LEARN PYTHON THE RIGHT WAY

HOW TO THINK LIKE A COMPUTER SCIENTIST

Ritza

Marketing as Education

Learn Python the right way

How to think like a computer scientist

Ritza

Contents

Copyright Notice

Foreword

By David Beazley

As an educator, researcher, and book author, I am delighted to see the completion of this book. Python is a fun and extremely easy-to-use programming language that has steadily gained in popularity over the last few years. Developed over ten years ago by Guido van Rossum, Python's simple syntax and overall feel is largely derived from ABC, a teaching language that was developed in the 1980's. However, Python was also created to solve real problems and it borrows a wide variety of features from programming languages such as C++, Java, Modula-3, and Scheme. Because of this, one of Python's most remarkable features is its broad appeal to professional software developers, scientists, researchers, artists, and educators.

Despite Python's appeal to many different communities, you may still wonder why Python? or why teach programming with Python? Answering these questions is no simple task—especially when popular opinion is on the side of more masochistic alternatives such as C++ and Java. However, I think the most direct answer is that programming in Python is simply a lot of fun and more productive.

When I teach computer science courses, I want to cover important concepts in addition to making the material interesting and engaging to students. Unfortunately, there is a tendency for introductory programming courses to focus far too much attention on mathematical abstraction and for students to become frustrated with annoying problems related to low-level details of syntax, compilation, and the enforcement of seemingly arcane rules. Although such abstraction and formalism is important to professional software engineers and students who plan to continue their study of computer science, taking such an approach in an introductory course mostly succeeds in making computer science boring. When I teach a course, I don't want to have a room of uninspired students. I would much rather see them trying to solve interesting problems by exploring different ideas, taking unconventional approaches, breaking the rules, and learning from their mistakes. In doing so, I don't want to waste half of the semester trying to sort out obscure syntax problems, unintelligible compiler error messages, or the several hundred ways that a program might generate a general protection fault.

One of the reasons why I like Python is that it provides a really nice balance between the practical and the conceptual. Since Python is interpreted, beginners can pick up the language and start doing neat things almost immediately without getting lost in the problems of compilation and linking. Furthermore, Python comes with a large library of modules that can be used to do all sorts of tasks ranging from web-programming to graphics. Having such a practical focus is a great way to engage students and it allows them to complete significant projects. However, Python can also serve as an excellent foundation for introducing important computer science concepts. Since Python fully supports procedures and classes, students can be gradually introduced to topics such as procedural abstraction, data structures, and object-oriented programming — all of which are applicable to later courses on Java or C++. Python even borrows a number of features from functional programming languages and can be used to introduce concepts that would be covered in more detail in courses on Scheme and Lisp.

In reading Jeffrey's preface, I am struck by his comments that Python allowed him to see a higher level of success and a lower level of frustration and that he was able to move faster with better results. Although these comments refer to his introductory course, I sometimes use Python for these exact same reasons in advanced graduate level computer science courses at the University of Chicago. In these courses, I am constantly faced with the daunting task of covering a lot of difficult course material in a blistering nine week quarter. Although it is certainly possible for me to inflict a lot of pain and suffering by using a language like C++, I have often found this approach to be counterproductive—especially when the course is about a topic unrelated to just programming. I find that using Python allows me to better focus on the actual topic at hand while allowing students to complete substantial class projects.

Although Python is still a young and evolving language, I believe that it has a bright future in education. This book is an important step in that direction. David Beazley University of Chicago Author of the Python Essential Reference

Preface

By Jeffrey Elkner

This book owes its existence to the collaboration made possible by the Internet and the free software movement. Its three authors—a college professor, a high school teacher, and a professional programmer—never met face to face to work on it, but we have been able to collaborate closely, aided by many other folks who have taken the time and energy to send us their feedback.

We think this book is a testament to the benefits and future possibilities of this kind of collaboration, the framework for which has been put in place by Richard Stallman and the Free Software Foundation.

How and why I came to use Python

In 1999, the College Board's Advanced Placement (AP) Computer Science exam was given in C++ for the first time. As in many high schools throughout the country, the decision to change languages had a direct impact on the computer science curriculum at Yorktown High School in Arlington, Virginia, where I teach. Up to this point, Pascal was the language of instruction in both our first-year and AP courses. In keeping with past practice of giving students two years of exposure to the same language, we made the decision to switch to C++ in the first year course for the 1997-98 school year so that we would be in step with the College Board's change for the AP course the following year.

Two years later, I was convinced that C++ was a poor choice to use for introducing students to computer science. While it is certainly a very powerful programming language, it is also an extremely difficult language to learn and teach. I found myself constantly fighting with C++'s difficult syntax and multiple ways of doing things, and I was losing many students unnecessarily as a result. Convinced there had to be a better language choice for our first-year class, I went looking for an alternative to C++.

I needed a language that would run on the machines in our GNU/Linux lab as well as on the Windows and Macintosh platforms most students have at home. I wanted it to be free software, so that students could use it at home regardless of their income. I wanted a language that was used by professional programmers, and one that had an active developer community around it. It had to support both procedural and object-oriented programming. And most importantly, it had to be easy to learn and teach. When I investigated the choices with these goals in mind, Python stood out as the best candidate for the job.

I asked one of Yorktown's talented students, Matt Ahrens, to give Python a try. In two months he not only learned the language but wrote an application called pyTicket that enabled our staff to report technology problems via the Web. I knew that Matt could not have finished an application of that scale in so short a time in C++, and this accomplishment, combined with Matt's positive assessment of Python, suggested that Python was the solution I was looking for.

Finding a textbook

Having decided to use Python in both of my introductory computer science classes the following year, the most pressing problem was the lack of an available textbook.

Free documents came to the rescue. Earlier in the year, Richard Stallman had introduced me to Allen Downey. Both of us had written to Richard expressing an interest in developing free educational materials. Allen had already written a first-year computer science textbook, How to Think Like a Computer Scientist. When I read this book, I knew immediately that I wanted to use it in my class. It was the clearest and most helpful computer science text I had seen. It emphasized the processes of thought involved in programming rather than the features of a particular language. Reading it immediately made me a better teacher.

How to Think Like a Computer Scientist was not just an excellent book, but it had been released under the GNU public license, which meant it could be used freely and modified to meet the needs of its user. Once I decided to use Python, it occurred to me that I could translate Allen's original Java version of the book into the new language. While I would not have been able to write a textbook on my own, having Allen's book to work from made it possible for me to do so, at the same time demonstrating that the cooperative development model used so well in software could also work for educational materials.

Working on this book for the last two years has been rewarding for both my students and me, and my students played a big part in the process. Since I could make instant changes whenever someone found a spelling error or difficult passage, I encouraged them to look for mistakes in the book by giving them a bonus point each time they made a suggestion that resulted in a change in the text. This had the double benefit of encouraging them to read the text more carefully and of getting the text thoroughly reviewed by its most important critics, students using it to learn computer science.

For the second half of the book on object-oriented programming, I knew that someone with more real programming experience than I had would be needed to do it right. The book sat in an unfinished state for the better part of a year until the open source community once again provided the needed means for its completion.

I received an email from Chris Meyers expressing interest in the book. Chris is a professional programmer who started teaching a programming course last year using Python at Lane Community College in Eugene, Oregon. The prospect of teaching the course had led Chris to the book, and he started helping out with it immediately. By the end of the school year he had created a companion project on our Website at http://openbookproject.net called *Python for Fun* and was working with some of my most advanced students as a master teacher, guiding them beyond where I could take them.

Introducing programming with Python

The process of translating and using How to Think Like a Computer Scientist for the past two years has confirmed Python's suitability for teaching beginning students. Python greatly simplifies programming examples and makes important programming ideas easier to teach.

The first example from the text illustrates this point. It is the traditional `hello, world` program, which in the Java version of the book looks like this:

```java
class Hello {

  public static void main (String[] args) {
      System.out.println ("Hello, world.");
  }
}
```

in the Python version it becomes:

```python
print("Hello, World!")
```

Even though this is a trivial example, the advantages of Python stand out. Yorktown's Computer Science I course has no prerequisites, so many of the students seeing this example are looking at their first program. Some of them are undoubtedly a little nervous, having heard that computer programming is difficult to learn. The Java version has always forced me to choose between two unsatisfying options: either to explain the class Hello, public static void main, String[] args„ statements and risk confusing or intimidating some of the students right at the start, or to tell them, Just don't worry about all of that stuff now; we will talk about it later, and risk the same thing. The educational objectives at this point in the course are to introduce students to the idea of a programming statement and to get them to write their first program, thereby introducing them to the programming environment. The Python program has exactly what is needed to do these things, and nothing more.

Comparing the explanatory text of the program in each version of the book further illustrates what this means to the beginning student. There are seven paragraphs of explanation of Hello, world! in the Java version; in the Python version, there are only a few sentences. More importantly, the missing six paragraphs do not deal with the big ideas in computer programming but with the minutia of Java syntax. I found this same thing happening throughout the book. Whole paragraphs simply disappear from the Python version of the text because Python's much clearer syntax renders them unnecessary.

Using a very high-level language like Python allows a teacher to postpone talking about low-level details of the machine until students have the background that they need to better make sense of the details. It thus creates the ability to put first things first pedagogically. One of the best examples of this is the way in which Python handles variables. In Java a variable is a name for a place that holds a value if it is a built-in type, and a reference to an object if it is not. Explaining this distinction requires a discussion of how the computer stores data. Thus, the idea of a variable is bound up with the hardware of the machine. The powerful and fundamental concept of a variable is already difficult enough for beginning students (in both computer science and algebra). Bytes and addresses do not help the matter. In Python a variable is a name that refers to a thing. This is a far more intuitive concept for beginning students and is much closer to the meaning of variable that they learned in their math courses. I had much less difficulty teaching variables this year than I did in the past, and I spent less time helping students with problems using them.

Another example of how Python aids in the teaching and learning of programming is in its syntax for functions. My students have always had a great deal of difficulty understanding functions. The main problem centers around the difference between a function definition and a function call, and the related distinction between a parameter and an argument. Python comes to the rescue with syntax that is nothing short of beautiful. Function definitions begin with the keyword `def`, so I simply tell my students, When you define a function, begin with `def`, followed by the name of the function that you are defining; when you call a function, simply call (type) out its name. Parameters go with definitions; arguments go with calls. There are no return types, parameter types, or reference and value parameters to get in the way, so I am now able to teach functions in less than half the time that it previously took me, with better comprehension.

Using Python improved the effectiveness of our computer science program for all students. I saw a higher general level of success and a lower level of frustration than I experienced teaching with either C++ or Java. I moved faster with better results. More students left the course with the ability to create meaningful programs and with the positive attitude toward the experience of programming that this engenders.

Building a community

I have received emails from all over the globe from people using this book to learn or to teach programming. A user community has begun to emerge, and many people have been contributing to the project by sending in materials for the companion Website at http://openbookproject.net/pybiblio.

With the continued growth of Python, I expect the growth in the user community to continue and accelerate. The emergence of this user community and the possibility it suggests for similar collaboration among educators have been the most exciting parts of working on this project for me. By working together, we can increase the quality of materials available for our use and save valuable time. I invite you to join our community and look forward to hearing from you. Please write to me at jeff@elkner.net.

Jeffrey Elkner
Governor's Career and Technical Academy in Arlington
Arlington, Virginia

Contributor List

To paraphrase the philosophy of the Free Software Foundation, this book is free like free speech, but not necessarily free like free pizza. It came about because of a collaboration that would not have been possible without the GNU Free Documentation License. So we would like to thank the Free Software Foundation for developing this license and, of course, making it available to us.

We would also like to thank the more than 100 sharp-eyed and thoughtful readers who have sent us suggestions and corrections over the past few years. In the spirit of free software, we decided to express our gratitude in the form of a contributor list. Unfortunately, this list is not complete, but we are doing our best to keep it up to date. It was also getting too large to include everyone who sends in a typo or two. You have our gratitude, and you have the personal satisfaction of making a book you found useful better for you and everyone else who uses it. New additions to the list for the 2nd edition will be those who have made on-going contributions.

If you have a chance to look through the list, you should realize that each person here has spared you and all subsequent readers from the confusion of a technical error or a less-than-transparent explanation, just by sending us a note.

Impossible as it may seem after so many corrections, there may still be errors in this book. If you should stumble across one, we hope you will take a minute to contact us. The email address (for the Python 3 version of the book) is p.wentworth@ru.ac.za . Substantial changes made due to your suggestions will add you to the next version of the contributor list (unless you ask to be omitted). Thank you!

Second Edition

- An email from Mike MacHenry set me straight on tail recursion. He not only pointed out an error in the presentation, but suggested how to correct it.
- It wasn't until 5th Grade student Owen Davies came to me in a Saturday morning Python enrichment class and said he wanted to write the card game, Gin Rummy, in Python that I finally knew what I wanted to use as the case study for the object oriented programming chapters.
- A special thanks to pioneering students in Jeff's Python Programming class at GCTAA during the 2009-2010 school year: Safath Ahmed, Howard Batiste, Louis Elkner-Alfaro, and Rachel Hancock. Your continual and thoughtfull feedback led to changes in most of the chapters of the book. You set the standard for the active and engaged learners that will help make the new Governor's Academy what it is to become. Thanks to you this is truly a student tested text.
- Thanks in a similar vein to the students in Jeff's Computer Science class at the HB-Woodlawn program during the 2007-2008 school year: James Crowley, Joshua Eddy, Eric Larson, Brian McGrail, and Iliana Vazuka.

- Ammar Nabulsi sent in numerous corrections from Chapters 1 and 2.
- Aldric Giacomoni pointed out an error in our definition of the Fibonacci sequence in Chapter 5.
- Roger Sperberg sent in several spelling corrections and pointed out a twisted piece of logic in Chapter 3.
- Adele Goldberg sat down with Jeff at PyCon 2007 and gave him a list of suggestions and corrections from throughout the book.
- Ben Bruno sent in corrections for chapters 4, 5, 6, and 7.
- Carl LaCombe pointed out that we incorrectly used the term commutative in chapter 6 where symmetric was the correct term.
- Alessandro Montanile sent in corrections for errors in the code examples and text in chapters 3, 12, 15, 17, 18, 19, and 20.
- Emanuele Rusconi found errors in chapters 4, 8, and 15.
- Michael Vogt reported an indentation error in an example in chapter 6, and sent in a suggestion for improving the clarity of the shell vs. script section in chapter 1.

First Edition

- Lloyd Hugh Allen sent in a correction to Section 8.4.
- Yvon Boulianne sent in a correction of a semantic error in Chapter 5.
- Fred Bremmer submitted a correction in Section 2.1.
- Jonah Cohen wrote the Perl scripts to convert the LaTeX source for this book into beautiful HTML.
- Michael Conlon sent in a grammar correction in Chapter 2 and an improvement in style in Chapter 1, and he initiated discussion on the technical aspects of interpreters.
- Benoit Girard sent in a correction to a humorous mistake in Section 5.6.
- Courtney Gleason and Katherine Smith wrote horsebet.py, which was used as a case study in an earlier version of the book. Their program can now be found on the website.
- Lee Harr submitted more corrections than we have room to list here, and indeed he should be listed as one of the principal editors of the text.
- James Kaylin is a student using the text. He has submitted numerous corrections.
- David Kershaw fixed the broken catTwice function in Section 3.10.
- Eddie Lam has sent in numerous corrections to Chapters 1, 2, and 3. He also fixed the Makefile so that it creates an index the first time it is run and helped us set up a versioning scheme.
- Man-Yong Lee sent in a correction to the example code in Section 2.4.
- David Mayo pointed out that the word unconsciously in Chapter 1 needed to be changed to subconsciously .
- Chris McAloon sent in several corrections to Sections 3.9 and 3.10.
- Matthew J. Moelter has been a long-time contributor who sent in numerous corrections and suggestions to the book.
- Simon Dicon Montford reported a missing function definition and several typos in Chapter 3. He also found errors in the increment function in Chapter 13.

- John Ouzts corrected the definition of return value in Chapter 3.
- Kevin Parks sent in valuable comments and suggestions as to how to improve the distribution of the book.
- David Pool sent in a typo in the glossary of Chapter 1, as well as kind words of encouragement.
- Michael Schmitt sent in a correction to the chapter on files and exceptions.
- Robin Shaw pointed out an error in Section 13.1, where the printTime function was used in an example without being defined.
- Paul Sleigh found an error in Chapter 7 and a bug in Jonah Cohen's Perl script that generates HTML from LaTeX.
- Craig T. Snydal is testing the text in a course at Drew University. He has contributed several valuable suggestions and corrections.
- Ian Thomas and his students are using the text in a programming course. They are the first ones to test the chapters in the latter half of the book, and they have make numerous corrections and suggestions.
- Keith Verheyden sent in a correction in Chapter 3.
- Peter Winstanley let us know about a longstanding error in our Latin in Chapter 3.
- Chris Wrobel made corrections to the code in the chapter on file I/O and exceptions.
- Moshe Zadka has made invaluable contributions to this project. In addition to writing the first draft of the chapter on Dictionaries, he provided continual guidance in the early stages of the book.
- Christoph Zwerschke sent several corrections and pedagogic suggestions, and explained the difference between gleich and selbe.
- James Mayer sent us a whole slew of spelling and typographical errors, including two in the contributor list.
- Hayden McAfee caught a potentially confusing inconsistency between two examples.
- Angel Arnal is part of an international team of translators working on the Spanish version of the text. He has also found several errors in the English version.
- Tauhidul Hoque and Lex Berezhny created the illustrations in Chapter 1 and improved many of the other illustrations.
- Dr. Michele Alzetta caught an error in Chapter 8 and sent some interesting pedagogic comments and suggestions about Fibonacci and Old Maid.
- Andy Mitchell caught a typo in Chapter 1 and a broken example in Chapter 2.
- Kalin Harvey suggested a clarification in Chapter 7 and caught some typos.
- Christopher P. Smith caught several typos and is helping us prepare to update the book for Python 2.2.
- David Hutchins caught a typo in the Foreword.
- Gregor Lingl is teaching Python at a high school in Vienna, Austria. He is working on a German translation of the book, and he caught a couple of bad errors in Chapter 5.
- Julie Peters caught a typo in the Preface.

Chapter 1: The way of the program

The goal of this book is to teach you to think like a computer scientist. This way of thinking combines some of the best features of mathematics, engineering, and natural science. Like mathematicians, computer scientists use formal languages to denote ideas (specifically computations). Like engineers, they design things, assembling components into systems and evaluating tradeoffs among alternatives. Like scientists, they observe the behavior of complex systems, form hypotheses, and test predictions.

The single most important skill for a computer scientist is **problem solving**. Problem solving means the ability to formulate problems, think creatively about solutions, and express a solution clearly and accurately. As it turns out, the process of learning to program is an excellent opportunity to practice problem-solving skills. That's why this chapter is called, The way of the program.

On one level, you will be learning to program, a useful skill by itself. On another level, you will use programming as a means to an end. As we go along, that end will become clearer.

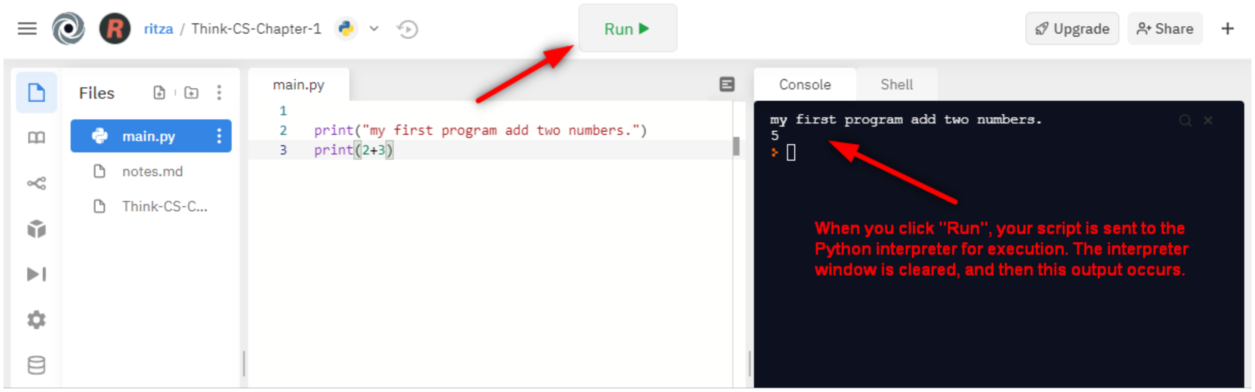
1.1. The Python programming language

The programming language you will be learning is Python. Python is an example of a high-level language; other **high-level languages** you might have heard of are C++, PHP, Pascal, C#, and Java.

As you might infer from the name high-level language, there are also **low-level languages**, sometimes referred to as machine languages or assembly languages. Loosely speaking, computers can only execute programs written in low-level languages. Thus, programs written in a high-level language have to be translated into something more suitable before they can run.

Almost all programs are written in high-level languages because of their advantages. It is much easier to program in a high-level language so programs take less time to write, they are shorter and easier to read, and they are more likely to be correct. Second, high-level languages are **portable**, meaning that they can run on different kinds of computers with few or no modifications.

The engine that translates and runs Python is called the **Python Interpreter**: There are two ways to use it: *immediate mode* and *script mode*. In immediate mode, you type Python expressions into the Python Interpreter window, and the interpreter immediately shows the result:



Python Interpreter

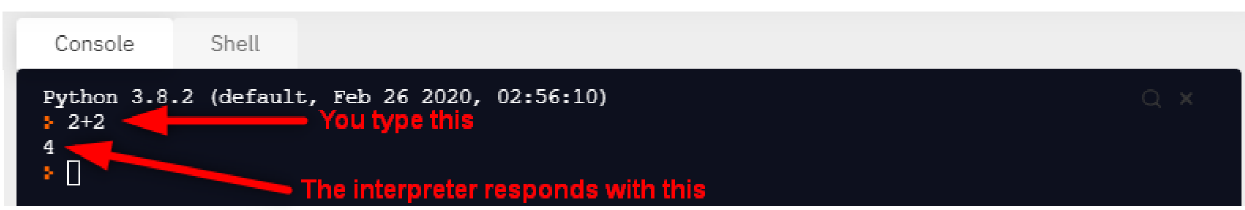
The >>> or > is called the **Python prompt**. The interpreter uses the prompt to indicate that it is ready for instructions. We typed `2 + 2`, and the interpreter evaluated our expression, and replied `4`, and on the next line it gave a new prompt, indicating that it is ready for more input.

Alternatively, you can write a program in a file and use the interpreter to execute the contents of the file. Such a file is called a **script**. Scripts have the advantage that they can be saved to disk, printed, and so on.

In this edition of the textbook, we use a program development environment called **Repl.it**. (It is available at https://repl.it/.) There are various other development environments. If you're using one of the others, you might be better off working with the authors' original book rather than this edition.

For example, we created a file named `main.py` using Repl.it. By convention, files that contain Python programs have names that end with `.py`

To execute the program, we can click the **Run** button in Repl.it:



Running a script in Repl.it

Most programs are more interesting than this one.

Working directly in the interpreter is convenient for testing short bits of code because you get immediate feedback. Think of it as scratch paper used to help you work out problems. Anything longer than a few lines should be put into a script.

1.2. What is a program?

A **program** is a sequence of instructions that specifies how to perform a computation. The computation might be something mathematical, such as solving a system of equations or finding the roots of a polynomial, but it can also be a symbolic computation, such as searching and replacing text in a document or (strangely enough) compiling a program.

The details look different in different languages, but a few basic instructions appear in just about every language:

input

- Get data from the keyboard, a file, or some other device.

output

- Display data on the screen or send data to a file or other device.

math

- Perform basic mathematical operations like addition and multiplication.

conditional execution

- Check for certain conditions and execute the appropriate sequence of statements.

repetition

- Perform some action repeatedly, usually with some variation.

Believe it or not, that's pretty much all there is to it. Every program you've ever used, no matter how complicated, is made up of instructions that look more or less like these. Thus, we can describe programming as the process of breaking a large, complex task into smaller and smaller subtasks until the subtasks are simple enough to be performed with sequences of these basic instructions.

That may be a little vague, but we will come back to this topic later when we talk about **algorithms**.

1.3. What is debugging?

Programming is a complex process, and because it is done by human beings, it often leads to errors. Programming errors are called **bugs** and the process of tracking them down and correcting them is called **debugging**. Use of the term bug to describe small engineering difficulties dates back to at least 1889, when Thomas Edison had a bug with his phonograph.

Three kinds of errors can occur in a program: syntax errors[1], runtime errors[2], and semantic errors[3].

[1]https://en.wikipedia.org/wiki/Syntax_error
[2]https://en.wikipedia.org/wiki/Runtime_(program_lifecycle_phase)
[3]https://en.wikipedia.org/wiki/Logic_error

It is useful to distinguish between them in order to track them down more quickly.

1.4. Syntax errors

Python can only execute a program if the program is syntactically correct; otherwise, the process fails and returns an error message. **Syntax** refers to the structure of a program and the rules about that structure. For example, in English, a sentence must begin with a capital letter and end with a period. this sentence contains a **syntax error**. So does this one

For most readers, a few syntax errors are not a significant problem, which is why we can read the poetry of E. E. Cummings without problems. Python is not so forgiving. If there is a single syntax error anywhere in your program, Python will display an error message and quit, and you will not be able to run your program. During the first few weeks of your programming career, you will probably spend a lot of time tracking down syntax errors. As you gain experience, though, you will make fewer errors and find them faster.

1.5. Runtime errors

The second type of error is a runtime error, so called because the error does not appear until you run the program. These errors are also called **exceptions** because they usually indicate that something exceptional (and bad) has happened.

Runtime errors are rare in the simple programs you will see in the first few chapters, so it might be a while before you encounter one.

1.6. Semantic errors

The third type of error is the **semantic error**. If there is a semantic error in your program, it will run successfully, in the sense that the computer will not generate any error messages, but it will not do the right thing. It will do something else. Specifically, it will do what you told it to do.

The problem is that the program you wrote is not the program you wanted to write. The meaning of the program (its semantics) is wrong. Identifying semantic errors can be tricky because it requires you to work backward by looking at the output of the program and trying to figure out what it is doing.

1.7. Experimental debugging

One of the most important skills you will acquire is debugging. Although it can be frustrating, debugging is one of the most intellectually rich, challenging, and interesting parts of programming.

In some ways, debugging is like detective work. You are confronted with clues, and you have to infer the processes and events that led to the results you see.

Debugging is also like an experimental science. Once you have an idea what is going wrong, you modify your program and try again. If your hypothesis was correct, then you can predict the result of the modification, and you take a step closer to a working program. If your hypothesis was wrong, you have to come up with a new one. As Sherlock Holmes pointed out, When you have eliminated the impossible, whatever remains, however improbable, must be the truth. (A. Conan Doyle, *The Sign of Four*)

For some people, programming and debugging are the same thing. That is, programming is the process of gradually debugging a program until it does what you want. The idea is that you should start with a program that does something and make small modifications, debugging them as you go, so that you always have a working program.

For example, Linux is an operating system kernel that contains millions of lines of code, but it started out as a simple program Linus Torvalds used to explore the Intel 80386 chip. According to Larry Greenfield, one of Linus's earlier projects was a program that would switch between displaying AAAA and BBBB. This later evolved to Linux (*The Linux Users' Guide* Beta Version 1).

Later chapters will make more suggestions about debugging and other programming practices.

1.8. Formal and natural languages

Natural languages are the languages that people speak, such as English, Spanish, and French. They were not designed by people (although people try to impose some order on them); they evolved naturally.

Formal languages are languages that are designed by people for specific applications. For example, the notation that mathematicians use is a formal language that is particularly good at denoting relationships among numbers and symbols. Chemists use a formal language to represent the chemical structure of molecules. And most importantly:

Programming languages are formal languages that have been designed to express computations.

Formal languages tend to have strict rules about syntax. For example, `3+3=6` is a syntactically correct mathematical statement, but `3=+6$` is not. `H2O` is a syntactically correct chemical name, but `2Zz` is not.

Syntax rules come in two flavors, pertaining to **tokens** and structure. Tokens are the basic elements of the language, such as words, numbers, parentheses, commas, and so on. In Python, a statement like `print("Happy New Year for ",2013)` has 6 tokens: a function name, an open parenthesis (round bracket), a string, a comma, a number, and a close parenthesis.

It is possible to make errors in the way one constructs tokens. One of the problems with `3=+6$` is that `$` is not a legal token in mathematics (at least as far as we know). Similarly, `2Zz` is not a legal token in chemistry notation because there is no element with the abbreviation `Zz`.

The second type of syntax rule pertains to the **structure** of a statement— that is, the way the tokens are arranged. The statement `3=+6$` is structurally illegal because you can't place a plus sign immediately after an equal sign. Similarly, molecular formulas have to have subscripts after the element name, not before. And in our Python example, if we omitted the comma, or if we changed the two parentheses around to say `print)"Happy New Year for ",2013(` our statement would still have six legal and valid tokens, but the structure is illegal.

When you read a sentence in English or a statement in a formal language, you have to figure out what the structure of the sentence is (although in a natural language you do this subconsciously). This process is called **parsing**.

For example, when you hear the sentence, "The other shoe fell", you understand that the other shoe is the subject and fell is the verb. Once you have parsed a sentence, you can figure out what it means, or the **semantics** of the sentence. Assuming that you know what a shoe is and what it means to fall, you will understand the general implication of this sentence.

Although formal and natural languages have many features in common — tokens, structure, syntax, and semantics — there are many differences:

ambiguity

- Natural languages are full of ambiguity, which people deal with by using contextual clues and other information. Formal languages are designed to be nearly or completely unambiguous, which means that any statement has exactly one meaning, regardless of context.

redundancy

- In order to make up for ambiguity and reduce misunderstandings, natural languages employ lots of redundancy. As a result, they are often verbose. Formal languages are less redundant and more concise.

literalness

- Formal languages mean exactly what they say. On the other hand, natural languages are full of idiom and metaphor. If someone says, "The other shoe fell", there is probably no shoe and nothing falling. You'll need to find the original joke to understand the idiomatic meaning of the other shoe falling. Yahoo! Answers thinks it knows!

People who grow up speaking a natural language—everyone—often have a hard time adjusting to formal languages. In some ways, the difference between formal and natural language is like the difference between poetry and prose, but more so:

poetry

- Words are used for their sounds as well as for their meaning, and the whole poem together creates an effect or emotional response. Ambiguity is not only common but often deliberate.

prose

- The literal meaning of words is more important, and the structure contributes more meaning. Prose is more amenable to analysis than poetry but still often ambiguous.

program

- The meaning of a computer program is unambiguous and literal, and can be understood entirely by analysis of the tokens and structure.

Here are some suggestions for reading programs (and other formal languages). First, remember that formal languages are much more dense than natural languages, so it takes longer to read them. Also, the structure is very important, so it is usually not a good idea to read from top to bottom, left to right. Instead, learn to parse the program in your head, identifying the tokens and interpreting the structure. Finally, the details matter. Little things like spelling errors and bad punctuation, which you can get away with in natural languages, can make a big difference in a formal language.

1.9. The first program

Traditionally, the first program written in a new language is called Hello, World! because all it does is display the words, Hello, World! In Python, the script looks like this: (For scripts, we'll show line numbers to the left of the Python statements.)

```python
print("Hello, World!")
```

This is an example of using the **print function**, which doesn't actually print anything on paper. It displays a value on the screen. In this case, the result shown is

```
Hello, World!
```

The quotation marks in the program mark the beginning and end of the value; they don't appear in the result.

Some people judge the quality of a programming language by the simplicity of the Hello, World! program. By this standard, Python does about as well as possible.

1.10. Comments

As programs get bigger and more complicated, they get more difficult to read. Formal languages are dense, and it is often difficult to look at a piece of code and figure out what it is doing, or why.

For this reason, it is a good idea to add notes to your programs to explain in natural language what the program is doing.

A **comment** in a computer program is text that is intended only for the human reader — it is completely ignored by the interpreter.

In Python, the # token starts a comment. The rest of the line is ignored. Here is a new version of Hello, World!.

```
#---------------------------------------------------
# This demo program shows off how elegant Python is!
# Written by Joe Soap, December 2010.
# Anyone may freely copy or modify this program.
#---------------------------------------------------

print("Hello, World!")     # Isn't this easy!
```

You'll also notice that we've left a blank line in the program. Blank lines are also ignored by the interpreter, but comments and blank lines can make your programs much easier for humans to parse. Use them liberally!

1.11. Glossary

algorithm

A set of specific steps for solving a category of problems.

bug

An error in a program.

comment

Information in a program that is meant for other programmers (or anyone reading the source code) and has no effect on the execution of the program.

debugging

The process of finding and removing any of the three kinds of programming errors.

exception

Another name for a runtime error.

formal language

Any one of the languages that people have designed for specific purposes, such as representing mathematical ideas or computer programs; all programming languages are formal languages.

high-level language

A programming language like Python that is designed to be easy for humans to read and write.

immediate mode

A style of using Python where we type expressions at the command prompt, and the results are shown immediately. Contrast with script, and see the entry under Python shell.

interpreter

The engine that executes your Python scripts or expressions.

low-level language

A programming language that is designed to be easy for a computer to execute; also called machine language or assembly language.

natural language

Any one of the languages that people speak that evolved naturally.

object code

The output of the compiler after it translates the program.

parse

To examine a program and analyze the syntactic structure.

portability

A property of a program that can run on more than one kind of computer.

print function

A function used in a program or script that causes the Python interpreter to display a value on its output device.

problem solving

The process of formulating a problem, finding a solution, and expressing the solution.

program

a sequence of instructions that specifies to a computer actions and computations to be performed.

Python shell

An interactive user interface to the Python interpreter. The user of a Python shell types commands at the prompt (>>>), and presses the return key to send these commands immediately to the interpreter for processing. The word shell comes from Unix. In the PyScripter used in this RLE version of the book, the Interpreter Window is where we'd do the immediate mode interaction.

runtime error

An error that does not occur until the program has started to execute but that prevents the program from continuing.

script

A program stored in a file (usually one that will be interpreted).

semantic error

An error in a program that makes it do something other than what the programmer intended.

semantics

The meaning of a program.

source code

A program in a high-level language before being compiled.

syntax

The structure of a program.

syntax error

An error in a program that makes it impossible to parse — and therefore impossible to interpret.

token

One of the basic elements of the syntactic structure of a program, analogous to a word in a natural language.

1.12. Exercises

1. Write an English sentence with understandable semantics but incorrect syntax. Write another English sentence which has correct syntax but has semantic errors.
2. Using the Python interpreter, type `1 + 2` and then hit return. Python evaluates this expression, displays the result, and then shows another prompt. `*` is the multiplication operator, and `**` is the exponentiation operator. Experiment by entering different expressions and recording what is displayed by the Python interpreter.
3. Type `1 2` and then hit return. Python tries to evaluate the expression, but it can't because the expression is not syntactically legal. Instead, it shows the error message:

```
File "<interactive input>", line 1
    1 2
      ^
SyntaxError: invalid syntax
```

In many cases, Python indicates where the syntax error occurred, but it is not always right, and it doesn't give you much information about what is wrong.

So, for the most part, the burden is on you to learn the syntax rules.

In this case, Python is complaining because there is no operator between the numbers.

See if you can find a few more examples of things that will produce error messages when you enter them at the Python prompt. Write down what you enter at the prompt and the last line of the error message that Python reports back to you.

4. Type `print("hello")`. Python executes this, which has the effect of printing the letters h-e-l-l-o. Notice that the quotation marks that you used to enclose the string are not part of the output. Now type `"hello"` and describe your result. Make notes of when you see the quotation marks and when you don't.
5. Type cheese without the quotation marks. The output will look something like this:

```
Traceback (most recent call last):
  File "<interactive input>", line 1, in ?
NameError: name 'cheese' is not defined
```

This is a run-time error; specifically, it is a NameError, and even more specifically, it is an error because the name cheese is not defined. If you don't know what that means yet, you will soon.

6. Type 6 + 4 * 9 at the Python prompt and hit enter. Record what happens.

Now create a Python script with the following contents:

```
6 + 4 * 9
```

What happens when you run this script? Now change the script contents to:

```
print(6 + 4 * 9)
```

and run it again.

What happened this time?

Whenever an expression is typed at the Python prompt, it is evaluated and the result is automatically shown on the line below. (Like on your calculator, if you type this expression you'll get the result 42.)

A script is different, however. Evaluations of expressions are not automatically displayed, so it is necessary to use the **print** function to make the answer show up.

It is hardly ever necessary to use the print function in immediate mode at the command prompt.

Chapter 2: Variables, expressions and statements

2.1. Values and data types

A **value** is one of the fundamental things — like a letter or a number — that a program manipulates. The values we have seen so far are `4` (the result when we added `2 + 2`), and `"Hello, World!"`.

These values are classified into different **classes**, or **data types**: `4` is an *integer*, and `"Hello, World!"` is a *string*, so-called because it contains a string of letters. You (and the interpreter) can identify strings because they are enclosed in quotation marks.

If you are not sure what class a value falls into, Python has a function called **type** which can tell you.

```
>>> type("Hello, World!")
<class 'str'>
>>> type(17)
<class 'int'>
```

Not surprisingly, strings belong to the class **str** and integers belong to the class **int**. Less obviously, numbers with a decimal point belong to a class called **float**, because these numbers are represented in a format called *floating-point*. At this stage, you can treat the words *class* and *type* interchangeably. We'll come back to a deeper understanding of what a class is in later chapters.

```
>>> type(3.2)
<class 'float'>
```

What about values like `"17"` and `"3.2"`? They look like numbers, but they are in quotation marks like strings.

```
>>> type("17")
<class 'str'>
>>> type("3.2")
<class 'str'>
```

They're strings!

Strings in Python can be enclosed in either single quotes (‘) or double quotes (“), or three of each (‘’’ or “””)

```
>>> type('This is a string.')
<class 'str'>
>>> type("And so is this.")
<class 'str'>
>>> type("""and this.""")
<class 'str'>
>>> type('''and even this...''')
<class 'str'>
```

Double quoted strings can contain single quotes inside them, as in `"Bruce's beard"`, and single quoted strings can have double quotes inside them, as in `'The knights who say "Ni!"'`.

Strings enclosed with three occurrences of either quote symbol are called triple quoted strings. They can contain either single or double quotes:

```
>>> print('''"Oh no", she exclaimed, "Ben's bike is broken!"''')
"Oh no", she exclaimed, "Ben's bike is broken!"
>>>
```

Triple quoted strings can even span multiple lines:

```
>>> message = """This message will
... span several
... lines."""
>>> print(message)
This message will
span several
lines.
>>>
```

Python doesn't care whether you use single or double quotes or the three-of-a-kind quotes to surround your strings: once it has parsed the text of your program or command, the way it stores the value is identical in all cases, and the surrounding quotes are not part of the value. But when the interpreter wants to display a string, it has to decide which quotes to use to make it look like a string.

```
>>> 'This is a string.'
'This is a string.'
>>> """And so is this."""
'And so is this.'
```

So the Python language designers usually chose to surround their strings by single quotes. What do you think would happen if the string already contained single quotes?

When you type a large integer, you might be tempted to use commas between groups of three digits, as in `42,000`. This is not a legal integer in Python, but it does mean something else, which is legal:

```
>>> 42000
42000
>>> 42,000
(42, 0)
```

Well, that's not what we expected at all! Because of the comma, Python chose to treat this as a pair of values. We'll come back to learn about pairs later. But, for the moment, remember not to put commas or spaces in your integers, no matter how big they are. Also revisit what we said in the previous chapter: formal languages are strict, the notation is concise, and even the smallest change might mean something quite different from what you intended.

2.2. Variables

One of the most powerful features of a programming language is the ability to manipulate **variables**. A variable is a name that refers to a value.

The **assignment statement** gives a value to a variable:

```
>>> message = "What's up, Doc?"
>>> n = 17
>>> pi = 3.14159
```

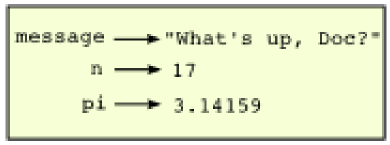
This example makes three assignments. The first assigns the string value `"What's up, Doc?"` to a variable named message. The second gives the integer `17` to `n`, and the third assigns the floating-point number `3.14159` to a variable called `pi`.

The assignment token, `=`, should not be confused with *equals*, which uses the token `==`. The assignment statement binds a *name*, on the left-hand side of the operator, to a *value*, on the right-hand side. This is why you will get an error if you enter:

```
>>> 17 = n
File "<interactive input>", line 1
SyntaxError: can't assign to literal
```

Tip:
When reading or writing code, say to yourself "n is assigned 17" or "n gets the value 17". Don't say "n equals 17".

A common way to represent variables on paper is to write the name with an arrow pointing to the variable's value. This kind of figure is called a **state snapshot** because it shows what state each of the variables is in at a particular instant in time. (Think of it as the variable's state of mind). This diagram shows the result of executing the assignment statements:



State Snapshot

If you ask the interpreter to evaluate a variable, it will produce the value that is currently linked to the variable:

```
>>> message
"What's up, Doc?"
>>> n
17
>>> pi
3.14159
```

We use variables in a program to "remember" things, perhaps the current score at the football game. But variables are *variable*. This means they can change over time, just like the scoreboard at a football game. You can assign a value to a variable, and later assign a different value to the same variable. (*This is different from maths. In maths, if you give* `x` *the value* `3`*, it cannot change to link to a different value half-way through your calculations!*)

```
>>> day = "Thursday"
>>> day
'Thursday'
>>> day = "Friday"
>>> day
'Friday'
>>> day = 21
>>> day
21
```

You'll notice we changed the value of `day` three times, and on the third assignment we even made it refer to a value that was of a different type.

A great deal of programming is about having the computer remember things, e.g. *The number of missed calls on your phone*, and then arranging to update or change the variable when you miss another call.

2.3. Variable names and keywords

Variable names can be arbitrarily long. They can contain both letters and digits, but they have to begin with a letter or an underscore. Although it is legal to use uppercase letters, by convention we don't. If you do, remember that case matters. `Bruce` and `bruce` are different variables.

The underscore character (_) can appear in a name. It is often used in names with multiple words, such as `my_name` or `price_of_tea_in_china`.

There are some situations in which names beginning with an underscore have special meaning, so a safe rule for beginners is to start all names with a letter.

If you give a variable an illegal name, you get a syntax error:

```
>>> 76trombones = "big parade"
SyntaxError: invalid syntax
>>> more$ = 1000000
SyntaxError: invalid syntax
>>> class = "Computer Science 101"
SyntaxError: invalid syntax
```

`76trombones` is illegal because it does not begin with a letter. `more$` is illegal because it contains an illegal character, the dollar sign. But what's wrong with `class`?

It turns out that `class` is one of the Python **keywords**. Keywords define the language's syntax rules and structure, and they cannot be used as variable names.

Python has thirty-something keywords (and every now and again improvements to Python introduce or eliminate one or two):

and	**as**	**assert**	**break**	**class**	**continue**
def	del	elif	else	except	exec
finally	for	from	global	if	import
in	is	lambda	nonlocal	not	or
pass	raise	return	try	while	with
yield	True	False	None		

You might want to keep this list handy. If the interpreter complains about one of your variable names and you don't know why, see if it is on this list.

Programmers generally choose names for their variables that are meaningful to the human readers of the program — they help the programmer document, or remember, what the variable is used for.

Caution

> *Beginners sometimes confuse "meaningful to the human readers" with "meaningful to the computer". So they'll wrongly think that because they've called some variable `average` or `pi`, it will somehow magically calculate an average, or magically know that the variable `pi` should have a value like `3.14159`. No! The computer doesn't understand what you intend the variable to mean.*
>
> *So you'll find some instructors who deliberately don't choose meaningful names when they teach beginners — not because we don't think it is a good habit, but because we're trying to reinforce the message that you — the programmer — must write the program code to calculate the average, and you must write an assignment statement to give the variable `pi` the value you want it to have.*

2.4. Statements

A **statement** is an instruction that the Python interpreter can execute. We have only seen the assignment statement so far. Some other kinds of statements that we'll see shortly are `while` statements, `for` statements, `if` statements, and `import` statements. (There are other kinds too!)

When you type a statement on the command line, Python executes it. Statements don't produce any result.

2.5. Evaluating expressions

An **expression** is a combination of values, variables, operators, and calls to functions. If you type an expression at the Python prompt, the interpreter **evaluates** it and displays the result:

```
>>> 1 + 1
2
>>> len("hello")
5
```

In this example `len` is a built-in Python function that returns the number of characters in a `string`. We've previously seen the `print` and the `type` functions, so this is our third example of a function!

The *evaluation* of an *expression* produces a value, which is why expressions can appear on the right hand side of assignment statements. A value all by itself is a simple expression, and so is a variable.

```
>>> 17
17
>>> y = 3.14
>>> x = len("hello")
>>> x
5
>>> y
3.14
```

2.6. Operators and operands

Operators are special tokens that represent computations like addition, multiplication and division. The values the operator uses are called **operands**.

The following are all legal Python expressions whose meaning is more or less clear:

```
20+32   hour-1   hour*60+minute   minute/60   5**2   (5+9)*(15-7)
```

The tokens `+`, `-`, and `*`, and the use of parenthesis for grouping, mean in Python what they mean in mathematics. The asterisk (`*`) is the token for multiplication, and `**` is the token for exponentiation.

```
>>> 2 ** 3
8
>>> 3 ** 2
9
```

When a variable name appears in the place of an operand, it is replaced with its value before the operation is performed.

Addition, subtraction, multiplication, and exponentiation all do what you expect.

Example: so let us convert 645 minutes into hours:

```
>>> minutes = 645
>>> hours = minutes / 60
>>> hours
10.75
```

Oops! In Python 3, the division operator `/`always yields a floating point result. What we might have wanted to know was how many whole hours there are, and how many minutes remain. Python gives us two different flavors of the division operator. The second, called **floor division** uses the token `//`. Its result is always a whole number — and if it has to adjust the number it always moves it to the left on the number line. So `6 // 4` yields `1`, but `-6 // 4` might surprise you!

```
>>> 7 / 4
1.75
>>> 7 // 4
1
>>> minutes = 645
>>> hours = minutes // 60
>>> hours
10
```

Take care that you choose the correct flavor of the division operator. If you're working with expressions where you need floating point values, use the division operator that does the division accurately.

2.7. Type converter functions

Here we'll look at three more Python functions, `int`, `float` and `str`, which will (attempt to) convert their arguments into types `int`, `float` and `str` respectively. We call these **type converter** functions.

The int function can take a floating point number or a string, and turn it into an int. For floating point numbers, it discards the decimal portion of the number — a process we call truncation towards zero on the number line. Let us see this in action:

```
>>> int(3.14)
3
>>> int(3.9999)             # This doesn't round to the closest int!
3
>>> int(3.0)
3
>>> int(-3.999)             # Note that the result is closer to zero
-3
>>> int(minutes / 60)
10
>>> int("2345")             # Parse a string to produce an int
2345
>>> int(17)                 # It even works if arg is already an int
17
>>> int("23 bottles")
```

This last case doesn't look like a number — what do we expect?

```
Traceback (most recent call last):
File "<interactive input>", line 1, in <module>
ValueError: invalid literal for int() with base 10: '23 bottles'
```

The type converter `float` can turn an integer, a float, or a syntactically legal string into a float:

```
>>> float(17)
17.0
>>> float("123.45")
123.45
```

The type converter `str` turns its argument into a string:

```
>>> str(17)
'17'
>>> str(123.45)
'123.45'
```

2.8. Order of operations

When more than one operator appears in an expression, the order of evaluation depends on the **rules of precedence**. Python follows the same precedence rules for its mathematical operators that mathematics does. The acronym PEMDAS is a useful way to remember the order of operations:

1. **P**arentheses have the highest precedence and can be used to force an expression to evaluate in the order you want. Since expressions in parentheses are evaluated first, `2 * (3-1)` is `4`, and `(1+1)**(5-2)` is `8`. You can also use parentheses to make an expression easier to read, as in `(minute * 100) / 60`, even though it doesn't change the result.
2. **E**xponentiation has the next highest precedence, so `2**1+1` is `3` and not `4`, and `3*1**3` is `3` and not `27`.
3. **M**ultiplication and both **D**ivision operators have the same precedence, which is higher than **A**ddition and **S**ubtraction, which also have the same precedence. So `2*3-1` yields `5` rather than `4`, and `5-2*2` is `1`, not `6`.

Operators with the same precedence are evaluated from left-to-right. In algebra we say they are left-associative. So in the expression `6-3+2`, the subtraction happens first, yielding `3`. We then add `2` to get the result `5`. If the operations had been evaluated from right to left, the result would have been `6-(3+2)`, which is `1`. (The acronym PEDMAS could mislead you to thinking that division has higher precedence than multiplication, and addition is done ahead of subtraction - don't be misled. Subtraction and addition are at the same precedence, and the left-to-right rule applies.)

Due to some historical quirk, an exception to the left-to-right left-associative rule is the exponentiation operator `**`, so a useful hint is to always use parentheses to force exactly the order you want when exponentiation is involved:

```
>>> 2 ** 3 ** 2     # The right-most ** operator gets done first!
512
>>> (2 ** 3) ** 2   # Use parentheses to force the order you want!
64
```

The immediate mode command prompt of Python is great for exploring and experimenting with expressions like this.

2.9. Operations on strings

In general, you cannot perform mathematical operations on strings, even if the strings look like numbers. The following are illegal (assuming that message has type string):

```
>>> message - 1        # Error
>>> "Hello" / 123      # Error
>>> message * "Hello"  # Error
>>> "15" + 2           # Error
```

Interestingly, the + operator does work with strings, but for strings, the + operator represents **concatenation**, not addition. Concatenation means joining the two operands by linking them end-to-end. For example:

```
fruit = "banana"
baked_good = " nut bread"
print(fruit + baked_good)
```

The output of this program is banana nut bread. The space before the word nut is part of the string, and is necessary to produce the space between the concatenated strings.

The * operator also works on strings; it performs repetition. For example, `'Fun'*3` is `'FunFunFun'`. One of the operands has to be a string; the other has to be an integer.

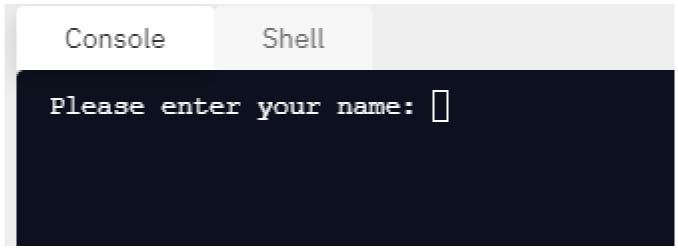
On one hand, this interpretation of + and * makes sense by analogy with addition and multiplication. Just as `4*3` is equivalent to `4+4+4`, we expect `"Fun"*3` to be the same as `"Fun"+"Fun"+"Fun"`, and it is. On the other hand, there is a significant way in which string concatenation and repetition are different from integer addition and multiplication. Can you think of a property that addition and multiplication have that string concatenation and repetition do not?

2.10. Input

There is a built-in function in Python for getting input from the user:

```
n = input("Please enter your name: ")
```

A sample run of this script in Repl.it would populate your input question in the console to the left like this:



Input Prompt

The user of the program can enter the name and press enter, and when this happens the text that has been entered is returned from the input function, and in this case assigned to the variable n.

Even if you asked the user to enter their age, you would get back a string like `"17"`. It would be your job, as the programmer, to convert that string into a int or a float, using the `int` or `float` converter functions we saw earlier.

2.11. Composition

So far, we have looked at the elements of a program — variables, expressions, statements, and function calls — in isolation, without talking about how to combine them.

One of the most useful features of programming languages is their ability to take small building blocks and **compose** them into larger chunks.

For example, we know how to get the user to enter some input, we know how to convert the string we get into a float, we know how to write a complex expression, and we know how to print values. Let's put these together in a small four-step program that asks the user to input a value for the radius of a circle, and then computes the area of the circle from the formula

$$\text{Area} = \pi r^2$$

Area of a circle

Firstly, we'll do the four steps one at a time:

```
response = input("What is your radius? ")
r = float(response)
area = 3.14159 * r**2
print("The area is ", area)
```

Now let's compose the first two lines into a single line of code, and compose the second two lines into another line of code.

```
r = float( input("What is your radius? ") )
print("The area is ", 3.14159 * r**2)
```

If we really wanted to be tricky, we could write it all in one statement:

```
print("The area is ", 3.14159*float(input("What is your radius?"))**2)
```

Such compact code may not be most understandable for humans, but it does illustrate how we can compose bigger chunks from our building blocks.

If you're ever in doubt about whether to compose code or fragment it into smaller steps, try to make it as simple as you can for the human to follow. My choice would be the first case above, with four separate steps.

2.12. The modulus operator

The modulus operator works on integers (and integer expressions) and gives the remainder when the first number is divided by the second. In Python, the modulus operator is a percent sign (`%`). The syntax is the same as for other operators. It has the same precedence as the multiplication operator.

```
>>> q = 7 // 3     # This is integer division operator
>>> print(q)
2
>>> r  = 7 % 3
>>> print(r)
1
```

So `7` divided by `3` is `2` with a remainder of `1`.

The modulus operator turns out to be surprisingly useful. For example, you can check whether one number is divisible by another—if `x % y` is zero, then `x` is divisible by `y`.

Also, you can extract the right-most digit or digits from a number. For example, `x % 10` yields the right-most digit of `x` (in base `10`). Similarly `x % 100` yields the last two digits.

It is also extremely useful for doing conversions, say from seconds, to hours, minutes and seconds. So let's write a program to ask the user to enter some seconds, and we'll convert them into hours, minutes, and remaining seconds.

```
total_secs = int(input("How many seconds, in total?"))
hours = total_secs // 3600
secs_still_remaining = total_secs % 3600
minutes =  secs_still_remaining // 60
secs_finally_remaining = secs_still_remaining  % 60

print("Hrs=", hours, "  mins=", minutes,
                             "secs=", secs_finally_remaining)
```

2.13. Glossary

assignment statement

A statement that assigns a value to a name (variable). To the left of the assignment operator, `=`, is a name. To the right of the assignment token is an expression which is evaluated by the Python interpreter and then assigned to the name. The difference between the left and right hand sides of the assignment statement is often confusing to new programmers. In the following assignment:

```
n = n + 1
```

`n` plays a very different role on each side of the `=`. On the right it is a value and makes up part of the expression which will be evaluated by the Python interpreter before assigning it to the name on the left.

assignment token

`=` is Python's assignment token. Do not confuse it with *equals*, which is an operator for comparing values.

composition

The ability to combine simple expressions and statements into compound statements and expressions in order to represent complex computations concisely.

concatenate

To join two strings end-to-end.

data type

A set of values. The type of a value determines how it can be used in expressions. So far, the types you have seen are integers (`int`), floating-point numbers (`float`), and strings (`str`).

evaluate

To simplify an expression by performing the operations in order to yield a single value.

expression

A combination of variables, operators, and values that represents a single result value.

float

A Python data type which stores *floating-point* numbers. Floating-point numbers are stored internally in two parts: a *base* and an *exponent*. When printed in the standard format, they look like decimal numbers. Beware of rounding errors when you use `floats`, and remember that they are only approximate values.

floor division

An operator (denoted by the token `//`) that divides one number by another and yields an integer, or, if the result is not already an integer, it yields the next smallest integer.

int

A Python data type that holds positive and negative whole numbers.

keyword

A reserved word that is used by the compiler to parse programs; you cannot use keywords like `if`, `def`, and `while` as variable names.

modulus operator

An operator, denoted with a percent sign (`%`), that works on integers and yields the remainder when one number is divided by another.

operand

One of the values on which an operator operates.

operator

A special symbol that represents a simple computation like addition, multiplication, or string concatenation.

rules of precedence

The set of rules governing the order in which expressions involving multiple operators and operands are evaluated.

state snapshot

A graphical representation of a set of variables and the values to which they refer, taken at a particular instant during the program's execution.

statement

An instruction that the Python interpreter can execute. So far we have only seen the assignment statement, but we will soon meet the `import` statement and the `for` statement.

str

A Python data type that holds a string of characters.

value

A number or string (or other things to be named later) that can be stored in a variable or computed in an expression.

variable

A name that refers to a value.

variable name

A name given to a variable. Variable names in Python consist of a sequence of letters (a..z, A..Z, and _) and digits (0..9) that begins with a letter. In best programming practice, variable names should be chosen so that they describe their use in the program, making the program *self documenting*.

2.14. Exercises

1. Take the sentence: All work and no play makes Jack a dull boy. Store each word in a separate variable, then print out the sentence on one line using print.
2. Add parenthesis to the expression `6 * 1 - 2` to change its value from `4` to `-6`.
3. Place a comment before a line of code that previously worked, and record what happens when you rerun the program.
4. Start the Python interpreter and enter `bruce + 4` at the prompt. This will give you an error:

```
NameError: name 'bruce' is not defined
```

   Assign a value to bruce so that `bruce + 4` evaluates to `10`.
5. The formula for computing the final amount if one is earning compound interest is given on Wikipedia as

   Compounded Interest Formula

$$A = P\left(1 + \frac{r}{n}\right)^{nt}$$

Where,

- P = principal amount (initial investment)
- r = annual nominal interest rate (as a decimal)
- n = number of times the interest is compounded per year
- t = number of years

Compounded Interest Formula

   Write a Python program that assigns the principal amount of $10000 to variable `P`, assign to `n` the value `12`, and assign to `r` the interest rate of 8%. Then have the program prompt the user for the number of years `t` that the money will be compounded for. Calculate and print the final amount after `t` years.

6. Evaluate the following numerical expressions in your head, then use the Python interpreter to check your results:

```
>>> 5 % 2
>>> 9 % 5
>>> 15 % 12
>>> 12 % 15
>>> 6 % 6
>>> 0 % 7
>>> 7 % 0
```

   What happened with the last example? Why? If you were able to correctly anticipate the computer's response in all but the last one, it is time to move on. If not, take time now to make up examples of your own. Explore the modulus operator until you are confident you understand how it works.
7. You look at the clock and it is exactly 2pm. You set an alarm to go off in 51 hours. At what time does the alarm go off? (*Hint: you could count on your fingers, but this is not what we're after. If you are tempted to count on your fingers, change the 51 to 5100.*)
8. Write a Python program to solve the general version of the above problem. Ask the user for the time now (in hours), and ask for the number of hours to wait. Your program should output what the time will be on the clock when the alarm goes off.

Chapter 3: Hello, little turtles!

There are many *modules* in Python that provide very powerful features that we can use in our own programs. Some of these can send email, or fetch web pages. The one we'll look at in this chapter allows us to create turtles and get them to draw shapes and patterns.

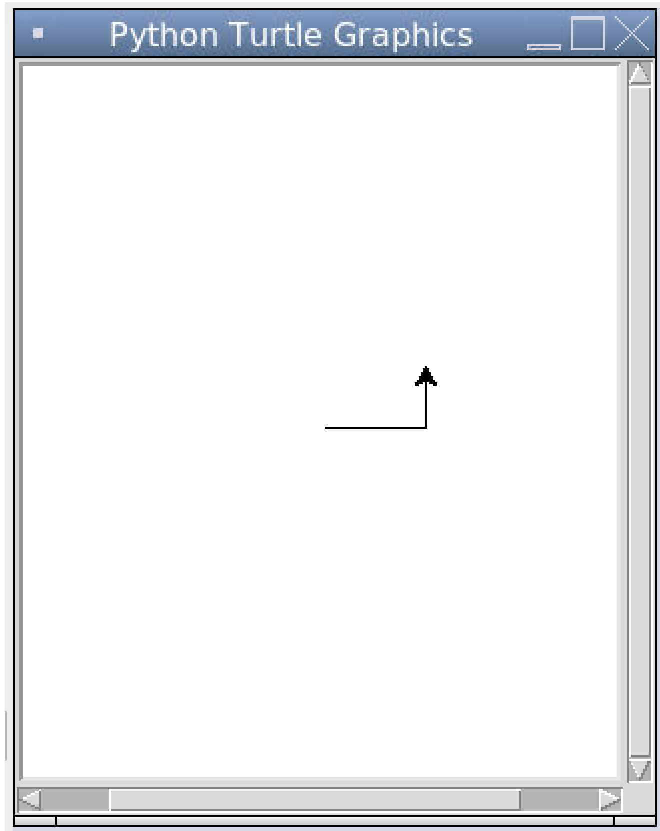
The turtles are fun, but the real purpose of the chapter is to teach ourselves a little more Python, and to develop our theme of *computational thinking*, or *thinking like a computer scientist*. Most of the Python covered here will be explored in more depth later.

3.1. Our first turtle program

Let's write a couple of lines of Python program to create a new turtle and start drawing a rectangle. (We'll call the variable that refers to our first turtle `alex`, but we can choose another name if we follow the naming rules from the previous chapter).

```
import turtle             # Allows us to use turtles
wn = turtle.Screen()      # Creates a playground for turtles
alex = turtle.Turtle()    # Create a turtle, assign to alex

alex.forward(50)          # Tell alex to move forward by 50 units
alex.left(90)             # Tell alex to turn by 90 degrees
alex.forward(30)          # Complete the second side of a rectangle

wn.mainloop()             # Wait for user to close window
```

When we run this program, a new window pops up:



Turtle Window

Here are a couple of things we'll need to understand about this program.

The first line tells Python to load a module named `turtle`. That module brings us two new types that we can use: the `Turtle` type, and the `Screen` type. The dot notation `turtle.Turtle` means "*The Turtle type that is defined within the turtle module*". (Remember that Python is case sensitive, so the module name, with a lowercase `t`, is different from the type `Turtle`.)

We then create and open what it calls a screen (we would prefer to call it a window), which we assign to variable `wn`. Every window contains a **canvas**, which is the area inside the window on which we can draw.

In line 3 we create a turtle. The variable `alex` is made to refer to this turtle.

So these first three lines have set things up, we're ready to get our turtle to draw on our canvas.

In lines 5-7, we instruct the **object** `alex` to move, and to turn. We do this by **invoking**, or activating, `alex's` **methods** — these are the instructions that all turtles know how to respond to.

The last line plays a part too: the `wn` variable refers to the window shown above. When we invoke its `mainloop` method, it enters a state where it waits for events (like keypresses, or mouse movement and clicks). The program will terminate when the user closes the window.

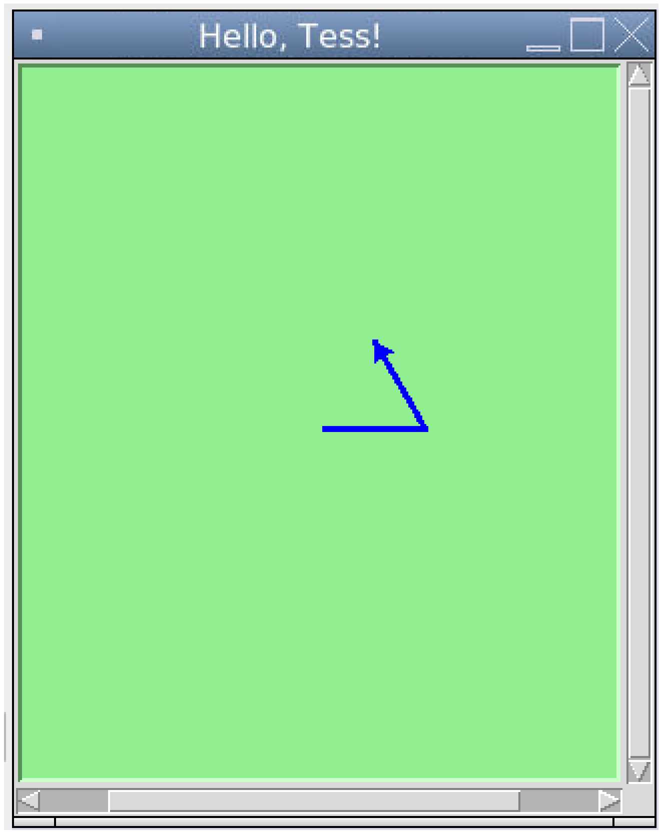
An object can have various methods — things it can do — and it can also have **attributes** — (sometimes called properties). For example, each turtle has a *color* attribute. The method invocation `alex.color("red")` will make `alex` red, and drawing will be red too. (Note the word *color* is spelled the American way!)

The color of the turtle, the width of its pen, the position of the turtle within the window, which way it is facing, and so on are all part of its current **state**. Similarly, the window object has a background color, and some text in the title bar, and a size and position on the screen. These are all part of the state of the window object.

Quite a number of methods exist that allow us to modify the turtle and the window objects. We'll just show a couple. In this program we've only commented those lines that are different from the previous example (and we've used a different variable name for this turtle):

```
import turtle
wn = turtle.Screen()
wn.bgcolor("lightgreen")       # Set the window background color
wn.title("Hello, Tess!")       # Set the window title

tess = turtle.Turtle()
tess.color("blue")             # Tell tess to change her color
tess.pensize(3)                # Tell tess to set her pen width

tess.forward(50)
tess.left(120)
tess.forward(50)

wn.mainloop()
```

When we run this program, this new window pops up, and will remain on the screen until we close it.



tess mainloop

Extend this program …

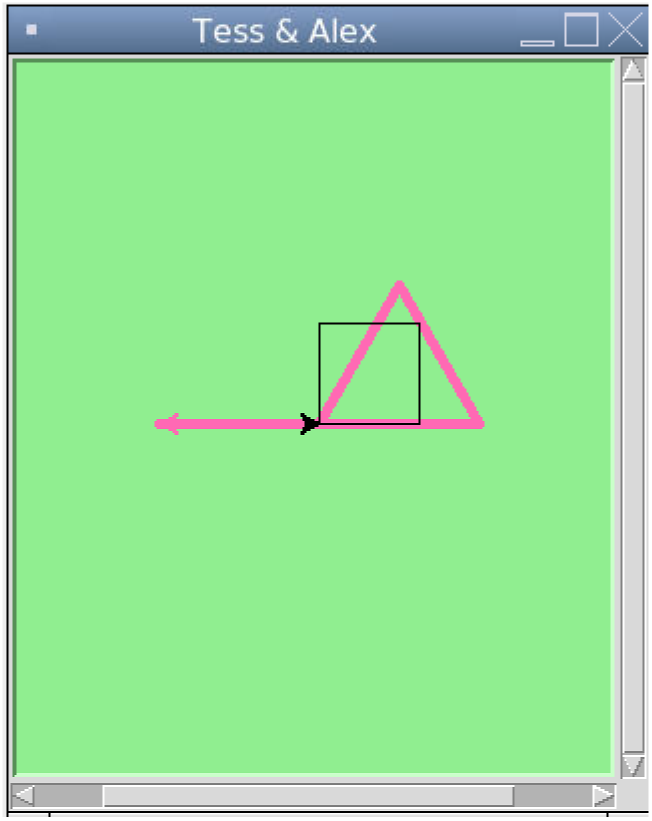
1. Modify this program so that before it creates the window, it prompts the user to enter the desired background color. It should store the user's responses in a variable, and modify the color of the window according to the user's wishes. (*Hint: you can find a list of permitted color names at http://www.tcl.tk/man/tcl8.4/TkCmd/colors.htm. It includes some quite unusual ones, like "peach puff" and "HotPink".*)
2. Do similar changes to allow the user, at runtime, to set tess' color.
3. Do the same for the width of `tess'` pen. *Hint: your dialog with the user will return a string, but tess'* `pensize` *method expects its argument to be an int. So you'll need to convert the string to an int before you pass it to* `pensize`.

3.2. Instances — a herd of turtles

Just like we can have many different integers in a program, we can have many turtles. Each of them is called an **instance**. Each instance has its own attributes and methods — so alex might draw with a thin black pen and be at some position, while `tess` might be going in her own direction with a fat pink pen.

```python
import turtle
wn = turtle.Screen()          # Set up the window and its attributes
wn.bgcolor("lightgreen")
wn.title("Tess & Alex")

tess = turtle.Turtle()        # Create tess and set some attributes
tess.color("hotpink")
tess.pensize(5)

alex = turtle.Turtle()        # Create alex

tess.forward(80)              # Make tess draw equilateral triangle
tess.left(120)
tess.forward(80)
tess.left(120)
tess.forward(80)
tess.left(120)                # Complete the triangle

tess.right(180)               # Turn tess around
tess.forward(80)              # Move her away from the origin

alex.forward(50)              # Make alex draw a square
alex.left(90)
alex.forward(50)
alex.left(90)
alex.forward(50)
alex.left(90)
alex.forward(50)
alex.left(90)

wn.mainloop()
```

Here is what happens when `alex` completes his rectangle, and `tess` completes her triangle:



Alex and Tess

Here are some *How to think like a computer scientist* observations:

- There are 360 degrees in a full circle. If we add up all the turns that a turtle makes, no matter what steps occurred between the turns, we can easily figure out if they add up to some multiple of 360. This should convince us that alex is facing in exactly the same direction as he was when he was first created. (Geometry conventions have 0 degrees facing East, and that is the case here too!)
- We could have left out the last turn for alex, but that would not have been as satisfying. If we're asked to draw a closed shape like a square or a rectangle, it is a good idea to complete all the turns and to leave the turtle back where it started, facing the same direction as it started in. This makes reasoning about the program and composing chunks of code into bigger programs easier for us humans!
- We did the same with tess: she drew her triangle, and turned through a full 360 degrees. Then we turned her around and moved her aside. Even the blank line 18 is a hint about how the programmer's mental chunking is working: in big terms, tess' movements were chunked as "draw the triangle" (lines 12-17) and then "move away from the origin" (lines 19 and 20).
- One of the key uses for comments is to record our mental chunking, and big ideas. They're not always explicit in the code.
- And, uh-huh, two turtles may not be enough for a herd. But the important idea is that the turtle module gives us a kind of factory that lets us create as many turtles as we need. Each instance

has its own state and behaviour.

3.3. The for loop

When we drew the square, it was quite tedious. We had to explicitly repeat the steps of moving and turning four times. If we were drawing a hexagon, or an octagon, or a polygon with 42 sides, it would have been worse.

So a basic building block of all programs is to be able to repeat some code, over and over again.

Python's **for** loop solves this for us. Let's say we have some friends, and we'd like to send them each an email inviting them to our party. We don't quite know how to send email yet, so for the moment we'll just print a message for each friend:

```
1 for f in ["Joe","Zoe","Brad","Angelina","Zuki","Thandi","Paris"]:
2     invite = "Hi " + f + ".  Please come to my party on Saturday!"
3     print(invite)
4 # more code can follow here ...
```

When we run this, the output looks like this:

```
Hi Joe.  Please come to my party on Saturday!
Hi Zoe.  Please come to my party on Saturday!
Hi Brad.  Please come to my party on Saturday!
Hi Angelina.  Please come to my party on Saturday!
Hi Zuki.  Please come to my party on Saturday!
Hi Thandi.  Please come to my party on Saturday!
Hi Paris.  Please come to my party on Saturday!
```

- The variable `f` in the for statement at line `1` is called the **loop variable**. We could have chosen any other variable name instead.

Lines `2` and `3` are the **loop body**. The loop body is always indented. The indentation determines exactly what statements are "in the body of the loop".

- On each *iteration* or *pass* of the loop, first a check is done to see if there are still more items to be processed. If there are none left (this is called the **terminating condition** of the loop), the loop has finished. Program execution continues at the next statement after the loop body, (e.g. in this case the next statement below the comment in line `4`).
- If there are items still to be processed, the loop variable is updated to refer to the next item in the list. This means, in this case, that the loop body is executed here `7` times, and each time `f` will refer to a different friend.
- At the end of each execution of the body of the loop, Python returns to the for statement, to see if there are more items to be handled, and to assign the next one to `f`.

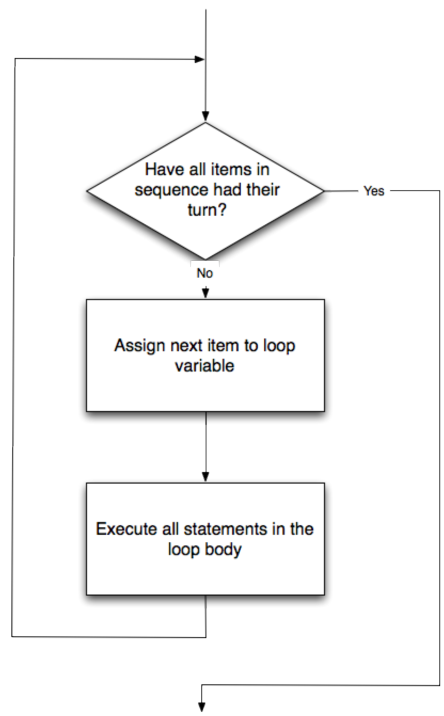
3.4. Flow of Execution of the for loop

As a program executes, the interpreter always keeps track of which statement is about to be executed. We call this the **control flow**, of the **flow of execution** of the program. When humans execute programs, they often use their finger to point to each statement in turn. So we could think of control flow as "Python's moving finger".

Control flow until now has been strictly top to bottom, one statement at a time. The for loop changes this.

Flowchart of a for loop

Control flow is often easy to visualize and understand if we draw a flowchart. This shows the exact steps and logic of how the for statement executes.



For loop flowchart

3.5. The loop simplifies our turtle program

To draw a square we'd like to do the same thing four times — move the turtle, and turn. We previously used 8 lines to have alex draw the four sides of a square. This does exactly the same, but using just three lines:

```
for i in [0,1,2,3]:
    alex.forward(50)
    alex.left(90)
```

Some observations:

- While "saving some lines of code" might be convenient, it is not the big deal here. What is much more important is that we've found a "repeating pattern" of statements, and reorganized our program to repeat the pattern. Finding the chunks and somehow getting our programs arranged around those chunks is a vital skill in computational thinking.
- The values `[0,1,2,3]` were provided to make the loop body execute `4` times. We could have used any four values, but these are the conventional ones to use. In fact, they are so popular that Python gives us special built-in range objects:

```
for i in range(4):
    # Executes the body with i = 0, then 1, then 2, then 3
for x in range(10):
    # Sets x to each of ... [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
```

- Computer scientists like to count from `0`!
- `range` can deliver a sequence of values to the loop variable in the `for` loop. They start at `0`, and in these cases do not include the `4` or the `10`.
- Our little trick earlier to make sure that alex did the final turn to complete 360 degrees has paid off: if we had not done that, then we would not have been able to use a loop for the fourth side of the square. It would have become a "special case", different from the other sides. When possible, we'd much prefer to make our code fit a general pattern, rather than have to create a special case.

So to repeat something four times, a good Python programmer would do this:

```
for i in range(4):
    alex.forward(50)
    alex.left(90)
```

By now you should be able to see how to change our previous program so that tess can also use a `for` loop to draw her equilateral triangle.

But now, what would happen if we made this change?

```
for c in ["yellow", "red", "purple", "blue"]:
    alex.color(c)
    alex.forward(50)
    alex.left(90)
```

A variable can also be assigned a value that is a list. So lists can also be used in more general situations, not only in the `for` loop. The code above could be rewritten like this:

```
# Assign a list to a variable
clrs = ["yellow", "red", "purple", "blue"]
for c in clrs:
    alex.color(c)
    alex.forward(50)
    alex.left(90)
```

3.6. A few more turtle methods and tricks

Turtle methods can use negative angles or distances. So `tess.forward(-100)` will move tess backwards, and `tess.left(-30)` turns her to the right. Additionally, because there are 360 degrees in a circle, turning 30 to the left will get tess facing in the same direction as turning 330 to the right! (The on-screen animation will differ, though — you will be able to tell if tess is turning clockwise or counter-clockwise!)

This suggests that we don't need both a left and a right turn method — we could be minimalists, and just have one method. There is also a *backward* method. (If you are very nerdy, you might enjoy saying `alex.backward(-100)` to move `alex` forward!)

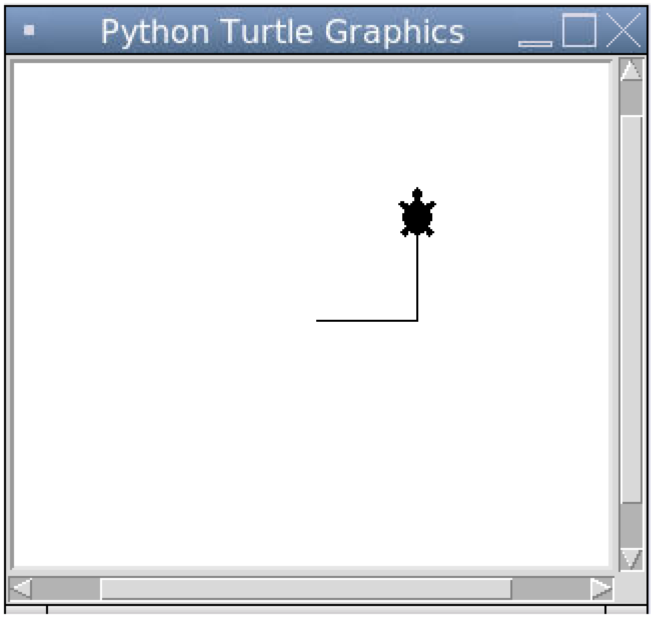
Part of thinking like a scientist is to understand more of the structure and rich relationships in our field. So revising a few basic facts about geometry and number lines, and spotting the relationships between left, right, backward, forward, negative and positive distances or angles values is a good start if we're going to play with turtles.

A turtle's pen can be picked up or put down. This allows us to move a turtle to a different place without drawing a line. The methods are

```
alex.penup()
alex.forward(100)     # This moves alex, but no line is drawn
alex.pendown()
```

Every turtle can have its own shape. The ones available "out of the box" are `arrow`, `blank`, `circle`, `classic`, `square`, `triangle`, `turtle`.

```
alex.shape("turtle")
```



Turtle Shape

We can speed up or slow down the turtle's animation speed. (Animation controls how quickly the turtle turns and moves forward). Speed settings can be set between `1` (slowest) to `10` (fastest). But if we set the speed to `0`, it has a special meaning — turn off animation and go as fast as possible.

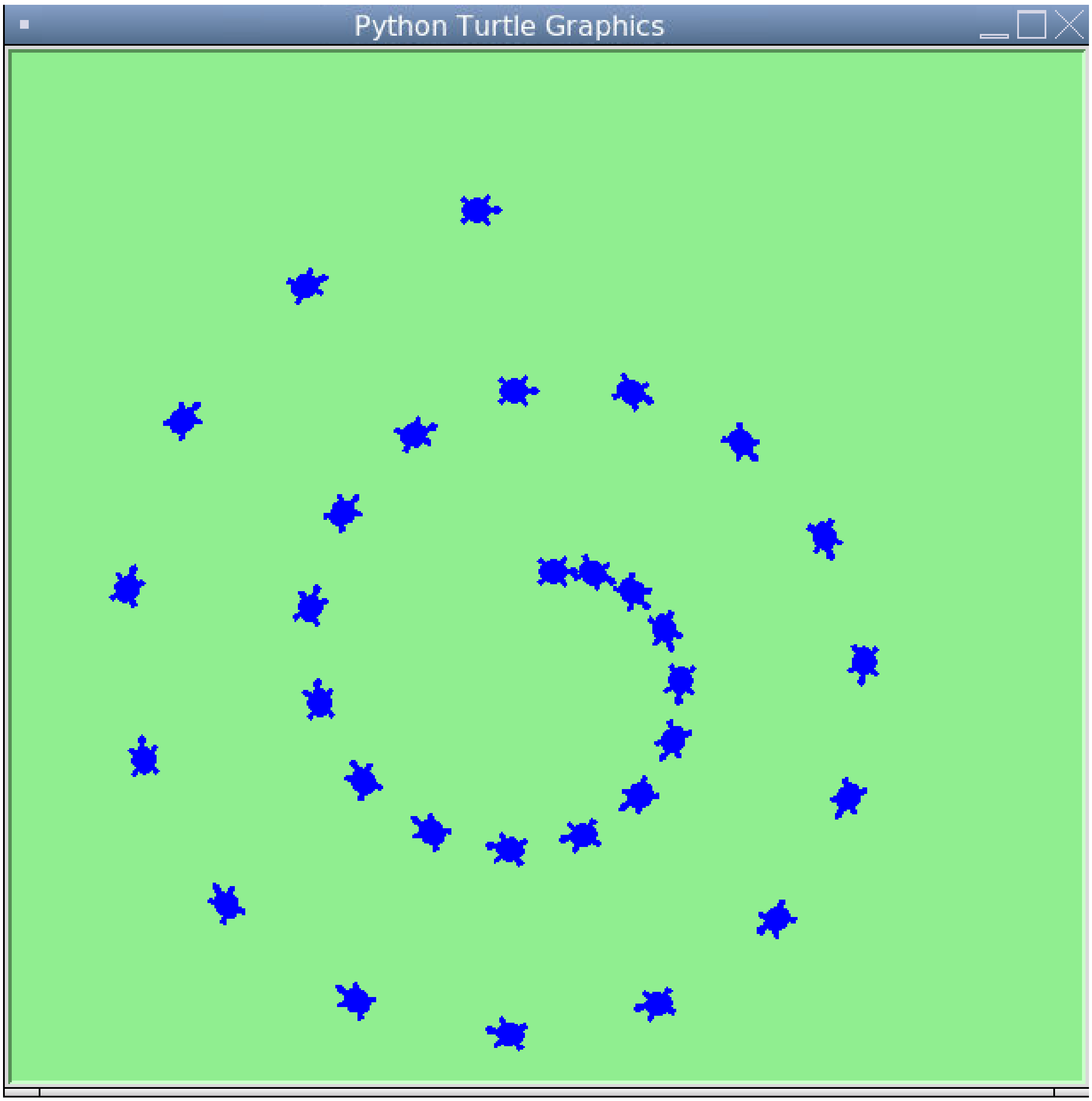
```
alex.speed(10)
```

A turtle can "stamp" its footprint onto the canvas, and this will remain after the turtle has moved somewhere else. Stamping works, even when the pen is up.

Let's do an example that shows off some of these new features:

```
import turtle
wn = turtle.Screen()
wn.bgcolor("lightgreen")
tess = turtle.Turtle()
tess.shape("turtle")
tess.color("blue")

tess.penup()                # This is new
size = 20
for i in range(30):
   tess.stamp()             # Leave an impression on the canvas
   size = size + 3          # Increase the size on every iteration
```

```
    tess.forward(size)        # Move tess along
    tess.right(24)            #  ...  and turn her

wn.mainloop()
```



Turtle Spiral

Be careful now! How many times was the body of the loop executed? How many turtle images do we see on the screen? All except one of the shapes we see on the screen here are footprints created by stamp. But the program still only has one turtle instance — can you figure out which one here is the real tess? (*Hint: if you're not sure, write a new line of code after the for loop to change tess' color, or to put her pen down and draw a line, or to change her shape, etc.*)

3.7. Glossary

attribute

Some state or value that belongs to a particular object. For example, tess has a color.

canvas

A surface within a window where drawing takes place.

control flow

See flow of execution in the next chapter.

for loop

A statement in Python for convenient repetition of statements in the body of the loop.

loop body

Any number of statements nested inside a loop. The nesting is indicated by the fact that the statements are indented under the `for` loop statement.

loop variable

A variable used as part of a `for` loop. It is assigned a different value on each iteration of the loop.

instance

An object of a certain type, or class. tess and alex are different instances of the class Turtle.

method

A function that is attached to an object. Invoking or activating the method causes the object to respond in some way, e.g. forward is the method when we say `tess.forward(100)`.

invoke

An object has methods. We use the verb invoke to mean activate the method. Invoking a method is done by putting parentheses after the method name, with some possible arguments. So `tess.forward()` is an invocation of the forward method.

module

A file containing Python definitions and statements intended for use in other Python programs. The contents of a module are made available to the other program by using the import statement.

object

A "thing" to which a variable can refer. This could be a screen window, or one of the turtles we have created.

range

A built-in function in Python for generating sequences of integers. It is especially useful when we need to write a for loop that executes a fixed number of times.

terminating condition

A condition that occurs which causes a loop to stop repeating its body. In the for loops we saw in this chapter, the terminating condition has been when there are no more elements to assign to the loop variable.

3.8. Exercises

1. Write a program that prints `We like Python's turtles!` 1000 times.
2. Give three attributes of your cellphone object. Give three methods of your cellphone.
3. Write a program that uses a `for` loop to print

```
One of the months of the year is January
One of the months of the year is February
...
```

4. Suppose our turtle tess is at heading `0` — facing east. We execute the statement `tess.left(3645)`. What does tess do, and what is her final heading?
5. Assume you have the assignment `xs = [12, 10, 32, 3, 66, 17, 42, 99, 20]`

   a. Write a loop that prints each of the numbers on a new line.

   b. Write a loop that prints each number and its square on a new line.

   c. Write a loop that adds all the numbers from the list into a variable called `total`. You should set the `total` variable to have the value `0` before you start adding them up, and print the value in total after the loop has completed.

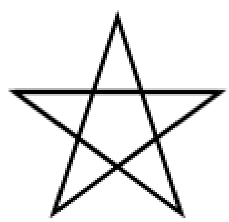
   d. Print the product of all the numbers in the list. (product means all multiplied together)
6. Use `for` loops to make a turtle draw these regular polygons (regular means all sides the same lengths, all angles the same):

   - An equilateral triangle
   - A square
   - A hexagon (six sides)
   - An octagon (eight sides)
7. A drunk pirate makes a random turn and then takes `100` steps forward, makes another random turn, takes another `100` steps, turns another random amount, etc. A social science student records the angle of each turn before the next 100 steps are taken. Her experimental data is `[160, -43, 270, -97, -43, 200, -940, 17, -86]`. (Positive angles are counter-clockwise.) Use a turtle to draw the path taken by our drunk friend.
8. Enhance your program above to also tell us what the drunk pirate's heading is after he has finished stumbling around. (Assume he begins at heading `0`).

9. If you were going to draw a regular polygon with 18 sides, what angle would you need to turn the turtle at each corner?
10. At the interactive prompt, anticipate what each of the following lines will do, and then record what happens. Score yourself, giving yourself one point for each one you anticipate correctly:

```
>>> import turtle
>>> wn = turtle.Screen()
>>> tess = turtle.Turtle()
>>> tess.right(90)
>>> tess.left(3600)
>>> tess.right(-90)
>>> tess.speed(10)
>>> tess.left(3600)
>>> tess.speed(0)
>>> tess.left(3645)
>>> tess.forward(-100)
```

11. Write a program to draw a shape like this:



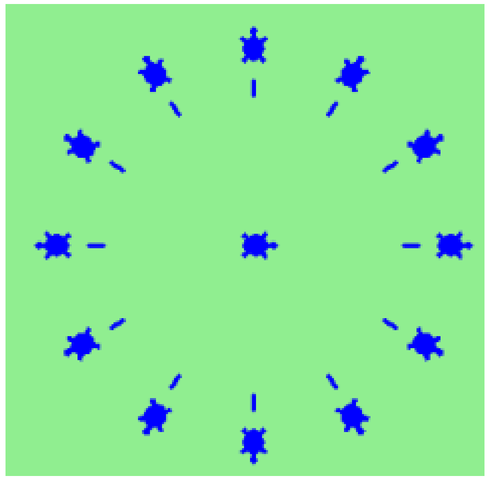
Star

Hints:

- Try this on a piece of paper, moving and turning your cellphone as if it was a turtle. Watch how many complete rotations your cellphone makes before you complete the star. Since each full rotation is 360 degrees, you can figure out the total number of degrees that your phone was rotated through. If you divide that by 5, because there are five points to the star, you'll know how many degrees to turn the turtle at each point.

- You can hide a turtle behind its invisibility cloak if you don't want it shown. It will still draw its lines if its pen is down. The method is invoked as `tess.hideturtle()`. To make the turtle visible again, use `tess.showturtle()`.

12. Write a program to draw a face of a clock that looks something like this:



Clock face

13. Create a turtle, and assign it to a variable. When you ask for its type, what do you get?
14. What is the collective noun for turtles? (Hint: they don't come in *herds*.)
15. What the collective noun for pythons? Is a python a viper? Is a python venomous?

Chapter 4: Functions

4.1. Functions

In Python, a **function** is a named sequence of statements that belong together. Their primary purpose is to help us organize programs into chunks that match how we think about the problem.

The syntax for a **function definition** is:

```
def NAME( PARAMETERS ):
    STATEMENTS
```

We can make up any names we want for the functions we create, except that we can't use a name that is a Python keyword, and the names must follow the rules for legal identifiers.

There can be any number of statements inside the function, but they have to be indented from the `def`. In the examples in this book, we will use the standard indentation of four spaces. Function definitions are the second of several **compound statements** we will see, all of which have the same pattern:

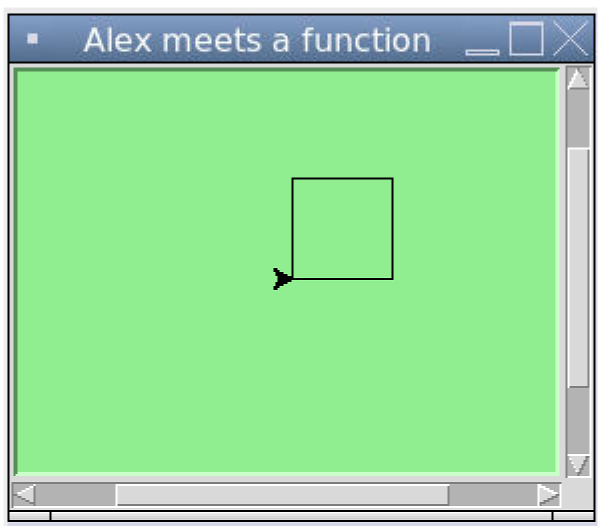
1. A header line which begins with a keyword and ends with a colon.
2. A **body** consisting of one or more Python statements, each indented the same amount — the *Python style guide recommends 4 spaces* — from the header line.

We've already seen the `for` loop which follows this pattern.

So looking again at the function definition, the keyword in the header is `def`, which is followed by the name of the function and some *parameters* enclosed in parentheses. The parameter list may be empty, or it may contain any number of parameters separated from one another by commas. In either case, the parentheses are required. The parameters specifies what information, if any, we have to provide in order to use the new function.

Suppose we're working with turtles, and a common operation we need is to draw squares. "Draw a square" is an abstraction, or a mental chunk, of a number of smaller steps. So let's write a function to capture the pattern of this "building block":

```
import turtle

def draw_square(t, sz):
    """Make turtle t draw a square of sz."""
    for i in range(4):
        t.forward(sz)
        t.left(90)


wn = turtle.Screen()          # Set up the window and its attributes
wn.bgcolor("lightgreen")
wn.title("Alex meets a function")

alex = turtle.Turtle()        # Create alex
draw_square(alex, 50)         # Call the function to draw the square
wn.mainloop()
```



alex function

This function is named `draw_square`. It has two parameters: one to tell the function which turtle to move around, and the other to tell it the size of the square we want drawn. Make sure you know where the body of the function ends — it depends on the indentation, and the blank lines don't count for this purpose!

Docstrings for documentation

If the first thing after the function header is a string, it is treated as a **docstring** and gets special treatment in Python and in some programming tools. For example, when we type a built-in function name with an unclosed parenthesis in Repl.it, a tooltip pops up, telling us what arguments the function takes, and it shows us any other text contained in the docstring.

Docstrings are the key way to document our functions in Python and the documentation part is important. Because whoever calls our function shouldn't have to need to know what is going on in the function or how it works; they just need to know what arguments our function takes, what it does, and what the expected result is. Enough to be able to use the function without having to look underneath. This goes back to the concept of abstraction of which we'll talk more about.

Docstrings are usually formed using triple-quoted strings as they allow us to easily expand the docstring later on should we want to write more than a one-liner.

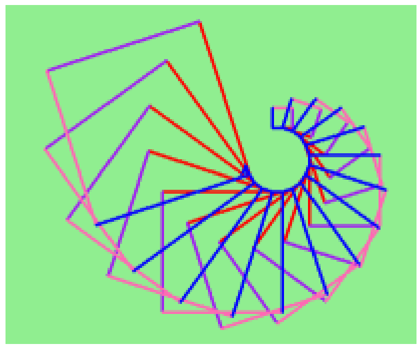
Just to differentiate from comments, a string at the start of a function (a docstring) is retrievable by Python tools at runtime. By contrast, comments are completely eliminated when the program is parsed.

Defining a new function does not make the function run. To do that we need a **function call**. We've already seen how to call some built-in functions like **`print`**, **`range`** and **`int`**. Function calls contain the name of the function being executed followed by a list of values, called *arguments*, which are assigned to the parameters in the function definition. So in the second last line of the program, we call the function, and pass alex as the turtle to be manipulated, and 50 as the size of the square we want. While the function is executing, then, the variable `sz` refers to the value `50`, and the variable t refers to the same turtle instance that the variable `alex` refers to.

Once we've defined a function, we can call it as often as we like, and its statements will be executed each time we call it. And we could use it to get any of our turtles to draw a square. In the next example, we've changed the draw_square function a little, and we get tess to draw 15 squares, with some variations.

```python
import turtle

def draw_multicolor_square(t, sz):
    """Make turtle t draw a multi-color square of sz."""
    for i in ["red", "purple", "hotpink", "blue"]:
        t.color(i)
        t.forward(sz)
        t.left(90)

wn = turtle.Screen()         # Set up the window and its attributes
wn.bgcolor("lightgreen")

tess = turtle.Turtle()       # Create tess and set some attributes
tess.pensize(3)

size = 20                    # Size of the smallest square
```

```
for i in range(15):
    draw_multicolor_square(tess, size)
    size = size + 10          # Increase the size for next time
    tess.forward(10)          # Move tess along a little
    tess.right(18)            #    and give her some turn

wn.mainloop()
```



Draw multicolor square

4.2. Functions can call other functions

Let's assume now we want a function to draw a rectangle. We need to be able to call the function with different arguments for width and height. And, unlike the case of the square, we cannot repeat the same thing 4 times, because the four sides are not equal.

So we eventually come up with this rather nice code that can draw a rectangle.

```
def draw_rectangle(t, w, h):
    """Get turtle t to draw a rectangle of width w and height h."""
    for i in range(2):
        t.forward(w)
        t.left(90)
        t.forward(h)
        t.left(90)
```

The parameter names are deliberately chosen as single letters to ensure they're not misunderstood. In real programs, once we've had more experience, we will insist on better variable names than this. But the point is that the program doesn't "understand" that we're drawing a rectangle, or that the parameters represent the width and the height. Concepts like rectangle, width, and height are the meaning we humans have, not concepts that the program or the computer understands.

Thinking like a scientist involves looking for patterns and relationships. In the code above, we've done that to some extent. We did not just draw four sides. Instead, we spotted that we could draw the rectangle as two halves, and used a loop to repeat that pattern twice.

But now we might spot that a square is a special kind of rectangle. We already have a function that draws a rectangle, so we can use that to draw our square.

```
def draw_square(tx, sz):        # A new version of draw_square
    draw_rectangle(tx, sz, sz)
```

There are some points worth noting here:

- Functions can call other functions.
- Rewriting `draw_square` like this captures the relationship that we've spotted between squares and rectangles.
- A caller of this function might say `draw_square(tess, 50)`. The parameters of this function, `tx` and `sz`, are assigned the values of the tess object, and the `int 50` respectively.
- In the body of the function they are just like any other variable.
- When the call is made to `draw_rectangle`, the values in variables `tx` and `sz` are fetched first, then the call happens. So as we enter the top of function `draw_rectangle`, its variable `t` is assigned the `tess` object, and `w` and `h` in that function are both given the value `50`.

So far, it may not be clear why it is worth the trouble to create all of these new functions. Actually, there are a lot of reasons, but this example demonstrates two:

1. Creating a new function gives us an opportunity to name a group of statements. Functions can simplify a program by hiding a complex computation behind a single command. The function (including its name) can capture our mental chunking, or *abstraction*, of the problem.
2. Creating a new function can make a program smaller by eliminating repetitive code.

As we might expect, we have to create a function before we can execute it. In other words, the function definition has to be executed before the function is called.

4.3. Flow of execution

In order to ensure that a function is defined before its first use, we have to know the order in which statements are executed, which is called the **flow of execution**. We've already talked about this a little in the previous chapter.

Execution always begins at the first statement of the program. Statements are executed one at a time, in order from top to bottom.

Function definitions do not alter the flow of execution of the program, but remember that statements inside the function are not executed until the function is called. Although it is not common, we can define one function inside another. In this case, the inner definition isn't executed until the outer function is called.

Function calls are like a detour in the flow of execution. Instead of going to the next statement, the flow jumps to the first line of the called function, executes all the statements there, and then comes back to pick up where it left off.

That sounds simple enough, until we remember that one function can call another. While in the middle of one function, the program might have to execute the statements in another function. But while executing that new function, the program might have to execute yet another function!

Fortunately, Python is adept at keeping track of where it is, so each time a function completes, the program picks up where it left off in the function that called it. When it gets to the end of the program, it terminates.

What's the moral of this sordid tale? When we read a program, don't read from top to bottom. Instead, follow the flow of execution.

Watch the flow of execution in action

Repl.it does not have "single-stepping" functionality. For this we would recommend a different IDE like PyScripter[a]

In PyScripter, we can watch the flow of execution by "single-stepping" through any program. PyScripter will highlight each line of code just before it is about to be executed.

PyScripter also lets us hover the mouse over any variable in the program, and it will pop up the current value of that variable. So this makes it easy to inspect the "state snapshot" of the program — the current values that are assigned to the program's variables.

This is a powerful mechanism for building a deep and thorough understanding of what is happening at each step of the way. Learn to use the single-stepping feature well, and be mentally proactive: as you work through the code, challenge yourself before each step: *"What changes will this line make to any variables in the program?"* and "Where will flow of execution go next?"

Let us go back and see how this works with the program above that draws 15 multicolor squares. First, we're going to add one line of magic below the import statement — not strictly necessary, but it will make our lives much simpler, because it prevents stepping into the module containing the turtle code.

```
import turtle
__import__("turtle").__traceable__ = False
```

Now we're ready to begin. Put the mouse cursor on the line of the program where we create the turtle screen, and press the F4 key. This will run the Python program up to, but not including, the line where we have the cursor. Our program will "break" now, and provide a highlight on the next line to be executed, something like this:

```
 1 import turtle
 2 __import__("turtle").__traceable__ = False
 3
 4 def draw_multicolor_square(t, sz):
 5     """Make turtle t draw a multi-color square of sz."""
 6     for i in ["red", "purple", "hotpink", "blue"]:
 7         t.color(i)
 8         t.forward(sz)
 9         t.left(90)
10
11 wn = turtle.Screen()          # Set up the window and its attributes
12 wn.bgcolor("lightgreen")
13
14 tess = turtle.Turtle()        # Create tess and set some attributes
15 tess.pensize(3)
16
17 size = 20                     # Size of the smallest square
18 for i in range(15):
19     draw_multicolor_square(tess, size)
20     size = size + 10          # Increase the size for next time
21     tess.forward(10)          # Move tess along a little
22     tess.right(18)            #  ...  and give her some extra turn
23
24 wn.mainloop()
25
```

PyScripter Breakpoint

At this point we can press the F7 key (*step into*) repeatedly to single step through the code. Observe as we execute lines 10, 11, 12, ... how the turtle window gets created, how its canvas color is changed, how the title gets changed, how the turtle is created on the canvas, and then how the flow of execution gets into the loop, and from there into the function, and into the function's loop, and then repeatedly through the body of that loop.

While we do this, we can also hover our mouse over some of the variables in the program, and confirm that their values match our conceptual model of what is happening.

After a few loops, when we're about to execute line 20 and we're starting to get bored, we can use the key F8 to "step over" the function we are calling. This executes all the statements in the function, but without having to step through each one. We always have the choice to either "go for the detail", or to "take the high-level view" and execute the function as a single chunk.

There are some other options, including one that allow us to resume execution without further stepping. Find them under the *Run* menu of PyScripter.

[a] https://sourceforge.net/projects/pyscripter/

4.4. Functions that require arguments

Most functions require arguments: the arguments provide for generalization. For example, if we want to find the absolute value of a number, we have to indicate what the number is. Python has a built-in function for computing the absolute value:

```
>>> abs(5)
5
>>> abs(-5)
5
```

In this example, the arguments to the `abs` function are `5` and `-5`.

Some functions take more than one argument. For example the built-in function `pow` takes two arguments, the base and the exponent. Inside the function, the values that are passed get assigned to variables called **parameters**.

```
>>> pow(2, 3)
8
>>> pow(7, 4)
2401
```

Another built-in function that takes more than one argument is `max`.

```
>>> max(7, 11)
11
>>> max(4, 1, 17, 2, 12)
17
>>> max(3 * 11, 5**3, 512 - 9, 1024**0)
503
```

`max` can be passed any number of arguments, separated by commas, and will return the largest value passed. The arguments can be either simple values or expressions. In the last example, `503` is returned, since it is larger than `33`, `125`, and `1`.

4.5. Functions that return values

All the functions in the previous section return values. Furthermore, functions like `range`, `int`, `abs` all return values that can be used to build more complex expressions.

So an important difference between these functions and one like `draw_square` is that `draw_square` was not executed because we wanted it to compute a value — on the contrary, we wrote `draw_square` because we wanted it to execute a sequence of steps that caused the turtle to draw.

A function that returns a value is called a **fruitful function** in this book. The opposite of a fruitful function is **void function** — one that is not executed for its resulting value, but is executed because it does something useful. (Languages like Java, C#, C and C++ use the term "void function", other languages like Pascal call it a **procedure**.) Even though void functions are not executed for their resulting value, Python always wants to return something. So if the programmer doesn't arrange to return a value, Python will automatically return the value `None`.

How do we write our own fruitful function? In the exercises at the end of chapter 2 we saw the standard formula for compound interest, which we'll now write as a fruitful function:

$$A = P\left(1 + \frac{r}{n}\right)^{nt}$$

Where,

- P = principal amount (initial investment)
- r = annual nominal interest rate (as a decimal)
- n = number of times the interest is compounded per year
- t = number of years

Compound interest

```python
def final_amt(p, r, n, t):
    """
      Apply the compound interest formula to p
       to produce the final amount.
    """

    a = p * (1 + r/n) ** (n*t)
    return a         # This is new, and makes the function fruitful.

# now that we have the function above, let us call it.
toInvest = float(input("How much do you want to invest?"))
fnl = final_amt(toInvest, 0.08, 12, 5)
print("At the end of the period you'll have", fnl)
```

- The return statement is followed by an expression (`a` in this case). This expression will be evaluated and returned to the caller as the "fruit" of calling this function.
- We prompted the user for the principal amount. The type of `toInvest` is a string, but we need a number before we can work with it. Because it is money, and could have decimal places, we've used the `float` type converter function to parse the string and return a float.
- Notice how we entered the arguments for 8% interest, compounded 12 times per year, for 5 years.
- When we run this, we get the output

```
At the end of the period you'll have 14898.457083
```

This is a bit messy with all these decimal places, but remember that Python doesn't understand that we're working with money: it just does the calculation to the best of its ability, without rounding. Later we'll see how to format the string that is printed in such a way that it does get nicely rounded to two decimal places before printing.

- The line `toInvest = float(input("How much do you want to invest?"))` also shows yet another example of *composition* — we can call a function like `float`, and its arguments can be the results of other function calls (like input) that we've called along the way.

Notice something else very important here. The name of the variable we pass as an argument — `toInvest` — has nothing to do with the name of the parameter — `p`. It is as if `p = toInvest` is executed when `final_amt` is called. It doesn't matter what the value was named in the caller, in `final_amt` its name is `p`.

These short variable names are getting quite tricky, so perhaps we'd prefer one of these versions instead:

```
def final_amt_v2(principalAmount, nominalPercentageRate,
                                    numTimesPerYear, years):
    a = principalAmount * (1 + nominalPercentageRate /
                         numTimesPerYear) ** (numTimesPerYear*years)
    return a

def final_amt_v3(amt, rate, compounded, years):
    a = amt * (1 + rate/compounded) ** (compounded*years)
    return a
```

They all do the same thing. Use your judgement to write code that can be best understood by other humans! Short variable names are more economical and sometimes make code easier to read: `E = mc2` would not be nearly so memorable if Einstein had used longer variable names! If you do prefer short names, make sure you also have some comments to enlighten the reader about what the variables are used for.

4.6. Variables and parameters are local

When we create a **local variable** inside a function, it only exists inside the function, and we cannot use it outside. For example, consider again this function:

```
def final_amt(p, r, n, t):
    a = p * (1 + r/n) ** (n*t)
    return a
```

If we try to use a, outside the function, we'll get an error:

```
>>> a
NameError: name 'a' is not defined
```

The variable a is local to final_amt, and is not visible outside the function.

Additionally, a only exists while the function is being executed — we call this its **lifetime**. When the execution of the function terminates, the local variables are destroyed.

Parameters are also local, and act like local variables. For example, the lifetimes of p, r, n, t begin when final_amt is called, and the lifetime ends when the function completes its execution.

So it is not possible for a function to set some local variable to a value, complete its execution, and then when it is called again next time, recover the local variable. Each call of the function creates new local variables, and their lifetimes expire when the function returns to the caller.

4.7. Turtles Revisited

Now that we have fruitful functions, we can focus our attention on reorganizing our code so that it fits more nicely into our mental chunks. This process of rearrangement is called **refactoring** the code.

Two things we're always going to want to do when working with turtles is to create the window for the turtle, and to create one or more turtles. We could write some functions to make these tasks easier in future:

```
def make_window(colr, ttle):
    """
      Set up the window with the given background color and title.
      Returns the new window.
    """
    w = turtle.Screen()
    w.bgcolor(colr)
    w.title(ttle)
    return w


def make_turtle(colr, sz):
```

```
    """
      Set up a turtle with the given color and pensize.
      Returns the new turtle.
    """
    t = turtle.Turtle()
    t.color(colr)
    t.pensize(sz)
    return t


wn = make_window("lightgreen", "Tess and Alex dancing")
tess = make_turtle("hotpink", 5)
alex = make_turtle("black", 1)
dave = make_turtle("yellow", 2)
```

The trick about refactoring code is to anticipate which things we are likely to want to change each time we call the function: these should become the parameters, or changeable parts, of the functions we write.

4.8. Glossary

argument

A value provided to a function when the function is called. This value is assigned to the corresponding parameter in the function. The argument can be the result of an expression which may involve operators, operands and calls to other fruitful functions.

body

The second part of a compound statement. The body consists of a sequence of statements all indented the same amount from the beginning of the header. The standard amount of indentation used within the Python community is 4 spaces.

compound statement

A statement that consists of two parts:

1. header - which begins with a keyword determining the statement type, and ends with a colon.
2. body - containing one or more statements indented the same amount from the header.

The syntax of a compound statement looks like this:

```
keyword ... :
    statement
    statement ...
```

docstring

A special string that is attached to a function as its `__doc__` attribute. Tools like Repl.it can use docstrings to provide documentation or hints for the programmer. When we get to modules, classes, and methods, we'll see that docstrings can also be used there.

flow of execution

The order in which statements are executed during a program run.

frame

A box in a stack diagram that represents a function call. It contains the local variables and parameters of the function.

function

A named sequence of statements that performs some useful operation. Functions may or may not take parameters and may or may not produce a result.

function call

A statement that executes a function. It consists of the name of the function followed by a list of arguments enclosed in parentheses.

function composition

Using the output from one function call as the input to another.

function definition

A statement that creates a new function, specifying its name, parameters, and the statements it executes.

fruitful function

A function that returns a value when it is called.

header line

The first part of a compound statement. A header line begins with a keyword and ends with a colon (:)

import statement

A statement which permits functions and variables defined in another Python module to be brought into the environment of another script. To use the features of the turtle, we need to first import the turtle module.

lifetime

Variables and objects have lifetimes — they are created at some point during program execution, and will be destroyed at some time.

local variable

A variable defined inside a function. A local variable can only be used inside its function. Parameters of a function are also a special kind of local variable.

parameter

A name used inside a function to refer to the value which was passed to it as an argument.

refactor

A fancy word to describe reorganizing our program code, usually to make it more understandable. Typically, we have a program that is already working, then we go back to “tidy it up”. It often involves choosing better variable names, or spotting repeated patterns and moving that code into a function.

stack diagram

A graphical representation of a stack of functions, their variables, and the values to which they refer.

traceback

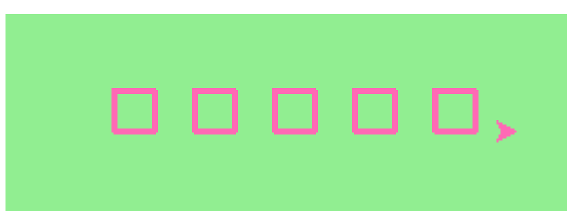
A list of the functions that are executing, printed when a runtime error occurs. A traceback is also commonly referred to as a *stack trace*, since it lists the functions in the order in which they are stored in the runtime stack.[4]

void function

The opposite of a fruitful function: one that does not return a value. It is executed for the work it does, rather than for the value it returns.

4.9. Exercises

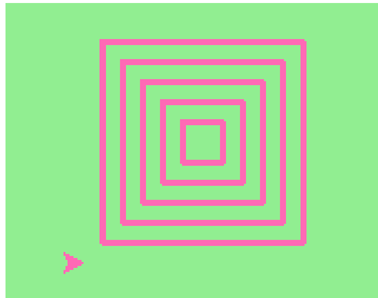
1. Write a void (non-fruitful) function to draw a square. Use it in a program to draw the image shown below. Assume each side is 20 units. (*Hint: notice that the turtle has already moved away from the ending point of the last square when the program ends.*)



Five Squares

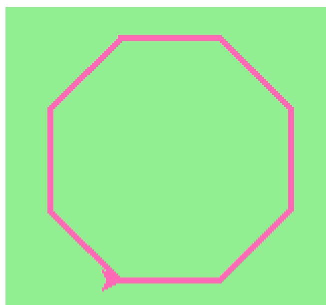
[4] http://en.wikipedia.org/wiki/Runtime_stack

2. Write a program to draw this. Assume the innermost square is 20 units per side, and each successive square is 20 units bigger, per side, than the one inside it.



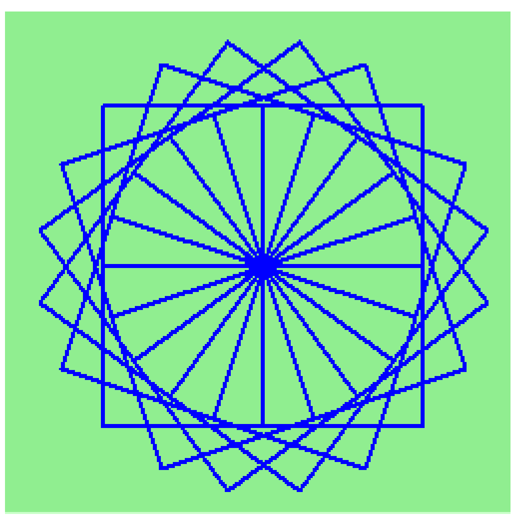
Nested Squares

3. Write a void function `draw_poly(t, n, sz)` which makes a turtle draw a regular polygon. When called with `draw_poly(tess, 8, 50)`, it will draw a shape like this:



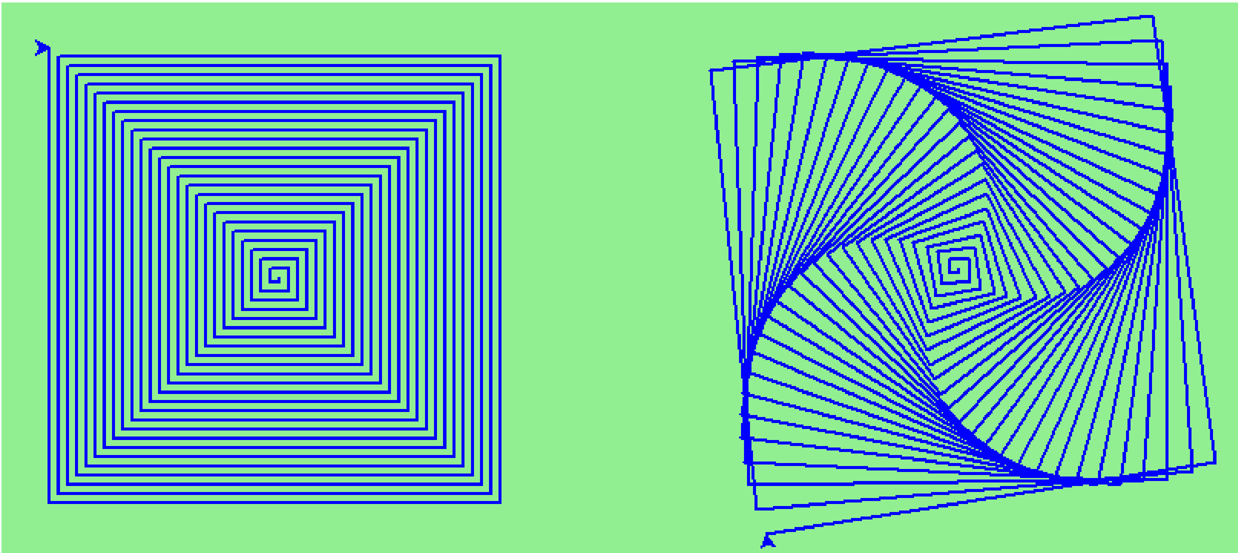
Regular Polygon

4. Draw this pretty pattern.



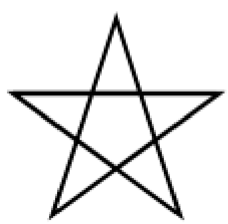
Pretty Pattern

5. The two spirals in this picture differ only by the turn angle. Draw both.



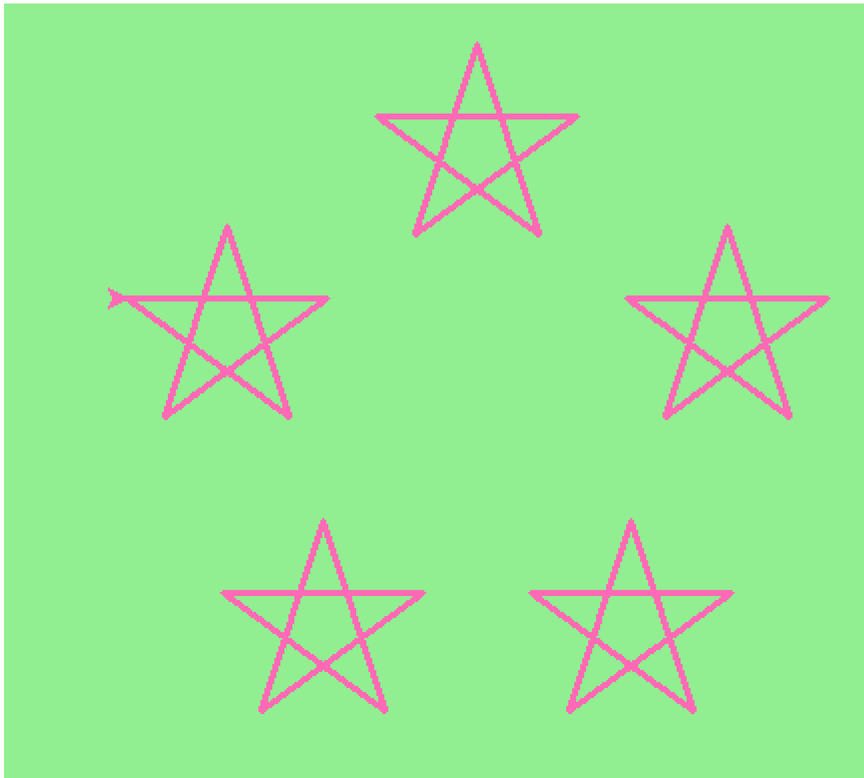
Spirals

6. Write a void function `draw_equitriangle(t, sz)` which calls `draw_poly` from the previous question to have its turtle draw a equilateral triangle.
7. Write a fruitful function `sum_to(n)` that returns the sum of all integer numbers up to and including `n`. So `sum_to(10)` would be `1+2+3...+10` which would return the value `55`.
8. Write a function `area_of_circle(r)` which returns the area of a circle of radius `r`.
9. Write a void function to draw a star, where the length of each side is 100 units. (*Hint: You should turn the turtle by 144 degrees at each point.*)



Star

10. Extend your program above. Draw five stars, but between each, pick up the pen, move forward by 350 units, turn right by 144, put the pen down, and draw the next star. You'll get something like this:



Five Stars

What would it look like if you didn't pick up the pen?

Chapter 5: Conditionals

Programs get really interesting when we can test conditions and change the program behaviour depending on the outcome of the tests. That's what this chapter is about.

5.1. Boolean values and expressions

A Boolean value is either true or false. It is named after the British mathematician, George Boole, who first formulated Boolean algebra — some rules for reasoning about and combining these values. This is the basis of all modern computer logic.

In Python, the two Boolean values are `True` and `False` (the capitalization must be exactly as shown), and the Python type is **`bool`**.

```
>>> type(True)
<class 'bool'>
>>> type(true)
Traceback (most recent call last):
  File "<interactive input>", line 1, in <module>
NameError: name 'true' is not defined
```

A **Boolean expression** is an expression that evaluates to produce a result which is a Boolean value. For example, the operator == tests if two values are equal. It produces (or *yields*) a Boolean value:

```
>>> 5 == (3 + 2)    # Is 5 equal to the result of 3 + 2?
True
>>> 5 == 6
False
>>> j = "hel"
>>> j + "lo" == "hello"
True
```

In the first statement, the two operands evaluate to equal values, so the expression evaluates to `True`; in the second statement, `5` is not equal to `6`, so we get `False`.

The == operator is one of six common **comparison operators** which all produce a bool result; here are all six:

```
x == y               # Produce True if ... x is equal to y
x != y               # ... x is not equal to y
x > y                # ... x is greater than y
x < y                # ... x is less than y
x >= y               # ... x is greater than or equal to y
x <= y               # ... x is less than or equal to y
```

Although these operations are probably familiar, the Python symbols are different from the mathematical symbols. A common error is to use a single equal sign (=) instead of a double equal sign (==). Remember that= is an assignment operator and == is a comparison operator. Also, there is no such thing as `=<` or `=>`.

Like any other types we've seen so far, Boolean values can be assigned to variables, printed, etc.

```
>>> age = 18
>>> old_enough_to_get_driving_licence = age >= 17
>>> print(old_enough_to_get_driving_licence)
True
>>> type(old_enough_to_get_driving_licence)
<class 'bool'>
```

5.2. Logical operators

There are three **logical operators**, `and`, `or`, and `not`, that allow us to build more complex Boolean expressions from simpler Boolean expressions. The semantics (meaning) of these operators is similar to their meaning in English. For example, `x > 0 and x < 10` produces `True` only if `x` is greater than `0` and at the same time, `x` is less than `10`.

`n % 2 == 0 or n % 3 == 0` is `True` if *either* of the conditions is `True`, that is, if the number `n` is divisible by `2` *or* it is divisible by `3`. (What do you think happens if `n` is divisible by both `2` and by `3` at the same time? Will the expression yield `True` or `False`? Try it in your Python interpreter.)

Finally, the `not` operator negates a Boolean value, so `not (x > y)` is `True` if `(x > y)` is `False`, that is, if `x` is less than or equal to `y`.

The expression on the left of the or operator is evaluated first: if the result is `True`, Python does not (and need not) evaluate the expression on the right — this is called *short-circuit evaluation*. Similarly, for the `and` operator, if the expression on the left yields `False`, Python does not evaluate the expression on the right.

So there are no unnecessary evaluations.

5.3. Truth Tables

A truth table is a small table that allows us to list all the possible inputs, and to give the results for the logical operators. Because the `and` and `or` operators each have two operands, there are only four rows in a truth table that describes the semantics of `and`.

a	**b**	**a and b**
False	False	False
False	True	False
True	False	False
True	True	True

In a Truth Table, we sometimes use `T` and `F` as shorthand for the two Boolean values: here is the truth table describing or:

a	**b**	**a or b**
F	F	F
F	T	T
T	F	T
T	T	T

The third logical operator, `not`, only takes a single operand, so its truth table only has two rows:

a	**not a**
F	T
T	F

5.4. Simplifying Boolean Expressions

A set of rules for simplifying and rearranging expressions is called an algebra. For example, we are all familiar with school *algebra* rules, such as:

```
n * 0 == 0
```

Here we see a different algebra — the Boolean algebra — which provides rules for working with Boolean values.

First, the `and` operator:

```
x and False == False
False and x == False
y and x == x and y
x and True == x
True and x == x
x and x == x
```

Here are some corresponding rules for the `or` operator:

```
x or False == x
False or x == x
y or x == x or y
x or True == True
True or x == True
x or x == x
```

Two not operators cancel each other:

```
not (not x) == x
```

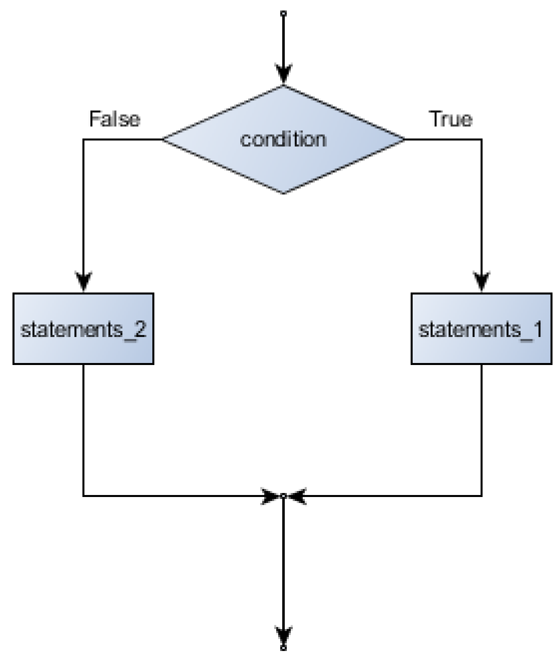
5.5. Conditional execution

In order to write useful programs, we almost always need the ability to check conditions and change the behavior of the program accordingly. **Conditional statements** give us this ability. The simplest form is the **`if`** statement:

```
if x % 2 == 0:
    print(x, " is even.")
    print("Did you know that 2 is the only even number that is prime?")
else:
    print(x, " is odd.")
    print("Did you know that multiplying two odd numbers " +
                                         "always gives an odd result?")
```

The Boolean expression after the `if` statement is called the **condition**. If it is true, then all the indented statements get executed. If not, then all the statements indented under the `else` clause get executed.

Flowchart of an `if` statement with an `else` clause



Flowchart - if else

The syntax for an if statement looks like this:

```
if BOOLEAN EXPRESSION:
    STATEMENTS_1        # Executed if condition evaluates to True
else:
    STATEMENTS_2        # Executed if condition evaluates to False
```

As with the function definition from the last chapter and other compound statements like `for`, the `if` statement consists of a header line and a body. The header line begins with the keyword `if` followed by a *Boolean expression* and ends with a colon (`:`).

The indented statements that follow are called a **block**. The first unindented statement marks the end of the block.

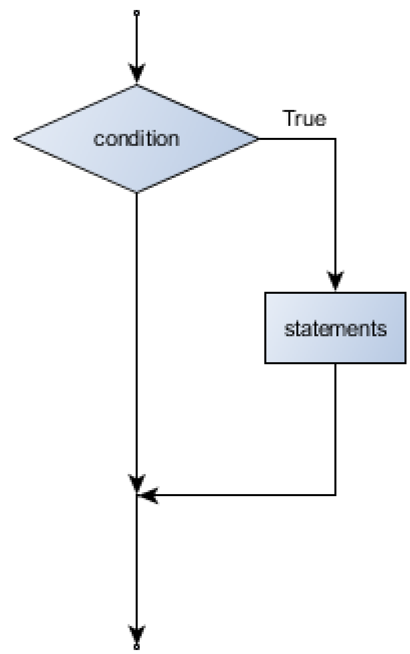
Each of the statements inside the first block of statements are executed in order if the Boolean expression evaluates to `True`. The entire first block of statements is skipped if the Boolean expression evaluates to `False`, and instead all the statements indented under the `else` clause are executed.

There is no limit on the number of statements that can appear under the two clauses of an `if` statement, but there has to be at least one statement in each block. Occasionally, it is useful to have a section with no statements (usually as a place keeper, or scaffolding, for code we haven't written yet). In that case, we can use the `pass` statement, which does nothing except act as a placeholder.

```
if True:          # This is always True,
    pass          #   so this is always executed, but it does nothing
else:
    pass
```

5.6. Omitting the else clause

Flowchart of an `if` statement with no `else` clause



Flowchart - if only

Another form of the `if` statement is one in which the `else` clause is omitted entirely. In this case, when the condition evaluates to `True`, the statements are executed, otherwise the flow of execution continues to the statement after the `if`.

```python
if x < 0:
    print("The negative number ",  x, " is not valid here.")
    x = 42
    print("I've decided to use the number 42 instead.")

print("The square root of ", x, "is", math.sqrt(x))
```

In this case, the `print` function that outputs the square root is the one after the `if` — not because we left a blank line, but because of the way the code is indented. Note too that the function call `math.sqrt(x)` will give an error unless we have an `import math` statement, usually placed near the top of our script.

Python terminology

Python documentation sometimes uses the term **suite** of statements to mean what we have called a *block* here. They mean the same thing, and since most other languages and computer scientists use the word block, we'll stick with that.

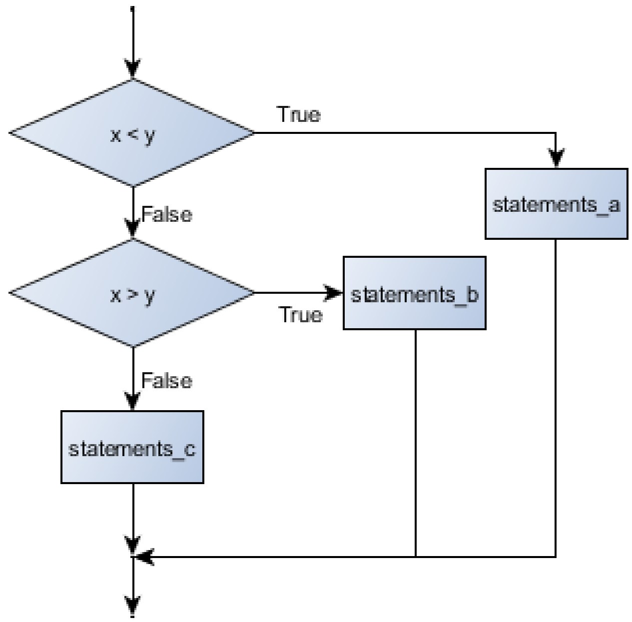
Notice too that `else` is not a statement. The `if` statement has two clauses, one of which is the (optional) `else` clause.

5.7. Chained conditionals

Sometimes there are more than two possibilities and we need more than two branches. One way to express a computation like that is a **chained conditional**:

```python
if x < y:
    STATEMENTS_A
elif x > y:
    STATEMENTS_B
else:
    STATEMENTS_C
```

Flowchart of this chained conditional



Flowchart - chained conditional

`elif` is an abbreviation of else if. Again, exactly one branch will be executed. There is no limit of the number of `elif` statements but only a single (and optional) final `else` statement is allowed and it must be the last branch in the statement:

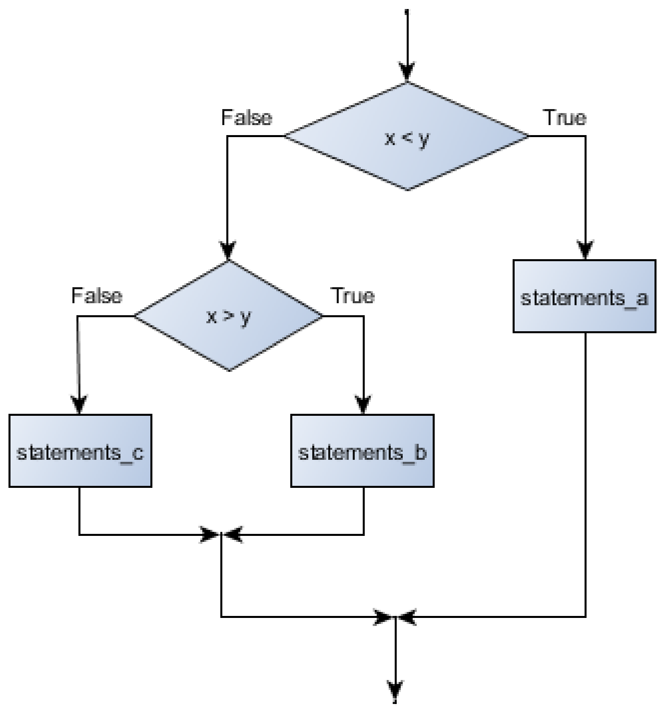
```
if choice == "a":
    function_one()
elif choice == "b":
    function_two()
elif choice == "c":
    function_three()
else:
    print("Invalid choice.")
```

Each condition is checked in order. If the first is false, the next is checked, and so on. If one of them is true, the corresponding branch executes, and the statement ends. Even if more than one condition is true, only the first true branch executes.

5.8. Nested conditionals

One conditional can also be **nested** within another. (It is the same theme of composability, again!) We could have written the previous example as follows:

Flowchart of this nested conditional



Flowchart - nested conditional

```
if x < y:
    STATEMENTS_A
else:
    if x > y:
        STATEMENTS_B
    else:
        STATEMENTS_C
```

The outer conditional contains two branches. The second branch contains another `if` statement, which has two branches of its own. Those two branches could contain conditional statements as well.

Although the indentation of the statements makes the structure apparent, nested conditionals very quickly become difficult to read. In general, it is a good idea to avoid them when we can.

Logical operators often provide a way to simplify nested conditional statements. For example, we can rewrite the following code using a single conditional:

```
if 0 < x:            # Assume x is an int here
    if x < 10:
        print("x is a positive single digit.")
```

The `print` function is called only if we make it past both the conditionals, so instead of the above which uses two `if` statements each with a simple condition, we could make a more complex condition using the `and` operator. Now we only need a single `if` statement:

```
if 0 < x and x < 10:
    print("x is a positive single digit.")
```

5.9. The return statement

The `return` statement, with or without a value, depending on whether the function is fruitful or void, allows us to terminate the execution of a function before (or when) we reach the end. One reason to use an *early return* is if we detect an error condition:

```
def print_square_root(x):
    if x <= 0:
        print("Positive numbers only, please.")
        return

    result = x**0.5
    print("The square root of", x, "is", result)
```

The function `print_square_root` has a parameter named `x`. The first thing it does is check whether `x` is less than or equal to `0`, in which case it displays an error message and then uses `return` to exit the function. The flow of execution immediately returns to the caller, and the remaining lines of the function are not executed.

5.10. Logical opposites

Each of the six relational operators has a logical opposite: for example, suppose we can get a driving licence when our age is greater or equal to 17, we can not get the driving licence when we are less than 17.

Notice that the opposite of `>=` is `<`.

operator	logical opposite
`==`	`!=`
`!=`	`==`
`<`	`>=`
`<=`	`>`
`>`	`<=`
`>=`	`<`

Understanding these logical opposites allows us to sometimes get rid of `not` operators. `not` operators are often quite difficult to read in computer code, and our intentions will usually be clearer if we can eliminate them.

For example, if we wrote this Python:

```python
if not (age >= 17):
    print("Hey, you're too young to get a driving licence!")
```

it would probably be clearer to use the simplification laws, and to write instead:

```python
if age < 17:
    print("Hey, you're too young to get a driving licence!")
```

Two powerful simplification laws (called de Morgan's laws) that are often helpful when dealing with complicated Boolean expressions are:

```python
not (x and y)  ==  (not x) or (not y)
not (x or y)   ==  (not x) and (not y)
```

For example, suppose we can slay the dragon only if our magic lightsabre sword is charged to 90% or higher, and we have 100 or more energy units in our protective shield. We find this fragment of Python code in the game:

```python
if not ((sword_charge >= 0.90) and (shield_energy >= 100)):
    print("Your attack has no effect, the dragon fries you to a crisp!")
else:
    print("The dragon crumples in a heap. You rescue the gorgeous princess!")
```

de Morgan's laws together with the logical opposites would let us rework the condition in a (perhaps) easier to understand way like this:

```
if (sword_charge < 0.90) or (shield_energy < 100):
    print("Your attack has no effect, the dragon fries you to a crisp!")
else:
    print("The dragon crumples in a heap. You rescue the gorgeous princess!")
```

We could also get rid of the `not` by swapping around the then and else parts of the conditional. So here is a third version, also equivalent:

```
if (sword_charge >= 0.90) and (shield_energy >= 100):
    print("The dragon crumples in a heap. You rescue the gorgeous princess!")
else:
    print("Your attack has no effect, the dragon fries you to a crisp!")
```

This version is probably the best of the three, because it very closely matches the initial English statement. Clarity of our code (for other humans), and making it easy to see that the code does what was expected should always be a high priority.

As our programming skills develop we'll find we have more than one way to solve any problem. So good programs are *designed*. We make choices that favour clarity, simplicity, and elegance. The job title *software architect* says a lot about what we do — we are *architects* who engineer our products to balance beauty, functionality, simplicity and clarity in our creations.

> ***Tip***
>
> *Once our program works, we should play around a bit trying to polish it up. Write good comments. Think about whether the code would be clearer with different variable names. Could we have done it more elegantly? Should we rather use a function? Can we simplify the conditionals?*
>
> *We think of our code as our creation, our work of art! We make it great.*

5.11. Type conversion

We've had a first look at this in an earlier chapter. Seeing it again won't hurt!

Many Python types come with a built-in function that attempts to convert values of another type into its own type. The `int` function, for example, takes any value and converts it to an integer, if possible, or complains otherwise:

```
>>> int("32")
32
>>> int("Hello")
ValueError: invalid literal for int() with base 10: 'Hello'
```

`int` can also convert floating-point values to integers, but remember that it truncates the fractional part:

```
>>> int(-2.3)
-2
>>> int(3.99999)
3
>>> int("42")
42
>>> int(1.0)
1
```

The float function converts integers and strings to floating-point numbers:

```
>>> float(32)
32.0
>>> float("3.14159")
3.14159
>>> float(1)
1.0
```

It may seem odd that Python distinguishes the integer value `1` from the floating-point value `1.0`. They may represent the same number, but they belong to different types. The reason is that they are represented differently inside the computer.

The `str` function converts any argument given to it to type string:

```
>>> str(32)
'32'
>>> str(3.14149)
'3.14149'
>>> str(True)
'True'
>>> str(true)
Traceback (most recent call last):
  File "<interactive input>", line 1, in <module>
NameError: name 'true' is not defined
```

`str` will work with any value and convert it into a string. As mentioned earlier, `True` is a Boolean value; true is just an ordinary variable name, and is not defined here, so we get an error.

5.12. A Turtle Bar Chart

The turtle has a lot more power than we've seen so far. The full documentation can be found at http://docs.python.org/py3k/library/turtle.html.

Here are a couple of new tricks for our turtles:

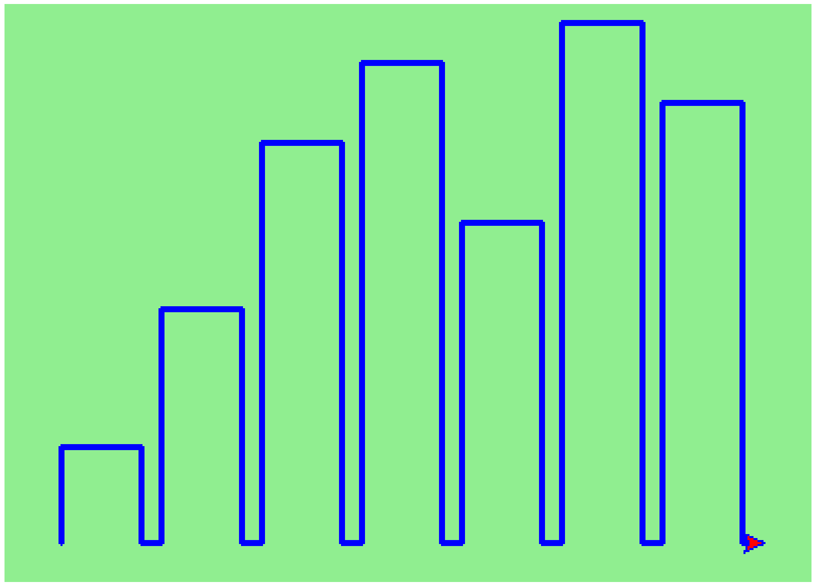
- We can get a turtle to display text on the canvas at the turtle's current position. The method to do that is `alex.write("Hello")`.
- We can fill a shape (circle, semicircle, triangle, etc.) with a color. It is a two-step process. First we call the method `alex.begin_fill()`, then we draw the shape, then we call `alex.end_fill()`.
- We've previously set the color of our turtle — we can now also set its fill color, which need not be the same as the turtle and the pen color. We use `alex.color("blue","red")` to set the turtle to draw in blue, and fill in red.

Ok, so can we get tess to draw a bar chart? Let us start with some data to be charted,

```
xs = [48, 117, 200, 240, 160, 260, 220]
```

Corresponding to each data measurement, we'll draw a simple rectangle of that height, with a fixed width.

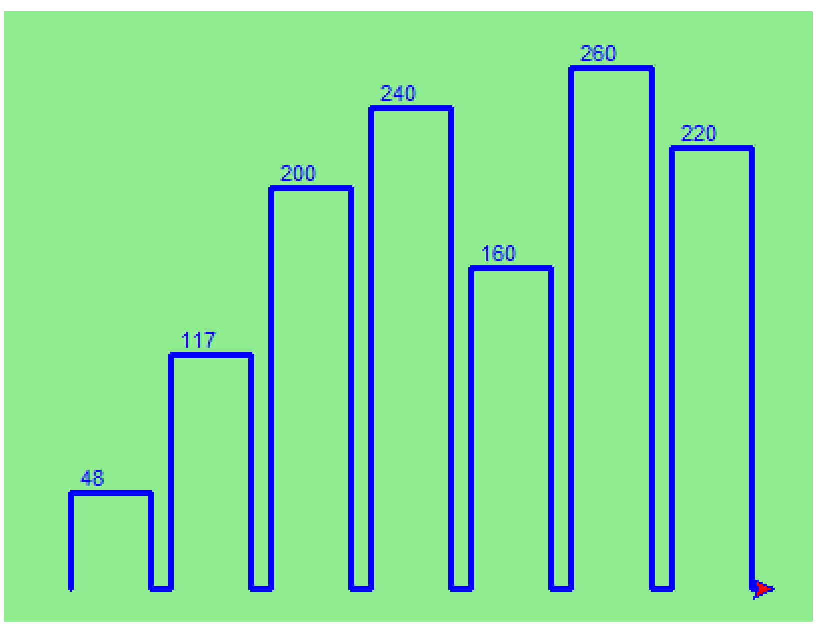
```
def draw_bar(t, height):
    """ Get turtle t to draw one bar, of height. """
    t.left(90)
    t.forward(height)     # Draw up the left side
    t.right(90)
    t.forward(40)         # Width of bar, along the top
    t.right(90)
    t.forward(height)     # And down again!
    t.left(90)            # Put the turtle facing the way we found it.
    t.forward(10)         # Leave small gap after each bar

...
for v in xs:              # Assume xs and tess are ready
    draw_bar(tess, v)
```



Simple bar chart

Ok, not fantastically impressive, but it is a nice start! The important thing here was the mental chunking, or how we broke the problem into smaller pieces. Our chunk is to draw one bar, and we wrote a function to do that. Then, for the whole chart, we repeatedly called our function.

Next, at the top of each bar, we'll print the value of the data. We'll do this in the body of `draw_bar`, by adding `t.write(' ' + str(height))` as the new third line of the body. We've put a little space in front of the number, and turned the number into a string. Without this extra space we tend to cramp our text awkwardly against the bar to the left. The result looks a lot better now:

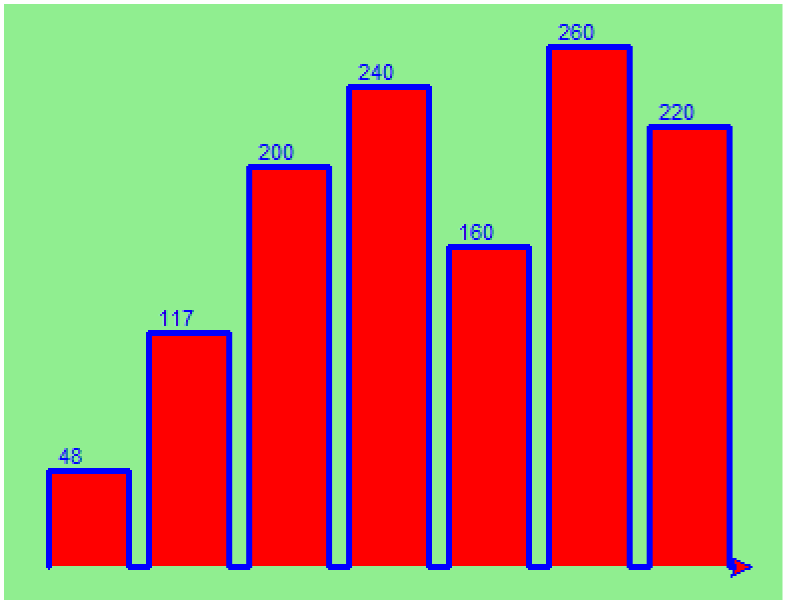


Numbered bar chart

And now we'll add two lines to fill each bar. Our final program now looks like this:

```
import turtle

def draw_bar(t, height):
    """ Get turtle t to draw one bar, of height. """
    t.begin_fill()           # Added this line
    t.left(90)
    t.forward(height)
    t.write("  "+ str(height))
    t.right(90)
    t.forward(40)
    t.right(90)
    t.forward(height)
    t.left(90)
    t.end_fill()             # Added this line
    t.forward(10)

wn = turtle.Screen()         # Set up the window and its attributes
wn.bgcolor("lightgreen")

tess = turtle.Turtle()       # Create tess and set some attributes
tess.color("blue", "red")
tess.pensize(3)

xs = [48,117,200,240,160,260,220]

for a in xs:
    draw_bar(tess, a)

wn.mainloop()
```

It produces the following, which is more satisfying:



Filled bar chart

Mmm. Perhaps the bars should not be joined to each other at the bottom. We'll need to pick up the pen while making the gap between the bars. We'll leave that (and a few more tweaks) as exercises for you!

5.13. Glossary

block

A group of consecutive statements with the same indentation.

body

The block of statements in a compound statement that follows the header.

Boolean algebra

Some rules for rearranging and reasoning about Boolean expressions.

Boolean expression

An expression that is either true or false.

Boolean value

There are exactly two Boolean values: `True` and `False`. Boolean values result when a Boolean expression is evaluated by the Python interpreter. They have type `bool`.

branch

One of the possible paths of the flow of execution determined by conditional execution.

chained conditional

A conditional branch with more than two possible flows of execution. In Python chained conditionals are written with `if` ... `elif` ... `else` statements.

comparison operator

One of the six operators that compares two values: `==`, `!=`, `>`, `<`, `>=`, and `<=`.

condition

The Boolean expression in a conditional statement that determines which branch is executed.

conditional statement

A statement that controls the flow of execution depending on some condition. In Python the keywords `if`, `elif`, and `else` are used for conditional statements.

logical operator

One of the operators that combines Boolean expressions: `and`, `or`, and `not`.

nesting

One program structure within another, such as a conditional statement inside a branch of another conditional statement.

prompt

A visual cue that tells the user that the system is ready to accept input data.

truth table

A concise table of Boolean values that can describe the semantics of an operator.

type conversion

An explicit function call that takes a value of one type and computes a corresponding value of another type.

wrapping code in a function

The process of adding a function header and parameters to a sequence of program statements is often referred to as "wrapping the code in a function". This process is very useful whenever the program statements in question are going to be used multiple times. It is even more useful when it allows the programmer to express their mental chunking, and how they've broken a complex problem into pieces.

5.14. Exercises

1. Assume the days of the week are numbered `0,1,2,3,4,5,6` from Sunday to Saturday. Write a function which is given the day number, and it returns the day name (a string).

2. You go on a wonderful holiday (perhaps to jail, if you don't like happy exercises) leaving on day number 3 (a Wednesday). You return home after 137 sleeps. Write a general version of the program which asks for the starting day number, and the length of your stay, and it will tell you the name of day of the week you will return on.
3. Give the logical opposites of these conditions

```
a > b
a >= b
a >= 18  and  day == 3
a >= 18  and  day != 3
```

4. What do these expressions evaluate to?

```
3 == 3
3 != 3
3 >= 4
not (3 < 4)
```

5. Complete this truth table:

p	q	r	(not (p and q)) or r
F	F	F	?
F	F	T	?
F	T	F	?
F	T	T	?
T	F	F	?
T	F	T	?
T	T	F	?
T	T	T	?

6. Write a function which is given an exam mark, and it returns a string — the grade for that mark — according to this scheme:

Mark	Grade
>= 75	First
[70-75)	Upper Second
[60-70)	Second
[50-60)	Third
[45-50)	F1 Supp
[40-45)	F2
< 40	F3

The square and round brackets denote closed and open intervals. A closed interval includes the number, and open interval excludes it. So `39.99999` gets grade `F3`, but `40` gets grade `F2`. Assume

```
xs = [83, 75, 74.9, 70, 69.9, 65, 60, 59.9, 55, 50,
                    49.9, 45, 44.9, 40, 39.9, 2, 0]
```

Test your function by printing the mark and the grade for all the elements in this list.

7. Modify the turtle bar chart program so that the pen is up for the small gaps between each bar.
8. Modify the turtle bar chart program so that the bar for any value of 200 or more is filled with red, values between [100 and 200) are filled with yellow, and bars representing values less than 100 are filled with green.
9. In the turtle bar chart program, what do you expect to happen if one or more of the data values in the list is negative? Try it out. Change the program so that when it prints the text value for the negative bars, it puts the text below the bottom of the bar.
10. Write a function `find_hypot` which, given the length of two sides of a right-angled triangle, returns the length of the hypotenuse. (*Hint:* `x ** 0.5` *will return the square root.*)
11. Write a function `is_rightangled` which, given the length of three sides of a triangle, will determine whether the triangle is right-angled. Assume that the third argument to the function is always the longest side. It will return `True` if the triangle is right-angled, or `False` otherwise.

    Hint: Floating point arithmetic is not always exactly accurate, so it is not safe to test floating point numbers for equality. If a good programmer wants to know whether `x` *is equal or close enough to* `y`*, they would probably code it up as:*

```
if  abs(x-y) < 0.000001:    # If x is approximately equal to y
    ...
```

12. Extend the above program so that the sides can be given to the function in any order.
13. If you're intrigued by why floating point arithmetic is sometimes inaccurate, on a piece of paper, divide 10 by 3 and write down the decimal result. You'll find it does not terminate, so you'll need an infinitely long sheet of paper. The representation of numbers in computer memory or on your calculator has similar problems: memory is finite, and some digits may have to be discarded. So small inaccuracies creep in. Try this script:

```
import math
a = math.sqrt(2.0)
print(a, a*a)
print(a*a == 2.0)
```

Chapter 6: Fruitful functions

6.1. Return values

The built-in functions we have used, such as `abs`, `pow`, `int`, `max`, and `range`, have produced results. Calling each of these functions generates a value, which we usually assign to a variable or use as part of an expression.

```
biggest = max(3, 7, 2, 5)
x = abs(3 - 11) + 10
```

We also wrote our own function to return the final amount for a compound interest calculation.

In this chapter, we are going to write more functions that return values, which we will call *fruitful functions*, for want of a better name. The first example is area, which returns the area of a circle with the given radius:

```
def area(radius):
    b = 3.14159 * radius**2
    return b
```

We have seen the return statement before, but in a fruitful function the `return` statement includes a **return value**. This statement means: evaluate the return expression, and then return it immediately as the result (the fruit) of this function. The expression provided can be arbitrarily complicated, so we could have written this function like this:

```
def area(radius):
    return 3.14159 * radius * radius
```

On the other hand, **temporary variables** like `b` above often make debugging easier.

Sometimes it is useful to have multiple `return` statements, one in each branch of a conditional. We have already seen the built-in `abs`, now we see how to write our own:

```
def absolute_value(x):
    if x < 0:
        return -x
    else:
        return x
```

Another way to write the above function is to leave out the `else` and just follow the `if` condition by the second `return` statement.

```
def absolute_value(x):
    if x < 0:
        return -x
    return x
```

Think about this version and convince yourself it works the same as the first one.

Code that appears after a return statement, or any other place the flow of execution can never reach, is called **dead code**, or **unreachable code**.

In a fruitful function, it is a good idea to ensure that every possible path through the program hits a `return` statement. The following version of `absolute_value` fails to do this:

```
def bad_absolute_value(x):
    if x < 0:
        return -x
    elif x > 0:
        return x
```

This version is not correct because if `x` happens to be `0`, neither condition is true, and the function ends without hitting a `return` statement. In this case, the `return` value is a special value called **`None`**:

```
>>> print(bad_absolute_value(0))
None
```

All Python functions return `None` whenever they do not return another value.

It is also possible to use a `return` statement in the middle of a `for` loop, in which case control immediately returns from the function. Let us assume that we want a function which looks through a list of words. It should return the first 2-letter word. If there is not one, it should return the empty string:

```
def find_first_2_letter_word(xs):
    for wd in xs:
        if len(wd) == 2:
           return wd
    return ""
>>> find_first_2_letter_word(["This",  "is", "a", "dead", "parrot"])
'is'
>>> find_first_2_letter_word(["I",  "like",  "cheese"])
''
```

Single-step through this code and convince yourself that in the first test case that we've provided, the function returns while processing the second element in the list: it does not have to traverse the whole list.

6.2. Program development

At this point, you should be able to look at complete functions and tell what they do. Also, if you have been doing the exercises, you have written some small functions. As you write larger functions, you might start to have more difficulty, especially with runtime and semantic errors.

To deal with increasingly complex programs, we are going to suggest a technique called **incremental development**. The goal of incremental development is to avoid long debugging sessions by adding and testing only a small amount of code at a time.

As an example, suppose we want to find the distance between two points, given by the coordinates `(x1, y1)` and `(x2, y2)`. By the Pythagorean theorem, the distance is:

$$distance = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Distance formula

The first step is to consider what a `distance` function should look like in Python. In other words, what are the inputs (parameters) and what is the output (return value)?

In this case, the two points are the inputs, which we can represent using four parameters. The return value is the distance, which is a floating-point value.

Already we can write an outline of the function that captures our thinking so far:

```
def distance(x1, y1, x2, y2):
    return 0.0
```

Obviously, this version of the function doesn't compute distances; it always returns zero. But it is syntactically correct, and it will run, which means that we can test it before we make it more complicated.

To test the new function, we call it with sample values:

```
>>> distance(1, 2, 4, 6)
0.0
```

We chose these values so that the horizontal distance equals `3` and the vertical distance equals `4`; that way, the result is `5` (the hypotenuse of a `3-4-5` triangle). When testing a function, it is useful to know the right answer.

At this point we have confirmed that the function is syntactically correct, and we can start adding lines of code. After each incremental change, we test the function again. If an error occurs at any point, we know where it must be — in the last line we added.

A logical first step in the computation is to find the differences `x2- x1` and `y2- y1`. We will refer to those values using temporary variables named `dx` and `dy`.

```
def distance(x1, y1, x2, y2):
    dx = x2 - x1
    dy = y2 - y1
    return 0.0
```

If we call the function with the arguments shown above, when the flow of execution gets to the return statement, `dx` should be `3` and `dy` should be `4`. We can check that this is the case in **PyScripter** by putting the cursor on the return statement, and running the program to break execution when it gets to the cursor (using the `F4` key). Then we inspect the variables `dx` and `dy` by hovering the mouse above them, to confirm that the function is getting the right parameters and performing the first computation correctly. If not, there are only a few lines to check.

Next we compute the sum of squares of `dx` and `dy`:

```
def distance(x1, y1, x2, y2):
    dx = x2 - x1
    dy = y2 - y1
    dsquared = dx*dx + dy*dy
    return 0.0
```

Again, we could run the program at this stage and check the value of `dsquared` (which should be `25`).

Finally, using the fractional exponent `0.5` to find the square root, we compute and return the result:

```
def distance(x1, y1, x2, y2):
    dx = x2 - x1
    dy = y2 - y1
    dsquared = dx*dx + dy*dy
    result = dsquared**0.5
    return result
```

If that works correctly, you are done. Otherwise, you might want to inspect the value of `result` before the return statement.

When you start out, you might add only a line or two of code at a time. As you gain more experience, you might find yourself writing and debugging bigger conceptual chunks. Either way, stepping through your code one line at a time and verifying that each step matches your expectations can save you a lot of debugging time. As you improve your programming skills you should find yourself managing bigger and bigger chunks: this is very similar to the way we learned to read letters, syllables, words, phrases, sentences, paragraphs, etc., or the way we learn to chunk music — from individual notes to chords, bars, phrases, and so on.

The key aspects of the process are:

1. Start with a working skeleton program and make small incremental changes. At any point, if there is an error, you will know exactly where it is.
2. Use temporary variables to refer to intermediate values so that you can easily inspect and check them.
3. Once the program is working, relax, sit back, and play around with your options. (There is interesting research that links "playfulness" to better understanding, better learning, more enjoyment, and a more positive mindset about what you can achieve — so spend some time fiddling around!) You might want to consolidate multiple statements into one bigger compound expression, or rename the variables you've used, or see if you can make the function shorter. A good guideline is to aim for making code as easy as possible for others to read.

Here is another version of the function. It makes use of a square root function that is in the `math` module (we'll learn about modules shortly). Which do you prefer? Which looks "closer" to the Pythagorean formula we started out with?

```
import math

def distance(x1, y1, x2, y2):
    return math.sqrt( (x2-x1)**2 + (y2-y1)**2 )
```

```
>>> distance(1, 2, 4, 6)
5.0
```

6.3. Debugging with print

Another powerful technique for debugging (an alternative to single-stepping and inspection of program variables), is to insert extra print functions in carefully selected places in your code. Then, by inspecting the output of the program, you can check whether the algorithm is doing what you expect it to. Be clear about the following, however:

- You must have a clear solution to the problem, and must know what should happen before you can debug a program. Work on *solving* the problem on a piece of paper (perhaps using a flowchart to record the steps you take) *before* you concern yourself with writing code. Writing a program doesn't solve the problem — it simply *automates* the manual steps you would take. So first make sure you have a pen-and-paper manual solution that works. Programming then is about making those manual steps happen automatically.
- Do not write **chatterbox** functions. A chatterbox is a fruitful function that, in addition to its primary task, also asks the user for input, or prints output, when it would be more useful if it simply shut up and did its work quietly.

For example, we've seen built-in functions like `range`, `max` and `abs`. None of these would be useful building blocks for other programs if they prompted the user for input, or printed their results while they performed their tasks.

So a good tip is to avoid calling `print` and `input` functions inside fruitful functions, *unless the primary purpose of your function is to perform input and output.* The one exception to this rule might be to temporarily sprinkle some calls to `print` into your code to help debug and understand what is happening when the code runs, but these will then be removed once you get things working.

6.4. Composition

As you should expect by now, you can call one function from within another. This ability is called **composition**.

As an example, we'll write a function that takes two points, the center of the circle and a point on the perimeter, and computes the area of the circle.

Assume that the center point is stored in the variables `xc` and `yc`, and the perimeter point is in `xp` and `yp`. The first step is to find the radius of the circle, which is the distance between the two points. Fortunately, we've just written a function, `distance`, that does just that, so now all we have to do is use it:

```
radius = distance(xc, yc, xp, yp)
```

The second step is to find the area of a circle with that radius and return it. Again we will use one of our earlier functions:

```
result = area(radius)
return result
```

Wrapping that up in a function, we get:

```
def area2(xc, yc, xp, yp):
    radius = distance(xc, yc, xp, yp)
    result = area(radius)
    return result
```

We called this function `area2` to distinguish it from the `area` function defined earlier.

The temporary variables `radius` and `result` are useful for development, debugging, and single-stepping through the code to inspect what is happening, but once the program is working, we can make it more concise by composing the function calls:

```
def area2(xc, yc, xp, yp):
    return area(distance(xc, yc, xp, yp))
```

6.5. Boolean functions

Functions can return Boolean values, which is often convenient for hiding complicated tests inside functions. For example:

```
def is_divisible(x, y):
    """ Test if x is exactly divisible by y """
    if x % y == 0:
        return True
    else:
        return False
```

It is common to give **Boolean functions** names that sound like yes/no questions. `is_divisible` returns either `True` or `False` to indicate whether the `x` is or is not divisible by `y`.

We can make the function more concise by taking advantage of the fact that the condition of the `if` statement is itself a Boolean expression. We can return it directly, avoiding the `if` statement altogether:

```
def is_divisible(x, y):
    return x % y == 0
```

This session shows the new function in action:

```
>>> is_divisible(6, 4)
False
>>> is_divisible(6, 3)
True
```

Boolean functions are often used in conditional statements:

```
if is_divisible(x, y):
    ... # Do something ...
else:
    ... # Do something else ...
```

It might be tempting to write something like:

```
if is_divisible(x, y) == True:
```

but the extra comparison is unnecessary.

6.6. Programming with style

Readability is very important to programmers, since in practice programs are read and modified far more often then they are written. But, like most rules, we occasionally break them. Most of the code examples in this book will be consistent with the *Python Enhancement Proposal 8* (PEP 8[5]), a style guide developed by the Python community.

We'll have more to say about style as our programs become more complex, but a few pointers will be helpful already:

- use 4 spaces (instead of tabs) for indentation
- limit line length to 78 characters
- when naming identifiers, use CamelCase for classes (we'll get to those) and lowercase_with_-underscores for functons and variables
- place imports at the top of the file
- keep function definitions together
- use docstrings to document functions
- use two blank lines to separate function definitions from each other
- keep top level statements, including function calls, together at the bottom of the program

[5] http://www.python.org/dev/peps/pep-0008/

6.7. Unit testing

It is a common best practice in software development to include automatic **unit testing** of source code. Unit testing provides a way to automatically verify that individual pieces of code, such as functions, are working properly. This makes it possible to change the implementation of a function at a later time and quickly test that it still does what it was intended to do.

Some years back organizations had the view that their valuable asset was the program code and documentation. Organizations will now spend a large portion of their software budgets on crafting (and preserving) their tests.

Unit testing also forces the programmer to think about the different cases that the function needs to handle. You also only have to type the tests once into the script, rather than having to keep entering the same test data over and over as you develop your code.

Extra code in your program which is there because it makes debugging or testing easier is called **scaffolding**.

A collection of tests for some code is called its **test suite**.

There are a few different ways to do unit testing in Python — but at this stage we're going to ignore what the Python community usually does, and we're going to start with two functions that we'll write ourselves. We'll use these for writing our unit tests.

Let's start with the `absolute_value` function that we wrote earlier in this chapter. Recall that we wrote a few different versions, the last of which was incorrect, and had a bug. Would tests have caught this bug?

First we plan our tests. We'd like to know if the function returns the correct value when its argument is negative, or when its argument is positive, or when its argument is zero. When planning your tests, you'll always want to think carefully about the "edge" cases — here, an argument of `0` to `absolute_value` is on the edge of where the function behaviour changes, and as we saw at the beginning of the chapter, it is an easy spot for the programmer to make a mistake! So it is a good case to include in our test suite.

We're going to write a helper function for checking the results of one test. It takes a boolean argument and will either print a message telling us that the test passed, or it will print a message to inform us that the test failed. The first line of the body (after the function's docstring) magically determines the line number in the script where the call was made from. This allows us to print the line number of the test, which will help when we want to identify which tests have passed or failed.

```
import sys

def test(did_pass):
    """  Print the result of a test.  """
    linenum = sys._getframe(1).f_lineno   # Get the caller's line number.
    if did_pass:
        msg = "Test at line {0} ok.".format(linenum)
    else:
        msg = "Test at line {0} FAILED.".format(linenum)
    print(msg)
```

There is also some slightly tricky string formatting using the format method which we will gloss over for the moment, and cover in detail in a future chapter. But with this function written, we can proceed to construct our test suite:

```
def test_suite():
    """ Run the suite of tests for code in this module (this file).
    """
    test(absolute_value(17) == 17)
    test(absolute_value(-17) == 17)
    test(absolute_value(0) == 0)
    test(absolute_value(3.14) == 3.14)
    test(absolute_value(-3.14) == 3.14)

test_suite()        # Here is the call to run the tests
```

Here you'll see that we've constructed five tests in our test suite. We could run this against the first or second versions (the correct versions) of `absolute_value`, and we'd get output similar to the following:

```
Test at line 25 ok.
Test at line 26 ok.
Test at line 27 ok.
Test at line 28 ok.
Test at line 29 ok.
```

But let's say you change the function to an incorrect version like this:

```
def absolute_value(n):   # Buggy version
    """ Compute the absolute value of n """
    if n < 0:
        return 1
    elif n > 0:
        return n
```

Can you find at least two mistakes in this code? Our test suite can! We get:

```
Test at line 25 ok.
Test at line 26 FAILED.
Test at line 27 FAILED.
Test at line 28 ok.
Test at line 29 FAILED.
```

These are three examples of *failing tests*.

There is a built-in Python statement called **assert** that does almost the same as our **`test`** function (except the program stops when the first assertion fails). You may want to read about it, and use it instead of our `test` function.

6.8. Glossary

Boolean function

A function that returns a Boolean value. The only possible values of the bool type are `False` and `True`.

chatterbox function

A function which interacts with the user (using `input` or `print`) when it should not. Silent functions that just convert their input arguments into their output results are usually the most useful ones.

composition (of functions)

Calling one function from within the body of another, or using the `return` value of one function as an argument to the call of another.

dead code

Part of a program that can never be executed, often because it appears after a `return` statement.

fruitful function

A function that yields a `return` value instead of `None`.

incremental development

A program development plan intended to simplify debugging by adding and testing only a small amount of code at a time.

None

A special Python value. One use in Python is that it is returned by functions that do not execute a `return` statement with a `return` argument.

return value

The value provided as the result of a function call.

scaffolding

Code that is used during program development to assist with development and debugging. The unit test code that we added in this chapter are examples of scaffolding.

temporary variable

A variable used to store an intermediate value in a complex calculation.

test suite

A collection of tests for some code you have written.

unit testing

An automatic procedure used to validate that individual units of code are working properly. Having a test suite is extremely useful when somebody modifies or extends the code: it provides a safety net against going backwards by putting new bugs into previously working code. The term *regression* testing is often used to capture this idea that we don't want to go backwards!

6.9. Exercises

All of the exercises below should be added to a single file. In that file, you should also add the `test` and `test_suite` scaffolding functions shown above, and then, as you work through the exercises, add the new tests to your test suite. (If you open the online version of the textbook, you can easily copy and paste the tests and the fragments of code into your Python editor.)

After completing each exercise, confirm that all the tests pass.

1. The four compass points can be abbreviated by single-letter strings as "`N`", "`E`", "`S`", and "`W`". Write a function `turn_clockwise` that takes one of these four compass points as its parameter, and returns the next compass point in the clockwise direction. Here are some tests that should pass:

```
test(turn_clockwise("N") == "E")
test(turn_clockwise("W") == "N")
```

   You might ask "What if the argument to the function is some other value?" For all other cases, the function should return the value `None`:

```
test(turn_clockwise(42) == None)
test(turn_clockwise("rubbish") == None)
```

2. Write a function `day_name` that converts an integer number `0` to `6` into the name of a day. Assume day `0` is "`Sunday`". Once again, return `None` if the arguments to the function are not valid. Here are some tests that should pass:

```
test(day_name(3) == "Wednesday")
test(day_name(6) == "Saturday")
test(day_name(42) == None)
```

3. Write the inverse function `day_num` which is given a day name, and returns its number:

```
test(day_num("Friday") == 5)
test(day_num("Sunday") == 0)
test(day_num(day_name(3)) == 3)
test(day_name(day_num("Thursday")) == "Thursday")
```

Once again, if this function is given an invalid argument, it should return `None`:

```
test(day_num("Halloween") == None)
```

4. Write a function that helps answer questions like '"Today is Wednesday. I leave on holiday in 19 days time. What day will that be?"' So the function must take a day name and a delta argument — the number of days to add — and should return the resulting day name:

```
test(day_add("Monday", 4) ==  "Friday")
test(day_add("Tuesday", 0) == "Tuesday")
test(day_add("Tuesday", 14) == "Tuesday")
test(day_add("Sunday", 100) == "Tuesday")
```

Hint: use the first two functions written above to help you write this one.

5. Can your `day_add` function already work with negative deltas? For example, `-1` would be yesterday, or `-7` would be a week ago:

```
test(day_add("Sunday", -1) == "Saturday")
test(day_add("Sunday", -7) == "Sunday")
test(day_add("Tuesday", -100) == "Sunday")
```

If your function already works, explain why. If it does not work, make it work.

Hint: Play with some cases of using the modulus function `%` (introduced at the beginning of the previous chapter). Specifically, explore what happens to `x % 7` when `x` is negative.

6. Write a function `days_in_month` which takes the name of a month, and returns the number of days in the month. Ignore leap years:

```
test(days_in_month("February") == 28)
test(days_in_month("December") == 31)
```

If the function is given invalid arguments, it should return `None`.

7. Write a function `to_secs` that converts hours, minutes and seconds to a total number of seconds. Here are some tests that should pass:

```
test(to_secs(2, 30, 10) == 9010)
test(to_secs(2, 0, 0) == 7200)
test(to_secs(0, 2, 0) == 120)
test(to_secs(0, 0, 42) == 42)
test(to_secs(0, -10, 10) == -590)
```

8. Extend `to_secs` so that it can cope with real values as inputs. It should always return an integer number of seconds (truncated towards zero):

```
test(to_secs(2.5, 0, 10.71) == 9010)
test(to_secs(2.433,0,0) == 8758)
```

9. Write three functions that are the "inverses" of `to_secs`:

   1. `hours_in` returns the whole integer number of hours represented by a total number of seconds.

   2. `minutes_in` returns the whole integer number of left over minutes in a total number of seconds, once the hours have been taken out.

   3. `seconds_in` returns the left over seconds represented by a total number of seconds.

   You may assume that the total number of seconds passed to these functions is an integer. Here are some test cases:

```
test(hours_in(9010) == 2)
test(minutes_in(9010) == 30)
test(seconds_in(9010) == 10)
```

It won't always be obvious what is wanted …

In the third case above, the requirement seems quite ambiguous and fuzzy. But the test clarifies what we actually need to do.

Unit tests often have this secondary benefit of clarifying the specifications. If you write your own test suites, consider it part of the problem-solving process as you ask questions about what you really expect to happen, and whether you've considered all the possible cases.

Since our book is titled *How to Think Like* … you might enjoy reading at least one reference about thinking, and about fun ideas like *fluid intelligence*, a key ingredient in problem solving. See, for example, http://psychology.about.com/od/cognitivepsychology/a/fluid-crystal.htm. Learning Computer Science requires a good mix of both fluid and crystallized kinds of intelligence.

10. Which of these tests fail? Explain why.

```
test(3 % 4 == 0)
test(3 % 4 == 3)
test(3 / 4 == 0)
test(3 // 4 == 0)
test(3+4  *  2 == 14)
test(4-2+2 == 0)
test(len("hello, world!") == 13)
```

11. Write a compare function that returns `1` if `a > b`, `0` if `a == b`, and `-1` if `a < b`

```
test(compare(5, 4) == 1)
test(compare(7, 7) == 0)
test(compare(2, 3) == -1)
test(compare(42, 1) == 1)
```

12. Write a function called hypotenuse that returns the length of the hypotenuse of a right triangle given the lengths of the two legs as parameters:

```
test(hypotenuse(3, 4) == 5.0)
test(hypotenuse(12, 5) == 13.0)
test(hypotenuse(24, 7) == 25.0)
test(hypotenuse(9, 12) == 15.0)
```

13. Write a function `slope(x1, y1, x2, y2)` that returns the slope of the line through the points `(x1, y1)` and `(x2, y2)`. Be sure your implementation of slope can pass the following tests:

```
test(slope(5, 3, 4, 2) == 1.0)
test(slope(1, 2, 3, 2) == 0.0)
test(slope(1, 2, 3, 3) == 0.5)
test(slope(2, 4, 1, 2) == 2.0)
```

Then use a call to `slope` in a new function named `intercept(x1, y1, x2, y2)` that returns the y-intercept of the line through the points `(x1, y1)` and `(x2, y2)`

```
test(intercept(1, 6, 3, 12) == 3.0)
test(intercept(6, 1, 1, 6) == 7.0)
test(intercept(4, 6, 12, 8) == 5.0)
```

14. Write a function called `is_even(n)` that takes an integer as an argument and returns `True` if the argument is an **even number** and `False` if it is **odd**.

    Add your own tests to the test suite.
15. Now write the function `is_odd(n)` that returns `True` when `n` is odd and `False` otherwise. Include unit tests for this function too.

    Finally, modify it so that it uses a call to `is_even` to determine if its argument is an odd integer, and ensure that its test still pass.
16. Write a function `is_factor(f, n)` that passes these tests:

```
test(is_factor(3, 12))
test(not is_factor(5, 12))
test(is_factor(7, 14))
test(not is_factor(7, 15))
test(is_factor(1, 15))
test(is_factor(15, 15))
test(not is_factor(25, 15))
```

    An important role of unit tests is that they can also act as unambiguous “specifications” of what is expected. These test cases answer the question “Do we treat 1 and 15 as factors of 15”?
17. Write `is_multiple` to satisfy these unit tests:

```
test(is_multiple(12, 3))
test(is_multiple(12, 4))
test(not is_multiple(12, 5))
test(is_multiple(12, 6))
test(not is_multiple(12, 7))
```

    Can you find a way to use `is_factor` in your definition of `is_multiple`?
18. Write the function `f2c(t)` designed to return the integer value of the nearest degree Celsius for given temperature in Fahrenheit. (*hint: you may want to make use of the built-in function, `round`. Try printing `round.__doc__` in a Python shell or looking up help for the round function, and experimenting with it until you are comfortable with how it works.*)

```
test(f2c(212) == 100)     # Boiling point of water
test(f2c(32) == 0)        # Freezing point of water
test(f2c(-40) == -40)     # Wow, what an interesting case!
test(f2c(36) == 2)
test(f2c(37) == 3)
test(f2c(38) == 3)
test(f2c(39) == 4)
```

19. Now do the opposite: write the function `c2f` which converts Celsius to Fahrenheit:

```
test(c2f(0) == 32)
test(c2f(100) == 212)
test(c2f(-40) == -40)
test(c2f(12) == 54)
test(c2f(18) == 64)
test(c2f(-48) == -54)
```

Chapter 7: Iteration

Computers are often used to automate repetitive tasks. Repeating identical or similar tasks without making errors is something that computers do well and people do poorly.

Repeated execution of a set of statements is called **iteration**. Because iteration is so common, Python provides several language features to make it easier. We've already seen the `for` statement in chapter 3. This the the form of iteration you'll likely be using most often. But in this chapter we've going to look at the `while` statement — another way to have your program do iteration, useful in slightly different circumstances.

Before we do that, let's just review a few ideas…

7.1. Assignment

As we have mentioned previously, it is legal to make more than one assignment to the same variable. A new assignment makes an existing variable refer to a new value (and stop referring to the old value).

```
airtime_remaining = 15
print(airtime_remaining)
airtime_remaining = 7
print(airtime_remaining)
```

The output of this program is:

```
15
7
```

because the first time `airtime_remaining` is printed, its value is `15`, and the second time, its value is `7`.

It is especially important to distinguish between an assignment statement and a Boolean expression that tests for equality. Because Python uses the equal token (=) for assignment, it is tempting to interpret a statement like `a = b` as a Boolean test. Unlike mathematics, it is not! Remember that the Python token for the equality operator is ==.

Note too that an equality test is symmetric, but assignment is not. For example, if `a == 7` then `7 == a`. But in Python, the statement `a = 7` is legal and `7 = a` is not.

In Python, an assignment statement can make two variables equal, but because further assignments can change either of them, they don't have to stay that way:

```
a = 5
b = a    # After executing this line, a and b are now equal
a = 3    # After executing this line, a and b are no longer equal
```

The third line changes the value of `a` but does not change the value of `b`, so they are no longer equal. (In some programming languages, a different symbol is used for assignment, such as `<-` or `:=`, to avoid confusion. Some people also think that variable was an unfortunate word to choose, and instead we should have called them assignables. Python chooses to follow common terminology and token usage, also found in languages like C, C++, Java, and C#, so we use the tokens = for assignment, == for equality, and we talk of variables.

7.2. Updating variables

When an assignment statement is executed, the right-hand side expression (i.e. the expression that comes after the assignment token) is evaluated first. This produces a value. Then the assignment is made, so that the variable on the left-hand side now refers to the new value.

One of the most common forms of assignment is an update, where the new value of the variable depends on its old value. Deduct 40 cents from my airtime balance, or add one run to the scoreboard.

```
1 n = 5
2 n = 3 * n + 1
```

Line 2 means *get the current value of `n`, multiply it by three and add one, and assign the answer to `n`, thus making `n` refer to the value*. So after executing the two lines above, `n` will point/refer to the integer `16`.

If you try to get the value of a variable that has never been assigned to, you'll get an error:

```
>>> w = x + 1
Traceback (most recent call last):
  File "<interactive input>", line 1, in
NameError: name 'x' is not defined
```

Before you can update a variable, you have to **initialize** it to some starting value, usually with a simple assignment:

```
1 runs_scored = 0
2 ...
3 runs_scored = runs_scored + 1
```

Line 3 — updating a variable by adding `1` to it — is very common. It is called an **increment** of the variable; subtracting `1` is called a **decrement**. Sometimes programmers also talk about bumping a variable, which means the same as incrementing it by `1`.

7.3. The `for` loop revisited

Recall that the for loop processes each item in a list. Each item in turn is (re-)assigned to the loop variable, and the body of the loop is executed. We saw this example in an earlier chapter:

```
for f in ["Joe", "Zoe", "Brad", "Angelina", "Zuki", "Thandi", "Paris"]:
    invitation = "Hi " + f + ".  Please come to my party on Saturday!"
    print(invitation)
```

Running through all the items in a list is called **traversing** the list, or **traversal**.

Let us write a function now to sum up all the elements in a list of numbers. Do this by hand first, and try to isolate exactly what steps you take. You'll find you need to keep some "running total" of the sum so far, either on a piece of paper, in your head, or in your calculator. Remembering things from one step to the next is precisely why we have variables in a program: so we'll need some variable to remember the "running total". It should be initialized with a value of zero, and then we need to traverse the items in the list. For each item, we'll want to update the running total by adding the next number to it.

```
def mysum(xs):
    """ Sum all the numbers in the list xs, and return the total. """
    running_total = 0
    for x in xs:
        running_total = running_total + x
    return running_total

# Add tests like these to your test suite ...
test(mysum([1, 2, 3, 4]) == 10)
test(mysum([1.25, 2.5, 1.75]) == 5.5)
test(mysum([1, -2, 3]) == 2)
test(mysum([ ]) == 0)
test(mysum(range(11)) == 55)  # 11 is not included in the list.
```

7.4. The `while` statement

Here is a fragment of code that demonstrates the use of the while statement:

```
1  def sum_to(n):
2      """ Return the sum of 1+2+3 ... n """
3      ss  = 0
4      v = 1
5      while v <= n:
6          ss = ss + v
7          v = v + 1
8      return ss
9
10 # For your test suite
11 test(sum_to(4) == 10)
12 test(sum_to(1000) == 500500)
```

You can almost read the `while` statement as if it were English. It means, while `v` is less than or equal to `n`, continue executing the body of the loop. Within the body, each time, increment `v`. When `v` passes n, return your accumulated sum.

More formally, here is precise flow of execution for a `while` statement:

- Evaluate the condition at line 5, yielding a value which is either False or True.
- If the value is False, exit the while statement and continue execution at the next statement (line 8 in this case).
- If the value is True, execute each of the statements in the body (lines 6 and 7) and then go back to the `while` statement at line 5.

The body consists of all of the statements indented below the while keyword.

Notice that if the loop condition is False the first time we get loop, the statements in the body of the loop are never executed.

The body of the loop should change the value of one or more variables so that eventually the condition becomes false and the loop terminates. Otherwise the loop will repeat forever, which is called an **infinite loop**. An endless source of amusement for computer scientists is the observation that the directions on shampoo, "lather, rinse, repeat", are an infinite loop.

In the case here, we can prove that the loop terminates because we know that the value of `n` is finite, and we can see that the value of `v` increments each time through the loop, so eventually it will have to exceed `n`. In other cases, it is not so easy, even impossible in some cases, to tell if the loop will ever terminate.

What you will notice here is that the `while` loop is more work for you — the programmer — than the equivalent `for` loop. When using a `while` loop one has to manage the loop variable yourself: give it an initial value, test for completion, and then make sure you change something in the body so that the loop terminates. By comparison, here is an equivalent function that uses `for` instead:

```
def sum_to(n):
    """ Return the sum of 1+2+3 ... n """
    ss  = 0
    for v in range(n+1):
        ss = ss + v
    return ss
```

Notice the slightly tricky call to the `range` function — we had to add one onto `n`, because `range` generates its list up to but excluding the value you give it. It would be easy to make a programming mistake and overlook this, but because we've made the investment of writing some unit tests, our test suite would have caught our error.

So why have two kinds of loop if `for` looks easier? This next example shows a case where we need the extra power that we get from the `while` loop.

7.5. The Collatz 3n + 1 sequence

Let's look at a simple sequence that has fascinated and foxed mathematicians for many years. They still cannot answer even quite simple questions about this.

The "computational rule" for creating the sequence is to start from some given `n`, and to generate the next term of the sequence from `n`, either by halving `n`, (whenever `n` is even), or else by multiplying it by three and adding 1. The sequence terminates when `n` reaches `1`.

This Python function captures that algorithm:

```
1  def seq3np1(n):
2      """ Print the 3n+1 sequence from n,
3          terminating when it reaches 1.
4      """
5      while n != 1:
6          print(n, end=", ")
7          if n % 2 == 0:        # n is even
8              n = n // 2
9          else:                 # n is odd
10             n = n * 3 + 1
11     print(n, end=".\n")
```

Notice first that the `print` function on line 6 has an extra argument `end=", "`. This tells the `print` function to follow the printed string with whatever the programmer chooses (in this case, a comma followed by a space), instead of ending the line. So each time something is printed in the loop, it is printed on the same output line, with the numbers separated by commas. The call to `print(n, end=".\n")` at line 11 after the loop terminates will then print the final value of `n` followed by a period and a newline character. (You'll cover the `\n` (newline character) in the next chapter).

The condition for continuing with this loop is `n != 1`, so the loop will continue running until it reaches its termination condition, (i.e. `n == 1`).

Each time through the loop, the program outputs the value of `n` and then checks whether it is even or odd. If it is even, the value of `n` is divided by `2` using integer division. If it is odd, the value is replaced by `n * 3 + 1`. Here are some examples:

```
>>> seq3np1(3)
3, 10, 5, 16, 8, 4, 2, 1.
>>> seq3np1(19)
19, 58, 29, 88, 44, 22, 11, 34, 17, 52, 26, 13,
                    40, 20, 10, 5, 16, 8, 4, 2, 1.
>>> seq3np1(21)
21, 64, 32, 16, 8, 4, 2, 1.
>>> seq3np1(16)
16, 8, 4, 2, 1.
>>>
```

Since `n` sometimes increases and sometimes decreases, there is no obvious proof that `n` will ever reach `1`, or that the program terminates. For some particular values of `n`, we can prove termination. For example, if the starting value is a power of two, then the value of `n` will be even each time through the loop until it reaches 1. The previous example ends with such a sequence, starting with `16`.

See if you can find a small starting number that needs more than a hundred steps before it terminates.

Particular values aside, the interesting question was first posed by a German mathematician called Lothar Collatz: the *Collatz conjecture* (also known as the *3n + 1 conjecture*), is that this sequence terminates for all positive values of `n`. So far, no one has been able to prove it or disprove it! (A conjecture is a statement that might be true, but nobody knows for sure.)

Think carefully about what would be needed for a proof or disproof of the conjecture "All positive integers will eventually converge to `1` using the Collatz rules". With fast computers we have been able to test every integer up to very large values, and so far, they have all eventually ended up at `1`. But who knows? Perhaps there is some as-yet untested number which does not reduce to `1`.

You'll notice that if you don't stop when you reach `1`, the sequence gets into its own cyclic loop: 1, 4, 2, 1, 4, 2, 1, 4 … So one possibility is that there might be other cycles that we just haven't found yet.

Wikipedia has an informative article about the Collatz conjecture. The sequence also goes under other names (Hailstone sequence, Wonderous numbers, etc.), and you'll find out just how many integers have already been tested by computer, and found to converge!

Choosing between for and while

Use a `for` loop if you know, before you start looping, the maximum number of times that you'll need to execute the body. For example, if you're traversing a list of elements, you know that the maximum number of loop iterations you can possibly need is "all the elements in the list". Or if you need to print the 12 times table, we know right away how many times the loop will need to run.

So any problem like "iterate this weather model for 1000 cycles", or "search this list of words", "find all prime numbers up to 10000" suggest that a `for` loop is best.

By contrast, if you are required to repeat some computation until some condition is met, and you cannot calculate in advance when (or if) this will happen, as we did in this `3n + 1` problem, you'll need a `while` loop.

We call the first case **definite iteration** — we know ahead of time some definite bounds for what is needed. The latter case is called **indefinite iteration** — we're not sure how many iterations we'll need — we cannot even establish an upper bound!

7.6. Tracing a program

To write effective computer programs, and to build a good conceptual model of program execution, a programmer needs to develop the ability to **trace** the execution of a computer program. Tracing involves becoming the computer and following the flow of execution through a sample program run, recording the state of all variables and any output the program generates after each instruction is executed.

To understand this process, let's trace the call to `seq3np1(3)` from the previous section. At the start of the trace, we have a variable, `n` (the parameter), with an initial value of `3`. Since `3` is not equal to `1`, the `while` loop body is executed. `3` is printed and `3 % 2 == 0` is evaluated. Since it evaluates to `False`, the `else` branch is executed and `3 * 3 + 1` is evaluated and assigned to `n`.

To keep track of all this as you hand trace a program, make a column heading on a piece of paper for each variable created as the program runs and another one for output. Our trace so far would look something like this:

```
n                 output printed so far
--                ---------------------
3                 3,
10
```

Since `10 != 1` evaluates to `True`, the loop body is again executed, and `10` is printed. `10 % 2 == 0` is `True`, so the `if` branch is executed and `n` becomes `5`. By the end of the trace we have:

```
n               output printed so far
--              ---------------------
3               3,
10              3, 10,
5               3, 10, 5,
16              3, 10, 5, 16,
8               3, 10, 5, 16, 8,
4               3, 10, 5, 16, 8, 4,
2               3, 10, 5, 16, 8, 4, 2,
1               3, 10, 5, 16, 8, 4, 2, 1.
```

Tracing can be a bit tedious and error prone (that's why we get computers to do this stuff in the first place!), but it is an essential skill for a programmer to have. From this trace we can learn a lot about the way our code works. We can observe that as soon as `n` becomes a power of `2`, for example, the program will require `log2(n)` executions of the loop body to complete. We can also see that the final `1` will not be printed as output within the body of the loop, which is why we put the special `print` function at the end.

Tracing a program is, of course, related to single-stepping through your code and being able to inspect the variables. Using the computer to **single-step** for you is less error prone and more convenient. Also, as your programs get more complex, they might execute many millions of steps before they get to the code that you're really interested in, so manual tracing becomes impossible. Being able to set a **breakpoint** where you need one is far more powerful. So we strongly encourage you to invest time in learning using to use your programming environment to full effect.

There are also some great visualization tools becoming available to help you trace and understand small fragments of Python code. The one we recommend is at http://pythontutor.com/

We've cautioned against chatterbox functions, but used them here. As we learn a bit more Python, we'll be able to show you how to generate a list of values to hold the sequence, rather than having the function print them. Doing this would remove the need to have all these pesky print functions in the middle of our logic, and will make the function more useful.

7.7. Counting digits

The following function counts the number of decimal digits in a positive integer:

```
def num_digits(n):
    count = 0
    while n != 0:
        count = count + 1
        n = n // 10
    return count
```

A call to `print(num_digits(710))` will print `3`. Trace the execution of this function call (perhaps using the single step function in PyScripter, or the Python visualizer, or on some paper) to convince yourself that it works.

This function demonstrates an important pattern of computation called a **counter**. The variable `count` is initialized to `0` and then incremented each time the loop body is executed. When the loop exits, `count` contains the result — the total number of times the loop body was executed, which is the same as the number of digits.

If we wanted to only count digits that are either `0` or `5`, adding a conditional before incrementing the counter will do the trick:

```
def num_zero_and_five_digits(n):
    count = 0
    while n > 0:
        digit = n % 10
        if digit == 0 or digit == 5:
            count = count + 1
        n = n // 10
    return count
```

Confirm that `test(num_zero_and_five_digits(1055030250) == 7)` passes.

Notice, however, that `test(num_digits(0) == 1)` fails. Explain why. Do you think this is a bug in the code, or a bug in the specifications, or our expectations, or the tests?

7.8. Abbreviated assignment

Incrementing a variable is so common that Python provides an abbreviated syntax for it:

```
>>> count = 0
>>> count += 1
>>> count
1
>>> count += 1
>>> count
2
```

`count += 1` is an abbreviation for `count = count + 1`. We pronounce the operator as "plus-equals". The increment value does not have to be `1`:

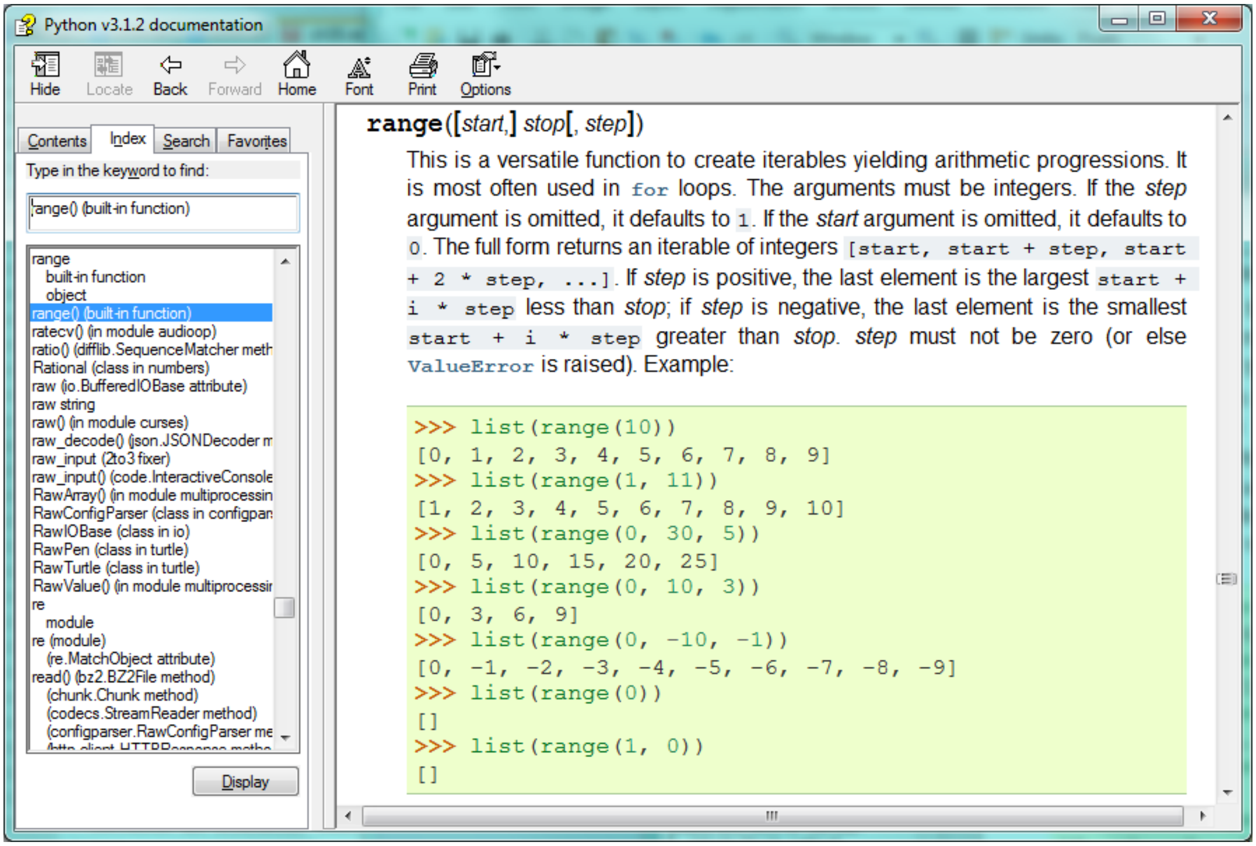
```
>>> n = 2
>>> n += 5
>>> n
7
```

There are similar abbreviations for `-=`, `*=`, `/=`, `//=` and `%=`:

```
>>> n = 2
>>> n *= 5
>>> n
10
>>> n -= 4
>>> n
6
>>> n //= 2
>>> n
3
>>> n %= 2
>>> n
1
```

7.9. Help and meta-notation

Python comes with extensive documentation for all its built-in functions, and its libraries. Different systems have different ways of accessing this help. In PyScripter, click on the Help menu item, and select Python Manuals. Then search for help on the built-in function `range`. You'll get something like this:



_images/help_range.png

Notice the square brackets in the description of the arguments. These are examples of **meta-notation** — notation that describes Python syntax, but is not part of it. The square brackets in this documentation mean that the argument is optional — the programmer can omit it. So what this first line of help tells us is that `range` must always have a `stop` argument, but it may have an optional `start` argument (which must be followed by a comma if it is present), and it can also have an optional `step` argument, preceded by a comma if it is present.

The examples from help show that `range` can have either 1, 2 or 3 arguments. The list can start at any starting value, and go up or down in increments other than 1. The documentation here also says that the arguments must be integers.

Other meta-notation you'll frequently encounter is the use of bold and italics. The bold means that these are tokens — keywords or symbols — typed into your Python code exactly as they are, whereas the italic terms stand for "something of this type". So the syntax description

for *variable* **in** *list*:

means you can substitute any legal variable and any legal list when you write your Python code.

This (simplified) description of the `print` function, shows another example of meta-notation in which the ellipses (...) mean that you can have as many objects as you like (even zero), separated by commas:

print([*object, ...*])

Meta-notation gives us a concise and powerful way to describe the pattern of some syntax or feature.

7.10. Tables

One of the things loops are good for is generating tables. Before computers were readily available, people had to calculate logarithms, sines and cosines, and other mathematical functions by hand. To make that easier, mathematics books contained long tables listing the values of these functions. Creating the tables was slow and boring, and they tended to be full of errors.

When computers appeared on the scene, one of the initial reactions was, "*This is great! We can use the computers to generate the tables, so there will be no errors.*" That turned out to be true (mostly) but shortsighted. Soon thereafter, computers and calculators were so pervasive that the tables became obsolete.

Well, almost. For some operations, computers use tables of values to get an approximate answer and then perform computations to improve the approximation. In some cases, there have been errors in the underlying tables, most famously in the table the Intel Pentium processor chip used to perform floating-point division.

Although a log table is not as useful as it once was, it still makes a good example of iteration. The following program outputs a sequence of values in the left column and 2 raised to the power of that value in the right column:

```
for x in range(13):   # Generate numbers 0 to 12
    print(x, "\t", 2**x)
```

The string `"\t"` represents a **tab character**. The backslash character in `"\t"` indicates the beginning of an **escape sequence**. Escape sequences are used to represent invisible characters like tabs and newlines. The sequence `\n` represents a **newline**.

An escape sequence can appear anywhere in a string; in this example, the tab escape sequence is the only thing in the string. How do you think you represent a backslash in a string?

As characters and strings are displayed on the screen, an invisible marker called the cursor keeps track of where the next character will go. After a `print` function, the cursor normally goes to the beginning of the next line.

The tab character shifts the cursor to the right until it reaches one of the tab stops. Tabs are useful for making columns of text line up, as in the output of the previous program:

```
0       1
1       2
2       4
3       8
4       16
5       32
6       64
7       128
8       256
9       512
10      1024
11      2048
12      4096
```

Because of the tab characters between the columns, the position of the second column does not depend on the number of digits in the first column.

7.11. Two-dimensional tables

A two-dimensional table is a table where you read the value at the intersection of a row and a column. A multiplication table is a good example. Let's say you want to print a multiplication table for the values from `1` to `6`.

A good way to start is to write a loop that prints the multiples of `2`, all on one line:

```
1 for i in range(1, 7):
2     print(2 * i, end="   ")
3 print()
```

Here we've used the `range` function, but made it start its sequence at `1`. As the loop executes, the value of `i` changes from `1` to `6`. When all the elements of the range have been assigned to `i`, the loop terminates. Each time through the loop, it displays the value of `2 * i`, followed by three spaces.

Again, the extra `end="   "` argument in the `print` function suppresses the newline, and uses three spaces instead. After the loop completes, the call to `print` at line `3` finishes the current line, and starts a new line.

The output of the program is:

```
2      4      6      8      10     12
```

So far, so good. The next step is to **encapsulate** and **generalize**.

7.12. Encapsulation and generalization

Encapsulation is the process of wrapping a piece of code in a function, allowing you to take advantage of all the things functions are good for. You have already seen some examples of encapsulation, including `is_divisible` in a previous chapter.

Generalization means taking something specific, such as printing the multiples of `2`, and making it more general, such as printing the multiples of any integer.

This function encapsulates the previous loop and generalizes it to print multiples of `n`:

```
def print_multiples(n):
    for i in range(1, 7):
        print(n * i, end="   ")
    print()
```

To encapsulate, all we had to do was add the first line, which declares the name of the function and the parameter list. To generalize, all we had to do was replace the value `2` with the parameter `n`.

If we call this function with the argument `2`, we get the same output as before. With the argument `3`, the output is:

```
3      6      9      12      15      18
```

With the argument `4`, the output is:

```
4      8      12      16      20      24
```

By now you can probably guess how to print a multiplication table — by calling `print_multiples` repeatedly with different arguments. In fact, we can use another loop:

```
for i in range(1, 7):
    print_multiples(i)
```

Notice how similar this loop is to the one inside `print_multiples`. All we did was replace the print function with a function call.

The output of this program is a multiplication table:

```
1       2       3       4       5       6
2       4       6       8       10      12
3       6       9       12      15      18
4       8       12      16      20      24
5       10      15      20      25      30
6       12      18      24      30      36
```

7.13. More encapsulation

To demonstrate encapsulation again, let's take the code from the last section and wrap it up in a function:

```python
def print_mult_table():
    for i in range(1, 7):
        print_multiples(i)
```

This process is a common **development plan**. We develop code by writing lines of code outside any function, or typing them in to the interpreter. When we get the code working, we extract it and wrap it up in a function.

This development plan is particularly useful if you don't know how to divide the program into functions when you start writing. This approach lets you design as you go along.

7.14. Local variables

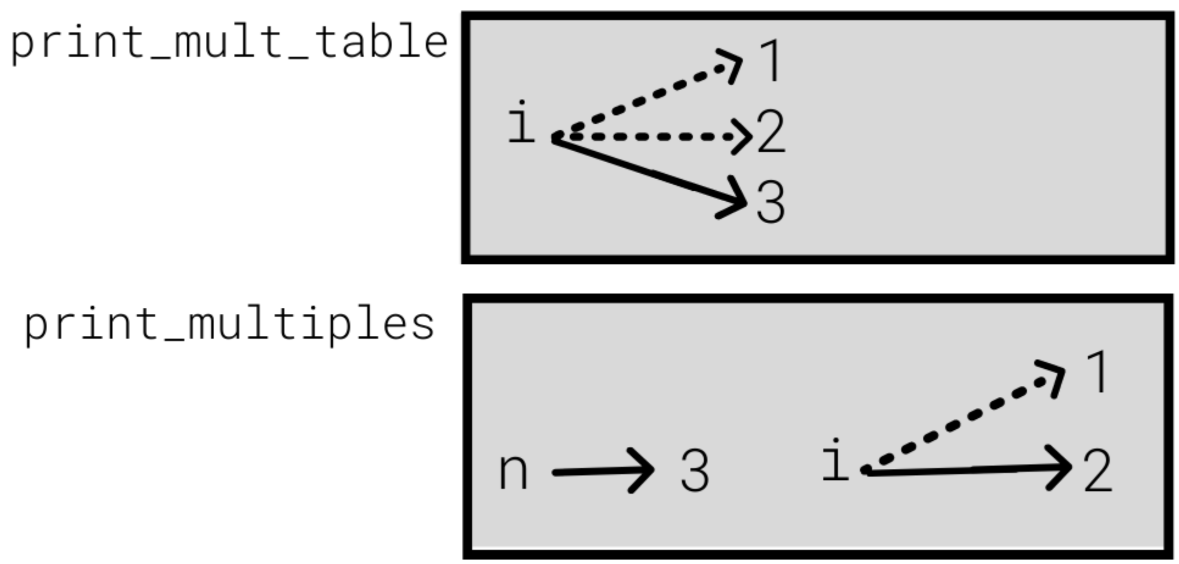
You might be wondering how we can use the same variable, `i`, in both `print_multiples` and `print_mult_table`. Doesn't it cause problems when one of the functions changes the value of the variable?

The answer is no, because the `i` in `print_multiples` and the `i` in `print_mult_table` are not the same variable.

Variables created inside a function definition are local; you can't access a local variable from outside its home function. That means you are free to have multiple variables with the same name as long as they are not in the same function.

Python examines all the statements in a function — if any of them assign a value to a variable, that is the clue that Python uses to make the variable a local variable.

The stack diagram for this program shows that the two variables named `i` are not the same variable. They can refer to different values, and changing one does not affect the other.



Stack 2 diagram

The value of `i` in `print_mult_table` goes from `1` to `6`. In the diagram it happens to be `3`. The next time through the loop it will be `4`. Each time through the loop, `print_mult_table` calls `print_multiples` with the current value of `i` as an argument. That value gets assigned to the parameter `n`.

Inside `print_multiples`, the value of `i` goes from `1` to `6`. In the diagram, it happens to be `2`. Changing this variable has no effect on the value of `i` in `print_mult_table`.

It is common and perfectly legal to have different local variables with the same name. In particular, names like `i` and `j` are used frequently as loop variables. If you avoid using them in one function just because you used them somewhere else, you will probably make the program harder to read.

The visualizer at http://pythontutor.com/ shows very clearly how the two variables `i` are distinct variables, and how they have independent values.

7.15. The break statement

The *break* statement is used to immediately leave the body of its loop. The next statement to be executed is the first one after the body:

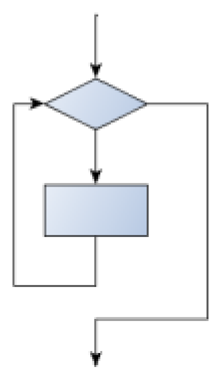
```
for i in [12, 16, 17, 24, 29]:
    if i % 2 == 1:  # If the number is odd
       break        #  ... immediately exit the loop
    print(i)
print("done")
```

This prints:

```
12
16
done
```

The pre-test loop — standard loop behaviour

`for` and `while` loops do their tests at the start, before executing any part of the body. They're called **pre-test** loops, because the test happens before (pre) the body. `break` and `return` are our tools for adapting this standard behaviour.



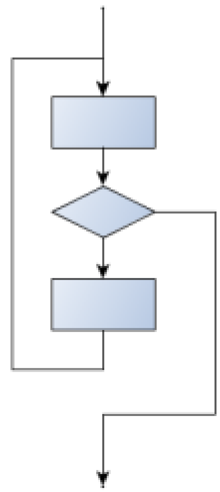
_images/pre_test_loop.png

7.16. Other flavours of loops

Sometimes we'd like to have the **middle-test** loop with the exit test in the middle of the body, rather than at the beginning or at the end. Or a **post-test** loop that puts its exit test as the last thing in the body. Other languages have different syntax and keywords for these different flavours, but Python just uses a combination of `while` and `if condition: break` to get the job done.

A typical example is a problem where the user has to input numbers to be summed. To indicate that there are no more inputs, the user enters a special value, often the value `-1`, or the empty string. This needs a middle-exit loop pattern: input the next number, then test whether to exit, or else process the number:

The middle-test loop flowchart



_images/mid_test_loop.png

```
1 total = 0
2 while True:
3     response = input("Enter the next number. (Leave blank to end)")
4     if response == "":
5         break
6     total += int(response)
7 print("The total of the numbers you entered is ", total)
```

Convince yourself that this fits the middle-exit loop flowchart: line 3 does some useful work, lines 4 and 5 can exit the loop, and if they don't line 6 does more useful work before the next iteration starts.

The `while bool-expr:` uses the Boolean expression to determine whether to iterate again. `True` is a trivial Boolean expression, so `while True:` means always do the loop body again. This is a language idiom — a convention that most programmers will recognize immediately. Since the expression on line 2 will never terminate the loop, (it is a dummy test) the programmer must arrange to break (or return) out of the loop body elsewhere, in some other way (i.e. in lines 4 and 5 in this sample). A clever compiler or interpreter will understand that line 2 is a fake test that must always succeed, so it won't even generate a test, and our flowchart never even put the diamond-shape dummy test box at the top of the loop!

Similarly, by just moving the `if condition: break` to the end of the loop body we create a pattern for a post-test loop. Post-test loops are used when you want to be sure that the loop body always executes at least once (because the first test only happens at the end of the execution of the first loop body). This is useful, for example, if we want to play an interactive game against the user — we always want to play at least one game:

```
while True:
    play_the_game_once()
    response = input("Play again? (yes or no)")
    if response != "yes":
        break
print("Goodbye!")
```

Hint: Think about where you want the exit test to happen.

Once you've recognized that you need a loop to repeat something, think about its terminating condition — when will I want to stop iterating? Then figure out whether you need to do the test before starting the first (and every other) iteration, or at the end of the first (and every other) iteration, or perhaps in the middle of each iteration. Interactive programs that require input from the user or read from files often need to exit their loops in the middle or at the end of an iteration, when it becomes clear that there is no more data to process, or the user doesn't want to play our game anymore.

7.17. An example

The following program implements a simple guessing game:

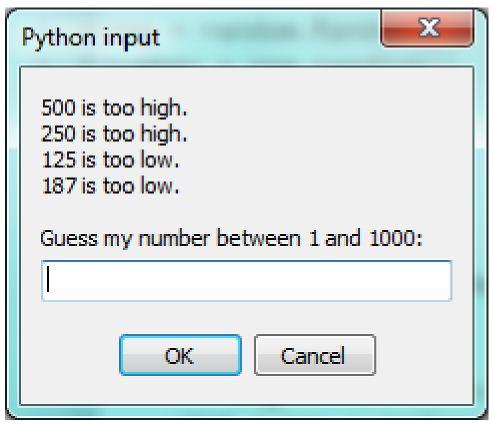
```
import random                   # We cover random numbers in the
rng = random.Random()           #  modules chapter, so peek ahead.
number = rng.randrange(1, 1000) # Get random number between [1 and 1000).

guesses = 0
msg = ""

while True:
    guess = int(input(msg + "\nGuess my number between 1 and 1000: "))
    guesses += 1
    if guess > number:
        msg += str(guess) + " is too high.\n"
    elif guess < number:
        msg += str(guess) + " is too low.\n"
```

```
15     else:
16         break
17
18 input("\n\nGreat, you got it in {0} guesses!\n\n".format(guesses))
```

This program makes use of the mathematical law of **trichotomy** (given real numbers `a` and `b`, exactly one of these three must be true: `a > b`, `a < b`, or `a == b`).

At line 18 there is a call to the `input` function, but we don't do anything with the result, not even assign it to a variable. This is legal in Python. Here it has the effect of popping up the input dialog window and waiting for the user to respond before the program terminates. Programmers often use the trick of doing some extra input at the end of a script, just to keep the window open.

Also notice the use of the `msg` variable, initially an empty string, on lines 6, 12 and 14. Each time through the loop we extend the message being displayed: this allows us to display the program's feedback right at the same place as we're asking for the next guess.



_images/python_input.png

7.18. The continue statement

This is a control flow statement that causes the program to immediately skip the processing of the rest of the body of the loop, for the current iteration. But the loop still carries on running for its remaining iterations:

```
for i in [12, 16, 17, 24, 29, 30]:
    if i % 2 == 1:      # If the number is odd
       continue         # Don't process it
    print(i)
print("done")
```

This prints:

```
12
16
24
30
done
```

7.19. More generalization

As another example of generalization, imagine you wanted a program that would print a multiplication table of any size, not just the six-by-six table. You could add a parameter to `print_mult_table`:

```python
def print_mult_table(high):
    for i in range(1, high+1):
        print_multiples(i)
```

We replaced the value 7 with the expression high+1. If we call `print_mult_table` with the argument 7, it displays:

```
1       2       3       4       5       6
2       4       6       8       10      12
3       6       9       12      15      18
4       8       12      16      20      24
5       10      15      20      25      30
6       12      18      24      30      36
7       14      21      28      35      42
```

This is fine, except that we probably want the table to be square — with the same number of rows and columns. To do that, we add another parameter to `print_multiples` to specify how many columns the table should have.

Just to be annoying, we call this parameter high, demonstrating that different functions can have parameters with the same name (just like local variables). Here's the whole program:

```
def print_multiples(n, high):
    for i in range(1, high+1):
        print(n * i, end="   ")
    print()

def print_mult_table(high):
    for i in range(1, high+1):
        print_multiples(i, high)
```

Notice that when we added a new parameter, we had to change the first line of the function (the function heading), and we also had to change the place where the function is called in `print_mult_table`.

Now, when we call `print_mult_table(7)`:

```
1       2       3       4       5       6       7
2       4       6       8       10      12      14
3       6       9       12      15      18      21
4       8       12      16      20      24      28
5       10      15      20      25      30      35
6       12      18      24      30      36      42
7       14      21      28      35      42      49
```

When you generalize a function appropriately, you often get a program with capabilities you didn't plan. For example, you might notice that, because `ab = ba`, all the entries in the table appear twice. You could save ink by printing only half the table. To do that, you only have to change one line of `print_mult_table`. Change

```
print_multiples(i, high+1)
```

to

```
print_multiples(i, i+1)
```

and you get:

```
1
2       4
3       6       9
4       8       12      16
5       10      15      20      25
6       12      18      24      30      36
7       14      21      28      35      42      49
```

7.20. Functions

A few times now, we have mentioned all the things functions are good for. By now, you might be wondering what exactly those things are. Here are some of them:

1. Capturing your mental chunking. Breaking your complex tasks into sub-tasks, and giving the sub-tasks a meaningful name is a powerful mental technique. Look back at the example that illustrated the post-test loop: we assumed that we had a function called `play_the_game_once`. This chunking allowed us to put aside the details of the particular game — is it a card game, or noughts and crosses, or a role playing game — and simply focus on one isolated part of our program logic — letting the player choose whether they want to play again.
2. Dividing a long program into functions allows you to separate parts of the program, debug them in isolation, and then compose them into a whole.
3. Functions facilitate the use of iteration.
4. Well-designed functions are often useful for many programs. Once you write and debug one, you can reuse it.

7.21. Paired Data

We've already seen lists of names and lists of numbers in Python. We're going to peek ahead in the textbook a little, and show a more advanced way of representing our data. Making a pair of things in Python is as simple as putting them into parentheses, like this:

```
year_born = ("Paris Hilton", 1981)
```

We can put many pairs into a list of pairs:

```
celebs = [("Brad Pitt", 1963), ("Jack Nicholson", 1937),
                                ("Justin Bieber", 1994)]
```

Here is a quick sample of things we can do with structured data like this. First, print all the celebs:

```
print(celebs)
print(len(celebs))
[("Brad Pitt", 1963), ("Jack Nicholson", 1937), ("Justin Bieber", 1994)]
3
```

Notice that the celebs list has just 3 elements, each of them pairs.

Now we print the names of those celebrities born before 1980:

```
for (nm, yr) in celebs:
   if yr < 1980:
        print(nm)
```

```
Brad Pitt
Jack Nicholson
```

This demonstrates something we have not seen yet in the `for` loop: instead of using a single loop control variable, we've used a pair of variable names, `(nm, yr)`, instead. The loop is executed three times — once for each pair in the list, and on each iteration both the variables are assigned values from the pair of data that is being handled.

7.22. Nested Loops for Nested Data

Now we'll come up with an even more adventurous list of structured data. In this case, we have a list of students. Each student has a name which is paired up with another list of subjects that they are enrolled for:

```
students = [
    ("John", ["CompSci", "Physics"]),
    ("Vusi", ["Maths", "CompSci", "Stats"]),
    ("Jess", ["CompSci", "Accounting", "Economics", "Management"]),
    ("Sarah", ["InfSys", "Accounting", "Economics", "CommLaw"]),
    ("Zuki", ["Sociology", "Economics", "Law", "Stats", "Music"])]
```

Here we've assigned a list of five elements to the variable `students`. Let's print out each student name, and the number of subjects they are enrolled for:

```python
# Print all students with a count of their courses.
for (name, subjects) in students:
    print(name, "takes", len(subjects), "courses")
```

Python agreeably responds with the following output:

```
John takes 2 courses
Vusi takes 3 courses
Jess takes 4 courses
Sarah takes 4 courses
Zuki takes 5 courses
```

Now we'd like to ask how many students are taking CompSci. This needs a counter, and for each student we need a second loop that tests each of the subjects in turn:

```python
# Count how many students are taking CompSci
counter = 0
for (name, subjects) in students:
    for s in subjects:                 # A nested loop!
        if s == "CompSci":
           counter += 1

print("The number of students taking CompSci is", counter)
```

```
The number of students taking CompSci is 3
```

You should set up a list of your own data that interests you — perhaps a list of your CDs, each containing a list of song titles on the CD, or a list of movie titles, each with a list of movie stars who acted in the movie. You could then ask questions like "Which movies starred Angelina Jolie?"

7.23. Newton's method for finding square roots

Loops are often used in programs that compute numerical results by starting with an approximate answer and iteratively improving it.

For example, before we had calculators or computers, people needed to calculate square roots manually. Newton used a particularly good method (there is some evidence that this method was known many years before). Suppose that you want to know the square root of `n`. If you start with almost any approximation, you can compute a better approximation (closer to the actual answer) with the following formula:

```
better = (approx + n/approx)/2
```

Repeat this calculation a few times using your calculator. Can you see why each iteration brings your estimate a little closer? One of the amazing properties of this particular algorithm is how quickly it converges to an accurate answer — a great advantage for doing it manually.

By using a loop and repeating this formula until the better approximation gets close enough to the previous one, we can write a function for computing the square root. (In fact, this is how your calculator finds square roots — it may have a slightly different formula and method, but it is also based on repeatedly improving its guesses.)

This is an example of an indefinite iteration problem: we cannot predict in advance how many times we'll want to improve our guess — we just want to keep getting closer and closer. Our stopping condition for the loop will be when our old guess and our improved guess are "close enough" to each other.

Ideally, we'd like the old and new guess to be exactly equal to each other when we stop. But exact equality is a tricky notion in computer arithmetic when real numbers are involved. Because real numbers are not represented absolutely accurately (after all, a number like `pi` or the square root of two has an infinite number of decimal places because it is irrational), we need to formulate the stopping test for the loop by asking "is `a` close enough to `b`"? This stopping condition can be coded like this:

```
if abs(a-b) < 0.001:  # Make this smaller for better accuracy
      break
```

Notice that we take the absolute value of the difference between `a` and `b`!

This problem is also a good example of when a middle-exit loop is appropriate:

```
def sqrt(n):
    approx = n/2.0     # Start with some or other guess at the answer
    while True:
        better = (approx + n/approx)/2.0
        if abs(approx - better) < 0.001:
            return better
        approx = better

# Test cases
print(sqrt(25.0))
print(sqrt(49.0))
print(sqrt(81.0))
```

The output is:

```
5.00000000002
7.0
9.0
```

See if you can improve the approximations by changing the stopping condition. Also, step through the algorithm (perhaps by hand, using your calculator) to see how many iterations were needed before it achieved this level of accuracy for sqrt(25).

7.24. Algorithms

Newton's method is an example of an algorithm: it is a mechanical process for solving a category of problems (in this case, computing square roots).

Some kinds of knowledge are not algorithmic. For example, learning dates from history or your multiplication tables involves memorization of specific solutions.

But the techniques you learned for addition with carrying, subtraction with borrowing, and long division are all algorithms. Or if you are an avid Sudoku puzzle solver, you might have some specific set of steps that you always follow.

One of the characteristics of algorithms is that they do not require any intelligence to carry out. They are mechanical processes in which each step follows from the last according to a simple set of rules. And they're designed to solve a general class or category of problems, not just a single problem.

Understanding that hard problems can be solved by step-by-step algorithmic processes (and having technology to execute these algorithms for us) is one of the major breakthroughs that has had enormous benefits. So while the execution of the algorithm may be boring and may require no intelligence, algorithmic or computational thinking — i.e. using algorithms and automation as the basis for approaching problems — is rapidly transforming our society. Some claim that this shift towards algorithmic thinking and processes is going to have even more impact on our society than the invention of the printing press. And the process of designing algorithms is interesting, intellectually challenging, and a central part of what we call programming.

Some of the things that people do naturally, without difficulty or conscious thought, are the hardest to express algorithmically. Understanding natural language is a good example. We all do it, but so far no one has been able to explain how we do it, at least not in the form of a step-by-step mechanical algorithm.

7.25. Glossary

algorithm

A step-by-step process for solving a category of problems.

body

The statements inside a loop.

breakpoint

A place in your program code where program execution will pause (or break), allowing you to inspect the state of the program's variables, or single-step through individual statements, executing them one at a time.

bump

Programmer slang. Synonym for increment.

continue statement

A statement that causes the remainder of the current iteration of a loop to be skipped. The flow of execution goes back to the top of the loop, evaluates the condition, and if this is true the next iteration of the loop will begin.

counter

A variable used to count something, usually initialized to zero and incremented in the body of a loop.

cursor

An invisible marker that keeps track of where the next character will be printed.

decrement

Decrease by `1`.

definite iteration

A loop where we have an upper bound on the number of times the body will be executed. Definite iteration is usually best coded as a `for` loop.

development plan

A process for developing a program. In this chapter, we demonstrated a style of development based on developing code to do simple, specific things and then encapsulating and generalizing.

encapsulate

To divide a large complex program into components (like functions) and isolate the components from each other (by using local variables, for example).

escape sequence

An escape character,\, followed by one or more printable characters used to designate a non printable character.

generalize

To replace something unnecessarily specific (like a constant value) with something appropriately general (like a variable or parameter). Generalization makes code more versatile, more likely to be reused, and sometimes even easier to write.

increment

Both as a noun and as a verb, increment means to increase by `1`.

infinite loop

A loop in which the terminating condition is never satisfied.

indefinite iteration

A loop where we just need to keep going until some condition is met. A `while` statement is used for this case.

initialization (of a variable)

To initialize a variable is to give it an initial value. Since in Python, variables don't exist until they are assigned values, they are initialized when they are created. In other programming languages this is not the case, and variables can be created without being initialized, in which case they have either default or garbage values.

iteration

Repeated execution of a set of programming statements.

loop

The construct that allows allows us to repeatedly execute a statement or a group of statements until a terminating condition is satisfied.

loop variable

A variable used as part of the terminating condition of a loop.

meta-notation

Extra symbols or notation that helps describe other notation. Here we introduced square brackets, ellipses, italics, and bold as meta-notation to help describe optional, repeatable, substitutable and fixed parts of the Python syntax.

middle-test loop

A loop that executes some of the body, then tests for the exit condition, and then may execute some more of the body. We don't have a special Python construct for this case, but can use `while` and `break` together.

nested loop

A loop inside the body of another loop.

newline

A special character that causes the cursor to move to the beginning of the next line.

post-test loop

A loop that executes the body, then tests for the exit condition. We don't have a special Python construct for this, but can use `while` and `break` together.

pre-test loop

A loop that tests before deciding whether the execute its body. `for` and `while` are both pre-test loops.

single-step

A mode of interpreter execution where you are able to execute your program one step at a time, and inspect the consequences of that step. Useful for debugging and building your internal mental model of what is going on.

tab

A special character that causes the cursor to move to the next tab stop on the current line.

trichotomy

Given any real numbers `a` and `b`, exactly one of the following relations holds: `a < b`, `a > b`, or `a == b`. Thus when you can establish that two of the relations are false, you can assume the remaining one is true.

trace

To follow the flow of execution of a program by hand, recording the change of state of the variables and any output produced.

7.26. Exercises

This chapter showed us how to sum a list of items, and how to count items. The counting example also had an `if` statement that let us only count some selected items. In the previous chapter we also showed a function `find_first_2_letter_word` that allowed us an "early exit" from inside a loop by using `return` when some condition occurred. We now also have `break` to exit a loop but not the enclosing function, and `continue` to abandon the current iteration of the loop without ending the loop.

Composition of list traversal, summing, counting, testing conditions and early exit is a rich collection of building blocks that can be combined in powerful ways to create many functions that are all slightly different.

The first six questions are typical functions you should be able to write using only these building blocks.

1. Write a function to count how many odd numbers are in a list.
2. Sum up all the even numbers in a list.
3. Sum up all the negative numbers in a list.
4. Count how many words in a list have length 5.
5. Sum all the elements in a list up to but not including the first even number. (Write your unit tests. What if there is no even number?)

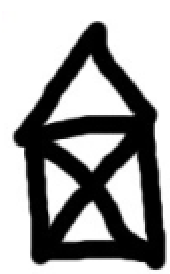
6. Count how many words occur in a list up to and including the first occurrence of the word “sam”. (Write your unit tests for this case too. What if “sam” does not occur?)
7. Add a print function to Newton’s sqrt function that prints out better each time it is calculated. Call your modified function with 25 as an argument and record the results.
8. Trace the execution of the last version of print_mult_table and figure out how it works.
9. Write a function print_triangular_numbers(n) that prints out the first n triangular numbers. A call to print_triangular_numbers(5) would produce the following output:

```
1       1
2       3
3       6
4       10
5       15
```

   (hint: use a web search to find out what a triangular number is.)
10. Write a function, is_prime, which takes a single integer argument and returns True when the argument is a prime number and False otherwise. Add tests for cases like this:

```
test(is_prime(11))
test(not is_prime(35))
test(is_prime(19911121))
```

   The last case could represent your birth date. Were you born on a prime day? In a class of 100 students, how many do you think would have prime birth dates?
11. Revisit the drunk pirate problem from the exercises in chapter 3. This time, the drunk pirate makes a turn, and then takes some steps forward, and repeats this. Our social science student now records pairs of data: the angle of each turn, and the number of steps taken after the turn. Her experimental data is [(160, 20), (-43, 10), (270, 8), (-43, 12)]. Use a turtle to draw the path taken by our drunk friend.
12. Many interesting shapes can be drawn by the turtle by giving a list of pairs like we did above, where the first item of the pair is the angle to turn, and the second item is the distance to move forward. Set up a list of pairs so that the turtle draws a house with a cross through the centre, as show here. This should be done without going over any of the lines / edges more than once, and without lifting your pen.



_images/tess_house.png

13. Not all shapes like the one above can be drawn without lifting your pen, or going over an edge more than once. Which of these can be drawn?

_images/tess_more_houses.png

Now read Wikipedia's article(http://en.wikipedia.org/wiki/Eulerian_path) about Eulerian paths. Learn how to tell immediately by inspection whether it is possible to find a solution or not. If the path is possible, you'll also know where to put your pen to start drawing, and where you should end up!

14. What will num_digits(0) return? Modify it to return 1 for this case. Why does a call to num_-digits(-24) result in an infinite loop? (hint: -1//10 evaluates to -1) Modify num_digits so that it works correctly with any integer value. Add these tests:

```
test(num_digits(0) == 1)
test(num_digits(-12345) == 5)
```

15. Write a function num_even_digits(n) that counts the number of even digits in n. These tests should pass:

```
test(num_even_digits(123456) == 3)
test(num_even_digits(2468) == 4)
test(num_even_digits(1357) == 0)
test(num_even_digits(0) == 1)
```

16. Write a function sum_of_squares(xs) that computes the sum of the squares of the numbers in the list xs. For example, sum_of_squares([2, 3, 4]) should return 4+9+16 which is 29:

```
test(sum_of_squares([2, 3, 4]) == 29)
test(sum_of_squares([ ]) == 0)
test(sum_of_squares([2, -3, 4]) == 29)
```

17. You and your friend are in a team to write a two-player game, human against computer, such as Tic-Tac-Toe / Noughts and Crosses. Your friend will write the logic to play one round of the game, while you will write the logic to allow many rounds of play, keep score, decide who plays, first, etc. The two of you negotiate on how the two parts of the program will fit together, and you come up with this simple scaffolding (which your friend will improve later):

```
# Your friend will complete this function
def play_once(human_plays_first):
    """
    Must play one round of the game. If the parameter
    is True, the human gets to play first, else the
    computer gets to play first.  When the round ends,
    the return value of the function is one of
    -1 (human wins),  0 (game drawn),   1 (computer wins).
    """
    # This is all dummy scaffolding code right at the moment...
    import random                  # See Modules chapter ...
    rng = random.Random()
    # Pick a random result between -1 and 1.
    result = rng.randrange(-1,2)
    print("Human plays first={0},  winner={1} "
                    .format(human_plays_first, result))
    return result
```

a. Write the main program which repeatedly calls this function to play the game, and after each round it announces the outcome as “I win!”, “You win!”, or “Game drawn!”. It then asks the player “Do you want to play again?” and either plays again, or says “Goodbye”, and terminates.
b. Keep score of how many wins each player has had, and how many draws there have been. After each round of play, also announce the scores.
c. Add logic so that the players take turns to play first.
d. Compute the percentage of wins for the human, out of all games played. Also announce this at the end of each round.
e. Draw a flowchart of your logic.

Chapter 8: Strings

8.1. A compound data type

So far we have seen built-in types like `int`, `float`, `bool`, `str` and we've seen lists and pairs. Strings, lists, and pairs are qualitatively different from the others because they are made up of smaller pieces. In the case of strings, they're made up of smaller strings each containing one **character**

Types that comprise smaller pieces are called **compound data types**. Depending on what we are doing, we may want to treat a compound data type as a single thing, or we may want to access its parts. This ambiguity is useful.

8.2. Working with strings as single things

We previously saw that each turtle instance has its own attributes and a number of methods that can be applied to the instance. For example, we could set the turtle's color, and we wrote `tess.turn(90)`.

Just like a turtle, a string is also an object. So each string instance has its own attributes and methods.

For example:

```
>>> ss = "Hello, World!"
>>> tt = ss.upper()
>>> tt
'HELLO, WORLD!'
```

`upper` is a method that can be invoked on any string object to create a new string, in which all the characters are in uppercase. (The original string `ss` remains unchanged.)

There are also methods such as `lower`, `capitalize`, and `swapcase` that do other interesting stuff.

To learn what methods are available, you can consult the Help documentation, look for string methods, and read the documentation. Or, if you're a bit lazier, simply type the following into a PyScripter script:

When you type the period to select one of the methods of `ss`, PyScripter will pop up a selection window showing all the methods (there are around 70 of them — thank goodness we'll only use a few of those!) that could be used on your string.

When you type the name of the method, some further help about its parameter and return type, and its docstring, will be displayed. This is a good example of a tool — PyScripter — using the meta-information — the docstrings — provided by the module programmers.

8.3. Working with the parts of a string

The **indexing operator** (Python uses square brackets to enclose the index) selects a single character substring from a string:

```
>>> fruit = "banana"
>>> m = fruit[1]
>>> print(m)
```

The expression `fruit[1]` selects character number 1 from `fruit`, and creates a new string containing just this one character. The variable `m` refers to the result. When we display `m`, we could get a surprise:

```
a
```

Computer scientists always start counting from zero! The letter at subscript position zero of `"banana"` is `b`. So at position `[1]` we have the letter `a`.

If we want to access the zero-eth letter of a string, we just place `0`, or any expression that evaluates to `0`, inbetween the brackets:

```
>>> m = fruit[0]
>>> print(m)
b
```

The expression in brackets is called an **index**. An index specifies a member of an ordered collection, in this case the collection of characters in the string. The index *indicates* which one you want, hence the name. It can be any integer expression.

We can use `enumerate` to visualize the indices:

```
>>> fruit = "banana"
>>> list(enumerate(fruit))
[(0, 'b'), (1, 'a'), (2, 'n'), (3, 'a'), (4, 'n'), (5, 'a')]
```

Do not worry about `enumerate` at this point, we will see more of it in the chapter on lists.

Note that indexing returns a *string* — Python has no special type for a single character. It is just a string of length 1.

We've also seen lists previously. The same indexing notation works to extract elements from a list:

```
>>> prime_nums = [2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31]
>>> prime_nums[4]
11
>>> friends = ["Joe", "Zoe", "Brad", "Angelina", "Zuki", "Thandi", "Paris"]
>>> friends[3]
'Angelina'
```

```
.. index::
    single: len function
    single: function; len
    single: runtime error
    single: negative index
    single: index; negative
```

8.4. Length

The `len` function, when applied to a string, returns the number of characters in a string:

```
>>> fruit = "banana"
>>> len(fruit)
6
```

To get the last letter of a string, you might be tempted to try something like this:

That won't work. It causes the runtime error `IndexError: string index out of range`. The reason is that there is no character at index position `6` in `"banana"`. Because we start counting at zero, the six indexes are numbered `0` to `5`. To get the last character, we have to subtract `1` from the length of `fruit`:

Alternatively, we can use negative indices, which count backward from the end of the string. The expression `fruit[-1]` yields the last letter, `fruit[-2]` yields the second to last, and so on.

As you might have guessed, indexing with a negative index also works like this for lists.

We won't use negative indexes in the rest of these notes — not many computer languages use this idiom, and you'll probably be better off avoiding it. But there is plenty of Python code out on the Internet that will use this trick, so it is best to know that it exists.

```
.. index:: traversal, for loop, concatenation, abecedarian series
```

```
.. index::
    single: McCloskey, Robert
    single: Make Way for Ducklings
```

8.5. Traversal and the `for` loop

A lot of computations involve processing a string one character at a time. Often they start at the beginning, select each character in turn, do something to it, and continue until the end. This pattern of processing is called a **traversal**. One way to encode a traversal is with a `while` statement:

This loop traverses the string and displays each letter on a line by itself. The loop condition is `ix < len(fruit)`, so when `ix` is equal to the length of the string, the condition is false, and the body of the loop is not executed. The last character accessed is the one with the index `len(fruit)-1`, which is the last character in the string.

But we've previously seen how the `for` loop can easily iterate over the elements in a list and it can do so for strings as well:

Each time through the loop, the next character in the string is assigned to the variable `c`. The loop continues until no characters are left. Here we can see the expressive power the `for` loop gives us compared to the `while` loop when traversing a string.

The following example shows how to use concatenation and a `for` loop to generate an abecedarian series. Abecedarian refers to a series or list in which the elements appear in alphabetical order. For example, in Robert McCloskey's book Make Way for Ducklings, the names of the ducklings are Jack, Kack, Lack, Mack, Nack, Ouack, Pack, and Quack. This loop outputs these names in order:

The output of this program is:

```
Jack
Kack
Lack
Mack
Nack
Oack
Pack
Qack
```

Of course, that's not quite right because Ouack and Quack are misspelled. You'll fix this as an exercise below.

```
.. index:: slice, string slice, substring, sublist
```

8.6. Slices

A *substring* of a string is obtained by taking a **slice**. Similarly, we can slice a list to refer to some sublist of the items in the list:

```
>>> s = "Pirates of the Caribbean"
>>> print(s[0:7])
Pirates
>>> print(s[11:14])
the
>>> print(s[15:24])
Caribbean
>>> friends = ["Joe", "Zoe", "Brad", "Angelina", "Zuki", "Thandi", "Paris"]
>>> print(friends[2:4])
['Brad', 'Angelina']
```

The operator `[n:m]` returns the part of the string from the n'th character to the m'th character, including the first but excluding the last. This behavior makes sense if you imagine the indices pointing *between* the characters, as in the following diagram:

If you imagine this as a piece of paper, the slice operator `[n:m]` copies out the part of the paper between the `n` and `m` positions. Provided `m` and `n` are both within the bounds of the string, your result will be of length (m-n).

Three tricks are added to this: if you omit the first index (before the colon), the slice starts at the beginning of the string (or list). If you omit the second index, the slice extends to the end of the string (or list). Similarly, if you provide value for `n` that is bigger than the length of the string (or list), the slice will take all the values up to the end. (It won't give an "out of range" error like the normal indexing operation does.) Thus:

```
>>> fruit = "banana"
>>> fruit[:3]
'ban'
>>> fruit[3:]
'ana'
>>> fruit[3:999]
'ana'
```

What do you think `s[:]` means? What about `friends[4:]`?

```
.. index:: string comparison, comparison of strings
```

8.7. String comparison

The comparison operators work on strings. To see if two strings are equal:

Other comparison operations are useful for putting words in lexicographical order:

This is similar to the alphabetical order you would use with a dictionary, except that all the uppercase letters come before all the lowercase letters. As a result:

```
Your word, Zebra, comes before banana.
```

A common way to address this problem is to convert strings to a standard format, such as all lowercase, before performing the comparison. A more difficult problem is making the program realize that zebras are not fruit.

```
.. index:: mutable, immutable, runtime error
```

8.8. Strings are immutable

It is tempting to use the `[]` operator on the left side of an assignment, with the intention of changing a character in a string. For example:

Instead of producing the output `Jello, world!`, this code produces the runtime error `TypeError: 'str' object does not support item assignment`.

Strings are **immutable**, which means you can’t change an existing string. The best you can do is create a new string that is a variation on the original:

The solution here is to concatenate a new first letter onto a slice of `greeting`. This operation has no effect on the original string.

```
.. index::
    single: in operator
    single: operator; in
```

8.9. The `in` and `not in` operators

The `in` operator tests for membership. When both of the arguments to `in` are strings, `in` checks whether the left argument is a substring of the right argument.

```
>>> "p" in "apple"
True
>>> "i" in "apple"
False
>>> "ap" in "apple"
True
>>> "pa" in "apple"
False
```

Note that a string is a substring of itself, and the empty string is a substring of any other string. (Also note that computer scientists like to think about these edge cases quite carefully!)

```
>>> "a" in "a"
True
>>> "apple" in "apple"
True
>>> "" in "a"
True
>>> "" in "apple"
True
```

The `not in` operator returns the logical opposite results of `in`:

```
>>> "x" not in "apple"
True
```

Combining the `in` operator with string concatenation using `+`, we can write a function that removes all the vowels from a string:

```
.. index:: traversal, eureka traversal, short-circuit evaluation, pattern of computa\
tion,
           computation pattern
```

8.10. A `find` function

What does the following function do?

In a sense, `find` is the opposite of the indexing operator. Instead of taking an index and extracting the corresponding character, it takes a character and finds the index where that character appears. If the character is not found, the function returns `-1`.

This is another example where we see a `return` statement inside a loop. If `strng[ix] == ch`, the function returns immediately, breaking out of the loop prematurely.

If the character doesn't appear in the string, then the program exits the loop normally and returns `-1`.

This pattern of computation is sometimes called a **eureka traversal** or **short-circuit evaluation**, because as soon as we find what we are looking for, we can cry "Eureka!", take the short-circuit, and stop looking.

```
.. index:: counting pattern
```

8.11. Looping and counting

The following program counts the number of times the letter `a` appears in a string, and is another example of the counter pattern introduced in counting.

```
.. index:: optional parameter, default value, parameter; optional
```

8.12. Optional parameters

To find the locations of the second or third occurrence of a character in a string, we can modify the `find` function, adding a third parameter for the starting position in the search string:

The call `find2("banana", "a", 2)` now returns `3`, the index of the first occurrence of "a" in "banana" starting the search at index 2. What does `find2("banana", "n", 3)` return? If you said, 4, there is a good chance you understand how `find2` works.

Better still, we can combine `find` and `find2` using an **optional parameter**:

When a function has an optional parameter, the caller may provide a matching argument. If the third argument is provided to `find`, it gets assigned to `start`. But if the caller leaves the argument out, then start is given a default value indicated by the assignment `start=0` in the function definition.

So the call `find("banana", "a", 2)` to this version of `find` behaves just like `find2`, while in the call `find("banana", "a")`, `start` will be set to the **default value** of `0`.

Adding another optional parameter to `find` makes it search from a starting position, up to but not including the end position:

The optional value for `end` is interesting: we give it a default value `None` if the caller does not supply any argument. In the body of the function we test what `end` is, and if the caller did not supply any argument, we reassign `end` to be the length of the string. If the caller has supplied an argument for `end`, however, the caller's value will be used in the loop.

The semantics of `start` and `end` in this function are precisely the same as they are in the `range` function.

Here are some test cases that should pass:

```
.. index:: module, string module, dir function, dot notation, function type,
           docstring
```

8.13. The built-in `find` method

Now that we've done all this work to write a powerful `find` function, we can reveal that strings already have their own built-in `find` method. It can do everything that our code can do, and more!

The built-in `find` method is more general than our version. It can find substrings, not just single characters:

```
>>> "banana".find("nan")
2
>>> "banana".find("na", 3)
4
```

Usually we'd prefer to use the methods that Python provides rather than reinvent our own equivalents. But many of the built-in functions and methods make good teaching exercises, and the underlying techniques you learn are your building blocks to becoming a proficient programmer.

8.14. The `split` method

One of the most useful methods on strings is the `split` method: it splits a single multi-word string into a list of individual words, removing all the whitespace between them. (Whitespace means any tabs, newlines, or spaces.) This allows us to read input as a single string, and split it into words.

```
>>> ss = "Well I never did said Alice"
>>> wds = ss.split()
>>> wds
['Well', 'I', 'never', 'did', 'said', 'Alice']
```

8.15. Cleaning up your strings

We'll often work with strings that contain punctuation, or tab and newline characters, especially, as we'll see in a future chapter, when we read our text from files or from the Internet. But if we're writing a program, say, to count word frequencies or check the spelling of each word, we'd prefer to strip off these unwanted characters.

We'll show just one example of how to strip punctuation from a string. Remember that strings are immutable, so we cannot change the string with the punctuation — we need to traverse the original string and create a new string, omitting any punctuation:

Setting up that first assignment is messy and error-prone. Fortunately, the Python `string` module already does it for us. So we will make a slight improvement to this program — we'll import the `string` module and use its definition:

Composing together this function and the `split` method from the previous section makes a useful combination — we'll clean out the punctuation, and `split` will clean out the newlines and tabs while turning the string into a list of words:

The output:

```
['Pythons', 'are', 'constrictors', ... , 'it', 'snake', 'POOP']
```

There are other useful string methods, but this book isn't intended to be a reference manual. On the other hand, the *Python Library Reference* is. Along with a wealth of other documentation, it is available at the Python website[6].

```
.. index:: string formatting, operations on strings, formatting; strings, justificat\
ion, field width
```

8.16. The string format method

The easiest and most powerful way to format a string in Python 3 is to use the `format` method. To see how this works, let's start with a few examples:

Running the script produces:

```
His name is Arthur!
I am Alice and I am 10 years old.
2**10 = 1024 and 4 * 5 = 20.000000
```

The template string contains place holders, `... {0} ... {1} ... {2} ...` etc. The `format` method substitutes its arguments into the place holders. The numbers in the place holders are indexes that determine which argument gets substituted — make sure you understand line 6 above!

But there's more! Each of the replacement fields can also contain a **format specification** — it is always introduced by the `:` symbol (Line 11 above uses one.) This modifies how the substitutions are made into the template, and can control things like:

- whether the field is aligned to the left `<`, center `^`, or right `>`
- the width allocated to the field within the result string (a number like `10`)
- the type of conversion (we'll initially only force conversion to float, `f`, as we did in line 11 of the code above, or perhaps we'll ask integer numbers to be converted to hexadecimal using `x`)

[6]https://www.python.org/

- if the type conversion is a float, you can also specify how many decimal places are wanted (typically, `.2f` is useful for working with currencies to two decimal places.)

Let's do a few simple and common examples that should be enough for most needs. If you need to do anything more esoteric, use help and read all the powerful, gory details.

This script produces the output:

```
Pi to three decimal places is 3.142
123456789 123456789 123456789 123456789 123456789 123456789
|||Paris          |||    Whitney    |||         Hilton|||Born in 1981|||
The decimal value 123456 converts to hex value 1e240
```

You can have multiple placeholders indexing the same argument, or perhaps even have extra arguments that are not referenced at all:

This produces the following:

```
Dear Paris Hilton.
 Paris, I have an interesting money-making proposition for you!
 If you deposit $10 million into my bank account, I can
 double your money ...


Dear Bill Gates.
 Bill, I have an interesting money-making proposition for you!
 If you deposit $10 million into my bank account I can
 double your money ...
```

As you might expect, you'll get an index error if your placeholders refer to arguments that you do not provide:

```
>>> "hello {3}".format("Dave")
Traceback (most recent call last):
  File "<interactive input>", line 1, in <module>
IndexError: tuple index out of range
```

The following example illustrates the real utility of string formatting. First, we'll try to print a table without using string formatting:

This program prints out a table of various powers of the numbers from 1 to 10. (This assumes that the tab width is 8. You might see something even worse than this if you tab width is set to 4.) In its current form it relies on the tab character (`\t`) to align the columns of values, but this breaks down when the values in the table get larger than the tab width:

```
i       i**2    i**3    i**5    i**10   i**20
1       1       1       1       1       1
2       4       8       32      1024    1048576
3       9       27      243     59049   3486784401
4       16      64      1024    1048576         1099511627776
5       25      125     3125    9765625         95367431640625
6       36      216     7776    60466176        3656158440062976
7       49      343     16807   282475249       79792266297612001
8       64      512     32768   1073741824      1152921504606846976
9       81      729     59049   3486784401      12157665459056928801
10      100     1000    100000  10000000000     100000000000000000000
```

One possible solution would be to change the tab width, but the first column already has more space than it needs. The best solution would be to set the width of each column independently. As you may have guessed by now, string formatting provides a much nicer solution. We can also right-justify each field:

Running this version produces the following (much more satisfying) output:

```
i  i**2  i**3    i**5        i**10                   i**20
 1     1     1       1            1                       1
 2     4     8      32         1024                 1048576
 3     9    27     243        59049              3486784401
 4    16    64    1024      1048576           1099511627776
 5    25   125    3125      9765625          95367431640625
 6    36   216    7776     60466176        3656158440062976
 7    49   343   16807    282475249       79792266297612001
 8    64   512   32768   1073741824     1152921504606846976
 9    81   729   59049   3486784401    12157665459056928801
10   100  1000  100000  10000000000   100000000000000000000
```

8.17. Summary

This chapter introduced a lot of new ideas. The following summary may prove helpful in remembering what you learned.

```
.. glossary::

    indexing (``[]``)
        Access a single character in a string using its position (starting from
        0).  Example: ``"This"[2]`` evaluates to ``"i"``.

    length function (``len``)
        Returns the number of characters in a string.  Example:
        ``len("happy")`` evaluates to ``5``.

    for loop traversal (``for``)
        *Traversing* a string means accessing each character in the string, one
        at a time.  For example, the following for loop:

            .. sourcecode:: python3

                for ch in "Example":
                    ...

        executes the body of the loop 7 times with different values of ``ch`` each t\
ime.

    slicing (``[:]``)
        A *slice* is a substring of a string. Example: ``'bananas and
        cream'[3:6]`` evaluates to ``ana`` (so does ``'bananas and
        cream'[1:4]``).

    string comparison (``>, <, >=, <=, ==, !=``)
        The six common comparison operators work with strings, evaluating according \
to
        `lexicographical` order.  Examples:
        ``"apple" < "banana"`` evaluates to ``True``.  ``"Zeta" < "Appricot"``
        evaluates to ``False``.  ``"Zebra" <= "aardvark"`` evaluates to
        ``True`` because all upper case letters precede lower case letters.

    in and not in operator (``in``, ``not in``)
        The ``in`` operator tests for membership. In the case of
        strings, it tests whether one string is contained inside another
        string.  Examples: ``"heck" in "I'll be checking for you."``
        evaluates to ``True``.  ``"cheese" in "I'll be checking for
        you."`` evaluates to ``False``.
```

8.18. Glossary

```
.. glossary::

    compound data type
        A data type in which the values are made up of components, or elements,
        that are themselves values.

    default value
        The value given to an optional parameter if no argument for it is
        provided in the function call.

    docstring
        A string constant on the first line of a function or module definition
        (and as we will see later, in class and method definitions as well).
        Docstrings provide a convenient way to associate documentation with
        code. Docstrings are also used by programming tools to provide interactive h\
elp.

    dot notation
        Use of the **dot operator**, ``.``, to access methods and attributes of an o\
bject.

    immutable data value
        A data value which cannot be modified.  Assignments to elements or
        slices (sub-parts) of immutable values cause a runtime error.

    index
        A variable or value used to select a member of an ordered collection, such as
        a character from a string, or an element from a list.

    mutable data value
        A data value which can be modified. The types of all mutable values
        are compound types.  Lists and dictionaries are mutable; strings
        and tuples are not.

    optional parameter
        A parameter written in a function header with an assignment to a
        default value which it will receive if no corresponding argument is
        given for it in the function call.

    short-circuit evaluation
```

```
        A style of programming that shortcuts extra work as soon as the
        outcome is know with certainty. In this chapter our ``find``
        function returned as soon as it found what it was looking for; it
        didn't traverse all the rest of the items in the string.

    slice
        A part of a string (substring) specified by a range of indices. More
        generally, a subsequence of any sequence type in Python can be created
        using the slice operator (``sequence[start:stop]``).

    traverse
        To iterate through the elements of a collection, performing a similar
        operation on each.

    whitespace
        Any of the characters that move the cursor without printing visible
        characters. The constant ``string.whitespace`` contains all the
        white-space characters.
```

8.19. Exercises

We suggest you create a single file containing the test scaffolding from our previous chapters, and put all functions that require tests into that file.

1. What is the result of each of the following:

```
>>> "Python"[1]
>>> "Strings are sequences of characters."[5]
>>> len("wonderful")
>>> "Mystery"[:4]
>>> "p" in "Pineapple"
>>> "apple" in "Pineapple"
>>> "pear" not in "Pineapple"
>>> "apple" > "pineapple"
>>> "pineapple" < "Peach"
```

2. Modify:
   so that `Ouack` and `Quack` are spelled correctly.
3. Encapsulate
   in a function named `count_letters`, and generalize it so that it accepts the string and the letter as arguments. Make the function return the number of characters, rather than print the answer. The caller should do the printing.

4. Now rewrite the count_letters function so that instead of traversing the string, it repeatedly calls the find method, with the optional third parameter to locate new occurrences of the letter being counted.
5. Assign to a variable in your program a triple-quoted string that contains your favourite paragraph of text — perhaps a poem, a speech, instructions to bake a cake, some inspirational verses, etc.

   Write a function which removes all punctuation from the string, breaks the string into a list of words, and counts the number of words in your text that contain the letter “e”. Your program should print an analysis of the text like this:

```
Your text contains 243 words, of which 109 (44.8%) contain an "e".
```

6. Print a neat looking multiplication table like this:

```
        1   2   3   4   5   6   7   8   9  10  11  12
   :--------------------------------------------------
  1:      1   2   3   4   5   6   7   8   9  10  11  12
  2:      2   4   6   8  10  12  14  16  18  20  22  24
  3:      3   6   9  12  15  18  21  24  27  30  33  36
  4:      4   8  12  16  20  24  28  32  36  40  44  48
  5:      5  10  15  20  25  30  35  40  45  50  55  60
  6:      6  12  18  24  30  36  42  48  54  60  66  72
  7:      7  14  21  28  35  42  49  56  63  70  77  84
  8:      8  16  24  32  40  48  56  64  72  80  88  96
  9:      9  18  27  36  45  54  63  72  81  90  99 108
 10:     10  20  30  40  50  60  70  80  90 100 110 120
 11:     11  22  33  44  55  66  77  88  99 110 121 132
 12:     12  24  36  48  60  72  84  96 108 120 132 144
```

7. Write a function that reverses its string argument, and satisfies these tests:
8. Write a function that mirrors its argument:
9. Write a function that removes all occurrences of a given letter from a string:
10. Write a function that recognizes palindromes. (Hint: use your `reverse` function to make this easy!):
11. Write a function that counts how many times a substring occurs in a string:
12. Write a function that removes the first occurrence of a string from another string:
13. Write a function that removes all occurrences of a string from another string: