

A close-up photograph of a green snake's head, showing its eyes and mouth. The snake is coiled, and its head is the central focus. The scales are a vibrant green with some lighter and darker patches. The mouth is slightly open, revealing a pinkish interior and some yellowish teeth.

# Exploring **Python**

Timothy A. Budd

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**by  
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# Preface

## To the student: Why Python?

Given so many other programming languages in the world, why should you learn Python as your first exposure to computer programming? Well, the real answer is that your instructor selected the both the language and this textbook for the course, so what choice do you have? Nonetheless, let me explain why this was a very good decision.

Python is easy, Python is fun, Python is educational, and Python is powerful.

Let's start with the powerful. If you look at the case studies toward the end of the book, you will see that you will end up learning how to do some very interesting things. Tasks like writing your own blog, automatically solving sudoku puzzles, reading your iTunes database, or writing a wiki. None of these take more than a page or two of Python code. This is considerably smaller than the equivalent programs would be in almost any other programming language.

Is it easy? Let me fudge and say it is *easier*. Computer programming in any language takes skill, organization, logic, and patience. Python is no different in this regard. What makes Python attractive is that you can begin so quickly and easily. Your first Python program can be as simple as  $2 + 3$ :

```
>>> 2 + 3
5
```

Thereafter the path to learning how to create your own complex applications is, we hope, at least clearly laid out, even if it will take some effort on your part.

## Active Learning

This book follows an attitude towards teaching that has been termed *active learning*. Rather than treating you, the student, as a passive repository into which knowledge is poured, active learning tries to engage you, the student, as a fully equal partner in the process of learning. Rather than simply telling you how some feature works, I will usually suggest experiments that you can perform to discover the answer on your own.

There are several benefits to this approach. First, it makes you use a different part of your brain than you would if you were simply reading. Second, it gives you, the student, a greater sense of ownership of the knowledge. Third, experimentation is often the fun part of programming. Lastly, by encouraging you to experiment in the discovery of simple information, I hope to instill habits that you will continue to carry with you throughout your programming career. Together, the intent is that active learning helps you more easily retain and use the information you have learned.

## What is Python?

For those looking for buzzwords, Python is a high-level, interpreted, reflective, dynamically-typed, open-source, multi-paradigm, general-purpose programming language. I could explain each of those terms in detail, but in the end the result would still not convey what makes Python programming different from other languages. There is no one thing in Python that is not found in other languages, but it is the elegant design and combination of these features into a single package that makes Python such a pleasure to use.

Python is sometimes described as a *scripting language*, for the simple reason that thousands of working programmers daily use the language in this fashion. That is, they use Python as a tool to quickly and easily glue together software applications and components written in many different languages. But such a categorization is far too narrow, and Python can justly be described as a general-purpose language, one that can you can use for almost any programming task you would like to perform.

This is not to say that Python is the only programming language you will ever need or will ever learn. A working computer scientist should know how to use many different tools, and that means he or she should have an appreciation of many different types of language. For example, because Python is interpreted, the resulting programs are often not as fast as those written in lower-level languages, such as C or C++. On the other hand, programs are much easier to write than they are in C. So there is a trade-off, an engineering compromise of the type common in computer science. Is less time in execution of the final program worth spending more time in development and debugging? For the beginning student, and in fact for the vast majority of computer programs, the answer is clearly no. (Another way to express this trade-off is to ask, “whose time is more important, your time or the computer’s?”) Low-level languages such as C have their place, but only for the small group of computer programs for which ultimate execution time is critically important. You may eventually work on such systems, but not in your first programming course.

Another important category of programming languages are those tied to a specific application. A good example of this category is the language PHP, a programming language used to create interactive web pages. (See [www.php.org](http://www.php.org)). A general-purpose language, such as Python, cannot hope to be as easy to use in this application area. But PHP is extremely clumsy to use for purposes other than web pages. If, or when, you start extensive work in such an application area you will want to learn how to use these tools.

Bottom line, Python is an excellent place to start. And to stay, for many of your programming tasks. But you should not assume that it is the last language you will ever need or learn. Fortunately, languages have many features in common with each other. A solid foundation in one language (such as Python) makes it much easier to learn a second

(or third, or forth). An appendix at the back of this book provides hints as to how one should approach the task of learning a new language.

## History of Python

Python was designed by Guido van Rossum while he was working at the CWI (the Centrum voor Wiskunde en Informatica; literally “center for wisdom and informatics”) a world-class research lab in the Netherlands. The CWI group he was associated with designed a programming language called ABC. I was fortunate to spend a year with this group in 1985. ABC was clearly intended as a pedagogical tool for teaching programming, and a great deal of work went into developing both the language and associated teaching material.<sup>1</sup> The language ABC had a number of features that were impressive for the time: a tightly integrated development environment, interactive execution, high level data types (lists, dictionaries, tuples and strings), dynamic memory management, strong typing without declaration statements and more. The idea to use indentation for nesting, and eliminate the brackets or BEGIN/END keywords found in most other languages, was taken directly from ABC. So was the idea of dynamic typing. Software development in ABC was both rapid and enjoyable, and totally unlike almost any other competing language. (The one exception might be Smalltalk, which was just becoming well known in 1985. Indeed, during my time at the CWI I was writing a book on Smalltalk, and part of the work I performed during that year was to explain to my colleagues in the ABC group the basic ideas of Object-Oriented programming, which I myself was only just beginning to understand).

Guido started designing Python around 1990. For those familiar with the earlier language the heritage of ABC in Python is clear. Guido discarded some of the annoying features of ABC, and kept all the best ideas, recasting them in the form of a more general-purpose language. By then the mechanisms of object-oriented programming were well understood, and the language included all the latest features. He added a number of features not found in ABC, such as a system for modularization and including libraries of useful utilities. Python was released to the world in 1991, and very quickly attracted a loyal following. Python’s design turned out to be general enough to address a much wider range of applications than ABC. (To be fair, the designers of ABC were focused on teaching, and never intended the language to be general-purpose). The features that programmers appreciated in 1990 are still the same today: ease of use, rapid software development, the right set of data types that help to quickly address most common programming problems.

## Python, Monty

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<sup>1</sup> See the Wikipedia entry on ABC for further discussion of this language. The Wikipedia entry for Python has a much more complete history of the language. There is also a Wikipedia entry that explains the concepts of active learning. Wikipedia is found on the web at [www.wikipedia.org](http://www.wikipedia.org).

The name, by the way, owes nothing to the reptile and everything to the 1970's BBC comedy series *Monty Python's Flying Circus*. Many die-hard Python programmers enjoy making sly references to this series in their examples. You don't need to have seen *Monty Python's Life of Brian*, *The Meaning of Life*, *And Now for something Completely Different*, or *Monty Python and the Holy Grail* or even *Spamalot* in order to become a Python programmer, but it can't hurt, either.

## To the Instructor

I will begin this section with the same question I used at the start of the preface to the students. Why is Python a better programming language for the first course than, say, C, C++, Java, C#, Delphi, Ada, or Eiffel, just to name a few alternatives? The answer, as I suggested earlier, is that students will find that Python provides a much easier entrance into the world of programming, yet is complete enough to provide a comprehensive introduction to all the important ideas in programming, and is fun to use.

The fact that Python can be used in both an interactive and textual style makes the barrier for the beginning student extremely low. This is not true for other languages. To write even the simplest Java program, for example, the instructor must explain (or worse, not explain and leave as a magic incantation) ideas such as classes, functions, standard input, static variables, arrays, strings, and more. In contrast, the first Python program can be as simple as  $2 + 3$ :

```
>>> 2 + 3
5
```

The positive influence of interactive execution for the beginning student cannot be overstated. It permits (and the conscientious instructor should encourage) an exploratory and active approach to learning. To find out how something works, try it out! This empowers the student to take control of his or her own voyage of discovery, instead of simply playing the role of a passive container into which the instructor (or the book) pours information. I have discussed this *active learning* approach in my earlier remarks for the student.

But the fact that simple things are easy to write in Python should not be an excuse to imagine that the language is just a toy. It is a credit to the good design skills of Guido van Rossum (the language designer) and countless others that simple ideas are simple to express, and complex ideas can also be illustrated with simple examples. In what other language might an introductory textbook include examples of a blog, a wiki, or an XML parser?

Python is also an excellent vehicle for teaching computer science. All the basic concepts of programming (ideas such as values, variables, types, statements, conditionals, loops, functions, recursion, classes, inheritance, just to name a few) can be found in Python. The student gaining experience with these topics in this language is therefore in an excellent position to more easily learn other languages at a later time. An appendix offers some

general hints on how to go about learning a second, or third, programming language. These hints work for both the student coming to Python with experience in a different language, as well as student to whom this book is directed, those learning Python is their first language.

## Organization of this Book

The first eleven chapters of this book present a more or less conventional introduction to programming. Students learn about variables, types, statements, conditionals, loops, functions, recursion, classes and inheritance. What makes my approach different from that found in many other books is an attitude of exploration. Basic ideas are explained, and then the reader is lead through a process of experimentation that helps them find and test the limits of their understanding. By making the learning process active, rather than simply a matter of absorption, we engage the reader in a wider range of cognitive operations, and hopefully make the material both more enjoyable to learn and easier to remember.

The chapters after the first eleven represent a series of case studies. These explore the use of Python in a number of representative programming tasks. These tasks include the creation of a blog, a sudoku solver, a wiki, reading an iTunes database as an example of parsing XML, and more. These are intended to both illustrate good Python programming style, and to open the readers mind to the range of problems that can be addressed using the language. The case study chapters should be examined only after the students have examined the first eleven chapters, as they assume a familiarity with that material. After the first eleven chapters, however, the organization is much less linear. Instructors should feel free to present the latter material in whatever order they wish, or pick and choose chapters as fits their needs.

Although the basic syntax of Python is covered in the first chapters and in an appendix, the book cannot be considered to be a substitute for a reference manual. Much of the power of Python derives not from the basic language syntax, but from the wide range of libraries that have been developed to address problems in different domains. Fortunately, excellent reference material can be found at the web site [www.python.org](http://www.python.org). Similarly, the scope of this book is purposely limited. Programs are generally restricted to no more than two pages in length. Readers interested in larger examples are encouraged to look at the much more comprehensive, encyclopedic, and **heavy** book *Programming Python*, by Mark Lutz (published by O'Reilly).

## Advanced Packages and Libraries

There is a huge amount of exciting and fun activity occurring right now in the Python universe. Unfortunately, most of this requires the programmer to download and install at least auxiliary libraries, if not complete applications. Examples include the integration of OpenGL and Python for 3-D visualization, game development systems such as PyGames, visual development environments such as Alice, and much, much more. For a number of reasons I have resisted talking about these topics in this book. First, I doubt if many

students encountering programming for the first time using Python will have the ability, even after a term or two experience with Python, to install such systems on their own. Second, the speed at which changes are occurring in this arena is phenomenal. Almost anything I could say in print would have a high likelihood of being obsolete, or even wrong, by the time the book went to press. On the positive side, if I am successful in my goal of encouraging the student to embrace the ideas of active learning, then by the time they are finished with this book they should have not only the knowledge, but the self-confidence, to find information on the internet on their own (and the internet is now where the most reliable and up-to-date information is to be found). Just try googling with the phrase “Python OpenGL”, or whatever topic you want to explore. To those students, I say: good hunting, and have fun!

## **Acknowledgements**

I’m sure there will be many.

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# Chapter 1 – Exploring Python

Almost everybody has used a computer. If you have used a bank ATM, you have used a computer. If you listen to music on an iPod, you have used a computer. If you have a cell phone, you have used a computer. Nowadays, even your credit card may have a computer embedded in it.

The fact that the computer can be used in such a wide variety of different applications is astounding. But the computer is really just an extremely fast calculating machine—it performs a great many very simple tasks with extreme rapidity. Before the computer could be used in any of the applications named above, somebody had to lay out the exact instructions required to perform the task. This process is termed *programming*.

A computer does not understand natural languages, such as English. You cannot tell the computer “Play for me again that tune you played last Tuesday afternoon around 4PM”. Instead, instructions for a computer must be presented in a very structured form, termed a *programming language*. There are a great many programming languages in common use. In this book you will learn one of these, a language named Python.

## Interactive Execution

Unlike many computer languages, Python allows the user to work in an interactive fashion, much like a calculator. You type an expression, and immediately the expression is executed and the result printed. If you start the Python system, you should first see a line containing version and copyright information. This will be immediately followed by a line beginning with three right arrows:

```
Python 2.3.5 (#1, Mar 20 2005, 20:38:20)
[GCC 3.3 20030304 (Apple Computer, Inc. build 1809)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

The three right arrows are the *expression prompt*. The prompt is telling you that the Python system is waiting for you to type an expression. The window in which the output is displayed and input is gathered is termed the *console*. Try entering a simple mathematical expression, such as `2 + 3`. After you hit return, you should see the result printed, followed by a new prompt.

```
>>> 2 + 3
5
>>>
```

You can try various other expressions to get used to this style of operation. (We will have a whole section on the range of operations that Python supports in a bit). You halt interactive execution by typing control-D or control-Z (that is, typing D while holding down the control key. It's control-D on Macintosh and Unix machines, control-Z on windows machines). Try halting execution and restarting the Python system until you feel

comfortable with the process. If you haven't made one already, try making a purposeful mistake. For example, try typing 2 plus three

```
>>> 2 plus three
```

The Python system doesn't know what to make of this statement. Therefore, it produces an error message; a text message that hopefully should tell you what it does not understand. Afterward the system resets itself, and issues a new prompt and waits for you to continue.

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

Almost all Python expressions are typed on a single line. You can see this if you type a binary operation, and forget to fill in the right side:

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

An exception to this rule occurs when expressions are typed in parenthesis. Each opening parenthesis must be matched to a closing parenthesis. If the closing parenthesis is not found, a *continuation prompt* is given. Normally this continuation prompt looks like an ellipsis, that is, three dots.

```
>>> (2 +
... 
```

The continuation prompt is telling you that there is more to the expression you need to type. Fill in the rest of the expression, hit return, and the expression will be evaluated as before:

```
>>> (2 +
... 3)
5
```

If you are faced with a three dot prompt and don't know what to do you can simply enter right parenthesis until you get back to the top-level prompt.

## Comments

Any text that appears after a hash-mark (#) is termed a *comment*. Comments are ignored by the Python system. They are used purely to communicate information to a human reader.

```
>>> 2 + 3 # print two plus three
5
```

In interactive input a line consisting entirely of comments will produce a continuation prompt. You can simply hit return to proceed.

```
>>> # nothing at all
...
>>>
```

While legal, comments are not common in interactive input. However they are very common when Python statements are gathered together in a file to form a program. We will describe this style of use in the next chapter.

## Types

Think of the information that is printed on your driver's license. There is your name, your age, your date of birth, a driver license number issued by the state, probably an indication whether or not you need corrective glasses, and so on. Notice that this information comes in a variety of forms. Your age is a number. Your name is a string. Whether or not you need lenses is a true/false value. In programming languages we call these different forms of information *types*. The Python language has several built-in types.

The type you have using up to this point is termed an *integer*. Integers are the counting numbers you are used to from mathematics, both positive and negative. Some programming languages place an upper bound on the size of integers you can use. Python does not. Integers can be as large as you can type.

[illegible]

On some systems you may find the capital letter L following the output, indicating that the result is Long. The integer type does not include fractional numbers, which in programming languages are termed *floating-point*. A floating-point number (or simply a *float*) has a decimal point and a fractional part. Arithmetic operations work with either integer or floating-point:

```
>>> 2.4 + 3.7
6.0999999999999996
```

Notice that floating-point numbers are subject to a phenomenon called *rounding error*. Computations that would be precise when performed in base-ten arithmetic may not be when performed in the internal computer arithmetic. Floating-point numbers can also be written in scientific notation. This format is written as a number followed by the letter e (or E, either works) and an integer. The integer represents a power of ten.

```
>>> 2.3e3
2300.0
>>> 2.3e47 + 5.2e46
2.8199999999999998e+47
>>> 1.0 + 2.3e47
2.2999999999999999e+47
```

Often you can ignore the distinction between integer and floating-point, and simply think of a value as being a number. There is one common situation where the difference is important, although this is an area where the definition of Python is in transition. For versions of Python before version 3, and for most other programming languages, the division operator (that is, the slash), works differently for integers and floating point values. For integers the result is the integer part of the quotient; any remainders are simply thrown away:

```
>>> 5 / 2
2
```

For floating point numbers the result is floating point:

```
>>> 5.0 / 2.0
2.5
```

When one argument is integer and the other is float, the integer is converted into float and the result is float:

```
>>> 5.0 / 2
2.5
>>> 5 / 2.0
2.5
```

This will change in Python version 3. After that point a single slash division will return a true division, that is, the value  $5/2$  will be 2.5. A new operator, written as two slashes, will be used to produce integer division.

Another common type is a *string*. Strings can use either single or double quote marks. This is useful when a string must include a quote mark:

```
>>> "hello"
'hello'
>>> 'hi there'
'hi there'
>>> "don't do that"
"don't do that"
>>> 'I said: "stop right now" '
'I said: "stop right now" '
```

Try creating several different string expressions, using both forms of quote mark.

The *boolean* type represents a true or false value. The most common way to produce a Boolean value is with a relational operator.

```
>>> 17 < 21
True
>>> (2/3) < (3/5)
False
```

The names True and False represent Boolean constants. There are also logical operators (and, or, not) that work with Boolean valued expressions in the expected fashion.

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

Python has a number of other built-in types. These include complex numbers (using, curiously, the letter J instead of the letter I to represent the square root of -1), lists, tuples, dictionaries, functions, and classes. We won't use complex numbers in this book, however the others will be examined in later chapters.

## Names (Variables)

Computers are used to manipulate information. Often lots of information. In order to help keep track of things, values can be given names. A value is given a name by means of an *assignment statement*, or simply an *assignment*. The text to the left of the assignment is the name, and the text to the right is the value that will be remembered for the name:

```
>>> name = 'fred'
>>> count = 7
```

After an assignment, if you use the name, the value stored for the name is remembered.

```
>>> name
'fred'
>>> count + 2
9
```

You can change the value stored with a name simply by assigning the name a new value:

```
>>> name = 'sally'
>>> name
'sally'
```

Notice that types are associated with values, not with names. A name can be given a different type simply by assigning it a new value:

```
>>> name = 5.0/2
>>> name
2.5
```

A name must begin with a letter or underscore, and can include any number or letters, digits, or underscores. A name cannot begin with a digit, nor include any characters other than letters, digits, or the underscore character.

A named value is often termed a *variable* (since it represents a quantity that can change over time, that is, can vary). You should at this point stop reading and experiment with the Python interpreter, creating and using several variable names, until you are comfortable with this idea. Variables are useful when we want to use a value more than once, or when we want to break a complicated computation into several smaller parts.

Do not call the = operator ‘equals’, as that confuses the concept with the mathematical notation of equality, which uses a different operator. Instead, the symbol should be read as “assignment”. So if you are reading aloud the statement given earlier you would say something like “the variable name is assigned the value sally”. If you want to represent the mathematical idea of equals, which is asking the question whether a variable is or is not holding a value in question, you must use the == operator:

```
>>> name == 'sally'
True
>>> name == 'name'
False
```

Which brings us to a discussion of ...

## Operators

Each of the built-in types brings with it a set of *operators*. The following are the binary operators recognized by Python. (Binary operators are those that appear between their two arguments, as in 2+4). Not all operators can be used with all types, and sometimes operators have surprising meanings. Try typing ‘abc’ \* 3, for example. The exercises at the end of this chapter will lead you through an exploration of the operations provided by Python.

+   -   \*   \*\*   /   %   <<   >>   &   |   ^   <   >   <=   >=   ==   !=   <>

The following can be used as unary operators

+   -   ~

You may remember from a mathematics class that multiplications are performed first, then additions. This is termed *precedence*. The order that operators are evaluated can be controlled using parenthesis. Using the idea of precedence, explain why the following two expressions produce different results.

```
>>> 5 + 2 * 3
11
>>> (5 + 2) * 3
21
```

In mathematics there is also an issue termed *associativity*. This applies when two operators with the same precedence are used in one after another. For example, does the sequence  $9 - 5 - 2$  evaluate to 6, which would be the same as  $9 - (5 - 2)$ , or to 2, which is the same result as  $(9 - 5) - 2$ ? Try it and see. What about  $12 / 2 * 3$ ? What does the latter expression tell you about the precedence of the multiplication and division operators?

Python has precedence and associativity rules for all operations. When in doubt about these rules you should use explicit parenthesis.

A few binary operations have a text name. The most common examples are the logical operations `and`, `or` and `not`.

```
>>> (3 < 7) and (4 < 5)
True
>>> (3 < 2) or (6 > 4)
True
```

Another operator with a text name is `in`. This can be used (among other purposes) to determine if a character value is found in a string. It returns `true` if the left argument is found in the right argument, and `false` otherwise.

```
>>> 'a' in 'abc'
True
>>> 'z' in 'abc'
False
```

Does the `in` operation work if the left argument is larger than a single character? Try it and see if you are correct.

## Functions

Not all operators use the binary operator syntax. An alternative syntax is termed the *function call* notation. In this notation the name of the operation is given first, followed by a list of the arguments surrounded by parenthesis. For example, the `abs` operation returns the absolute value of the argument:

```
>>> abs(-3)
3
```

Just as the parenthesis in an arithmetic expression indicated that the enclosed expression needed to be evaluated first, the arguments to a function are first calculated, and then the function is applied:

```
>>> abs(2 - 3 * 7) # first calculate 2-3*7, which is -19
19
```

The function `len` returns the number of characters (that is, the length) of a string.



```
>>> len('abc')
3
>>> len('ha' * 4)
8
```

Most operations defined using this syntax have a fixed number of arguments. However, a few can take any number of arguments. An example is the `min` function, which returns the smallest of the arguments, regardless how many are given:

```
>>> min(2, 3)
2
>>> min(5, 6, 2.2, 17)
2.2
```

An important class of functions are used to convert values from one type to another. The function `int`, for example, can be used to convert a string into an integer. The function `str` goes the other way, converting a value (such as a number) into a string:

```
>>> int("42")
42
>>> int("42") + 2
44
>>> "42" + "2"
'422'
>>> str(42+2)
'44'
>>> str(42+2) + "2"
'442'
```

The `int` function can also be used to convert a floating point value into an integer. For example, suppose you live in a state where the sales tax rate is 8.7%. How much will you pay for an item marked \$10.52?

```
>>> 8.7 * 10.52
91.523999999999987
```

Since fractional pennies are not part of US currency, we can convert the amount in cents using the `int` function:

```
>>> int(8.7 * 10.52)
91
```

Most states, however, don't simply truncate the fractional cent amount, but instead round to the nearest cent. There is a function that will do this, but for a floating-point argument it returns a floating-point result:

```
>>> round(8.7 * 10.52)
92.0
```

We can combine `round` and `int` to return a value that is both rounded and integer:



## Print Statement

An even simpler way to produce multipart output is to use the *print* statement. The print statement takes a series of values separated by commas. Each value is converted into a string (by implicitly invoking the `str` function) and then printed. Additionally, quote marks are removed from printed strings.

```
>>> print 'answer is', eval(expr)
answer is 5
```

The print statement also formats numbers slightly differently than simple expressions. For example, it produces fewer digits for floating values:

```
>>> 1.0/3
0.33333333333333331
>>> print 1.0/3
0.333333333333
```

Finally, the print statement recognizes a few commands that can be used to format input. These are termed escape characters, and are written as a character following a backslash. The most common is the newline character, written `\n`. This moves the output on to a new line. The tab character, `\t`, moves the output to the next tab stop. To print a literal backslash character you use two slashes, `\\`.

```
>>> print "one\ntwo\tthree"
one
two      three
```

Escape characters can also be used to embed a quote mark within a quoted string.

```
>>> print 'don\'t do that'
don't do that
```

We will discuss the print statement, as well as other Python statements, in more detail in the next chapter. Escape characters are described in Appendix A. Experiment with the print statement and various different types of expressions.

## Input from the User

The combination of `eval` and `raw_input` occurs so frequently that Python provides this combination as a standard function, named `input`. Use `input` if you are reading a number, and `raw_input` if you want the response stored as a string.

```
>>> x = input("type a number:") # user types a response, e.g. 5
>>> print x + 2
7
```

We can illustrate the use of `input` by a simple series of statements to convert a temperature from Celsius to Fahrenheit.

```
>>> c = input("what is the temp in Sault St. Marie, Ontario?")
what is the temp in Sault St. Marie, Ontario?
17
>>> f = c * 9.0 / 5.0 + 32
>>> print 'across the river, in Sault St. Marie, Michigan, it is ', f
across the river, in Sault St. Marie, Michigan, it is 62.6
```

## Indexing (Slicing)

Another common operation uses the square brackets. This is termed *indexing*, or *slicing*. An index or slice returns a portion of a larger value. In a string this can be used to produce a substring. Index values start at zero, and extend upwards to the number of characters in the string minus one. When a single argument is given it is one character out of the string. When two integers are written, separated by a colon, it is termed a slice. The second value is an ending position. A portion of the string starting at the given position up to but not including the ending position is produced.

```
>>> 'abc'[1]
'b'
>>> 'realtor'[2:6]
'alto'
```

You should at this point stop reading, and experiment with the slicing operator with various different strings and argument values, until you are comfortable with the notation.

If a colon is given but the last number is omitted the result is the remainder of the string starting from the given position.

```
>>> 'recurrent'[2:]
'current'
```

Finally, if no number is given before the colon the result is the initial string up to but not including the given position.

```
>>> 'halter'[:4]
'halt'
```

Strings are *immutable*, meaning they cannot be changed once assigned. Instead, a new string constructed out of an existing string can be formed in parts, using slicing commands.

```
>>> word = 'red'
>>> word[1] = 'a'    # show word cannot be changed
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
TypeError: object doesn't support item assignment

>>> word = 'b' + word[:2] + 'a' + word[2:]
>>> word    # change red to bread
'bread'
```

Slicing may seem complicated, but is an extremely powerful operation. You should experiment with different slicing possibilities until you feel comfortable with the technique. And remember that whenever you are in doubt about the meaning of an expression you can simply try some examples at the keyboard.

The concepts of indexing and slicing are also used with the list and dictionary data types, which we will investigate in a later chapter.

## Modules and dot notation

Another common syntax is termed dot (or class) notation. A name can be qualified by the class or module in which it is defined. A module is a library of functions used to provide a service. Most Python programs will use one or more modules. An example is the `math` module, which defines a number of common mathematical functions. To tell the Python system you want to make use of the services provided by the module you type an *import* statement, such as the following:

```
>>> import math
```

After the import statement you can then use the functions defined in the `math` module. Each value or function is preceded by the name of the module in which it is defined.

```
>>> math.pi    # a value defined in the math module
3.1415926535897931
>>> math.sin(math.pi/2.0)
1.0
>>> math.sqrt(1000)
31.622776601683793
```

There are many modules defined in the standard Python distribution, and many more can be downloaded from public sources. The use of these modules greatly simplifies the creation of Python applications.

Let us use the `math` library to write statements that will solve a quadratic equation. A quadratic equation has the form  $ax^2 + bx + c = 0$ . Recall that such an equation has two solutions for the value of  $x$ , and these are given by the formula

$$x = -b \pm \sqrt{b^2 - 4ac} / 2a$$

The input to our program consists of the three values  $a$ ,  $b$  and  $c$ . These can be read using the `input` function. The outputs are the two values given by the formula.

```
>>> import math
>>> a = input('type the value for the coefficient a')
>>> b = input('type the value for the coefficient b')
>>> c = input('type the value for the coefficient c')
>>> d = b * b - 4 * a * c
>>> d = math.sqrt(d)
```

```
>>> print 'first root is ', (-b + d) / (2 * a)
>>> print 'second root is ', (-b - d) / (2 * a)
```

## An Attitude of Exploration

In this chapter we have introduced many new concepts and expressions. The reader may at first feel overwhelmed by the amount of information to remember. Don't worry. With experience and practice all these ideas become second nature. As we noted in the discussion on slicing, an important part of gaining experience is experimentation. The interactive nature of the Python system makes experimentation extremely easy. Even experienced Python programmers will frequently start an interactive session just to type small statements and expressions to remind themselves how a particular operator or function works. You should develop this attitude of exploration, and whenever you are in doubt about a feature, try it out!

## Bitwise Operators <sup>\*1</sup>

If you have followed the instructions to explore the meaning of the various operators provided by the Python system you may have been confused by the operators `<<`, `>>`, `&`, `|`, `^` and `~`. These operations make sense if you understand that computers process information in a different form than you are used to.

Humans work with numbers in a base-10 system. When we see a value, such as 4,372, we read this as representing 4 times one thousand (that is,  $10^3$ ) plus 3 times one hundred ( $10^2$ ), plus seven times 10 ( $10^1$ ) plus 2. Internally, computers work in a much simpler system. They work with only two values, 0 and 1, termed *bits*, and a number system based on 2.

Any number can be written in base 2. Take, for example, the number 42. This is written 101010. To convert back and forth, read the number from the right side, rather than the left. 101010 is 0 times 1 plus 1 times 2 plus 0 times 4 ( $2^2$ ) plus 1 times 8 ( $2^3$ ) plus 0 times 16 ( $2^4$ ) plus 1 times 32 ( $2^5$ ).  $2 + 8 + 32 = 42$ .

The operators `<<`, `>>`, `&` and `|` are best understood if you convert their arguments into this internal binary representation. Take, for example, the left shift operator, `<<`. This operation shifts the left argument represented in base two by an amount given by the right argument. For instance, consider the expression `5 << 3`. The value 5 is 0101 in binary. Shift this left by 3 places, and you have 0101000. Convert this back to base 10, and you have the value 40.

```
>>> 5 << 3
40
```

---

<sup>1</sup> Sections marked with an asterisk indicate advanced and/or optional material, and can (probably should) be omitted on your first reading. Once you have grasped the remainder of the chapter, come back and examine the more advanced sections.

The `>>>` operator shifts values to the right. See if you can figure out the binary representation for the value 15. Then, using that representation, explain the following behavior:

```
>>> 15 >> 2
3
```

The operators `&` and `|` perform a bitwise *and* and *or*, respectively. These operations work bit by bit. A 1 bit can be thought of as corresponding to the logical value true, and a 0 as the logical value false. An *and* of two bits is 1 if both bits are 1, and an *or* is 1 if either bit is 1. This is just like a logical *and* if true if both arguments are true, and a logical *or* is true if either argument is true. So the bitwise `&` of 5 and 12 (0101 and 1100, respectively) is 4 (0100) while the bitwise `|` is 13 (1101).

```
>>> 5 & 12
4
>>> 5 | 12
13
```

The `^` operator is known as an *exclusive-or*. The exclusive-or of two bits is 1 if either is 1, but not both. So `5^12` is 9 (1001).

```
>>> 5 ^ 12
9
```

The unary operator `~` performs a *bitwise inverse*. In the result every bit that was 0 becomes 1 and every bit that was 1 becomes 0. Because of the way that negative numbers are stored in the computer a positive value becomes negative, and a negative value will become positive.

```
>>> ~4
-5
>>> ~ -7
6
```

A version of the `int` function that takes a string and a base can be used to convert base-2 numbers (or any other base, for that matter) into base-10 integers:

```
>>> int("0101", 2)
5
```

Bitwise operations are useful in certain situations, but are infrequent in practice.

## Encodings \*

The underlying hardware for a computer works with simple zeros and ones. These are called *bits*. All values manipulated by a computer must ultimately be represented by bits. The way the bits are interpreted is what gives meaning to the values.

You started to explore this in the previous section, where you experimented with the encoding for integer values. An integer value, such as 42, is encoded as a string of bits, for example 101010. For efficiency reasons computers normally work with a fixed block of bits. Some of the more common blocks are the byte (8 bits) and the word (on most machines, 32 bits). Integers, for example, are commonly stored as a 32-bit word. This means that the value 42 is really

[illegible]

A single character is normally stored as a byte, that is an 8-bit quantity. You can find the integer value of a character, as an integer, using the function named `ord` (short for ordinal).

```
>>> ord('a')
97
```

This tells you that internally the character ‘a’ is stored as the integer value 97. The mapping of characters to integer values is given by a standard, called ASCII (the American Standard Code for Information Interchange). We say that “the ASCII representation of the character a is 97”.

An 8 bit byte allows 256 different values. This is fine for roman based languages with a small number of letters (for example, 26 letters in English), but is insufficient for languages such as Chinese or Korean. Letters in these languages are encoded in a 16-bit form, termed Unicode. Using a web search you can find the Unicode values for letters in various languages.

A string is represented internally by a series of eight bit bytes. For example, the word 'Python' is represented internally as:

80	121	116	104	111	110
----	-----	-----	-----	-----	-----

The numbers are the ASCII representation for the six characters. Use the `ord` function to determine how these particular numbers were selected. A block like this is sometimes termed an array. We will have much more to say about arrays in a later chapter. An integer that is larger than 32 bits is similarly represented by an array of integers.

By the way, the function `chr` (short for ‘character’) is the opposite of `ord`. It takes an integer value, and returns the corresponding character:

```
>>> print chr(97)
'a'
```

A floating-point number is typically represented using a two integers, similar to the idea of scientific notation. In scientific notation a value of 24.35 can be represented as  $2435 \times 10^{-2}$ . The base can be omitted, and only the two integers 2435 and -2 need be represented.



-2	2435
----	------

Computers, as we noted earlier, work in base 2 rather than base 10, however the underlying idea is the same.

Larger data types require a more complicated encoding, ultimately, however, everything must be reduced to bits. Consider a picture. You may know that pictures are made up of little dots, termed pixels. Each of these dots is a distinct color. You may remember from an art class that all colors can be created from the basic colors red, green and blue. In a computer a color is often encoded as three bytes that represent the amount of red, green or blue. This is termed the RGB encoding. Each pixel in this system requires 24 bits (that is three colors times 8 bits for each color).

A simple way to represent a picture would be an array of pixels. In a 640 by 480 pixel picture (a common size for digital images) this would require 921,600 bytes (that's 640 times 480 times 3). Because large images are relatively common there are various more sophisticated techniques used to represent pictures that use less memory than the array of pixel format, but the ideas are similar.

Sounds, movies, in fact all data values manipulated by a computer must ultimately be encoded as a series of bits.

## Exercises

- Examine each of the following expressions. Predict what the result should be, then evaluate the expression using the Python interpreter to check your predictions. Explain what the type is for each expression. If an expression is illegal, explain why.
  - $10 / 5$
  - $5 / 10$  (or  $5 // 10$  in newer Python systems)
  - $5.0 / 10$
  - $10 \% 4 + 8 / 4$
  - $3 ** 10 / 3$
- Translate each of the following mathematical expressions into an equivalent Python representation.
  - $(3 + 4)(7)$
  - $n(n - 1) / 2$
  - $\text{sqrt}(a * a + b * b)$
- Explain the difference between  $42 + 2$  and  $"42" + "2"$ . What is the  $+$  operator doing in each case?
- What is wrong with this version of the quadratic formula?

$$r1 = (-b + d) / 2 * a$$

5. Write a series of Python statements that will first ask the user to type today's exchange rate between US Dollars and Euros. Next, ask the user to type a value in Dollars. Finally, print the equivalent value in Euros.
6. Write a Python statement that reads a numeric value from the user, placing it into a variable named x. Then write a print statement that will print the values x, x<sup>2</sup>, x<sup>3</sup> and x<sup>4</sup>. Use tab characters to separate the four resulting values. Write a second print statement, but use newline characters instead of tab stops.
7. Write three Python statements. The first should read a number from the user that represents a temperature in Fahrenheit, placing the value into a variable named f. The second statement should convert the value into Celsius, placing the result into a variable named c. The third statement should print the values of f and s with a descriptive notation.
8. Write a series of Python statements that will read a number from the user that represents the radius of a circle. Then use a print statement to show the circles diameter, circumference and area. You can import the math module and use the constant math.pi to represent the constant  $\pi$ .
9. Write a series of Python statements that will import the math module, read a number from the user that represents an angle given in radians, and then prints the sine and cosine for the given angle.
10. Try writing a print statement that uses the escape character \b. What do you think this is doing? Try placing several characters before and after the \b. Try typing several in a row after a series of characters.
11. Try writing a print statement that uses the escape character \a. What do you think this is doing? Can you think of a use for this feature?
12. Python supports eighteen different binary operators. Experiment with each of these, using arguments that are integer, floating point, and string. Not all operators work with each argument type. Fill in the following table. For each operator, give either a short description and indicate the type of the result or the words NOT LEGAL.

Operator	Integer	Floating point	String
+			
-			
*			
**			
/			
%			

<<			
>>			
&			
^			
<			
>			
<=			
>=			
==			
!=			
<>			

13. Assume the variable named `n` holds a positive integer value. How do you determine the last digit of `n`? (Hint, what does the `%` operator do?)
14. You have probably discovered that the `%` operator performs the remainder operation when used with two positive integer arguments. But what does it do when one or both arguments are negative?

```
>>> 11 % 3
2
>>> 11 % -3
-1
>>> -11 % 3
1
>>> -11 % -3
-2
```

Try to come up with an explanation of this behavior. To do so, make a chart of the values from -15 to 15, and for each compute the result when used with the mod operator and the value 3. Then do the same chart with -3. Can you see a pattern? From this pattern can you explain the behavior of the mod operator?

15. Your explorations of the chart in exercise 1 may not have led you to explore what happens if the arguments are different types. Try each of the eighteen operators using the value `'abc'` as the left argument and the value `2` as the right argument. Which of the 19 operators are legal? Can you explain what the result represents? Reverse the arguments, using `2` as the left argument and `'abc'` as the right. Which are still legal?
4. Can you select values for `x` and `y` in the expression `-x + y` that will help you determine the precedence of the unary `-` operation in comparison to the binary `+` operator?
5. Python allows relational operators to be *chained*. If `x` is a number, what do you think the expression `3 < x < 5` means? Can you design an experiment to test your

guess? What about  $5 > x > 2$ . Does an expression such as  $2 < x < 4$  make any sense? What does it mean?

6. You may have noticed that integers come in two flavors, small integers and long. You can see this using the exponentiation operator. A value  $2^8$  is a normal integer, while  $2^{100}$  is long.

```
>>> 2**8
256
>>> 2**100
1267650600228229401496703205376L
```

The L at the end of the number indicates the value is Long. (If your system does not supply the L the same information can be found using the function named `type`). Find experimentally the smallest integer I for which `2 ** I` is long.

7. Each row in the following table consists of a starting word and an ending word. Assign the starting word to the name `w`. Then using only indexing and slicing commands, convert the starting word into the ending word. The first is done for you as an example.

Starting word	Ending word	command
<code>w = 'kyoto'</code>	<code>'tokyo'</code>	<code>w[3:] + w[:3]</code>
<code>'bread'</code>	<code>'bead'</code>	
<code>'kartasura'</code>	<code>'surakarta'</code>	
<code>'listen'</code>	<code>'silent'</code>	

8. What happens when you try to index a string value with a number that is out of range? Such as `'abcdef'[9]`? What happens when you use a negative number, such as `'abcdef'[-2]`? How about `'abcdef'[-9]`? Can you provide a rule to explain the result?
9. Assume that the name `w` is assigned the value `'abcdef'`. Explain the meaning of each of the following: `w[2]`, `w[2:]`, `w[:2]`, `w[2:4]`, `w[:]`.
10. Try typing the following expressions: `'abc'[0]`, `'abc'[0][0]`, `'abc'[0][0][0]`, `'abc'[0][0][0][0]`. Can you explain what is going on here?
11. What happens if you try to divide an integer value by zero?
12. What happens if you type control-D (control-Z on windows machines) when the Python system is waiting for input for a call on `raw_input`?
13. Assume that a year contains 365 days (that is, ignore leap years). Let `y` be the name holding a value that represents an age in years (e.g., 23). Write an

expression that represents the number of seconds in that period (e.g., the number of seconds in 23 years).

14. Using the fact that the unary `~` inverts each bit in an integer, and the knowledge of the binary representation for positive numbers, experimentally discover the representation of negative numbers. For example, you know the representation of 5 is 0101. The following tells you that the internal representation of -6 is the inverse, that is 1010. Experiment with other values. Can you develop a general rule that explains the representation of a negative number as the inverse of a positive number?

```
>>> ~ -6
5
```

15. The functions `max` and `min` can also be used with string arguments. What is the value of `max('abc')`? Of `min('abc')`? Can you explain the meaning of the result? Using `max` and `min`, can you tell which is larger, the lower case letter 'a' or the upper case letter 'A'? What about 'a' and '0'?
16. Include the module named `random`, and then print the value of the expression `random.random()`. Do it several times. What do you think the expression represents? Try typing `random.randint(a, b)` with various different integer values for `a` and `b`. What does it return? What happens if you use non-integer arguments with `randint`?
17. What happens if you take the square root of a negative number? Try importing the `cmath` module and using `cmath.sqrt()` instead. Now what happens?
18. Most of the assignment operations can be combined with an assignment, to form what is known as an assignment operator. For example, what do you suppose is the value of the variable `a` after the following two commands. Write down the statements you might use to verify your guess. Give examples to demonstrate what various other assignment operators do. What would happen if the following example used strings instead of integers?

```
>>> a = 7
>>> a += 5
```

19. The function `int` can be used to convert a float into an integer, as in `int(2.9)`. It can also be used to convert a string containing an integer into an `int`, as in `int("2")`. You might then be tempted to think that it could convert a string containing a float into an `int`, as in `int("2.9")`. Does this work?
20. What is the value of `int("0101", 3)`. Explain how this value is derived. Then do the same for `int("0101", x)` for values of `x` between 4 and 10.

21. How many different possibilities can be represented using two binary digits (or bits?) How many with three? with 8?
22. The section on encodings gave an intuition for how floating point numbers could be encoded as a pair of integers. Do a web search using the terms “floating point encoding” and find a more detailed description of the actual encoding used by most computers.
- 23.

## Chapter 2 - Creating Python Programs

While using python in an interactive fashion is easy and powerful, it becomes tiresome when you need to perform the same task more than once. Each time requires you to enter the commands all over again. Fortunately, there is an alternative. Python statements can be stored in a file. You can then direct the Python system to read and execute the commands from the file, rather than from the console. Such a file is termed a Python *program*.

There are a few differences between commands that are typed at the console and those read from a file. To see these, try typing the lines shown at right directly into the

```
# a simple python program
5 + 2
print 5 + 2
name = raw_input("what is your name?")
print 'hello' , name
```

Python system. Then enter the lines into a text file using your favorite text editor, such as Notepad or SimpleText. (If you use a wordprocessor, such as Word, make sure you save the document as a text file). Traditionally python programs are stored in a file with the extension .py. Name your file hello.py. Once you have created the file, start the python system and give the file name on the command line, as follows:

```
python hello.py
```

Can you see any differences in execution? Notice that simple expressions, such as the line 5+2, are displayed when Python is running an interactive session, but do not appear when input is coming from a file. The only output you see will come from the print statements. Experiment by making changes in the file hello.py and executing the resulting file. If you have not already done so, try making an error, such as misspelling a name or leaving out a value for the addition operator. What happens? How is the error message different from the error message you get in the interactive session?

### A Temperature Conversion Program

Let us take an example from the previous chapter and rewrite it as a program. Enter the following statements into a file named tempConv.py:

```
# tempConv.py
# A Celsius to Fahrenheit conversion program
# written by Robin Smith, July 2007

print "This program will convert a temperature in Celsius"
print "to the equivalent temperature in Fahrenheit"
c = input("What is the temperature in Celsius you wish to convert? ")
f = c * 9.0 / 5.0 + 32
print "The equivalent temperature in Fahrenheit is", f
```

Notice some of the features of this file that are characteristic of Python programs. First, the program begins with some informative comments. These should always include the

purpose of the file, as well as the name of the author and date of creation. Often, as shown here, the first line will be the name of the file in which the program is stored, however this convention is not always followed.

The body of the program contains the statements that will be executed when the program is run using the Python interpreter. A common feature is for these to begin with some helpful print statements that will remind the user what the program is doing and what the inputs represent. Having stored the file `tempConv.py`, you should then try executing the file several times using different numbers for the input value. Can you empirically discover the temperature at which the Celsius and Fahrenheit values are the same?

No program should ever be written without being tested. What values should you use to test your program? For a program such as this you can start with values for which you know the correct answer.

```
$ python tempConv.py
This program will convert a temperature in Celsius
to the equivalent temperature in Fahrenheit
What is the temperature in Celsius you wish to convert? 0
The equivalent temperature in Fahrenheit is 32.0

$ python tempConv.py
This program will convert a temperature in Celsius
to the equivalent temperature in Fahrenheit
What is the temperature in Celsius you wish to convert? 100
The equivalent temperature in Fahrenheit is 212.0
```

These two well-known values are correct. After a few more sample points, you can be assured that this simple program is working properly. (This is not to say that testing is always this easy; it's not. We will have more to say about testing programs after we have introduced a bit more Python syntax).

Try rewriting the quadratic equation solver from the previous chapter as a program. What values might you use to test your program? As you are testing, can you find any deficiencies in the program?

## Statements

A python program consists of a sequence of python *statements*. The term *code* is often used to describe statements that have been organized into a program. In the previous chapter you encountered three forms of statement; the assignment statement, the print statement and the import statement. Two of these three are used in this sample program. In this chapter you will learn about several more forms of statement.

Writing a Python program has many advantages over immediate execution. One, it allows you to execute the same series of statements over and over. For example, you might want to do the same calculation with different input values. Second, it allows for the possibility that one person (the *programmer*) might create a Python program that will then be



executed by somebody else (the *user*). The user might not even know the Python programming language, or how to program, or know that the program they are using was written in Python. Third, you have undoubtedly noticed that it is difficult to write more than a few statements in Python without making mistakes. Common mistakes include using an incorrect name, an improper operator, leaving out punctuation, and so on. When Python statements are collected into a program, these errors can be corrected by editing the file. The revised program can then be easily executed, without the need to retype the statements. This process is termed *debugging* (that is, removing the errors, or “bugs”, from a program). Fourth, a Python program is an artifact, an object that can be shared with others. Good programmers learn by reading each others code, as much as from reading introductions such as this chapter. As you mature your programming skills, you should practice reading code as a form of literature, noticing what makes a program easy to read, and what features make programs more difficult to read.

## Assignment

In the last chapter you were introduced to the assignment statement. The assignment is used to associate a name with the result of evaluating an expression.

```
f = c * 9.0 / 5.0 + 32
```

This form is actually a special case of the assignment. Python permits any number of variables to appear on the left side separated by commas. The same number of expressions must then appear on the right side, again separated by commas.

```
sum, diff, prod = x + y, x - y, x * y
```

The expressions are evaluated, and each is assigned to the corresponding variable. In this case, the effect is the same as the three statements:

```
sum = x + y
diff = x - y
prod = x * y
```

This is sometime termed a *simultaneous assignment statement*. One use for simultaneous assignment is to read more than one value from the user in a single statement. For example, we could read all three coefficients in our quadratic solver from last chapter with the following statement:

```
a,b,c = input("type the coefficients a, b and c, separated by commas")
```

This form of assignment can occasionally be useful. Here is a more subtle example. The statement

```
x, y = y, x
```

will exchange the values of the variables `x` and `y`. Try typing the statements in an interactive session to convince yourself that it has this effect. Now try the simple rewriting we used above and see what happens:

```
x = y
y = x
```

Why doesn't this sequence of statements have the effect you want? An exchange of values in two variables is a common requirement in many programs, and Python provides a powerful yet simple solution to this difficulty.

## Conditionals

Another common task is to choose between two or more alternative possibilities depending upon the outcome of a test. This is termed a *conditional*. To see a

```
print 'The exam had 40 points'
score = input("What was your score?")
percent = 100 * score / 40.0
print 'Your percentage was', percent
if percent >= 90.0:
    print "Congratulations, you got an A"
```

conditional being used in practice consider the program shown at right. The program prompts the user to enter a value, performs a simple calculation, and prints the result. In this case it is converting a test score (a number between 0 and 40) into a percentage. As a final step, however, the program tests the value stored in the variable named `percent`. If this value is larger than 90, an encouraging statement will be printed. If the value is not greater than 90, no statement will be printed.

You should experiment by executing this program with various values and noticing the way it works. You can also try typing the same statements in an interactive session. An important feature to note is the use of spaces and tab stops. Up to now all our statements have started in the first column. In this program the pattern has changed. The statement following the `if` statement is indented by striking the tab character once.

At this point, if you have embraced the experimental approach advocated in the previous chapter, a number of questions should be entering your thoughts. What happens if you forget to type the tab character? What happens if you use spaces instead of tabs? What happens if you type two tabs instead of one? Rather than telling you the answer, you should immediately go and try these alternatives and see the results for yourself.

```
if percent >= 90.0:
    print "congratulations, you got an A"
    print "you are doing well in this class"
print "see you in class next week"
```

More than one statement can be controlled by a conditional. To do this, simply type each statement using the same

indentation; that is, the same number of tab stops. When the indentation returns to the previous level the statements are no longer being controlled by the `if`. You can see this behavior by replacing the `if` statement with something similar to the statements shown at left.

An if statement produces one of two outcomes. Either the condition is true, in which case the indented statements are executed, or it is not true, in which case control moves to the next statement at the original level of indentation. Sometimes you would like

to perform an action in the latter case, one that will not be executed if the if condition is true. This can be accomplished by an *else* statement, as shown at right. Again, you should experiment with the else statement, and notice how Python executes statements depending upon the result of the condition test.

```
if percent >= 90.0:
    print "congratulations, you got an A"
    print "you are doing well in this class"
else:
    print "you did not get an A"
    print "see you in class next week"
```

If statements can be nested inside each other. To do this, simply indent the new statement, adding one new tab for the new level of control. But you need to be careful. An else statement is matched to a preceding if by the indentation level. Compare the following two examples. Predict what the outcome of each will be, then execute the programs to test your prediction.

```
if percent >= 90.0:
    if percent >= 95.0:
        print 'you get an A+!'
    else:
        print 'you get an A'
```

```
if percent >= 90.0:
    if percent >= 95.0:
        print 'you get an A+!'
else:
    print 'you get an A'
```

## Nested if statements and elif

Often a series of tests can have a number of outcomes. One way to write this would be to use nested if statements. The following is an example:

```
if percent >= 90.0:
    print 'congratulations, you got an A'
else:
    if percent >= 80.0:
        print 'you got a B'
    else:
        if percent >= 70.0:
            print 'you got a C'
        else:
            print 'your grade is less than a C'
```

This situation is common, and the nested statement solution is less than ideal since it tends to creep across the page and lining up the correct number of tabs can be a problem. To solve this Python uses the elif statement, which is a combination of else and if. The statement above can be written as follows:

```
if percent >= 90.0:
```

```

        print 'Congratulations, you got an A'
elif percent >= 80.0:
    print 'You got a B'
elif percent >= 70.0:
    print 'You got a C'
else:
    print 'Your grade is less than a C'

```

## Single Statements

Frequently the statement under control of an if or else (called the *body* of the condition) is only a single statement. If the statement is short it is permitted to appear on the same line as the if or else, following the colon.

```

if percent >= 90.0: print 'Congratulations, you got an A'
elif percent >= 80.0: print 'You got a B'
elif percent >= 70.0: print 'You got a C'
else: print 'Your grade is less than a C'

```

This format can make programs considerably shorter, although slightly more dense and hence possibly difficult to read.

## Testing Conditional Statements

When you are testing a program that contains conditional statements you should strive to follow the following principles

- For each conditional statement, make sure you examine at least one test case in which the conditional is true, and one in which the conditional is false.
- Make sure you execute every statement in the program
- When a conditional includes relational comparison statements (less than, less than or equal, and so on), try to come as “close as possible” with a comparison that is true, and one that is false. If possible, include a value in which the comparison is equal, so that you can catch errors where a “less than or equal” is written that should have been a simple “less than”.

Let us use these principles to test our program, which we will assume has been stored in a file named examEval.py:

```

$ python examEval.py
The exam had 40 points
What was your score? 40
Your percentage was 100.0
Congratulations, you got an A

$ python examEval.py
The exam had 40 points
What was your score? 37
Your percentage was 92.5
Congratulations, you got an A

$ python examEval.py

```

```
The exam had 40 points
What was your score? 36
Your percentage was 90.0
Congratulations, you got an A
```

```
$ python examEval.py
The exam had 40 points
What was your score? 35
Your percentage was 87.5
You got a B
```

```
$ python examEval.py
The exam had 40 points
What was your score? 32
Your percentage was 80.0
You got a B
```

```
$ python examEval.py
The exam had 40 points
What was your score? 31
Your percentage was 77.5
You got a C
```

```
$ python examEval.py
The exam had 40 points
What was your score? 25
Your percentage was 62.5
Your grade is less than a C
```

If the comparison operations had used the wrong operations (less than instead of less than or equal) then the values 36 and 32 would have produced the wrong results. It is only after you have tested your program on a number of different inputs, and understand how those inputs are forcing the flow of control through your program, that you can have some degree of confidence that it is producing the correct result.

## While Loops

Another common need is to execute a statement repeatedly. This is termed a *loop*. The simplest type of loop is a *while* loop. To illustrate a while loop consider the calculation of compound interest. If you have  $d$  dollars that is being compounded at  $p$  percent interest, the interest earned at the end of one year is  $d * p / 100.0$ . Assuming you compound the interest, the new balance will be the old balance plus the interest. To calculate the result for one year you could write a program such as the following:

```
d = input("what is your initial balance?")
p = input("what is the interest rate (as a number)?")
d = d + d * p / 100.0
print "your new balance after one year is", d
```

Now you want to determine how much money you will have after five years. This can be computed as follows:

```
d = input("what is your initial balance?")
```

```

p = input("what is the interest rate (as a number)?")
year = 1
while year <= 5:
    d = d + d * p / 100.0
    print 'your new balance after year', year, 'is', d
    year = year + 1
print 'your final balance is', d

```

Study the program carefully. Notice which statements are indented, and which statements are not. Again, try experimenting with variations. What will happen if (by mistake) you forget to indent the statement `year = year + 1`? What changes do you want to make if instead of 5 years you want to do the calculation for 7 years? What if you want to read the number of years from the user? Imagine that you do the latter, and the user enters the value 0 for the number of years. What will your program do then?

The condition being tested by a while loop can be any true/false value. Here is another simple program. This program will read a series of values from the user, count the number of items, and print their average. The user indicates the end of the input by typing the special value -1.

```

sum = 0.0
count = 0
num = input("enter your number:")
while num != -1:
    sum = sum + num
    count = count + 1
    num = input("enter your number:")
print "average is ", sum / count

```

What will happen if the user enters -1 the very first time, without entering any numbers? Predict the outcome in this case, then try the program and see if it matches your prediction. Is the result very helpful? Can you think of a way, using if statements, to produce a more helpful result in this case and still produce the same result in the normal case?

## Testing While Loops

Just as there are guidelines for testing conditional statements, there are good guidelines for testing loops. These include the following:

- If a loop can execute an indefinite number of times, try to come up with an input that will force the loop to not execute at all, that is, execute zero iterations. This is probably the most easily overlooked error
- Try to find an input that forces the loop to execute only once.
- Find an input that forces the program to execute more than one time.
- If there is an upper bound on the number of iterations of the loop, try to find values that barely meet the upper bound, meet the upper bound, and exceed the upper bound.

Using these guidelines we would easily uncover the error described earlier:

```
$ python ave.py
enter your number: 12
enter your number: -1
average is 12.0

$ python ave.py
enter your number: 12
enter your number: 9
enter your number: 18
enter your number: -1
average is 13.0

$ python ave.py
enter your number: -1
average is
Traceback (most recent call last):
  File "ave.py", line 8, in ?
    print 'average is ', sum / count
ZeroDivisionError: float division
```

## Break, Continue and Pass Statements <sup>\*1</sup>

It is not uncommon to want to end a loop in the middle of execution. The break statement allows you to do this. It “breaks” out of the current loop. For example, rather than writing two different calls in the input function, the average computing loop could be written as follows:

```
sum = 0.0
count = 0
while True:
    num = input("enter your number:")
    if num == -1:
        break
    sum = sum + num
    count = count + 1
print "average is ", sum / count
```

Compare carefully this version of the loop with the one given earlier. Can you see any advantages to this approach? Can you identify any drawbacks?

The continue statement is similar to a break, only it immediately returns to the condition test of the loop (“continuing” execution of the loop).

Finally, a pass statement does nothing at all. There are two common situations where this is useful. First, it is sometimes easier to express a positive condition than a negative one. This can then be written as a conditional statement that does nothing, following by an else that does real work:

---

<sup>1</sup> Sections marked with an asterisk indicate advanced or optional material that can be skipped on first reading.

```

if a<b and x<3:
    pass # do nothing here
else:
    doRealWork(x, y)

```

Pass statements are also sometimes used in the body of a function. We will have examples of this in a later chapter.

## For loops

Loops that run through an arithmetic progression, such as 1, 2, 3, 4, 5, tend to be the most common. The loop given earlier that counted years from 1 to 5 was a typical example. For this particular case there is a simpler type of statement, termed a *for* statement. This could be written as follows:

```

for year in range(1, 6):
    d = d + d * p / 100.0
    print 'your new balance after year', year, 'is', d

```

There is actually more going on here than meets the eye. The function *range* is behind the scenes constructing a list containing the elements 1, 2, 3, 4 and 5. (That is, values up to but not including the second argument). The for statement is then iterating over elements of the list. However, we were not going to talk about lists until Chapter 4. And, in truth, most Python programmers think of this construct as an *idiom* without even recognizing that range is a function or that it is producing a list. Instead, it is simply a convenient way to write a loop that runs through a simple sequence.

A for statement is, in the strictest sense, never necessary. That is, anything that can be done using a for can be done using a while. For example, the statement above could be written as follows:

```

year = 1
while year < 6:
    d = d + d * p / 100.0
    print 'your new balance after year', year, 'is', d
    year = year + 1

```

However, there are advantages of the for statement over the while. Notice that the while loop requires a separate statements to perform both the initialization of the variable year as well as the increment. If either of these statements are omitted the program will fail to work properly. Furthermore, the for statement makes it clear that the type of loop being produced is an arithmetic progression, something that is only discovered after careful analysis of the while loop version. For these reasons the for statement should be preferred when it is appropriate.

The range function can take one, two or three arguments. Try executing the following, substituting the expressions range(5) (as shown), range(2, 8), and range(2, 8, 3). Then



write a short description of what the range function does when presented with one, two or three arguments.

```
for i in range(5):  
    print i
```

The for statement can also be used to loop over the letters in a string. Try executing the following:

```
for ch in 'abacadabra':  
    if ch in 'aeiou':  
        print 'letter ', ch, 'is a vowel'  
    else:  
        print 'letter ', ch, 'is not a vowel'
```

The exercises at the end of the chapter will help you hone your skills using conditionals and loops in Python programs.

## Levels of Abstraction

*Abstraction* is the process of purposefully hiding some details so that you can more easily see others. It is the principle means by which we handle complex systems. If you look at a map of the world, for example, you will see very large structures, such as mountain ranges or oceans, but you will not see individual streets as you would if you looked at a map of a city or town. In the first map the small details have been *abstracted away*, so that the larger details can be more easily understood.

Abstraction is used in computer programming as well. As we have noted already, the creation of a program opens the possibility that one person, the *programmer*, might create a Python program that will then be executed by somebody else, the *user*. Each of these individuals view the program at different levels of abstraction. The user simply needs to understand the purpose of the program, its input and output behavior. For example, they feed the program a number that represents a temperature in Celsius, and it returns a number that represents the equivalent temperature in Fahrenheit. The programmer, on the other hand, understands the program at an entire different level of abstraction. The programmer must understand the *process* by which the program produces the correct result for a given input.

As we progress through our exploration of Python, we will see this idea repeated several times in different forms. That is, we will encounter mechanisms (such as functions, the topic of the next chapter), that allow the user to experience two or more levels of abstraction. As with programs, these can usually be described as the “what” level of abstraction, where you understand what is being done, and the “how” level of abstraction, where you understand how the task is being accomplished.

Curiously, because details can become so numerous, it is what you can safely forget that is often much more important than what you must remember. For instance, most users need only to know that the function named `sqrt` in the `Math` module produces square roots

of numeric arguments. They don't generally want to, and certainly don't need to, know exactly how this result is produced.

## The Software Development Process

Although the programs you are developing at this point are exceedingly simple, it is not too early to begin thinking about the process that occurs when any new computer application is created. In general, we can divide this process into a number of stages or steps:

**Analyze the problem.** If you are creating the program for somebody else (typically called “the client”), try to determine exactly what the problem involves. Create a few test cases that can be used to see if you are on the right track, and find agreement with the client on what the correct input and output values should be for these test cases.

**Create initial specifications.** Describe in as formal fashion as you can what your program will do. A useful tool at this point is the idea of a scenario. A scenario (sometimes termed a use-case) is a simple story. The scenario shows what it will “look like” to use the program. This can be accompanied by pictures or mock-ups. Once again, have the client examine the stories to make sure they are in agreement with the original vision. What is important here is to describe the essential “look and feel” of the application, as well as *what* it will do, and not *how* it will produce the desired result.

**Create a design.** Using the specifications and the scenarios, create a design for the overall structure of the program. This is where you start to worry about how each task is to be performed. It is not uncommon that during this part of the process you uncover unanticipated details, exceptional conditions, or possibilities for generalizing your program to a wider range of values. When this happens you can create new scenarios and again work with the client to see if they satisfy the original vision.

**Implement the design.** Translate your design into a working Python program. Remove all the syntactic errors in the program, until it appears to be working for a reasonable set of values.

**Test and Debug the program.** Once you think your program is working, then test it in a more systematic fashion. Begin with the test cases you created during your analysis of the program. If any of these produce the wrong results, then it may be necessary to go back and change your design or your implementation. Once you have the program working on these inputs, then consider the guidelines presented earlier for testing conditional statements or loops. Do the test cases you have written already satisfy these guidelines? If not, create new test cases for these situations. Once you have the program working correctly with these new test cases, make sure you show them to the client to verify that the correct result is being produced.

**Maintenance.** Few programs remain untouched once they are given over to others to use. It may be that new bugs are discovered. It may be that users decide they want new

abilities that were not envisioned in the original design. Changes that are made after an initial release are termed, somewhat euphemistically, maintenance. Many programs evolve quite dramatically over years of use.

This is an idealized view of the software development process, but the realities are often somewhat different. As you progress through your studies of computer science you will encounter several other approaches. One very popular current approach is termed extreme programming. Using Xp, the client works side by side with the developer, programs are written rapidly (rapid prototyping) and frequently tossed out and rewritten (refactored in the terminology of Xp). However, it is still useful to know the various stages in the ideal design process, if for no other reason than to help you decide what to do next.

## Exercises

1. Write a series of Python statements that will read three numeric values from the user, and then print the largest of the three.
2. Write a series of Python statements that will read three strings from the user, and then print them in dictionary order. (Note: you can compare two strings using the relational operators).
3. Three numbers,  $a$ ,  $b$  and  $c$ , are called a Pythagorean triple if  $a^2 + b^2 = c^2$ . An example is the triple 3, 4 and 5, since  $9 + 16 = 25$ . Pythagorean triples can represent, for example, the length of sides in a right triangle. Write a series of Python statements that will read three numbers into variables named  $a$ ,  $b$  and  $c$  and then print a message saying whether or not they are a Pythagorean triple.
4. Using a for loop, print a table of Celsius/Fahrenheit equivalences. Let  $c$  be the Celsius temperatures, ranging from 0 to 100. For each value of  $c$ , print the corresponding Fahrenheit temperature.
5. Using a for loop, print a table of powers of  $x$ , where  $x$  ranges from 1 to 10. For each value  $x$ , print the quantity  $x$ ,  $x^2$ , and  $x^3$ . Using tab characters in your print statement to make the values line up nicely.
6. Using a while loop, produce a simple table of sines, cosines and tangents. Make the variable  $x$  range from 0 to 3 in steps of 0.1. For each value of  $x$ , print the value of  $\text{math.sin}(x)$ ,  $\text{math.cos}(x)$  and  $\text{math.tan}(x)$ .
7. Using a series of nested for loops, find all Pythagorean triples consisting of positive integers less than or equal to 20.
8. Remember the formula for the roots of a quadratic equation. For the equation  $ax^2 + bx + c = 0$ , the roots are  $-b \pm \sqrt{b^2 - 4ac} / 2a$ . If the discriminant (the quantity under the square root) is positive there are two real roots, if zero there is one double root, and if negative there are two complex roots. Write a program to

read the values a, b and c and produce a message saying how many roots the equation has and their form.

9. Write a program that will accept as input a series of names and salaries. Using the name “End” to mark the end of the sequence of values. After the values have been entered, print the average salary, and the names and salaries of those individuals with the highest and lowest salary.
10. Hourly workers typically earn overtime when they work more than 40 hours per week. For example, overtime pay might be 150% of the regular salary for the additional hours. Write a Python program that will ask the user for their hourly wage, then for the hours they have worked in the past week. With these two values print the wages earned for the week.
11. Drivers compute their miles per gallon by recording their odometer reading each time they fill the gas tank. Subtracting the previous odometer reading yields the miles traveled, and dividing by the gallons entered yields the miles per gallon. Write a program that reads values from the user until they enter the value -1 for the odometer reading. After the 2<sup>nd</sup> set of figures, print the miles per gallon for each fill up.
12. What is the effect of a print statement that ends with a comma? Try writing two such statements in succession in a program. Can you think of a use for this behavior?
13. Perhaps surprisingly, a number can be used as the conditional portion of an if or while statement. Experiment with this idea. Under what conditions is a number considered to be true? Can you think of a situation where you might want to use a while loop with an integer condition?
14. Perhaps even more surprising, a string can also be used as the conditional in an if or a while statement. Explore this use. Under what conditions is a string considered to be true?
15. Having answered the previous question, what would you think would be the result of the expression 0 or 3? Try it. What does it actually produce? Try various other expressions using integers and the operators *and* and *or*. Can you come up with a rule to predict the outcome? Does your rule explain expressions such as 3 and 4 and 5?
16. Having answered exercise 3, predict the output of the following statements, and then test your answer. What was your prediction? Was it correct?

```
x = 'able'
while x:
    print x
    x = x[1:]
```

17. A year is a leap year if it is divisible by 4, unless it is divisible by 100 and not by 400. Write a program that reads an integer value, and prints “leap year” or “not leap year”.
18. Write a program that reads an integer value *n* from the user, then produces *n* lines of output. The first line contains 1 star, the second 2 stars, and so on until the last line, which should have *n* stars. Can you write this using only a single loop? Hint: remember what the expression ‘+’\*5 does.

```
Enter a size: 5
+
++
+++
++++
+++++
```

19. Write program that reads two integer values *n* and *m* from the user, then produces a box that is *n* wide and *m* deep, such as the following:

```
Enter a width: 5
Enter a height: 4
@@@@@
@      @
@      @
@@@@@
```

20. What does the range loop do if it is given negative numbers? Experiment with negative values in the first, second or third location and try to come up with a general rule.
21. Write a program that reads a word, and prints the number of letters in the word, the number of vowels in the word, and the percentage of vowels.

```
Enter a word: sequoia
Letters: 7
Vowels: 5
Percentage of vowels: 71.42
```

22. Python has a feature that is somewhat unusual for programming languages. The for and while loops can also take an else clause, just like an if statement. The following is an example:

```
year = 0
i = 0
while year < 5:
    i = i+ year
    year = year + 1
else:
    print 'year is', year
```

Experiment with various loops and the else statement, and see if you can discover the rule that tells you under what circumstances the else statement is executed. Try using a loop with a break statement. Describe the experiments you performed, their results, and your conclusions.

23. Import the module named sys, and try executing the function sys.exit("message") with some string value. What is the result? Try putting this statement in the middle of a loop. What does it do?
24. The function random.randint from the random module can be used to produce an integer from a range of values. For example, random.randint(1,6) produces the values 1 to 6 with equal probability. Such a value can be used, for example, to simulate the roll of a die. Using this technique, write a program that will play several rounds on the popular dice game known as "craps". The rules of craps are as follows: A player rolls a pair of dice. If the sum of dice is either 7 or 11 on the first throw, the player wins. If the sum is 2, 3 or 12 on the first throw, the player loses. Any other sum becomes the players "point". To win, the player must continue rolling the dice until a roll matches the point. This is termed "making the point". If the player rolls a seven before making the point the player loses.
25. Use a random number generator to create a program to play "guess my number". The computer selects a random number, and prompts the user for a guess. At each step the computer responds either "you are right", "too low", or "too high". The loop continues until the user guesses the correct number.
26. Random numbers can also be used to create a simple tutor program. For example, suppose you are teaching multiplication. A program might randomly select two numbers between 1 and 9, and ask a question such as the following:

How much is 6 times 8?

The student types the answer, and the computer checks that it is either correct or not, issuing an appropriate message. Write a program that will loop 10 times producing questions of this form and checking the answers.

## Chapter 3 - Defining Functions

In the previous chapter you learned how to create a Python program, by placing a series of Python statements into a file. One advantage of doing so was to make it easier to execute the same pattern of statements more than once. Another advantage was that it allowed a user (either the original programmer or another person) to execute a program without detailed knowledge of how it worked.

We gave a name to the latter goal, calling it *abstraction*. The use of a program allowed us to separate the “what is the task to be done” from the “how is the task done”; that is, the description of the task to be accomplished from the details of how the task was performed. In this way the user of the temperature conversion program, for example, could think merely of the task being performed, and not about the details of how this task was accomplished.

The same issues frequently arise *within* a program during the course of execution. That is, the same operations may be required several times in different parts of a program. Or the programmer may wish to collect a series of statements together so that they can think about them as a unit. The easiest way to do this is to create a *function*.

A function is a way of packaging a group of statements for later execution. The function is given a name. The name then becomes a short-hand, or handle, to describe the process. Once defined, the user can think of the task by the name, and not by the steps involved. Once again, we have separated the “what” from the “how”.

Most functions require some initial information in order to perform their task. Information that the function needs is passed by parameters. These are simply given names, and the values are attached to the names when the function is executed. A function is created using a `def` statement (short for definition). The following is an example:

```
def areaOfRect (w, h):  
    # compute the area of a rectangle with width w and height h  
    return w * h
```

Notice that the syntax for the function definition follows a pattern similar to the *if* and *while* statements. The colon indicates the beginning of a group of statements. The statements being collected (and there can be more than one) are distinguished by being indented by a tab stop. These are termed the *body* of the function. New features include the keyword (`def`) and the parameter list – the list of names enclosed in parenthesis following the function name. A new type of statement, the *return* statement, indicates the value that will be used in place of the function invocation. It is common (although not required) that a comment be placed inside the function to describe its purpose.

Sometimes functions do not return a value. We will see an example in the next section. If the end of the function body is encountered without finding a return statement, control is passed back to the point of execution.

You have already seen the syntax used to invoke a function. The name of the function to be executed is given, followed by a list of *arguments*; values that will be matched to the names given in the parameter list. Following invocation the statements in the body of the function will be executed. When the function returns, the resulting value will be used as the value of the expression.

```
print 'the area of rectangle 2 by 3 is', areaOfRect(2, 3)
print 'the area of rectangle 2.5 by 3.2 is ', areaOfRect(2.5, 3.2)
print 'the area of rectangle 2 by 7.2 is', areaOfRect(2, 7.2)
print 'silly values produce silly results', areaOfRect('abc', 3)
```

You can create function definitions in interactive mode as well, although it is not common to do so. Simply use a tab before each line that will be part of the body of the function, and hit return after all the statements have been entered.

You should at this point stop reading and try creating several functions, both in interactive mode and in a program, until you are comfortable with both the syntax for function creation and function invocation. For example, try creating a function that takes a temperature in Celsius and returns the equivalent temperature in Fahrenheit. Another function could return the cube of the argument (that is, the argument multiplied by itself three times). Write a function that takes the radius of a circle and returns its area. Write a function that returns the minimum of three argument values.

There are several reasons for writing functions. Two of the most important are that it *raises the level of abstraction* and is a form of *software reuse*. By raising the level of abstraction, we mean that the programmer can now think of the function as a black-box; in the example above, as a “area-calculating” device. This allows the programmer to concentrate on *what* needs to be done, rather than *how* it is performed. For example, when you invoke the function `math.sqrt` you simply think of it as the square-root function. You do not need to know that there is actually a complicated series of actions required to calculate the square root of a value.

A second reason for using functions is that they are a form of *software reuse*. Programs are much easier to create when they are constructed out of higher-level building blocks, rather than low-level statements. You may have noticed this already in the use of modules, such as the `math` module. You can reuse the facilities provided by the `math` module, without needing to rewrite them in every program that uses a trig function or a square root. Eventually you will learn how to create your own modules, and share your own functions with other Python programmers.

Functions can use information from their surrounding program. For example, suppose you want to write a program to compute the volume of a sphere given its radius. The formula, you may remember, is  $v = \pi r^3$ . The value  $\pi$  is given by a symbolic constant in the `Math` module. You can import this module into the program, then use the value in a function definition.



```
import Math
...
def volumeOfRadius ( r ):
    # compute volume of sphere given radius
    return Math.pi * r * r
```

Using this function you could, for example, determine how many Earths could fit into the planet Jupiter

```
>>> ve = volumeOfRadius (6378000) # earth radius in meters
>>> vj = volumeOfRadius (71492000) # Jupiter radius
>>> print 'volume of earth', ve
>>> print 'volume of jupiter', vj
>>> print 'ratio of volumes', vj / ve
```

Parameters can often be used to generalize one problem, making applicable to a wider range of cases. We can illustrate this with a function to print the roman numeral equivalent of an integer. Recall that the roman number system had the following digits: I = 1, V = 5, X = 10, L = 50, C = 100, D = 500 and M = 1000. For larger numbers a bar was added to the character to denote multiplication by 1000, so  $\overline{V}$  for 5000,  $\overline{X}$  for 10000. The first nine numbers seem to follow no easy pattern, so we write it simply as a long sequence of if/elif statements:

```
def romanNumber(n):
    # return equivalent of n written in roman numerals
    if n == 0: return '' # romans had no zero
    elif n == 1: return 'I'
    elif n == 2: return 'II'
    elif n == 3: return 'III'
    elif n == 4: return 'IV'
    elif n == 5: return 'V'
    elif n == 6: return 'VI'
    elif n == 7: return 'VII'
    elif n == 8: return 'VIII'
    elif n == 9: return 'IX'
    else print 'number is out of range', n
```

This example illustrates a useful Python shorthand: if the body of an if or elif is only a single statement it can be written on the same line as the conditional test. When we consider numbers larger than ten, we discover an interesting pattern. Values larger than 10 are treated in exactly the same way, except that X, L and C are used instead of I, V and X. That is, a number such as 70 is written LXX. The ones place is simply appended to the end, so that a number such as 74 is written as LXXIV, which is LXX and IV appended. If we generalized the roman digit function with the characters to print for I, V and X, then we could use one function for both purposes.

```
def romanDigit(n, onechar, fivechar, tenchar):
    # return equivalent of n written in roman numerals
    # using given chars for one, five and ten
    if n == 0: return '' # romans had no zero
    elif n == 1: return onechar
    elif n == 2: return onechar + onechar
```

```

        elif n == 3: return onechar + onechar + onechar
        elif n == 4: return onechar + fivechar
        elif n == 5: return fivechar
        elif n == 6: return fivechar + onechar
        elif n == 7: return fivechar + onechar + onechar
        elif n == 8: return fivechar + onechar + onechar + onechar
        elif n == 9: return onechar + tenchar
        else print 'number is out of range', n

def romanNumber (n):
    # print equivalent of n written in roman numbers
    return romanDigit(n/10, "X", "L", "C")+romanDigit(n%10, "I", "V", "X")

```

The function shown will work for values up to 99, the generalization to 1000's simply requires adding another call with "C" for the ones digit, "D" for the 500, and M for the 1000.

Some experimentation is probably necessary to find the proper combination of division and mod operators to isolate the desired digits.

```

>>> print 2847 % 10 # use mod to get last digit
7
>>> print 2847 /10 # use division to remove last digit
284
>>> print (2847 / 10) % 10 # combine to get tens digit
4
>>> print (2847/100) % 10 # generalize to hundreds digit
8

```

Python programmers frequently start an interactive session to experiment with expressions and remind themselves of the use of operators during the course of developing a program. Having seen the general pattern, we can then create the roman number function:

```

def romanNumber (n):
    # print equivalent of n written in roman numbers
    return (romanDigit(n/1000, "M", "Vb", "Xb") +
            romanDigit((n/100) % 10, "C", "D", "M") +
            romanDigit((n/10) % 10, "X", "L", "C") +
            romanDigit(n%10, "I", "V", "X"))

```

Note the use of a parenthesis to allow the expression to span multiple lines. The key idea here is that we have generalized the basic function by adding additional parameters. This then allowed us to use the generalized function as part of another function, calling on the first function with a variety of different parameters.

```

>>> print romanNumber(47)
XLVII
>>> print romanNumber(847)
DCCCXLVII
>>> print romanNumber(2007)
MMVII

```

Let us examine another example. In a previous chapter you used the formula to compute the money earned on a given balance assuming a fixed interest rate. You could encapsulate this in a function as follows:

```
def interestEarned (balance, rate):  
    # amount earned by a balance invested at the given interest rate  
    return balance * rate / 100.0
```

Now suppose you wanted to determine how many years it would take for \$1000 invested at 4.5% interest to grow to \$1200. This could be computed by the following loop:

```
bal = 1000  
year = 0  
while bal < 1200:  
    bal = bal + interestEarned(bal, 4.5)  
    year = year + 1  
print 'it will take', year, 'years'
```

Typically a program will contain many functions. It is common for one function to invoke another. For example, suppose you wanted to create a separate function to record the action of compounding; that is, adding the interest back into the balance. You could write this as follows:

```
def compound (balance, rate):  
    # return the updated balance assuming interest is compounded  
    return balance + interestEarned (balance, rate)
```

Now if you wanted to find out how much \$1700 would become in ten years assuming a 5% return rate you can write the following statements:

```
bal = 1700  
for i in range(0, 10):  
    bal = compound(bal, 5)  
print 'after 10 years the balance is', bal
```

Suppose you wanted to take this one step further, and encapsulate the loop for the year iteration inside a function. You could write this as follows:

```
def compoundYear (balance, rate, numYears):  
    # return balance assuming interest compounded for number of years  
    for year in range(0, numYears):  
        balance = compound(balance, rate)  
    return balance
```

Now you can easily answer questions such as “how much will \$1350 become after 5 years with a 7% rate of return?”

```
print "$1350 at 7% after 5 years is', compoundYear(1350, 7, 5)
```

## Functions as Building Blocks

The roman number example illustrated the idea of treating a function as a building block, using one function in the development of another. Here is one more example. Many style guidelines suggest putting all program code inside function definitions. The principle function is often termed `main`. (The use of the name `main` is merely convention in Python; however in many other programming languages, such as Java or C, the principle function is required to have this name). For example, here is how we could have rewritten the temperature program from the previous chapter:

```
def main():
    # A Celsius to Fahrenheit conversion program
    # written by Robin Smith, July 2007

    print "This program will convert a temperature in Celsius"
    print "to the equivalent temperature in Fahrenheit"
    c = input("What temperature in Celsius you wish to convert? ")
    f = c * 9.0 / 5.0 + 32
    print "The equivalent temperature in Fahrenheit is", f

main()
```

The only statement, outside of function definitions, is the one invocation of the function `main`. (Which, by the way, is also an example of a function with no return statement). However, this function suffers from a common programming design flaw, which is to combine too many actions into one unit. In particular, a good design will almost always separate interaction (that is, input and output statements) from computation. What if in the next program you needed a similar Celsius to Fahrenheit conversion, but these were embedded in a larger task, or the messages you wanted printed were different?

The solution is to abstract away the conversion calculation, putting it into its own function:

```
def convCelsiusToFahrenheit ( c ):
    # convert a temperature in Celsius to equivalent Fahrenheit
    return c * 9.0 / 5.0 + 32

def main():
    # A Celsius to Fahrenheit conversion program
    # written by Robin Smith, July 2007

    print "This program will convert a temperature in Celsius"
    print "to the equivalent temperature in Fahrenheit"
    c = input("What temperature in Celsius you wish to convert? ")
    f = convCelsiusToFahrenheit ( c )
    print "The equivalent temperature in Fahrenheit is", f
```

You should think of functions as building blocks. By separating the calculation from the output we have created a more general-purpose building block, one that can now be more easily used in different projects. You should practice the art of identifying “chunks” of computation that can be abstracted into a useful building block.

## Testing Functions

In earlier chapters we discussed guidelines for testing statements, such as conditionals and loops. Testing a function simply involves finding parameter values that will test the statements in the body of the function. For example, can you find parameter values that will force every conditional to be both true and false? Can you find parameter values that will force a loop to execute zero times?

Let us illustrate this process with an example program that purposely has an error, and see how systematic testing can uncover the error. Along the way we will introduce another useful debugging technique, which is the code walkthrough.

Imagine you need to write a function that will take three sides of a triangle, and characterize them as either equilateral (all sides equal), isosceles (two sides the same), or scalene (all sides different). You might write a function similar to this:

```
def triType (a, b, c):
    # characterize a triangle as equilateral, isosceles, or scalene
    if a == b:
        if b == c:
            return 'equilateral'
        else:
            return 'isosceles'
    elif b == c:
        return 'isosceles'
    else:
        return 'scalene'
```

On the surface this function looks reasonable. So the first step is to define a few test cases from the specification itself. Certainly you need a set of values that are all equal (such as 2,2,2), and a set that is all different (such as 2, 3, 4). Then you need values in which two sides are equal. How many ways can this occur? There appear to be three possibilities, represented by (2, 2, 3), (2, 3, 2), and (3, 2, 2). Notice that these initial test cases were produced simply by thinking about the specifications of the problem itself, and not considering anything at all about the design of the program.

If we test the program using these five values we get a surprising result:

```
>>> print triType(2,2,2)
equilateral
>>> print triType(2,2,3)
isosceles
>>> print triType(2,3,2)
scalene
>>> print triType(3,2,2)
isosceles
>>> print triType(2,3,4)
scalene
```

Opps, why does the value (2, 3, 2) produce a wrong result? To find out, we perform a *code walkthrough*. This means sitting down with paper and pencil, and simulating the action of the computer on the given input. Like the computer, we will need to remember the values of the various variables. So we write down the current values, as shown at left.

$a = 2$ $b = 3$ $c = 2$
-------------------------------

We then pretend we are the computer, executing statements in turn. You can use something like a tick mark, or crossing out a statement after you have simulated it, to remember where you are. In this fashion we find ourselves quickly at the following point:

```
def triType (a, b, c):
    # characterize a triangle as equilateral, isosceles, or scalene
    if a == b:
        if b == c:
            return 'equilateral'
        else:
            return 'isosceles'
    elif b == c:
        return 'isosceles'
    else:
        return 'scalene'
```

We find ourselves at the last return statement, about to return the result 'scalene', even though two of the three input values are the same. This shows us that we need to perform one more test before the end:

```
elif a == c:
    return 'isosceles'
else:
    return 'scalene'
```

You should practice the art of testing functions, and remember to test all functions in your program before you decide that everything is working properly.

## Name Scopes

In an earlier chapter you learned how to attach a name to a value using an assignment statement. A function provides another way to create names and give them values. When the function is invoked the arguments are evaluated, then the resulting quantities are assigned to the parameter names. Once the parameters are initialized, the statements in the body of the function are executed.

If you simply use a name from the surrounding (that is, global) scope, the values are as you would probably expect:

```
>>> x = 4
>>> def scopeTest (a):
...     return x + a
```

```
>>> print scopeTest(3)
7
>>> print 'x is', x
x is 4
```

However, if you define (or redefine) a global variable name, the results may seem surprising:

```
>>> x = 4
>>> def scopeTest (a):
...     x = 7 # reassign value of x?
...     return x + a

>>> print scopeTest(3)
10
>>> print 'x is', x
x is 4
```

Why didn't the value of `x` change? The answer is that a new variable named `x` was created. Parameter names, and any variable that is assigned inside the function, are *local* to the function in which they are defined. This means that the name can only be used inside the body of a function. We call the body of the function the *scope* of the parameter names. The function is said to create a *local scope*, whereas names defined outside the function have a *global scope*. A local name that is the same as a global name is sometimes said to create a value that *shadows* the global, since it makes it so that you cannot (easily) see the global value. Once a function returns the name and values of parameters are no longer meaningful. Changing the local values inside the function has no effect on the global scope.

You should at this point stop and experiment with function definitions and assignment statements in order to get a better feel for Python's scope rules.

As with the naming of global variables, the naming of parameters should be a task to be considered carefully. Names should be chosen to make the meaning of the program clear. This implies that names should be evocative, and easy to understand. Short names are often easier to read, but do not make them too short. Using “balance” to hold a bank balance is often a better choice of names than either “b” or “checkingAccountBalance”.

Why do programming languages have name scopes? The reason is that without scopes all names would have to be unique. An analogy will help illustrate the concept. City names are in some sense similar to variable names. The normal resolution rule in the United States is that no two cities can have the same name if they are both in the same state. You cannot have two Springfields in Illinois, for example. But nothing prevents two cities from having the same name if they are in different states. There are cities that use the name Springfield in both Oregon and Illinois, as well as many other states. The scope of the name is the state, and while within the scope the name is unique, across two or more scopes there can be multiple values with the same name.

The scope rule allows programmers to safely use simple variable names, such as `n` or `p`, without worry that a different function in another part of the program will end up modifying the value held by a variable. This permits several programmers to more easily work on the same job, and it allows a programmer to use the work of another programmer (such as with an import statement), without having to worry about what names the module might alter in the current scope.

## Writing a Function that Calls Itself

Suppose you want to write a function that will convert an integer into its text name. The value 347, for example, should produce “three hundred forty seven”. Such a function might be useful in a program to print a check. If the number is less than twenty the structure of the program is tedious, but not complex.

```
def numToString (num):
    if num == 0: return ''
    elif num == 1: return 'one'
    elif num == 2: return 'two'
    ...
    elif num == 19: return 'nineteen'
```

Complete this function definition and verify it produces the correct result for values between 0 and 19. (One can argue with producing an empty string for 0, but assume that is the desired output for now). What about a number such as 27? It would be tedious to go through all ten values between 20 and 29, particularly when they have such a simple structure. The “twenty” part is easy. To get the “seven” part, we can notice that this is a problem that we have *already solved*. That is, we know how to convert the value 7 into “seven” – we simply call the function `numToString`. With that insight, we can add the clauses that return the result for these values as follows:

```
elif num <= 29: return 'twenty ' + numToString(num%10)
```

Study carefully what is happening in the last line. The value `num%10` is returning the remainder after the value `num` is divided by 10. That is, for a value such as 27, it will return 7. Invoking `numToString` on this value will produce the string “seven”. The addition operator is concatenating this to the string “twenty”. Type in this new part of the program and verify that it works for values between 20 and 29. Using this as a pattern, finish the definitions for values in the range 30 to 99.

One about 347? This should produce “three hundred forty seven”. But notice again that portions of this result are simply values we already know how to produce. For example, if we compute `num//100` this will yield 3, which we can then transform into “three”.<sup>1</sup> Examine the following line

---

<sup>1</sup> Prior to Python version 3 this could have been written `num / 100`. After version 3 the division operator will return a float value. To return integer division the `//` form must be used.



```
elif num <= 999:
    return (numToString(num//100) + ` hundred ` +
            numToString(num%100))
```

The expression in the `return` statement has been placed into a parenthesis simply to make it easier to break over multiple lines (recall that Python continues reading multiple lines until it finds matches all parenthesis). Study this line carefully until you understand what it is doing. Then add this to the function `numToString`, and verify that it produces the correct result for values in the range 100 to 999. Then do the same for thousands. A number such as 347982 should produce “three hundred forty seven thousand nine hundred eighty two”. Finally, add the rule for millions.

A function that calls itself is said to be *recursive*. The creation of recursive functions is an extremely powerful technique. Any recursive function can be divided into two parts. First, there must be one or more *base cases*. These are values that are handled without the benefit of recursion. In our example, the base cases are the integers 0 to 19. Next, there are *recursive cases*. These are values that are handled by “reducing” the problem to a “simpler” problem of the same form. The words reducing and simpler are placed in quotes, because the meaning will be different in each new situation. Here reducing means using division, and a simpler problem means a number that is smaller than the original. The function is then invoked on the simpler problem, and the result used to construct the solution to the original problem.

The exercises at the end of the chapter will give you the opportunity to explore recursive functions in more detail.

## A Cautionary Tale regarding Recursive Functions\*<sup>2</sup>

Recursive functions can in the right circumstances be extremely powerful, as the example of converting a number into the text equivalent shows. However, there can also be dangers that the programmer should avoid. A classic cautionary tale involves the computation of Fibonacci numbers. Fibonacci numbers are defined using a recursive formula as follows:  $\text{fib}(0) = 0$ ,  $\text{fib}(1) = 1$ ,  $\text{fib}(n) = \text{fib}(n-1) + \text{fib}(n-2)$ . They were introduced in 1202 by a mathematician named Fibonacci in the following simple story:

A certain man put a pair of rabbits in a place surrounded on all sides by a wall. How many pairs of rabbits can be produced from that pair in a year if it is supposed that every month each pair begets a new pair which from the second month on becomes productive?

The first few Fibonacci numbers are 0, 1, 1, 2, 3, 5, 8, 13. This series turns up in a surprising number of places. For example, the ratio of successive Fibonacci numbers converges to a constant value approximately 1.618. This has been termed the *golden*

---

<sup>2</sup> Sections with a trailing \* indicate optional or more complicated material that can be omitted on first reading.

*ratio*. The golden ratio appears in many places in nature, as well as in architecture in the size of windows and rooms.

Computation of the *i*th Fibonacci number can be performed with a relatively straightforward function:

```
def ifib(n):
    a, b = 0, 1
    for i in range(0, n):
        a, b = b, a+b
    return a
```

You should try this function out on a few examples to verify that it works. What is the 35<sup>th</sup> Fibonacci number?

Because the definition is recursive, it is tempting to write a recursive version of the function, as follows:

```
def rfib(n):
    if n == 0: return 0
    if n == 1: return 1
    return rfib(n-2) + rfib(n-1)
```

You should verify that this function also works and produces the correct result. If you try to calculate the 35<sup>th</sup> Fibonacci number, what happens? Why is the recursive version so much slower than the program that used the loop? The answer is that for each value of *n*, the recursive program is making two calls on itself. For a large number, each of these would require two calls. Each of these in turn also requires two calls. So to compute the *n*<sup>th</sup> Fibonacci number requires approximately  $2 \times 2 \times \dots \times 2$  recursive calls, or  $2^n$ . This is termed *exponential complexity*, and can bring even the fastest computers to their knees.

You should be careful to not draw the wrong lesson from this story. This is not telling you that recursion is dangerous or bad, merely that you must understand what you are doing. Problems in which at each step you either handle a base case or make a single recursive call are generally just as fast in either a recursive or non-recursive form. It is only when one step makes two or more recursive calls that you need to think carefully. In later courses you will learn techniques termed “complexity analysis” that can be used to estimate the running time of various algorithms.

## Using Global Names inside of Functions \*

There are times when you want a function to modify a variable from the global name scope. To accomplish this you must first tell the Python system that you intend to use the global name. This is accomplished using the *global* statement. Compare the execution of the following example program with the earlier example, and note carefully the differences.

```
def scopeTest (a):
```

```

    global b
    b = 8
    print 'inside the function a is ', a
    print 'inside the function b is ', b

a = 1
b = 2
scopeTest(7)
print 'after the function, a is', a
print 'after the function, b is', b

```

A function that does anything other than returning a value is said to be producing a *side effect*. Typical side effects are printing some output, or changing a value. The function shown here does both.

You should think carefully about using the global statement, or in general using any side effects at all. Notice, for example, that there is nothing in the name of the function that indicates it will, as a side effect, alter the value of the variable b. If you only need to *access* a variable you do not need the global statement, it is only necessary if you want to change a global variable. Only use a global statement when you find no other alternative way to accomplish the same task.

## Raising Exceptions

What will happen in the `compoundYears` function if the interest rate is negative? Or, if the number of years is less than zero? Even if the arithmetic does not produce an error, such a situation is much more likely to be the result of an error in logic than an expected outcome. What should the function do in such situations?

```

def compoundYear (balance, rate, numYears):
    # return balance assuming interest compounded for number of years
    for year in range(0, numYears):
        balance = compound(balance, rate)
    return balance

```

One possibility is to do nothing, and let the execution continue. The most common consequence of this choice is for an error to be compounded by further errors, until a result that is totally meaningless is produced. Another possibility is to print a message, but then proceed anyway. This was the technique we used in the roman number conversion program. A far better alternative is to check you values for validity, and if they are not valid to immediately halt execution and tell the user. This is known as *defensive programming*.

How should you tell the user that something is wrong? The proper way to do this in Python is to use a *raise* statement. This is known as raising an exception. The following rewriting of the function `compoundYear` shows how this is done:

```

def compoundYear (balance, rate, numYears):
    # return balance assuming interest compounded for number of years
    if rate < 0:

```

```

        raise RuntimeError, 'Negative interest rate'
    if numYears < 0:
        raise RuntimeError, 'Negative number of years'
    for year in range(0, numYears):
        balance = compound(balance, rate)
    return balance

```

Now if the user tries to invoke the function with an improper value an error message will be produced, just like those generated for bad arguments to the built-in operations.

```

>>> print 'after 10 years', compoundYear(1000, -5, 3)
Traceback (most recent call last):
  File "compound.py", line 21, in ?
    print 'after 10 years', compoundYear(1000, -5, 3)
  File "compound.py", line 12, in compoundYear
    raise RuntimeError, 'Negative interest rate'
RuntimeError: Negative interest rate

```

Whenever possible you should check the validity of arguments inside a function, and raise a `RuntimeError` if they are incorrect. In a later chapter you will learn the flip side of exceptions, how to catch and handle an exception that has been raised by a function.

At this point go back and add error checking to some of the earlier functions we developed in this chapter. What condition needs to be tested in the function that returned the volume of a sphere? Add a statement to check this condition and raise an exception if it is not satisfied. The roman number conversion program simply printed a message when the input was invalid. Replace this with a statement that raises an exception.

## Functions are values \*

A function is really just another type of value, and the `def` statement is really just a special sort of assignment statement.

```

def newfun(a):
    print 'the argument is', a

>>> print newfun
<function newfun at 0x64bb0>

```

Just like any other value, you can assign a function value to a different variable. You can then use that variable as if it were a function:

```

>>> x = newfun
>>> x(3)
the argument is 3

```

As with all variables, function names can be reassigned, either with an assignment or another `def` statement:

```

>>> newfun = 7.5
>>> print newfun
7.5

```

Function definitions are in fact executable statements, just like an assignment or a print statement. It is legal to place a function definition inside a conditional, for example:

```
if a < b:
    def minvalue():
        return a
else:
    def minvalue():
        return b
```

The uses of this feature are, perhaps not surprisingly, rare.

## A few words about Nothing \*

Suppose you write a function that finishes without returning a value, but nevertheless save the result in a variable. What is the value of that variable? To find out, try writing the following function and discovering the outcome of the indicated statements:

```
def nothing():
    print "sorry, nothing here"

>>> a = nothing()
>>> print a      # fill in with the result you discover

>>> print type(a)
```

The value `None` is the sole instance of the class `NoneType`. It is used in a variety of situations where a placeholder value is necessary, but no other obvious candidates present themselves. You can access this value using the name `None`. For example, you might want to use this to initialize a variable when you don't know what value it will eventually hold.

## Exercises

1. The program to convert integers into their string equivalent does not handle either negative numbers or zero correctly. This is most easily handled by creating a second function that recognizes these as special cases, and then invokes the recursive function in the general case. Write this second function. Why can't the recursive function return "zero" when it is given the value 0?
2. Many programs loop until the user indicates they want to stop. Write a function named "cont()" that takes no arguments. The function should print the message "continue?" and wait for the user to respond. If the user types "Yes", "y" or "Y", then return true, otherwise return false.
3. An exercise in the previous chapter described how to use the function `random.randint` to simulate the roll of a die. Embed this technique in a function

named `diceroll` that takes no arguments but returns a value from 1 to 6, marking the number of dots on a dice roll. Use this function to rewrite your craps program from the earlier chapter.

4. A year is a leap year if it is divisible by 4, unless it is divisible by 100 and not by 400. Write a function that takes an integer value representing a year, and returns a Boolean result indicating whether or not the year is a leap year.
5. Using the leap year function above, and your knowledge of how many days each month has, write a function that takes a year and a day number and returns a string representing the month and date. For example, the input 2006 237 would return [need to compute].
6. Write a function that takes a positive integer  $n$ , then produces  $n$  lines of output. The first line contains 1 star, the second 2 stars, and so on until the last line, which should have  $n$  stars. Can you write this using only a single loop? Hint: remember what the expression `'+'*5` does.

Enter a size: 5

```
+
```

```
++
```

```
+++
```

```
++++
```

```
+++++
```

7. Numbers in base 16 are termed hexadecimal. The letters A through F are generally used to represent the “digits” 10 through 15. If a number  $x$  is larger than 16, the quantity  $x \% 16$  yields the smallest “digit”, while the quantity  $x / 16$  yields the value to the left of the smallest digit. Using these observations, write a function that takes an integer value and returns the hexadecimal equivalent expressed as a string.
8. The number of combinations of  $n$  things taken  $m$  at a time is written  $(n \ m)^3$ . This can be defined recursively by the following formulas.  $(n \ 0) = 1$ ,  $(n \ n) = 1$ ,  $(n \ m) = (n-1 \ m) + (n-1 \ m-1)$ . Write a recursive function named `comb(n, m)` to compute this value.
9. If  $a$  is a number and  $n$  is a positive integer, the quantity  $a^n$  can obviously be computed by multiplying  $n$  times. A much faster algorithm uses the following observations. If  $n$  is zero,  $a^n$  is 1. If  $n$  is even,  $a^n$  is the same as  $(a * a)^{n/2}$ . If  $n$  is odd,  $a^n$  is the same as  $a * a^{n-1}$ . Using these observations, write a recursive function for computing  $a^n$ .
10. If a function finishes without a return statement, what is the value returned? (To find out, try writing a function without a return statement, and then print the value

---

<sup>3</sup> Need to find out how to make word set this correctly.

returned by an invocation). What information can you discover when you use the `type()` function on this value?

11. What happens when you use a function name, without arguments, in a print statement? What value is produced when you use the `type()` function on a function name?
12. A very simple recursive function is factorial. The definition of factorial (written  $n!$ ) says that  $0!$  is 1, and in general  $n!$  is  $n * (n-1)!$ . For example,  $5!$  is 120, which is  $5 * 4 * 3 * 2 * 1$ . What is the base case? What is the induction case? What should you do if the argument is less than zero? Write the factorial function using your ideas.
13. Using your factorial function, write a function that estimates the value of the mathematical constant  $e$  using the formula:

$$e = 1 + 1/1! + 1/2! + 1/3! + 1/4! + \dots$$

Stop after ten terms. Print both your computed value and the value stored in the `math` module as `math.e`.

14. Is the value `None` considered to be true or false? That is, if you use this value in an if statement, is the attached statement executed or not?
15. Try executing the following program. Can you explain what is going on?

```
def outer(x):
    def inner(y):
        return x + y
    return inner

x = outer(3)
print x(4)
```

16. What happens if a global statement refers to a variable that has not been assigned in the global scope. Make a prediction as to what you think should happen, and then write a program to test your hypothesis.
17. A palindrome is a string that reads the same both forwards and backwards, for example the word “rotor” or the sentence “rats live on no evil star”. Testing for the palindrome property is easy if you think recursively. If a string has zero or one character, it is a palindrome. If it has more than two characters, test to see if the first character matches the final character. If not, then the word is not a palindrome. Otherwise, strip off the first and final characters, and recursively perform the palindrome test. Write a recursive function using this approach.
18. Normally, palindromes are allowed to have capital letters, embedded spaces and punctuation, all of which is ignored in the palindrome test. Examples of this form

are “A man, a plan, a canal, Panama!” or “Madam, I’m adam”. The palindrome test you wrote in the previous question can be easily extended to allow this form. If the first letter is upper case, convert it to lower case and test the resulting word. If the first letter is a space or punctuation, remove it and test the remainder. Otherwise do the same with the final letter. Rewrite the palindrome test function using this approach.

19. Another classic problem that illustrates the power of recursive definitions is the “towers of Hanoi”. In this problem there are three poles labeled A, B and C. Initially a number of disks of decreasing size are all on pole A. The goal of the puzzle is to move all disks from pole A to pole B without ever moving a disk onto another disk with smaller size. The third pole can be used as a temporary during this process.

If you try to solve this problem in a conventional fashion you will quickly find yourself frustrated trying to determine the first move. Should you move the littlest disk from A to B, or from A to C? But the recursive version is very simple. Rewrite the problem as a call on `Hanoi(n, x, y, z)` where `n` is the size of the stack, and `x`, `y` and `z` are strings representing the starting pole (initially ‘A’), the target pole (initially ‘B’) and the temporary pole (initially ‘C’). The task can be thought of recursively as follows. If `n` is 1, then move one disk from pole `x` to pole `y`. Otherwise, recursively call `Hanoi` to move `n-1` disks from `x` to `z`, using `y` as the temporary. Then move one disk from `x` to `y`, which leaves pole `x` empty. Finally move `n-1` disks from pole `z` to pole `y`, using `x` as the temporary. Write the towers of Hanoi as a recursive function, printing out a message each time a disk is moved from one pole to another. Would using zero as a base case work even better? What action is required to move zero disks from one pole to the next?



## Chapter 4 - Strings, Lists and Tuples

In Chapter 1 you encountered the *string* data type. In this chapter we will explore strings in more detail, and introduce two other related data types in the Python programming language, the *list* and the *tuple*.

A list is created using square brackets. At its simplest, a list is simply a collection of values, separated by commas:

```
>>> lst = [1, 4, 7, 9, 12] # create a list with five elements
>>> lst
[1, 4, 7, 9, 12]
```

There is no requirement that a list contain elements of the same type. The following creates a list consisting of an integer, a real, a string, and another list.

```
>>> lsttwo = [1, 2.4, 'abc', lst]
>>> lsttwo
[1, 2.4, 'abc', [1, 4, 7, 9, 12]]
```

Just as an open parenthesis makes the Python system continue reading until it is closed, an open bracket can also start a list that extends over multiple lines:

```
>>> lstthree = [1, 2
...             3, 4,
...             5]
>>> lstthree
[1, 2, 3, 4, 5]
```

A list is in many ways similar to a string, and so many of the operations you explored in chapter 1 can be applied to either type. These include indexing, slicing, the *in* test, using the plus operator for catenation, using the multiplication operator for repetition, the *len* function, and the *max* and *min* functions. The function *list* can be used to convert a string into a list of characters. Examples of these are shown on the right.

Unlike a string, a list is *mutable*. This means that the elements in a list can be changed after it is created. This can occur in a number of ways. It can happen as a result of using an index as target of an assignment:

```
>>> lst = [1, 4, 7, 9, 12]
>>> lst[1] = 5
>>> lst
[1, 5, 7, 9, 12]
```

```
>>> lst[2]
7
>>> lst[1:3]
[4, 7]
>>> lst[2:]
[7, 9, 12]
>>> lst[:2]
[1, 4]
>>> 4 in lst
True
>>> 5 in lst
False
>>> lst + [3, 4]
[1, 4, 7, 9, 12, 3, 4]
>>> len(lst)
5
>>> [2, 3] * 4
[2, 3, 2, 3, 2, 3, 2, 3]
>>> max(lst)
12
>>> min(lst)
1
>>> list('abc')
['a', 'b', 'c']
```

A slice can also be the target of an assignment. The value on the right hand side must also be a list, however it is not necessary that this list have the same number of elements as the slice. The list will be enlarged or reduced in size as necessary.

```
>>> lst[1:3] = [9, 8, 7, 6]
>>> lst
[1, 9, 8, 7, 6, 9, 12]
```

The del statement can be used to delete an element from a list. This is effectively the same as assigning a one-element slice with an empty list.

```
>>> del lst[3]
>>> lst
[1, 9, 8, 6, 9, 12]
```

Lists also provide a number of operations written using dot notation. Here the list being modified is followed by a dot, then the name of the operation and an argument list. The following table summarizes the operations that use this form:

s.append(x)	Appends element x to s
s.extend(ls)	Appends (extends) list s with list ls
s.count(x)	Count number of occurrences of x in s
s.index(x)	Returns the index of first occurrence of x
s.pop()	Returns and removes last element from s
s.pop(i)	Return and removes element i from s
s.remove(x)	Searches for x and removes it from s
s.reverse()	Reverse elements of s in place
s.sort()	Sort elements of s into ascending order
s.insert(i, x)	Inserts x at location i

The value to the left of the dot is the list being manipulated. The following illustrate the use of some of these operations.

```
>>> lst = [1, 7, 3, 9, 2]
>>> lst.append(5)
>>> lst
[1, 7, 3, 9, 2, 5]
>>> lst.extend([8, 4])
>>> lst
[1, 7, 3, 9, 2, 5, 8, 4]
>>> lst.count(5)
1
>>> lst.index(5)
5
>>> lst.pop()
4
>>> lst
[1, 7, 3, 9, 2, 5, 8]
>>> lst.sort()
>>> lst
```

```
[1, 2, 3, 5, 7, 8, 9]
```

Often lists are grown, using the append operator, starting from an empty list. A simple pair of square brackets are used to create the initial empty list.

```
>>> lst = [ ]
>>> lst.append(3)
>>> lst
[3]
>>> lst.append(7)
>>> lst
[3, 7]
```

## Example Program – Finding Average and Standard Deviation

Back in Chapter 2 we presented a program that would compute the average of a list of number. The end of the list was indicated by the value -1:

```
sum = 0.0
count = 0
num = input("enter your number:")
while num != -1:
    sum = sum + num
    count = count + 1
    num = input("enter your number:")
print "average is ", sum / count
```

Suppose now we want to compute some other statistics. A common statistic is the standard deviation. The standard deviation tells you how the values are scattered – a small value means they were clustered together, and a large value indicates they are widely separated. To compute the standard deviation you first compute the average. Let us call this value ave. Next, you compute the difference of each value from the average. This tells you how far the value is from the average. The difference is squared so as to remove the positive/negative distinction, and all the differences are summed. The sum is divided by the size of the collection, so it will be independent of the number of elements. Finally, the standard deviation is the square root of the resulting sum.

$$\text{std dev} = \sqrt{\text{summation } (xi - \text{ave})^2 / n}$$

Let us rewrite the program from chapter 2 so that it first places all the elements into a list, then uses functions to compute the different statistics. First, the main program:

```
def main(): # use the main program convention from last chapter
    # program to compute average, standard dev of list of numbers
    print "enter values to be analyzed, use -1 to end list"
    data = [ ] # our list of values
    num = input("enter your number:")
    while num != -1:
        data.append(num) # add value to data list
        num = input("enter our number:")
    ave = average(data)
```

```

print 'average of data values is ', ave
std = std(data, ave)
print 'standard deviation is ', std

```

The main function copies values into a list. The average function must examine each element in this list. You have seen already how this can be done, but you may not have recognized it. The range function used in earlier chapter constructed a list, and the `for` statement was used to iterate over the elements of the list:

```

for year in range(0, 10):

```

But, in fact, the `for` statement can be used to cycle over any list of values, and not simply those produced by a range. So the function average can be written as follows:

```

def average (data):
    # compute average of a list of numbers
    sum = 0.0 # make sum into a floating point number
    for x in data:
        sum = sum + x
    if len(data) == 0: return 0
    else: return sum / len(data)

```

Since lists can be indexed, an alternative way to write the loop would have been to loop over the set of index values, as follows:

```

for i in range(0, len(data)):
    sum = sum + data[i]

```

Or even to use a while loop:

```

i = 0
while (i < len(data)):
    sum = sum + data[i]
    i = i + 1

```

Which of these alternatives do you find easier to read and understand?

What does the function average return if there are no elements in the data list? Does this seem like a reasonable value? Do you think it would have been better to raise an exception in this situation?

The function to compute the standard deviation uses `sqrt` from the Math module. So we need to remember to import this module in the program somewhere before the function is defined.

```

import Math

def std (data, ave):
    # compute standard deviation of values from average
    diffs = 0.0
    for x in data:
        xdiff = x - ave # compute difference from average

```

```

        diffs = diffs + xdiff * xdiff # squared
    if len(data) == 0: return 0
    else: return Math.sqrt(diffs/len(data))

```

You will find lists of numbers to be extremely useful in all sorts of applications.

## Fixed size lists are Arrays

There are times when you want to create a fixed size list, but you will not know until later what values will be stored in the list. Such an object is similar to an *array* in other programming languages. The typical Python solution is to use the repetition operator and a list containing the value `None`:

```

>>> a = [None]*5
>>> a
[None, None, None, None, None]

```

The variable is now a list with five elements, but the positions do not yet have any useful value stored in them. In some applications the array will hold numeric data, and zero is a more appropriate initial value.

```

>>> data = [0]*5

```

An exercise at the end of the chapter will illustrate one use for an array of numbers.

A two dimensional array is usually represented in Python by a list of lists. However, the initialization of such a value is not as easy as the initialization of a one-dimensional list. Here is an example that illustrates the most common technique.

```

>>> data = [None] * 5
>>> for i in range(0,5):
...     data[i] = [0] * 5
...
>>> data
[[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0],
 [0, 0, 0, 0, 0]]
>>> data[2][2] = 7
>>> data
[[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 7, 0, 0], [0, 0, 0, 0, 0],
 [0, 0, 0, 0, 0]]

```

## Append works by side effect

Note carefully that `append` and `extend` work by *side effect*, altering the list to the left of the dot. The value these functions return is the constant `None`.

```

>>> lst = [1, 2, 3]
>>> print lst.append(4)
None

```

A common beginners mistake is to reassign the value returned by this function to the list variable. The student is then surprised at the result.

```
>>> lst = [1, 2, 3]
>>> lst = lst.append(4)
>>> print lst
None
```

## Lists and Loops

In a previous chapter you learned how the `for` statement can be used to loop over the characters in a string, and how the `range` function can be used with the `for` statement to loop over an arithmetic progression. In fact, `range` is simply a function that produces a list of values:

```
>>> range(1, 6)
[1, 2, 3, 4, 5]
```

The `for` statement can be used with any list. Elements are examined one by one, assigned to the loop variable, and the body of the loop is executed.

```
>>> lst = [3, 5, 7]
>>> for x in lst: print x
3
5
7
```

An interesting function named `zip` takes two lists, and produces a list of tuples representing their pairs:

```
>>> zip([1, 2, 3],[5, 6, 7])
[(1, 5), (2, 6), (3, 7)]
```

When combined with the multiple assignment you learned about in chapter 2, this produces an easy and elegant way to loop over two lists in parallel:

```
>>> one = [1, 2, 3]
>>> two = [5, 6, 7]
>>> for x, y in zip(one, two):
...     print 'x', x, 'and y', y
x 1 and y 5
x 2 and y 6
x 3 and y 7
```

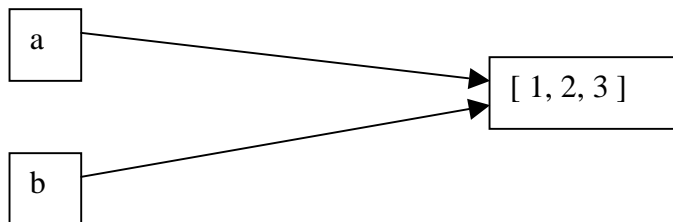
## Assignment and References

Now that we have a mutable data type we can discuss a subtle but nevertheless very important concept. This is the idea of *references*, and in particular the fact that assignment copies references and not values.

Imagine that we create a list and assign it to a variable named `a`. Next we assign the variable `a` to another variable `b`. Finally we make a change to part of `b`. What do you think will be the value being held in `a`?

```
>>> a = [1, 2, 3]
>>> b = a
>>> b[1] = 7
>>> a
[1, 7, 3]
```

Where you surprised at the answer? After all, it was `b` that was changed, and not variable `a`. What is going on here? The answer is that assignment makes the name on the left *refer* to the same object as the value on the right. Another term that is often used is to say that the name `b` is an *alias* for the value stored in variable `a`. In technical terms, we say that Python uses *reference assignment*. This can be visualized as follows:



It is important to understand the semantics of assignment for lists, because it can frequently be the source of subtle programming errors. Any time you are changing the value in a list you need to think carefully whether any other variable refers to the same value. (By the way, not all programming languages use reference semantics for assignment. Some use the alternative, termed *copy semantics*. As you proceed through your career as a programmer you will undoubtedly learn many programming languages. Each time you learn a new language you should carefully examine aspects such as the meaning of assignment).

Sometimes you want to avoid the trap of reference assignment by making a true copy. The easiest way to do this in Python is to use a slice, as in the following:

```
>>> a = [1, 2, 3]
>>> b = a[:] # use a slice instead of a simple name
>>> b[1] = 7
>>> a
[1, 2, 3]
```

The slice makes a copy of the value. Now a change to one will not alter the other. (Although there is a deeper subtlety concerning what sort of copy. This will be explored in the exercises).

Function parameters act like a form of assignment, and here also arguments pass references and so the same alias situations can arise. Consider the following sneaky function.

```
def sneaky (n):  
    n[1] = 'a'
```

The function changes one of the fields in the argument value. You can see this by passing a list, and looking at the result after the function call.

```
>>> a = [1, 2, 3]  
>>> sneaky(a)  
>>> a  
[1, 'a', 3]
```

Sometimes you want to be able to change a list that is passed through a parameter. But just as often you do not want this to occur. Bottom line, be aware of the semantic rules for assignment and parameter passing, and make sure you write the statement that will have the effect you intend.

## Identity and Equality

Having a mutable type also allows us to introduce another important concept, the difference between *identity* and *equality*. There is a joke that will help illustrate the difference. A man walks into a pizza parlor. He sits down, and the waiter approaches him and asks what he would like to order. He looks around, points to a nearby patron and says, “I’ll have what she is eating”. The waiter immediately goes to the woman, picks up the pizza in front of her, and places it in front of the man.

The reason why this story is funny is because in normal discourse we use the concept of equality in two very different ways. Sometimes we use equality to mean being exactly the same thing. (For example, we say that the planet Venus is the evening star). Sometimes we use equality to mean being functionally similar in all important aspects, even if not exactly the same thing. (One pepperoni pizza is equivalent to another).

When values are immutable, such as with numbers or strings, the distinction is largely unimportant. You can’t change it, so you don’t notice that two variables are holding exactly the same thing. But it becomes relevant when we have mutable types, such as lists (and, later, dictionaries and classes). For this reason there are two separate operators. The operator you have seen, `==`, is testing equality. The identity testing operator is called *is*. Two lists are equal if they are the same length and their corresponding elements are equal. Two lists are identical if they are exactly the same object. You can see the difference with a simple test, such as the following:

```
>>> if [1, 2, 3] == [1, 2, 3]: print 'equal'  
equal  
>>> if [1, 2, 3] is [1, 2, 3]: print 'identical'  
>>>
```



The two lists are equal, but not identical. On the other hand, if you assign a value stored in one variable to another variable, then the values held by the two variables are both identical and equal:

```
>>> a = [1, 2, 3]
>>> b = a
>>> if a is b: print 'identical'
identical
```

Use the identity testing operator, `is`, if you need to determine if two variables hold exactly the same object. Use the equality operator, `==`, if you simply need to know if they have same value, even if they are not the same object.

## Sorted Lists

A sorted list is a list in which the elements appear in order. This is frequently needed when producing output, for example to print string values in alphabetical order. There are two major ways to produce a sorted list. The built-in function named `sorted` will produce a sorted version of a list:

```
>>> sorted([4, 2, 6, 3, 1])
[1, 2, 3, 4, 6]
```

Alternatively, the member function `sort` will reorder the values in a list so that they appear in order:

```
>>> lst = [4, 2, 6, 3, 1]
>>> lst.sort()
>>> lst
[1, 2, 3, 4, 6]
```

The `sort` function can alternatively take as argument a comparison function. The comparison function takes two arguments, and returns a negative value if the first is “smaller” than the second, zero if they are equal, and a positive value if the first is larger. Such a function is needed if the list contains values that do not recognize the standard comparison operators, or if the sense of the ordering is non-standard.

```
def smallerThan(x, y):
    if x < y: return 1
    if x == y: return 0
    return -1

>>> lst.sort(smallerThan)
>>> lst
[6, 4, 3, 2, 1]
```

The next section will have another example of a sorting function. Sorted lists are important because they can be searched much more quickly than unsorted lists. To understand why, think about finding a telephone number in a telephone book. It is easy, because the telephone books lists names in order. Next, think about trying to find the

name attached to a given number. This is much more difficult, because you would need to compare the number to each entry in the book.

Searching a sorted list is similar to the “guess my number” game. You begin by comparing the test value to the middle of the list. If it is smaller, you next search the first half of the list. If it is larger, you search the last half. Again, you break the section of the list you are searching in half and compare to the element you find there. In this fashion, you are first searching the entire list, then  $\frac{1}{2}$  the list, then  $\frac{1}{4}$ , then  $\frac{1}{8}$ , and so on. This process is termed binary search. As the telephone book example illustrates, binary search is extremely fast. A list of one billion elements can be searched with no more than 20 comparisons.

While writing a binary search algorithm is an interesting exercise (see end of chapter), most of the time you will want to use the version that is provided as part of the standard Python distribution. The function is found in the module named `bisect`. The function `bisect.insort(lst, item)` places the item into a sorted list. The function `bisect.bisect(lst, item)` returns the index of the point in the list where item could be inserted in order to maintain the sorted property. It is an easy matter (again, see exercises at the end of the chapter) to use this to test a value to see if it is in the collection, or remove a value from the collection.

## Example – Sorted List of Names and Ages

Let us illustrate a number of the features we have been discussing by creating a simple program that will read a list of names and ages, then prints the list sorted by ages. The first decision to make is the representation for the name, age combination. An easy solution is to use a two-element list, so that the final data will be stored as a lists of lists, something like the following:

```
[[ 'fred smith', 42], [ 'robin jones', 38], [ 'alice johnson', 29]]
```

The program will read the name and age information in separate lines, using `raw_input` for one one, since we want a string, and `input` for the other, so that it will be converted into a number:

```
data = []
name = ''
while name != 'done':
    name = raw_input("enter name, or 'done' to finish: ")
    if name != 'done':
        age = input("enter age for " + name + ": ")
        data.append([name, age])
```

Once the loop completes all the information will be contained in the list named `data`. If we try to sort this list we will get an error, since list elements cannot be compared to each other. Instead, we need to define a comparison function. As we saw in the previous section, this function must take two arguments, and return an integer value. In this case the two arguments are lists, and we can compare the age field:

```
def compareIndexOne (x, y):
    # compare two lists based on index value 1
    if x[1] < y[1]: return -1
    if x[1] == y[1]: return 0
    return 1
```

Using this function we can then complete the program by sorting the data list, then printing each element:

```
data.sort(compareIndexOne)
for element in data:
    print 'name: ', element[0], ' age: ', element[1]
```

## Tuples

A *tuple* is similar to a list, but is formed using parenthesis rather than square brackets. Like strings, tuples are immutable, meaning they cannot be changed once they are created. In all other respects they are identical to a list. This means that any of the list operations that do not change the value of the tuple are valid. A list can be changed into a tuple, and vice versa.

```
>>> tup = (1, 2, 3, 2, 1)
>>> 2 in tup
True
>>> list(tup)
[1, 2, 3, 2, 1]
>>> tuple(['a', 'b', 'c'])
('a', 'b', 'c')
>>> tuple('abc')
('a', 'b', 'c')
```

A common use for tuples is the need to return two or more values from a function. The following function, for example, takes a string or list as argument, and returns both the largest and the smallest element as a tuple.

```
def minAndMax (info):
    # return both largest and smallest
    return (min(info), max(info))

>>> minAndMax('abcd')
('a', 'd')
>>> minAndMax([1, 2, 5, 7])
(1, 7)
```

Back in Chapter 2 you encountered multiple assignment. What we did not tell you at that point was that multiple assignment works by creating a tuple of expressions from the right hand side, and a tuple of targets from the left, and then matching each expression to a target. Because multiple assignment uses tuples to work, it is often termed *tuple assignment*. The number of names must match the number of elements in the tuple.

```
>>> a, b = minAndMax('abcd')
>>> a
'a'
>>> b
'd'
```

The comma operator implicitly creates a tuple. This is used in the following common programming idiom. Try executing the instructions as shown and examining the resulting values. Can you explain what is happening using the idea of tuple assignment?

```
>>> x = 'apples'
>>> y = 'oranges'
>>> x, y = y, x
```

Tuple assignment also works inside of lists. The following assigns the values of variables `x` and `y` to 3 and 4, respectively:

```
>>> [x, y] = [3, 4]
```

Upon first hearing about tuples, students frequently ask why they are necessary. They seem to be less useful than lists, since their entire behavior is a subset of the things you can do with a list. The answer is that tuples are immutable. Once created, you are guaranteed they can never be changed. There are places where such guarantees are important. We will see one such place in the next chapter, where only immutable values can be used as an index into a dictionary. But there are many more examples.

## Tuples and String Formatting <sup>\*1</sup>

Tuples are sometimes used to encapsulate an indefinite (or variable) number of arguments, so that a function or operator can deal with just a single entity. An example is the *string formatting operator*, written `%`. If you followed the advice in Chapter 1 to experiment with this operator you might have been confused by an odd error message:

```
>>> "abc" % 'def'
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
TypeError: not all arguments converted during string formatting
```

Here is a more proper example of the use of this operator:

```
>>> 'int %d float %g and string %s' % (17, 3.14, "abc")
'int 17 float 3.14 and string abc'
```

Notice how the right argument for the `%` operator is a tuple that wraps several values. The left argument is a *formatting string*. This string can contain a number of special markers that indicate where values from the tuple are to be inserted and what type they

---

<sup>1</sup> Section headings marked with an asterisk indicate optional or more complicated material that can be skipped on first reading

should be. Some of the markers are %d for integers (digits), %g for floats, %s for strings, %% for a literal percent sign. The result is a string with the values inserted in the specified locations. This somewhat cryptic technique is based on a function found in the C standard library. A more complete explanation of the string formatting operator can be found in Appendix A.

## String Functions

There are a number of useful operations that can be performed with string. Among these are the following:

s.capitalize()	Capitalizes first character of s
s.capitalize()	Capitalizes first letter of each word in s
s.count(sub)	Count number of occurrences of sub in s
s.find(sub)	Find first index of sub in s, or -1 if not found
s.index(sub)	Find first index of sub in s, or raise ValueError if not found
s.rfind(sub)	Same as find, but last index
s.rindex(sub)	Same as index, but last index
s.lower()	Convert s to lower case
s.split()	Return a list of words in s
s.join(lst)	Join a list of words into a single string with s as separator
s.strip()	Strip leading/trailing white space from s
s.upper()	Convert s to upper string
s.replace(old, new)	Replace all instances of old with new in string

One of the most useful of these is the function *split*. This function takes a string (typically a line of input from the user) and splits it into individual words. A word is defined as a sequence of characters not including spaces or tabs. Another useful function is *lower*, which converts text into lower case. The following illustrates the use of these functions

```
>>> line = raw_input("What is your name?")
What is your name? Timothy Alan Budd
>>> lowname = line.lower()
>>> print lowname.split()
['timothy', 'alan', 'budd']
```

Other useful functions will search a string for a given text value, or strip leading or trailing white space from a string.

An alternative version of *split* takes as argument the separator string. The string is broken into a list using the separator as a division. This can be useful, for example, for breaking a file path name into parts:

```
>>> pathname = '/usr/local/bin/ls'
>>> pathname.split('/')
['usr', 'local', 'bin', 'ls']
```

The inverse of `split` is the function `join`. The argument to `join` is a list of strings. The value to the left of the dot is the separator that will be placed between each element. Often this is simply an empty string. The values in the list are laminated along with the separator to produce the result string.

```
>>> lst = ['abc', 'pdq', 'xyz']
>>> print '::'.join(lst)
abc::pdq::xyz
```

In earlier versions of Python this functionality was provided by the `string` module. Users needed to import the `string` module. In addition, the prefix for operations was the name `string`, and the string itself as passed as the first argument:

```
import string
...
>>> print string.split(string.lower(line))
```

This style is found in many Python programs, and users should be familiar with both techniques. However, the `string` module is now deprecated, and it is likely that these functions will be dropped from a future version of the language.

## An Example Application – Palindrome Testing

A palindrome is a word that reads the same forwards and backwards, such as ‘rotor’. Writing a function to test for the palindrome property is both a nice exercise in string functions, as well as a good example of a recursive function. Strings with length zero or one are obviously a palindrome. For a longer string, strip off the first and last characters. If they are different, then the input is not a palindrome. However, if they are the same, the recursively call the testing function with the string that results when the first and final characters are removed:

```
def palTest (s):
    if len(s) <= 1: return True
    elif s[0] != s[-1] : return False
    else: return palTest(s[1:len(s)-1])

>>> print palTest("rotor")
True
>>> print palTest("refried")
False
>>> print palTest("rats live on no evil star")
True
```

More complicated palindromes allow both upper and lower cases, as well as punctuation. An example is “A man, a plan, a canal, Panama!”. To handle these, we simply add new cases to our `palTest` function. If the first letter is not a letter it is stripped away. Similarly if the last letter is not a letter it is stripped away. Only when we know that both values are letters do we compare their lower case value:

```
def isLetter ( c ):
```

```

    # return true if c is a letter
    return ('a' <= c <= 'z') or ('A' <= c <= 'Z')

def palTest (s):
    if len(s) <= 1: return True
    elif not isLetter(s[0]): return palTest(s[1:])
    elif not isLetter(s[-1]): return palTest(s[:-1])
    elif s[0].lower() != s[-1].lower(): return False
    else: return palTest(s[1:len(s)-1])

>>> print palTest("A man, a plan, a canal, Panama!")
True

```

## An Example Application – Date Conversion

Split is one of the most useful string functions, and you will find it in many different applications. For example, suppose you want to write a function that converts a date of the form '4/1/2007' into the form 'Apr 1, 2007'. Simply split the original using the slash as a separator, then use month (which is an integer) to index into a list of month names. Remember that index values go from zero to the list size, whereas we normally use 1 to represent the first month. To handle this we subtract one from the month value:

```

def longDate (date):
    monthNames = ['Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun',
                  'Jul', 'Aug', 'Sep', 'Oct', 'Nov', 'Dec']
    month, day, year = date.split('/')
    return monthNames[eval(month)-1] + ' ' + day + ', ' + year

>>> print longDate('4/1/2007')
Apr 1, 2007

```

Note that the split returned a collection of strings, so that the month would be represented by the string value '4'. It was necessary to use the eval function to convert this into an integer in order to index into the list of month names.

## An Example Application – Encryption

Imagine you want to pass a message to a friend, but you don't want other people to be able to read it. To do this you must disguise the text in some fashion. This process is known as encryption. The reverse process, taking the encrypted message and retrieving the original, is known as decryption.

Many encryption algorithms work by treating a character value as a number. You might remember that in chapter 1 you encountered the function ord that did just this:

```

>>> print ord('a')
97

```

A very simple encryption function would take a string, translate each character into a number, convert each number into a string, and concatenate these together to obtain the hidden message:

```
def encrypt (text):
    result = ''
    for c in text:
        result = result + ' ' + str(ord(c))
    return result

>>> hidden = encrypt("Mike loves mary")
>>> print hidden
77 105 107 101 32 108 111 118 101 115 32 109 97 114 121
```

To decrypt the hidden message, break the input into the text of individual numbers, convert each text number into an integer, then convert each integer into a character:

```
def decrypt (text):
    result = ''
    for num in text.split():
        result = result + chr(eval(num))
    return result
```

Decryption now undoes the work of encryption:

```
>>> print decrypt (hidden)
Mike loves mary
```

This encryption scheme is not entirely satisfactory. In particular, the encoded string is much longer than the original. One common alternative that avoids this problem is called rot13, a variation on the caesar cipher. In rot13 letters are “rotated” by 13 positions through the alphabet, so that ‘a’ becomes ‘n’, ‘b’ becomes ‘o’, and so on. One nice property of rot13 is that the same function both encodes and decodes a message.

To define the rot13 function we first need to figure out how to translate a single character. Let us assume that we are working only with lower case letters. One way would be to use the function ord. But let us see another possibility. If we define a variable holding the alphabet, then we can use the string function named index to convert a letter into a number between 0 and 25. To find the rot13 equivalent we add 13 to this value, then take the remainder when divided by 26. This once more gives us a value between zero and 25. This is a value we can use as a subscript in our alphabet, to yield a new character. Putting all this together gives us the following:

```
def rot13char (c):
    alphabet = 'abcdefghijklmnopqrstuvwxyz'
    idx = alphabet.find( c )
    idx = (idx + 13) % 26
    return alphabet[idx]
```

The rot13char algorithm should only be called with lower case character values. To do this, we can easily convert a string into all lower case, then test to see if a character is in the given range. If so, we convert it. If not, we keep it untouched:

```
def rot13 (s):
```



```

result = ''
for c in s.lower():
    if 'a' <= c <= 'z':
        result = result + rot13char(c)
    else: result = result + c
return result

```

The encoded string is now no longer than the original:

```

>>> print rot13("I'm happy to see this!")
v'a unddm hc grr huvg!

```

Even more important, two encodings return the original string (albeit with all lower case letters):

```

>>> print rot13(rot13("Rats live on no evil star"))
rats live on no evil star

```

## An Example Program – Eliza

We can illustrate the use of string and list functions with a simple but amusing program. This is a rewriting of a classic and well-known computer game, originally called Eliza. The program simulates a Gestalt psychotherapist, and conducts a sort of question-and-answer session with the user. An example session might be the following:

```

Hello. Welcome to therapy. What is your name? Tim
Well Tim. What can we do for you today? I am writing a book on Python
Tell me more. Do you know Python?
Why do you want to know? Even my mother is learning how to program in
Python
Tell me more about your mother.
...

```

Although seeming intelligent, the Eliza program has no innate understanding of the words. Instead, the program simply looks for simple patterns in the reply, and responds with one of many canned phrases. For example, the program looks at the first two words. If they are “I” “feel” or “I” “think” then the program will ask why the user feels that way. If the user mentions a relative, such as their mother, then the program asks for more information. If the user simply hits return without a reply, then the program tells the user to talk. If no other pattern matches a simple open-ended reply is given. These are only a small sample of the rules that can be written-all to simulate intelligence where there is none.

```
# Eliza - a gestalt therapy program written by Tim Budd

import string

def getReply (line, words):
    # find a reply based on the words
    if len(words) == 0: return "You have to talk to me. "
    if line[-1] == '?': return "Why do you want to know? "
    if "mother" in words: return "Tell me more about your mother. "
    if "father" in words: return "Tell me more about your father. "
    if "uncle" in words: return "Tell me about your uncle. "
    if "sister" in words: return "Tell me about your sister. "
    if "brother" in words: return "Tell me about your brother. "
    if words[0] == "i" and words[1] == "feel": return "Why do you feel that way? "
    if words[0] == "i" and words[1] == "think": return "Do you really think so? "
    return "Tell me more. "

name = raw_input("Hello. Welcome to Therapy. What is your name? ")
print "Type quit any time you want to finish."
line = raw_input("Well " + name + ". What can we do for you today? ")

while line != "quit":
    line = line.lower()
    reply = getReply(line, line.split())
    line = raw_input(reply)
```

Notice how the function `string.lower` is used to convert characters to lower case, and the function `string.split` to break the input line into individual words. Once broken, the patterns (and many others) are easy to describe.

## Triple Quoted String, Raw strings and Escape Characters <sup>\*2</sup>

---

<sup>2</sup> Section headings marked with an asterisk indicate optional or advanced material.

In addition to single and double quotes, strings can also be defined using triple quotes. These are written using three single (‘’) or double (‘’’) quote marks. Triple quoted strings can both span multiple lines and include single or double quote marks.

```
>>> line = '''Robin said:
"don't shoot!" just as the
rifle went off'''
>>> print line
Robin said:
"don't shoot" just as the
rifle went off
```

String literals can also include *escape characters*. These are characters that are preceded by a back slash. The backslash indicates that the following character is to be given a special meaning. Examples include `\t` for the tab character, `\n` for a newline character, `\'` and `\''` for single and double quotes, and `\\` for a backslash character itself. These can be used, for example, to create a string that includes both single and double quote marks.

```
>>> line = "she replied: \"I didn't mean to do it!\""
>>> line
she replied: " I didn't mean to do it!"
```

The newline character produces a carriage return when it is printed.

```
>>> print "red\nbeans\nand\nrice"
red
beans
and
rice
```

Finally, *raw strings* turn off the processing of escape sequences. This is useful when you want to create a string that contains many backslash characters. A raw string is preceded by the character `r`

```
>>> print r'red\nbeans\nand\nrice'
red\nbeans\nand\nrice
```

## Exercises

1. Perhaps surprisingly, a list can be used where a condition is expected, such as in the test part of an if or while statement. Experimentally investigate this use. Under what situations is a list considered to be true? Under what situations is it false? Provide examples to illustrate your answers.
2. The list function can be used to convert a string into a list, as in `list('abc')`. Explain how to convert the resulting list back into a string.

3. The `del` statement deletes a single element from a list. It is claimed that this is effectively the same as assigning an empty list to a one-element slice. Demonstrate this by providing the equivalent assignment statement to the following example of `del`.

```
>>> lst = [1, 9, 8, 7, 5]
>>> del lst[3]
```

4. Can slices be used with the `del` statement? Provide an example to show what will happen.
5. Why is it necessary to have both the functions `append` and `extend`? What is the result of the following expression that uses `append` where it probably intended to use `extend`?

```
>>> lst = [1, 2, 3]
>>> lst.append([4, 5, 6])
```

6. Can you use the addition assignment operator, `+=`, with two lists? What is the result?
7. Show how to use the `is` operator to demonstrate that assignment creates a duplicate reference, and not a true copy. Then use the same operator to demonstrate that a slice assignment does create a copy.
8. What happens if you pass a three element tuple to the function `sneaky`? What error message is produced? What happens if you pass a three element string?
9. Show how to get the effect of the `lst.append` operator with a combination of `lst.insert` and `len`.
10. Suppose you use the `lst.remove` operator to remove an element that is repeated in a list. For example, removing the value 3 from the list `[1, 2, 3, 4, 3, 5, 3]`. Which value is removed? What is the effect of `remove` if the element is not found in the list?
11. What does `lst.index` do if you search for an element that is not found in the list?
12. What does the `lst.insert` function do if you pass it a negative offset?
13. What does `lst.pop` do if you pass it a negative offset? What does it do if you pass it an offset that is larger than the number of elements in the list?
14. Comparison of two strings is based on the ASCII ordering. This means that uppercase letters (all of them) come before lowercase letters. Many applications require a sort that is case independent, such as you find in a dictionary. Show how to achieve this effect by writing a comparison function for the sort operation.

Hint: convert both arguments to lower case, using the function `lower()`, then compare the resulting values.

15. The function `randint` from the `random` module can be used to produce random numbers. A call on `random.randint(1, 6)`, for example, will produce the values 1 to 6 with equal probability. Write a program that loops 1000 times. On each iteration it makes two calls on `randint` to simulate rolling a pair of dice. Compute the sum of the two dice, and record the number of times each value appears. After the loop, print the array of sums. You can initialize the array using the idiom shown earlier in this chapter:

```
times = [0] * 12    # make an array of 12 elements, initially zero
```

16. A classic problem that can be solved using an array is the random walk. Imagine a drunken man standing on the center square of a sidewalk consisting of 11 squares. At each step the drunk can elect to go either right or left. How long will it be until he reaches the end of the sidewalk, and how many times will he have stood on each square? To solve the problem, represent the number of times the drunk has stood on a square as an array. This can be created and initialized to zero with the following statement:

```
times = [0] * 11
```

Use the function `random.randint` from the `random` module to compute random numbers. The function `random.randint(0,1)` will produce the values 0 and 1 with equal probability. Maintain a value that indicates the current location of the drunk, and at each step of the simulation move either right or left. Display the value of the array after each step.

17. The two dimensional variation on the random walk starts in the middle of a grid, such as an 11 by 11 array. At each step the drunk has four choices: up, down, left or right. Earlier in the chapter we described how to create a two-dimensional array of numbers. Using this data type, write a simulation of the two-dimensional random walk.
18. One list is equal (`==`) to another if they have the same length and the corresponding elements are equal. It is perhaps surprising that lists can also be compared with the relational operators, such as `<`. Experiment with this operator, and see if you can develop a general rule to explain when one list is less than another.

```
>>> [1, 2] < [1, 2, 3]
True
>>> [4, 5] < [1, 2, 3]
False
>>>
```

14. When you use the + operator to concatenate two lists, does it make a copy or a reference of the arguments? Show an example to demonstrate your answer.

19. What does the following statement do? Can you think of a good use for this type of statement?

```
a, b, c, d = range(4)
```

20. While the slice trick is a common idiom for making a copy, it only works if the elements in the list are themselves simple values. To see the problem, examine the following. What do you predict will be printed as the value of c? Try executing the statements. Did the result match your prediction? Explain the outcome using the concept of references.

```
>>> a = [1, 2]
>>> b = [a, 3]
>>> c = b[:]
>>> a[0] = 7
>>> b[1] = 8
>>> c
```

The slice assignment trick is returning what is termed a *shallow copy*. A true and complete copy of a multi-level value is termed a *deep copy*. To make a deep copy you can include the module named copy and invoke the function copy.deepcopy(x). Show that if this function is used in the example above that the result is different from the shallow copy outcome.

21. Examine the result, and explain the difference between the following two expressions.

```
>>> lst = [1, 2, 3]
>>> lst * 3
...
>>> [ lst ] * 3
...
```

22. If you take the second expression above, and subsequently change the value lst, what happens to the result? Explain this behavior using the ideas of deep and shallow copies from earlier questions.

```
>>> lst = [1, 2, 3]
>>> arr = [ lst ] * 3
>>> lst[1] = 7
>>> print arr # what will you see?
```

23. What if you tried to avoid the problem above using the slice copy idiom. What happens if you change an element in the array? Explain the result using the ideas of deep and shallow copy and references.

```
>>> lst = [1, 2, 3]
```

```
>>> arr = [ lst[:] ] * 3
>>> arr[1][1] = 7
>>> print arr    # what will you see?
```

24. What does the string.count function do if the pattern overlaps with itself? For example, suppose you want to count the number of times that the string “sis” occurs in the word “frisisisisip”. There are two potential values – the overlapping count and the non-overlapping count. Which is produced by the function? Describe a way to find the other value.
25. What does the string.replace function do if the pattern value overlaps with itself? For example, suppose you want to replace all the occurrences of “sis” in “frisisisisip” with “xix”.
26. What does the string.replace function do if the replacement introduces new instances of the pattern. For example, what if you replace the string “sis” with “xis” in “frisisip”.
27. A variation on the split function uses an argument. What does the following produce? Try various other expressions, and explain what value is returned by this version of split.

```
>>> line = '12:43:13:24:43'
>>> print line.split(":")
```

28. The module random provides a number of functions that produce random numbers. The most useful are the functions random.random(), which returns a floating point value in the range (0.0, 1.0), and the function random.randint(a, b), which produces a random integer N distributed  $a \leq N \leq b$ . Using the latter, write a function that takes a list and returns a randomly selected element.
29. Many more rules can be added to the response generator for the Eliza program. Examples include responding to “I want” or “I think” with a question that asks why the client wants or things that way (perhaps even including the text of the material that follows the first two words), a randomly generated generic response taken from a list of different possibilities if nothing else is appropriate, searching for a key word such as “computer” and responding with something like “computers can be so annoying, can’t they?”. Think of some more question and answer patterns and implement them in your own version of Eliza.
30. In an earlier chapter we explained that the range function, normally used in a for statement, actually produces a list. With the benefit of your knowledge of lists, explain what the function range(x, y, z) produces.
31. A polygon can be represented by a list of (x, y) pairs where each pair is a tuple: [(x<sub>1</sub>, y<sub>1</sub>), (x<sub>2</sub>, y<sub>2</sub>), (x<sub>3</sub>, y<sub>3</sub>), ..., (x<sub>n</sub>, y<sub>n</sub>)]. Write a recursive function to compute the area of a polygon. This can be accomplished by “cutting off” a triangle, using the

fact that a triangle with corners  $(x_1, y_1)$ ,  $(x_2, y_2)$ ,  $(x_3, y_3)$  has area  $(x_1y_1 + x_2y_2 + x_3y_2 - y_1x_2 - y_2x_3 - y_3x_1) / 2$ .

[ picture ]

32. As noted earlier in this chapter, the function `bisect` in the module of the same name takes as argument a sorted list and an element. It returns the index where the element could be inserted, if desired, so as to not violate the sorted characteristic of the list. Show how to use this function to create a simple collection abstraction. Your collection should implement the following functions:

`add(lst, ele)` – add the element into the collection

`test(lst, ele)` – return true if the element is in the collection, false otherwise

`remove(lst, ele)` – return the element from the collection if it is there, otherwise do nothing

33. Write the function `bisect` that matches the definition given in the previous question. That is, `bisect(lst, ele)` should return the position of in the `lst` where the element could be inserted so as to not violate ordering. Do this using the binary search idea. That is, first compare the element to the value stored in the middle of the list. Then search either the first half or the second half of the list. Do this repeatedly until you have found the proper position. Hint: Maintain variables `low` and `high` that are indices of the lowest possible and largest possible position, and loop as long as `low` is different from `high`.



## Chapter 5 - Dictionaries

The next built-in Python type we will examine is the *dictionary*. A dictionary is an indexed data structure, and uses the same square bracket syntax for indexing as a list. But in a dictionary the indices are not positions, but values. Any immutable type can be used as an index. Strings are most common, but numbers and tuples work as well. An example will help illustrate the idea. A empty pair of curly braces creates a new dictionary, just like an empty pair of square braces were used to create an empty list. New elements are placed into the dictionary simply by using an index in an assignment.

```
>>> dct = { } # create a new dictionary
>>> dct['name'] = 'chris smith'
>>> dct['age'] = 27
>>> dct['eyes'] = 'blue'
```

The index expression is termed a *key*, while the element stored in association with the key is termed a *value*. Dictionaries are also some times termed *maps*, *hashes* or *associative arrays*. Just as individual elements in a list can be accessed by indexing, values are returned from a dictionary using the indexing operation. An equivalent function is named `get`. Both will produce an error if the index has not yet been assigned, however, a useful two-argument version of `get` will return the second argument if the index is not valid. The value stored with a given key can be changed simply by assignment.

```
>>> print dct['name']
chris smith
>>> print dct.get('age')
27
>>> print dct['weight']
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
KeyError: 'weight'
>>> print dct.get('weight', 0) # use 0 as default value
0
>>> dct['age'] = 28 # change the value
>>> print dct['age']
28
```

As with a list, the function `len` can be used to determine the number of elements (the length) of the dictionary. Also the `del` function can be used to delete an element from a dictionary.

```
>>> del dct['age']
>>> print dct['age']
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
KeyError: 'age'
```

Just as a list can be created with an initial set of values, a dictionary can also be initialized at the time it is created. Each key/value pair is written using a colon, and the list of these pairs are separated by commas:

```
>>> info = {'name':'robin jones', 'age':53, 'weight':203}
>>> print info['name']
robin jones
```

As with parenthesized expressions and lists, an open curly brace for a dictionary literal makes the Python system keep reading until the closing curly brace is found:

```
>>> info = {'name' : 'robin jones',
...         'age' : 53,
...         'weight' : 203}
```

The most common operations for a dictionary are shown in the table at right. You should at this point try creating a few dictionaries and examining the results of various expressions.

The function `has_key` can be used to test if a given value is a legitimate key.

This can be used to avoid the error message that will be produced if an illegal key is used:

```
if info.has_key('age'):
    ageinfo = key['age']
else:
    ageinfo = 21 # use 21 as a default value in nothing else known
```

However, notice that this common idiom can be replaced using the alternative form of the function `get`:

```
ageinfo = info.get('age', 21)
```

Despite the relatively small set of operations for dictionaries, they are one of the most powerful and commonly used data types in Python programs. Dictionaries indexed by strings are often used to store records of information. (Taking the place of data types such as “struct” in C or “record” in Pascal). Dictionaries whose elements are themselves lists or other dictionaries are used to store hierarchical values. We will see an example in the concordance program at the end of this chapter.

Dictionaries indexed by integers can be used like lists. You might wonder why you would ever want to do this. One situation is for sparse vectors. Imagine you have a list of integers, but most of the elements have value zero. There are non-zero entries at positions

<code>len(d)</code>	Number of elements in d
<code>d[k]</code>	Item in d with key k
<code>d[k] = v</code>	Set item in d with key k to v
<code>del d[k]</code>	Delete item k from dictionary d
<code>d.clear()</code>	Remove all items from dictionary d
<code>d.copy()</code>	Make a shallow copy of d
<code>d.has_key(k)</code>	Return 1 if d has key k, 0 otherwise
<code>d.items()</code>	Return a list of (key, value) pairs
<code>d.keys()</code>	Return a list of keys in d
<code>d.values()</code>	Return a list of values in d
<code>d.get(k)</code>	Same as <code>d[k]</code>
<code>d.get(k, v)</code>	Return <code>d[k]</code> if k is valid, otherwise return v

2, 17, and 523. Using a list you would need to have at least 524 positions. Using a vector you need only store the elements that are nonzero:

```
data = {2:27, 17:329, 523:42}
```

Using the second form of the get statement to access elements, the default value is returned on all but the nonzero elements:

```
>>> data.get(523, 0)
42
>>> data.get(525, 0)
0
```

## Example: Counting Elements

The get function that allows for a default value can greatly simplify many problems. For example, the following simple function takes a list, and returns a dictionary representing a count of the number of times each value appears:

```
def frequency (lst):
    counts = { }
    for ele in lst:
        counts[ele] = counts.get(ele, 0) + 1
    return counts

>>> frequency(['abc', 'def', 'abc', 'pdq', 'abc'])
{'abc': 3, 'pdq': 1, 'def': 1}
```

Let us use this idea to write a program that reads lines of text from the input until a line with the single word 'quit' is entered. After each line is read it is split into individual words, and a frequency count is kept of each word. Once the terminating line is found the frequency of each word is reported.

```
def main ():
    freq = { }
    line = raw_input()
    while line != 'quit':
        words = line.split()
        for word in words:
            freq[word] = freq.get(word, 0) + 1
        line = raw_input()
    # now all words have been read
    for word in freq:
        print word + ' occurs ' + freq[word] + ' times'
```

If the input is:

```
it was the best of times
it was the worst of times
quit
```

Output will be:

```

of occurs 2 times
it occurs 2 times
times occurs 2 times
worst occurs 1 times
the occurs 2 times
was occurs 2 times
best occurs 1 times

```

## Example – Tabulating Club Dues

Let us continue the example from the previous section with a simple variation. Imagine that there is a club with several members, and that the monthly dues each member has paid is recorded as follows:

```

chris:2.34
robin:1.50
fred:3.23
robin:3.75
chris:4.35

```

Notice that members may have contributed more than once (say, over several meetings). We need a program that will read inputs in this form, say terminated<sup>1</sup> by a line containing the word 'quit', and then print a list of the amounts each member has contributed. The program will have a structure very similar to the example given earlier. The major difference is that input will be split using the colon as spacer, and that the second value will be converted into a number using the function named eval:

```

def main ():
    dues = { }
    line = raw_input()
    while line != 'quit':
        words = line.split(':')
        dues[words[0]] = dues.get(words[0], 0.0)+eval(words[1])
        line = raw_input()
    # now all lines have been read
    for name in dues:
        print name, ' has paid ',dues[name], ' in dues'

```

## Combining two dictionaries with update

Two lists can be combined using catenation, or append. This concept does not make sense for dictionaries, however a somewhat similar operation is provided by the update method. This method takes as argument another dictionary. The values from the argument dictionary are copied into the receiver, possibly overwriting an existing entry.

```

>>> dictone = {'abc':3, 'def':7, 'xyz': 9}

```

---

<sup>1</sup> At the moment we are limited by the need to read input directly from the user. Soon enough we will encounter file I/O, and when we do we can change our programs to read values from a file until end of file is reached.

```
>>> dicttwo = {'def':5, 'pdq': 4}
>>> dictone.update(dicttwo)
>>> print dictone
{'xyz': 9, 'abc': 3, 'pdq': 4, 'def': 5}
```

## Making Copies

Remember that Python uses reference semantics from assignment. If you simply assign one dictionary to a new variable, they end up referring to the same collection. A change to one will end up modifying both:

```
>>> dictone = {'abc': 3, 'def': 7}
>>> dicttwo = dictone
>>> dicttwo['xyz'] = 12
>>> print dictone
{'xyz': 12, 'abc': 3, 'def': 7}
```

To make an independent copy of a dictionary you can use the method `copy`.

```
>>> dictone = {'abc': 3, 'def': 7}
>>> dicttwo = dictone.copy()
>>> dicttwo['xyz'] = 12
>>> print dictone
{'abc': 3, 'def': 7}
```

When a dictionary is passed as an argument the parameter is simply assigned the argument value. Hence both refer to the same value. A change to the dictionary inside the function will remain after the function returns.

```
def sneaky (d):
    d['ha'] = 'ho'

>>> a = {'one':1, 'two': 2}
>>> sneaky(a)
>>> print a
{'one':1, 'two':2, 'ha':'ho'}
```

Sometimes, having the function fill in values in the dictionary is the behavior you want. Other times it is a sign of error. If you find a dictionary holding strange values one possibility is to make copies of the dictionary before passing it into any function, in case the function is mistakenly filling in new values.

## Zip List Initialization <sup>\*2</sup>

The function `dict` takes a list of two-element tuples, and converts them into a dictionary with the first element in each tuple representing the key and the second representing the value:

---

<sup>2</sup> Sections marked with an asterisk indicate advanced or optional material and can be omitted on first reading.

```
>>> x = dict([('name', 'fred'), ('age', 42), ('weight', 175)])
>>> x
{'name': 'fred', 'age': 42, 'weight': 175}
```

This might at first not seem particularly useful, since the dictionary literal is so much easier. But remember the function `zip`? Many times you will find yourself with a list of keys, and separately with a list of values. `Zip` makes it easy to convert this into a list of tuples, which can then be used to create a dictionary.

```
>>> keys = ['name', 'age', 'weight']
>>> values = ['fred', 42, 175]
>>> x = dict(zip(keys, values))
>>> x
{'name': 'fred', 'age': 42, 'weight': 175}
```

## Loops

Just as a `for` statement can be used to loop over the elements in a list, a *for* can also be used to cycle through the values in a dictionary. If you simply use the dictionary as the target of the `for` statement, the values returned are the keys for the collection:

```
>>> for e in info:
...     print e
'name'
'age'
'weight'
```

Sometimes (actually, rarely) you want to iterate over the set of values. This can be done using the function `values()`:

```
>>> for e in info.values():
...     print e
'fred'
42
175
```

The order the elements are stored in a dictionary is purposely undefined, and may even change during the course of execution. Often you want to examine the elements in a particular sequence, for example in ascending order of keys. This can be accomplished by sorting the list returned by the `keys` operation:

```
for e in sorted(info.keys()): # cycle through keys in sorted order
```

## Example - A Concordance

A concordance is an alphabetical listing of the words in a text, along with the line numbers on which each word occurs. A dictionary is a natural data structure for representing a concordance. The words in the text will be used as a key, while the value will be the line numbers on which the word appears. Because a word can appear on more

```

from string import split

def countWords (words, dct, lineNumber):
    # update dictionary for each word
    # with line number
    for word in words:
        lst = dct.get(word, [])
        lst.append(lineNumber)
        dct[word] = lst

# step 1, read lines until finished
line = raw_input()
lineNumber = 0
dct = { }
while line != 'quit':
    lineNumber += 1
    countWords(split(line), dct, lineNumber)
    line = raw_input()

# step 2, print results
for w in sorted(dct.keys()):
    print w, ': ', dct[w]

```

than one line, we use a list of line numbers. So our basic data structure is a dictionary, keyed by strings, holding a list of integers.

The concordance program breaks into two steps. In step 1 the input is read, line by line, until the end. Here we will use a line with the single word 'quit' to represent the end of input. (In the chapter on files we will describe a better solution to this

problem). Once the input has been read, the second step is to print the result.

Breaking the input into words is easy using the function `split` found in the module `string`. Here we introduce a new feature. If all you need from a module is a single function, you can use a *from* statement. The *from* statement

**from** module-name **import** function

imports just a single function from a module. In addition, the function is placed into the local scope. This means the function can be used without the module qualification. In this case it means the function is simply called `split`, rather than `string.split`.

The program is shown at left. A function has been defined to perform the task of updating the counts on the words in a single line. An example execution might produce results such as the following:

```

$ python concordance.py
it was the best of times
it was the worst of times
quit
best : [1]
it : [1, 2]
of : [1, 2]
the : [1, 2]
times : [1, 2]
was : [1, 2]
worst : [2]

```

There are several changes that can be made to improve this program. For example, the same word might appear on one line more than once. So the line number should only be appended to the list if it is not already found in the list. Also words with upper case letters

and lower case letters should be combined. This can be easily accomplished by converting the line into all lower case before it is split. Both of these changes should be relatively easy for you to make. The following is somewhat more complicated: punctuation should be removed, so that periods and commas are not counted as part of a word. One way to do this would be to translate each occurrence of a period or comma into a space. Can you figure out how to do this?

## Dynamic Programming \*

In a previous chapter we analyzed two different functions to compute the Fibonacci numbers. There we found that the recursive program ran much more slowly than the iterative version. However, there is a way to make the recursive version run just as fast as the other. This technique is termed *dynamic programming*. In its simplest form, dynamic programming can be expressed as a pair of principles. Never compute anything until you need to; but, having computed a result, remember it and don't compute it again. We can use a dictionary to store values as they are computed. Because this dictionary must be shared across multiple calls to the Fibonacci function, it must be declared global. Our revised function can be written as follows:

```
fibs = {0:0, 1:1} # base cases, fib(0) is 0, fib(1) is 1

def rfib(n):
    global fibs
    if not fibs.has_key(n):
        fibs[n] = rfib(n-2) + rfib(n-1)
    return fibs[n]
```

You can verify that the recursive version is now just as fast as the looping program presented in the earlier chapter.

## Persistent Variables

A *persistent* variable is a variable that can retain its value across multiple executions. Behind the scenes, such values are stored in a file, similar to those we will describe in the next chapter. However, the user can make use of the persistence facilities without needing to use explicit file commands.

The easiest facility for providing object persistence is the `shelve` module. This can be imported using the statement

```
import shelve
```

As the name suggests, a shelf can be thought of as a platform for storing values. Shelves are given names. (Behind the scene, these are translated into file names). The user opens or creates a new shelf using the `shelve.open` function. This function returns the shelf as the result. The shelf can then be used as if it were a dictionary. Values stored into the dictionary are written to the shelf, and are retained even after execution of the program



has finished. Values are read from the shelf using the same indexing operations as the dictionary. The following is a simple example:

```
import shelve

data = shelve.open("information") # file is named information
data['name'] = 'fred smith' # put information into shelve
print data['name'] # get information out of shelve

data.close() # close the shelf before quitting
```

As with dictionaries, the `del` operation can be used to delete an item from a shelf, the `function` has-key used to see if a key is value, and the `function` keys used to produce a list of all legal key values.

## Example - A Telephone Database

An example program can help illustrate the use of persistent variables. This program will maintain a telephone database. Commands to use the database will be the following:

```
whois phone-number # find the information associated with a number
add phone-number information # will add information to the database
search keyword # find all the entries that include keyword
quit # halt the application
```

A shelf named “phoneinfo” is used to store the telephone database. A loop reads

```
# telephone database application
# written by Tim Budd

import shelve

database = shelve.open("phoneinfo")
print "Commands are whois, add, search and quit"

line = raw_input("command: ")
while line != 'quit':
    words = line.split()
    if words[0] == 'whois':
        print words[1],":",database[words[1]]
    elif words[0] == 'add':
        database[words[1]] = " ".join(words[2:])
    elif words[0] == 'search':
        for e in database.keys():
            if database[e].find(words[1]) != -1:
                print e,":",database[e]
    line = raw_input("comand: ")
database.close()
```

commands from the user. The `string.split` function is used to break the command into parts. The first word is used to determine which action to perform. Depending upon the action selected, the database is consulted to find appropriate information. Before the application quits the database is closed.

An example session with this program might go as follows:

```
Commands are whois, add, search and quit
command: add 2347531 fred smith
command: add 9842354 robin jones
command: quit
```

Later, another session could proceed as follows:

```
Commands are whois, add, search and quit
command: whois 2347531
2347531 : fred smith
command: search fred
2347531 : fred smith
command: search jones
9842354 : robin jones
command: quit
```

You should experiment with this program, and verify that the information stored in the database is remembered between executions.

The program as given is simple but not very robust. You can easily make it better with a few simple additions. You should be able to make each of the following:

- If the user simply hits return without typing anything, the list stored in words will be empty. In this case print a line reminding the user what commands are valid.
- If the telephone number provided by the whois command is not found you should print a helpful message and not produce an indexing error (as will happen now).
- If the search for a pattern does not result in any value you should tell the user.
- You should add a command named “delete” that will remove a given telephone number from the database.

Notice that the heart of the program is very small. However, making the program more robust in the face of errors will not only improve users satisfaction with the system, but will make the program considerably longer. It is common that well over half of the length of a program will be devoted to error handling and recovery. You need to remember this both when writing programs and when reading Python programs written by others. In examining the code for a new program, learn to identify the key ideas that are at the heart of the system.

## Internal Dictionaries <sup>\*3</sup>

---

<sup>3</sup> Sections marked with a star contain optional or advanced material that can be skipped on first reading.

Dictionaries and lists are used extensively throughout the Python system to store internal values. For example, the set of variable names that are valid at any point in time is stored in a dictionary. At the global level you can access this dictionary using the function `globals()`. Within a function you can access a separate dictionary used to store local variables using the function `locals()`. The following trivial program will illustrate these values.

```
def test(a):
    b = 7
    print 'locals are:', locals()
    c = 12
    print 'locals are now:', locals()

test(5)
```

Executing this program produces the following:

```
locals are: {'a': 5, 'b': 7}
locals are now: {'a': 5, 'c': 12, 'b': 7}
```

Although these dictionaries are accessible and, in theory, can be modified by the user, doing so is tricky and can cause subtle errors.

## Exercises

1. Using the function `frequency`, write a function that will produce a histogram from a list. A histogram shows in a visual fashion, such as with stars, the number of times an item occurs in a list. For example, the histogram for the data used to illustrate the `frequency` function might appear as follows:

```
abc ***
pdq *
def *
```

2. Using lists, write the function `unique(lst)` that takes a list as argument, and returns a list in which all duplicate values have been removed. For example, given the input `['abc', 'def', 'abc', 'xyz', 'def']` the function would return `['abc', 'def', 'xyz']`.
3. What is the result if you convert a dictionary into a list using the `list()` function?
4. What type of value is returned by `has_key()`? Explain why you can nevertheless use this value in a Boolean test, such as an `if` statement or a `while`.
5. What error message is produced if you index a dictionary with a mutable type, such as a list.

6. What is the effect of the following statements? Can you think of a use for such a construct?

```
num = raw_input("type a number less than 4")
print {1:"one",
      2:"two",
      3:"three",
      4:"four"}.get(num, "bad number")
```

7. Importing a function using a `from` statement has two benefits. It allows you to include just a single function name, and it adds the function name to the local space. The latter actually produces faster execution, since it avoids a run-time lookup of the function. (That is, when you execute `string.split`, the Python system actually looks up the name `split` in the module `string` each time the function is executed). To measure the improvements this can produce, try calling the function `split` on a fixed string in a loop that executes 10000 times. Determine how fast this program will run when using an `import` statement and `string.split`, and when using a `from` statement. Is the difference significant?

## Chapter 6 – Files

You already have experience creating files, such as the python program file, using a word processor. From this experience you should realize that a file is simply a sequence of characters stored on your computer or network. One of the things that makes a file different from a string or list of characters is that the file exists even after a program ends. This makes a file useful for maintaining information that must be remembered for a long period of time, such as the persistent values managed with the shelve module that you examined in Chapter 5.

Within a Python program a file is represented by a value of type *file*. This value does not actually hold the contents of the file, rather the value is a portal through which the user can access the contents of the file. A file stored on disk might easily contain more characters than can be held by a variable in memory. You can think of the file object as a window through which you can see the file itself. Like a window, the file variable only allows you to view a portion of the file at a time.

A file value is used in three distinct steps. First, the file is opened. This establishes the link between the file value in the Python program and the information stored on the disk. Next, values are read or written to the file. The process involves bringing characters in from the disk and storing them in a string in the Python program, or alternatively taking the contents of a string in your program and writing them out to the disk. When all values have been either read or written, the last step is to close the file. These operations are performed by the following commands:

<code>f = open("filename")</code>	Open a file, return file value
<code>f = open("filename", "w")</code>	Open a file for writing
<code>f.read()</code>	Return a single character value
<code>f.read(n)</code>	Return no more than n character values
<code>f.readline()</code>	Return the next line of input
<code>f.readlines()</code>	Return all the file as a list
<code>f.write(s)</code>	Write string s to file
<code>f.writelines(lst)</code>	Write list lst to file
<code>f.close()</code>	Close file

The most common way to obtain information from a file is through the command `readline`. The function returns an empty string when the end of the file is detected. The function `read` is used to obtain a fixed number of characters. It may return a smaller number of characters than requested, if the end of file is found before the requested number of characters have been found. The function `write` is used to copy a string into a file. The functions `readlines` or `writelines` can be used to read an entire file into a list, or to copy an entire list into a file.

To gain some experience with these functions first create a small test file. For example, create a file with the four lines shown at right, placing them into a file named

Peas porrage Hot  
Peas porrage Cold  
Peas porrage in the Pot  
Nine Days Old!

peas.txt. Then try executing each of the programs shown below. Make a prediction of what the program will do before trying each one out. Are your predictions correct? Were you surprised at any output? Can you explain why programs 2 and 3 use the function `rstrip`? Why is this not needed in programs 4 and 5?

---

```
f = open("peas.txt")
line = f.readline()
while line:
    print line.swapcase()
    line = f.readline()
```

---

```
f = open("peas.txt")
line = f.readline()
while line:
    line = line.rstrip()
    print line.capitalize()
    line = f.readline()
```

---

```
f = open("peas.txt")
line = f.readline()
while line:
    line = line.rstrip()
    lst = list(line)
    lst.reverse()
    print "".join(lst)
    line = f.readline()
```

---

```
f = open("peas.txt")
fout = open("peas2.txt", "w")
lst = f.readlines()
lst.reverse()
for x in lst:
    fout.write(x)
fout.close()
```

---

```
f = open("peas.txt")
fout = open("peas2.txt", "w")
lst = f.readlines()
lst.sort()
fout.writelines(lst)
fout.close()
```

---

## Warning! Opening a file for write removes old values

Copy the four lines given earlier into a file named `peas2.txt`. Then try executing the following two lines:

```
>>> f = open("peas2.txt", "w")
>>> f.close()
```

Open the file with notepad or some other word processor. What has happened? Remember, opening a file for writing causes the old values in the file to be deleted. This is true even if no new values are written into the file.

## Rewriting Word Count Program

Let us rewrite the word count program from Chapter 6 so that the input is now being read from a file, rather than directly from the user. Changes to the program include altering where the input comes from, and the condition to test for end of file:

```
def freqCount (f): # f is a file of input
    freq = { }
    line = f.readline()
    while line:
        words = line.split()
        for word in words:
            freq[word] = freq.get(word, 0) + 1
        line = f.readline()
    return freq

def main ():
    f = open("text.txt")
    freq = freqCount(f)
    # now all words have been read
    for word in freq:
        print word + ' occurs ' + freq[word] + ' times'
```

We have also in this example employed some of the ideas of encapsulation we discussed in earlier chapters. We have now separated the gathering of the frequencies from printing the results, and opened the file in the main program, passing the file value to the frequency counting function.

## Operating System Commands

The operating system (such as Windows, Mac, or Unix) is normally in charge of the management of files. There are a number of useful operating system commands that can be executed from within a Python program by including the `os` module. The two most useful commands are `os.remove(name)`, which deletes (removes) the named file, and `os.rename(oldname, newname)`, which renames a file. We will see examples of both of these in the case study at the end of this chapter. There are many other functions in the `os` module, however the use of these facilities is beyond the scope of this book. The most common and useful functions are described in Appendix A.

```
>>> import os
>>> os.remove("gone.txt") # delete file named gone
>>> os.rename("fred.txt", "alice.txt") # fred becomes alice
```

## Files and for

A file value can be used in a `for` statement. The resulting loop reads from the file line by line, and assigns the line to the `for` variable:

```
f = open("peas.txt")
for line in f:
    print line.reverse()
```

This can often make programs that manipulate files considerably shorter than the equivalent form using a while statement. For example, our frequency counting function is reduced to the following:

```
def freqCount (f): # f is a file of input
    freq = { }
    for line in f:
        words = line.split()
        for word in words:
            freq[word] = freq.get(word, 0) + 1
    return freq
```

## Recovering from Exceptions

What happens if you try to open a file that does not exist? As you might expect, the Python system complains, and responds by throwing an exception, an `IOError`. Normally the exception causes execution to halt with an error message. You have seen examples of this in earlier chapters, as well as probably many more examples in your own programming.

There are times when you would like to catch an exception and continue with execution, perhaps by performing some recovery action. This can be accomplished by using a *try statement*. The classic example of a try statement with a file open is the following:

```
try:
    f = open("input.txt")
except IOError, e:
    print 'unable to open the file input.txt'
else:
    ... # do something with file f
    f.close()
```

The open statement may or may not raise an `IOError`. If it does, the statements in the except part of the try statement are executed. If not, the statements in the else part are executed. The try statement is in this sense similar to a conditional, selecting one of two alternatives.

Any type of exception can be caught in a try statement. The variable name in the except part is attached to whatever text, if any, was used with the raise statement. You saw examples of the use of the raise statement in Chapter 3.

## Standard I/O \*<sup>1</sup>

The print statement, and the functions `raw_input` and `input`, are actually special uses of more general file commands. The print statement writes characters to a file that is

---

<sup>1</sup> Sections marked with an asterisk contain optional or advanced material that can be omitted on first reading.



normally attached to a display window, while the input functions read from a file that is attached to the user keyboard. These files can be accessed by importing the `sys` module. The standard input is available as the value of the variable `sys.stdin`, while the standard output is `sys.stdout`. Error messages are actually written to a different file, named `sys.stderr`, although normally this goes to the same place as `sys.stdout`.

One use for these variables is to take a program that is written as if it was reading from a file, and instead read from the console input. For example, we might invoke our frequency counting program developed earlier in the chapter as follows:

```
def main():
    # invoke frequency program, reading from console input
    freq = freqCount(sys.stdin)
    # now all words have been read
    for word in freq:
        print word + ' occurs ' + freq[word] + ' times'
```

To mark the “end of file” the user enters control-D (or control-Z on windows machines).

A more subtle use of the `system` module is to change these variables, thereby altering the effect of the standard functions. To see an example, by executing the following program, and then examining the files `output.txt` and `error.txt`.

```
import sys
sys.stdout = open('output.txt', 'w')
sys.stderr = open('error.txt', 'w')
print "see where this goes"
print 5/4
print 7.0/0
sys.stdout.close()
sys.stderr.close()
```

There are several other functions and variables defined in the `sys` module. The function `sys.exit("message")` can be used to terminate a running Python program. The function `sys.argv` is a list of the command line-options passed to a program. On systems that support command line arguments these are often used to pass information, such as file names, into a program. Assume that `echo.py` is the following simple program:

```
import sys
print sys.argv
```

The following might be an example execution:

```
$ python echo.py abc def
['echo.py', 'abc', 'def']
```

Notice that the name of the Python function is the first argument, while other command line arguments follow as string values.

Some of the other features of the sys module will be explored in the exercises at the end of the chapter.

## Persistence and Pickle \*

In an earlier chapter you learned about the shelve module. As you might expect, the implementation of the shelve module makes extensive use of file commands. There is an alternative module that is also useful in saving and restoring the values of Python variables. This module is, somewhat humorously, known as pickle. (When you pickle a fruit or vegetable you are saving it for long term storage). A more common name for pickling is *serialization*.

The pickle module supplies two functions, dump and load. These can be used to save the contents of most Python variables to a file and later restore their values. The following is an example

```
import pickle
...
object = ... # create some Python value
f = open(filename, 'w')
pickle.dump(f, object)
```

Later, perhaps in a different program or at a different time, the contents of the variable can be retrieved from the file as follows:

```
import pickle
...
f = open(filename, 'w')
object = pickle.load(f)
```

Multiple objects can be saved and restored in the same file. However the user is responsible for remembering the order that values were saved. Most Python objects can be saved and restored using pickle and/or shelve. However a few special objects, such as file values themselves, maintain an internal state that cannot be stored using these facilities.

## Example – File Sort

As an example program presented earlier shows, it is easy to sort the lines of a file if your computer has sufficient memory to maintain the contents of the file in a list. Simply read the file into the list, sort the list, then write the list out to a new file. But what if you have a very large file, one that is too big to fit into memory?

The algorithm used to solve this problem is known as *file sort*. The file sort algorithm uses a number of temporary files as intermediate storage areas. The approach works in three steps. In step 1, the original file is read in small units, say 100 lines at a time. Each unit is sorted and written out to a temporary file. Once these have been created the second step begins. In this step pairs of temporary files are merged into a new file. To merge two

files requires only one line at a time from each, and so memory size is not a problem. This merge process continues until there is just one file remaining. This file will then have the desired outcome. As a final step the single remaining temporary file is renamed to the desired result.

This application is considerably longer than any we have considered up to this point, and so we can also use it as a vehicle to demonstrate an approach to designing large programs. This approach is known as *step-wise refinement*. It works by describing the initial program at a high level of abstraction using functions to represent major tasks, and then refining each of those functions in turn until the entire application has been developed.

Consider the main program. Let us assume that the input is contained in the file `input.txt`, and the output should go into file `output.txt`. At a high level, we can describe the algorithm as follows:

```
import os

# step 1: make all the temporary files
try
    fin = open("input.txt")
except IOError:
    print 'unable to open input.txt'
else:
    tlist = makeTempFiles(fin)

# step 2: merge temp files
while len(tlist) > 1:
    mergeTwoIntoOne(tlist)

# step 3: rename the remaining temp file
tname = tlist.pop()
os.rename(tname, "output.txt")
```

Assuming that the as yet unwritten functions `makeTempFiles` and `mergeTwoIntoOne` do the right things, it is relatively easy to see that this program will work as we expect. The function `makeTempFiles` must read the file found in `input.txt` and break it into smaller units, storing each in a temporary file, and returning a list of the temporary file names. The function `mergeTwoIntoOne` should take this list of temporary files, remove two (We know there are at least two because of the while loop), merge the two into a new temporary file, and place the new temporary back into the list. So we have reduced the problem of writing our original application to the simpler problem of writing these two functions. Let us take each one in turn.

The routine `makeTempFiles` is slightly tricky, because it is looping over two things at once. There is the loop reading lines from the input file, and there is the loop creating the temporary files and writing to each. The whole process ends when the readline from the original input file returns an empty string. A Boolean variable, named `done`, will help address this problem. This variable will be set to true once an end of file has been detected. With this insight, the structure of the function becomes more clear:

```

def makeTempFiles (fin)
    # read from fin and break into temp files
    tnames = [ ] # make empty list of temp files
    done = False
    while not done:
        tn = makeTempFileName()
        tnames.append(tn)
        fn = open(tn, "w")
        lines = [ ]
        I = 0
        while not done and I < 100:
            I = I + 1
            line = fin.readline()
            if line:
                lines.append(line)
            else:
                done = True
        lines.sort() # sort the last 100 lines read
        fn.writelines(lines)
        fn.close()
    return tnames

```

A list of file names is created. Initially this list is empty. We don't know how many temporary files will be produced, the loop uses a Boolean variable named `done` that will be set to true once an end of file is encountered. The routine `makeTempFileName` is used to make a new temporary file name. The temporary file is opened for writing and an inner loop reads no more than 100 lines. This loop can also terminate early if an end of input is encountered. Regardless how it terminates, the lines are sorted and written to the temporary.

We have used step-wise refinement again in this design. During the process of writing the function we have acted as if we already had written a function named `makeTempFileName`. Assuming that this function returns a new and unique temporary file name, we can examine the function `makeTempFiles` and convince ourselves that it is correct. So we have once more reduced the task to a simpler function.

The function `makeTempFileName` is one of those rare places where the *global* statement is useful. We want this function to create a stream of names such as `t1.txt`, `t2.txt`, `t3.txt` and so on. We can easily do this using a counter. But the counter itself must exist at the global level, not have scope local to the function. So we simply create the counter at the global level, and use the `global` statement to indicate that within the function the name refers to the global variable.<sup>2</sup>

```

topTemp = 0
def makeTempFileName():

```

---

<sup>2</sup> In reality we don't need to write the function `makeTempFileName`, since this service is provided by a function named `mktemp` in the `tempfile` module that is included as part of the standard library. (See Appendix A). However, we couldn't pass up the opportunity to illustrate a legitimate use of the `global` command.

```

global topTemp
topTemp = topTemp + 1
return "t" + str(topTemp) + ".txt"

```

Returning to the top level, we find we have not yet written the function `mergeTwoIntoOne`. This function takes the list of temporary file names. It removes two of the files, and creates a new temporary, and merges the two files into one. We first abstract away the merge itself, so that we can concentrate on the steps required to manage the files:

```

def mergeTwoIntoOne (tlist):
    ta = tlist.pop(0) # first file name
    tb = tlist.pop(0) #second file name
    tn = makeTempFileName() # make output file name
    tlist.append(tn)
    fa = open(ta)
    fb = open(tb)
    fn = open(tn, "w")
    mergeFiles(fa, fb, fn)
    fa.close()
    fb.close()
    os.remove(ta) # remove temp files
    os.remove(tb)
    fn.close()

```

Notice that we have once again made use of the function `makeTempFileName` that we wrote earlier. Assuming that `mergeFiles` works as advertised, it is easy to see that this function is performing the correct task.

The remaining step is to write the routine `mergeFiles`. Once more this is moderately tricky because we are looping over two things at once, namely reading lines from the first file, and from the second. One of these two will eventually reach an end of input, but there is no way to predict which one it will be. So the algorithm divides into two sections. In the first step lines are read from each file, and the smallest line written to the output. This continues until one of the two files reaches the end. In the second step any remaining lines from the remaining file are copied.

```

def mergeFiles (fa, fb, fn):
    # merge the contents of fa and fb into fn
    # step 1, merge as long as both files have lines
    linea = fa.readline()
    lineb = fb.readline()
    while linea and lineb:
        if linea < lineb:
            fn.write(linea)
            linea = fa.readline()
        else:
            fn.write(lineb)
            lineb = fb.readline()
    # step 2 - write remaining lines
    # only one of the following will do anything
    while linea:
        fn.write(linea)

```

```

        linea = fa.readline()
    while lineb:
        fn.write(lineb)
        lineb = fb.readline()

```

That's it. We have started from a high level description of the original problem, reduced each task to smaller problems, and then repeatedly addressed each of the smaller problem until everything is reduced to simple Python statements. All that is left is putting together the pieces, and verifying that it works as it should.

## Reading from a URL \*

The `urllib` module provides a simple way to read the contents of a file stored at a specific URL. It returns an object that uses the same interface as a file.

```

import urllib

remotefile = urllib.urlopen("http://www.python.org")
line = remotefile.readline()
while line:
    print line
    line = remotefile.readline()

```

The `urllib` effectively hides all the details of network access, allowing the programmer to just think about what they want to do with all that data.

## Exercises

1. Write a program that will prompt the user for a file name, then print all lines from the file that contain the Python comment character `#`.
2. Write a program that will prompt the user for a file name, read all the lines from the file into a list, sort the list, then print the lines in sorted order. (Alternatively, you can read the file name from the command line using `sys.argv`).
3. Discover what interrupt is produced by each of the following. Then, for each, write a small example program that illustrates catching the exception using a `try` statement and continuing with execution after the interrupt.
  - Division by zero
  - Opening a file that does not exist
  - Indexing a list with an illegal value
  - Using an improper key with a dictionary
  - Passing an improperly formatted expression to the function `expr()`
4. The `sys` module defines two string variables, `sys.ps1` and `sys.ps2`. In an interactive session try printing the values of these variables. Try changing these to `“+++”` and `“***”` in an interactive session. Can you determine what they are used for?

5. Another variable defined in `sys` is `sys.maxint`. What is the value of this variable? What is the type of the result if you add 1 to this value? What if you take the arithmetic inverse of this value?
6. Write a program that asks the user for a file name, then prints the number of characters, words and lines in the file. (Alternatively you can read the file names from the command line using `sys.argv`).
7. Write a program that catenates the contents of several files into one file. Prompt the user for the names of the source file, and the name of the destination file. (Alternatively you can read the file names from the command line using `sys.argv`).
8. Write a program that will prompt the user for a string and a file name, then prints all lines in the file that contain the string.
9. Most Unix systems will have a list of correctly spelled words stored in a file `/usr/dict/words`. You can use this file to make a simple spell checker. Read the file into a data structure such as a list. Then read the text file, breaking it apart into individual words, and checking each word against the dictionary. Print any word you find that is not found in the dictionary.

## Chapter 7 – Classes

In Chapter 3 you learned about *encapsulation* as a technique to be used to control complexity. In particular, that chapter introduced the concept of the *function* as one mechanism of encapsulation. Having written a function, the programmer can then think of the task the function is performing at a higher design level (e.g., this function returns a new temporary file name) rather than at the low level of implementation details (e.g., this function adds 1 to a global counter of file names, then concatenates the resulting value with a string to produce a new name). We termed this process *abstraction*, as it allows the user to abstract away the “how” details, and emphasize the “what”.

Many times a collection of several functions and/or data values are unified in the sense of being linked to a common purpose. A typical example is that they provide a *service* that can then be used by other functions. It is useful to be able to bundle these functions together so that they can be thought of as a unit. That is, we want a mechanism that will encapsulate several functions and/or data values, in much the same fashion that a function encapsulated a single action. This mechanism is the *class*.

A class definition begins with the keyword `class`. The keyword is followed by the class name, a parenthesized list of parent classes, and a colon. We will have more to say about parent classes later in this chapter, for the moment we will simply use the standard parent class named `object`. Following the class heading, indented by a tab stop, will be a series of function definitions. Functions defined within a class are known as *methods*. The following is an example:

```
class BankAccount(object):
    # define a class to simulate a bank account
    def __init__(self):
        # initialize the bank account with zero balance
        self.balance = 0
    def deposit(self, amount):
        # deposit the given amount into the account
        self.balance = self.balance + amount
    def withdraw(self, amount):
        # withdraw the given amount from the account
        self.balance = self.balance - amount
    def getBalance(self):
        # return the balance in the account
        return self.balance
```

It is important to note that the class definition by itself does not create any instances of the class. (Instances are also known as *objects*). There can be many different bank accounts, just like there are many different integers that are, nevertheless, all instances of the same type. The class description defines the behavior common to all instances of the class. To create an instance of the class, the user invokes the class name as if it were a function. There can be several instances of the same class.

```
>>> myAccount = BankAccount() # create an instance of BankAccount
>>> secondAccount = BankAccount() # create another
```



The functions defined within the class description are invoked using the dot notation you are already familiar with from modules and the built-in types.

```
>>> myAccount.deposit(200)
>>> secondAccount.deposit(125)
>>> myAccount.withdraw(75)
>>> secondAccount.withdraw(50)
>>> print myAccount.getBalance()
125
>>> print secondAccount.getBalance()
75
```

If you have been reading carefully, you should already be asking yourself questions regarding several curious features of the class definition. First, if the function *deposit* as written used two argument values, why when it was invoked was there only one argument passed? (Similarly for *withdraw* and *getBalance*). The answer to this question is that the *receiver* for the command, that is, the value to the left of the dot, is *implicitly* passed to the function as the first argument. It is this feature that allows one to distinguish the two (or more) different instances of the class. By convention this first argument is named *self*, but in fact any legal name can be used.

An important responsibility of the class value is to store any data fields that the object requires. In this case the one data field being maintained is the bank account balance. These data fields are written using the same dot notation as if they were fields in the class value. Just as you created a new name by assigning a value to it, here a new data field is created the first time it is assigned a value. It is important to note that these data fields must always be qualified by the instance of the class in which they are found.

Notice once again the elements of abstraction and information hiding in the class mechanism. The programmer bundles together a series of related functions. The user of the class (who need not be the same as the original programmer) can once more characterize instances of this class by the services they are providing, and need not have detailed knowledge of the ways in which these services are implemented.

## Constructors

A curious feature of the class definition is the function named `__init__`. The Python system generally uses two underscores before and after a name to designate functions or data values that are used implicitly, behind the scenes. You might have encountered a few of these, perhaps by accident, in your explorations of the Python system. The `init` function is termed a *constructor*. It is used to initialize a newly created instance of the class. You never directly invoke the constructor. Instead, the constructor is called implicitly as part of the process of creating a new object.

In addition to the required class argument (that is, *self*), constructors can take other arguments. The value for these additional arguments must then be provided when the instance of the class is created. We might have wanted, for example, to allow an initial

balance to be set when the object is first created. This would have been written as follows:

```
class BankAccount(object):
    # create a class to simulate a bank account
    def __init__(self, initBalance):
        # create new account with given initial balance
        self.balance = initBalance
    ...
```

The values for these additional arguments would be provided as part of the expression that created the new value:

```
>>> newAccount = BankAccount(500) # create bank account with $500
```

By the way, classes and objects maintain several internal data fields. Since these are normally not expected to be used by the programmer, they follow the double-underscore convention. A class, for example, maintains its name as a string

```
>>> print BankAccount.__name__
BankAccount
```

Every instance of a class maintains a reference to the class that created it:

```
>>> print newAccount.__class__
__main__.BankAccount
```

Another internal value used by classes is the instance dictionary. This is stored in a field named `__dict__`. You can see this value by printing the field:

```
>>> print newAccount.__dict__
{'balance': 500}
```

Internally, a statement such as

```
self.balance = self.balance + amount
```

is translated into

```
self.__dict__['balance'] = self.__dict__['balance'] + amount
```

It is even possible to make changes to the data fields by manipulating this field using dictionary commands, although this is not encouraged. (See next section).

## Respect Class Boundaries

It is legal to access the data fields defined within an object directly, but is generally considered poor form. For example, rather than using the method `getBalance()` you could access the data field `balance`:

```
>>> # this is legal, but not encouraged
>>> print myAccount.balance
200
```

If accessing a data field is considered poor form, it is even worse to change the value of a data field from outside the object:

```
>>> # this is also legal, but really really not encouraged
>>> myAccount.balance = 500
>>> print myAccount.getBalance()
500
```

Readers with a background in Java or C++ will remember that those languages prevent this type of behavior using the visibility modifiers `private`, `protected` and `public`. Python does not include this feature. In essence, everything in python is `public`. But exploiting this ability by, for example, modifying the internal data values of an object from outside the class, is a guaranteed way to make your programs difficult to read, understand and maintain. Always respect class boundaries, and encapsulate all modification of class values within those boundaries. (But also see the section on Dynamic Records later in this chapter for an exception to this rule).

## Calling Methods from inside other Methods

It is possible for one method to invoke another in the same class. For example, suppose we wanted to add a *transfer* method. A transfer takes as arguments the amount to be moved, and a second bank account into which the money should be placed. It then does a combination of withdraw and deposit. The transfer could be written as follows:

```
class BankAccount(object):
    ...
    def transfer (self, amount, toAccount):
        # transfer the amount from one account to another
        self.withdraw(amount)
        toAccount.deposit(amount)
```

A transfer is invoked as follows:

```
>>> myAccount = BankAccount(500)
>>> newAccount = BankAccount(100)
>>> myAccount.transfer(200, newAccount)
>>> print myAccount.getBalance()
200
>>> print newAccount.getBalance()
300
```

Look carefully at the definition of the function `transfer`. Notice that to invoke the method `withdraw` you must explicitly name the object to which it refers (namely, our `self`), just as the `deposit` method names the account that it is changing. Again, users of languages such

as Java or C++ are prone to forget this, as the value `self` (called **this** in those languages) can be omitted in this situation.

## Exceptions within Methods

As you learned in earlier chapters, good defensive programming requires you to verify that requests for action make sense before you attempt them. In this case, it would be better if our banking system checked that the balance was sufficient before performing a withdrawal. If there are insufficient funds, it should raise an exception:

```
class BankAccount(object):

    ...
    def withdraw (self, amount):
        if self.balance < amount:
            raise ValueError, "insufficient funds"
        self.balance = self.balance - amount
```

Normally exceptions cause immediate termination and the display of an appropriate message.

```
>>> ba.withdraw(600)
Traceback (most recent call last):
  File "Chapter3.code", line 45, in ?
    ba.withdraw(600)
  File "Chapter3.code", line 30, in withdraw
    raise ValueError, "insufficient funds"
ValueError: insufficient funds
```

However, as you learned in earlier chapters, the programmer can catch exceptions using a mechanism termed a *try statement*. If you place a call on a piece of code that might throw an exception within a try statement, the exception is caught by the try statement and a recovery is executed. Any statements within the try statement after the point the exception is raised are ignored.

```
>>> try:
    ba.withdraw(600)
    # notice the following will not be executed
    print "wow, free money!"
except ValueError, e:
    print "no such luck"
    print "error message is ", e

no such luck
error message is insufficient funds
```

## Objects are References

Like lists, objects are internally stored as references. This is important for both assignment and parameter passing. Remember that when an assignment statement assigns an object to a new name, the new name and the old name reference the same value.

```
>>> bobsAccount = new BankAccount()
>>> bobsAccount.deposit(300)
>>> alicesAccount = bobsAccount
>>> alicesAccount.withdraw(250)
>>> print bobsAccount.getBalance()
50
```

The same result can occur when an object is passed as argument to a function. Consider the following function definition:

```
def winLottery (winner):
    winner.deposit(1000000)

>>> bobsAccount = BankAccount(50)
>>> winLottery(bobsAccount)
>>> print bobsAccount.getBalance()
1000050
```

When you have a program that produces strange results and objects look like they are inexplicably changing values, examine carefully all the assignment statements for the object and all the places that the value has been passed as an argument. There may be an alias being created for the object under a different name, and changes to the alias are being seen as changes to the original object.

## Printing

What happens if you try printing a value of type `BankAccount` using a print statement?

```
>>> print bobsAccount
<__main__.BankAccount object at 0xd6db0>
```

As the programmer, you can control what information gets printed for a class. Try defining a method named `__str__` (`self`). Remember, methods that begin with two underscores represent functions that are used internally, and are not expected to be invoked directly by the user. In this case, the `__str__` method is used to convert a value from type object to a string. You can produce whatever useful information you want with this string.

```
class BankAccount(object):
    ...
    def __str__(self):
        return 'Bank Account Object, balance = ' + self.balance
```

Now if you print the value of a bank account in a print statement, you will see a more informative message.

```
>>> print bobsAccount
Bank Account Object, balance = 1000050
```

## Inheritance

*Inheritance* is used to build classes that are more specialized variations on an abstract concept. Imagine, for example, that you now need a representation for checking accounts. In addition to the behavior of standard bank accounts, a checking account has a method for recording checks. Checks have a number and person to whom they are written as well as an amount. The information on checks that have been received is maintained in a dictionary. Another method allows you to query the information recorded for a particular check number.

```
class CheckingAccount (BankAccount):
    def __init__ (self, initBal):
        BankAccount.__init__(self, initBal)
        self.checkRecord = { }
    def processCheck (self, number, toWho, amount):
        self.withdraw(amount)
        self.checkRecord[number] = (toWho, amount)
    def checkInfo (self, number):
        if self.checkRecord.has_key(number):
            return self.checkRecord [ number ]
        else:
            return 'no such check'
```

The fact that `BankAccount` is listed in parenthesis following the class name is the indication that inheritance is being used. This signals that a checking account is a more specialized type of bank account. We often call the class `BankAccount` the *parent class*, and the new class `CheckingAccount` the *child class*. Inheritance means that the new class has access to all the functionality of the bank account class, as well as all the data fields. Note how the initialization method in the new class must explicitly invoke the initialization method in the parent class. When a class name is used to the left of the dot the value `self` must be passed as an explicit argument, as shown here. When the value `self` is used to the left of the dot, it is omitted from the argument list.

The new class can define new data fields, as well as new methods. Here we have added a data field that will hold a dictionary for recording the information on checks that have been processed. When a check is received, the information is stored in this dictionary. In addition, the amount written on the check is deducted from the account. Once more, notice the requirement that when invoking a method in the parent class the receiver `self` must be explicitly written.

```
>>> # create a checking account with an initial balance of $300
>>> ca = CheckingAccount(300)
>>> ca.processCheck(100, "Gas Company", 72.50)
>>> ca.processCheck(101, "Electric Company", 53.12)
>>> print ca.checkInfo(100)
('Gas Company', 72.50)
```

Because the child class inherits methods from the parent class, you can invoke any of those functions as well:

```
>>> ca.deposit(50)
>>> print ca.getBalance()
224.38
```

Notice that the checking account performs the withdrawal of funds from the account before recording the check. If the withdrawal throws an exception the control flows immediately to a surrounding try block. This means that the recording would *not* be performed.

```
>>> # following will throw exception
>>> ca.processCheck(102, "Cable Company", 800.12)
>>> print ca.getBalance()
224.38
>>> print ca.checkInfo(102)
no such check
```

When you develop code that uses exceptions you should be aware of what statements could potentially cause an exception to occur, and think about what you want to happen in that situation. For example, suppose you wanted to record checks even if there were insufficient funds to honor them. One possibility would be to simply place the code to update the dictionary before the call on `self.withdraw()`. Another possibility would be to catch the exception within the class `CheckingAccount`, handle the error (perhaps including other actions), and then if you want rethrow the exception so that it can be handled by any further try statements in the code that is using the check account.

```
class CheckingAccount (BankAccount):
    ...
    def processCheck (self, number, toWho, amount):
        try:
            self.withDraw(amount)
        except ValueError, e:
            print "check returned for insufficient funds"
            self.checkRecord[number] = (toWho, amount)
            raise ValueError, "insufficient funds " + amount
```

## The is-a Test

Inheritance implies that one class is a more specialized form of another. This is often described as the *is-a* relationship, after a simple test you can use to determine if inheritance is appropriate. To apply the is-a test, form an English sentence that links the two concepts, such as “A Checking Account is a Banking Account”. If the sentence “sounds right” to your ear, then inheritance is appropriate.

The is-a test relation can be compared to the has-a relation. For example, a bank account has a balance. Has-a implies containment; that is, the first holds a data field of the second type. (A bank account holds a data field that maintains a balance). Both types of relation are important, and both use the services of an existing idea to build a new abstraction.

Because a class that uses inheritance automatically includes all the behavior and data fields defined in the parent class, and instance of a child class can be used where you might expect to find an instance of the parent class. This is termed *polymorphism*.

```
>>> # ba should be any type of BankAccount
>>> ba = CheckingAccount(100) # a checking account is-a BankAccount
>>> ba.deposit(50)
>>> ba.withdraw(40)
>>> print ba.getBalance()
110
```

## Inheritance and Software Reuse

When inheritance is used to construct a new class the code that is inherited from the parent class need not be rewritten. Often this can result in a significant savings in development time. This benefit is particularly useful when the same class is used as a parent class to multiple child classes. This savings in code development is known as *software reuse*.

The benefits of software reuse become even more pronounced when you can make use of a parent class developed by another Python programmer; perhaps a class distributed as part of an existing library. When this happens you only need to describe what is new or different about the new class. Any methods or data values shared with the more general class are obtained for free as a benefit of inheritance.

## Overriding

It is sometimes necessary for a child class to modify or replace the behavior inherited from the parent class. This is termed *overriding*. To override a method the child class simply redefines the function using the same name and arguments. If the overriding function needs to invoke the original function in the parent class the class name must be explicitly provided, and the receiver moved to the first argument location. To illustrate, suppose the designer of the class `CheckingAccount` wants to print a message every time a withdrawal is made. This could be written as follows:

```
class CheckingAccount (BankAccount):
    ...
    def withdraw (self, amount):
        print 'withdrawing ', amount
        BankAccount.withdraw(self, amount)
```

## Classes, Types and Tests

Each class definition creates a new type. This can be seen using the function `type()`:

```
>>> print type(myAccount)
<type 'instance'>
```



```
>>> print type(BankAccount)
<type 'classobj'>
```

To test for membership in a class use the built-in function `isinstance(obj, cname)`. This function returns `True` if the object `obj` belongs to the class `cname` or any class derived from `cname`:

```
>>> print isinstance(myAccount, CheckingAccount)
True
>>> print isinstance(myAccount, BankAccount)
True
>>> print isinstance(secondAccount, CheckingAccount)
False
```

Similarly, the built-in function `issubclass(A, B)` returns `True` if the class `A` is a subclass of `B`:

```
>>> print issubclass(CheckingAccount, BankAccount)
True
```

By using various symbolic values found in the `types` module, the function `isinstance` can also be used to perform type checking for any of the built-in types. For example

```
>>> import types
>>> isinstance(3, types.IntType)
True
>>> isinstance(3, types.FloatType)
False
```

## Class Variables <sup>\*1</sup>

It is possible for a class definition to include assignment statements made at the same level as method definitions.

```
class BankAccount:
    accountType = "bank account"
    def __init__(self, initialBalance):
        ...
```

Such values are known as class variables. They can be printed using the same dot notation used to invoke methods:

```
>>> print newAccount.accountType
bank account
```

---

<sup>1</sup> Sections marked with an asterisk describe advanced or optional material, and can (perhaps should) be omitted on first reading.

However, class variables are *shared* among all instances of the class. That is, there is only one value stored for this variable, and the value is accessible using any instance of the class.

## Multiple Inheritance \*

It is possible for a new class definition to specify inheritance from more than one parent class.

```
class A (object):
    def doA (self):
        print "I'm an a"

class B (object):
    def doB (self):
        print "I'm a b"

class C (A, B):
    def doC (self):
        print "I'm a c"
```

Instances of the new class can use methods from either parent:

```
>>> v = C()
>>> v.doC
I'm a C
>>> v.doA()
I'm an A
>>> v.doB()
I'm a B
```

This is termed *multiple inheritance*. While the idea seems appealing, there are several subtle issues involved in the use of this technique. For example, what happens if the same method is inherited from both parents? In general, the use of multiple inheritance should be avoided whenever possible.

## Classes as Dynamic Records \*

In an earlier section we suggested as a general principle that class data fields should never be used outside the class definition. However, an idiom that is common in the Python community directly violates this principle. Consider the following simple class definition:

```
class EmTee (object):
    pass
```

The class definition stores no variables, and has a null class definition, which is only required because Python does not allow you to create totally empty class definitions. As you might expect, you can create an instance of this class.

```
>>> myData = EmTee()
```

What you might find surprising is that you can then assign new data fields to this object, as follows:

```
>>> myData.name = "Fred Smith"
>>> myData.age = 42
>>> print myData.name
Fred Smith
```

Python programmers often use this feature to create “one-off” records; that is, data structures that have only a single instance. This allows a number of values to be collected under one name, for example to make them easy to pass to a function.

## Exercises

1. Create a class `Rectangle`. The constructor for this class should take two numeric arguments, which are the width and height. Add methods to compute the area and perimeter of the rectangle, as well as methods that simply return the height and width. Add a method `isSquare` that returns a Boolean value if the rectangle is a square.
2. Define a class `Fraction` that represents a fractional value. The constructor for this class should take two integer values, which represent the numerator and the denominator for this class. Add methods to add, subtract, multiply, and divide two fractional values. What happens if you try to print a fractional value? Add a `__str__` method that converts a fractional value into a string.
3. One of the oldest known functions is Euclid’s GCD function. This can be used to determine the Greatest Common Divisor of two positive integer values. The GCD function can be written as follows:

```
def gcd (n, m): # assume n, m > 0
    while n != m:
        if n > m: n = n - m
        else: m = m - n
    return n
```

Try the function with several different values to convince yourself it is correct. Using the `gcd` function, rewrite the constructor for the fractional class to ensure each fraction is placed in the lowest common denominator form. To do this, divide both the numerator and the denominator have no common divisor. Also make sure that the denominator is not a negative number. If the argument to the constructor has a negative denominator, invert the sign on both values. With these changes a fraction such as `Fraction(2, -4)` would end up being the same as `Fraction(-1, 2)`.

4. What happens if you compare two fractional values? To fix this, you can implement the single method `__cmp__` (`self, arg`). All the relational operators use this one function. This function should take two fractional values, and return a result that is negative if the first is less than the second, zero if they are equal, and positive if the first is larger than the second. After implementing this function, verify that each of the six relational operators now works as expected.
5. What happens if you use a fraction as a test in an if statement? Other numeric values are true if the value is nonzero, and false otherwise. To check this condition, the Python interpreter will try to execute a method named `__nonzero__(self)`. Add this method to the class `Fraction` and verify that a fractional value can now be used in an if statement.
6. Suppose that Python did not have the complex data type. Write a class `Complex` for performing arithmetic with complex numbers. The constructor for this class should take two floating point values. Add methods for adding, subtracting, and multiplying two complex numbers. Add a `__str__` method so that a complex number prints as the real and imaginary parts separated by a plus sign, with the constant `I` after the imaginary part.
7. What happens if you define a method and forget to use the first argument to hold the class instance? The following is an example. What message is produced if you create an instance of `TestError` (call it `a`) and invoke the method `a.value()`? What happens if you type the expression `TestError.value()`?

```
class TestError (object):
    def value(): # error, no self value
        return 4
```

8. Can you create a program that will illustrate the fact that class variables are shared among all instances of a class?
9. Actually class definitions, just like function definitions, are really a special type of assignment. What do you get if you print a class name? What happens if you reassign a class name (for example, use a class name in an assignment statement). What happens if you assign a class name to another variable, and then use that variable as if it were the original class?
10. Another internal method that is occasionally useful to override is `__nonzero__`. This method is invoked implicitly when an object is used in a conditional, such as an if or while statement. To see this, try creating a class such as the following:

```
class Box (object):
    def __init__ (self, ival):
        self.value = ival
```

What happens if you use an instance of the class `Box` in an if statement?

```
>>> aBox = Box(3)
>>> if aBox:
```

Now try defining the method `__nonzero__(self)` so that it returns true if the value held by the box is even, and False otherwise. Now what happens when you use the value in an if statement?

11. The definition of `__nonzero__` in the previous question can have a practical use. Many programmers familiar with Java or C miss the fact that assignment in those languages is an operator, and can therefore be used in places such as a loop:

```
while (c = gets()) // will loop as long as c
    // returns a true, nonzero value
...
```

This behavior can be simulated by a variation on our Box class. Define methods to get and set the value of the box. Then define the `__nonzero__` method to return the current value. Show how these can then be used to perform an assignment as part of a larger Boolean expression:

```
data = Box()
while data.set(someexpression):
    print data.get()
```

12. The method `__cmp__(self, other)` is implicitly invoked by the relational operators such as `<`, `<=`, `>`, `>=`, `==`, `!=` and `<>`. Create the class Box as described in the previous question. What error message is produced when you compare two instances of this class? Now define the method `__cmp__` so that it returns -1 if the value held in the box is less than the value held in the box referenced by the parameter `other`, is 0 if they are equal, and 1 if the value is greater than the value of `other`. Test each of the relational operators to see that they now work.
13. The method `__str__(self)` is used to create a string representation of an object. What happens if you call `str(aBox)` on an instance of Box (described in the previous question). Override the method `__str__` to produce the string “the value in the box is x”, where x is the string representation of the value. Now what happens when you invoke the function `str`?
14. Each of the mathematical operations has a corresponding internal method name. For example, the `+` operation is internally performed by executing the method named `__add__(self, other)`. Try adding two instances of class Box. What message is produced? Then override the method `__add__` so that it adds the contents of the current box and the box described by `other`, returning a new box with the sum. Now what happens when two boxes are added together? Other methods can be used to provide indexing or slicing operations.
15. When using multiple inheritance, what happens if the same method is inherited from both parents? Which one is selected when the function is invoked using an

instance of the child? If the child overrides the method, how can it invoke the method in the parent class?

16. A particularly troublesome form of multiple inheritance is called *diamond inheritance*. Here there is one parent class that is inherited by two child classes. Each of the child classes is then used as a parent to a new class.

```
class A (object):
    def __init__ (self):
        self.value = 0
    def getValue (self):
        return self.value

class B (A):
    ...
class C (A):
    ...
class D(B, C):
    ...
```

Notice that class A is a “grandparent” to class D in two ways, both through class B and class C. A curious question is then how many copies of the data fields defined in class A does an instance of class D possess? Write a small simple program to answer this question. That is, a program that will produce one answer if an instance of D has only one data field, and a different answer if an instance of D has two data fields.

## Chapter 8: Functional Programming

Programming a computer is a complicated task, and like most complicated tasks there are many different ways to think about the process. The term *language paradigm* is sometimes used to describe the mental model that the programmer envisions as he or she is creating a program. The model we have used to this point is termed the *imperative paradigm*. This model views the computer as a combination of processor and memory. Instructions (such as assignment statements) have the effect of making changes to memory. The task of programming consists of placing statements in their proper sequence, so that by a large number of small transformations to memory the desired result is eventually produced.

You might be surprised to learn that this is not the only possible way to think about the process of computation. In this chapter and the following we will describe two alternative models. Each differs from the imperative paradigm not in the way the computer operates, but in the way that the programmer *thinks* about the task of programming.

### The Functional Programming Paradigm

The term *functional programming* does not simply imply programming with functions, but is used to describe an alternative to the imperative programming paradigm. As the name suggests, the creation of functions is an important part of functional programming. But simply defining a few functions does not mean that you are programming in a functional style. There were many functions defined in earlier chapters, and yet we did not call those functional programs.

The key characteristic of a program developed in the functional programming style is that it creates new values by a process of *transformation*. Generally values are represented as lists, or dictionaries. This simple description requires further explanation. The traditional imperative style of programming produces complex values by modification; by making a large number of small changes to an existing data structure. For example, creating a dictionary of values, then systematically setting each value independently of the others. Since small changes can often be accompanied by small errors, and small errors may only produce a minimal effect, debugging imperative programs can be frustratingly difficult.

By emphasizing *transformation*, rather than *modification*, functional programs work on a larger scale. Transformations are often more uniform, and much simpler to write and debug. Errors, when they do occur, tend to be larger and thus easier to find and eliminate. The difference between a functional and an imperative style is best illustrated by examples, as we will shortly present.

### Mapping, Filtering and Reduction

The process of transformation can be subdivided into several common forms. The three most common varieties of transformation are mapping, filtering, and reduction.

A *mapping* is a one to one transformation. Each element in the source is converted into a new value. The new values are gathered into a collection, leaving the original collection unchanged. For example, suppose that you begin with the list [1, 2, 3, 4, 5] and map using the transformation  $x*2+1$ . The result would be the list [3, 5, 7, 9, 11].

A *filtering* is the process of testing each value in a list with a function, and retaining only those for which the function is true. If you begin with the list [1, 2, 3, 4, 5] and filter with a function that returns true on the odd values, the result would be the list [1, 3, 5].

A *reduction* is the process of applying a binary function to each member of a list in a cumulative fashion. If you begin with the list [1, 2, 3, 4, 5] and reduce using the addition operation, the result would be  $((((1 + 2) + 3) + 4) + 5)$ , or 15.

Each of these three basic tasks is provided by a function in the Python library. Notice that the definition of each of these functions talk about invoking another function as part of the process. The function used in this case is passed as an argument. A function that uses another function that is passed as an argument is sometimes referred to as a *higher-order* function.

## Lambda Functions

When a function is required as an argument, one possibility is to simply pass the name of a previously-defined function:

```
def even(x):
    return x % 2 == 0

>>> a = [1, 2, 3, 4, 5]
>>> print filter(even, a)
[2, 4]
```

However, because the functions that are passed as argument to maps, reductions and filters are often simple, and are usually used nowhere else, it is inconvenient to require the programmer to define them using the standard `def` keyword. An alternative is a mechanism to define a nameless function as an expression. This type of expression is termed a *lambda*. The following example illustrates the syntax:

```
lambda x, y : x + y
```

The body of the lambda function must be a simple expression. Because it must be written on one line, it cannot contain any complex logic, such as conditional statements or loops. Generally a lambda is passed as argument to either `map`, `filter` or `reduce`. The following illustrates the application of each of these functions:

```
>>> a = [1, 2, 3, 4, 5]
>>> print map(lambda x : x * 2 + 1, a)
[3, 5, 7, 9, 11]
>>> print filter(lambda x: x % 2 == 0, a)
[2, 4]
```



```
>>> print reduce(lambda x, y: x + y, a)
15
```

Notice that the original list, held in the variable named `a`, remains unchanged. The functions `map`, `filter` and `reduce` produce new lists that are transformations of the argument.

The function `filter` requires an argument that is itself a function that takes only one argument, and returns a Boolean value. A one-argument function that returns a Boolean result is termed a *predicate*.

## List Comprehensions

An even simpler form of functional programming is provided by a *list comprehension*. Instead of defining a list by a sequence of elements, lists can be characterized by a process. This process is described by a series of keywords:

```
[ expr for var in list if expr ]
```

Here `var` is a variable name, and `list` is an existing sequence. The optional `if` part requires an expression that evaluates true or false. Only those elements that evaluate to be true are examined. To construct the new sequence each element in the original list is examined. If it passes the `if` expression test the initial expression is evaluated, and the resulting value added to the new list. In this fashion the list comprehension combines aspects of both a filter and a map. The following example illustrates the use of a list:

```
>>> a = [1, 2, 3, 4, 5]
>>> print [x*2 for x in a if x < 4]
[2, 4, 6]
```

List comprehensions are often simpler to read than the equivalent expression formed using `filter` and `map`, in part because they do not require an explicit lambda function. However, both forms are useful, and a Python programmer should be familiar with each.

List comprehensions are often used as the body of a function. The function definition provides a convenient syntax and a way to provide names to arguments, and the list comprehension is an easy to understand and debug way to write the body of the function.

```
>>> def listOfSquares(a):
    return [x*x for x in a]
>>> listOfSquares([1, 2, 3])
[1, 4, 9]
```

The range of the list comprehension need not be a simple identifier. For example, if `a` is a list of numbers, the following will print every other elements of the list.

```
>>> [a[i] for i in range(0,len(a)) if i%2 == 0]
[1, 3, 5]
```

Operation on dictionaries are often performed by selecting values from the range of keys, then returning the items with the selected key:

```
>>> d = {1:'fred', 7:'sam', 8:'alice', 22:'helen'}
>>> [d[i] for i in d.keys() if i%2 == 0]
['alice', 'helen']
```

## Example: Computing an Intersection

We can illustrate the difference between an imperative approach and a functional approach using a simple example. Suppose you have two lists (call them a and b), and you need to construct a third list containing their intersection. That is, the third list should have only those elements that are found in both lists. We will assume that both lists represent sets in which no value is repeated more than once.

An imperative approach would construct a new empty list, and in a doubly nested loop test each element in the first against each element in the second. This might be written as follows:

```
intersect = []    # build an empty set
for x in a:
    for y in b:
        if x == y:
            intersect.append(y)
# intersect now represents the final set
print "intersection is ", intersect
```

A slightly better, but still imperative, approach would simply loop over the first set, and test each element in the second. The single loop will be much faster than the double loop of the first example.

```
intersect = []    # build an empty set
for x in a:
    if x in b:
        intersect.append(x)
print "intersection is ", intersect
```

If you were thinking in a functional programming fashion, you would notice that the intersection is a subset of the elements in either set. This naturally suggests the result can be formed using filter. All that is necessary is an argument that will determine whether or not each element should be retained. Using lambda this can be written as follows:

```
intersect = filter(lambda x: x in b, a)
```

In one simple expression this replaces a loop and a conditional test that previously required several lines. Because it is simpler, there are fewer opportunities to make a mistake. It is relatively easy to look at the expression, understand what it is doing, and verify that it is correct.

The list comprehension form is even shorter. There is no need for the lambda expression, as the if keyword is performing a similar task:

```
intersect = [ x for x in a if x in b ]
```

Or as a function:

```
def intersect(a, b):  
    return [x for x in a if x in b]
```

Notice the features that make this solution characteristic of functional programming. Most importantly, rather than making a succession of small changes to a value, the function is building the result as a transformation of one or more value to produce a new value.

## Example: Prime Number Sieve

Because lists are recursive, functional programs that manipulate lists are often written in a recursive fashion. We can illustrate this by considering the problem of finding prime numbers using the sieve of Eratosthenes. This technique, first described by the Greek mathematician Eratosthenes in the 3rd century BC, works as follows. Start with a list of the numbers from 2 to some limit, written in order. Select the first element, which will be a prime number. Then strike out (that is, remove) all the values that are a multiple of the number. Repeat until the list is empty.

We describe the thought process you might follow in creating a program written in the functional programming style to perform this task. It is easy enough to create a list of values from two onwards using the range function:

```
>>> a = range(2, 16)      # produce a list from 2 to 15  
>>> print a  
[2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]
```

Accessing the first element is easy, it is simply `a[0]`. The remainder of the list with the first element removed is also easy, it is `a[1:]`. What about the task of striking out those elements that are multiples of the first element? A test to see if one value is divisible by another can be formed using the remainder, or mod operator, `%`. If the remainder is zero then the value is divisible. You can verify this with a few examples:

```
>>> print 5 % 2 == 0  
False  
>>> print 6 % 2 == 0  
True
```

Using this idea, a filter to eliminate all multiples of the first element can be written as follows:

```
>>> print filter(lambda x: x % a[0] != 0, a[1:])  
[3, 5, 7, 9, 11, 13]
```

Alternatively, you could use list comprehensions:

```
>>> print [ x for x in a[1:] if x % a[0] != 0 ]
[3, 5, 7, 9, 11, 13]
```

Having determined how to filter out multiples of a given value, the definition of the sieve function is then a straightforward recursive function:

```
def sieve(a):
    if a:          # that is, if a is non-empty
        return a[0:1]+sieve(filter(lambda x: x % a[0] != 0, a[1:]))
    else:
        return [ ]
```

Remember that a list is considered to be true inside an if statement if it is non-empty. Testing the value `a` is shorthand for testing `len(a) != 0`. Notice how the body of the function closely parallels the definition. To form a sieve, you remove the first element, then strike out multiples of the element, and recursively invoke sieve on the remainder. The first element, the one you earlier removed, is known to be prime. So you add that value to the result of the recursive call on sieve. The expression `a[0:1]` returns a list containing the first element, as opposed to `a[0]`, which would return the first element itself. Keeping the first element in list form allows the use of the `+` operator to append the two lists. The alternative would have been to write `[a[0]]`, explicitly extracting the first element and then placing it into a list.

You can test the sieve function by passing it the list of integers from 2 onwards:

```
>>> sieve(range(2, 20))
[2, 3, 5, 7, 11, 13, 17, 19]
```

## Example: Insertion Sort

As we noted in the prime sieve, the design of a program in the functional style often proceeds by defining the characteristic of the desired solution, rather than the step-by-step process used to produce the solution. For this reason the paradigm is often called an example of *declarative programming*. This can be illustrated by an example. Suppose you wanted to program the process of performing an insertion sort. An insertion sort works by repeatedly inserting a new value into a sorted list. Therefore, a subtask of insertion sort is to perform a single insertion.

What are the characteristics of an insertion? If we have a sorted list, named `a`, and a new element `x`, an insertion can be defined as follows:

```
if a is empty, then [x] is an insertion
otherwise if x < a[0], then [x] + a is an insertion
otherwise append a[0] to the insertion(x, a[1:])
```

This yields the following recursive function:

```
def insertion (a, x):
    if not a:      # that is, if a is empty
        return [ x ]
    elif x < a[0]:
        return [ x ] + a
    else:
        return a[0:1] + insertion(a[1:], x)
```

Having defined an insertion, the process of insertion sort is simply a matter of performing an insertion on each element in turn. One way to do this would be with another recursive function:

```
def insertionSort (a):
    if a:
        return insertion(insertionSort(a[1:]), a[0])
    else:
        return [ ]
```

This function can be read in the following fashion. An insertion sort of an empty list is simply the empty list. Otherwise, an insertion sort is formed by inserting the first element (that is, `a[0]`) into the list yielded by performing an insertion sort on the remainder.

Repeatedly performing the same operation should make you think of the functions `apply` and `reduce`. Can either of those be used in this situation? The function `insertion` would at first not seem to be a candidate for reduction, since the arguments are two different types. However, an alternative form of `reduce` makes this possible. This form takes three arguments: the original list, the reduction function, and an identity element that will be used as the first element to start the process. Using an empty set as the identity, we can rewrite insertion sort as follows:

```
def insertionSort2(a):
    return reduce(insertion, a, [ ])
```

If you imagine the execution of this function on a small list you can see how the result is produced. Imagine starting with the list `[3, 2, 1]`. The result will be generated by the expression

```
insertion(1, insertion(2, insertion(3, [ ])))
```

The innermost expression will insert 3 into the empty list. The value 2 will then be inserted into the resulting list. Finally the value 1 will be inserted. The result will be a new list into which every element has been inserted.

## Example: QuickSort

The sorting algorithm quick sort provides another illustration of how a problem can be described as a transformation. Quick sort is a recursive algorithm that works by (a)

selecting some element, termed the pivot, (b) dividing the original list into three parts, namely those that are smaller than the pivot, those equal to the pivot, and those larger than the pivot, and (c) recursively sorting the first and third, appending the results to obtain the final solution.

Once you have described the quick sort algorithm in this fashion, the solution is a simple transliteration:

```
def quicksort(a):
    if a:
        # there are various ways of selecting the pivot
        # we simply choose the middle element
        pivot = a[len(a)/2]
        return (quicksort([x for x in a if x < pivot]) +
                [x for x in a if x == pivot] +
                quicksort([x for x in a if x > pivot]))
    else:
        return [ ]
```

We have illustrated higher order functions by passing lambda expressions to functions such as filter and map. The flip side is to write a function that accepts a function as argument. For example, you might want a sorting function that allows the user to provide the comparison test as an argument, rather than using the < operator. The quick sort algorithm rewritten to allow the comparison test to be passed as argument is as follows:

```
def quicksort(a, cmp):
    if a:
        pivot = a[len(a)/2]
        return (quicksort([x for x in a if cmp(x, pivot)], cmp) +
                [x for x in a if x == pivot] +
                quicksort([x for x in a if cmp(pivot, x)], cmp))
    else:
        return [ ]
```

This version of quicksort could be invoked as follows:

```
>>> a = [1, 6, 4, 2, 5, 3, 7]
>>> print quicksort(a, lambda x, y: x > y)    # sort backwards
[7, 6, 5, 4, 3, 2, 1]
```

## Simple Reductions

Many common tasks can be implemented as a form of reduction. The easiest form of reduction is the sum of the elements in a list.

```
>>> a = [1, 2, 3, 4, 5]
>>> print reduce(lambda x, y: x + y, a)
15
```

If you want to give this a simple name you can wrap the call on reduce inside a function definition:

```
def sum(a):  
    return reduce(lambda x, y: x + y, a)
```

To form the product of a list you need the three argument form of reduce. The third argument is an identity, the value used to begin the series of applications. For multiplication the identity is 1.

```
>>> print reduce(lambda x, y: x * y, a, 1)  
120
```

But there is much more that can be done with reduce. Consider computing the length of a list. Admittedly, you would probably never do it this way, since there is a built-in function named len for this purpose. But it's a good exercise in thinking about a problem as a reduction. What is the length of an empty list? Zero, which fortunately is the default value. For a function you need a lambda that takes two arguments, ignores the second, and simply adds 1 to the first.

```
>>> print reduce(lambda x, y: x + 1, a)  
5
```

How about computing the average of a list? Its simply a combination of a sum and dividing by the length:

```
def average(a):  
    return sum(a)/len(a)
```

Reductions need not be arithmetic. Imagine performing a reduction using the function that appends an element to the end of a list, using an empty list as the identity. The result is a copy of a list:

```
>>> print reduce(lambda x, y: x + [y], a, [ ])  
[1, 2, 3, 4, 5]
```

This might not seem particularly useful. But if we substitute another list for the empty list as the third argument, the result is a function that appends two lists:

```
def append(a, b):  
    return reduce(lambda x, y: x + [y], b, a)  
>>> print append([1, 2, 3], [5, 6, 7])  
[1, 2, 3, 5, 6, 7]
```

Perhaps more interesting is the effect if the function appends to the front rather than to the back. The result is a reverse of a list:

```
>>> print reduce(lambda x, y: [y] + x, a, [ ])  
[5, 4, 3, 2, 1]
```

This has just scratched the surface of the types of operations that can be performed using functional techniques. Once you start to think about how a problem can be addressed

using techniques such as mapping, filtering and reduction you will find many other applications.

## Computing Variance of a List

The computation of the variance of a list of numbers illustrates how a longer function can be computed in a series of steps that are each functional. A variance of a list is defined as the sum of squares of differences of each number from the mean (average). To compute the variance the average is first computed. As we noted earlier, this is simply the sum of the elements divided by the number of elements. Next, the difference of each element from the average is computed as a mapping. A second mapping computes the squares. Finally, to compute the variance the sum of the squares is computed, and divided by the length.

```
def variance(a):
    average = sum(a)/len(a)    # compute average
    difs = map(lambda x: x - average, a)
    sqs = map(lambda x: x * x, difs)
    return      sum(sqs)/len(a)
```

Notice how each step in the program is a transformation that acts on an entire collection as a whole, without the need to write a loop. By eliminating explicit loops the program is both shorter and easier to understand. This makes functions written in a functional style much easier to debug and correct.

## Combining Functional and Object-Oriented Programming

It is possible to write programs entirely in a functional fashion. However, it is more common to use functional programming features, and combine them with other techniques. An individual function might be written in a functional fashion, while the remainder of a program is imperative. The last chapter introduced the idea of a class, which is central to yet another paradigm, object-oriented programming. It is common for a class to include individual methods (functions) that are themselves written in a functional fashion. To become a skilled Python programmer you need to learn both the mechanics of all these techniques, as well as being able to identify those situations in which it is appropriate to use one approach or another.

## Iterating over Multiple Lists \*<sup>1</sup>

The function `map` can optionally take more than one list. The function in the first argument must itself take as many arguments as there are lists. The following, for example, will return the pairwise sum of two lists.

```
>>> print map(lambda x, y: x + y, [1, 2, 3], [9, 8, 7])
```

---

<sup>1</sup> Sections marked with an asterisk indicate optional or advanced material, and can be skipped on first reading.



```
[10, 10, 10]
```

If either list is shorter than the other the shorter list is padded with elements of value `None`.

List comprehensions can also in general have any number of **for** and **if** keywords. The effect is to loop over *all combinations* of the possible values. This can be illustrated by an expression that produces tuple pairs:

```
>>> print [(a, b) for a in [1, 2, 3] for b in [7, 8, 9]]
[(1, 7), (1, 8), (1, 9), (2, 7), (2, 8), (2, 9), (3, 7), (3, 8), (3, 9)]
```

If conditions can work with all variables that have been defined by a **for** clause. The following saves only those tuples where the sum of the two numbers is even:

```
>>> print [(a, b) for a in [1, 2, 3] for b in [7, 8, 9] if (a+b)%2==0]
[(1, 7), (1, 9), (2, 8), (3, 7), (3, 9)]
```

The production of all pairs of values is sometimes termed an *inner product*. Occasionally it is necessary to run down two equal-length lists *in parallel*. This is sometimes termed a *dot product*. A common Python idiom to perform this task is the built-in function named `zip`. The following illustrates the effect of `zip`:

```
>>> zip([1, 2, 3], [7, 8, 9])
[(1, 7), (2, 8), (3, 9)]
```

Tuple assignment can be used inside a list comprehension to break apart the elements formed by a `zip`:

```
>>> print [a+b for (a,b) in zip([1, 2, 3],[4, 5, 6])]
[5, 7, 9]
```

## Exercises

1. Write a lambda function for each of the following:
  - a. Take one argument and return true if it is nonzero
  - b. Take one argument and return true if it is odd
  - c. Take two arguments, and return their sum
  - d. Take two arguments, and return true if their sum is odd
  - e. Take three arguments, and return true if the produce of the first two is less than or equal to the third
2. Let `a` be the list of values produced by `range(1, 11)`. Using the function `map` and a lambda argument, write an expression that will produce each of the following
  - a. A list of squares of the values
  - b. A list of cubes of the values
  - c. A list where each element is larger by one than the corresponding element in the original list

3. Let `a` be the list of values produced by `range(1, 11)`. Using the function `filter` and a `lambda` argument, write an expression that will produce each of the following:
- A list of the even values in `a`
  - A list of the values in `a` divisible by 3

4. The expression `reduce(lambda x, y: x - y, range(1, 5))` produces the result `-8`. Explain the meaning of this value; that is, what computation it represents.

5. Explain the following execution of the function `filter`. Hint: remember how integer values are interpreted when a Boolean is required.

```
>>> filter(lambda x: x, [4, 0, 6, 3, 0, 2])
[4, 6, 3, 2]
```

6. What happens if you `reduce` over an empty list? What if you use the optional third argument form of `reduce`?
7. Using `reduce`, write a function named `ave(lst)` that will return the average of a list of numbers.
8. Let `a` be the list of integer values. Explain what the following expression is returning:

```
reduce(lambda x, y: x and y, filter(lambda x: x % 2 == 0, a))
```

What would the function be returning if the `lambda` used the `or` operator rather than the `and` operator?

9. Using what you learned from the previous question, write a function named `forAll` that takes two arguments. The first argument should be a list. The second argument should be a predicate, a one-argument function that returns a Boolean result. The function `forAll` should return `true` if the predicate returns `true` when applied to all elements of the list.

10. A `lambda` is simply a value. This means that `lambda` can be, for example, stored in a list. The following shows one such example. What will be the result for the expression `d[1](2)`?

```
d = [lambda x: x+1, lambda x: x*2, lambda x: x ** 3]
```

11. Let `a` be the list of values produced by `range(1,11)`. Write a list comprehension that will produce each of the following:
- The values in `a` that are less than or equal to 5
  - The squares of the values in `a`
  - The cubes of the values in `a` that are less than or equal to 5
  - The squares of those values in `a` that are even

12. Write three versions of a function that will take a list as argument, and return a list containing the cubes of the elements that are evenly divisible by 2. First write the function using standard loops and if statements. Then write the function using a combination of filter and map. Finally write the function using a list comprehension. Which form is shorter? Which do you think is easier to understand?
13. Using a combination of filter and the built-in function len, write a function that will take a list and a function as two arguments, and return a count of the number of elements of the list for which the function returns true.
14. In an earlier chapter you learned that functions defined using the def keyword create their own *scope*. This means that parameters as well as variables assigned within the function have local scope, and changes to these values do not alter the value of similarly named variable at the global level. Write an example function that will show that lambda functions also produce their own scope. Lambda cannot contain assignments, but the names of the parameters can be the same as values in the surrounding scope. Show that the use of a parameter does not alter a similarly named value in the surrounding scope.
15. Write a function that takes a list and a function as arguments, and using a list comprehension returns a list containing the *positions* of the elements in the list for which the function returns true.
16. Write a function named evenFilter that takes as argument a dictionary of elements indexed by integer keys. Using only a list comprehension, return the values of the elements associated with the keys that are evenly divisible by two:

```
>>> data = {1:"one", 2:"two", 5:"five", 6:"six"}
>>> print evenFilter(data)
["two", "six"]
```

17. A lambda function is just a value. If you want, you can assign this value to a variable:

```
f = lambda x : x * 2 + 1
```

You can then use this variable like a function:

```
>>> print f(3)
7
```

What are some of the ways that a function defined in this fashion is similar to a function defined using the def statement? What are some ways that they are different?

18. Define the difference of two lists as a list comprehension. The difference consists of the elements in the first list that are not part of the second.

19. Using the difference function you wrote in the previous question, define a function that returns the union of two sets that are represented by lists. A union contains all elements that are found in either list, but if the same element is found in both lists it is only included once.
20. Using the function ave for computing the average of a list that you wrote in an earlier question, write a function names topStudent that will take a dictionary indexed by name and holding a list of exam scores. The function should return the list of names for those students who have an average greater than 90%. The following shows an example of the input for this function:

```
{'sam': [.85, .90, .94], 'alice': [.74, .96, .34]}
```

21. The following four expressions represent a series of steps in the development of an expression to produce a well-known sequence. Examine the value of the last expression, and identify the sequence. Then explain what each of the three previous expressions are doing, that is, what values they are each producing.

```
range(2, 25)
[ range(2, i) for i in range(2, 25)]
[ [ x for x in range(2, i) if i % x == 0] for i in range(2, 25)]
[ i for i in range(2, 25) if len([x for x in range(2, i) if i%x==0])==0]
```

22. There are times when you want to include an if statement in a lambda. Of course, since the body of a lambda must be an expression, this is difficult. But not impossible. Recall that the logical operators and or return the first value that can be interpreted as a Boolean true. Can you can see this by executing the following expressions. Using this idea, explain how the following lambda very nearly produces the smaller of the two arguments. There is one case where it will not work. Can you figure out what this might be?

```
>>> (3 < 4) and 5
5
>>> (4 < 3) or 7
7
>>> f = lambda x, y: ((x < y) and x) or y
>>> f(5, 6)
5
>>> f(7, 9)
7
>>> f(0, 3)
3
```

By the way, the conventional workaround for this problem is to wrap part of the results in a list, and then access the first element of the list. The following shows this. Explain why this solves the problem for the special case identified earlier. Note, this is not considered to be a paragon of clarity in Python programming.

```
>>> f = lambda x, y: (((x < y) and [x]) or [y])[0]
>>> f(0, 4)
0
```

## Chapter 9: Object-Oriented Programming

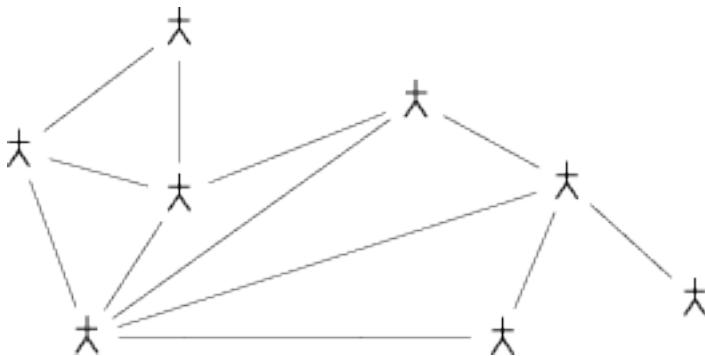
Chapter 8 introduced the notion of a programming *paradigm*. The term paradigm, you will recall, refers to the mental model, or metaphor, that is used to describe the task being performed by the programmer. The simplest paradigm is the imperative model. In imperative programming you view computation as a process of making small changes to memory, until by a long sequence of small changes the desired result is produced. The functional paradigm, described in Chapter 8, views the task of computation as a process of *transformation*. By performing a sequence of transformations on a value, the desired result is produced. This chapter we will introduce a third paradigm, the *object-oriented* model. In the object-oriented paradigm, a program is viewed as a collection of computing agents, each of which is providing a service that can be used by the others.

The functional programming model requires the ability to create functions, but the paradigm is much more than the simple use of this mechanism. In a similar fashion, the object-oriented paradigm is built on the mechanics of defining classes, creating instances of those classes, and the use of inheritance. These were all introduced in Chapter 7. However, the object-oriented *paradigm* refers to the model of computation built on top of these facilities, and not just the mechanics of defining classes.

### Community

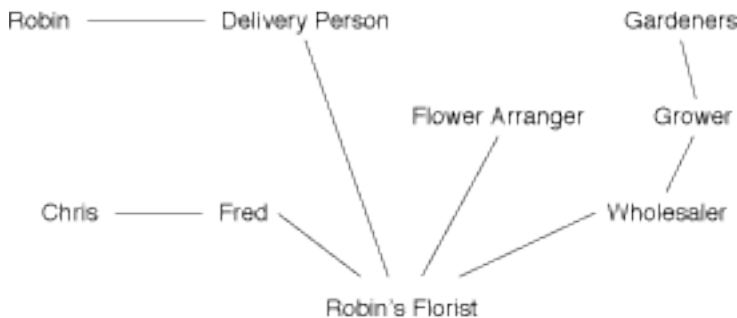
As we noted in Chapter 7, a *class* is an encapsulation mechanism, a way to bundle together a number of data values and functions. Properly designed, these items should be united in some purpose. That is, the class, by means of the functions it defines, is providing a *service* that can be used by other objects.

A program written in the object-oriented style can be viewed as a *community* of interacting agents. Each member of the community has a part to play, a service that they provide to other members of the community. Objects interact with each other by invoking functions defined within the class. In the object-oriented literature this is termed *message passing*.



The idea of message passing can be compared to the way problems are solved in the real world. Consider the task of sending flowers to a friend who lives in another city. To do

this you interact with a local florist. In OO parlance, you pass a message to the florist. The florist is an agent providing a service that you are using. This florist will, in turn, pass messages to a florist in the city where your friend lives. That florist will have acquired flowers for the arrangement by dealing with a wholesaler, who will interact with growers, delivery persons, and so on. So an entire community is working cooperatively to solve your problem, and that the objects in this community interact by passing messages to each other.



Object-oriented programming has become the dominant paradigm in recent years largely because the metaphor of messages being passed to service providers is similar to problem solving techniques that programmers are familiar with from everyday life. Because of this, intuition and skills from life experiences can readily be applied to object-oriented programs.

In programming languages objects embody this idea of a service provider. A data structure is a simple example of a service being provided by an instance of a class. An object can, for example, provide the services of a stack. To do so the object provides the user with methods to push an item on to the top of the stack, access the topmost element in the stack, and remove an item from the stack. But you might, in some project, require the use of two or more stacks. To address this issue, object-oriented languages divide the task of object creation into two parts, the *class* and the *instance*.

A class is like a cookie cutter, or a template. It is a design specification, a repository for behavior. The class itself does not provide behavior beyond object creation. Using the class the programmer can create one or more instances of the class, termed *objects*. An object is a realization of the class. It is a working entity. All instances of the same class will have their own data fields, but will have the same functionality.

An example will illustrate some of the mechanisms of class design and creation. The following creates our stack class, using a list as the underlying storage area:

```

class Stack(object):
    def __init__(self):
        self.storage = [ ]
    def push(self, newValue):
        self.storage.append(newValue)
    def top(self):
        return self.storage[len(self.storage) - 1]
    def pop(self):

```

```

        result = self.top()
        self.storage.pop()
        return result
    def isEmpty (self):
        return len(self.storage) == 0

```

To create an instance of this class you use the class name as if it were a function:

```

>>> # create two stacks
>>> stackOne = Stack()
>>> stackTwo = Stack()

```

Once created, you access the functionality provided by the class (that is, pass a message to the object) using the dot operator, as in the following:

```

>>> stackOne.push(12)
>>> stackTwo.push('abc')
>>> stackOne.push(23)
>>> print stackOne.top()
23
>>> stackOne.pop()
>>> print stackOne.top()
12
>>> print stackTwo.top()
'abc'

```

## Using The Stack: AN RPN Calculator

Another class might use the services of the stack class. For example, suppose we are building a calculator that performs operations in reverse polish notation. RPN means that operations are performed by pushing arguments on to a stack, and then performing operations using the topmost elements of the stack. For example, the calculation conventionally written as  $2 * (3 + 7)$  would be written in RPN as  $2\ 3\ 7\ +\ *$ . It would be evaluated by pushing the values 2, 3 and 7 on to the stack, then performing the addition with the topmost two elements, pushing the result on to the stack. Finally the multiplication would be performed using the top two elements on the stack, leaving the result sitting in the stack.

The heart of our RPN calculator is a class for performing calculations and managing the stack. We will simplify the design of this class by using lambda functions to specialize a common function for performing binary operations:

```

class CalculatorEngine(object):
    def __init__ (self):
        self.dataStack = Stack()
    def pushOperand (self, value):
        self.dataStack.push(value)
    def currentOperand (self):
        return self.dataStack.top()
    def performBinary (self, fun):
        right = self.dataStack.pop()
        left = self.dataStack.pop()

```

```

        self.dataStack.push(fun(left, right))
def doAddition (self):      self.performBinary(lambda x, y: x+y)
def doSubtraction (self):  self.performBinary(lambda x, y: x-y)
def doMultiplication (self): self.performBinary(lambda x, y: x*y)
def doDivision (self):     self.performBinary(lambda x, y: x/y)
def doTextOp (self, op):
    if (op == '+'): self.doAddition()
    elif (op == '-'): self.doSubtraction()
    elif (op == '*'): self.doMultiplication()
    elif (op == '/'): self.doDivision()

```

The user of the calculator engine can either explicitly call the appropriate function (doAddition, do Subtraction, and so on) or invoke the function doTextOp. However, forcing the end-user to pass messages to the calculator engine is not very friendly. A better design would create another class whose only purpose is to provide a useful user interface. This function will request a line of input, use split to break the line into parts, loop over the elements of the list invoking the appropriate function from the calculator engine. and finally printing the value remaining on top of the stack. Execution of the function halts if the user enters a blank line:

```

class RPNCalculator(object):
    def __init__ (self):
        self.calcEngine = CalculatorEngine()

    def eval (self, line):
        words = line.split(" ")
        for item in words:
            if item in '+-*/':
                self.calcEngine.doTextOp(item)
            else: self.calcEngine.pushOperand(int(item))
        return self.calcEngine.currentOperand()

    def run (self):
        while True:
            line = raw_input("type an expression: ")
            if len(line) == 0: break
            print self.eval(line)

```

The following is an example illustrating the use of the calculator function:

```

>>> calc = RPNCalculator()
>>> calc.run
type an expression:  3 4 +
7
type an expression: 3 4 + 2 *
14
type an expression: 3 4 2 + *
24
type an expression:
>>>

```

The program at this point is not very robust in reaction to errors in the input. In the exercises at the end of the chapter we will suggest ways that this could be improved.



## Separating the Model from the View

Notice that the calculator application is constructed out of three separate classes; the stack, the calculator engine, and the calculator itself. Each class is providing a distinct service that can be considered independent of the others. As we noted earlier, they work as a *community* to complete the operations of the calculator application. The stack is simply implementing a simple data structure, and knows nothing about how it is being used. The calculator engine encapsulates the logic concerning how the stack is being used to perform arithmetic instructions, but knows nothing about the user interface. The final class, the RPNCalculator, provides the user interface, but knows nothing about the logic of the task at hand.

There are many advantages to separating the application into several classes. One advantage is that it makes the program easier to understand, as each class has only one purpose, and can be examined and studied in isolation. Another important reason is software reuse, since general-purpose classes, such as our stack, can be easily carried from one project to the next.

The division between the calculator engine, which has no user interaction, from the calculator, which interacts with the user but has no knowledge of the calculator function, deserves more investigation. This latter division is common enough to be recognized as a principle of good design and to be given a name. The *view* is the object that interacts with the end user. The *model* is the logic that actually implements whatever task is being performed. Placing these in separate classes is known as *separating the model from the view*. There are many practical advantages to this separation.

One advantage is that there may be many views for the same model. For example, we might want to implement a graphical user interface. We will examine such interfaces in Chapter x. The graphical interface can be implemented as a new class that embodies only user interaction issues, and not on the calculation itself. Thus, separating the model from the view makes it easier to reuse existing code, as well as making change to one part of an application without affecting other sections.

As you practice object-oriented programming skills, you should look for opportunities to separate each new application into classes that provide services to other parts of the system. Recognize situations such as the separation between model and view, and design your program using good software practices.

## An Infix Calculator

While the use of the function `string.split` to divide the line into tokens simplified the development of the RPN calculator, it also introduced some problems. First, it required spaces around every number and every operator. Second, many people find the RPN notation difficult to understand. We can solve both problems by adding yet another layer on top of our calculator application. The class `InfixCalculator` will read an expression written in normal arithmetic notation, including parenthesis, and translate the expression

into RPN. After translating the expression, the RPN calculator will then be invoked to evaluate the expression.

The process of finding a meaning in a textual string is termed *parsing*. The Python interpreter uses parsing, for example, as the first step in determining out the meaning of each expression. The technique we will use here is termed operator-precedence parsing. It has the advantage of being very simple; however, it works only for simple arithmetic expressions. The parser in the Python interpreter is much more robust and complicated.

The idea behind operator precedence parsing is to maintain a stack of pending operators. These are operators for which the left argument is known, but the right argument is not. Operands are copied into the output buffer as soon as they are recognized. As soon as both arguments for an operator is recognized it is also copied into the output.

The examination of a few examples will help uncover what needs to be done. To handle a simple expression such as  $3 + 4$ , the value 3 would be copied to the output buffer. Next, the operator  $+$  would be saved in the operator stack, since the right argument is not yet known. The value 4 is copied into the output. As a final step, all operators from the operator stack are copied into the output. The result is the expression  $3\ 4\ +$ , which is the RPN for this input.

Next, consider the input  $3 + 4 * 7$ . As before, the value 3 and copied to the output, the operator  $+$  is pushed on the stack, and the value 4 is copied to the output. The next symbol is the operator  $*$ . To determine whether or not the operator in the operator stack should be processed, the precedence of the operator  $*$  is compared to that of the operator currently on top of the stack. Since the  $*$  has higher precedence, it is simply pushed on the stack. The result is then the RPN expression  $3\ 4\ 7\ *\ +$ .

Contrast this with the processing of the input  $3 * 4 + 7$ . Here, when the precedence of the second operator, the  $+$ , is compared to the first, the  $*$ , we find the precedence of the value on the stack is higher. Therefore the operator in the stack is popped and copied to the output. This results in the expression  $3\ 4\ *\ 7\ +$ .

Finally let us consider the impact of the use of parenthesis. When a left parenthesis is encountered it is simply pushed on the stack. Parenthesis has a low precedence, so it will never be popped from the stack by an operator. When the corresponding right parenthesis is encountered, all operators from the stack above the left parenthesis are simply copied to the output.

The program that embodies these ideas is shown below. You should simulate the execution of the program on a few examples to convince yourself it is doing the right thing.

```
class Calculator(object):
    def __init__(self):
        self.calcEngine = RPNCalculator()
        self.opStack = Stack()
```

```

def eval (self, line):
    self.outLine = ''
    i = 0
    while i < len(line):
        if line[i] == '(':
            self.opStack.push('(')
        elif line[i] == ')': self.doParen()
        elif line[i] in '+-*/':
            self.doBinary(line[i])
        elif line[i] in '0123456789':
            self.outLine += line[i]
        i = i + 1
    while not self.opStack.isEmpty():
        self.doOp(self.opStack.pop())

def run (self):
    while True:
        line = raw_input("type an expression: ")
        if len(line) == 0: break
        print self.eval(line)

def doParen (self):
    while self.opStack.top() != '(':
        op = self.opStack.pop()
        self.doOp (op)
    self.opStack.pop() # remove the left paren

def doOp (self, op):
    self.outLine += (' ' + op + ' ')

def prec (self, op):
    if op == '/' or op == '*': return 2
    elif op == '+' or op == '-': return 1
    return 0

def doBinary (self, topop):
    self.outLine += ' '
    if self.opStack.isEmpty(): self.opStack.push(topop)
    else:
        nextop = self.opStack.top()
        if self.prec(topop) <= self.prec(nextop):
            self.doOp(nextop)
            self.opStack.pop()
        self.opStack.push(topop)

```

Separating reading the line of input from evaluating the line, using the function eval, means that this class, too, could be used as a component in a larger application. In Chapter x we will illustrate this by adding a graphical user interface to our calculator. As with the Infix calculator program, our interest in presenting the operator precedence algorithm is not so much the program itself (although it is one of the classic computer algorithms that all students should know), but rather the way in which this program reflects an object-oriented design. The calculator program makes use of a stack to hold operators as part of the parsing process. To do this, it is using the services of the stack class. It also uses the RPN calculator to produce the actual result after parsing. The RPN

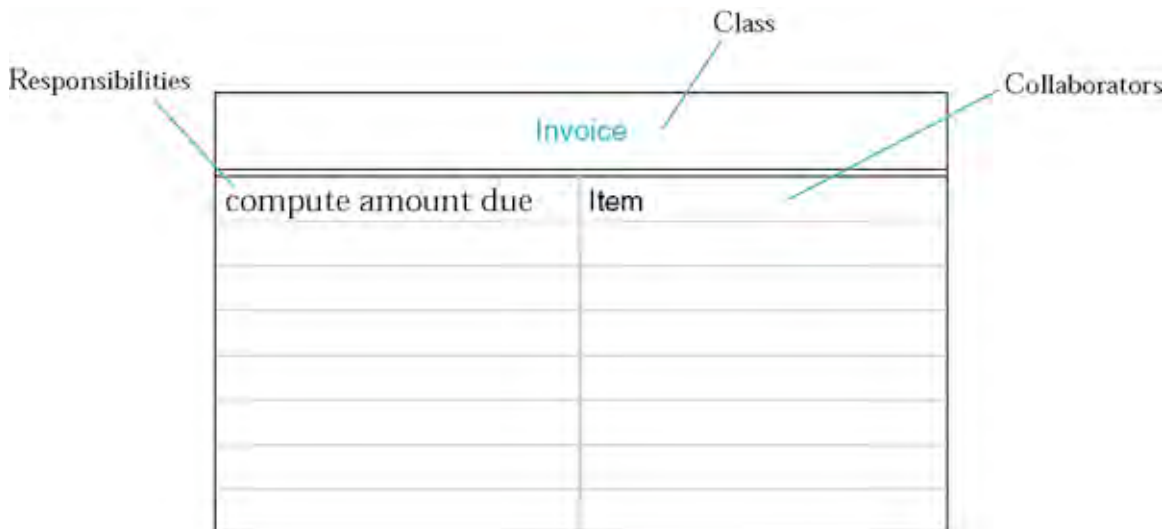
Calculator is used to evaluate an expression written in RPN notation. To do so it also uses the services of the stack class. The original calculator need not know that the RPN calculator is using a stack, it only knows the service that is being provided. Each member of the community is providing a simple service that is defined by the interface (functions) they provide to the other objects in the program.

## Discovering Objects

We have emphasized the view that objects are *entities* that provide *services*. This simple but key insight provides a heuristic that can be used to help identify what should and should not be an object when designing a new application. To apply this heuristic, start by writing one or more stories that describe the execution of your new application from the users point of view. These stores are often termed *scenarios*, or *use-cases*.

Next, go through your scenarios, and highlight each noun with one colored pen, and each verb with a different colored pen. The verbs represent the tasks to be done; the what. But in an object-oriented world, a task can only be performed if somebody does it, the who. The nouns define (as a first approximation) the entities in the community that make up your application. Match each action (verb) with an agent (noun). That is, match each what with a who.

A useful tool in this process is the CRC card. The letters in the name stand for Class, Responsibility, and Collaborators. We will explain only the first two of these. For each agent (noun) write the name of the agent on an index card. Below this write a short English language description of the responsibilities of this agent.



A collection of scenarios and CRC cards is a good starting place for the process of designing a new application. Walk through the scenarios, and for each action (verb) make sure you have identified an agent (represented by a CRC card) responsible for performing the action.

Once you are satisfied that you have captured all the actions necessary to make your application work as you expect, the CRC cards can then be used as a basis for coding the classes in your application.

## Duck Typing

In the object-oriented paradigm, classes are characterized by the services they provide. A consequence of this view is that any value can be replaced by another value, as long as the replacement provides the same service, that is, the same actions using the same names. This is true even if the implementation of the service is radically different.

This can be illustrated by an alternative implementation of a stack. This implementation uses an idea termed a linked list. While common in many other programming languages, the linked list approach would typically not be used in Python since the built-in list type is both faster and easier.

A linked list is formed using an auxiliary data type termed a link. A link simply holds a value and a reference to another link:

```
class Link(object):
    def __init__(self, v, n)
        self.value = v
        self.next = n
```

When a new element is pushed on the stack, it is stored in a new link. When the value is removed from the stack, the currently first link is skipped over. This approach is embodied in the following implementation of a stack:

```
class LinkStack(object):
    def __init__(self):
        self.firstLink = None
    def push(self, newValue):
        self.firstLink = Link(newValue, self.firstLink)
    def top(self):
        return self.firstLink.value
    def pop(self):
        result = self.top()
        self.firstLink = self.firstLink.next
        return result
    def isEmpty(self):
        return self.firstLink == None
```

To change our program to use a LinkStack rather than a Stack we only need change the statement that constructs the value. Because both classes implement the same interface, the rest of the program is oblivious to the change.

In an abstract sense, we have created a “type” that represents the concept of the stack, and both classes implement this type. However, this is only an abstract characterization, and there is no actual entity that represents this type. This idea is often termed *duck typing*,

after the folk saying: “if it walks like a duck, and talks like a duck, then it probably is a duck”. Duck typing is found in dynamically typed object-oriented languages, such as Python. (Another programming language with similar features is Smalltalk). Strongly typed languages, such as Java and C++, use an entirely different approach to typing.

## Encapsulation and Properties

We have emphasized that the hallmark of object-oriented programming is the view that an object is providing a service that can be used by other objects. The features of this service are defined by the functions, or methods, defined by the class that created the object. The user of the service need only know the names of the operations and the correct arguments. For example, the user of the stack class need only know the names push, pop, top and isEmpty. The user of the stack need not know that the underlying values are stored in a list. This is termed *encapsulation*, or *information hiding*, and is one of the most important means for controlling complexity.

An important design guideline for object-oriented programming says that one object should never directly modify a data field in another object. Doing this breaks the encapsulation barrier the class is intended to preserve. But often a class seems to exist only as a repository of data; that the purpose of the class is to hold a data value. These two seemingly conflicting goals are resolved through the intervention of methods whose sole purpose is to all the access of modification of data values. These functions are termed getters and setters.

For example, suppose we want to define a simple class to represent a time duration, where a period of time is defined by hours, minuets and seconds. A class definition that shows getters and setters for each unit can be written as follows:

```
class TimeDuration(object) :
    def __init__ (self, h, m, s):
        self._hour = h
        self._min = m
        self._sec = s
    def setHour (self, h): self._hour = h
    def setMinute (self, m): self._min = m
    def setSecond (self, s): self._sec = m
    def getHour (self): return self._hour
    def getMinute (self): return self._min
    def getSecond (self): return self._sec
```

Here the actual data values are being stored in field names that begin with underscores. While nothing in the Python language prevents direct access to these data fields, the underscore is a convention widely followed in the Python programming community to indicate that the name is purely internal to the class.<sup>1</sup> To access or set the data field the getter or setter should be invoked:

---

<sup>1</sup> You have undoubtedly encountered a variety of names that begin or end with underscores as you have explored the Python universe, starting with the `__init__` method

```
>>> t = TimeDuration(3, 20, 15)
>>> print t.getHour()
3
>>> t.setHour(4)
>>> print t.getHour()
4
```

There are many advantages to the getter and setter convention. The presence of these functions documents the fact that the data fields might potentially be changed. Furthermore, it is sometimes desirable to perform more than simply using the data field, for example it might be desirable to print a message on a log each time a value is changed. Setters often check the validity of the new value before making a change. The setter function can throw an exception, for example, if the new value is not proper. The encapsulation within a function of the action makes this easy to do.

Nevertheless, the function call syntax can sometimes complicate the readability of a program. For this reason, there is a mechanism termed a *property* that hides the function call syntax, permitting the appearance of direct access to a data field while actually performing the actions of the getter and setter functions.

To create a property a class invokes a built-in function. This function takes two arguments. The first is the name of the getter function. The second is the name of the setter function. The value None can be used in place of either argument in order to create a field that can read but not set, or set but not read. The following illustrates this use:

```
class TimeDuration(object):
    def __init__(self, h, m, s):
        self._hour = h
        self._min = m
        self._sec = s
    def setHour (self, h): self._hour = h
    def setMinute (self, m): self._min = m
    def setSecond (self, s): self._sec = s
    def getHour (self): return self._hour
    def getMinute (self): return self._min
    def getSecond (self): return self._sec
    hour = property(getHour, setHour)
    min = property(getMinute, None)
    sec = property(None, setSecond)
```

Attempting to use a value incorrectly will produce an error.

```
>>> t = TimeDuration(3, 20, 32)
>>> t.hour
3
>>> t.hour = 4
```

---

used for initializing a newly constructed object. The general rule of thumb is a name that begins with an underscore should never be used directly, but is instead intended for internal system-level or class-level manipulation.

```
>>> print t.hour
4
>>> print t.sec
AttributeError: unreadable attribute
>>> t.min = 42
AttributeError: can't set attribute
```

You should use properties whenever you have a value that can be set or used outside the class boundaries and you want to avoid the function call syntax.

## Exercises

1. How does the RPN calculator respond to each of the following errors in input?
  - a. 3 4+ error, no space between 4 and plus
  - b. 3 + error, not enough operands
  - c. 3 4 5 + error, not enough operators
2. Modify the RPN calculator to pop the final operand from the stack, and produce an error message if the stack is then empty. What changes do you need to make to the Calculator engine? Which of the errors from question 1 can now be caught?
3. Modify the RPN calculator to place the evaluation of the expression in a try block, catching the error and printing a message. Which of the errors from exercise 1 can now be caught?
4. Suppose you wanted to add the modular division operator, %, to the RNP calculator. Can you do this making only changes to the class RPNCalculator, without modifying the class CalcEngine?
5. Suppose you are designing the software for a vending machine. What should the interface for your system be? You need to handle two classes of users. One type of user is depositing coins and requesting items from the machine. The other category of user is restocking the inventory of the machine. Specify the actions for each. Then design a system to support those actions. Does it make sense to divide your implementation into separate classes to manage features such as counting the money, managing the inventory?
6. Suppose you are designing the software for an ATM (Automatic Teller Machine). Write at least three different scenarios describing the use of your system. From these, create CRC cards to describe the various classes that might be used to implement your design. Walk through your scenarios to make sure that all activity is matched to a class.
7. Suppose you are designing software for an automated video rental kiosk. This system allows the user to browse movie clips, select a limited number of movies to rent, check and verify a credit card, and finally dispense movies that the user



has selected. Create at least three different scenarios for the use of this system. From these develop a design that includes at least four different classes. Create the CRC cards for your design.

8. Rewrite the class Link to use properties so that both the link and value fields are read-only.
9. Functions, including methods, are simply values that happen to be stored in a name space so that they can be accessed in the appropriate way. When a method does nothing more than invoke another function with the same arguments, an alternative to defining the method is to simply name the attribute with the value of the correct function. For example, the method named push in the class stack could be written as follows:

```
class Stack(object):
    def __init__(self):
        self.storage = [ ]
        self.push = self.storage.append
    def top (self): ...
```

First, verify that this does indeed work, and that the push method can be used with an instance of stack as before. Next, compare and contrast this style of definition with the conventional style. Can you see any advantages to one over the other?

## Chapter 10: Scopes, Name Spaces and Modules

As projects become large, a major challenge for the programmer is the management of details. Most often, these details are manifest as a proliferation of names (names of variables, names of functions, names of modules). If there are too many details no one person can remember them all. Worse, the same names can, perhaps unintentionally, collide. A collision occurs when one name is used for two or more entirely different purposes. Collisions can be fatal because one section of code may be depending upon a value being held in a variable with a given name. If that variable is overridden with a different value, chaos can ensue. Hence, the control of complexity really amounts to managing access to names.

Most programming languages, including Python, manage names chiefly through the use of *name spaces*. A name space, or scope, is an encapsulation, a packaging of names. As with all encapsulations, the scope works by creating levels of abstraction. The scope can be viewed from the “outside” as a single entity, or it can be viewed from the “inside” as a collection of names and values. Furthermore, different scopes can hold values with the same name without danger of collision. This feature allows the programmer to use short and easy to remember names, without worrying that the names will conflict with another variable in a different scope.

Our discussion of name spaces will be divided into three major topics. First, we will introduce the LEGB rule for simple variables. The second topic will be a discussion of qualified names, including class variables. Finally we will discuss the idea of modules, and show how to create your own module.

### The LEGB rule

In Chapter 3 you learned how to write function definitions. There you learned that variables assigned within the body of a function are implicitly made local. Parameters also have local scope. Local scope meant that they had meaning only within the body of the function. If there happened to be a global variable with the same name, the two values were distinct.

```
>>> x = 42
>>> def afun():
...     x = 12
...     print x
>>> afun()
12
>>> print x    # function has not changed the global variable
42
```

This example illustrates two of the four levels in the LEGB rule. The L stands for local, such as the variable named `x` that is assigned within the function. The G stands for global, which is the scope for variables defined at the top level, such as the variable `x` that is holding the value 42.

The other two levels, E and G, represent *enclosing* function definitions, and the dictionary of *built-in* functions. The LEGB rule says that when Python is looking for a meaning to attach to a name it searches the scopes in the order Local, Enclosing, Global and finally Built-in.

The E level is perhaps the least frequently encountered. This occurs when one function is defined inside another. Each function definition creates a new scope for variables assigned at that level. But functions can also access variables from the surrounding context. A somewhat contrived example will make this easier to understand:

```
def a(x):
    def b(y):
        print x + y
    y = 11
    b(3)
    print y # note that y is unchanged

>>> a(4)
7
11
```

When the function `a` is invoked the variables `x` and `y` are characterized by the Python interpreter as local to the function. When the nested function `b` is invoked it creates its own local scope, containing a new variable with the name `y`. This variable `y` has value 3, whereas the variable that was local to `a` contained value 11. The body of `b` can access both local variables, such as `y`, and variables that are local to surrounding functions, such as the variable `x`.

Scopes are sometimes described by a series of nested boxes. To find a match for a given variable the boxes are examined from the inside out until the name is found.

[ picture ]

Lambda functions (introduced in Chapter 8) are simply a shorthand method for defining functions. They also create their own local scope, which is distinct from the surrounding function scope. In the following the variable named `x` created inside the lambda is distinct from the variable named `x` that is the parameter for the surrounding function.

```
def a(x):
    f = lambda x: x + 3
    print f(3)
    print x # see that x is unchanged

>>> a(4)
7
4
```

The last level of the LEGB rule is the built-in scope. This is the scope containing functions that are initially part of any Python program. These include functions such as `open` (for opening files) or `zip` (for combining two lists into one). Because these are

simply names in the final scope level, they can be overridden in a different scope. For example, the programmer is free to write their own function named `open`. However, such actions should be taken with great care, as most users will expect the names in the built-in scope to refer to the standard functions. Overriding the function named `open` would prevent access to the standard function from within the new scope.

## The `dir` function

A function named `dir` (short for “directory”) can be used to access a list of the names in the current scope. If you print the value returned by this function at the topmost level you will get the global scope. If you print the value within a function you will get the local scope for that function.

```
>>> z = 12
>>> def dirtest():
...     x = 42
...     print dir()
>>> print dir()
['__builtins__', '__doc__', '__name__', 'dirtest', 'z']
>>> dirtest()
['x']
```

If you give an argument to the `dir` function you can discover the scope for the object. This works for functions, classes and modules.

```
>>> dir(dirtest)
['__call__', '__class__', '__delattr__', '__dict__', '__doc__',
 '__get__', '__getattr__', '__hash__', '__init__', '__module__',
 '__name__', '__new__', '__reduce__', '__reduce_ex__', '__repr__',
 '__setattr__', '__str__', 'func_closure', 'func_code', 'func_defaults',
 'func_dict', 'func_doc', 'func_globals', 'func_name']
>>> dir(math)
['__doc__', '__file__', '__name__', 'acos', 'asin', 'atan', 'atan2',
 'ceil', 'cos', 'cosh', 'degrees', 'e', 'exp', 'fabs', 'floor', 'fmod',
 'frexp', 'hypot', 'ldexp', 'log', 'log10', 'modf', 'pi', 'pow',
 'radians', 'sin', 'sinh', 'sqrt', 'tan', 'tanh']
```

## The `global` statement

In general the programmer has very little control over the scope level for variables. There are two exceptions to this rule, the **`global`** statement and the **`from`** statement for modules. The latter will be discussed as part of the larger exploration of modules. The `global` statement, which you first encountered in Chapter 3, tells the Python compiler that the indicated name is to refer to the variable in the global scope rather than the default, which would be the variable in the local scope.

```
def fun():
    global x
    x = 42    # now changes global, not local variable
>>> x = 12
>>> fun()
```

```
>>> print x
42
```

Notice that the global statement is necessary only if a variable is the target of an assignment. If a variable is simply being used then the LEGB rule already specifies that the global variable will be accessed.

```
def fun():
    global x
    x = x + y  # both x and y are global
>>> x = 3
>>> y = 4
>>> fun()
>>> print x
7
```

The fact that *access* to global variables is easy within functions but that *modification* is difficult (requires an explicit statement) is a purposeful design decision. The use of global variables can make programs difficult to understand, since assigning a global variable explicitly breaks an encapsulation barrier. There are times when this is necessary, and so it should be possible, but the language forces the programmer to think about the issue each time this feature is used.

## Class Scopes

Classes create a new scope in much the same fashion as function definitions. However, a curious feature is that class scopes are not part of the LEGB rule. The effect is that methods defined within a class can see their surrounding scope, but cannot see the class scope. Normally classes are defined at the top level, and so the surrounding scope for the method definitions is the global level. However, nothing in the language prevents a class as being defined inside a function. In this case the surrounding scope for the methods is the surrounding function, not the class.

```
def silly():
    x = 12
    class A:
        x = 42
        def foo(self):
            print x
            print self.x
    return A()
>>> anA = silly()  # create an instance of our inner class
>>> anA.foo()
12 # prints x local to silly, not x in class A
42 # prints x in class scope
```

The LEGB rule is why methods must go through the self variable to reference other methods or values defined at the class level.

There are two different types of variables that can be defined within a class scope. Variables that are simply defined at the class level are shared by all instances of the class.

The initialization of these variables is performed only once, the first time the class statement is executed. Variables defined using the variable `self` are unique to each instance of the class. The following example illustrates class variables being used to count the number of instances of the class that have been created.

```
class CountingClass:
    count = 0
    def __init__(self):
        count = count + 1

>>> a = CountingClass()
>>> b = CountingClass()
>>> print 'number of initializations:', CountingClass.count
number of initializations: 2
```

## Scopes, Names and References

Note that scope is a property of a *name*, not a property of a *value*. Two names can refer to the same value in Python, and they can frequently have different scopes. This can be illustrated by the following example:

```
class Box(object):
    def __init__(self, v): self.value = v

def newScope(x):
    y = x
    y.value = 42

>>> a = Box(3)
>>> newScope(a)
>>> print a.value
42
```

The variable `a` has global scope. When passed as argument to the function `newScope` it is assigned to the variable `x`. This variable is then used to assign to variable `y`. At this point all three variables, `a`, `x` and `y`, refer to the same object. But `x` and `y` have local scope. Nevertheless, a change to the internal state of the variable (in this case, changing the `value` attribute), will have an effect on the value referenced by the global variable `a`.

## Qualified Names

A qualified name is a name is denoted by a period following a base, as in `object.attribute`. To determine the meaning of the qualified name, the meaning of the base is first determined using, for example, the LEGB rule. Once the base is known, the attribute is then determined in reference to the base. There are several different types of names that can be qualified. These include the following:

- Classes. The attribute must be a variable defined within the class body

- Instances or Objects. The attribute is a data field used to store the state of the object, or a method defined for the object
- Instances of Built-in types (such as List or Dictionary). Again the attribute can be a data field or, more commonly, a function (method) defined as part of the type
- Modules. The attribute is a data value or function defined in the module.

Qualified names serve much the same purpose as name scopes. By insisting that names be qualified by a base, they limit the poliferation of names in the broader scope. Similarly, the same name can be used in more than one qualified fashion, and will refer to the attribute appropriate to the base.

Much of the mechanism associated with name scopes is built using simple dictionaries. For example, the current local name scope can always be found using the function `locals()`, and the current global scope using the function `globals()`. Classes store their name space in a field named `__dict__`, as do modules. All of these values can be examined by the programmer, although modifications to these values should only be performed with great care.

```
class A(object):
    x = 1
    def foo(self):
        return 'foo'
    def bar(self):
        return x

>>> print A.__dict__
{'__module__': '__main__', 'bar': <function bar at 0x4b470>,
 '__dict__': <attribute '__dict__' of 'A' objects>, 'x': 1, 'foo':
<function foo at 0x4b3f0>, '__weakref__': <attribute '__weakref__' of
'A' objects>, '__doc__': None}
```

## Modules

We have been using modules since chapter 3, and yet we have not explained what a module is or showed how to create your own modules. Now, with the benefit of an understanding of name spaces, we can do both.

The construction of a module is very simple. A module is simply a Python file, exactly the same as the program files you have been building since Chapter 2. What is different is the handling of the names in the module. This occurs during the execution of the import statement.

The import statement scans a file and executes each statement in the program, in exactly the same fashion as occurs when the file is given as argument to the Python interpreter. The only difference is that rather than using the standard local dictionary, the names of all values defined within the module are stored in their own dictionary. This dictionary is then held by a value of type module. Referencing a qualified name, `modName.x`, is in fact shorthand for the dictionary reference `modName.__dict__['x']`.

You can see this if you examine the type associated with a module name after executing the import statement:

```
>>> import string
>>> print type(string)
<type 'module'>
>>> print string.__dict__['split']
<function split at 0x6b270>
```

It is now easy to explain the meaning of the from statement in terms of name spaces. When a from statement is encountered the effect is to first import the specified module, constructing the module dictionary. The given attribute from this dictionary is then *copied* into the local dictionary. Thereafter, the attribute can be used without qualification, exactly as if it had been defined in the local space.

```
from modName import attribute
```

The difference between a simple import and a from import can have an important effect on execution time. Suppose you are using only the function bar from module foo. One approach would be to import the module:

```
import foo
```

You could then use the function bar by means of the qualified name, foo.bar(). However, each time you use this expression there are two run-time lookups performed. The first is to find the meaning for the variable foo in the current name space. Next, a run-time lookup is performed to find the data field named bar in the dictionary associated with the value foo. If, on the other hand, you import just a single function:

```
from foo import bar
```

Then the function bar is placed in the local name space. The function can then be invoked without qualification, as bar(). Discovering the meaning of this name only requires one search, since the name is found in the local name space.

Most of the time the difference in execution is not noticeable. However, if imported functions are used within a loop and executed many times the difference in execution can be significant.

## Avoiding Namespace Collisions when Importing Modules

It is possible to use a wildcard character (the \* character) to import everything from a module into the current name space. However, this should be done with care because any name in the current environment that matches a name in the imported namespace will be overridden. For example, suppose you have sometime stored in a variable named e and then import everything from the math module:

```
>>> e = 42
```



```
>>> from math import *
>>> print e
2.71828182846
```

The math module defines the value `e`. (It is the base of the natural logarithms). This definition has now replaced the earlier value associated with the name.

One way to avoid namespace collisions when performing an import is to use the optional **as** clause on the **from** import statement. This clause allows the programmer to import a value, but give it a new name in the local space.

```
>>> e = 42
>>> from math import e as eConst
>>> print e
42
>>> print eConst
2.71828182846
```

## Creating your own Module

Creating your own module is surprisingly easy. A module is exactly like a Python program, simply a list of Python statements in a file. The only difference is that the module is loaded using an import statement, rather than by being given directly to the Python interpreter.

Normally files that are used as modules contain only class and function definitions. However, this is just convention, and nothing in the language prevents the user from placing other types of statements in the module. All the statements will be executed when the module is loaded by the import statement.

The following illustrates a typical module. Here the module simply defines three functions for common data structures (a stack, a queue, and a set).

```
#
# Module for simple collection classes
#

class Stack(object):
    def __init__(self):
        self.storage = [ ]

    def push (self, newValue):
        self.storage.append(newValue)

    def top (self):
        return self.storage[len(self.storage) - 1]

    def pop (self):
        result = self.top()
        self.storage.pop()
        return result
```

```

    def isEmpty (self):
        return len(self.storage) == 0

class Queue(object):
    def __init__ (self):
        self.storage = [ ]

    def add (self, newValue):
        self.push = self.storage.append(newValue)

    def front (self):
        return self.storage[0]

    def removeFront (self):
        result = front()
        del self.storage[0]
        return result

    def isEmpty (self):
        return len(self.storage) == 0

class Set(object):
    def __init__ (self):
        self.storage = [ ]

    def add (self, newValue):
        if not newValue in self.storage:
            self.storage.append(newValue)

    def contains (self, testValue):
        return testValue in self.storage

    def remove (self, testValue):
        i = self.storage.find(testValue)
        if i:
            del(self.storage[i])

```

## Testing the Namespace within a Module

Frequently a program can be used either as a stand-alone application or as a module for a larger system. For example, the calculator program we developed in Chapter 9 works as an application using a textual interface. However, we can also reuse the code for this application in another system that uses a GUI interface, as we will see in Chapter x.

When this occurs there are usually statements that you do not want to execute when the program is loaded as a module. Fortunately, the name of the current module is held in an internal variable called `__name__`. The top-level program executed by the Python interpreter is given the name `__main__`. Testing this value provides a means to conditionally execute statements. In our Calculator program from Chapter 9, for example, we could replace the final statements with the following:

```

# only execute if we are being run as top level program
if __name__ == "__main__":

```

```
calc = Calculator()  
calc.run()
```

Now the commands that begin the application will only be executed when the program is selected as the top-level command from the Python interpreter, not when the file is loaded as a module.

## An Emphasis on Reuse

The biggest feature that distinguishes modern software development from earlier approaches is an increased emphasis on software reuse. Rather than expecting that every program will be written entire new from the first line to the last, applications are now almost always constructed from reusable software libraries. These libraries can be as simple as our data structure module described earlier, or much more complicated systems for performing network connections or parsing XML files.

One of the features that distinguishes Python is that it provides an extremely rich set of existing modules that can be reused in any new application. We have seen a number of these already. A few more will be used in the case studies in the second part of this book. Many more are documented on the Python website, at [www.python.org](http://www.python.org).

Equally important, Python makes it easy, almost trivial, to create your own modules. A module is nothing more than a Python program stripped of the main driving statements.

As you advance in your Python programming you will learn about many more useful modules. You should also strive to acquire a mindset that recognizes and values reusable code in your own programs. When you find a set of classes or functions that you think are general enough to be used for two or more different applications, package them as a module and use the same code in each of the new programs. Doing so will make you more productive, and make your programs more reliable and error-free.

## Exercises

1. Consider the following program fragment. Imagine execution has reached the print statement. Assign a letter from LEGB to each of the following identifiers according to whether the name is Local, from an Enclosing Scope, Global or Built-in.
2. Try creating a simple function, such as the following, and print out the values in the locals dictionary. What values do you see? Are you surprised at any of the entries in this dictionary? What values are stored in the dictionary returned by the function `globals()` at the point where the locals dictionary is being displayed?

3. Try creating a nested function, such as the following, and print out the values in the locals dictionary. What values do you see? Are you surprised at any of the entries in this dictionary?
4. Try creating a simple class, such as the following. What values are stored in the class dictionary, which can be accessed as the attribute `__dict__` following the class name.
5. Try creating a class that inherits from another class, such as the following. What values are stored in the class dictionary?
6. Try creating a simple module, such as the one described in the section on creating your own module. After loading the module, examine the module dictionary. This value can be accessed as the `__dict__` attribute following the module name. Are there any values in this dictionary that surprise you? What purpose do you think these additional values serve?
7. If you look at the value of the dictionary returned by `globals()`, you will find a key named `__builtin__`. What do you think this represents? What type of value is this? How can you find what the values stored in this value?
8. If you call the function `dir` on a value of type class you will find a number of fields that begin with two underscores. As we have noted elsewhere, these typically indicate fields that are manipulated internally. Among the fields for a class are the following: `__bases__`, `__dict__`, `__doc__`, `__module__` and `__name__`. Experiment with different class definitions and, by examining the values for these fields, see if you can figure out what they represent.
9. If you create an instance of a class, you can also invoke the `dir` function on this value. Fields in this dictionary include `__class__` and `__dict__`. Experiment with different class definitions and see if you can figure out what these represent.

## Chapter 11 – Advanced Features

This chapter will explain a few of the more advanced aspects of Python. These features are not commonly employed in most programs, but you may find them useful in special situations.

### Keyword Arguments

All of the examples we have used up to this point have matched actual argument values to parameters positionally – that is, the first argument is assigned to the first parameter, the second to the second, and so on. However, you can also pass function arguments by explicitly naming each parameter and specifying a value. In this case the order of the arguments is unimportant, and need not match the order of the parameters:

```
def printInfo (name, age, gender):
    print 'Name: ', name, 'Age: ', age, 'Gender: ', gender

>>> printInfo('sam smith', 32, 'male')
Name: sam smith Age: 32 Gender: male
>>> printInfo(name='robin jones', age=18, gender='female')
Name: robin jones Age: 18 Gender: female
>>> printInfo(age=12, gender='male', name='chris brown')
Name: chris brown Age: 12 Gender: male
```

If you omit any named parameters a `TypeError` will be produced:

```
>>> printInfo(name='randy jones', age=22)
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
TypeError: printInfo() takes exactly 3 non-keyword arguments (2 given)
```

You can mix positional and keyword arguments in the same call, providing the positional arguments are listed first:

```
>>> printInfo('robin smith', gender='female', age=23)
Name: robin smith Age: 23 Gender: female
```

### Default Parameter Values

Parameter names in a function definition can optionally be followed by an assignment. The value to the right of the assignment is termed the default value, and will be assigned to the parameter if the call does not provide an alternative argument value.

```
def incr (x, y = 1):
    return x + y

>>> incr(7)
8
>>> incr(7, 3)
10
```

The expressions appearing in default parameters are evaluated only once, at the time the function is defined. They are not reevaluated each time the function is called.

```
>>> a, b, c = 4, 5, 6
>>> def incr(x, y=b): return x + y
>>> b = 12 # change the value of b
>>> incr(2) # uses the value b had when function defined
7
```

## Variable Length Argument Lists

If an asterisk (\*) is placed in front of the last argument name, all remaining parameters are placed into a tuple and passed to this argument. This allows functions to take a variable number of arguments:

```
def many(name, *values):
    print name, values

>>> many("zero")
zero ()
>>> many("one", "abc")
one ('abc',)
>>> many("two", "abc", 23)
two ('abc', 23)
>>> many("three", "abc", 23, 3.1415)
three ('abc', 23, 3.1415000000000002)
```

If the last argument is preceded by two asterisks, all the remaining keyword arguments (those that have not already been matched to a parameter) are placed into a dictionary that is passed through the argument. Note that the keys in this dictionary are strings representing the argument names.

```
def echo(**args):
    for e in args.keys(): print e, ":", args[e]

>>> echo(a=3)
a : 3
>>> echo(a=3, b='abc', c=3.14)
a : 3
c : 3.14
b : abc
```

You can combine the variable positional argument with the variable keyword argument, as long as the latter is written last. Any remaining positional parameters will be assigned to the first, while any remaining keyword arguments will be assigned to the latter.

```
def silly(name, number, *vargs, **kargs):
    print name, ': ', number
    print vargs
    print kargs
>>> silly('one', 32)
```

```

one : 32
()
{}
>>> silly('two', 42, 3.14, 42, x=32, z='z')
two : 42
(3.1400000000000001, 42)
{'x': 32, 'z': 'z'}

```

## Apply and Call

As we noted in Chapter 6, a function is simply a value like any other value. Functions can be assigned to a variable, passed as argument, or returned from a function. The function `apply` takes as argument a function and a list of arguments. The function is invoked binding the elements of the list to the function parameters. The resulting value is then returned as the result of calling `apply`.

```

def sum(x, y): return x + y

>>>> apply(sum, [7, 3])
10

```

Keyword arguments can be passed in a dictionary supplied as the third argument. Note that the dictionary represents the variable names as strings:

```

>>> apply(sum, [], {'y':4, 'x':12})
16

```

## Object Overloading

Any legal Python operation can be applied to a user-defined type. The programmer can provide a behavior for the operation by defining a function with the appropriate name. It is only when the interpreter is unable to find a function with the appropriate name that an error will be generated. Because the functions are used internally they follow the two underscore prefix and suffix convention.

For example, suppose you want to create a `Box` object that stores a numeric value. Two `Boxes` can be added, resulting in a new `Box` that holds their sum. You could achieve this behavior by writing the following class:

```

class Box (object):
    def __init__ (self, v):
        self.value = v
    def __str__ (self):
        return 'Box [' + str(self.value) + ']'
    def __add__ (self, right):
        return Box(self.value + right.value)

>>> print Box(3)
Box[3]
>>> print Box(3) + Box(4)
Box[7]

```

This example also illustrates the use of the function `__str__`, which is internally invoked to convert a user-defined object into a string. When two instances of a `Box` are added, the function `__add__` is invoked. In this case, the `add` function is creating a new `Box` that holds the sum of the argument values.

Other operators are implemented in a similar fashion. The following table lists a few of the more common operators, and their functional equivalent:

<code>a + b</code>	<code>add (a, b)</code>
<code>A - b</code>	<code>__sub__ (a, b)</code>
<code>A * b</code>	<code>mul (a, b)</code>
<code>A / b</code>	<code>div (a, b)</code>
<code>A % b</code>	<code>mod (a, b)</code>
<code>A &amp; b</code>	<code>__and__ (a, b)</code>
<code>- a</code>	<code>neg (a)</code>
<code>Len(a)</code>	<code>len (a)</code>
<code>a.b</code>	<code>__getitem__ (a, b)</code>
<code>a.b = c</code>	<code>setitem (a, b, c)</code>
<code>Str(a)</code>	<code>str (a)</code>
<code>If a</code>	<code>nonzero (a)</code>
<code>Int(a)</code>	<code>__int__ (a)</code>
<code>A(b, c, d)</code>	<code>call (a, b, c, d)</code>

## Regular Expressions and String Processing

The method `find` is used to find a fixed string embedded within a larger string. For example, to locate the location of the text “fis” within the string “existasfisamatic”, you can execute the following:

```
>>> s = 'existasfisamatic'
>>> s.find('fis')
7
```

The length of the search string (in this case, 3) gives you the size of the matched text. But what if you were searching for a floating point constant? A number has not only an indefinite number of digits, but it may or may not have a fractional part, and it may or may not have an exponent. Even if you can locate the start of the string (by, for example, searching for a digit character), how do you determine the length of the matched text?

The solution is to use a technique termed regular expressions. Regular expression notations were being used by mathematicians and computer scientists even before computers were common. The particular notation used by the Python library derives from conventions originating with the Unix operating system. In Python the regular expression package is found in the module named `re`.



The regular expression notation will at first seem cryptic; but it has the advantage of being short and, with practice, easy to understand and remember. The most common regular expression notations are shown in the table at right. Symbols such as ^ and \$ are used to represent the start and end of a string. Parenthesis can be used for grouping, and the \* and + signs are used to represent the idea of one-or-more, or zero-or-more, respectively. Square brackets denote *character classes*; a single character from a given set of values. Dashes help simplify the description of a range of characters, for example a-f represents the set abcdef, and A-Z can be used to match any capital letter.

Text	Matches literal
&	Start of string
\$	End of string
(...)*	Zero or more occurrences
(...)+	One or more occurrences
(...)?	Optional (zero or one)
[chars]	One character from range
[^chars]	One character not from range
Pat   pat	Alternative (one or the other)
(...)	Group
.	Any char except newline

Let us see how to define a regular expression for floating point literals. The basic unit is the digit. This is a single character from a range of possibilities (sometimes termed a *character class*). The square brackets are used surround the list of possible characters. So this could be written as [0123456789]. However, when the characters are part of a sequential group of ASCII characters the regular expression library allows you to simply list the starting and ending points, as in [0-9]. (Other common sequences of characters are the lower case letter, a-z, and the upper case letters, A-Z). Since our floating point number begins with one or more digits, we need to surround the pattern with a parenthesis and a plus sign, as in ([0-9])+.

Next, we need a pattern to match a decimal point followed by zero or more digits. Literal characters generally represent themselves, but the period has a special meaning, and so it must be escaped. So this is \.([0-9]\*)?. If we want to make it optional, we surround it with a question mark, as in (\.([0-9]\*))?.

Finally, we have the optional exponent part, which is followed by an optional sign, and a number consisting of one or more digits. This is ([eE]( [+ - ] )? ([0-9])+)?. Putting everything together gives us our final pattern:

```
([0-9])+(\.[0-9]*)?([eE]( [+ - ] )? ([0-9])+)?
```

Having defined the regular expression pattern, we must then compile it into a *regular expression object*. The regular expression object is an internal form used for pattern matching. This the following illustrates this process:

```
>>> import re
>>> pat = re.compile("([0-9])+(\.[0-9]*)?([eE]( [+ - ] )? ([0-9])+)?" )
```

Make sure you qualify the name compile with the prefix re. There is another function named compile in the standard library, which does a totally different task. The pattern then supports a number of different search operations. The simplest of these is named

search. This operation takes as argument a text string, and returns a match object. Again, make sure you qualify the name. A match object support various different operations. One is to test whether or not the match was successful:

```
>>> text = "the value 2.45e-35 is close to correct"
>>> mtcobj = pat.search(text)
>>> if mtcobj: print "found it"
found it
```

However, the match object can also tell you the start and ending positions of the matched text:

```
>>> print mtcobj.start(), mtcobj.end()
10 18
>>> text[mtcobj.start():mtcobj.end()]
2.45e-35
```

A table in Appendix A lists the most common operations found in the regular expression module.

## Iterators and Generators

The for loop has the general form:

```
for ele in collection:
```

In earlier chapters we have seen how various different types of collection can be used with a for loop. If the collection is a string, the loop iterates over the characters in the string. If it is a list, the elements in the list are generated. If the collection is a dictionary, the elements refer to the keys for the dictionary. Finally, if the collection is a file, the elements produced are the individual lines from the file.

It is also possible to create a user defined object that interacts with the for statement. This happens in two steps. In the first step, the for statement passes the message `__iter__` to the collection. This function should return a value that understands the iterator protocol. The iterator protocol consists of a single method, named `next`, that is expected to produce values in turn until the collection is exhausted. Once exhausted, the function must raise a `StopIteration` exception.

The following two classes illustrate this behavior. The first class maintains a collection of values stored in a list. When an iterator is requested, it creates an instance of another class named `SquareIterator`. The `SquareIterator` class cycles through the values in the list, returning the square of every element.

```
class SquareCollection (object):
    def __init__ (self):
        self.values = [ ]
    def add (self, v):
        self.values.append(v)
```

```

    def __iter__(self):
        return SquareIterator(self)

class SquareIterator (object):
    def __init__(self, c):
        self.container = c
        self.index = 0
    def next (self):
        if self.index >= len(self.container.values):
            raise StopIteration
        result = self.container.values[self.index] ** 2
        self.index += 1
        return result

>>> s = SquareCollection()
>>> s.add(3)
>>> s.add(4)
>>> s.add(2)
>>> for e in s:  print e
9
16
4
>>>

```

If the `__iter__` method is not defined, the `for` statement tries an older and simpler protocol. It generates a series of index values, from 0 onwards, and invokes the method `__getitem__`. This method either returns a value, or raises an exception. The loop continues until the exception is raised. Here is a simple class that illustrates this behavior. Notice that this time the class does not hold any actual values, only the upper limit for execution:

```

class SquareTo (object):
    def __init__(self, m):
        self.max = m
    def __getitem__(self, i):
        if i >= self.max:
            raise StopIteration
        return i ** 2

```

Executing a `for` loop with an instance of this class produces a sequence of squares:

```

>>> for e in SquareTo(5): print e
0
1
4
9
16
>>>

```

The iterator technique is useful for collection classes, but can be awkward in other situations. A useful abstraction that is layered on top of iterators is the idea of a generator. A generator is a function that can be suspended in the middle of execution, and restarted from the point of suspension. To suspend a function simply use the statement `yield` instead of the statement `return`. A suspended function can be restarted until it either

executes a normal return, or until it runs out of statements to execute (that is, “falls off the end”).

The following is an example generator. This function produces values from the Fibonacci sequence until they exceed the limit given by the argument:

```
def genfib (n):
    a = 0
    yield a
    b = 1
    yield b
    while b < n:
        a, b = b, a+b
        yield b
```

When used in a for statement, the generator runs through its values:

```
>>> for e in genfib(20): print e
0
1
1
2
3
5
8
13
21
>>>
```

Behind the scenes, the generator is producing a value that satisfies the iterator protocol. You can see this by capturing the value and executing the method next that it supports.

```
>>> x = genfib(3)
>>> x.next()
0
>>> x.next()
1
>>> x.next()
... # so on, until
>>> x.next()
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
StopIteration
>>>
```

## Module Reload

As we described in Chapter 10, when an import statement is executed the associated module is executed and the resulting namespace is stored in a variable with the module name. However, if the programmer tries to import the same module twice, the second import has no effect. This can be seen by creating a simple module that has a side effect,

such as printing a value. Create a file named `printMe.py` with nothing more than a print statement:

```
print 'Print me!'
```

If you try to import the file more than once, only the first will have any effect:

```
>>> import PrintMe
Print Me!
>>> import PrintMe
>>>
```

If you want to re-execute an already imported module you must use the statement **reload**. The argument for this statement is the previously created module object:

```
>>> reload(PrintMe)
Print Me!
<module 'PrintMe' from 'PrintMe.pyc'>
>>>
```

This feature is chiefly used when debugging a module, as it permits the programmer to make changes to the module file, then reload the file to see the effects of the change.

## Documentation Strings

Besides comments, Python supports an alternative mechanism for providing documentation on functions, classes, modules and methods. This is termed a docstring. Syntactically, a docstring is simply a string that appears immediately after the line containing the `def` in a function or method, or the keyword `class` in a class description, or at the beginning of a file for a module. For illustration, consider the following simple module stored in a file name `docStringTest.py`:

```
'''This is a module
to illustrate the docstring
facility'''

class Aclass (object):
    'you can describe a class here'

    def aMethod (self):
        "this method returns 3"
        return 3

def aFun (x, y):
    "this function multiplies x and y"
    return x * y
```

The comments contribute marginally to the readability of the code, but probably no more so than would comments that used the `#` syntax. However, the advantage of docstrings is that they are recognized by the Python interpreter, and stored along with the objects as an attribute named `__doc__`. This attribute can be read at runtime:

```

>>> import docStringTest
>>> print docStringTest.__doc__
This is a module
to illustrate the docstring
facility
>>> print docStringTest.Aclass.__doc__
you can describe a class here
>>> print docStringTest.Aclass.aMethod.__doc__
this method returns 3
>>> print docStringTest.aFun.__doc__
this function multiplies x and y
>>>

```

While most programmers are unlikely to spend the time creating docstrings for their own code, it is fortunate that the creators of the modules in the standard distribution have done so. You can discover basic information about most built-in functions and modules simply by printing their doc strings:

```

>>> print abs.__doc__
abs(number) -> number

```

Return the absolute value of the argument.

```

>>> print range.__doc__
range([start,] stop[, step]) -> list of integers

```

Return a list containing an arithmetic progression of integers.  
range(i, j) returns [i, i+1, i+2, ..., j-1]; start (!) defaults to 0.  
When step is given, it specifies the increment (or decrement).  
For example, range(4) returns [0, 1, 2, 3]. The end point is omitted!  
These are exactly the valid indices for a list of 4 elements.

```

>>> import random
>>> print random.randint.__doc__
Return random integer in range [a, b], including both end points.
>>>

```

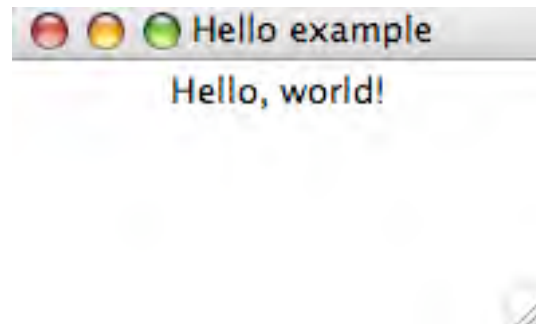
## Chapter x: GUI programming with Tkinter

These days most computer users have little difficulty interacting with computer programs by means of a Graphical User Interface, or GUI. Conventions in GUI programming that are now commonplace include such items as windows, menus, buttons, text boxes and scroll bars. The Python language does not provide a standard library for creating GUI components, but a number of different libraries have been adapted to work with Python.

In this chapter we will explore the most commonly used library, named Tkinter. The Tkinter library was first developed in conjunction with a different programming language, named Tcl. Since then the Tcl/Tkinter facility has been ported to a number of different platforms and languages. The Tkinter module is normally found as part of every Python installation.

### Variations on Hello World

The traditional first example for any GUI library is a window that displays a hopelessly cheerful message. Using the Tkinter module this would be performed as follows:



```
import Tkinter

root = Tkinter.Tk()
root.title("Hello example")
root.geometry("200x100")

w = Tkinter.Label(root, text="Hello, world!")
w.pack()

root.mainloop()
```

Let us examine this program line by line. The import statement loads the Tkinter library. As with most windowing systems, Tkinter is based around the concept of nested rectangular regions, called windows or frames. The highest level frame is termed the root frame, and is returned as the value of the function Tk(). The function named title sets the title of this region, while the function named geometry takes a string that represents the size of the window as a width and height pair.

Within the root window we place a label, which is among the simplest form of GUI widget (or component). A label takes a simple text message. The Tkinter library is somewhat unusual in that many of the arguments for the functions defined in the library employ keyword arguments, rather than the more conventional placement arguments. See Chapter 11 for a discussion of keyword arguments.

The function pack makes the label component visible, while the function named mainloop initiates the windowing main loop. The program halts when the user clicks on the close box for the main window. The picture shows what this program looks like on

one platform, the Macintosh. The graphical components follow the conventions of the underlying operating system, and hence will have a different look on different platforms.

Because the Tkinter library defines a large number of symbolic values as well as functions, it becomes tedious to preface each with the name Tkinter. By using the **from** form of the import statement, the definitions in the module become part of the local name space, and the prefix can be omitted. In this fashion the program becomes slightly less wordy:

```
from Tkinter import *

root = Tk()
root.title("Hello example")
root.geometry("200x100")

w = Label(root, text="Hello, world!")
w.pack()

root.mainloop()
```

We will use this convention in the remaining examples.

## Event Driven Programming

GUI systems are an example of *Event Driven Programming*, sometimes termed *reactive systems*. In normal programming the flow of control is dictated by the programmer, and the end user normally has very little control over execution. In event driven programming the end user specifies the actions to perform using features such as buttons, text boxes or scroll bars. The program then *reacts* to the users actions, performing whatever action is required. For this reason, event-driven programs are also sometimes termed *asynchronous*.

The Tkinter library attaches actions to graphical components using a technique termed a *callback*. The programmer specifies a function to be invoked, attaching this to a graphical component when the component is created. Later, when the end user interacts with the component (say, pressing a button), the function will be invoked.



We can illustrate this with a slightly more complicated version of our hello world program. This version has two buttons and will also react to mouse presses in the region of the window. When the mouse is pressed, the text "hello" is printed at the location given by the mouse press. By means of the buttons, the user can change the text of the message.



```

from Tkinter import *

root = Tk()
root.geometry("300x300")
root.title("Hello mouse world")
canvas = Canvas(root)
text = "hello"

def sayHello():
    global text
    text = "hello"

def sayGoodbye():
    global text
    text = "goodbye"

def buttonPressed(evt):
    if evt.widget == canvas:
        canvas.create_text(evt.x, evt.y, text=text)

hellob = Button(root, text="Hello", command=sayHello)
goodbyeb = Button(root, text="Good Bye", command=sayGoodbye)
root.bind("<Button-1>", buttonPressed)

canvas.pack()
hellob.pack()
goodbyeb.pack()

root.mainloop()

```

The structure of the program is similar to the first example. The root window is placed into the variable named `root`. On the root window we will place a canvas. A *canvas* is a type of component that understands a number of graphical operations. In addition to the canvas our application will have two more components, both instances of the class `Button`. The constructor for each of these buttons requires as argument the name of a function that will be invoked when the button is pressed. Because the button cannot be created until these functions are known, the assignment statement that creates the button must appear after the function definitions. Similarly the action for the button press is specified by a callback function given as argument to the function `root.bind`. (The latter is, inconsistently, given by a positional argument while the button uses a keyword argument). Various different arguments for the `bind` function can be used to attach commands to a variety of mouse motions.

The functions for the button press simply change the value of the global variable named `text`. The argument for the button event requires an argument that will be given a value of type `event`. The event object records such information as the widget in which the event occurred, and the `x` and `y` locations for the event. Because this function is invoked for all mouse down events, even the button presses, an `if` statement is used to verify that the mouse was pressed inside the canvas. In this case, we print a text message at the given `y` and `y` coordinate.

The program ends by making the components visible, and then starting the event loop. As the user clicks the various components the display is updated.

## Sliders, Fonts, other variations

We can illustrate a few more of the capabilities of Tkinter by adding a slider to the bottom of the screen that can be used to change the size of the text, and a drop down menu that can be used to change the font.

First, we explain the slider. There are two types of sliders in Tkinter, Scrollbars and Scales. Scrollbars are used exclusively with lists and canvases, while Scales are used for any numerical display. The constructor for the scale takes the lower and upper bounds for the range of values, an orientation, and the name of a callback function. Because the word **from** is a keyword in Python, the lower bound is set by an argument named `_from` (note the underscore). The callback function is presented with a string argument, which is the value of the scroll bar. The functions `set` and `get` can also be used to set or retrieve the value of the slider. A slider typically spans the entire width of the window. This can be indicated by an argument given in the `pack` command:

```
size = 10 # variable that will be set by slider

def updateSize(svalue): # call back for slider
    global size
    size = int(svalue)

slide = Scale(root, from_=5, to=24, orient=HORIZONTAL, command=updateSize)
slide.set(12)

slide.pack(fill=X)
```

To change the size of the text being printed simply alter the text printing command as follows:

```
canvas.create_text(evt.x, evt.y, text=text, font=("Times", size))
```

We will next add features to alter the font using menu commands. As with the size, we create a global variable to hold the font name, and some call back functions to change the value held by this variable.

```
fontname="Times"

def settimes():
    global fontname
    fontname = "Times"

def sethelvetica():
    global fontname
    fontname = "Helvetica"

menubar = Menu(root)
fontMenu = Menu(menubar)
```

```
fontMenu.add("command",label="Times", command=settimes)
fontMenu.add_command(label="Helvetica", command=sethelvetica)
menubar.add_cascade(label="Font", menu=fontMenu)
```

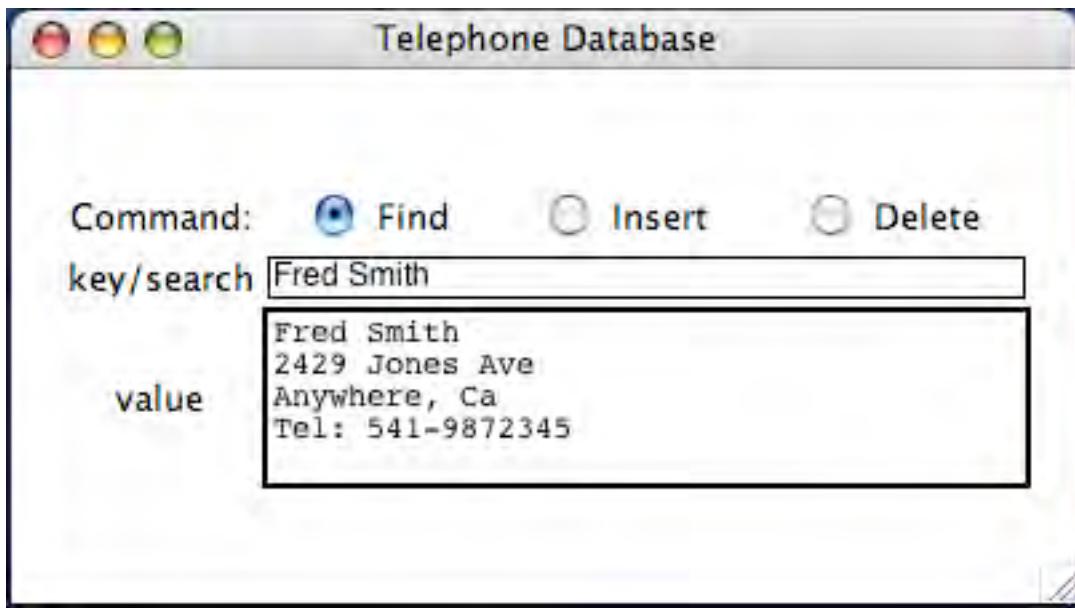
Next, two new menus are created. The one stored in `menubar` will be the top level menu, while the one stored in the variable `fontMenu` will be a cascaded menu, displayed when the font menu is selected. The latter will each have a call back function attached to them. The `create_text` command is now changed to use the font name stored in the global variable. As a final step, the top level window must be told to use the new menu bar. This is accomplished using the following command, typically right before calling the function `mainloop`.

```
root.config(menu=menubar)
```

With these two changes the user can dynamically alter both the font and the size of the text displayed.

## Telephone Database Updated

Our next example improves the telephone database application originally presented in Chapter 5 by giving it a graphical user interface. As in the chapter 5 application, the example will use the `shelve` module to provide persistence to values between sessions. The window for this application looks like the following:



The command to be performed is indicated by a series of *radio buttons*. A radio button allows only one command to be pressed at a time. When the button is pressed a variable is changed and a callback function is invoked. The key field used for indexing or inserting a value into the database is specified by a widget of type `Entry`, while the text of the value stored is a widget of type `Text`.

This example also uses a more complicated layout manager, called a grid layout. The pack layout, used in the earlier examples, placed widgets one on top of another top to bottom. The grid layout allows the programmer to specify the location of widgets within a grid of components. Each component is assigned a row and column number within this grid. Components are allowed to span over several grid cells. For example, the entry component spans three different cells.

```
import shelve
from Tkinter import *

data = shelve.open("database")
root = Tk()
root.geometry("400x200")
root.title("Telephone Database")

# make some of the widgets
cmd = IntVar()
lab = Label(root, text="Command:")
k1 = Label(root, text="key/search")
ke = Entry(root, width=40)
v1 = Label(root, text="value")
ve = Text(root, width=40, height=5)

def doRadio():
    c = cmd.get() # get the command number
    if c == 1: # search
        ve.delete("1.0", END)
        if data.has_key(ke.get()):
            ve.insert(END, data[ke.get()])
        else:
            ve.insert(END, "no information for key" + ke.get())
    elif c == 2: # insert
        data[ke.get()] = ve.get("1.0", END)
        ve.delete("1.0", END)
        ve.insert(END, "database has been updated")
    else: # delete
        del data[ke.get()]
        ve.delete("1.0", END)
        ve.insert(END, "entry has been deleted")

# finish making widgets
r1=Radiobutton(root,text="Find",variable=cmd,value=1, command=doRadio)
r2=Radiobutton(root,text="Insert",variable=cmd,value=2,command=doRadio)
r3=Radiobutton(root,text="Delete",variable=cmd,value=3,command=doRadio)

# lay out the grid
lab.grid(row=0, column=0)
r1.grid(row=0, column=1)
r2.grid(row=0, column=2)
r3.grid(row=0, column=3)
k1.grid(row=1, column=0)
ke.grid(row=1, column=1, columnspan=3)
v1.grid(row=2, column=0)
ve.grid(row=2, column=1, columnspan=3)

# loop over main program, save database after user quits
```

```
root.mainloop()
data.close()
```

Do not try to mix the pack and grid layout commands. Doing so invariably results in the windowing system falling into a loop. If you feel you need to mix the two styles, place the grid items into a Frame (see next section), then pack the frame into the outer window.

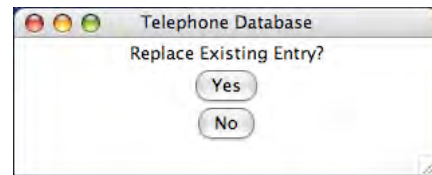
There are only a few statements in the program that are different from those seen in earlier examples. The radio buttons communicate with their call back function by means of a global variable of type IntVar. An Intvar can be set and read. There are similar widgets named StringVar and DoubleVar for storing and retrieving string and floating point values.

Insertions and deletions in the text component are specified by a string that indicates a row and column location. The initial location is given by the string "1.0". This indicates the zero character in the first line. The end of the text area is described by the symbolic constant END. Specifying these two values to the delete command will erase the value stored in the component. Alternatively, specifying these two values in the get method will return the entire text string.

Finally, we here for the first time see a statement appearing after the call on mainloop. This statement will be executed after the user has halted the program by hitting the close button on the main window. In this case, the statement is closing the shelf database.

## Adding a Dialog

Hitting the insert radio button changes the entry stored in the database under the given key. This has the effect of erasing anything stored previously under the key. This might be the intended behavior; but, on the other hand, it might not. If there is an existing entry, it might be prudent to ask the user whether or not they really want to overwrite it.



In the GUI convention, this type of action is performed by a dialog. A *dialog* is a special type of window, which appears when the system requires further information from the user before it can proceed. Execution halts until the dialog is answered.

We can implement a dialog by creating a special class for the window:

```
class YesNoDialog (Toplevel):
    def __init__ (self, par, t, var):
        Toplevel.__init__(self, par)
        self.geometry("300x300")
        self.parent = par
        self.var = var
        f = Frame(self)
        lab = Label(f, text=t)
        byes = Button(f, text="Yes", command=self.ok)
        bno = Button(f, text="No", command=self.notok)
```

```

        lab.pack()
        byes.pack()
        bno.pack()
        f.pack()
        self.wait_window(self)
    def ok (self):
        self.var.set("yes")
        self.parent.focus_set()
        self.destroy()
    def notok (self):
        self.var.set("no")
        self.parent.focus_set()
        self.destroy()

```

This class inherits behavior from a Tkinter class named Toplevel, used to create top level windows. The constructor for the dialog takes as argument the parent window (in our case, the root window), the text to be displayed, and an instance of StringVar through which the result will be passed back to the application. A Frame is created to hold the components of our dialog. Our dialog will consist of a label, and two buttons marked “yes” and “no”. When an instance of the dialog is created, it suspends execution of the main window and shifts focus to itself by means of the function named wait\_window. After the user hits one of the buttons, the string variable is set, the focus returned to the parent class, and the window is destroyed.

To create a dialog, the programmer first creates a string variable, then creates an instance of class YesNoDialog. The constructor for the latter will not complete until the user has addressed the dialog. After this, testing the value of the string variable will indicate the user's response:

```

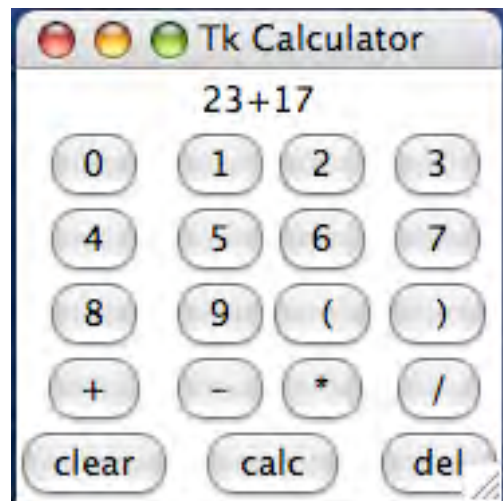
yesNoVar = StringVar()
YesNoDialog(root, "Overwrite existing entry?", yesNoVar)
if yesNoVar.get() == 'yes':
    ...

```

## Calculator Program

The final example program we present updates the calculator originally described in Chapter 9, placing a graphical user interface on top of the calculator engine. Once again we will use a grid component, and a number of buttons. In this example we have placed the GUI creation in the constructor for a class, in keeping with the object-oriented theme of the calculator program created in Chapter 9.

Because the majority of the buttons differ from each other only in the text they specify, we have here defined the call back functions using



lambda expressions. The lambda can, in turn, invoke a method in the class, passing the character for the button as argument to the method. The alternative would have required defining a separate method for each button. The clear and delete buttons both manipulate the string variable used by the label. The calculate button is slightly larger than the others. When pressed, the calculate button passes the text in the label to the calculator engine developed in Chapter 9. (Here we have assumed that the calculator program has been repackaged as a module, named Calc. Modifications to remove the two lines that start the textual application were described in Chapter 10). The value returned by this function is then placed into the label variable. This is in keeping with the themes of community and software reused developed in that chapter. Having written the calculator program, there is no reason to reinvent that program. Instead, we can simply use it as a service provided to the CalcGui class.

```
from Tkinter import *
import Calc

root = Tk()
root.title("Tk Calculator")

class CalcGui (object):
    def __init__ (self):
        # load the calculator engine
        self.calcEngine = Calc.Calculator()
        # now create the gui
        self.labelString = StringVar()
        lab = Label(root, textvariable=self.labelString)
        b0 =Button(root,text="0",command=lambda: self.buttonAction('0'))
        b1 =Button(root,text="1",command=lambda: self.buttonAction('1'))
        b2 =Button(root,text="2",command=lambda: self.buttonAction('2'))
        b3 =Button(root,text="3",command=lambda: self.buttonAction('3'))
        b4 =Button(root,text="4",command=lambda: self.buttonAction('4'))
        b5 =Button(root,text="5",command=lambda: self.buttonAction('5'))
        b6 =Button(root,text="6",command=lambda: self.buttonAction('6'))
        b7 =Button(root,text="7",command=lambda: self.buttonAction('7'))
        b8 =Button(root,text="8",command=lambda: self.buttonAction('8'))
        b9 =Button(root,text="9",command=lambda: self.buttonAction('9'))
        blp=Button(root,text=" ( ",command=lambda:self.buttonAction('('))
        brp=Button(root,text=" )",command=lambda:self.buttonAction(')'))
        bplus=Button(root,text="+",command=lambda:self.buttonAction('+'))
        bminus=Button(root,text="-",command=lambda:self.buttonAction('-'))

        btimes=Button(root,text="*",command=lambda:self.buttonAction('*'))
        bdivide=Button(root,text="/",command=lambda: self.buttonAction(
        '/'))

        bclear= Button(root, text="clear", command=self.doClearButton)
        bcal = Button(root, text="calc", command=self.doCalcButton)
        bdel = Button(root, text="del", command=self.doDelButton)
        lab.grid(row=0, column=0, columnspan=4)
        b0.grid(row=1, column=0)
        b1.grid(row=1, column=1)
        b2.grid(row=1, column=2)
        b3.grid(row=1, column=3)
        b4.grid(row=2, column=0)
        b5.grid(row=2, column=1)
```

```

        b6.grid(row=2, column=2)
        b7.grid(row=2, column=3)
        b8.grid(row=3, column=0)
        b9.grid(row=3, column=1)
        blp.grid(row=3, column=2)
        brp.grid(row=3, column=3)
        bplus.grid(row=4, column=0)
        bminus.grid(row=4, column=1)
        btimes.grid(row=4, column=2)
        bdivide.grid(row=4, column=3)
        bclear.grid(row=5, column=0)
        bcal.grid(row=5, column=1, columnspan=2)
        bdel.grid(row=5, column=3)

    def buttonAction (self, c):
        self.labelString.set(self.labelString.get() + c)

    def doClearButton(self):
        self.labelString.set(" ")

    def doCalcButton(self):
        self.labelString.set(self.calcEngine.eval(self.labelString.get()))

    def doDelButton(self):
        self.labelString.set(self.labelString.get()[::-1])

if __name__ == "__main__": # only do if invoked as application
    c = CalcGui()
    root.mainloop()

```

## Further information on Tkinter

Basic information on Tkinter can be discovered using the Python system itself, and the online help facility (see Appendix A). Appendix A also includes a bare-bones description of the more basic Tkinter functions. For a more comprehensive tutorial, a google search using the words “Python Tkinter” will reveal a number of sources for information on using the Tkinter system in Python.

A larger collection of useful widgets have been developed on top of Tkinter and packaged as the *Python Megawidgets* library. These can be obtained from [pmw.sourceforge.net](http://pmw.sourceforge.net).

Alternative GUI toolkits for Python include the Python Gimp Toolkit ([www.daa.com.au/~james/puygtk](http://www.daa.com.au/~james/puygtk)) and the Python Open GL toolkit ([pyopengl.sourceforge.net](http://pyopengl.sourceforge.net)). The Jython system is a Python interpreter written entirely in Java. Because it is a Java program, it can access the Java windowing toolkits (both AWT and Swing). An alternative way to put a graphical interface on a program is to use a web browser. This possibility is explored in a series of examples in Chapters x-y.

## Exercises



1. Try changing the size of the buttons in the hello world program using the options `width=n` and `height=n`. What is the effect? The description of the `Slide` widget showed how to make the component as wide as the window using the argument `pad=X` with the `pack` command. What happens if you do this with a button?
2. Another option for the `pack` command is `side=loc`, where *loc* is one of `LEFT`, `RIGHT`, `TOP`, `BOTTOM` or `CENTER`. Experiment using this option on the buttons from the hello world example and explain their effect.
3. Write a simple temperature conversion utility that consists of an entry field and two buttons. When the button labeled Celsius is pressed the entry field is converted from Fahrenheit to Celsius. Conversely, when the button labeled Fahrenheit is pressed the value is converted from Celsius to Fahrenheit.
4. Rewrite the temperature conversion utility to use a scale and a label. The user selects a temperature in Celsius using the scale, and the equivalent temperature in Fahrenheit is shown in the label.
5. The text of a button can be set using a `textvariable=var` option, rather than the `text=str`. This causes the current value of a `StringVar` to be the text displayed on the button. Modify the hello world program so that the text displayed at button down events can be set by an entry box.
6. As in the previous question, rewrite the Hello World program so that the text displayed when a mouse down occurs can be changed dynamically. However, this time add a menu bar and menu items so that the text can be selected from a variety of alternatives specified by a menu item.
7. Rewrite the application from the previous question so that one of the menu items produces a dialog box in which the user can enter the text to be displayed on mouse down events.
8. Rewrite the hello world that reacts to mouse events to use a grid layout rather than the pack layout. Place the two buttons side by side underneath the canvas widget.
9. Keypress events are captured in a similar fashion to mouse presses, by binding the root window using the selector `<KeyPress>` and a callback function. The callback is given a single argument of type `Event`. The field named `char` in this object holds the value of the key that was pressed. Create an application that captures key presses and displays the value as a string in a `Label` widget.
10. Add a search feature to the telephone database. When the search radio button is pressed, the text in the key field is used as a search pattern. The first entry in which the search pattern occurs is printed. If no entry in the database matches the search pattern a message is printed.

11. Using a grid layout, rewrite the yes/no dialog to place the buttons next to each other underneath the text message.
12. Using the different selectors for the bind method (see Appendix A), write a simple application that prints the location of mouse down, mouse motion, mouse enter and exit actions. Each event requires a different call back function. The function should simply print a message in a label box indicating the type of event that has occurred.
13. Try adding the following two lines to constructor for the dialog class. What do you predict they will do?

```
self.bind("<Return>", self.ok)
self.bind("<Escape>", self.notok)
```
14. Generalize the yes/no dialog by adding a pair of optional parameters that describe the text of the buttons. The optional values should be yes and no, but the user could replace these if they wanted with true/false or zero/or or any other binary choice.

## Case Study: Web Based Applications

In this chapter we begin the first of three case studies that explore one of the major application areas for Python programs, using Python in support of web-based programming. The application in this chapter will be purposely simple, a rewriting of the *Eliza* application first explored in Chapter xx. What will be different in this chapter will be that the application is initiated from a web page using a browser. Since the program is run from within the browser, the web browser is the graphical interface for this type of program.

In the following chapter we will develop a simple blog (a web log). A blog is a vehicle for one author (the *blog writer*) to share their ideas and opinions with many readers. In the third case study, in Chapter xx, we will develop a wiki. A wiki is a vehicle for many authors to cooperate in the publication of information.

### Client/Server Computing

All three of these applications are initiated from commands embedded in a web page. Since web pages can be shared, this style of operation means that users can be anywhere in the world; all that is needed is a web browser connected to the internet. The computer on which the user (the web browser) is running is different from the computer in which the Python program is executed. This style of execution is known as *client/server computing*. The client/server model is a simple way to allow sharing between two or more computers across a network. The end user runs an application, typically a web browser, on one computer; the client machine. This application sends a request for information (for example, a request for a web page) to another computer, the server. The server bundles the response for the information, such as the web page, and sends it back to the client. The client computer then formats and displays the response.

picture

A client/server application must be viewed in several parts. There will be the code that runs on the client machine, the code that will run on the server machine, and the commands that will be transferred between the two.

Web pages are normally represented by files stored in a particular location, often a directory named `public_html`. A special application named the *web server* runs on the server machine. This application accepts requests for web pages, and returns the file containing the commands for the web page.

Programs that are intended to be run in response to commands originated in web servers are often termed *cgi-bin* programs. The term *cgi-bin* stands for “common gateway interface binary”, and describes the protocol that such programs use to communicate with each other. Cgi-bin programs frequently must be stored in a particular directory, such as a directory in the `public_html` area named `cgi_bin`. The details vary from system to system

depending upon how your web server has been configured. You should consult your system administrator for details on your particular installation.

## html formatting commands

As we noted earlier, web pages are simply text files. What makes them unique is that they are stored in a particular location (typically a directory named `public_html`) that is known to the web server. Secondly, web pages are written using commands that are read by the web browser in order to determine formatting. These commands are known as html (short for hyper-text mark-up language). The source for a typical web page looks like the following. This source would produce the image shown on the right.

```
<html>
<title>An Example Web Page</title>
<body>
<h1>A Simple Web page!</h1>
<p>
Hello. This is a simple web page
</body>
</html>
```



Notice that the commands for the web page consist of a series of commands, called *tags*. Some of these tags come in matched pairs. For example, the tag `<h1>` creates a heading. The end of the heading is indicated by the tag `</h1>`.

There are many applications that allow a user to create web pages without knowing the html commands used to represent the information. Browsers will often include these features, so that the same application can be used to format and create web pages. Often these applications allow the user to toggle between the graphical view and the html view. You might experiment with such a system in order to see how html commands are used to describe a variety of different representations.

This chapter will not describe html commands, although neither will we use very complicated commands. Many readers will already be familiar with html, and numerous tutorials are readily available on the web or in books.

## Form based Web Pages

One of the simplest varieties of interaction with a web page is constructed using *forms*. A form allows the programmer to place on a web page graphical elements, such as text boxes and buttons. The form then specifies the name of a program that should be executed on the server side to handle the values entered into the form. The form for our eliza application is as follows:

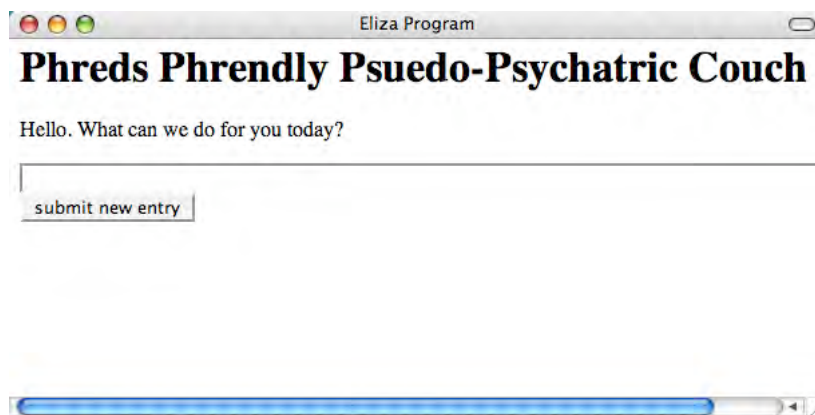
```
<html>
<title>Eliza Program</title>
```

```

<body>
<h1>Phreds Phrendly Pseudo-Psychiatric Couch</h1>
<p>
<form action = "/cgi-bin/cgiwrap/~lisa/eliza.py" method="GET">
<p>
Hello. What can we do for you today?
<p>
<input type="text" name="line" size="80">
<br>
<input type="submit" value="submit new entry">
</form>
</body>
</html>

```

The html commands shown will produce a web page that looks like the following:



The *action* entry in the form tag is telling the web browser the name of the program to run in response to the command. The text shown here is using `cgiwrap`, which is a popular tool for running `cgi-bin` scripts in a university setting. This command will run the program named `eliza.py` (a Python program) that is in the directory belonging to a programmer named `lisa`. You should consult your system administrator for the commands that are appropriate to your web server installation.

The program `eliza.py` is a python program, but it is a python program that must produce html commands. The fact that there are two languages being mixed in the same file is a frequent source of confusion for new users. The html commands are simply generated by a series of print statements. The program can be written as follows:

```

#!/usr/local/bin/python
import cgi
import string

def getReply (line, words):
    # find a reply based on the words
    # ... as in Chapter xx
    return "Tell me more. "

```

```

print "Content-type: text/html"
print
print "<html><body>"
print "<title>Eliza Program</title>"
print "<h1>Couch</h1>"

form = cgi.FieldStorage()

    # figure out our reply
line = form['line'].value
print '<p><i>' + line + '</i>'
reply = getReply(line, string.split(line))

print '<p> <form action = "/cgi-bin/cgiwrap/~lisa/eliza.py"
method="GET">'
print '<p><i>' + line + '</i>'
print '<p>' + reply
print '<p> <input type="text" name="line" size="80">'
print '<br> <input type="submit" value="submit new entry">'
print '</form> </body>'
print '</html>'

```

The comment on the first line is a convention that tells the web server the correct utility program (in this case, the python interpreter) to run in order to process this file. Once again, the exact location of the python interpreter may vary from system to system, and so you should ask your system administrator for the correct form of this instruction. This is followed by a pair of import statements for the libraries to include, and a function definition. The function definition is taken from Chapter xx, and is not repeated here.

The initial print statements, after the imports and the function definition, simply produce the html header commands. Compare this with the header commands in the original html script. Preceding this is a line with the text “Content-type: text/html”. This line informs the web browser that the remainder of the output should be interpreted as html commands.

The cgi module provides a simple way to get hold of the contents the user placed in the cgi fields. These values are placed into a dictionary by the command `cgi.FieldStorage()`. The program shows how to access the text written in the text box marked (in the original form) with the name ‘line’.

The processing of this line of input is exactly the same as the processing of the line of input in the eliza program examined in Chapter xx. A response is produced and presented to the user, at the same time requesting a new line of input. So that the user can continue the conversation indefinitely, print statements are used to produce a new form. This new form matches exactly the form used in the original web page. If the user now types a new response, the same program will be invoked, which will produce a new web page, and so on ad infinitum.

## Triple Quote Strings

Notice how the cgi-bin program begins with a series of print statements. These can be reduced to a single statement using a special form of string constant. A triple-quoted string, as the name suggests, begins and ends with three quote marks. However, unlike other string literals, a triple quoted string is allowed to span multiple lines. It is also allowed to include other quote characters (both single and double).

The starting print statement for the application could be written using triple quotes as follows:

```
print '''Content-type: text/html

<html><body>
<title>my-blog</title>
<h1>Couch</h1>'''
```

The entire five lines of output are represented by a single string. A similar string can be used to print the standard text that terminates the web page. Another common use for triple quoted strings is to represent literal values that include both single and double quotes:

```
line = '''He said: "don't do it!" '''
```

## Debugging cgi-bin programs

Because cgi-bin programs are normally both invoked and viewed through a web browser, they can be annoyingly difficult to debug. The following tricks can help save you many hours of frustration.

First, while the command `cgi.FieldStorage` will only make sense when run from a web browser, the majority of the rest of the application is simply a Python program. This means it can be run from your Python interpreter, like any other Python program. To avoid error messages from the cgi commands, simply replace these commands with a comment, and substitute a dummy assignment during the process of debugging. This might look like the following:

```
# remove the user of the cgi module for now
# form = cgi.FieldStorage()
# line = form['line'].value
# the following is simply a dummy value
line = "You look like my mother"
```

Now the program can be run directly from the command line:

```
python eliza.py
```

Doing this will allow you to discover the vast majority of syntax and logic errors before you ever start trying to connect the program to the web browser.

But even when your python program runs without compiler error messages, it can still have errors that are difficult to detect when placed into use. In part this is because the output must be expressed as html commands. This can complicate the common debugging trick of writing out values using print statements. A simple solution is to use the html tags for preformatted text, `<pre>` and `</pre>`. Anything that appears between these two tags is simply displayed by the web browser. So a typical session might have commands such as the following:

```
# debugging commands, I need to find out these values
print '<pre>'
print 'the value coming in is' + form['line'].value
print '</pre>'
```

Run time error messages are sent to `sys.stderr`, which is sometimes ignored by web browsers. These messages can be diverted into the standard output using the command

```
sys.stderr = sys.stdout
```

Placing this line before some commands that you suspect might be producing an error, and placing the entire contents within a pre command (so that any output is displayed) can be very effective.

```
print '<pre>'
sys.stderr = sys.stdout
... # some Python commands you suspect might produce an error
print '</pre>'
```

Now any error message that are produced will be formatted as html commands by the browser.

## Exercises

1. Explore various other html commands. What does the command `<i>text</i>` do? How about the `<b>text</b>` command? How do you produce a numbered list in html? A bulleted list?
2. Write a form that asks the user for a name, and then invokes a python program that produces the lyrics for the name game song. The name game, you will remember, takes a name, such as “sally”, and places it in a rhyme such as the following: “Sally Sally bo Bally! Bananna fanna fo Fally! Fee fi mo Mally! SALLY!”
3. Explore using triple quotes in interactive mode. What can you do with triple quotes that you cannot do with single or double quotes?
4. Explore various other types of html form elements. These include buttons, text lines, text boxes, check boxes, radio button, and pull down menus.



## Case Study: A Simple Blog

In this case study we will continue our exploration of applications that use the internet, and employ a web browser for their graphical interface. In this chapter we will create a simple blog for a programmer named Tina. Unlike the eliza program examined in the previous chapter, the blog will allow multiple different actions. To illustrate an alternative way to structure an application, rather than a single Python program each of these actions will each be represented by separate Python programs.

The term *blog* is short for web-log. A blog is a vehicle for one author (the *blog writer*) to share their ideas and opinions with many readers. This can be contrasted to a *wiki*, which we will describe in Chapter xx. A wiki is a vehicle for many authors to cooperate in the publication of information. Simple blogs can be thought of as a form of public, on-line diary, with readership limited to the author and a few friends. At the other extreme, popular blogs become almost like newspaper columns, with loyal readers looking forward to regular (sometimes daily) postings. Blogs vary greatly in the quality of presentation, as well as writing. Complicated blogs can incorporate pictures, sound, movement, and complex layout, while simple blogs are nothing more than a series of text entries. In this chapter we will create a relatively simple blog, and suggest a number of improvements that readers can make on their own.

As with the eliza program, execution for our blog begins with a web page. The web page has a simple appearance as follows:



The text for this web page is as follows:

```
<html>
<title>Tina Smith's Web Log</title>
<body>
<h1>Welcome to Tina's World</h1>
<p>
From this page you can read Tina's blog and,
if you are on Tina's machine, you can create new entries.
<p>
<form action = "/cgi-bin/cgiwrap/~tina/tinablog/read.py" method="GET">
```

```

<input type="submit" value="Read Tina's Blog">
</form>
<p>
<form action = "/cgi-bin/cgiwrap/~tina/tinablog/newentry.py"
method="GET">
<input type="submit" value="Submit New Entry">
</form>
</body>
</html>

```

As in the previous chapter, forms are used to specify a program to be executed when a button has been pressed. In this application each button is described by its own form. This allows the two different buttons to invoke different forms. The first button is used to read the entries in the blog, and the second is used to create a new entry. As described in the previous chapter, each form is matched to a Python program that will be executed to process the contents of the form. These Python programs must exist in a specific directory (frequently called cgi-bin) in Tina's web page area. In order to simplify the management of these programs Tina has placed them in a subdirectory, named tinablog.

We will explore the second program first. The program newentry.py (shown below) uses a module we have not seen before. The module os provides information about the operating system on which a Python program is being executed. In this case, we only want the program to work if it is running on Tina's personal machine. (In the exercises we will suggest various other ways to keep other people from making new entries).

```

#!/usr/local/bin/python
import cgi
import os

print '''Content-type: text/html

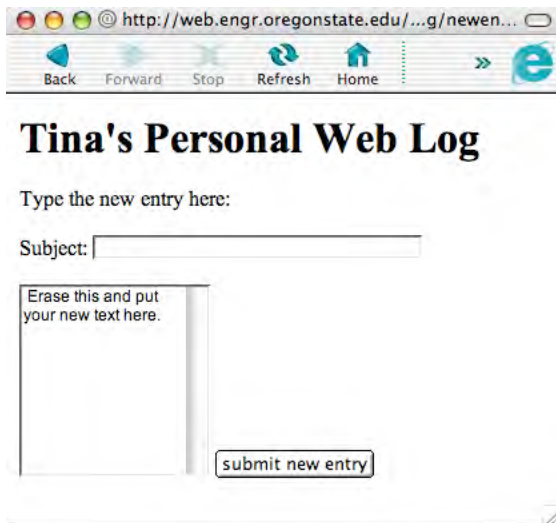
<html>
<body>
<h1>Tina's Personal Web Log</h1>'''

if os.environ['REMOTE_HOST'] == "tina.stateuniversity.edu":
    # read the existing database
    print '''Type the new entry here:
    <p>
    <form action = "/cgi-bin/cgiwrap/~tina/tinablog/submit.py"
method="GET">
    Subject: <input name="subject" size="40">
    <p>
    <textarea name="text" rows="10" columns="80">
    Erase this and put your new text here.
    </textarea>
    <input type="submit" value="submit new entry">
    </form>'''
else:
    print "<p>sorry, Tina only allows submissions from her machine"

print '''</body></html>'''

```

Assuming that the program is running on Tina's machine, a new form is created. This form allows the user to type a subject and the text for a new entry. These commands produce a web page that looks like the following:



When Tina hits the submit button, the program `submit.py` is executed. This program has the following definition:

```
#!/usr/local/bin/python
import cgi
import os
import time
import shelve

print '''Content-type: text/html

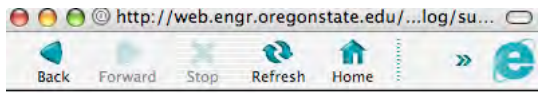
<html>
<body>
<h1>Tina's Personal Web Log</h1>'''

if os.environ['REMOTE_HOST'] == "tina.stateuniversity.edu":
    # get the form values and the database
    form = cgi.FieldStorage()
    dbase = shelve.open("database")
    # place the value into the database
    dbase[str(time.time())] = (form['subject'].value,
form['text'].value)
    # print a reassuring message
    print "<p>Your message has been added to Tina's blog"
else:
    print "<p>sorry, Tina only allows submissions from her machine"

print '''</body></html>'''
```

In addition to using the `os` module to restrict execution to Tina's machine, this program uses another new module, named `time`. The `time` module provides access to various functions dealing with times and dates. In this case, we will use the current time (a value

accessed by `time.time()`) as the key for the database. Since keys must be immutable, the value returned by the time function is converted into a string. Using time as a key ensures that no two entries will have the same key, and also makes it easy to sort the entries into chronological order. The `shelve` module, described in Chapter x, is used to provide a persistent storage area. The subject and the text are combined into a tuple that is stored in this database. If everything works successfully, a reassuring message is presented to the user.



## Tina's Personal Web Log

Your message has been added to Tina's blog



The final Python program for the blog application is used to read and display the previously entered contents of the blog. This program simply loads the database produced by the `shelve` module, and formats each entry.

```
#!/usr/local/bin/python
import cgi
import shelve
import time

print '''Content-type: text/html

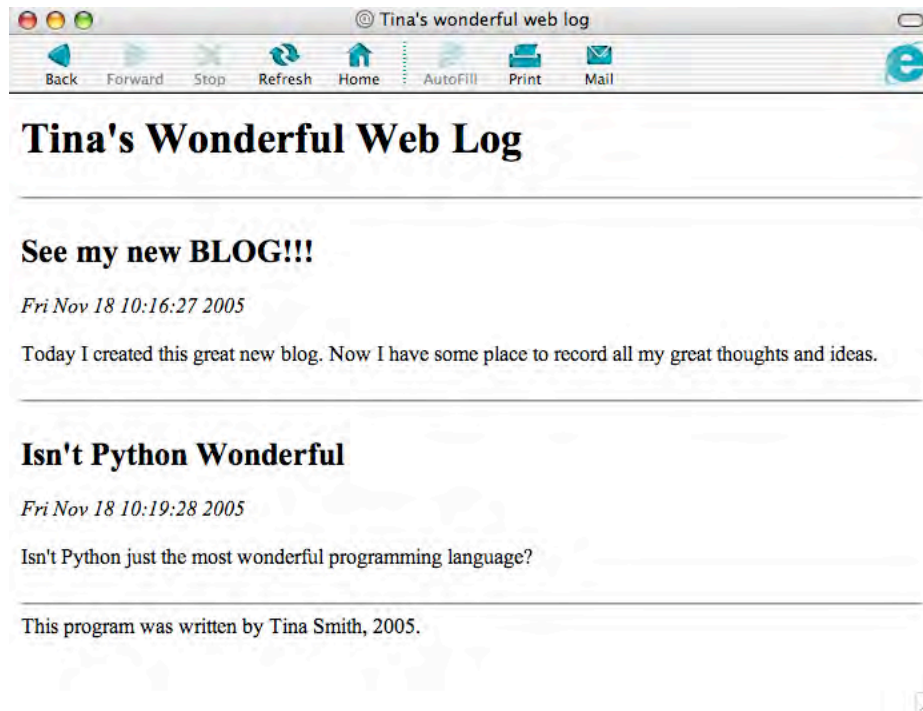
<html>
<title>Tina's wonderful web log</title>
<body>
<h1>Tina's Wonderful Web Log</h1>'''

form = cgi.FieldStorage()
dbase = shelve.open("database")

for entry in dbase.keys():
    # get time entry was placed
    t = float(entry)
    # get text of entry
    (subject, text) = dbase[entry]
    # now print it out
    print "<hr><h2>", subject, "</h2>"
    print "<p><i>" + time.ctime(t) + "</i>"
    print "<p>", text
    print "<p>"

print '''<hr>
This program was written by Tina Smith, 2005.
</body></html>'''
```

A method in the time module can be used to convert the time value (which is stored as a floating-point value) into a more human readable string. The database entry is separated into the subject and text portions, and each are displayed with appropriate formatting strings. Output from Tina's blog might look as follows:



In the exercises we will suggest several different variations you might want to make for this simple blog. In programming these exercises you would be well advised to reread the suggestions presented in the previous chapter on debugging cgi-bin programs.

## Exercises

1. Tina's blog ensures that only Tina can make new entries by now allowing input unless it is from a specific machine. This both too restrictive, since Tina may work on many different machines, and not restrictive enough, since several different users may work on Tina's machine. An alternative is to use a password. A password can be simply a text box on the original page. Instead of checking the machine, check the contents of the password box and only permit the entry if it matches a specific value.
2. The new entry page will fail if the user does not type any text in the subject area. This can be easily checked by seeing if the form has an entry for the value 'subject'. Add this test, and if no subject was typed use the default text '(no subject)'

3. Many blogs allow only the author to create new entries, but allow anybody else to make a comment entry. Add the ability to make comments by adding a button marked “comment” that will produce a new web page allowing the user to enter comment material. This information is then stored in a third entry in the database. Comments should then be displayed along with the original entry.
4. The current implementation displays the entire blog in one large file. An alternative would be to display the subject lines only, making each into a button that when pressed displays only the given entry. Show how to implement this feature.
5. Having implemented the ability to display just one blog entry as described in the previous question, show how to add a feature that will allow users to search for a blog entry that contains a given search string. Do this by creating a new text line for the search text, then examining each blog entry in turn using a method such as `string.find()`. If the search string is found in the entry then display it.

## Case Study: A Wiki Web

A *blog*, such as the one created in the last chapter, is designed to let one writer share thoughts and opinions with many readers. A *wiki web*, on the other hand, is designed to allow many individuals to share in the creation of a common database of information. The most famous Wiki Web is the wikipedia (<http://wikipedia.org>) a free on-line encyclopedia containing articles on almost every imaginable topic. Anybody with a web browser can connect to the wikipedia and create a new entry that describes a topic of interest. Similarly, anybody can edit an article to correct errors (either grammatical or factual) or add further information. A community of readers for the wikipedia periodically examine recently altered articles to weed out inappropriate content, but such deletions are rare in comparison to the vast amount of useful information.

The wiki web we develop in this chapter is much simpler, and closer in spirit to the original wiki web (<http://c2.com/cgi/wiki/>). The basic idea of the wiki is that information is organized using topic words, termed *pattern words*. A pattern word is written as a single word with embedded capital letters, for example PatternWord. (This convention grew up in the context of the study of ideas termed design patterns, hence the name. However, the idea of the Wiki has since transcended its original use in the design pattern community). Each PatternWord is matched to a page, similar to a web page, that describes the idea or concept. These descriptions can themselves contain pattern words, which automatically become hyper-links to their associated page. The result is a collection of tightly interconnected web pages that mirror the way that information is connected.

The first page our Wiki will display is, by convention, named FrontPage. It might look as follows:



### FrontPage

Welcome to Python Wiki ([PyWiki](#) for short).

[PyWiki](#) is a resource for recording information on the [PythonProgrammingLanguage](#).

You can also find further information on [LibraryModules](#).

---

Commands: [edit FrontPage](#), [index](#)

---

Internet zone

Notice how the PatternWords on the page have been rendered as hyper-links. There are two special links at the bottom of the page, one for editing the current page and one for producing an index of all the current pages. If the user clicks on a link, such as the one for PyWiki, a new page will be produced.

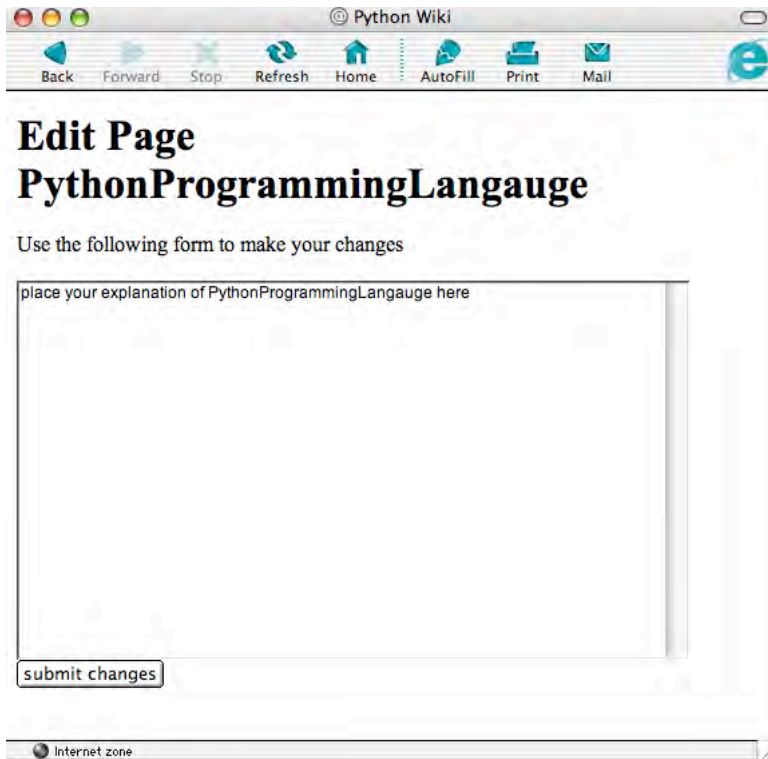


Pattern words can be written before the associated pages have been described. For example, suppose there does not yet exist any entry for PythonProgrammingLangaugue. Clicking on that link will produce the following:



By clicking on the button marked *edit* at the bottom of the page, the user can produce a form that will allow the creation of a new page.





By typing in the text area, the user can create their own description of the topic PythonProgrammingLangaue. Simple conventions are used for formatting. A blank line will be formatted as the start of a new paragraph. A line consisting of two dashes (--) will be formatted as a horizontal bar.

When they are finished typing, they then hit the submit changes button. This produces the following window.



The last window to display occurs when the user types the index command. This produces a window containing all currently recognized pattern words in the wiki:



## Index of PyWiki Entries

Click on an entry to view page

[FrontPage](#)  
[PyWiki](#)  
[PythonProgrammingLangauge](#)

The key feature of the wiki is that anybody with a web browser can enter changes, and by doing so add information to the wiki. The result is an ever changing and growing document that captures knowledge from an entire community of users, rather than simply one individual.

## Implementing our Wiki

The implementation of our wiki, like the previous two case studies, begins with a web page. In our case the web page will simply provide a link to the first python program:

```
<html>
<body>
<h1>Python Wiki</h1>
<p>
Click <a href="/cgi-bin/cgiwrap/~lisa/pywiki/wiki.py">here</a> to
enter the world of Python Wiki.
</body>
</html>
```

As in the previous chapter, the Python program must be placed in a cgi-bin directory. We have grouped the several python scripts that will be used in this application into a directory named pywiki. A subdirectory in this directory, named db (for database), will contain files for each of the pattern words.

The file wiki.py is the heart of the application. It is a program with a simple structure, although it uses a few features we have not yet explored.

```
#!/usr/local/bin/python
#
# pyWiki main page
#
import re
import cgi

# create regular expression patterns to match input lines
pat1 = re.compile('^$') # empty line
pat2 = re.compile('^--$') # line of dashes
pat3 = re.compile('([A-Z][a-z0-9]+([A-Z][a-z0-9]+)+)') # pattern word

print '''Content-type: text/html

<html>
```

```

<title>Python Wiki</title>
<body>'''

# get our page number
form = cgi.FieldStorage()
if form.has_key('page'):
    page = form['page'].value
else:
    page = 'FrontPage'

print '<h1>' + page + '</h1><p>'
# try to open file
try:
    fileName = "db/" + page
    f = open(fileName, 'r')
    for line in f:
        line = line.rstrip()
        if pat1.search(line): print '<p>'
        elif pat2.search(line): print '<hr>'
        elif pat3.search(line):
            print pat3.sub(r'<a href="wiki.py?page=\1">\1</a>', line)
        else: print line
except:
    print '<p>Sorry. There is no page named ' + page
else:
    f.close()

# no matter what, give opportunity to edit it
print '<hr><p>Commands: <a href="edit.py?page=' + page + '">edit ' +
page + '</a>, <a href="index.py">index</a>'
print '''</body></html>'''

```

The new feature used in this program is the *regular expression* package, found in the module named `re`. Regular expressions were discussed briefly in Chapter 11. Ignoring the regular expressions, the structure of the program is very simple. It prints the standard prolog for all web pages. It then looks to see if there is any cgi form value with the name 'page'. If not, the default value 'FrontPage' is used. A try block then attempts to open a file with the given name in a directory of files named "db". If this fails (typically because the file does not exist) then a message is produced telling the user that no information can be found. If the file open succeeds then the file is read, and each line is individually formatted. At the end a pair of print statements are used to produce html commands for invoking a script named `edit.py` and for ending the web page.

Notice the particular form for the anchor in the html commands produced at the end. This line is producing an anchor that might look as follows:

```
<a href="edit.py?page=PiWiki">edit PiWiki</a>
```

The information following the question mark is an argument that is being passed to the script `edit.py`. The value of this argument is accessed using the same `cgi.fieldStorage` mechanism used to access values entered in a form.

## Regular Expressions

As we explored in Chapter 11, regular expressions are a technique for defining patterns used in the process of searching a text string. A pattern can be a simple string, for example, searching for the starting location of the string “sip” in the word “Mississippi”. Or a pattern can be much more complex, such as finding the location of the first doubled-letter that is followed by a vowel and then followed by another doubled-letter.

The variables `pat1`, `pat2`, and `pat3` in our `wiki` program represent three different regular expression patterns. The first pattern is `'^$',` This matches the start of a string followed by the end of a string, that is, an empty string. Since the strings in question are going to be lines read from a file, this will match an empty line. The second pattern is `^--$'`. This matches lines consisting of two dash marks and nothing more. The third pattern, used to find pattern words, is by far the most complex. It is `'([A-Z][a-z0-9]+([A-Z][a-z0-9]+)+)'`. Let us analyze this pattern in steps. The pattern `[A-Z]` matches a capital letter. The pattern `[a-z0-9]+` matches a run of one or more lower case letters or numbers. The pattern `([A-Z][a-z0-9]+)+` represents one or more capital letters followed by a sequence of one or more lower case letters. Appending the latter to the former produces a pattern that matches *two* or more capital letters followed by lower case letters, that is, a pattern word. These are surrounded by an additional set of parenthesis to form what is termed a *group*.

The regular expression module (named `re`) provides a number of useful functions for manipulating strings using regular expressions. The function `re.compile` translates a string representing a regular expression into an internal form called a *pattern*. The function `pat.search`, where `pat` is a pattern, returns a value that is nonempty if a pattern can be matched in a string. We are here simply using the result of this function in a conditional statement, however the value can also be used to find the starting and ending position of the match.

The loop at the heart of our program examines each line of the file in turn. If an empty line is found an html paragraph start tag (`<p>`) is printed. If a pair of dashes is found a horizontal line tag (`<hr>`) is printed. The third pattern, looking for `PatternWords`, is more complicated.

The function `pat.sub` is used to replace all non-overlapping occurrences of a pattern with another value. The first argument in the latter is the replacement string, while the second is the string to be examined. The replacement string can be a simple string, or it can include values of the form `\n`, where `n` is a number. The latter are used to indicate groups from the matched string. In this case, we are using the value `\1` to find the text of the pattern word. A pattern word is replaced by an html anchor of the form

```
<a href="wiki.py?page=PatternWord">PatternWord</a>
```

Notice how the pattern word appears twice in the replacement. If none of the three patterns match in a line, the line is simply printed. The remainder of the application is similar to the case studies presented in the previous chapters.

## The edit Page

If the user selects the *edit* button at the bottom of a wiki page, the following application is invoked:

```
#!/usr/local/bin/python
#
# PyWiki edit page interface
#
import cgi

print '''Content-type: text/html

<html>
<title>Python Wiki</title>
<body>'''

# get our page number
form = cgi.FieldStorage()
if form.has_key('page'):
    page = form['page'].value
else:
    page = 'FrontPage'

print '<h1>Edit Page ' + page + '</h1>'

print '''<p>Use the following form to make your changes
<p><form action="/cgi-bin/cgiwrap/~budd/pywiki/submit.py" method="GET"
border=2>
<textarea name="content" rows="20" cols="80">'''

# keep text if we know it
try:
    fileName = "db/" + page
    f = open(fileName, 'r')
    for line in f.readlines():
        print line.rstrip()
except:
    print 'place your explanation of ' + page + ' here'

print '''</textarea>
<br><input type="submit" value="submit changes">'''
print '<input type="hidden" name="page" value="' + page + '">'
print '</form>'

print '''</body></html>'''
```

This Python program is very similar to those we have seen in the previous two chapters. It produces standard html for a header. This is followed by a form that includes a text box in which the user can make changes. This text box is initialized either with the current text of the file that describes the pattern word (if the file exists), or by a sentence of instructions (if the file does not yet exist). The application ends by emitting the standard html instructions for the end of a page.

When the user hits the submit button, the following application is invoked:

```

#!/usr/local/bin/python
#
# wiki submit edits interface
#
import cgi

print '''Content-type: text/html

<html>
<title>Python Wiki</title>
<body>'''

# get our page number
form = cgi.FieldStorage()
if form.has_key('page'):
    page = form['page'].value
else:
    page = 'missing page'
if form.has_key('content'):
    content = form['content'].value
else:
    content = ''

print '<h1>Change Page ' + page + '</h1>'

# open file and make changes
try:
    fileName = "db/" + page
    f = open(fileName, "w")
    f.write(content)
    print '<p>Your changes have been entered'
except:
    print '<p>Your changes failed for some reason'

print '<p>Click <a href="/cgi-bin/cgiwrap/~budd/pywiki/wiki.py?page=' +
page + '">here</a>'
print 'to see updated contents of page ' + page

print '''</body></html>'''

```

This program simply saves the entered text, producing either a simple message indicating everything was successful, or a warning message if for some reason the file could not be written.

## The index Application

All that remains is the application that produces an index of those pattern words that currently exist in the database. This application is as follows:

```

#!/usr/local/bin/python
#
# wiki index interface
# produce index page of all entries
#

```

```

import glob

print '''Content-type: text/html

<html>
<title>Python Wiki</title>
<body>
<h1>Index of PyWiki Entries</h1>
<p>Click on an entry to view page<p>'''

# files, read file names, strip off directory name
files = [x[3:] for x in glob.glob('db/*')]
files.sort()
for name in files:
    print '<br><a href="wiki.py?page='+name+'">'+name+'</a>'

print '''</body></html>'''

```

The glob module is useful for finding file names in a directory. The argument string represents a directory name, with the \* character representing a “wild card”, which can be matched by anything. The result will be a list of file names that match the string. In our application, file names have a one-to-one correspondence with pattern words. The command x[3:] is used to strip off the first three character, that is the text “db/”. This list of names is sorted, so that the patterns are in alphabetical order. A loop is then used to produce html tags that will, when pressed, link the user to the appropriate page.

That’s it. With four small Python programs we have created our completed Wiki Web application. The following exercises will help explore some of the ideas introduced in this chapter.

## Exercises

1. One problem with the PatternWord convention is that it can frequently make the English in a sentence sound awkward. For example, the PatternWord may be a singular noun, and it is used in a sentence that requires a plural value. One solution is to separate the PatternWord used as an identification and the representation of the word in the text. This could be done as a pattern such as {PatternWord!textual form}. When a pattern such as this is found, the link is made to the pattern word, but it is printed using the alternative form: <a href=”wiki.py?page=PatternWord”>textual form</a>. Modify the wiki.py program to recognize words using this format.
2. Some wiki’s allow the user to enter html commands directly, such as using <i>text</i> to get italicized text. Other wiki’s do not. What is the behavior of the wiki described in this chapter? Can you think of arguments for and against this decision?
3. Add a pattern that looks for embedded urls of the form <http://web> page, and makes them into anchor tags.
4. Another common feature of wiki is a command to view recently changed pages, listed in order of their modification. To produce this, maintain a file named recentChanges. Each time a file is changed append a line to this file containing

the file name and date. Then implement a program that will be run in response to a command to view the recent changes. This program will take each line of the recent changes file and format it as a link to the correct wiki page.



## Chapter x: A Sudoku Solver

Sudoku is the name given to a popular logic puzzle. Each Sudoku puzzle is represented by a nine by nine grid, which is further subdivided into nine 3 by 3 blocks. Several of the cells are initially filled by values between 1 and 9. The objective is to fill the remaining cells with digits so that no digit is ever repeated in any column, row, or three-by-three block. An example Sudoku is shown at right.

				9		5	8	2
					2			
8	7			1	5	6		
2								5
	5	8				3	4	
7								9
		5	1	3			2	7
			6					
9	3	7		5				

In this chapter we will present a simple Sudoku solver. That is, a computer program written in Python that will solve simple Sudoku's, such as the one shown here. More complex examples of the genre require more subtle heuristics than those we will describe, although towards the end we outline some of the ways that this program could be improved. More importantly, the purpose of this example is to illustrate functional programming techniques, and in particular the use of list comprehensions in Python as an example of the ideas of functional programming.

### Representation

```
[[0,0,0,0,9,0,5,8,2],  
[0,0,0,0,0,2,0,0,0],  
[8,7,0,0,1,5,6,0,0],  
[2,0,0,0,0,0,0,0,5],  
[0,5,8,0,0,0,3,4,0],  
[7,0,0,0,0,0,0,0,9],  
[0,0,5,1,3,0,0,2,7],  
[0,0,0,6,0,0,0,0,0],  
[9,3,7,0,5,0,0,0,0]]
```

We start with defining a representation for the puzzle. As is typical in Python, a two dimensional matrix will be represented by a list in which each element is itself a list. The representation of the puzzle shown above is presented at left.

In order to make the program more general, the values will be read from a data file. In the data file each line will consist of nine characters, using 0 to represent a blank space. The task of reading such a file and creating the initial list can serve as a useful example comparing the task of writing list comprehensions to ordinary Python code. A first cut at a function to read the puzzle data might look as follows:

```
def readPuzzle(f): # f is input file  
    puzzle = []  
    for line in f.readlines():  
        row = []  
        for ch in line.rstrip():  
            row.append(int(ch))  
        puzzle.append(row)  
    return puzzle
```

You can read the logic of this function as follows. First, create an empty list for the final result. Then read the input file line by line. Create an empty row for this line of the puzzle. After stripping off the trailing newline character (an artifact of textual input), read the line character by character. Convert each character into an integer, and add it to the row list. After reading

the entire row, add the row list to the puzzle list. After reading each line of the input file, return the resulting puzzle list.

Any time you see the pattern

```
newlist = [ ]  
for ...:  
    newlist.append(...)
```

You have a situation that is ripe for replacement with a list comprehension. What the list comprehension does is to succinctly encode the creation of a new list through a process of transformation, by moving the loop from the outside to the inside of the expression. The inner loop of this function can be replaced by the following:

```
[ int(ch) for ch in line.rstrip()]
```

The list comprehension is shorter, eliminates one unnecessary variable, and clearly indicates that the objective of the process is to create a list, and that the list will contain integer values formed by transforming each character in the line.

Having transformed the inner loop, we can now do the same to the outer loop, resulting in the following one-line function definition:

```
def readPuzzle (f):  
    return [ [int(a) for a in list(line.rstrip())] for line in f.readlines()]
```

Once you learn to read list comprehensions, the resulting function is both considerably shorter, faster, and easier to understand.

## Accessing Puzzle Data

Having decided on the representation of the puzzle, the next step is to define functions that will return an individual row, and individual column, and an individual block. Each of these will return a list containing the indicated data. Both the column and block are converted into a list; for example the center right block of the puzzle is represented by the list [0,0,5,3,4,0,0,9]. The methods to compute these values will take the puzzle matrix as argument, since in a moment we will introduce a second matrix and will eventually want to perform the same data access on both.

There is a slight complication in that Python indexes lists starting from 0, and so the set of legal index values is 0 through 8, while the set of data values of interest is 1 through 9. This just means we need to be careful to distinguish index data from matrix data. The global values `r9` and `r19` help keep this distinction clear. The first is the set of index values (starting with zero), while the second is the set of data values (starting with one).

```

import sys

r9 = range(9)
r19 = range(1,10)

def readPuzzle(f):
    return [ [int(a) for a in list(line.rstrip())) for line in f.readlines()]

def row(i, grid):
    return grid[i]

def column(j, grid):
    return [grid[i][j] for i in r9]

def block(i,j, grid):
    return [grid[(i/3)*3+a][(j/3)*3+b] for a in range(3) for b in range(3)]

def missing(lst):
    return [x for x in r19 if x not in lst]

def possible(i,j):
    if puzzle[i][j]: return []
    else:
        return [x for x in r19 if x in missing(row(i, puzzle)) and
                x in missing(column(j, puzzle)) and x in missing(block(i,j, puzzle))]

def makePossibles():
    return [[possible(i,j) for j in r9] for i in r9]

def drop(lst, i):
    return [lst[j] for j in range(len(lst)) if i != j]

def flatten(lst):
    return [x for y in lst for x in y]

def checkAllBut(x, lst, pos):
    return x not in flatten(drop(lst, pos))

puzzle = readPuzzle(open(sys.argv[1]))
changed = True
while changed:
    changed = False
    possibles = makePossibles()
    for i in r9:
        for j in r9:
            if len(possibles[i][j]) == 1:
                puzzle[i][j] = possibles[i][j][0]
                changed = True
            for x in possibles[i][j]:
                if (checkAllBut(x, block(i, j, possibles), (i%3)*3 + j%3) or
                    checkAllBut(x, column(j, possibles), i) or
                    checkAllBut(x, row(i, possibles), j)):
                    changed = True
                    puzzle[i][j] = x

for I in r9: # print solution
    print puzzle[I]

```

## The Possibles Matrix

The first step in solving a Sudoku Puzzle is to compute the set of possible values for each square. Since values cannot be repeated in any row, column, or block the set of possibles is determined by starting with the values one through nine, then eliminating any value that occurs elsewhere in the row, column or block. We can once again use a list to represent the set of values. The initial possible sets for the center right block of our Sudoku is shown at right.

[1,7,8]	[1,6,7]	[]
[]	[]	[1,6]
[1,2,8]	[1,6]	[]

The computation of the possibles matrix illustrates another hallmark of functional program; the creation of general purpose functions that can be mixed and matched with each other to produce a variety of effects. The function `missing` takes as argument a list, and returns the list containing the values between 1 and 9 that are not in the argument list.

```
def missing (lst):  
    return [x for x in r19 if x not in lst]
```

By separating the computation of the missing data from the collection of the row, column or block data we make it possible to mix these operations, by passing different arguments to the function. This is illustrated by the function `possible`, which computes the possible set for a specific (i,j) pair. A value is possible if it is in the missing set for both the row and the column and the block. If the puzzle block is already filled, the possible set is empty. The function `makePossibles` uses the function `possible` to create a matrix of all the possible sets.

## A Solution Hueristic

If a possibles set contains just a single element, then that value must be the correct value for the cell. However, this fortuitous event does not occur very often; that would make the puzzle far too easy. However, another pattern can also be used to infer a value. If a value occurs in a possibles set, and does not occur in any other possibles set in the same block (or row, or column), then the value must be the correct answer for that cell. This situation occurs in the set of possibles shown earlier. Here the value 2 occurs only in the lower lefthand cell. Since no other cell in the block has a 2, we know this must be the location for this digit. (This will subsequently lead to identifying the 8 as the solution of the upper left square, then 7 as the value in the upper middle square).

To detect this situation we first need to construct the set of possibles from a row, column or block without a specific element. This is accomplished by the function named `drop`. Again, because `drop` is separated from the computation of the row, column or block data, the same function can be used with each. Next, the resulting data is a list of lists. To tell if a value is or is not found in the data, we need to reduce this to a list of values. This is termed flattening a list. For example, flattening the list `[[1, 2],[3,2,4]]` produces the list `[1,2,3,2,4]`. This task is performed by the function `flatten`. With these two tools, the test to

determine if a value *x* does not occur in, for example, the possibilities for row *i* and column *j* is removed can be determined as follows

```
x not in flatten(drop(row(i, possibles), j))
```

We need to perform a similar task for each row, column and block. So we can factor out the common task into a function named `checkAllBut`. This function takes a single element, a list, and a position. It removes the position from the list, and checks that the element does not occur in the list. By changing the arguments passed to this function we can use the same logic to test both rows, columns and blocks.

We now have all the pieces needed to make our puzzle solver. The main program computes the set of possibles, then loops over each cell. If the possibles set has just one element, then it must be the correct value. Otherwise each element in the possibles set is examined, and for each the function `checkAllBut` is invoked three times, once to check row data, once to check column data, and once to check block data. If any of these works, then the value is correct.

Of course, changing the values in the puzzle will change the values in the possibles sets. Using paper and pencil puzzlers simply erase the values from the given sets, and then rescan the entire grid to see if any new moves are enabled. For example, in the block described earlier the placement of the 2 then leads to the discovery of the placement for the 8, which then leads to the placement of the 7. Since the grid must be scanned multiple times anyway, our approach will be to recompute the possibles matrix on each scan, and keep a flag to determine if any changes have been made during the scan. If a scan is made with no changes detected, then either the solution has been found or we have reached the limit of this solution heuristic.

## Improvements

This program implements just two simple heuristics for solving Sudoku puzzles. There are many puzzles for which this is not sufficient. Here is another heuristic you can add, called the pairs test. If two squares have the same pair of possible values, then you can eliminate those values from all other squares in the same block. This situation occurs in the block shown at right. We cannot yet determine which of the two lower squares will have a 1 and which will have a 5, but we know that they will go into these two squares, and therefore cannot be found anywhere else in the block. Erasing the values from the other squares reveals that 3 must be the value for the middle square. This then leads to the discovery of the 8 in the square above, and so on.

4	[1,3,5,8]	[1,3,5,7,8,9]
[1,3,5,6,7,9]	[1,3,5]	[1,3,5,6,7,9]
[1,5]	2	[1,5]

Another heuristic is the box line technique. This moves in the forward, “must”, direction, rather than in the backward “cannot”, direction. Suppose we know from examination of the other values in a row or column that the value 9 must be in the third column above. Then we can eliminate the value from the first column, which may be enough to force a

value. Further hints on solving even more difficult puzzles can be found by googling the work sudoku online.

## **Benefits**

Our purpose in this discussion has not been to discuss a Sudoku solver, since this program works only with very simple puzzles. Instead, our purpose has been to illustrate the idea of functional program as represented by list comprehensions in the language Python. The advantages of this style of programming are numerous. Functions tend to be short, faster than their more traditional alternatives, and easy to read. Furthermore, errors made in the development of list comprehensions tend to have a major effect. When it comes to debugging, big errors are much easier to find than small ones, so a change that causes the wrong result to be produced on almost every input is likely to be discovered very quickly. The result is a faster and more reliable program.

As a secondary issue, note that the approach to solution described in this chapter is markedly different from the approach described in Chapter x. Here we have started with the representation of the data, and moved upwards towards a solution. This is often termed a “bottom-up” approach. In most problems programmers produce a solution using a combination of top-down and bottom-up development, sometimes working from the objective downwards using refinement, sometimes working from the representation upwards using composition. When the two finally meet in the middle a solution has been found.

## **Exercises**

## Chapter X: Using XML to read an iTunes database

Computers are increasingly used communicate with each other, that is, to share information. But computers do not actually “talk” in the sense of using a natural language. Instead, they simply pass information from one place to another. By itself, information has very little structure and is therefore prone to misunderstanding. To motivate the need for XML, imagine two computers that need to compare information regarding items in an inventory and the quantity and cost of each. One way might be to simply represent the information on each product in three successive lines of text, such as the following:

```
Toast O'Matic
42
12.95
Kitchen Chef Blender
193
47.43
```

Did you immediately understand that there are currently 42 Toast O'Matics in the inventory and that they cost \$12.95 each? Compare the description just given to the following XML encoding of the same data:

```
<inventory>
<product>
<name>Toast O'Matic</name>
<onHand>42</onHand>
<price>12.95</price>
</product>
<product>
<name>Kitchen Chef Blender</name>
<onHand>193</onHand>
<price>47.43</price>
</product>
</inventory>
```

This example illustrates both the advantages and the disadvantages of the XML format. The advantage is that the information is more self-documenting. It is clear what each field represents. You can read the information and immediately know what it means. Since the information is ordinary text, it can be read by both humans and computers. On the other hand, the XML description is longer, and more difficult to process. You cannot simply use three “readLine” statements to extract the information on each product. Instead, a tool called a *parser* must be used to read the XML description.

Another advantage of the XML format is that it allows for evolution and change in the data format. For example, suppose that next week your firm decides to add an additional

field in the inventory database to represent the manufacturer of the product. In the XML format this is simply a new field

```
<product>
<name>Toast O'Matic</name>
<onHand>42</onHand>
<price>12.95</price>
<manufacturer>General Toaster, Inc</manufacturer>
</product>
```

Existing programs that extract information from the inventory will simply ignore the new field, while new programs can make use of this information. For reasons such as these, XML has readily become a de-facto standard for encoding data that is shared between programs.

Notice that XML is very similar to the language HTML used on web pages (as, for example, in Chapter x). Both use tags to describe information. However, in XML tags must always have an ending element, while in HTML the ending tag can often be omitted. Furthermore, HTML has a small set of predefined tags that are used for one purpose, namely to communicate the layout of a web page. XML tags are unstructured and by themselves have no meaning until a program that reads the XML file provides one.

## iTunes database in XML

You probably have at least one database described using XML on your computer right now. If you use iTunes to organize your music collection you should be able to find a file named “iTunes Music Library.xml”. This is can be found in your iTunes directory. This is simply a text file, so you should be able to examine it with a simple text editor (such as SimpleText or Notepad). The beginnings of this file might look something like the following:

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE plist PUBLIC "-//Apple Computer//DTD PLIST 1.0//EN"
"http://www.apple.com/DTDs/PropertyList-1.0.dtd">
<plist version="1.0">
<dict>
  <key>Major Version</key><integer>1</integer>
  <key>Minor Version</key><integer>1</integer>
  <key>Application Version</key><string>6.0.1</string>
  <key>Features</key><integer>1</integer>
  <key>Music
Folder</key><string>file://localhost/Users/budd/Music/iTunes/iTunes%20Music/</string>
  <key>Library Persistent ID</key><string>E4D128BB1074A394</string>
  <key>Tracks</key>
  <dict>
    <key>123</key>
    <dict>
      <key>Track ID</key><integer>123</integer>
```



```
<key>Name</key><string>Don't Know Why</string>
<key>Artist</key><string>Norah Jones</string>
<key>Composer</key><string>Jesse Harris</string>
<key>Album</key><string>Come Away With Me</string>
<key>Genre</key><string>Jazz</string>
<key>Kind</key><string>AAC audio file</string>
```

The structure of this file is typical of all XML documents. The first line identifies the version of XML used to encode the information. The second line identifies the document type, or DOCTYPE. Among the information provided by the document type is the reference to a file (in this case, <http://www.apple.com/DTDs/PropertyList-1.0.dtd>) where the meanings of the various tags is described. You should enter this URL into your browser and examine the file it denotes. This file, termed a data definition file, gives the names of the tags that will be used in the remainder of the document.

The majority of the document is described as a plist. A plist is simply a list, similar to the list data type in Python. The first element of this list is a dict. This is a collection of key and value pairs, similar to the dictionary data type in Python. What follows is a series of keys and their associated values. Each key is a string. However, the values have different types. Some are integers, some are strings, and one, the tracks field, is another dictionary.

The tracks dictionary is used to record information about each song (track) stored in the database. Information that is stored includes the name of the song, the name of the artist, the composer, album, and other information.

We will use this file as our example to illustrate how Python programs can read and manipulate information stored in an XML database.

## Parsing XML files using the DOM model

XML files are simply text files. Thus you could, if you wanted, simply read the file descriptions line by line using the standard file commands. However, reading the tag fields, separating the tag names from the enclosed data, and matching an opening tag with the associated closing tag are complex operations you would like to avoid, if possible. Fortunately, there are a number of XML parsers designed to simplify this process.

```
import xml.dom.minidom

def removeText (node):
    return [x for x in node.childNodes if x.nodeType !=
xml.dom.Node.TEXT_NODE]

def readInfo (tag, node):
    if node.nodeType != xml.dom.Node.ELEMENT_NODE: return None
    if node.tagName == 'string':
        return node.firstChild.data
    elif node.tagName == 'integer':
        return int(node.firstChild.data)
    elif node.tagName == 'date':
        return node.firstChild.data
```

```

        elif node.tagName == 'dict':
            return readKeys(removeText(node))
        return None

def readKeys (lst):
    i = 0
    dict = { }
    while i < len(lst):
        if lst[i].nodeType == xml.dom.Node.ELEMENT_NODE and lst[i].tagName
== 'key':
            tag = lst[i].firstChild.data
            i += 1
            dict[tag] = readInfo(tag, lst[i])
            i += 1
    return dict

itunesdb = xml.dom.minidom.parse("iTunes Music Library.xml")
topnodes = removeText(itunesdb.documentElement)
topdict = readKeys(removeText(topnodes[0]))
trackdict = topdict.get('Tracks', {})

for track in trackdict:
    song = trackdict.get(track)
    print
    song.get('Name', ''), ':' , song.get('Artist', ''), ':' , song.get('Year', '')

```

Figure 1: The DOM parser for the iTunes database

There are two general approaches to the task of processing an XML file, and therefore two general libraries in common use. One approach is to read the entire XML document into one huge structure, and then to break the structure apart to find the items of interest. Here the parser does its job, returning a value to the programmer. The programmer then manipulates the returned value. This is termed the DOM, or Document Object Model approach. This is easiest if the document is small or must be shared with many sections of a program. The second approach is to interact more dynamically with the parser. The parser alerts the program each time an item has been read. The program can then do with the item what it wants. The parser and the programmers code run side by side, and no single representation of the entire XML file is ever built. This approach is preferable if the XML file is very large. We will illustrate both types of parser.

Our first program is shown in Figure 1. Outside the function definitions (which we will describe shortly), the program itself is less than ten lines of code. The function named `parse` is doing the majority of the real work. You should start by experimenting with this function in interactive mode. After you have located your iTunes XML file, try entering the following three lines:

```

>>> import xml.dom.minidom
>>> itunesdb = xml.dom.minidom.parse("iTunes Music Library.xml")
>>> print(itunesdb.documentElement)
[<DOM Text node "\n">, <DOM Element: dict at 0x261d78>, <DOM Text node
"\n">]

```

This short experiment illustrates one of the drawbacks of XML parsers. The parser does not know what part of the input is important, and so it saves everything, including newline and space characters. In this case, the text that appears before and after the dictionary tag is unimportant. The function `removeText` (Figure 1) is a simple routine to remove these extraneous text nodes, leaving the elements of interest.

After removing the extra text nodes, the dictionary itself is the first (and only) node. If you examine the initial lines of the iTunes database printed earlier, you see that the structure of the database is a dictionary containing information about the database itself. One of the fields in this dictionary is named `Tracks`; which includes one track for each song in the database. That field itself holds a dictionary with entries for such information such as the song name, artist, composer, and so on.

The function `readKeys` is used to reconstruct a Python dictionary from the XML representation. If you examine the database given earlier, you see that an XML dictionary consists of a key element which is immediately followed by the associated data value. The parser returns the entire list of nodes as a single list. The method `readKeys` finds each key, saves the tag name, and then uses the next node as the value stored at the given key. The function `readInfo` is used to perform the conversion between an XML node and the equivalent Python representation. Integers are converted using the function `int`, dictionaries are handled by a recursive call to `readKeys`, and all other values (such as strings and dates) are simply left as is.

Having converted the XML form into a Python structure, the entry with name `'Tracks'` is accessed to get the dictionary of songs. A loop is used to access each individual song, and a print statement generates some of the information about each song. Example output might look as follows:

```
Feelin' The Same Way : Norah Jones : 2002
Come Away With Me : Norah Jones : 2002
Shoot The Moon : Norah Jones : 2002
Que Creias : Selena : 1992
Missing My Baby : Selena : 1992
Las Cadenas : Selena : 1992
Siempre Estoy Pensando En Ti : Selena : 1992
All Of Me : Billie Holiday : 1996
You Go To My Head : Billie Holiday : 1996
Nightingale : Norah Jones : 2002
```

In the exercises we will suggest various extensions that could be made to this program.

## **Parsing XML with the SAX model**

The alternative to the DOM model is SAX, the *Simple API for XML*. The SAX model is structured around the idea of “events”. Events are actions of interest to the programmer. For each event, the programmer can define code that will handle the event. For the XML parser, there are three major categories of events. The first occurs when the start of a tag has been recognized, the second occurs when the text between tags has been recognized,

and the third and final event is the processing of an end tag. Each of these is handled by a method in the class `xml.sax.handler.ContentHandler`. To make a specialized type of parser, the programmer simply constructs a new class that inherits from this class and overrides the appropriate methods. Such a class is shown in Figure 2.

```
import xml.sax.handler

class ItunesHandler (xml.sax.handler.ContentHandler):
    def __init__ (self):
        self.keyText = ""
        self.tag = ""
        self.info = {}

    def startElement (self, name, attributes):
        self.tag = name

    def characters (self, data):
        if (self.tag == "key"): self.keyText = data
        elif (self.tag and self.keyText):
            self.info[self.keyText] = data
            if (self.keyText == 'Album'):
                print self.info['Name'], ': ', self.info['Artist']
            self.keyText = ''

    def endElement (self, name):
        self.tag = ""

parser = xml.sax.make_parser()
handler = ItunesHandler()
parser.setContentHandler(handler)
parser.parse("iTunes Music Library.xml")
```

**Figure 2:** The SAX parser for the iTunes library

The class `ItunesHandler` defines internal data values that will be manipulated as the parser scans the XML file. As the start of each tag is recognized the name of the tag is stored in an internal variable named `tag`. This value is set to blank at the end of the associated tag. Between these, the method `characters` is used to process the tag contents. If the tag is a key the data is stored in the internal variable `keyText`. Otherwise, assuming that both tag and key are set the information is saved in the internal variable named `info`.

Notice that the SAX parser ignores most data fields, and simply processes those of interest; namely the keys associated with individual songs in the database. Using the fact that the ‘Album’ entry is one of the last fields recorded for each song, when an Album is found the information for the song is printed.

Just as you did with the DOM parser, you should experiment with the SAX parser, both in interactive mode and in simple programs, to see how each of the three methods is invoked as the XML file is processed.

## Exercises

1. Examine the DTD (Document Definition file) described by the DOCTYPE entry in the iTunes database. What XML tags does it describe?
2. Assuming you have access to your own iTunes XML database file, how would you use a text editor to discover what information is stored for each track (song) in the database?
3. How would you write a Python program using the DOM parser to uncover the information?
4. Our application outputs just a small bit of information about each song, then moves on to the next. The order that values are printed will match that of the database. This is not characteristic of most XML applications. Instead, most applications will gather a large amount of information, then produce summaries or digests in a different order. By starting from the DOM parsing application, rewrite the program to produce each of the following:
  - Produce an alphabetized list of all songs in the database, and for each song list the composer and artist.
  - Produce an alphabetized list of each album in the database, and for each album generate an alphabetized list of songs.
  - Produce an alphabetized list of composers, and for each composer produce a list of all songs, artists and albums containing work by the composer.
5. Compare the XML database described at the beginning of this chapter with the iTunes database. While both are legal XML they differ in, for example, the way they treat data types (such as integers and strings). Describe these differences.
6. Compare and contrast the DOM and SAX model of parsing. How are they similar? How are they different? Can you imagine situations where one would be preferable to the other? Combine your observations with the analysis you performed for Question 5. Does the way the XML document describes information favor one approach over the other?

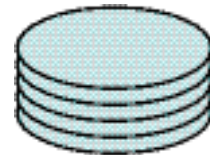
## Chapter X: Data Structures

As you have probably noticed from the many example programs presented in this book, *collections* of values are part of almost any nontrivial computer program. The Python primitive types list, tuple and dictionary are extremely flexible, and as a consequence the Python programmer seldom needs to write their own classes for storing collections. Nevertheless, the formal study of collection classes, termed *data structures*, is an important part of the discipline of computer science. In this chapter we will present a short introduction to this field.

### Levels of Abstraction

As you learned in the chapter on function definition, *abstraction* is a mechanism used to manage complexity. Abstraction means to emphasize certain features and to ignore others. In an atlas, for example, a map of a continent will note large-scale features, such as mountain ranges and rivers, and ignore smaller features, such as city streets. These features, however, become important in more regional maps, such as a city map.

Collections can be similarly considered at many different levels of abstraction. At the highest level we can simply describe the idea or concept of a collection. Often this is done by a metaphor, appealing to the listeners experience with everyday life examples. For example, we say that a Stack is a collection organized by the principle that the only item that can be removed is the item most recently inserted; similar to the way that a stack of dishes are organized. A queue, on the other hand, is also organized by time, but the item removed is the item that has been in the queue the longest. A line of people waiting to get into a theater is an appropriate mental image. This is termed the ADT, or *Abstract Data Type* description of a collection.



At the next level we can give names to collection operations. This is sometimes termed the *interface level* description. We might say that to insert a value into a stack you use the push operation, and to remove an item you use the pop operation. Notice that for somebody to use a collection they need only the interface description. Most likely, for example, you have only the interface description of the dictionary data type in Python, and do not have any idea how it is actually implemented.

Finally, at the lowest level we have the implementation level description. This is telling you how the collection is actually stored and manipulated in the internal part of the system. These details ideally should be encapsulated, so that most users do not need to see them. But, of course, somebody (such as the module developer) must know them.

In this chapter we will examine all three levels. However, our discussion of implementation techniques will, by necessity, be very cursory. There are many textbooks that will treat the implementation of data structures in much more detail.

### Containers as Abstractions

Traditionally collections are divided into two categories based on how they are used. These are containers in which the times of insertion are important, versus those in which values are important. Of course, these two categories describe how the container is being *used*, not how it operates; and so the same implementation (such as a list) can often be used in either fashion. Nevertheless, the division represents a time-honored starting place for the examination of containers.

We have already described the two most common abstractions in which the time of insertion is most important. These are the stack and the queue. Both can be easily constructed using a list as the underlying storage area for values. The stack appends the value to the end and uses the list method `pop` to remove an item, while the queue uses the `pop` method from the front.

Why would you want to use these classes, instead of using the list operations directly? There are several reasons. Most importantly, the classes `stack` and `queue` restrict use so that only the provided operations can modify the collection. You are guaranteed that the item removed from a queue will be the item that has been in the queue the longest. If you simply use a list there is no guaranteed that another user, perhaps accidentally, perhaps maliciously, might not insert a new value into the middle of a collection.

```
class stack (object):
    def __init__(self):
        self.stack = []
    def push (self, value):
        self.stack.append(value)
    def pop (self):
        return self.stack.pop()
    def isEmpty (self):
        return len(self.stack) == 0

class queue (object):
    def __init__(self):
        self.queue = []
    def insert (self, value):
        self.queue.append(value)
    def remove (self):
        return self.queue.pop(0)
    def isEmpty (self):
        return len(self.queue) == 0
```

Even when the list type is being used directly, programmers will often use abstraction names to describe how the type is being manipulated. A programmer might say, for example, that “this list is being used in a stack-like fashion” (or “being used as a stack”). So it is useful for all programmers to be familiar with the traditional names for these abstractions.

A combination data structure, termed a deque, (short for double-ended queue) allows items to be inserted or removed from either end. This is also easily implemented using a list.

The other major category of collections are those in which the value of elements is more important than the time of insertion. In general the big three operations for these containers are inserting a value, removing a value, and testing to see whether a value is held in the container. Variations on these operations, as well as other more minor operations, are particular to each category of abstraction.

A *bag* is the simplest type of collection. A value can be added to a bag, a value can be removed from a bag, and a test can be performed to see if an item is found in the bag. The same item can appear in a bag more than one time. Again, these are easy to simulate using list operations. As we described in Chapter 11, defining the method `__iter__` allows a bag to be used in a `for` statement. Similarly, defining the method `__in__` allows the test operation to be performed using the `in` operator.

An ordered bag (or sorted bag) maintains values in sorted order based on their value. Of the basic abstractions this is probably the most difficult to implement using a list. The sort method can be used to order the elements, however thereafter maintaining the order can be complicated. A useful help is the module

`bisect`. The method `bisect.bisect` performs a *binary search*. A binary search is similar to the way you play “guess the number”. It starts in the middle, compares the element found there to the value you seek. If it is smaller, it searches the upper half, if larger, it searches

the smaller half. Using a binary search on an ordered collection is much faster than the sequential loop used in the bag algorithm. The `bisearch` function returns the position where the item is found, or where it can be inserted

```
class bag:
    def __init__(self):
        self.storage = []

    def add (self, value):
        self.storage.append(value)

    def size (self):
        return len(self.storage)

    def test (self, value):
        for v in self.storage:
            if v == value: return True
        return false

    def __in__ (self, value):
        return self.test(value)

    def remove (self, value):
        for i in len(self.storage):
            if self.storage[i] == value:
                self.storage.pop(i)
        return

    def __iter__ (self):
        return iter(self.storage)
```

```
import bisect

class sortedBag (object):
    def __init__(self):
        self.storage = []

    def add (self, value):
        insertionPoint = bisect.bisect(self.storage, value)
        self.storage.insert(insertionPoint, value)

    def size (self):
        return len(self.storage)

    def test (self, value):
        insertionPoint = bisect.bisect(self.storage, value)
        return insertionPoint < self.size() and self.storage[insertionPoint] == value

    def remove (self, value):
        insertionPoint = bisect.bisect(self.storage, value)
        if insertionPoint < self.size(): self.storage.pop(insertionPoint)

    def __iter__ (self):
        return iter(self.storage)
```



without destroying the ordering. The latter can be larger than the set of legal index values, if the item being sought is larger than any existing value. For this reason the remove and test methods must first examine the value returned by bisearch to see if it is legal.

```
class set(object):
    def __init__(self):
        self.storage = []

    def add(self, value):
        if not self.test(value):
            self.storage.append(value)

    def size(self):
        return len(self.storage)

    def test(self, value):
        for v in self.storage:
            if v == value: return True
        return False

    def __in__(self, value):
        return self.test(value)

    def remove(self, value):
        for i in len(self.storage):
            if self.storage[i] == value:
                self.storage.pop(i)
        return

    def union(self, aSet):
        newSet = set()
        for x in self.storage:
            newSet.add(x)
        for x in aSet:
            newSet.add(x)
        return newSet

    def intersection(self, aSet):
        newSet = set()
        for x in aSet:
            if x in self:
                newSet.add(x)
        return newSet
```

A *set* differs from a bag in two important respects. First, each item in a set is unique. That is, the same item cannot appear more than once in a set. This is usually enforced by the add method, simply not adding a value if it is already in the collection. Second, sets incorporate new operations that combine one set with another. For example, an intersection returns the elements that are found in both sets, while a union represents the elements found in both sets. These concepts are familiar to most programmers from mathematics or the use of Venn diagrams.

As an abstraction, a *dictionary* is very similar to the Python built-in class of the same name. A dictionary must support key/value pairs, inserting new values into the collection as a pair, and accessing or removing values using the key.

A *priority queue* maintains values that have a precedence, or priority. Values can be inserted into the priority queue in any order, but when an element is removed it is the value with highest priority. A simulation of a hospital waiting room, for example, might want to maintain a list of

patients in priority based on the severity of their injury. A simple way to implement a priority queue is through a sorted list, although there are other techniques that are more efficient.

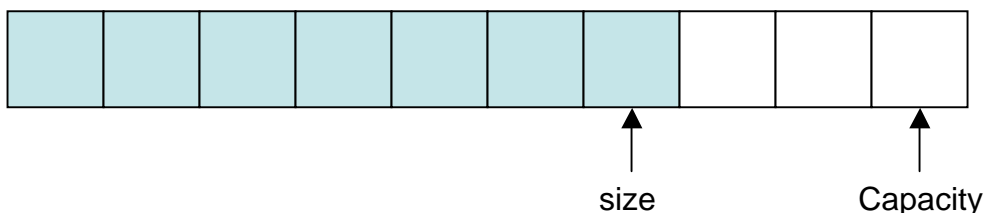
## Traditional Implementation Techniques

Although our simple implementations of data structure abstractions have been built on top of a list, this is not the only way. And in fact the list is a high level abstraction itself that must ultimately be implemented using more primitive features.

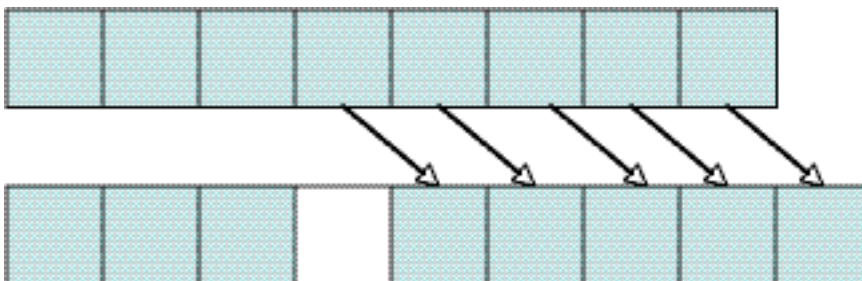
The exploration of data structure implementation techniques traditionally begins with an array. An array is a fixed-length block of memory.



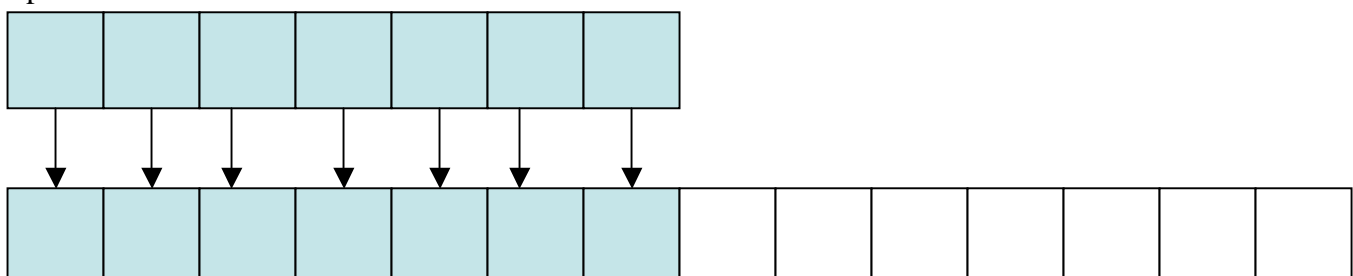
Because elements in the array are placed end-to-end, accessing a value is very fast. On the other hand, because the array is fixed length it can be hard to use for collections. A common solution is to make the block larger than necessary, and store elements in the front. This is often termed a *dynamic array*, or in some languages, a *vector*. There are then two values that characterize the extent of the collection, the size (that is, number of elements in the collection) and the capacity (the number of elements in the block of memory).



Adding an element in the middle of the collection is complicated by the fact that the existing values must be moved over to make room for the new value.



If many elements are added to the collection, the size will eventually reach the capacity. At this point a new block of memory with increased capacity is requested, and the values copied into the new structure.

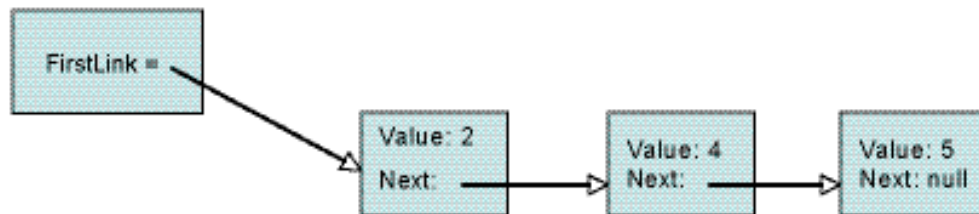


In Python you can simulate an Array using a list and the multiplication operator. For instance, the command

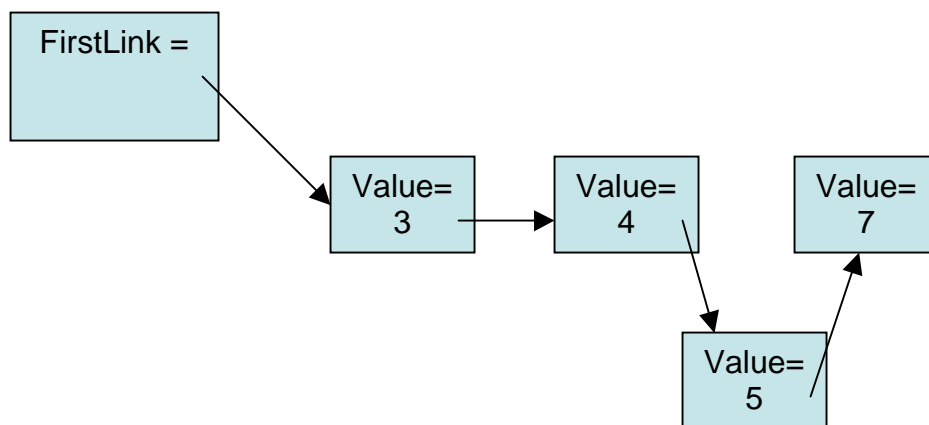
```
[ None ] * 10
```

creates a block of ten elements, each holding the value None. Using this approach the exercises at the end of the chapter will lead you through the design of a Vector abstraction. (We note again that for Python users this is purely an academic exercise, as the built-in list datatype provides all these abilities and more. However, a programmer may not always have the privilege of working in Python. Hence, a working knowledge of how various data types are implemented is valuable information).

An alternative implementation technique is termed the linked list. Here each value is stored in a small structure. This structure contains both the value and a reference to the next element in a chain. The collection itself simply maintains a pointer to the first (or sometimes the first and the last) link in this chain.



The advantage of a linked list is that adding a new element does not require sliding values around in a block. However, finding where a new value should be inserted requires walking down the list of links.



In Chapter 9 we noted how a linked list could be developed using a pair of classes. The class Link is used to store an individual link value:

```
class Link(object):  
    def __init__(self, v, n)
```

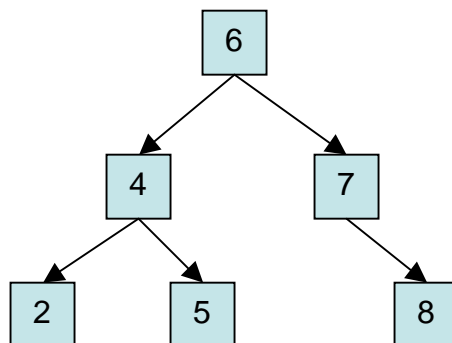
```
self.value = v
self.next = n
```

The class `LinkedList` maintains a pointer to the first Link. Operations on the list are performed by walking down the chain of links:

```
class LinkedList (object):
    def __init__ (self):
        self.firstLink = None
    def add (self, newElement):
        self.firstLink = Link(newElement, self.firstLink)
    def test (self, testValue): # see if test value is in collection
        pass
    def remove (self, testValue): # remove value from collection
        pass
    def len (self): # return size of collection
        pass
```

In the exercises you will explore the development of this class. (Again, for the Python programmer this is a purely academic exercise, since the List data structure is built-in. But the approach used here can be applied in many different languages).

Both the vector and the linked list suffer from the problem that most operations (such as searching to see if a value is contained in the collection) require a traversal of the entire structure. To address this problem an programmer may use more complex data structures. One such possibility is a *binary search tree*. A binary tree is formed out of nodes, similar to the links in a linked list. However each node can reference two possible child nodes (called the left and right children). In a binary search tree the values in each node are larger than or equal to the values in the left children, and smaller than or equal to the values in the right children.



Inserting a value into or removing a value from a binary search tree requires only a traversal from the top to bottom, which is much faster than examining every elements as is required by a vector or linked list.

The implementation of a binary search tree uses a class termed a `Node`. Each node holds a single value, and pointer to left and right subtrees:

```
class Node (object):
    def __init__ (self, v, l, r):
        self.value = v
```

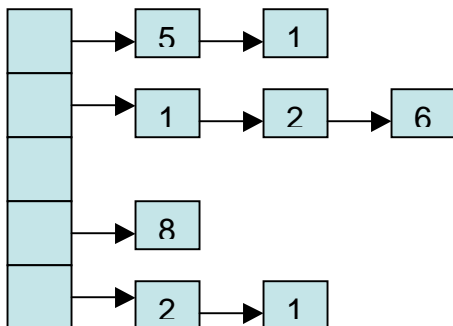
```
self.left = l
self.right = r
```

The tree maintains a reference to the root node for the collection. In the exercises you can explore the implementation of this data structure.

```
class BinarySearchTree (object):
    def __init__ (self):
        self.root = None
    def add (self, newValue):
    ...
```

An even more complicated implementation technique is the *hash table*. A hash table is a combination of an array and a linked list. The function named `hash()` takes an immutable value in Python (number, string or tuple) and returns an integer. You should try invoking this with different values to see the effect. Integer values simply return their own value as a hash, while for floats, tuples and strings the rules are more complicated. Because the arguments are immutable, the same argument will always return the same value.

To make a container, an array is first created. This array will hold links in a linked list. When an element is inserted, its hash value is computed and the remainder determined when divided by the table size. The value is then placed into the linked list at the given location. The following shows a few example values assuming a hash table of size 5.



Notice that the elements do not appear to be ordered by their values in any particular way. Assuming that the lists do not become too long, insertions and removals from a hash table can be very fast. In order to assure good performance one trick is to increase the size of the table when a threshold of values have been reached (for example, when the number of elements is three times the size of the table).

Hash tables are typically used to implement the dictionary data type. Here each link in the linked lists will maintain both the key and values for the dictionary. The hash value for each entry is determined by the hash value of the key. This is why the list returned by the method `keys()` for a dictionary is not guaranteed to have any order; since it typically results from a simple walk through the hash table. Similarly if a sufficient number of values are inserted into a dictionary a new table may be created, resulting in the reorganization of the hash table. This usually results in the values being shuffled. This is

one more reason why the order of values returned by the method `dict.keys()` is not specified.

To implement a hash table you would again use a pair of classes. Like the links in a linked list or the nodes in a binary search tree, the first class, `Association`, stores the values in the collection as well as a link field to the next association.

```
class Association (object):
    def __init__ (self, k, v, n):
        self.key = k
        self.value = v
        self.next = n
```

The hash table class stores a table of values, and the number of elements currently being maintained in the table. Here we make a table that initially maintains ten values:

```
class Hashtable (object):
    def __init__ (self):
        self.table = [None] * 10
        self.count = 0
    def add (self, newKey, newValue):
    def has_key (self, key):
    ...
```

The implementation of some of the operations for a hash table is explored in exercises at the end of the chapter.

We have in this small chapter only been able to scratch the surface of the study of data structures. Much more information and analysis can be found in any textbook on the subject.

## Exercises

1. Provide a class definition for a deque, which allows insertions and removals from both ends of a queue. Your class should support the operations `addFront`, `addBack`, `removeFront`, `removeBack`, and `isEmpty`. You can use a list for the underlying implementation.
2. You can use the methods in the module named `time` to discover the current time. This can then be used to measure execution time. Use this technique to measure the difference between a linear search, such as is performed using our simple bag implemented, and the binary search of the `sortedBag` class. Create a collection with 10,000 random integers. Then measure the amount of time to test whether 10,000 other random integers are found in the collection. Do the execution times for the simple bag and sorted bag differ?
3. Chapter 8 described the set operations using a functional, rather than an imperative approach. Complete the implementation of the set data type using techniques such as list comprehensions.

4. If Python did not already have a List data type, you might need to implement a data structure such as the dynamic array or vector described in this chapter. In this exercise you will explore how this can be done. Begin by creating the following class definition:

```
class Vector (object):
    def __init__ (self):
        self.data = [ None ] * 5
        self.size = 0
        self.capacity = 5
    def add (self, newValue): # add an element to the collection
        pass
    def insert (self, I, newValue): # insert at location i
        pass
    def remove (self, i): # remove value at location i
        pass
    def test (self, testValue): # see if collection contains element
        pass
    def __iter__(self): return self.data.__iter__()
    def size (self): return self.size
```

Implement the functions add and insert. Add places the new element at the end of the collection, while insert places the new element at a specific point. Both need to check that the size does not exceed the capacity before placing the value. If it does, then the size of the array stored in self.data should be doubled and the capacity modified appropriately. Remove should delete an element at the given location. This reduces the size, but not the capacity. Test should see if the value is held in the collection.

5. Chapter 11 described how operators in Python can be overloaded by defining functions with special built-in names. To overload the indexing operators that two methods are \_\_getitem\_\_(self, index) and \_\_setitem\_\_(self, index, value). The first provides the meaning when a value is indexed, while the second is used to implement the assignment to an indexed value. Provide implementations of these for your Vector class, and demonstrate that the new class understands the Python index syntax.
6. Complete the implementation of the LinkedList abstraction by providing methods for testing to see if a value is held in the collection, and removing a value. Of the two, testing is easiest, while removing is tricky because you need to modify the previous link, or the first link if you remove the initial value.
7. The problem of removal described in the previous question is mitigated if links maintain both references to the next and references to the previous link. This is termed a doubly-linked list. However, adding to a doubly-linked list is more complicated. Modify the LinkedList and Link classes to use the doubly-linked list idea.

8. Provide implementations of the methods `__getitem__(self, index)` and `__setitem__(self, index, value)` used in the execution of the indexing operators. Are these more or less efficient than those you implemented for the vector class?
9. A binary search tree is formed using two classes, a class for each node in the tree and a class that represents the tree itself. These were described earlier in the chapter. Using these classes, implement the method for adding a new element to a collection. The add method first examines the root. If the root is None, then the collection is empty, and a new node is created and assigned to the root. Otherwise, if value being inserted is compared to the value of the root. If it is smaller and there is no left child, a new node is created and becomes the left child. Otherwise, if the element is larger and there is no right child, a new node is created and becomes the right child. If there is a child node, the same process is repeated to insert the value into the child node. Note that values are always therefore being inserted at the leaves of the tree.
10. What happens if you use the previous algorithm and elements are inserted in order, for example the values 1 to 10, in order smallest to largest. What sort of tree do you get? There are various algorithms that can be used to rebalance the tree, but they are beyond the scope of this book.
11. Compute the hash values for 1, 1.4, 'a', and ('a', 'b')? Is the hash value of a long integer related to the value of the integer?
12. What happens if you give a mutable value, such as a list, to the function hash?
13. Finish the implementation of the method that is used to add a new key and value pair into a hash table. The function hash is only guaranteed to return an integer value. How do you convert this into an index into the table? Once you have an index, how do you add the element to the collection?
14. Extend the hash table you started in the previous questions by adding methods to test whether a key is found in the collection, and to remove the association with a given key from the collection.
15. Chapter 11 discussed how operators are implemented internally using methods with special names. Provide implementations for the methods `__getitem__(self, key)` and `__setitem__(self, key, value)` and demonstrate that your hash table will now work with the index syntax. That is, a value can be accessed as `table[key]`, and a new value inserted into the table using `table[key] = value`.
16. Chapter 11 discussed the iterator protocol, which is used internally to perform the actions required by the for statement. Implement an iterator for your hash table.
17. A useful internal method to overload is `__cmp__(self, object)`. This is invoked by the relational operators, such as `<` and `>=`. The `cmp` function should return a



negative value if the first object is less than the second, zero if they are equal, and positive value if the first is larger than the second. Add this operation to the class Association so that two Associations are compared based on the comparisons of their keys.

18. Having defined in the previous question the comparison between associations based on keys, now provide an implementation of a priority queue data structure. The priority queue, like a dictionary, holds key and value pairs. However, the elements are sorted based on their keys. You can use a simple sorted list for this purpose. This allows the value with the smallest key (called the value with highest priority) to be quickly accessed and removed.
19. With a little bit of experimentation you can determine the size of the hash table that is actually used by the Python interpreter to implement a dictionary. Try executing the following statements. Looking at the result, how big do you think the hash table used by a dictionary is initially?

```
d = {}
d[1] = 1
for i in range(2,50):
    d[i] = i
    print d.keys()
    del d[i]
```

## Appendix A: Brief Python Reference

Any printed document represents only a snapshot that freezes a moment in time. Python is an evolving language, and hence one can and should expect that future versions of the language will add new features or alter the meaning of existing features. Because of this dynamic nature, the most reliable references are those found on-line, which will always be updated to reflect the current language definition.

The most reliable source for all things python is <http://www.python.org>.

The easiest source of information regarding Python execution is provided by the Python system itself. Most built-in functions and modules in the standard library are documented with docstrings. (See Chapter 11). You can view this information by typing the `__doc__` attribute:

```
>>> print range.__doc__
range([start,] stop[, step]) -> list of integers

Return a list containing an arithmetic progression of integers.
range(i, j) returns [i, i+1, i+2, ..., j-1]; start (!) defaults to 0.
When step is given, it specifies the increment (or decrement).
For example, range(4) returns [0, 1, 2, 3]. The end point is omitted!
These are exactly the valid indices for a list of 4 elements.
>>>
```

Slightly more extensive information can be obtained using the on-line help system. From inside an interactive Python session, type the command `help()`. This will produce a new prompt. If you type the name of a module, or of a file within a module, it will produce helpful documentation.

```
>>> help()
help> random.randint
Help on method randint in random:

random.randint = randint(self, a, b) method of random.Random instance
    Return random integer in range [a, b], including both end points.
help>
```

type control-D, or the command quit to exit the on-line help system.

### Types in Python

There are approximately two dozen types that are built into the Python interpreter. These can be divided into a smaller number of categories, as shown in the following table.

Null type	The null object has type <code>NoneType</code> . There is precisely one null object, written <code>None</code> . This value has no attributes or operations, and it evaluates to false in expression
Numerics	Numbers are represented by a variety of types, such as <code>IntType</code> ,

	LongType, FloatType, and ComplexType. They each recognize a variety of numeric operations.
Sequences	Sequences include Strings (StringType), Lists (ListType), tuples (TupleType) and ranges. A variety of operations are used to access or modify the values held in the collection.
Mappings	The dictionary (DictType) allows values to be referenced by key.
Callable	Callable types recognize the function call syntax. Types in this category include the BuiltInFunctionType, BuiltInMethodType, ClassType, FunctionType (for user defined functions), and MethodType.
Modules	ModuleType is the type associated with a module that has been imported into a running program
Classes	A class definition creates a value of ClassType
Files	Opening a file creates a value of FileType
Internal	There are various other internal types created in the Python system, such as CodeType which represented a compiled Python function.

## Numeric Types

Integers are internally represented by two types. A value of IntType has a limited range, typically  $-2^{31}$  to  $2^{31}$ . A value of LongType has arbitrary precision. However, the user is normally unaware of this distinction, as both types support the same set of operations and an IntType is implicitly converted into a LongType when necessary. Complex numbers are represented by a pair of floating-point numbers. The real and imaginary parts of a complex number  $z$  are accessed as  $z.real$  and  $z.imag$ .

The following operator tokens are recognized:

+	Addition
-	Subtraction
*	Multiplication
**	Exponentiation
/	Division
//	Integer division
%	Remainder for numeric types
<<	Left shift (integer only)
>>	Right shift (integer only)
&	Bitwise and of integer values
	Bitwise or of integer values
^	Bitwise exclusive or of integer values
~	Bitwise negation of integer value
<	Less than comparison
>	Greater than comparison
<=	Less than or equal comparison
>=	Greater than or equal comparison
==	Equality comparison

!=	Inequality comparison
<>	Alternative form for Inequality Comparison
Abs(x)	Absolute value of x
Divmod(x,y)	Return tuple (int (x/u), x % y))
Pow(x, y, m)	Returns (x ** y) % m
Round(x)	Rounds floating value x to nearest integer

The only unary operators are unary negation and the unary plus operator.

The division operator returns a true division, hence 5/2 return 2.5. The operator // can be used to produce an integer division.

For floating point values, the modular division operator  $x \% y$  is defined to be  $x - \text{int}(x/y) * y$ .

Comparisons can be chained. An expression such as  $x < y < z$  is interpreted as  $(x < y)$  and  $(y < z)$ . An expression such as  $x < y > z$  is legal, but confusing.

Operations involving values of different types may result in values being coerced. Integers are converted to float, floating values to complex. If no coercion can be applied to permit values to be of the same type an error is reported.

Some operators are overloaded with alternative meanings when applied to non-numeric arguments. For example, the + operator is used for sequence catenation, the % operator for string formatting, and the \* operator for sequence repetition.

It is sometimes necessary to convert a value from one type to another. The following are some common functions for this purpose:

Int(x)	Convert x into an integer
Long(x)	Convert x into a long intger
Float(x)	Convert x into a floating point number
Complex(r, i)	Convert into a complex number with real part r and imaginary part i
Str(x)	Convert x into a string
Repr(x)	Convert x into an expression string
Eval(str)	Evaluates string as expression and returns result
Tuple(s)	Converts a sequence s into a tuple
List(s)	Converts sequence s into a list
Chr(x)	Converts integer into a character
Ord(x)	Converts a single character into its integer (ordinal) value
Hex(x)	Converts integer into a hexadecimal string
Oct(x)	Converts integer into an octal string

## Boolean Types

The constants True and False are representatives of the Boolean type. Operators such as the relational operators (<, >, <=, >=, ==, != and <>) as well as the logical operators and, or and not will return a Boolean type.

However, any Python object can also be used as a Boolean value in situations where a true/false value is required. Examples of such situations include the conditionals in an if or while statement, or as argument to a logical operator such as and, or or not. Rules for converting a value into a Boolean include the following:

- Any nonzero integer is considered to be true. Zero is considered to be false
- Any nonempty string, list, tuple or dictionary is considered to be true. An empty value is considered to be false.
- The special value None is considered to be false.

## Sequence Types (Strings, Lists and Tuples)

A sequence is an ordered set of values indexed by position. This general category includes strings, lists and tuples. Strings are sequences of characters, while lists and tuples can contain any legal Python object. Strings and tuples are immutable; once created they cannot be modified. Lists allow insertion, deletion and substitution of elements.

The following table lists operations that are common to all sequences:

S[i]	Return element I in sequence s
S[i:j]	Return slice starting at position I extending to position j. Omitting first argument indicates the start of the sequence. Omitting second argument indicated end of sequence.
Len(s)	Return number of elements in sequence
Min(s)	Minimum value in s
Max(s)	Maximum value in s
s.count(x)	Count occurrences of x in s
s.index(x)	Return the smallest position I where s[i] equals x

Because lists can be dynamically modified, they support a number of additional functions shown in the following table:

List(s)	Convert sequence s into a list
s.append(x)	Append new element x to end of s
s.extend(l)	Extend list with new list l (append all elements)
s.insert(I, x)	Insert x at indicated position
s.pop()	Returns last element and removes it from the list
s.pop(i)	Returns element I and removes it from the list
s.remove(x)	Searches for x and removes it from s
s.reverse()	Reverses items of s in place
s.sort()	Sort items of s in place

s.sort(comp)	Sort items using comp as comparison function
--------------	--

There are a large number of higher-level operations that are particular to strings. Since strings are immutable these do not actually alter the leftmost value, but instead return a new value in which the transformation has been applied.

s.capitalize()	Return a string in which the first letter has been made upper case
s.center(n)	Return a string in which s is centered in a string of width n
s.endswith(e)	Return true if s ends with the string e
s.isalnum()	Return true if s is all alphabetic or numeric
s.isalpha()	Return true if s is all alphabetic
s.isdigit()	Return true if s is all digit characters
s.islower()	Return true if s is all lower case
s.isspace()	Return true if s is all space, tab or newlines
s.isupper()	Return true if s is all upper case
s.join(seq)	Join elements of seq together, placing a copy of s between each
s.ljust(w)	Place s to the left of a new string of width w
s.lower()	Return string in which all characters are lower case
s.lstrip()	Strip any spaces from the left of the string
s.replace(o,n)	Replace all occurrences of o with n
s.rjust(w)	Place s to the right of a new string of width w
s.rstrip()	Strip any spaces or newlines from s
s.split(sep)	Return list of s that is split by occurrences of sep
s.startswith(p)	Return true if s begins with prefix p
s.strip()	Strip whitespace from both start and end of s
s.swapcase()	Turn upper case letters to lower, and vice versa
s.upper()	Make all letters upper case

In older versions of Python the string functions described above were imported from the string module, and the value to the left of the dot was written as the first argument. That is, instead of writing

```
s.split(' ')
```

The programmer would write

```
import string
string.split(s, ' ')
```

You are still likely to see strings used in this way in older Python programs.

## String formatting

As noted earlier, the % operator is overloaded to perform string formatting. The left argument is a string that may contain formatting directives. If there is only one directive in the formatting string the argument argument is the value to be printed. Otherwise, the right argument must be a tuple containing the appropriate number of values. The formatting directives are as follows:

%d or %i	Decimal integer
%u	Unsigned integer
%o	Octal integer
%x	Hexidecimal integer
%f or %e	Floating point
%s	String
%c	Single character from integer
%%	Literal %

Here are a few examples

```
>>> 'Value is %d' % (42)
Value is 42
```

## Mapping Types (Dictionaries)

A mapping type is a collection that uses keys to locate values. Unlike sequences, the keys do not represent positions, but are instead Python values. Items used as a key must be immutable. Typically strings are used as a key, less frequently numbers or tuples are also used. Keys must also be unique; only one value can be stored for any particular key.

The following table lists methods and operations that can be applied to mapping types:

Len(m)	Returns number of items in m
M[k]	Returns the item of m with key k
M[k] = v	Sets the value associated with key k to v
Del m[k]	Deletes item with key k from m
m.clear()	Removes all items from m
m.copy()	Returns a copy of m
m.has_key(k)	Return true if m has a value stored with key k
m.items()	Returns a list of (key, value) pairs
m.keys()	Returns a list of key values
m.update(b)	Adds all objects from b to m
m.values()	Returns a list of all values in m
m.get(k, d)	If k is a valid key, return m[k], otherwise return d

Using an invalid key will raise a KeyError exception. The programmer can either use has\_key(k) to test whether a map has a given key before access, or use the get method which will return a default value if the key is not legal.





## Built-In Functions

Certain functions are designated as built-in, meaning that they do not need to be imported from any module before they can be used. (More accurately, the built-in module is automatically imported by the Python interpreter at the start of execution). Being built-in does not mean that the names are reserved. The programmer can override any name with a new definition, although such actions should only be taken with care. The following table lists the more common built-in functions.

Abs(x)	Return the absolute value of x
Apply(f, a)	Performs function call on f using arguments a
Callable(o)	Returns true if o is a callable object
Chr(i)	Converts an integer between 0 and 255 into a one character string
Cmp(x, y)	Compares x and y and return a negative value if $x < y$ , a zero if x is equal to y, and a positive value if $x > 0$ . Any two objects can be compared, although the result may not be meaningful except for numbers
Coerce(x, y)	Return a tuple in which x and y are converted into a common type
Complex(r, i)	Returns a complex number with real part r and imaginary part i
Eval(str)	Evaluate string str and return result
Filter(f, s)	Returns a list consisting of the objects from sequence s in which the function f returns true
Float(x)	Returns floating point equivalent to x
Getattr(o, a)	Returns attribute a from object o, same as o.a
Globals()	Returns dictionary of global name space
Hasattr(o, a)	Returns true if o has an attribute named a
Hash(o)	Returns a integer hash value for immutable object o.
Hex(x)	Returns a string containing hex value of x
Input(str)	Same as eval(raw_input(str))
Isinstance(o, c)	Returns true if o is an instance of class c
Issubclass(c, c2)	Returns true if c is a subclass of class c2
Len(s)	Returns number of items contained in s
List(s)	Returns list containing elements from sequence s
Locals()	Returns dictionaries of local namespace
Long(x)	Convert number or string x into a long integer
Map(f, s)	Applies function f to each item of sequence s, returns new sequence
Max(s)	Returns maximum value from sequence s
Min(s)	Returns minimum value from sequence s
Oct(x)	Converts integer x into an octal string
Open(n, m)	Opens file n and returns file object. m should be 'r', 'w'.
Ord(x)	Returns the integer value (ordinal) for single character c
Pow(x, y, m)	Returns $(x ** y) \% m$
Range(s, t, m)	Returns a list of integers from s to t step m. If m is omitted default is 1.
Raw_input(s)	Prints prompt s and returns user response as string
Reduce(f, s, i)	Applies binary function f to sequence s cumulatively. Value i is

	identity used with first value. If I is omitted it is default to zero
Repr(x)	Returns a string representation of x
Round(x)	Rounds floating point value x
Setattr(o, a, x)	Sets attribute a in object o to x, same as o.a = x
Str(x)	Returns string representation of x
Tuple(s)	Converts sequence s into a tuple
Type(x)	Returns the type of x

# Python Syntax

## Comments

A hash mark (#) indicates the start of a comment. Any text following the hash mark until the end of the current line is ignored by the Python interpreter.

## Expressions

Integers consist of one or more digit characters. Floating point numbers have an embedded decimal point, and/or an optional signed exponent. The exponent is indicated by the letter e or E, followed by an optionally signed integer. Various examples are shown at right. Integers can also be written in octal or hexadecimal. A number beginning with 0 and containing only the digits 0-7 is interpreted as an octal constant. A number beginning with the literal 0x or 0X, followed by the digits 0-9 and the letters A-F is interpreted as a hexadecimal number. A complex number is written as a pair of numbers realpart+imaginarypart, where the imaginarypart is followed by the letter j or J.

```
0
123
12.34
.4
12.
4.3e3
4.3e-3
042
0xFACE
12+4j
```

Valid operators for numbers and other built-in types were described in the earlier discussion on types.

## Assignment statements

An assignment statement is written a series of one or more comma-separated targets, the assignment operator, and an equal number of comma-separated expressions, or a tuple that contains the correct number of values. Various examples are shown at right.

```
a = 8
a, b = 4, 2
a, b = (4, 2)
x = (4, 2)
a, b = x
a, b = b, a
```

## Conditional (IF) statements

A conditional statement is indicated by the keyword if. This is followed by an expression that is interpreted as a Boolean value (see earlier discussion of the Boolean type). After the expression there must be a colon. A single statement can follow the colon, and will be executed if the expression is true. Otherwise, a block of statements can be written on succeeding lines, indented one more tab stop than the if statement. The entire block will be executed if the expression is true, and ignored if it is not.

Regardless of which form is used, an if statement can be followed by an else part. The else statement will be executed only if the if was not. The keyword elif can be used to combine an else and a following if.

```
if a < min: min = a
```

```
if x < y:
```

```

        print 'smaller value is ', x
        min = x

if x < y:
    print 'smaller value is x', x
    min = x
else:
    print 'smaller value is y', y
    min = y

if x < y:
    min = x
elif z < x:
    min = z

```

### **Pass statement**

The statement pass is a null operation. It has no effect whatsoever. A pass statement is normally used in the body of a conditional when an alternative action is being performed by the else part.

```

if x < y:
    pass
else:
    min = x

```

### **Loops**

The simplest type of loop is a while loop. A while loop is written as a keyword while, followed by a Boolean expression. The statements in the loop will be executed as long as the expression evaluates true. A break statement contained within the body of the loop will immediately halt the loop. A continue statement will force execution back to the conditional test for the loop. An optional else statement following the loop will be executed as long as the loop executed normally, without the benefit of a break statement.

```

while x < y:
    x = x + 1
    if (x > 20): break
else:
    print 'did not reach 20'

```

A for loop assigns to a target a succession of elements from a list of other collection. A range statement can simplify the creation of a list of values from an arithmetic progression. The arguments to range are a starting value, termination test (which is not part of the collection) and step size. For example, range(1, 7, 3) would produce the list

containing the elements 1 and 4. If the argument to a for statement is a dictionary the list of keys are used. If the argument is a file a list consisting of each line of the file is used. Break, continue and else statements can be used with a for, with the same meaning as when used with a while statement.

```
for x in range(1, 7, 3): pass
```

## Function definitions

A function definition is indicated using the def keyword. This is followed by the function name, a parenthesized list of arguments, and a colon. The body of the function is indented one tab space, similar to the looping statements described earlier. A return statement within the body of the function halts execution and returns the indicated value.

```
def smallest(x, y):
    if x < y:
        return x
    else:
        return y
```

If a function reaches the end of the statement list without encountering a returns statement value None is implicitly returned. Although normally functions are defined at the top level, they are actually an executable statement, and can be embedded in an if conditional.

```
if x < y:
    def minValue():
        return x
else:
    def minValue():
        return y
```

Functions that do not return an explicit value are often called procedures. Such functions can be invoked as statements, without using the results. Functions defined inside of class definitions are termed methods.

An alternative method for defining short functions is the lambda operator. A lambda function consists of the keyword lambda, a list of arguments, a colon, and an expression that is the body of the function. Notice that lambda functions do not have a name, and consist of only a single expression. These functions are normally used as argument to another function call.

```
aList = map(bList, lambda x: x + 1)
```

## Class definitions

A class is indicated by the keyword `class`, followed by the class name, and a parenthesized list of parent classes. Variables and methods defined in parent classes automatically become part of the new class. The built-in class object can be used as a parent class in the absence of any other obvious choice.

Earlier versions of Python allowed the parent class list to be omitted. However, such usage should now be avoided, as the introduction of the newer style classes also fixed a number of subtle problems with the class definition mechanism.

```
class Stack(object):
    def __init__(self):
        self.storage = [ ]
    def push (self, newValue)
        self.storage.append(newValue)
    def pop (self)
        return self.storage.pop()
```

Within a class description function definitions, called methods, must have a first argument that represents the class object. Conventionally this argument is named `self`. Data fields can be created simply by assigning to an attribute of this object. A method named `__init__` (two underscores before and after the name `init`) is invoked as part of the process of creating a new instance of the class. This function, termed a constructor, is used to perform any necessary initialization for the class.

### **The import statement**

Statements beginning with the keyword `import` specify that a library of Python statements, called an import library, should be included in the current program. A suffix, typically `.py`, is appended to the name that follows the import to form a file name. The indicated file is interpreted and executed, and the resulting local namespace is stored in a variable using the import name. Thereafter features defined by this file can be accessed using the import name as the base for a qualified name.

```
import string

spring.split('abc def ghi', " ")
```

The `from` statement is a variation on an `import`. It imports the indicated library, then places the indicated names into the current local namespace. The imported features can then be used just as if they were defined in the current file. This results in simpler names, and can also produce faster execution since there is one less dynamic lookup needed to determine the meaning of a name.

## Modules in the Standard Library

The standard library distributed with every Python interpreter contains a large number of modules. The following sections will only describe the most common functions found in the most commonly used modules. Much more complete documentation and descriptions of other modules can be found in the on-line documentation at the Python.org web site.

### Module sys

The module named sys contains variables and functions that pertain to the operation of the operator and the underlying operating system.

Argv	The list of command-line options passed to the program
Maxint	Largest integer supported by IntType
Modules	Dictionary for mapping module names to loaded modules
Platform	String describing current platform
Ps1	String containing text for primary prompt, normally >>>
Ps2	String for secondary prompt, normally ...
Stdin	File object for standard input
Stdout	File object for standard output
Stderr	File object for error output
Exit(n)	Exits function by raising SystemExit exeption

### module types

The types module simply defined names for all the built-in object types. This is useful in conjunction with the built-in isinstance() function. The following illustrates this use

```
import types
if isistance (s, types.ListType):
    print 's is a list'
else:
    print 's is not a list'
```

Names defined by the types module include the following: BuiltinFunctionType, CodeType, ComplexType, ClassType, DictType, DictionaryType, FileType, FloatType, FrameType, FunctionType, InstanceType, IntType, LambdaType, ListType, LongTYpe, MethodType, ModuleType, NoneType, SinceType, StringType, TupleType, TypeTYpe.

### Module Math

The math module defines standard mathematical functions. These functions work with integers and floats, but not with complex numbers.

Constants include math.pi and math.e. Functions include acos, asin, atan, ceil, cos, exp, fabs, floor, log, log10, sin, sqrt, and tan.

## Module random

The random module provides the ability to generate random numbers, or select a random element from a sequence.

Choice(s)	Select an element in random from s
Randint(a, b)	Return a random integer greater than or equal to a and less than or equal to b
Random()	Return a random number between zero and one
Randrange(a, b)	Return a random value from a range. Like the range function, the upper limit is not included in the collection.

## Module shelve

The shelve module provides a simple way to save and restore the value of objects across several different executions. The open statement opens a file, called a shelf, that will be used to store the values. Thereafter the shelf can be used just like a dictionary. Values assigned to the shelf are stored in the file. When a value is read from the shelf, the associated value is access from the dictionary. A close statement should always be used with a shelf to ensure that all remaining values are copied to the associated file.

Db = Open(filename)	Open or create a shelf
Db['key']	Access value in shelf with given key
Db['key'] = x	Store value x in shelf with given key
Db.close()	Close the associated shelf

## Module time

Time in Python is measures as the number of seconds since the “epoch”. The epoch is January 1, 1970 on Unix and windows systems, and January 1, 1900 on the Macintosh.

Time()	Return seconds since the epoch
Gmtime(seconds)	Converts time into a tuple representing (year, month, day, hour, minute, second, weekday, day, dst). The latter is 1 if daylight savings is in effect, 0 if not, and -1 if no information is available. Typically invokes as gmtime(time())
Localtime(seconds)	Same format as gmtime, but for local timezone
Mktime(tuple)	Takes a tuple in the format of gmtime() and returns a number representing seconds in the format of time()
Asctime(tuple)	Takes a tuple in the format of gmtime() and converts to string of form ‘Tue June 11 20:45:22 2006’
Clock()	Returns the current CPU time in seconds as a floating point number
Strftime(format, tuple)	Produces a string representation of a time represented as a tuple as produced by gmtime according to the format



	described by the first argument. Formatting string described below
Strptime(string, format)	Reads a string representing a time described by the format, and returns a tuple similar to gmtime

The formatting commands used by strftime and strptime can include the following:

%a	Abbreviated weekday name
%A	Full weekday name
%b	Abbreviated month name
%B	Full month name
%c	Appropriate date and time representation
%d	Day of the month as a decimal number
%H	Hour (24 hour clock) as a number
%I	Hour (12 hour clock) as a number
%%j	Day of the year as a number
%m	Month as a decimal number
%M	Minute as a decimal number
%p	AM or PM
%S	Seconds as a decimal number
%U	Week number (0-53) of the year
%w	Weekday as a decimal number
%x	Appropriate date representation
%X	Locals appropriate time representation
%y	Year without century as a decimal number (0-99)
%Y	Year with centry as a decimal number
%Z	Timezone name
%%	The % character

## Module re

This module provides support for searching using regular expressions. The concept of regular expressions is described in Chapter 11. The following table lists the more common patterns for forming regular expressions:

Text	Matches literal
&	Start of string
\$	End of string
(...)*	Zero or more occurrences
(...)+	One or more occurrences
(...)?	Optional (zero or one)
[chars]	One character from range
[^chars]	One character not from range
Pat   pat	Alternative (one or the other)
(...)	Group

.	Any char except newline
---	-------------------------

Regular expressions are first compiled into a regular expression object (or pattern).

```
pat = re.compile(str)
```

The pattern is then used in a variety of different searches. A search returns a match object. The operations supported by a regular expression object include the following:

mo = pat.searc( text)	Search text for pattern, return match object
Mo = pat.match(text)	Search anchored at start of string
Lst = pat.Split(text)	Break text by occurrences of patterns. Returns a list of strings
Lst = pat.Findall(text)	Returns a list of matches of pattern
Pat.Sub(rep, text)	Substitutes first occurrences of pattern with rep

A match object supports the following operations:

m.start()	Start of matched text
m.end()	End of matched text
m.span()	Tuple of start and end

In addition, a match object can be used where a Boolean is expected, such as in an if or while statement. The value is considered to be true if the mach was successful, and false otherwise.

## Module os

This module provides an interface to common operating system services. Among the services provided by this module are the following:

Environ	A mapping object representing the current environment variables
Name	The name of the current operating system
Mkdir(path)	Makes a directory
Unlink(path)	Unlinks (deletes) a file
Rename(src, dst)	Renames a file

There are many more functions provided in this module, however the use of these facilities is complex, and beyond the scope of this book.

## module tempfile

This module provides functions useful for creating temporary files that are used just while a program is executing and then discarded.

Mktemp()	Returns a unique temporary filename
----------	-------------------------------------

Mktemp(suffix)	Returns a unique temporary filename with given suffix
TemporaryFile(mode)	Creates a temporary file with the given mode

## Module glob

The function glob in the module of the same name will return a list containing all filenames in a directory that match a pattern. The pattern can be specified using notation similar to that employed by the regular expression matcher. For example, glob.glob("\*.html") will return a list of files with the html suffix. The function os.chdir in the os module can be used to change the working directory prior to calling glob.

## Module Tkinter

The Tkinter module is used to create graphical user interfaces using the Tkinter library. Like most GUI libraries, the Tkinter facility is based around the idea of windows, frames, menus, and buttons and other graphical widgets. Because the Tkinter library defines a large number of symbolic names and values, it is usually simply included as part of the local name space using the following command:

```
from Tkinter import *
```

The root window for the Tkinter application is accessed using the function Tk(). Among the commands the root window understands are the following:

Title("string")	Sets the title for the main window
Geometry("size")	Sets the size of the window in pixels. The size is specified as widthxheight.
Mainloop()	Starts the main loop for the GUI system. The program will will for user interaction, or until the main window is closed.

In addition, the root window is used as the parent window when creating graphical widgets.

Widgets are graphical items that occupy space in a window. Example widgets include buttons, canvas, scroll bars and the like. The first argument in the constructor for each widget is always the parent window, which is initially the root window. Subsequent arguments are normally specified in keyword format, rather than positional form.

Widget(parent, options)	Constructor. Parent is parent window.
Width=n	Set width of widget. Unit is either characters or pixels
Height=n	Set height of widget
Fb=str	Set foreground color of widget. Example strings include "Red", "Blue"
Bg=str	Set background color of widget
Bind(selection, function)	Bind a callback function to an event on the

	widget. Events include <Button-1>, <ButtonRelease-1>, <Enter>, <Leave>, <B1-Motion>, <KeyPress>, <KeyRelease>
--	---

Widgets also understand the following layout directives:

Pack( <i>options</i> )	Place the widget following the previous. Options include side=LEFT (or RIGHT, TOP or BOTTOM), fill=YES (or NO)
Grid(row=n, column=n, <i>options</i> )	Place widget into a grid. Options include rowspan=n, columnspan=n
Place(relx=n.n, rely=n.n, <i>options</i> ) Place(x=n, y=n, <i>options</i> )	Place a widget in a location relative to the upper left corner of parent. The values are between 0.0 and 1.0. Location can also be specified as an absolute x,y position.

Widgets include Frame, Label, Entry, Text, button, Checkbutton, Radiobutton, Menu, Canvas, Scale, Listbox, Scrollbar and Menubutton.

Button and key press events cause the call back function to be invoked with an argument of type Event. The event object holds a number of different data fields, including the following

X, y	The coordinates the event occurred
Char	The character pressed

A Frame is a general purpose container for other widgets. Frames do not implement any additional methods beyond those common to all widgets.

A Label is a simple widget for displaying text of an image. In addition to the options common to all widgets (height, width, fg, bg) a label supports the following:

Text="str"	Set text for label
Font=("name", size)	Set font for text
Justify=loc	Location is LEFT, RIGHT or CENTER
Bitmap=map	A bitmap to be used in place of the text
Image=img	An image to be used in place of text
Relief=c	C is either FLAT, SUNKEN, RAISED, GROOVE or RIDGE. Borderwidth must be nonzero
Borderwidth=n	Width of border (in pixels)
Anchor=c	C is N, NE, E, SE, S, SW, W, NW or CENTER (default)
Cursor=c	Cursor to show when mouse is moved over the label
Textvariable=v	Track image on label according to the value of StringVar v.

The textvariable option can be used to dynamically change the image on a label by changing the value held in a variable of type StringVar. This mechanism is common to many widgets.

```

s = StringVar()
s.set("one")
lab = Label(root, textvariable=s) # text is initially "one"
s.set("two") # now text on label is "two"

```

An Entry is used to retrieve a single line of text from the user. It understands the following options:

Textvariable=v	Track value of entry with string variable
Show=c	Show character c instead of typed character (used for reading passwords, for example)

The value of an entry can be returned using the method get. Text can also be manipulated using insert(index, text) or delete(from, to), which changes the value of the string at the given locations.

A Text allows multi-line textual input. Locations in a text are specified as a string with the format "line.column". Lines begin with 1 and columns with zero, so that the initial location is "1.0". The symbolic constant END refers to the end of a text object. Text objects understand methods to insert and delete values at a given location.

A button is an that can be pressed. When pressed, the call back function specified as an option to the constructor for the button is invoked. Options that a button understands include the following:

Text=str	Text displayed on button
Bitmap=b	Bitmap displayed on button
Command=fun	Function invoked when pressed
Font=f	Font used in button
Padx=n, pady=n	Padding used between text and button border
Relief=c	C is SUNKEN, RAISED, GROOVE, RIDGE or FLAT
State=n	N is NORMAL (default), ACTIVE or DISABLED
Testvariable=v	Take text of button from string variable
Borderwidth=n	Width of border for button

A checkbutton is similar, but must specify an instance of IntVar or StringVar as the "variable" option. This variable is set to 1 if the button is selected, and 0 otherwise. You can change the value of this variable using the options ovalue and offvalue. A radio button is also similar, but uses the option value=n to specify the value to be assigned to the variable when the button is pressed.

A canvas is a widget that supports a number of commands that can be used to draw graphical images. These include the following

Create <code>line(x1, y1, x2, y2, ... xn, yn)</code>	Create lines connecting the points
Create <code>_arc(x1, y1, x2, y2)</code>	Create an arc in the bounded box
Create <code>oval(x1, y1, x2, y2)</code>	Create an oval in the bounded box
Create <code>rectangle(x1, y2, x2, y2)</code>	Create a rectangle in the bounded box
Create <code>text(x, y, text=str)</code>	Print text at given position

## Appendix B: How to Learn a Second (or Third) Programming Language

This is not a book on how to write computer programs. This is a book on how to write computer programs in Python. As I noted in the Preface, Python is an excellent first programming language, as it is a wonderful vehicle for learning programming concepts. Ideas such as variables, types, functions, and classes are found in many languages, and the knowledge you gain here can be a foundation on which you can build your programming skills.

Programming languages have an interesting relationship to the study of computer science. Languages come and go with surprising rapidity in our field. In almost no other engineering discipline do people change their fundamental tools with such frequency. This being the case, you can expect that over the course of your career you will, from time to time, be called upon to acquire new skills. This naturally leads to the question: How should you approach this task? That is, how should you go about learning a new programming language? Fortunately, there are a few simple hints that can make this job easier. These are summarized in Figure 1.

Hint 1: Learn the basic syntax  
Hint 2: Study the primitive data types  
Hint 3: Study the basic data structures  
Hint 4: Examine the built-in operations  
Hint 5: Become familiar with the programming environment  
Hint 6: Determine the class of problems the language was designed to solve  
Hint 7: See if there are useful libraries  
Hint 8: Emulate, Copy and Steal.  
Hint 9: Experiment, Evolve and Redo  
Hint 10: Have fun.

**Figure 1: Hints for Learning a New Language**

*Hint 1: Learn the basic syntax.* Syntax is an essential first step in understanding a language, but learning syntax should never be confused with learning a language. By emphasizing certain aspects and hiding others, languages embody a style of thought, a perspective, what we call a *paradigm*. Ultimately, it is internalizing this style of thought that is most important. But to reach that point, you must first be able to read and write simple statements in the language.

Find out how to write the language features you are familiar with. How do you write a comment? How do you write a conditional? An assignment? A simple arithmetic expression? A loop?

For comments, Python uses a sharp sign (#). Anything following the sharp sign to the end of line is considered to be a comment. The following is a simple assignment:

```
max = 100    # set the maximum value in the search range
```

Unlike many languages (such as Java and C) indentation is very important in Python. The body of a conditional statement is indented, as in the following example:

```
# compute the smaller of a and b
if a < b:
    m = a
else:
    m = b
```

Rather than using brackets or curly braces, all adjacent statements at the same level of indentation are considered to be a block. The block ends when the indentation returns to the previous level. The following while loop illustrates this technique:

```
# find first Fibonacci number larger than 100
a = 1
b = 1
while b < 100:
    c = a + b
    a = b
    b = c
print b    # will print the number we seek
```

An interesting feature of Python is the multiple assignment. This feature allows several expressions to be evaluated at once, then assigned to several targets. Use of this feature often eliminates the need for temporary variables. The previous bit of code could be written in a more Python-esq fashion as follows:

```
# find first Fibonacci number larger than 100
a = 1
b = 1
while b < 100:
    a, b = b, a + b
print b    # will print the number we seek
```

The result is both shorter and eliminates the unnecessary temporary variable `c`.

Indentation can be repeated to multiple levels, as in the following:

```
# compute the smaller of a, b and c
if a < b:
    if c < a:
        m = c
    else:
        m = a
else:
    if c < b:
        m = c
    else:
        m = b
```



Notice the if statement following the else in the code fragment just shown. This combination occurs in many problems. If extended to three or more levels it can become unwieldy, as in the following:

```
# perform the operation OP on a and b
if op == '+':
    r = a + b
else:
    if op == '-':
        r = a - b
    else:
        if op == '*':
            r = a * b
```

To handle this situation, Python provides an elif statement, which is a combination of an else and an if:

```
if op == '+':
    r = a + b
elif op == '-':
    r = a - b
elif op == '*':
    r = a * b
```

Functions are defined using the keyword `def`. The body of the function is indented. The function definition halts when the indentation returns to the previous level.

```
def remainder(a, b):
    q = a/b
    r = a - q*b
    return r
```

Although there may be many other aspects of syntax that will eventually become important (scoping rules, how to create classes, modules and the like), the simple ability to read assignments and control flow statements will allow you to get started in the exploration of the language, and is sufficient for now.

*Hint 2: Study the basic data types.* A programming language is a complex tool, built out of more fundamental tools. The most basic tools in the programming language are the primitive types. Almost all languages provide you with simple integers. How about long or short integers? Signed and unsigned? Enumerated types? Characters? Strings? Does the language support floating point values, and if so what ranges? If you are going to be doing numerical programming it might be useful to have complex numbers. Are they provided? If your problem requires you to use a data type that is not supported by the language, you might find it easier to use a different language rather than trying to build the facilities you need in an inappropriate language.

As a language, Python provides a small but surprisingly flexible set of primitive types. The language is dynamically typed (more on that topic in Hint 4) and so blurs the distinction between integers and floating point. Since variables are not given declared types, the only type characterization of a variable is the value it currently holds. A variable can at one point be integer, and later be transformed into a non-integer value:

```
numValue = 5                # an integer
numValue = numValue / 2.0    # numValue is now 2.5
```

Most languages impose a size restriction on integers. For example, in Java an integer is stored in 32 bits, meaning the largest integer is  $2^{31}-1$ , or 2147483647. Python makes no such restriction. Integer values are as large as necessary. This can be illustrated by the following loop, which will print various powers of 2 up to  $2^{100}$ .

```
n = 10
while n <= 100:
    print 2 ** n
    n = n + 10
```

Strings are formed using *either* single or double quotes. Python makes no distinction between single character values and strings.

```
name = "fred"
middleInitial = 'e'
```

By using both single and double quotes, Python makes it easy to embed a quote mark in the middle of a string:

```
message = 'ann said: "is my painting dry yet?" '
reply = "no, it's not"
```

There are many useful operations that can be performed on the string types. A summary of operations used with primitive data types can be found in Appendix A.

*Hint 3: Study the basic data structures.* This refers to the primitive data structures provided as part of the language itself, and not to any higher level data abstractions formed using the primitive mechanisms. (Those will be covered in Hint 7, on libraries). Almost all languages provide arrays. Many provide strings, and a few go even further. A language such as APL provides linear homogeneous arrays, Lisp makes it easy to write list structures, and Snobol provides generous support for strings. (If you have never heard of any of these languages, don't worry). Perl provides tables (indexed dictionary-like structures) as a basic tool. C provides structures, C++ adds classes, and Java supports both classes and interfaces. Any problem you envision solving must ultimately be expressed in the data types provided by the language, so a basic understanding of the implications of the choices you have is a foundation upon which everything else is built.

Start by asking yourself how the features in the new language you are learning are different from those in the languages you have previously encountered. Take, for example, an array. In most programming languages you declare a variable as an array type. You may also need to declare the size (that is, the number of elements) in the array as part of the declaration. Since Python is dynamically typed, you do neither. The concept of an array has been generalized to a mechanism known as the list. To create a list, you simply assign a variable a list value. You can create an array-like list expression as follows:

```
names = ["john", "paul" , "george", "ringo"]
```

Lists are indexed by integers starting with zero. The indexing operation can be used to either access or modify an individual member of a list:

```
a = names[2]          # sets a to "george"
names[3] = "fred"     # changes last element to fred
```

You can extract or reassign a portion of a list using the slicing operation. A *slice* is a generalization of a subscript. Instead of a single index expression, a colon and a second integer representing a size follow the expression:

```
print names[1:2]      # prints "paul" and "george"
```

If the second argument is omitted the slice refers to the remainder of the list:

```
print names[1:]       # prints "paul", "george" and "fred"
```

A slice can be used as a target of an assignment. The value being assigned need not have the same number of elements as the slice. The array is expanded or reduced to fit.

```
names[1:2] = ["sally", "ann", "alice"]
# list is now john, sally, ann, alice, and fred
```

Since the language is dynamically typed, lists can contain values of different types. Lists can even contain other lists, as in the following:

```
# name, age, children's names
info = ['fred smith', 43, ['george', 'alice']]
```

The slicing operation can also be applied to strings.

A *tuple* in Python is closely related to a list. A tuple is formed by enclosing a group of comma-separated values inside a parenthesis. Tuples support most of the same operations as lists, such as indexing and slicing. The only difference is that you cannot modify the contents of a tuple once it has been created.

```
info = ('fred smith', 43, ('george', 'alice'))
```

```
name = info[0]          # access is allowed
info[0] = 'sam smith'    # error, modification is not allowed
```

A form of assignment termed a *multiple assignment* breaks a tuple into individual components and assigns each part to a separate variable.

```
name, age, children = info
print name              # will print 'fred smith'
```

This feature is useful when a function needs to return multiple values. The function simply wraps the values into a tuple. After the call, the function result is unwrapped into the individual pieces.

A *dictionary* generalizes the list in yet another direction. A dictionary is what is termed an associative array. Elements are stored as key/value pairs. Rather than using integer offsets, elements in a dictionary are accessed using the key. Strings are the most common type for the key, however the language permits any Python value to be used. Curly braces are used to create a dictionary. Any initial keys and values are provided as colon separated pairs:

```
# create a dictionary of names and ages
ageDict = { "fred" : 42 , "sally" : 39, "ann" : 28 }
```

To access or modify members of a dictionary the key is used as an index:

```
annAge = ageDict["ann"]
ageDict["fred"] = 43      # fred got one year older
ageDict["sam"] = 12       # new elements added just by assigning to them
```

Appendix A provides a summary of the operations that can be used with the primitive data types.

Do not be surprised if it takes a while for the true power of a data structure to sink in. Whether you are conscious of it or not, a programmer will always approach a problem using the tools they know best. If you have a background in an object-oriented languages, such as Java or C++, when faced with a new data type your first impulse will be to create a new class. In Python the vast majority of the time this will be wrong, and rather than creating a new class you should look for a way to use the existing data structures (lists and dictionaries) to store your information.

Python also supports classes and modules, but these will be discussed later in a separate chapter.

*Hint 4: Examine the built-in operations.* In as much as built-in data structures bring with them their own set of operations this is largely combined with hint 3. As you learn about strings you can notice that the + operator is also used to perform string catenation. As we have seen, the \*\* operator is used for exponentiation. The append method can be used to

attach a new element to a list. The method `has_key` can be used to determine if a particular key is valid for a given dictionary. As we have noted previously, these operations are summarized in Appendix A.

However, there may also be operations that are not associated with any particular data structure. An example we have seen already is the statement `print`. This statement converts the text that follows into a string, and places the string on an area called the standard output (typically a window set aside for that purpose). Commas can separate multiple arguments:

```
print "the minimum of a and b is " , r
```

A `for` statement can be used to examine each element in a string, list or tuple:

```
names = ("john", "paul", "george", "ringo")
for name in names:
    print "member of the band: " , name
```

A special form termed a *range* can be used to create arithmetic sequences. The function creates a list of integers.

```
a = range(5)           # a is [0, 1, 2, 3, 4]
b = range(1, 8)         # b is [1, 2, 3, 4, 5, 6, 7, 8]
c = range(1, 8, 3)       # c is [1, 4, 7]
d = range(8, 1, -3)      # d is [8, 5, 2]
```

A *range* is commonly combined with a `for` statement to create a loop that runs over an arithmetic progression

```
for a in range(5, 100, 5):
    print "2 raised to ", a, " is ", 2**a
```

To loop over the elements of a dictionary first form the list of keys:

```
for name in names.keys():
    print "age of ", name, " is ", ageDict[name]
```

*Hint 5: Become familiar with the programming environment.* The programming environment for a new language may be very different from the one you are used to. If your first language was C or Java, for example, you are used to thinking in terms of the steps edit, compile, execute, debug and edit again. You might have even used an IDE, or Integrated Development Environment, that helps reduce the time between each of these steps.

Python is an interpreted programming language. This reduces even further the time between program entry and execution. Statements can be typed directly at the keyboard and will be executed immediately. This feature is extremely useful during the initial

stages of learning, when you are exploring the basic data types and the effect of operations on those data types.

The python interpreter can be used in two different ways. When used in interactive mode expressions are typed directly at the keyboard, and are immediately examined and executed. An example session is shown in Figure 2. This style of programming is extremely useful when you are first learning the language, as you can experiment with different expressions and examine the result.

```
$ python
Python 2.3 (#1, Sep 13 2003, 00:49:11)
[GCC 3.3 20030304 (Apple Computer, Inc. build 1495)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> num = 5
>>> num = num / 2.0
>>> print num
2.5
>>> n = 10
>>> while n <= 100:
...     print 2 ** n
...     n = n + 10
...
1024
1048576
1073741824
1099511627776
1125899906842624
1152921504606846976
1180591620717411303424
1208925819614629174706176
1237940039285380274899124224
1267650600228229401496703205376
```

**Figure 2:** An Example Interactive Python Session

The alternative technique is to place an entire Python program into a file with the extension `.py`. This file can be imported into an interactive session during development. Once developed, the program can then be executed simply by clicking on the program icon.

Some of the features of the programming environment (such as how to indicate the execution of a Python program stored in a file) will be specific to the operating system you are using. However, no matter what operating system is used, Python includes the idea of the standard input, output and error output. Most often the standard input corresponds to keyboard input, and the standard and error output are displayed on windows. However, there are operating system specific ways that these can be changed.

We earlier noted that Python is a *dynamically typed* language. This is different from many programming languages, which are termed *statically typed*. In a statically typed

language the idea of a variable type is tied to a variable name, usually by means of a declaration statement. For example, the following statement in Java declares the variable names to be an array of String values. The only value this variable can maintain is an array of string.

```
String [ ] names;
```

In a dynamically typed language, on the other hand, types are associated not with names but with values. A variable can be said to be currently holding a list of strings, but nothing prevents the same variable from later being assigned a different type of value.

```
info = ['fred', 'sam', 'alice'] # variable holding a list of strings
info = 42                       # now holding an integer
```

As you gain experience with Python you will learn both the advantages of dynamic typing (flexibility, ease of use, speed) and some of the disadvantages (it is easy to pass the wrong type of value to a function, and this error will not be detected until the value is used).

*Hint 6: Determine the class of problems the language was designed to solve.* Languages do not develop in isolation; they are created for a reason, usually a specific type of problem. Study the type of problems the language is being used to address. Try to understand what features of the language make this type of problem easier, and why those same features might make other types of problems difficult.

Python is described as a general purpose programming language. However, the very same features that on the positive side contribute to rapid code development and ease of use are also features that on the negative side can consume a lot of execution time. These features include dynamic typing, infinite precision integers, and high level data structures such as lists and dictionaries. In the vast majority of cases machines now days are so fast that the user will not notice the execution time cost, and the benefits will outweigh the drawbacks. But there will be situations, such as complex numerical simulations, where every execution cycle must be counted and an interpreted language would not be appropriate.

The case studies presented in later chapters will give a good indication of the type of problems that Python can be used for.

*Hint 7: See if there are useful libraries.* The programming language you use to work in is just the first tool. Often there are libraries of useful extensions that the programming language designer or others have developed that can also be extremely useful. Smalltalk comes with a massive library of existing code. The standard template library in C++ is a large collection of common data structures. Java has an extensive collection of libraries for many different problem domains. Why reinvent the wheel when the majority of work for a problem may already have been developed? Use the Internet or other search tools to discover useful resources.

Libraries of existing Python code can be included in a new program using the import statement.

```
import string          # loads the string module
```

Most implementations of Python come with an extensive library of resources useful for mathematics, string handling, database management, network programming, and other useful tasks. The standard libraries are summarized in Appendix B. Many more have been developed by other programmers and are accessible using the Internet.

*Hint 8: Emulate, Copy and Steal.* A good place to start is with existing and working copies of programs. Download a moderately complex program. Make certain you can get it to execute correctly on your system, which may be slightly different from the system on which it was developed. Study these existing programs to figure out how they work, and how the different language features are being used.

The case studies presented beginning with Chapter x are a good place to begin your examination of Python programs. Computer programs can, and should, be considered to be a form of literature. Learn how to read a program in order to understand what it does and how it works. You will find that in a typical programming career you will spend far more time reading programs that have been developed by others than you will writing your own code.

*Hint 9: Experiment, Evolve and Redo.* Once you have a few working programs, experiment by making changes. Can you evolve a working program to make it solve a slightly different problem? Can you take one small part of a program and change how it addresses whatever problem it is solving? Try redoing a program you have previously written in another language. Don't make a statement-for-statement copy, but think about how the language features of the new language can be best put to use in the rewritten version. Note carefully what is easier to do in the new language, and what is harder.

When you are faced with a new problem, think carefully about previous problems that you have seen that possess features in common with the new problem. Then reexamine the programs you created. Practice experimentation, emulation, and evolution.

*Hint 10: Have fun.* Developing computer programs can be an extremely difficult task, but it is also one of the most satisfying when a program finally works as you want it to. Most computer scientists first become interested in the field due to the sheer joy of programming. Try not to make the task drudgery. Experiment with projects that are whimsical and fun. Knowledge with pleasant associations is likely to be retained.