In this case, we use an assert statement to let Nose know that to_celsius(100) should be 38:

Download modules/assert.py

```
import nose
from temp_with_doc import to_celsius

def test_freezing():
    '''Test freezing point.'''
    assert to_celsius(32) == 0

def test_boiling():
    '''Test boiling point.'''
```

RGB and Hexadecimal

In the red-green-blue (or RGB) color system, each pixel in a picture has a certain amount of the three primary colors in it, and each color component is specified by a number in the range 0–255 (which is the range of numbers that can be represented in a single 8-bit byte).

By tradition, RGB values are represented in *hexadecimal*, or base-16, rather than in the usual base-10 decimal system. The "digits" in hexadecimal are the usual 0–9, plus the letters A–F (or a–f). This means that the number after 9_{16} is not 10_{16}, but A_{16}; the number after A_{16} is B_{16}, and so on, up to F_{16}, which is followed by 10_{16}. Counting continues to $1F_{16}$, which is followed by 20_{16}, and so on, up to FF_{16} (which is $15_{10}\times16_{10} + 15_{10}$, or 255_{10}).

An RGB color is therefore six hexadecimal digits: two for red, two for green, and two for blue. Black is therefore #000000 (no color of any kind), while white is #FFFFFF (all colors saturated), and #008080 is a bluish-green (no red, half-strength green, half-strength blue).

```
    assert to_celsius(212) == 100

def test_roundoff():
    '''Test that roundoff works.'''
    assert to_celsius(100) == 38 # NOT 37.777...

if __name__ == '__main__':
    nose.runmodule()
```

When the code is executed, each test will have one of three outcomes:

- *Pass.* The actual value matches the expected value.
- *Fail.* The actual value is different from the expected value.
- *Error.* Something went wrong inside the test itself; in other words, the test code contains a bug. In this case, the test doesn't tell us anything about the system being tested.

Run the test module; the output should be as follows:

```
...
----------------------------------------------------------------------
Ran 3 tests in 0.002s

OK
```

As before, the dots tell us that the tests are passing.

Just to prove that Nose is doing the right thing, let's compare to_celsius's result with 37.8 instead:

Download modules/assert2.py
```
import nose
from temp_with_doc import to_celsius
def test_to_celsius():
    '''Test function for to_celsius'''
    assert to_celsius(100) == 37.8
if __name__ == '__main__':
    nose.runmodule()
```

This causes the test case to fail, so the dot corresponding to it is replaced by an "F," an error message is printed, and the number of failures is listed in place of OK:

```
F
======================================================================
FAIL: Test function for to_celsius
----------------------------------------------------------------------
Traceback (most recent call last):
  File "/python25/lib/site-packages/nose/case.py", line 202, in runTest
    self.test(*self.arg)
  File "assert2.py", line 6, in test_to_celsius
    assert to_celsius(100) == 37.8
AssertionError
----------------------------------------------------------------------
Ran 1 test in 0.000s

FAILED (failures=1)
```

The error message tells us that the failure happened in test_to_celsius on line 6. That is helpful, but the reason for failure can be made even clearer by adding a description of what is being tested to each assert statement.

Download modules/assert3.py
```
import nose
from temp_with_doc import to_celsius
def test_to_celsius():
    '''Test function for to_celsius'''
    assert to_celsius(100) == 37.8, 'Returning an unrounded result'
if __name__ == '__main__':
    nose.runmodule()
```

That message is then included in the output:

```
F
======================================================================
FAIL: Test function for to_celsius
----------------------------------------------------------------------
Traceback (most recent call last):
  File "c:\Python25\Lib\site-packages\nose\case.py", line 202, in runTest
    self.test(*self.arg)
  File "assert3.py", line 6, in test_to_celsius
    assert to_celsius(100) == 37.8, 'Returning an unrounded result'
AssertionError: Returning an unrounded result

----------------------------------------------------------------------
Ran 1 test in 0.000s

FAILED (failures=1)
```

Having tested test_to_celsius with one value, we need to decide whether any other test cases are needed. The description of that test case states that it is a positive value, which implies that we may also want to test our code with a value of 0 or a negative value. The real question is whether our code will behave differently for those values. Since all we're doing is some simple arithmetic, we probably don't need to bother; in future chapters, though, we will see functions that are complicated enough to need several tests each.

Let's move on to test_above_freezing. The function it is supposed to test, above_freezing, is supposed to return True for any temperature above freezing, so let's make sure it does the right thing for 89.4. We should also check that it does the right thing for a temperature below freezing, so we'll add a check for -42.

Finally, we should also test that the function does the right thing for the dividing case, when the temperature is exactly freezing. Values like this are often called *boundary cases*, since they lie on the boundary between two different possible behaviors of the function. Experience shows that boundary cases are much more likely to contain bugs than other cases, so it's always worth figuring out what they are and testing them.

The test module, including comments, is now complete:

Download modules/test_freezing.py

```
import nose
from temp_with_doc import above_freezing

def test_above_freezing():
    '''Test function for above_freezing.'''
    assert above_freezing(89.4), 'A temperature above freezing.'
    assert not above_freezing(-42), 'A temperature below freezing.'
    assert not above_freezing(0), 'A temperature at freezing.'

if __name__ == '__main__':
    nose.runmodule()
```

When we run it, its output is as follows:

```
.
----------------------------------------------------------------------
Ran 1 test in 0.000s

OK
```

Whoops—Nose believes that only one test was run, even though there are three assert statements in the file. The reason is that as far as Nose is concerned, each function is one test. If some of those functions want to check several things, that's their business. The problem with this is that as soon as one assertion fails, Python stops executing the function it's in. As a result, if the first check in test_above_freezing failed, we wouldn't get any information from the ones after it. It is therefore generally a good idea to write lots of small test functions, each of which only checks a small number of things, rather than putting dozens of assertions in each function.

4.6 Style Notes

Anything that can go in a Python program can go in a module, but that doesn't mean that anything *should*. If you have functions and variables that logically belong together, you should put them in the same module. If there isn't some logical connection—for example, if one of the functions calculates how much carbon monoxide different kinds of cars produce, while another figures out how strong bones are given their diameter and density—then you shouldn't put them in one module just because you happen to be the author of both.

Of course, people often have different opinions about what is logical and what isn't. Take Python's math module, for example; should functions to multiply matrices go in there too or in a separate linear algebra module? What about basic statistical functions? Going back to the previous paragraph, should a function that calculates gas mileage go in the same module as one that calculates carbon monoxide emissions? You can always find a reason why two functions should *not* be in the same module, but 1,000 modules with one function each are going to be hard for people (including you) to find their way around.

As a rule of thumb, if a module has less than half a dozen things in it, it's probably too small, and if you can't sum up the contents and purpose of a module in a one- or two-sentence docstring, it's probably too large. These are just guidelines, though; in the end, you will have to decide based on how more experienced programmers have organized modules like the ones in the Python standard library and eventually on your own sense of style.

4.7 Summary

In this chapter, we learned the following:

- A module is a collection of functions and variables grouped together in a file. To use a module, you must first import it. After it has been imported, you refer to its contents using `modulename.thingname`.
- Put docstrings at the start of modules or functions to describe their contents and use.
- Every "thing" in a Python program is an object. Objects have methods, which work just like functions but are associated with the object's type. Methods are called using `object.methodname`, just like the functions in a module.
- You can manipulate images using the `picture` module, which has functions for loading, displaying, and manipulating entire images, as well as inspecting and modifying individual pixels and colors.
- Programs have to do more than just run to be useful; they have to run correctly. One way to ensure that they do is to test them, which you can do in Python using the Nose module. Since you usually can't test every possible case, you should focus your testing on boundary cases.

4.8 Exercises

Here are some exercises for you to try on your own:

1. Import module `math`, and use its functions to complete the following exercises:
   a. Write a single expression that rounds the value of `-4.3` and then takes the absolute value of that result.
   b. Write an expression that takes the ceiling of sine of 34.5.
2. In the following exercises, you will work with Python's `calendar` module:

   a. Visit the Python documentation website at http://docs.python.org/modindex.html, and look at the documentation on the calendar module.

   b. Import the calendar module.

   c. Read the description of the function isleap. Use isleap to determine the next leap year.

   d. Find and use a function in module calendar to determine how many leap years there will be between the years 2000 and 2050, inclusive.

   e. Find and use a function in module calendar to determine which day of the week July 29, 2016 will be.

3. Using string methods, write expressions that do the following:

   a. Capitalize 'boolean'.

   b. Find the first occurrence of '2' in 'CO2 H2O'.

   c. Find the second occurrence of "2" in 'CO2 H2O'.

   d. Determine whether 'Boolean' begins with a lowercase.

   e. Convert "MoNDaY" to lowercase letters and then capitalize the result.

   f. Remove the leading whitespace from " Monday".

4. The example used to explain import * was as follows:

```
>>> from math import *
>>> '%6f' % sqrt(8)
'2.828427'
```

   Explain why there are quotes around the value 2.828427.

5. Why do you think the media module mentioned in Section 4.3, *Objects and Methods*, on page 46 isn't part of the standard Python library? How do you think Python's developers decide what should be in the standard library and what shouldn't? If you need something that isn't in the standard library, where and how can you find it?

6. Write a program that allows the user to choose a file and then shows the picture twice.

7. Write a program that allows the user to choose a file, sets the red value of each pixel in the picture to 0, and shows the picture.

8. Write a program that allows the user to pick a file, halves the green value of each pixel in the picture, and shows the picture.

9. Write a program that allows the user to pick a file and makes it grayscale; it should calculate the average of red, green, and blue values of each pixel and then set the red, green, and blue values to that average.

10. Write a program that allows the user to pick a file, doubles the red value of each pixel in the picture, and shows the picture. What happens when a value larger than 255 is calculated?

11. Media outlets such as newspapers and TV stations sometimes "enhance" photographs by recoloring them or digitally combine pictures of two people to make them appear together. Do you think they should be allowed to use only unmodified images? Given that almost all pictures and TV footage are now digital and have to be processed somehow for display, what would that rule actually mean in practice?

12. Suppose we want to test a function that calculates the distance between two XY points:

Download modules/distance.py

```python
import math

def distance(x0, y0, x1, y1):
    '''Calculate the distance between (x0, y0) and (x1, y1).'''

    return math.sqrt((x1 - x0) ** 2 + (y1 - y0) ** 2)
```

a. Unlike the rounding-off version of to_celsius, this returns a floating-point number. Explain why this makes testing more difficult.

b. A friend of yours suggests testing the function like this:

Download modules/test_distance.py

```python
import nose
from distance import distance


def close(left, right):
    '''Test if two floating-point values are close enough.'''

    return abs(left - right) < 1.0e-6

def test_distance():
    '''Test whether the distance function works correctly.'''

    assert close(distance(1.0, 0.0, 1.0, 0.0), 0.0), 'Identical points fail.'
    assert close(distance(0.0, 0.0, 1.0, 0.0), 1.0), 'Unit distance fails.'

if __name__ == '__main__':
    nose.runmodule()
```

Explain what your friend is trying to do. As gently as you can, point out two flaws in his approach.

CHAPTER 5

Lists

Up to this point, each variable we have created has referred to a single number or string. In this chapter, we work with collections of data and use a Python type named list. Lists contain 0 or more objects, and they allow us to store data such as 90 experiment measurements or 10,000 student IDs. We'll also see how to access files and represent their contents using lists.

5.1 Lists and Indices

Table 8, *Gray whale census*, on page 68, from http://www.acschannelislands.org/2008CountDaily.pdf, shows the number of gray whales counted near the Coal Oil Point Natural Reserve in a two-week period in the spring of 2008.

Using what we have seen so far, we would have to create fourteen variables to keep track of these numbers (see Figure 15, *Life without lists*, on page 68). If we wanted to track an entire year's worth of observations, we'd need 366 (just in case it was a leap year). Even worse, if we didn't know in advance how long we wanted to watch the whales, we wouldn't know how many variables to create.

The solution is to store all the values together in a *list*. Lists show up everywhere in the real world: students in a class, the kinds of birds native to New Guinea, and so on. To create a list in Python, we put the values, separated by commas, inside square brackets:

Download lists/whalelist.py
```
# Number of whales seen per day
[5, 4, 7, 3, 2, 3, 2, 6, 4, 2, 1, 7, 1, 3]
```

A list is an object; like any other object, it can be assigned to a variable:

```
>>> whales = [5, 4, 7, 3, 2, 3, 2, 6, 4, 2, 1, 7, 1, 3]
>>> whales
```

Day	Number of Whales
1	5
2	4
3	7
4	3
5	2
6	3
7	2
8	6
9	4
10	2
11	1
12	7
13	1
14	3

Table 8—Gray whale census

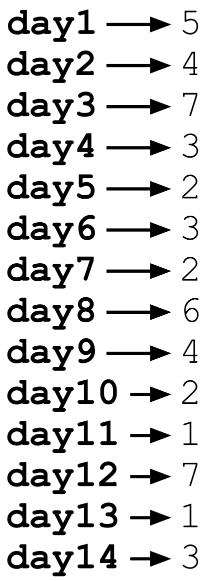


Figure 15—Life without lists

```
[5, 4, 7, 3, 2, 3, 2, 6, 4, 2, 1, 7, 1, 3]
```

In Figure 16, *List example,* on page 70, we can see a memory model of whales after this assignment. It's important to keep in mind that the list itself is one object but may contain references to other objects (shown by the arrows).

So, how do we get at the objects in a list? By providing an *index* that specifies the one we want. The first item in a list is at index 0, the second at index 1, and so on.[1] To refer to a particular item, we put the index in square brackets after a reference to the list (such as the name of a variable):

```
>>> whales = [5, 4, 7, 3, 2, 3, 2, 6, 4, 2, 1, 7, 1, 3]
>>> whales[0]
5
>>> whales[1]
4
>>> whales[12]
1
>>> whales[13]
3
```

We can use only those indices that are in the range from zero up to one less than the length of the list. In a fourteen-item list, the legal indices are 0, 1, 2, and so on, up to 13. Trying to use an out-of-range index is an error, just like trying to divide by zero.

```
>>> whales = [5, 4, 7, 3, 2, 3, 2, 6, 4, 2, 1, 7, 1, 3]
>>> whales[1001]
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
IndexError: list index out of range
```

Unlike most programming languages, Python also lets us index backward from the end of a list. The last item is at index -1, the one before it at index -2, and so on:

1. Yes, it would be more natural to use 1 as the first index, as human languages do. Python, however, uses the same convention as languages like C and Java and starts counting at zero.

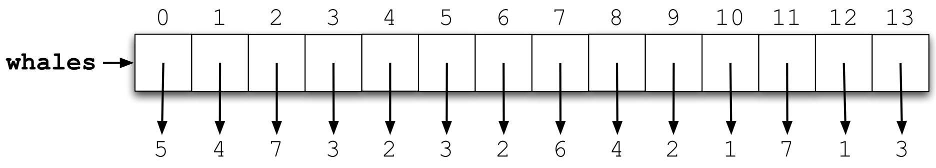


Figure 16—List example

```
>>> whales = [5, 4, 7, 3, 2, 3, 2, 6, 4, 2, 1, 7, 1, 3]
>>> whales[-1]
3
>>> whales[-2]
1
>>> whales[-14]
5
```

We can assign the values in a list to other variables:

```
>>> whales = [5, 4, 7, 3, 2, 3, 2, 6, 4, 2, 1, 7, 1, 3]
>>> third = whales[2]
>>> print 'Third day:', third
Third day: 7
```

The Empty List

Zero is a useful number, and as we saw in Chapter 3, *Strings*, on page 27, the empty string is often useful as well. There is also an *empty list*, in other words, a list with no items in it. As you might guess, it is written []. Trying to index an empty list always results in an error:

```
>>> whales = []
>>> whales[0]
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
IndexError: list index out of range
>>> whales[-1]
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
IndexError: list index out of range
```

This follows from the definition of legal index:

- Legal indices for a list of N items are the integers in the set $\{i: 0 \leq i < N\}$.
- The length of the empty list is 0.
- Legal indices for the empty list are therefore the elements of the set $\{i: 0 \leq i < -1\}$.
- Since this set is empty, there are no legal indices for the empty list.

Lists Are Heterogeneous

Lists can contain any type of data, including integers, strings, and even other lists. Here is a list of information about the element Krypton, including its name, symbol, melting point (in degrees Celsius), and boiling point (also in degrees Celsius). Using a list to aggregate related information is somewhat prone to error; a better, but more advanced, way to do this is described in Chapter 13, *Object-Oriented Programming*, on page 245.

```
>>> krypton = ['Krypton', 'Kr', -157.2, -153.4]
>>> krypton[1]
'Kr'
>>> krypton[2]
-157.19999999999999
```

5.2 Modifying Lists

Suppose we're typing in a list of the noble gases[2] and our fingers slip:

```
>>> nobles = ['helium', 'none', 'argon', 'krypton', 'xenon', 'radon']
```

The error here is that we typed 'none' instead of 'neon'. Rather than retyping the whole list, we can assign a new value to a specific element of the list:

```
>>> nobles = ['helium', 'none', 'argon', 'krypton', 'xenon', 'radon']
>>> nobles[1] = 'neon'
>>> nobles
['helium', 'neon', 'argon', 'krypton', 'xenon', 'radon']
```

In Figure 17, *List mutation*, on page 72, we show what the assignment to nobles[1] did. It also shows that lists are *mutable*, in other words, that their contents can be changed after they have been created. In contrast, numbers and strings are *immutable*. You cannot, for example, change a letter in a string after you have created it. Methods that appear to, like upper, actually create new strings:

```
>>> name = 'Darwin'
>>> capitalized = name.upper()
>>> print capitalized
'DARWIN'
>>> print name
'Darwin'
```

The expression L[i] behaves just like a simple variable (see Section 2.4, *Variables and the Assignment Statement*, on page 14). If it's on the right, it means "Get the value of the item at location i in the list L." If it's on the left,

2. A *noble gas* is one whose outermost electron shell is completely full, which makes it chemically inert.

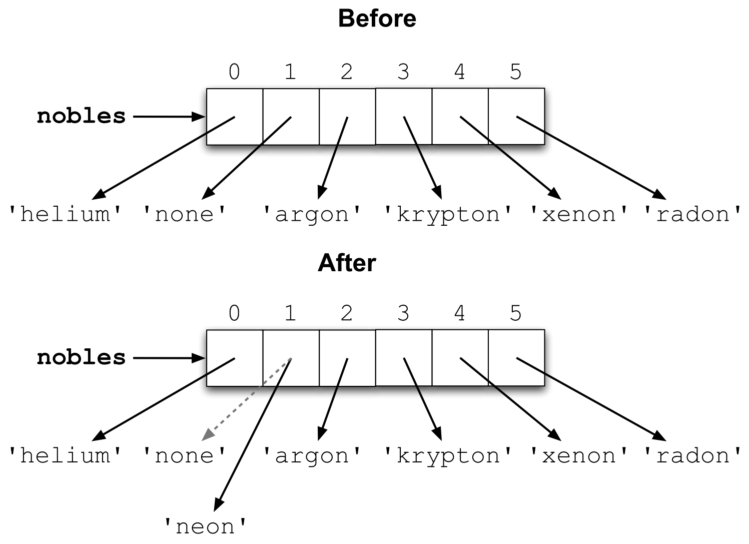

Before
0 1 2 3 4 5
nobles
'helium' 'none' 'argon' 'krypton' 'xenon' 'radon'
After
0 1 2 3 4 5
nobles
'helium' 'none' 'argon' 'krypton' 'xenon' 'radon'
'neon'

Figure 17—List mutation

it means "Figure out where item i in the list L is located so that we can overwrite it."

5.3 Built-in Functions on Lists

Section 2.6, *Function Basics*, on page 18 introduced a few of Python's built-in functions. Some of these, such as len, can be applied to lists as well, as can others we haven't seen before (see Table 9, *List functions*, on page 73). Here they are in action working on a list of the half-lives[3] of our plutonium isotopes:

```
>>> half_lives = [87.74, 24110.0, 6537.0, 14.4, 376000.0]
>>> len(half_lives)
5
>>> max(half_lives)
376000.0
>>> min(half_lives)
14.4
>>> sum(half_lives)
406749.14000000001
```

3. The half-life of a radioactive substance is the time taken for half of it to decay. After twice this time has gone by, three quarters of the material will have decayed; after three times, seven eighths, and so on.

Function	Description
len(L)	Returns the number of items in list L
max(L)	Returns the maximum value in list L
min(L)	Returns the minimum value in list L
sum(L)	Returns the sum of the values in list L

Table 9—List functions

We can use the results of the built-in functions in expressions; for example, the following code demonstrates that we can check whether an index is in range[4]:

```
>>> half_lives = [87.74, 24110.0, 6537.0, 14.4, 376000.0]
>>> i = 2
>>> i < len(half_lives)
True

>>> half_lives[i]
6537.0
>>> j = 5
>>> j < len(half_lives)
False
>>> half_lives[j]
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
IndexError: list index out of range
```

Like all other objects, lists have a particular type, and Python complains if you try to combine types in inappropriate ways. Here's what happens if you try to "add" a list and a string:

```
>>> ['H', 'He', 'Li'] + 'Be'
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: can only concatenate list (not "str") to list
```

That error report is interesting. It hints that we might be able to concatenate lists with lists to create new lists, just as we concatenated strings to create new strings. A little experimentation shows that this does in fact work:

```
>>> original = ['H', 'He', 'Li']
>>> final = original + ['Be']
>>> final
['H', 'He', 'Li', 'Be']
```

4. We'll take a closer look at comparisons in the next chapter.

As shown in Figure 18, *List concatenation*, on page 75, this doesn't modify either of the original lists. Instead, it creates a new list whose entries refer to the entries of the original lists.

So if + works on lists, will `sum` work on lists of strings? After all, if `sum([1, 2, 3])` is the same as `1 + 2 + 3`, shouldn't `sum('a', 'b', 'c')` be the same as `'a' + 'b' + 'c'`, or `'abc'`? The following code shows that the analogy can't be pushed that far:

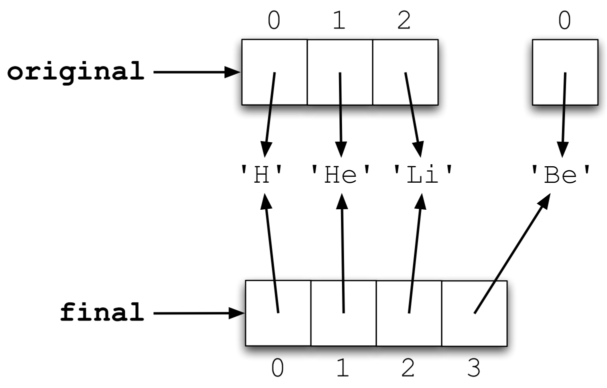


Figure 18—List concatenation

```
>>> sum(['a', 'b', 'c'])
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unsupported operand type(s) for +: 'int' and 'str'
```

On the other hand, you *can* multiply a list by an integer to get a new list containing the elements from the original list repeated a certain number of times:

```
>>> metals = 'Fe Ni'.split()
>>> metals * 3
['Fe', 'Ni', 'Fe', 'Ni', 'Fe', 'Ni']
```

As with concatenation, the original list isn't modified; instead, a new list is created. Notice, by the way, how we use `string.split` to turn the string `'Fe Ni'` into a two-element list `['Fe', 'Ni']`. This is a common trick in Python programs.

5.4 Processing List Items

Lists were invented so that we wouldn't have to create 1,000 variables to store a thousand values. For the same reason, Python has a *for loop* that lets us process each element in a list in turn, without having to write one statement per element. The general form of a `for` loop is as follows:

```
for <code:bold>variable</code:bold> in <code:bold>list</code:bold>:
    <code:bold>block</code:bold>
```

As we saw in Section 2.6, *Function Basics*, on page 18, a block is just a sequence of one or more statements. `variable` and `list` are just a variable and a list.

When Python encounters a loop, it executes the loop's block once for each value in the list. Each pass through the block is called an *iteration*, and at the start of each iteration, Python assigns the next value in the list to the specified variable. In this way, the program can do something with each value in turn.

For example, this code prints every velocity of a falling object in metric and imperial units:

```
>>> velocities = [0.0, 9.81, 19.62, 29.43]
>>> for v in velocities:
...     print "Metric:", v, "m/sec;",
...     print "Imperial:", v * 3.28, "ft/sec"
...
Metric: 0.0 m/sec; Imperial: 0.0 ft/sec
Metric: 9.81 m/sec; Imperial: 32.1768 ft/sec
Metric: 19.62 m/sec; Imperial: 64.3536 ft/sec
Metric: 29.43 m/sec; Imperial: 96.5304 ft/sec
```

Here are two other things to notice about this loop:

- In English we would say "for each velocity in the list, print the metric value, and then print the imperial value." In Python, we said roughly the same thing.
- As with function definitions, the statements in the loop block are indented. (We use four spaces in this book; check with your instructors to find out whether they prefer something else.)

In this case, we created a new variable v to store the current value taken from the list inside the loop. We could equally well have used an existing variable. If we do this, the loop still starts with the first element of the list—whatever value the variable had before the loop is lost:

```
>>> speed = 2
>>> velocities = [0.0, 9.81, 19.62, 29.43]
>>> for speed in velocities:
...     print "Metric:", speed, "m/sec;",
...
Metric: 0.0 m/sec
Metric: 9.81 m/sec
Metric: 19.62 m/sec
Metric: 29.43 m/sec
>>> print "Final:", speed
Final: 29.43
```

Either way, the variable is left holding its last value when the loop finishes. Notice that the last print statement is not indented, so it is not part of the for loop. It's executed after the for loop has finished and is executed only once.

Nested Loops

We said earlier that the block of statements inside a loop could contain anything. This means that it can also contain another loop.

This program, for example, loops over the list inner once for each element of the list outer:

```
>>> outer = ['Li', 'Na', 'K']
>>> inner = ['F', 'Cl', 'Br']
>>> for metal in outer:
...     for halogen in inner:
...         print metal + halogen
...
...
LiF
LiCl
LiBr
NaF
NaCl
NaBr
KF
KCl
KBr
```

If the outer loop has N_o iterations and the inner loop executes N_i times for each of them, the inner loop will execute a total of N_oN_i times. One special case of this is when the inner and outer loops are running over the same list of length N, in which case the inner loop executes N^2 times. This can be used to generate a multiplication table; after printing the header row, we use a nested loop to print each row of the table in turn, using tabs to make the columns line up:

Download lists/multiplication_table.py

```
def print_table():
    '''Print the multiplication table for numbers 1 through 5.'''
    numbers = [1, 2, 3, 4, 5]
    # Print the header row.
    for i in numbers:
        print '\t' + str(i),
    print # End the header row.
    # Print the column number and the contents of the table.
    for i in numbers:
        print i,
        for j in numbers:
            print '\t' + str(i * j),
        print # End the current row.
```

Here is print_table's output:

Download lists/multiplication_out.txt

```
>>> from multiplication_table import *
>>> print_table()
        1       2       3       4       5
1       1       2       3       4       5
2       2       4       6       8       10
3       3       6       9       12      15
4       4       8       12      16      20
5       5       10      15      20      25
```

Notice when the two different kinds of formatting are done: the print statement at the bottom of the program prints a new line when outer loop advances, while the inner loop includes a tab in front of each item.

5.5 Slicing

Geneticists describe *C. elegans* (nematodes, or microscopic worms) using three-letter short-form markers. Examples include Emb (embryonic lethality), Him (High incidence of males), Unc (Uncoordinated), Dpy (dumpy: short and fat), Sma (small), and Lon (long). We can thus keep a list:

```
>>> celegans_markers = ['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Sma']
>>> celegans_markers
['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Sma']
```

It turns out that Dpy worms and Sma worms are difficult to distinguish from each other, so they are not as useful as markers in complex strains. We can produce a new list based on celegans_markers, but without Dpy or Sma, by taking a *slice* of the list:

```
>>> celegans_markers = ['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Sma']
>>> useful_markers = celegans_markers[0:4]
```

This creates a new list consisting of only the four distinguishable markers (see Figure 19, *Slicing doesn't modify lists.*, on page 79).

The first index in the slice is the starting point. The second index is *one more than* the index of the last item we want to include. More rigorously, list[i:j] is a slice of the original list from index i (inclusive) up to, but not including, index j (exclusive).[5]

The first index can be omitted if we want to slice from the beginning of the list, and the last index can be omitted if we want to slice to the end:

5. Python uses this convention to be consistent with the rule that the legal indices for a list go from 0 up to one less than the list's length.

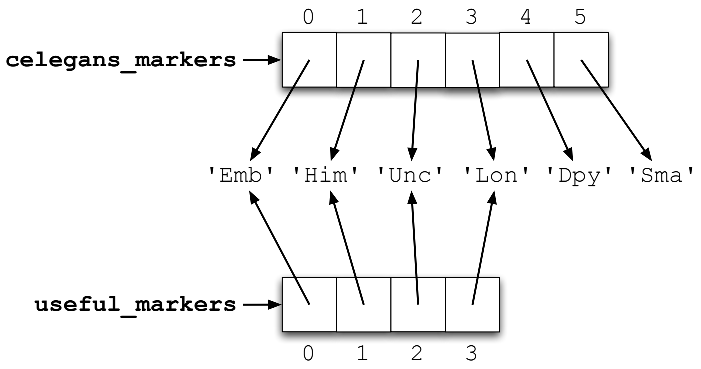


Figure 19—Slicing doesn't modify lists.

```
>>> celegans_markers = ['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Sma']
>>> celegans_markers[:4]
['Emb', 'Him', 'Unc', 'Lon']
>>> celegans_markers[4:]
['Dpy', 'Sma']
```

To create a copy of the entire list, we just omit both indices so that the "slice" runs from the start of the list to its end:

```
>>> celegans_markers = ['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Sma']
>>> celegans_copy = celegans_markers[:]
>>> celegans_markers[5] = 'Lvl'
>>> celegans_markers
['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Lvl']
>>> celegans_copy
['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Sma']
```

5.6 Aliasing

An *alias* is an alternative name for something. In Python, two variables are said to be aliases when they refer to the same value. For example, the following code creates two variables, both of which refer to a single list (see Figure 20, *Aliasing lists*, on page 80). When we modify the list using one of the variables, references through the other variable show the change as well:

```
>>> celegans_markers = ['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Sma']
>>> celegans_copy = celegans_markers
>>> celegans_markers[5] = 'Lvl'
>>> celegans_markers
['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Lvl']
>>> celegans_copy
['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Lvl']
```

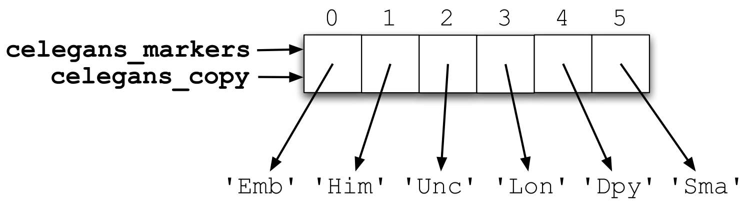


Figure 20—Aliasing lists

Aliasing is one of the reasons why the notion of mutability is important. For example, if x and y refer to the same list, then any changes you make to the list through x will be "seen" by y, and vice versa. This can lead to all sorts of hard-to-find errors in which a list's value changes as if by magic, even though your program doesn't appear to assign anything to it. This can't happen with immutable values like strings. Since a string can't be changed after it has been created, it's safe to have aliases for it.

Aliasing in Function Calls

Aliasing occurs when we use list parameters as well, since parameters are variables.

Here is a simple function that takes a list, sorts it, and then reverses it:

```
>>> def sort_and_reverse(L):
...     '''Return list L sorted and reversed.'''
...     L.sort()
...     L.reverse()
...     return L
...
>>> celegans_markers = ['Emb', 'Him', 'Unc', 'Lon', 'Dpy', 'Lvl']
>>> sort_and_reverse(celegans_markers)
['Unc', 'Lvl', 'Lon', 'Him', 'Emb', 'Dpy']
>>> celegans_markers
['Unc', 'Lvl', 'Lon', 'Him', 'Emb', 'Dpy']
```

This function modifies list L, and since L is an alias of celegans_markers, that list is modified as well.

5.7 List Methods

Lists are objects and thus have methods. Some of the most commonly used are listed in Table 10, *List methods*, on page 82. Here is a sample interaction showing how we can use these methods to construct a list containing all the colors of the rainbow:

Where Did My List Go?

Beginning programmers often forget that many list methods return None rather than creating and returning a new list. (Experienced programmers sometimes forget too.) As a result, their lists sometimes seem to disappear:

```
>>> colors = 'red orange yellow green blue purple'.split()
>>> colors
['blue', 'green', 'orange', 'purple', 'red', 'yellow']
>>> sorted_colors = colors.sort()
>>> print sorted_colors
None
```

As we discussed in Section 4.5, *Testing*, on page 55, mistakes like these can quickly be caught by writing and running a few tests.

```
>>> colors = 'red orange green black blue'.split()
>>> colors.append('purple')
>>> colors
['red', 'orange', 'green', 'black', 'blue', 'purple']
>>> colors.insert(2, 'yellow')
>>> colors
['red', 'orange', 'yellow', 'green', 'black', 'blue', 'black', 'purple']
>>> colors.remove('black')
>>> colors
['red', 'orange', 'yellow', 'green', 'blue', 'purple']
```

It is important to note that all these methods modify the list instead of creating a new list. They do this because lists can grow very, very large—a million patient records, for example, or a billion measurements of a magnetic field. Creating a new list every time someone wanted to make a change to such a list would slow Python down so much that it would no longer be useful; having Python guess when it should make a copy, and when it should operate on the list in place, would make it impossible to figure out.

It's just as important to remember that all of these methods except pop return the special value None, which means "There is no useful information" or "There's nothing here." Python doesn't display anything when asked to display the value None. Printing it, on the other hand, shows us that it's there:

```
>>> x = None
>>> x
>>> print x
None
```

Finally, a call to append is not the same as using +. First, append appends a single value, while + expects two lists as operands. Second, append modifies the list rather than creating a new one.

Method	Description
L.append(v)	Appends value v to list L
L.insert(i, v)	Inserts value v at index i in list L, shifting following items to make room
L.remove(v)	Removes the first occurrence of value v from list L
L.reverse()	Reverses the order of the values in list L
L.sort()	Sorts the values in list L in ascending order (for strings, alphabetical order)
L.pop()	Removes and returns the last element of L (which must be nonempty)

Table 10—List methods

5.8 Nested Lists

We said in *Lists Are Heterogeneous*, on page 71 that lists can contain any type of data. That means that they can contain other lists, just as the body of a loop can contain another loop. For example, the following nested list describes life expectancies in different countries:

Download lists/lifelist.py
```
[['Canada', 76.5], ['United States', 75.5], ['Mexico', 72.0]]
```

As shown in Figure 21, *Nested lists*, on page 83, each element of the outer list is itself a list of two items. We use the standard notation to access the items in the outer list:

```
>>> life = [['Canada', 76.5], ['United States', 75.5], ['Mexico', 72.0]]
>>> life[0]
['Canada', 76.5]
>>> life[1]
['United States', 75.5]
>>> life[2]
['Mexico', 72.0]
```

Since each of these items is also a list, we can immediately index it again, just as we can chain together method calls or pass the result of one function call as an argument to another function:

```
>>> life = [['Canada', 76.5], ['United States', 75.5], ['Mexico', 72.0]]
>>> life[1]
['United States', 75.5]
>>> life[1][0]
'United States'
>>> life[1][1]
75.5
```

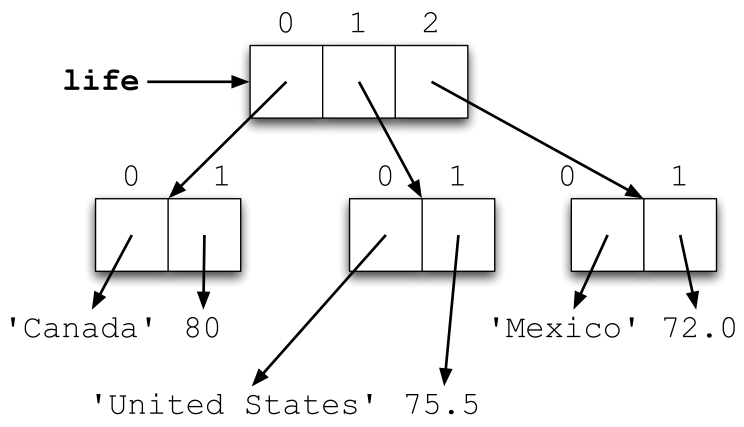


Figure 21—Nested lists

We can also assign sublists to variables:

```
>>> life = [['Canada', 76.5], ['United States', 75.5], ['Mexico', 72.0]]
>>> canada = life[0]
>>> canada
['Canada', 76.5]
>>> canada[0]
'Canada'
>>> canada[1]
76.5
```

Assigning a sublist to a variable creates an alias for that sublist (see Figure 22, *Aliasing sublists*, on page 84). As before, any change we make through the sublist reference will show up when we access the main list, and vice versa:

```
>>> life = [['Canada', 76.5], ['United States', 75.5], ['Mexico', 72.0]]
>>> canada = life[0]
>>> canada[1] = 80.0
>>> canada
['Canada', 80.0]
>>> life
[['Canada', 80.0], ['United States', 75.5], ['Mexico', 72.0]]
```

5.9 Other Kinds of Sequences

Lists aren't the only kind of sequence in Python. You've already met one of the others: strings. Formally, a string is an immutable sequence of characters. The "sequence" part of this definition means that it can be indexed and sliced like a list to create new strings:

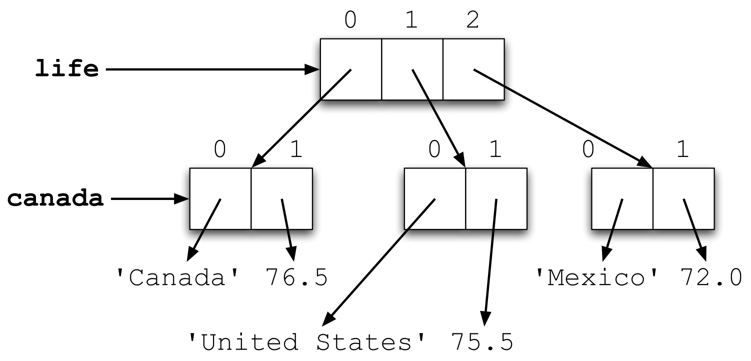


Figure 22—Aliasing sublists

```
>>> rock = 'anthracite'
>>> rock[9]
'e'
>>> rock[0:3]
'ant'
>>> rock[-5:]
'acite'
>>> for character in rock[:5]:
...     print character
...
a
n
t
h
r
```

Python also has an immutable sequence type called a *tuple*. Tuples are written using parentheses instead of square brackets; like strings and lists, they can be subscripted, sliced, and looped over:

```
>>> bases = ('A', 'C', 'G', 'T')
... for b in bases:
...    print b
A
C
G
T
```

There is one small catch: although () represents the empty tuple, a tuple with one element is *not* written as (x) but instead as (x,) (with a trailing comma). This has to be done to avoid ambiguity. If the trailing comma weren't required, (5 + 3) could mean either 8 (under the normal rules of arithmetic) or the tuple containing only the value 8. This is one of the few places where Python's syntax leaves something to be desired....

Once a tuple is created, it cannot be changed:

```
>>> life = (['Canada', 76.5], ['United States', 75.5], ['Mexico', 72.0])
>>> life[0] = life[1]
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
TypeError: object does not support item assignment
```

However, the objects inside it *can* still be changed:

```
>>> life = (['Canada', 76.5], ['United States', 75.5], ['Mexico', 72.0])
>>> life[0][1] = 80.0
>>> life
(['Canada', 80.0], ['United States', 75.5], ['Mexico', 72.0])
```

This is because it's actually sloppy English to say that something is "inside" a tuple. It would be more accurate to say this: "The references contained in a tuple cannot be changed after the tuple has been created, though the objects referred to may themselves change."

Newcomers to Python often ask why tuples exist. The answer is that they make some operations more efficient and others safer. We won't get far enough in this book to explain the former, but we will explore the latter in Chapter 9, *Sets and Dictionaries*, on page 165.

5.10 Files as Lists

Most data is stored in files, which are just ordered sequences of bytes. Those bytes may represent characters, pixels, or postal codes; the important thing is that they're in a particular order, which means that lists are usually a natural way to work with them.

In order to read data from a file, we must first open it using Python's built-in function open:

```
>>> file = open("data.txt", "r")
```

The first argument to open is a string containing the name of the file. The second argument indicates a *mode*. The three options are "r" for reading, "w" for writing, and "a" for appending. (The difference between writing and appending is that writing a file erases anything that was already in it, while appending adds new data to the end.)

The result of open is *not* the contents of the file. Instead, open returns a *file object* whose methods allow the program to access the contents of the file.

The most fundamental of these methods is read. When it is called without any arguments, it reads all the data in the file and returns it as a string of characters. If we give read a positive integer argument, it reads only up to that many characters; this is useful when we are working with very large files. In either case, if there's no more data in the file, the method returns an empty string.

Although read gives us access to the bytes in a file, we usually use higher-level methods to do our work. If the file contains text, for example, we will probably want to process it one line at a time. To do this, we can use the file object's readline method, which reads the next line of text from the file. A line is defined as being all the characters up to and including the next end-of-line marker (see Section 3.3, *Multiline Strings*, on page 30). Like read, readline returns an empty string when there's no more data in the file.

The neatest thing about readline is that Python calls it for us automatically when a file object is used in a for loop. Assume this data is in a file called data.txt:

Download lists/data.txt
```
Mercury
Venus
Earth
Mars
```

This program opens that file and prints the length of each line:

```
>>> data = open('data.txt', 'r')
>>> for line in data:
...     print len(line)
...
8
6
6
5
```

Take a close look at the last line of output. There are only four characters in the word *Mars*, but our program is reporting that the line is five characters long. The reason for this is that each of the lines we read from the file has an end-of-line character at the end. We can get rid of it using string.strip, which returns a copy of a string that has leading and trailing whitespace characters (spaces, tabs, and newlines) stripped away:

```
>>> data = open('data.txt', 'r')
>>> for line in data:
...     print len(line.strip())
...
```

```
7
5
5
4
```

This example shows the result of applying strip to a string with leading and trailing whitespace:

```
>>> compound = "     \n  Methyl butanol   \n"
>>> print compound

  Methyl butanol



>>> print compound.strip()
Methyl butanol
```

Note that the space inside the string is unaffected: string.strip takes whitespace only off the front and end of the string.

Using string.strip, we can now produce the correct output when reading from our file:

```
>>> file = open('data.txt', 'r')
>>> for line in file:
...     line = line.strip()
...     print len(line)
...
7
5
5
4
```

Command-Line Arguments

We said earlier that the file data.txt contains the name of planets. To finish the example, let's go back to reading that file but display only a certain range of the lines. We'll provide the start and end line numbers when we run the program. For example, we might want to read the first three lines one time and lines 2 to 4 another time.

We can do this using *command-line arguments*. When we run a program, we can send arguments to it, much like when we call a function or method. These values end up in a special variable of the system module sys called argv, which is just a list of the arguments (as strings).

sys.argv[0] always contains the name of the Python program being run. In this case, it is read_lines_range.py. The rest of the command-line arguments are in sys.argv[1], sys.argv[2], and so on.

Here, then, is a program that reads all the data from a file and displays lines with line numbers within the start and end line range:

Download lists/read_lines_range.py

```
''' Display the lines of data.txt from the given starting line number to the
given end line number.

Usage: read_lines_range.py start_line end_line '''

import sys

if __name__ == '__main__':

    # get the start and end line numbers
    start_line = int(sys.argv[1])
    end_line = int(sys.argv[2])

    # read the lines of the file and store them in a list
    data = open('data.txt', 'r')
    data_list = data.readlines()
    data.close()

    # display lines within start to end range
    for line in data_list[start_line:end_line]:
        print line.strip()
```

If you are using Wing 101, you can set the command line arguments for your script using the Source->Current File Properties... menu item. Then select the debug tab and type your values into the Run Arguments text box.

5.11 Comments

The previous line-reading program is one of the longest we have seen to date—so long, in fact, that we have added *comments* as well as a docstring. The docstring is primarily for people who want to use the program; it describes *what* the program does but not *how*.

Comments, on the other hand, are written for the benefit of future developers.[6] Each comment starts with the # character and runs to the end of the line. We can put whatever we want in comments, because Python ignores them completely. Here are a few rules for good commenting:

6. Including future versions of ourselves, who might have forgotten the details of this program by the time a change needs to be made or a bug needs to be fixed.

- Assume your readers know as much Python as you do (for example, don't explain what strings are or what an assignment statement does).
- Don't comment the obvious—the following comment is *not* useful:

  ```
  count = count + 1  # add one to count
  ```

- Many programmers leave comments beginning with "TODO" or "FIXME" in code to remind themselves of things that need to be written or tidied up.
- If you needed to think hard when you wrote a piece of software, you should write a comment so that the next person doesn't have to do the same thinking all over again. In particular, if you develop a program or function by writing a simple point-form description in English, then making the points more and more specific until they turn into code, you should keep the original points as comments. (We will discuss this style of development further in Chapter 10, *Algorithms,* on page 181.)
- Similarly, if a bug was difficult to find or if the fix is complicated, you should write a comment to explain it. If you don't, the next programmer to work on that part of the program might think that the code is needlessly complicated and undo your hard work.
- On the other hand, if you need lots of comments to explain what a piece of code does, you should clean up the code. For example, if you have to keep reminding readers what each of the fifteen lists in a function are for, you should break the function into smaller pieces, each of which works only with a few of those lists.

And here's one more rule:

- An out-of-date comment is worse than no comment at all, so if you change a piece of software, read the comments carefully and fix any that are no longer accurate.

5.12 Summary

In this chapter, we learned the following:

- Lists are used to keep track of zero or more objects. We call the objects in a list its elements and refer to them by position using indices ranging from zero to one less than the length of the list.
- Lists are mutable, which means that their contents can be modified. Lists can contain any type of data, including other lists.

- Slicing is used to create new lists that have the same values or a subset of the values of the originals.
- When two variables refer to the same object, we call them aliases.
- Tuples are another kind of Python sequence. Tuples are similar to lists, except they are immutable.
- When files are opened and read, their contents are commonly stored in lists of strings.

5.13 Exercises

Here are some exercises for you to try on your own:

1. Assign a list that contains the atomic numbers of the six alkaline earth metals—beryllium (4), magnesium (12), calcium (20), strontium (38), barium (56), and radium (88)—to a variable called `alkaline_earth_metals`.
2. Which index contains radium's atomic number? Write the answer in two ways, one using a positive index and one using a negative index.
3. Which function tells you how many items there are in `alkaline_earth_metals`?
4. Write code that returns the highest atomic number in `alkaline_earth_metals`. (Hint: use one of the functions from Table 9, *List functions*, on page 73.)
5. What is the difference between `print 'a'` and `print 'a',`?
6. Write a `for` loop to print all the values in list `celegans_markers` from Section 5.5, *Slicing*, on page 78, one per line.
7. Write a `for` loop to print all the values in list `half_lives` from Section 5.5, *Slicing*, on page 78, all on a single line.
8. Consider the following statement, which creates a list of populations of countries in eastern Asia (China, DPR Korea, Hong Kong, Mongolia, Republic of Korea, and Taiwan), in millions: `country_populations = [1295, 23, 7, 3, 47, 21]`. Write a `for` loop that adds up all the values and stores them in variable `total`. (Hint: give `total` an initial value of zero, and, inside the loop body, add the population of the current country to `total`.)
9. Create a list of temperatures in degrees Celsius with the values 25.2, 16.8, 31.4, 23.9, 28, 22.5, and 19.6, and assign it to a variable called `temps`.
10. Using one of the list methods, sort `temps` in ascending order.

11. Using slicing, create two new lists, cool_temps and warm_temps, which contain the temperatures below and above 20 degrees celsius, respectively.

12. Using list arithmetic, recombine cool_temps and warm_temps in into a new list called temps_in_celsius.

13. Write a for loop to convert all the values from temps_in_celsius into Fahrenheit, and store the converted values in a new list temps_in_fahrenheit. The list temps_in_celsius should remain unchanged.

14. Create a nested list where each element of the outer list contains the atomic number and atomic weight for an alkaline earth metal. The values are beryllium (4 and 9.012), magnesium (12 and 24.305), calcium (20 and 40.078), strontium (38 and 87.62), barium (56 and 137.327), and radium (88 and 226). Assign the list to a variable alkaline_earth_metals.

15. Write a for loop to print all the values in alkaline_earth_metals, with the atomic number and atomic weight for each alkaline earth metal on a different line.

16. Write a for loop to create a new list called number_and_weight that contains the elements of alkaline_earth_metals in the same order but not nested.

17. Suppose the file alkaline_metals.txt contains this:

    ```
    4 9.012
    12 24.305
    20 20.078
    38 87.62
    56 137.327
    88 226
    ```

    Write a for loop to read the contents of alkaline_metals.txt, and store it in a nested list with each element of the list contains the atomic number and atomic weight for an element. (Hint: use string.split.)

18. Draw a memory model showing the effect of the following statements:

    ```
    values = [0, 1, 2]
    values[1] = values
    ```

19. The following function does not have a docstring or comments. Write enough of both to make it easy for the next person to understand what the function does, and how, and then compare your solution with those of at least two other people. How similar are they? Why do they differ?

    ```
    def mystery_function(values):
       result = []
       for sublist in values:
    ```

```
        result.append([sublist[0]])
        for i in sublist[1:]:
            result[-1].insert(0, i)

    return result
```

20. Section 5.2, *Modifying Lists*, on page 71 said that strings are immutable. Why might mutable strings be useful? Why do you think Python made them immutable?

21. What happens when you sort a list that contains a mix of numbers and strings, such as `[1, 'a', 2, 'b']`? Is this consistent with the rules given in Chapter 3, *Strings*, on page 27 and Chapter 6, *Making Choices*, on page 93 for how comparison operators like < work on numbers and strings? Is this the “right” thing for Python to do, or would some other behavior be more useful?

CHAPTER 6

Making Choices

This chapter introduces another fundamental concepts of programming: making choices. We have to do this whenever we want to have our program behave differently depending on the data it's working with. For example, we might want to do different things depending on whether a solution is acidic or basic.

The statements we'll meet in this chapter for making choices are called *control flow* statements, because they control the way the computer executes programs. We have already met one control flow statement—the loops introduced in Section 5.4, *Processing List Items*, on page 75—and we will meet others in future chapters as well. Together, they are what give programs their "personalities."

Before we can explore control flow statements, we must introduce a Python type that is used to represent truth and falsehood. Unlike the integers, floating-point numbers, and strings we have already seen, this type has only two values and three operators, but it is extremely powerful.

6.1 Boolean Logic

In the 1840s, the mathematician George Boole showed that the classical rules of logic could be expressed in purely mathematical form using only the two values "true" and "false." A century later, Claude Shannon (later the inventor of information theory) realized that Boole's work could be used to optimize the design of electromechanical telephone switches. His work led directly to the use of *Boolean logic* to design computer circuits.

In honor of Boole's work, most modern programming languages use a type named after him to keep track of what's true and what isn't.

In Python, that type is called bool (without an "e"). Unlike int and float, which have billions of possible values, bool has only two: True and False. True and False are values, just as much as the numbers 0 and -43.7. It feels a little strange at first to think of them this way, since "true" and "false" in normal speech are adjectives that we apply to other statements. As we'll see, though, treating True and False as nouns is natural in programs.

Boolean Operators

There are only three basic Boolean operators: and, or, and not. not has the highest precedence, followed by and, followed by or.

not is a unary operator; in other words, it is applied to just one value, like the negation in the expression -(3 + 2). An expression involving not produces True if the original value is False, and it produces False if the original value is True:

```
>>> not True
False
>>> not False
True
```

In the previous example, instead of not True, we could simply use False; and instead of not False, we could use True. Rather than apply not directly to a Boolean value, we would typically apply not to a Boolean variable or a more complex Boolean expression. The same goes for the following examples of Boolean operators and and or, so although we apply them to Boolean constants in the following examples, we'll give an example of how they are typically used at the end of this section.

and is a binary operator; the expression left and right is True if both left and right are True, and it's False otherwise:

```
>>> True and True
True
>>> False and False
False
>>> True and False
False
>>> False and True
False
```

or is also a binary operator. It produces True if *either* operand is True, and it produces False only if both are False:

```
>>> True or True
True
>>> False or False
```

```
False
>>> True or False
True
>>> False or True
True
```

This definition is called *inclusive or*, since it allows both possibilities as well as either. In English, the word *or* is also sometimes an *exclusive or*. For example, if someone says, “You can have pizza or tandoori chicken,” they probably don’t mean that you can have both. Like most programming languages, Python always interprets or as inclusive. We will see in the exercises how to create an exclusive or.

We mentioned earlier that Boolean operators are usually applied to Boolean expressions, rather than Boolean constants. If we want to express “It is not cold and windy” using two variables cold and windy that contain Boolean values, we first have to decide what the ambiguous English expression means: is it not cold but at the same time windy, or is it not both cold and windy? A *truth table* for each alternative is shown in Figure 23, *Relational and equality operators*, on page 96, and the following code snippet shows what they look like translated into Python:

```
>>> (not cold) and windy
>>> not (cold and windy)
```

Relational Operators

We said earlier that True and False are values. The most common way to produce them in programs is not to write them down directly but rather to create them in expressions. The most common way to do that is to do a comparison using a *relational operator*. For example, 3<5 is a comparison using the relational operator < whose value is True, while 13≥77 uses ≥ and has the value False.

As shown in Table 11, *Relational and Equality Operators*, on page 97, Python has all the operators you’re used to using. Some of them are represented using two characters instead of one, like <= instead of ≤.

The most important representation rule is that Python uses == for equality instead of just =, because = is used for assignment. Beginners often mix the two up and type x = 3 when they meant to check whether the variable x was equal to three. This always produces a syntax error, but if you don’t know what to look for, it can be hard to spot the reason.

cold	windy	(not cold) and windy	not (cold and windy)
True	**True**	False	False
True	**False**	False	True
False	**True**	True	True
False	**False**	False	True

Figure 23—Relational and equality operators

All relational operators are binary operators: they compare two values and produce True or False, as appropriate. The "greater than" > and "less than" < operators work as expected:

```
>>> 45 > 34
True
>>> 45 > 79
False
>>> 45 < 79
True
>>> 45 < 34
False
```

We can compare integers to floating-point numbers with any of the relational operators. Integers are automatically converted to floating point when we do this, just as they are when we add 14 to 23.3:

```
>>> 23.1 >= 23
True
>>> 23.1 >= 23.1
True
>>> 23.1 <= 23.1
True
>>> 23.1 <= 23
False
```

The same holds for "equal to" and "not equal to":

```
>>> 67.3 == 87
False
>>> 67.3 == 67
False
>>> 67.0 == 67
True
>>> 67.0 != 67
False
>>> 67.0 != 23
True
```

Symbol	Operation
>	Greater than
<	Less than
>=	Greater than or equal to
<=	Less than or equal to
==	Equal to
!=	Not equal to

Table 11—Relational and Equality Operators

Of course, it doesn't make much sense to compare two numbers that you know in advance, since you would also know the result of the comparison. Relational operators therefore almost always involve variables, like this:

```
>>> def positive(x):
...     return x > 0
...
>>> positive(3)
True
>>> positive(-2)
False
>>> positive(0)
False
```

Combining Comparisons

We have now seen three types of operators: arithmetic, Boolean, and relational.

Here are the rules for combining them:

- Arithmetic operators have higher precedence than relational operators. For example, + and / are evaluated before < or >.
- Relational operators have higher precedence than Boolean operators. For example, comparisons are evaluated before `and`, `or`, and `not`.
- All relational operators have the same precedence.

These rules mean that the expression 1 + 3 > 7 is evaluated as (1 + 3) > 7, not as 1 + (3 > 7). These rules also mean that you can often skip the parentheses in complicated expressions:

```
>>> x = 2
>>> y = 5
>>> z = 7
>>> x < y and y < z
True
```

It's usually a good idea to put the parentheses in, though, since it helps the eye find the subexpressions and clearly communicates the order to anyone reading your code:

```
>>> (x < y) and (y < z)
True
```

It's very common in mathematics to check whether a value lies in a certain range, in other words, that it is between two other values. You can do this in Python by combining the comparisons with `and`:

```
>>> x = 3
>>> (1 < x) and (x <= 5)
True
>>> x = 7
>>> (1 < x) and (x <= 5)
False
```

This comes up so often, however, that Python lets you *chain* the comparisons:

```
>>> x = 3
>>> 1 < x <= 5
True
```

Most combinations work as you would expect, but there are cases that may startle you:

```
>>> 3 < 5 != True
True
>>> 3 < 5 != False
True
```

It seems impossible for both of these expressions to be `True`. However, the first one is equivalent to this:

```
(3 < 5) and (5 != True)
```

while the second is equivalent to this:

```
(3 < 5) and (5 != False)
```

Since 5 is not `True` or `False`, the second half of each expression is `True`, so the expression as a whole is `True` as well.

This kind of expression is an example of something that is a bad idea even though it is legal.[1] We strongly recommend that you only chain comparisons in ways that would seem natural to a mathematician, in other words, that you use < and <= together, or > and >= together, and nothing else. If you're tempted to do something else, resist. Use simple comparisons and combine them with and in order to keep your code readable. It's also a good idea to use parentheses whenever you think the expression you are writing may not be entirely clear.

Applying Boolean Operators to Integers, Floats, and Strings

We have already seen that Python converts ints to floats in mixed expressions. It also converts numbers to bools, which means that the three Boolean operators can be applied directly to numbers. When this happens, Python treats 0 and 0.0 as False and treats all other numbers as True:

```
>>> not 0
True
>>> not 1
False
>>> not 5
False
>>> not 34.2
False
>>> not -87
False
```

Things are more complicated with and and or. When Python evaluates an expression containing either of these operators, it always does so from left to right. As soon as it knows enough to stop evaluating, it stops, even if some operands haven't been looked at yet. The result is the last thing that was evaluated, which is *not* necessarily either True or False.

This is much easier to demonstrate than explain. Here are three expressions involving and:

```
>>> 0 and 3
0
>>> 3 and 0
0
>>> 3 and 5
5
```

1. Sort of like going on a roller coaster right after eating two extra large ice cream sundaes back to back on a dare.

In the first expression, Python sees a 0, which is equivalent to False, and immediately stops evaluating. It doesn't need to look at the 3 to know that the expression as a whole is going to be false, since and is true only if both operands are true (see Figure 24, *Short-circuit evaluation*, on page 101).

In the second expression, though, Python has to check both operands, since knowing that the first one (the 3) isn't false is not enough to know what the value of the whole expression will be. Python also checks both operands in the third expression; as you can see, it takes the value of the last thing it checked as the value of the expression as a whole (in this case, 5).

With or, if the first operand is considered to be true, or evaluates to that value *immediately*, without even checking the second operand. The reason for this is that Python already knows the answer: True or X is True, regardless of the value of X.

If the first operand is equivalent to False, though, or has to check the second operand. Its result is then that operand's value:

```
>>> 1 or 0
1
>>> 0 or 1
1
>>> True or 0
True
>>> 0 or False
False
>>> False or 0
0
>>> False or 18.2
18.199999999999999
```

(Remember, computers can't represent all fractions exactly: the last value in the previous code fragment is as close as it can get to 18.2.)

We claimed that if the first operand to the or operator is true, then or evaluates to that value immediately without evaluating the second operand. In order to show that this is what happens, try an expression that divides by zero:

```
>>> 1 / 0
Traceback (most recent call last):
  File "<string>", line 1, in <string>
ZeroDivisionError: integer division or modulo by zero
```

Now use that expression as the second operand to or:

```
>>> True or 1 / 0
True
```

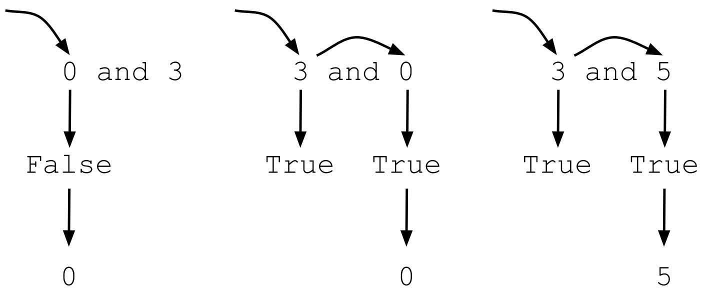


Figure 24—Short-circuit evaluation

Since the first operand is true, the second operand is not evaluated, so the computer never actually tries to divide anything by zero.

It's possible to compare strings with each other, just as you would compare numbers. The characters in strings are represented by integers: a capital *A*, for example, is represented by 65, while a space is 32, and a lowercase *z* is 172.[2] Python decides which string is greater than which by comparing corresponding characters from left to right. If the character from one string is greater than the character from the other, the first string is greater than the second. If all the characters are the same, the two strings are equal; if one string runs out of characters while the comparison is being done (in other words, is shorter than the other), then it is less. The following code fragment shows a few comparisons in action:

```
>>> 'A' < 'a'
True
>>> 'A' > 'z'
False
>>> 'abc' < 'abd'
True
>>> 'abc' < 'abcd'
True
```

Like zero, the empty string is equivalent to False; all other strings are equivalent to True:

```
>>> '' and False
''
>>> 'salmon' or True
'salmon'
```

2. This encoding is called *ASCII*, which stands for "American Standard Code for Information Interchange." One of its quirks is that all the uppercase letters come before all the lowercase letters, so a capital *Z* is less than a small *a*.

There’s Such a Thing as Being Too Clever

An expression like y = x and 1/x works, but that doesn’t mean you should use it, any more than you should use this:

```
result = test and first or second
```

as a shorthand for the following:

```
if test:
    result = first
else:
    result = second
```

Programs are meant to be readable. If you have to puzzle over a line of code or if there’s a high likelihood that someone seeing it for the first time will misunderstand it, it’s bad code, even if it runs correctly.

Python can also convert Booleans to numbers: True becomes 1, while False becomes 0:

```
>>> False == 0
True
>>> True == 1
True
>>> True == 2
False
>>> False < True
True
```

This means that you can add, subtract, multiply, and divide using Boolean values:

```
>>> 5 + True
6
>>> 7 - False
7
```

But “can” isn’t the same as “should”: adding True to 5, or multiplying the temperature by current_time<NOON, will make your code much harder to read. In practice, programmers routinely rely on conversion *to* Booleans but rarely if ever use conversions in the other direction.

6.2 if Statements

The basic form of an if statement is as follows:

```
if <code:bold>condition</code:bold>:
    <code:bold>block</code:bold>
```

The *condition* is an expression, such as name != '' or x < y. Note that this doesn't have to be a Boolean expression. As we discussed in *Applying Boolean Operators to Integers, Floats, and Strings*, on page 99, non-Boolean values are automatically converted to True or False when required.

In particular, 0, None, the empty string '', and the empty list [] all are considered to be false, while all other values that we have encountered are considered to be true.

If the condition is true, then the statements in the block are executed; otherwise, they are not. As with loops and functions, the block of statements must be indented to show that it belongs to the if statement. If you don't indent properly, Python might raise an error, or worse, might happily execute the code that you wrote but, because some statements were not indented properly, do something you didn't intend. We'll briefly explore both problems in this chapter.

Here is a table of solution categories based on pH level:

pH Level	**Solution Category**
0–4	Strong acid
5–6	Weak acid
7	Neutral
8–9	Weak base
10–14	Strong base

We can use an if statement to print a message only when the pH level given by the program's user is acidic:

```
>>> ph = float(raw_input())
6.0
>>> if ph < 7.0:
...     print "%s is acidic." % (ph)
...
6.0 is acidic.
```

(Recall from Section 3.6, *User Input*, on page 33 that we have to convert user input from a string to a float before doing the comparison.)

If the condition is false, the statements in the block are not executed:

```
>>> ph = float(raw_input())
8.0
>>> if ph < 7.0:
...     print "%s is acidic." % (ph)
...
>>>
```

If we don't indent the block, Python lets us know:

```
>>> ph = float(raw_input())
6.0
>>> if ph < 7.0:
... print "%s is acidic." % (ph)
  File "<stdin>", line 2
    print "%s is acidic." % (ph)
        ^
IndentationError: expected an indented block
```

Since we're using a block, we can have multiple statements, which are executed only if the condition is true:

```
>>> ph = float(raw_input())
6.0
>>> if ph < 7.0:
...     print "%s is acidic." % (ph)
...     print "You should be careful with that!"
...
6.0 is acidic.
You should be careful with that!
```

When we indent the first line of the block, the Python interpreter changes its prompt to ... until the end of the block, which is signaled by a blank line:

```
>>> ph = float(raw_input())
8.0
>>> if ph < 7.0:
...     print "%s is acidic." % (ph)
...
>>> print "You should be careful with that!"
You should be careful with that!
```

If we don't indent the code that's in the block, the interpreter complains:

```
>>> ph = float(raw_input())
8.0
>>> if ph < 7.0:
...     print "%s is acidic." % (ph)
... print "You should be careful with that!"
  File "<stdin>", line 3
    print "You should be careful with that!"
        ^
SyntaxError: invalid syntax
```

If the program is in a file, then no blank line is needed. As soon as the indentation ends, Python assumes that the block has ended as well. This is therefore legal:

```
ph = 8.0
if ph < 7.0:
    print "%s is acidic." % (ph)
print "You should be careful with that!"
```

In practice, this slight inconsistency is never a problem, and most people never even notice it.

Of course, sometimes there are situations where a single decision isn't sufficient. If there are multiple criteria to examine, there are a couple of ways to handle it. One way is to use multiple if statements. For example, we might print different messages depending on whether a pH level is acidic or basic:

```
>>> ph = float(raw_input())
8.5
>>> if ph < 7.0:
...     print "%s is acidic." % (ph)
...
>>> if ph > 7.0:
...     print "%s is basic." % (ph)
...
8.5 is basic.
>>>
```

In Figure 25, *if statement*, on page 106, we see that both conditions are always evaluated, even though we know that only one of the blocks can be executed. We can merge both cases by adding another condition/block pair using the elif keyword (which stands for "else if"); each condition/block pair is called a *clause*:

```
>>> ph = float(raw_input())
8.5
>>> if ph < 7.0:
...     print "%s is acidic." % (ph)
... elif ph > 7.0:
...     print "%s is basic." % (ph)
...
8.5 is basic.
>>>
```

The difference between the two is that the elif is checked only when the if above it was false. In Figure 26, *elif statement*, on page 106, we can see the difference pictorially, with conditions drawn as diamonds, other statements as rectangles, and arrows to show the flow of control.

An if statement can be followed by multiple elif clauses. This longer example translates a chemical formula into English:

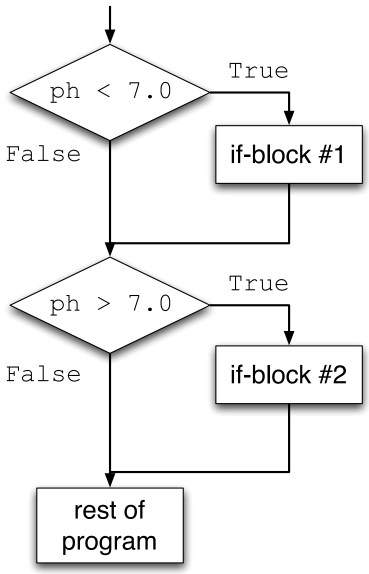


Figure 25—if statement

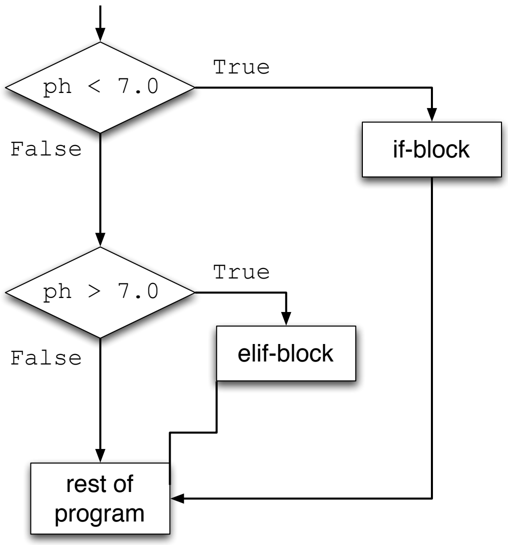


Figure 26—elif statement