Think Like a Computer Scientist

with Python and Replit

Ritza

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Contents

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.

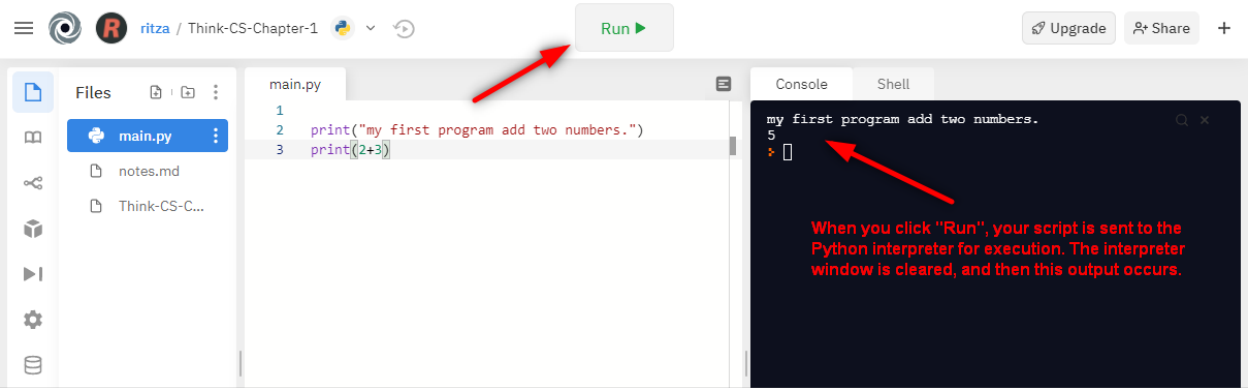
1.1. The Python programming language

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

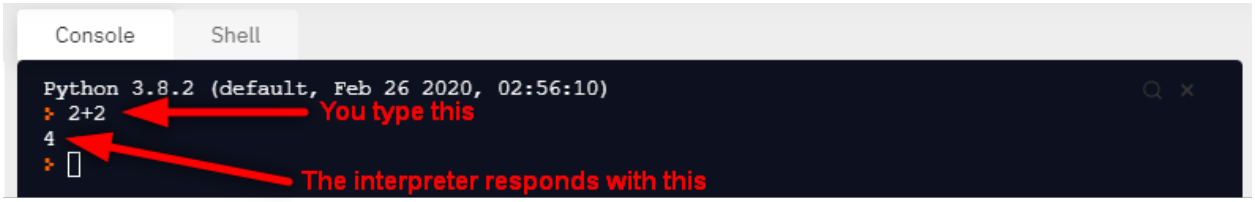
The >>> or > is called the **Python prompt**. The interpreter uses the prompt to indicate that it is ready for instructions. We typed `2 + 2`, and the interpreter evaluated our expression, and replied `4`, and on the next line it gave a new prompt, indicating that it is ready for more input.

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.)

```
1 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

```
1 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`.

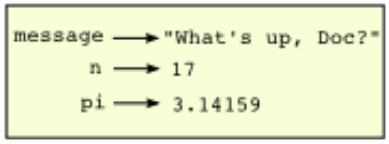
The assignment token, =, should not be confused with *equals*, which uses the token ==. The assignment statement binds a *name*, on the left-hand side of the operator, to a *value*, on the right-hand side. This is why you will get an error if you enter:

```
>>> 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.

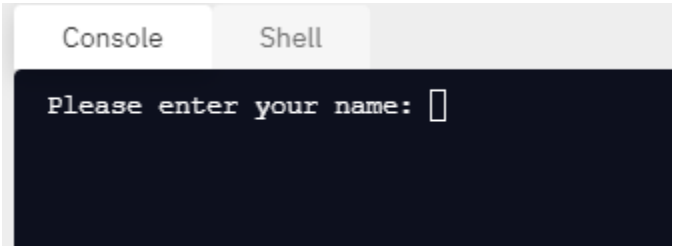
On one hand, this interpretation of + and * makes sense by analogy with addition and multiplication. Just as `4*3` is equivalent to `4+4+4`, we expect `"Fun"*3` to be the same as `"Fun"+"Fun"+"Fun"`, and it is. On the other hand, there is a significant way in which string concatenation and repetition 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.

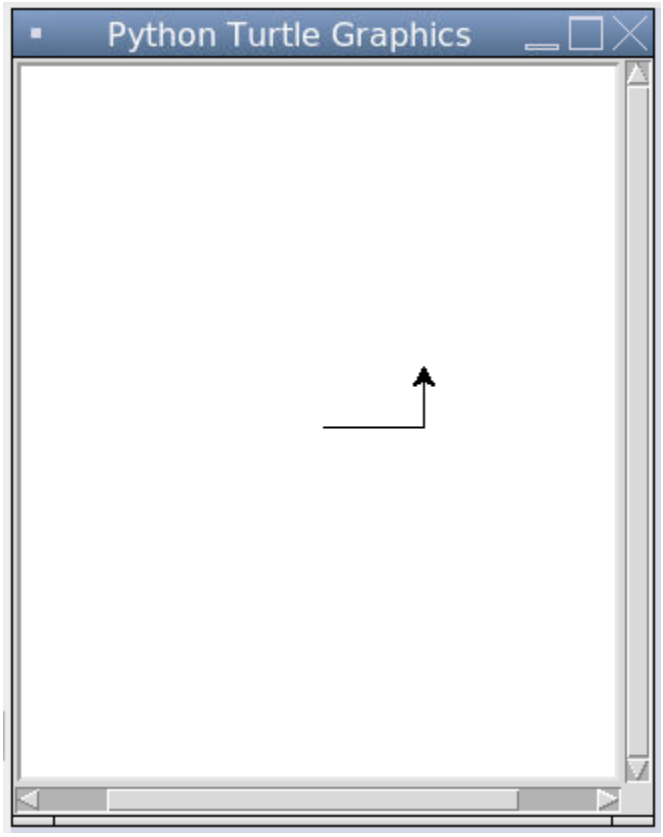
The turtles are fun, but the real purpose of the chapter is to teach ourselves a little more Python, and to develop our theme of *computational thinking*, or *thinking like a computer scientist*. Most of the Python covered here will be explored in more depth later.

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).

```
1  import turtle              # Allows us to use turtles
2  wn = turtle.Screen()       # Creates a playground for turtles
3  alex = turtle.Turtle()     # Create a turtle, assign to alex
4
5  alex.forward(50)           # Tell alex to move forward by 50 units
6  alex.left(90)              # Tell alex to turn by 90 degrees
7  alex.forward(30)           # Complete the second side of a rectangle
8
9  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

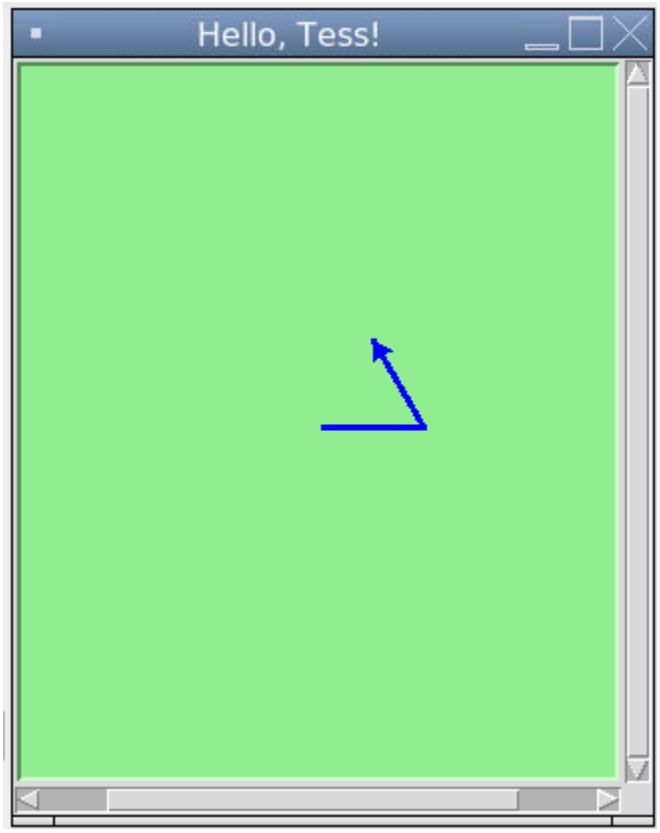
`alex.color("red")` will make `alex` red, and drawing will be red too. (Note the word *color* is spelled the American way!)

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`.

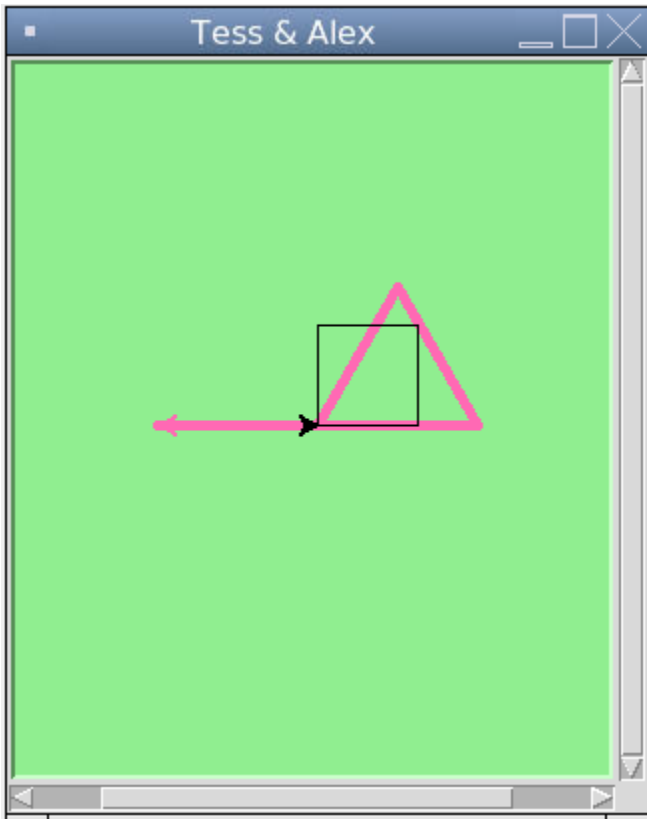
3.2. Instances — a herd of turtles

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.

```
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`.

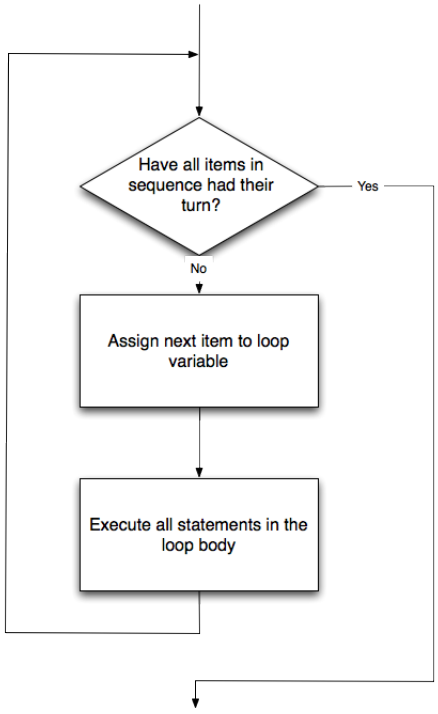
3.4. Flow of Execution of the for loop

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!)

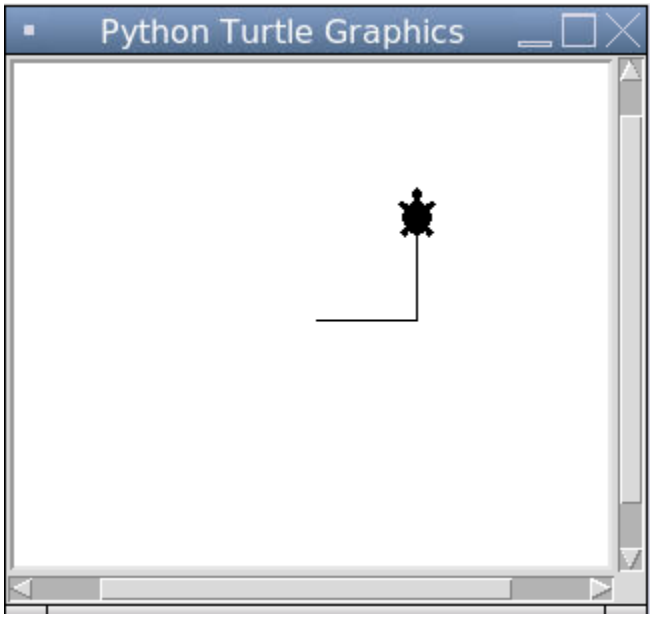
Part of thinking like a scientist is to understand more of the structure and rich relationships in our field. So revising a few basic facts about geometry and number lines, and spotting the relationships between left, right, backward, forward, negative and positive distances or angles values is a good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

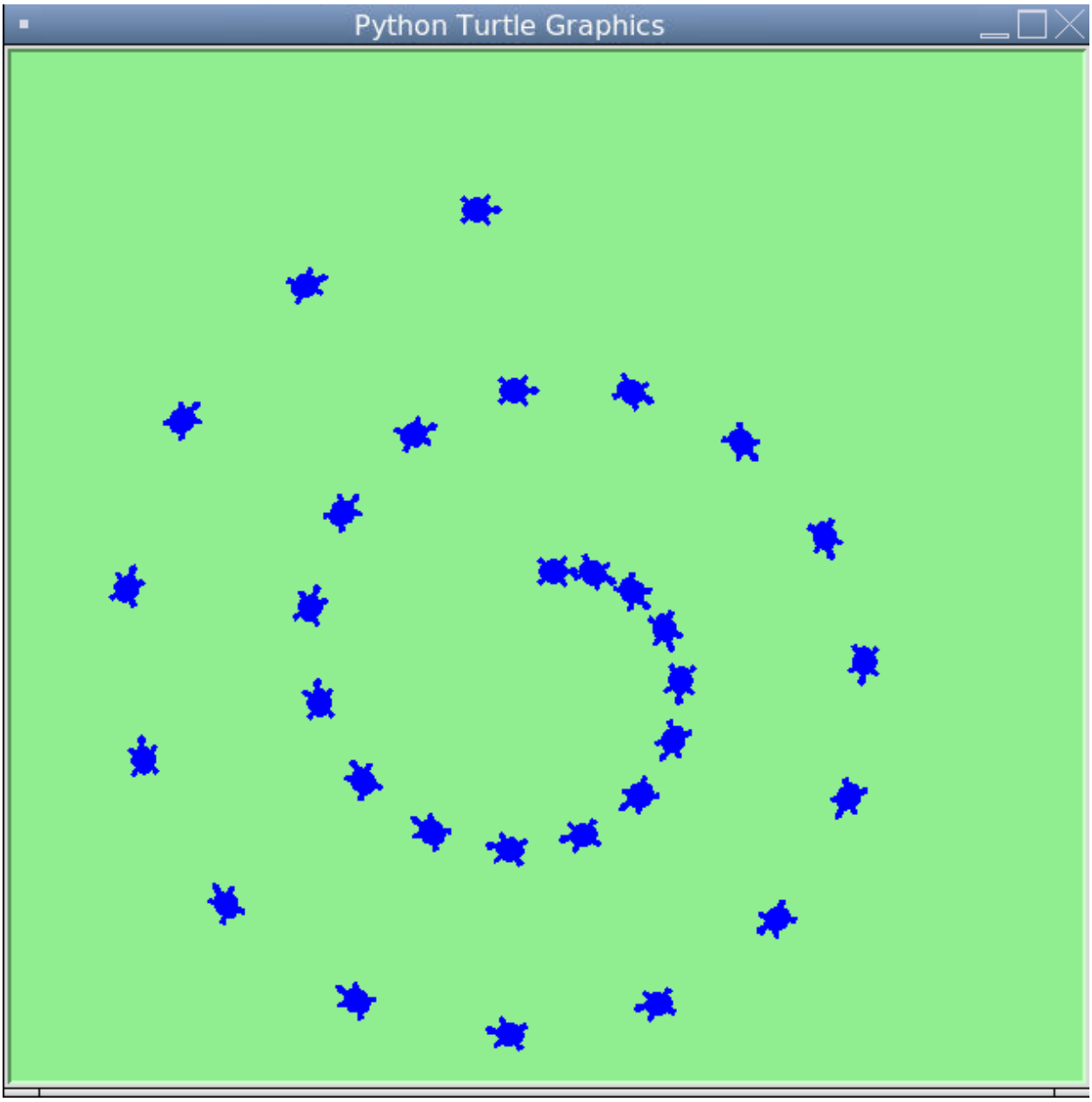
```
alex.speed(10)
```

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
```

```
13      tess.forward(size)        # Move tess along
14      tess.right(24)            #  ...  and turn her
15
16  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:

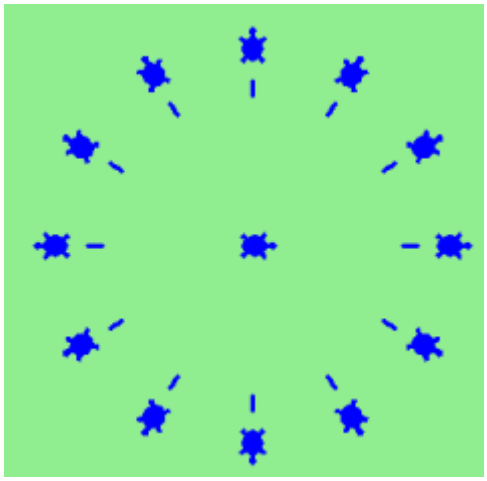
Star

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:

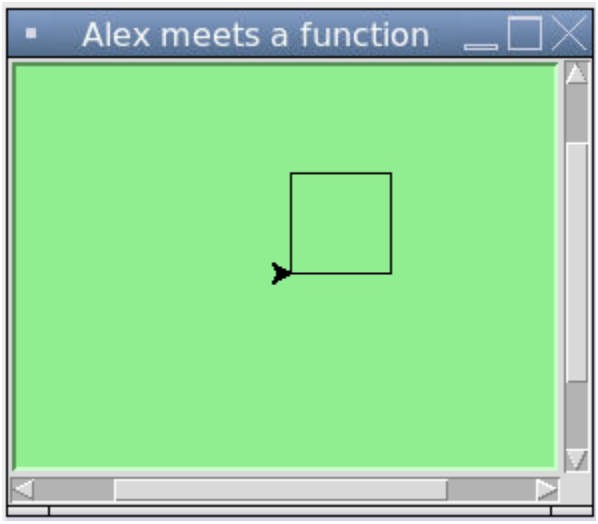
1. A header line which begins with a keyword and ends with a colon.
2. A **body** consisting of one or more Python statements, each indented the same amount — the *Python style guide recommends 4 spaces* — from the header line.

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.

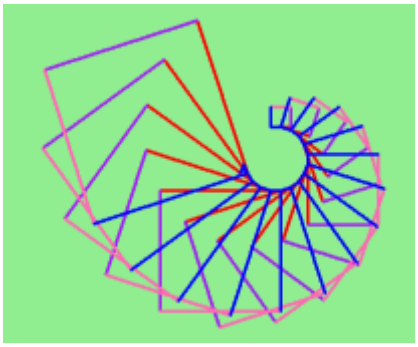
Just to differentiate from comments, a string at the start of a function (a docstring) is retrievable by Python tools at runtime. By contrast, comments are completely eliminated when the program is parsed.

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.

```
1  import turtle
2
3  def draw_multicolor_square(t, sz):
4      """Make turtle t draw a multi-color square of sz."""
5      for i in ["red", "purple", "hotpink", "blue"]:
6          t.color(i)
7          t.forward(sz)
8          t.left(90)
9
10 wn = turtle.Screen()        # Set up the window and its attributes
11 wn.bgcolor("lightgreen")
12
13 tess = turtle.Turtle()      # Create tess and set some attributes
14 tess.pensize(3)
15
16 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.

```
1 def draw_square(tx, sz):        # A new version of draw_square
2     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.

```
1  import turtle
2  __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.

[3] 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

```
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

```
1    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:

```
1  def final_amt_v2(principalAmount, nominalPercentageRate,
2                                    numTimesPerYear, years):
3      a = principalAmount * (1 + nominalPercentageRate /
4                           numTimesPerYear) ** (numTimesPerYear*years)
5      return a
6
7  def final_amt_v3(amt, rate, compounded, years):
8      a = amt * (1 + rate/compounded) ** (compounded*years)
9      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

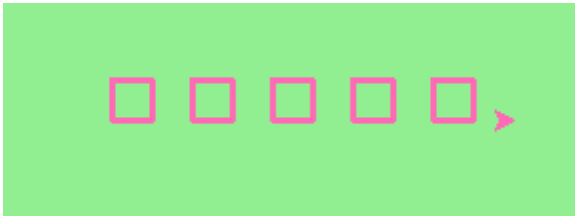
A list of the functions that are executing, printed when a runtime error occurs. A traceback is also commonly referred to as a *stack trace*, since it lists the functions in the order in which they are stored in the runtime stack.[4]

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

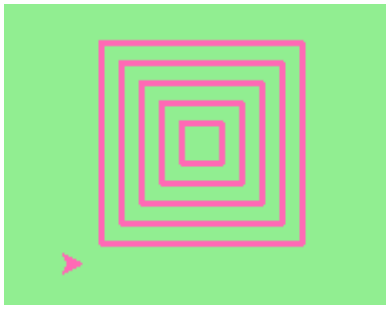
1. Write a void (non-fruitful) function to draw a square. Use it in a program to draw the image shown below. Assume each side is 20 units. (*Hint: notice that the turtle has already moved away from the ending point of the last square when the program ends.*)



Five Squares

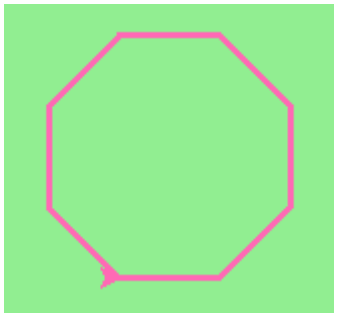
[4] http://en.wikipedia.org/wiki/Runtime_stack

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.



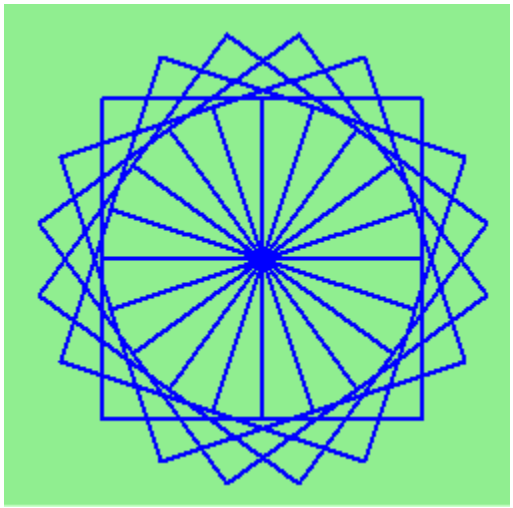
Nested Squares

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:



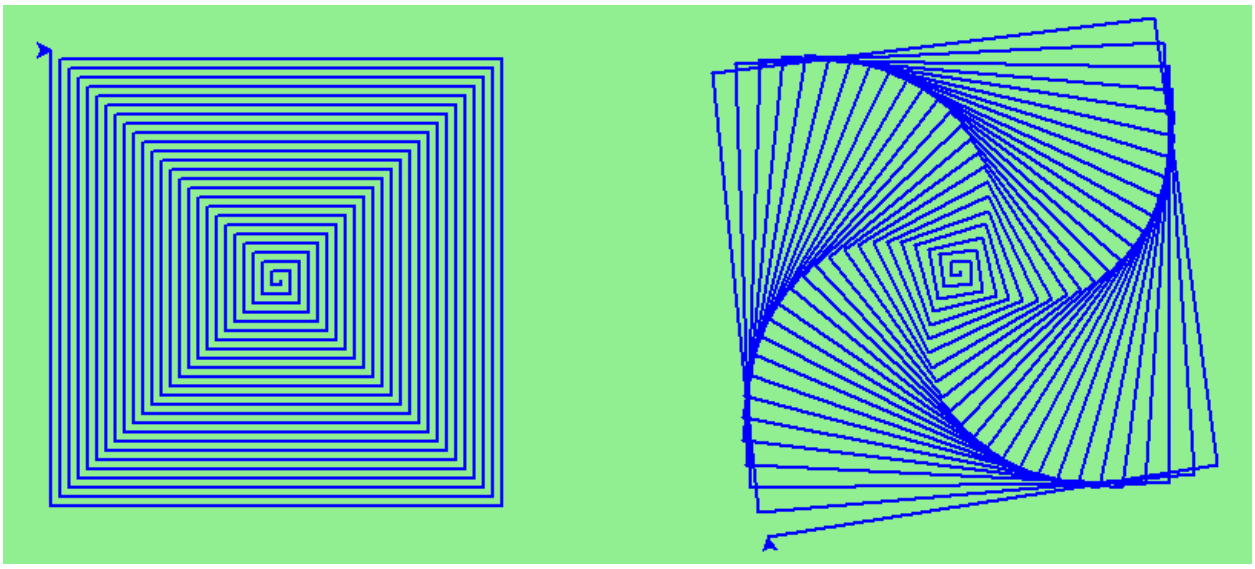
Regular Polygon

4. Draw this pretty pattern.



Pretty Pattern

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

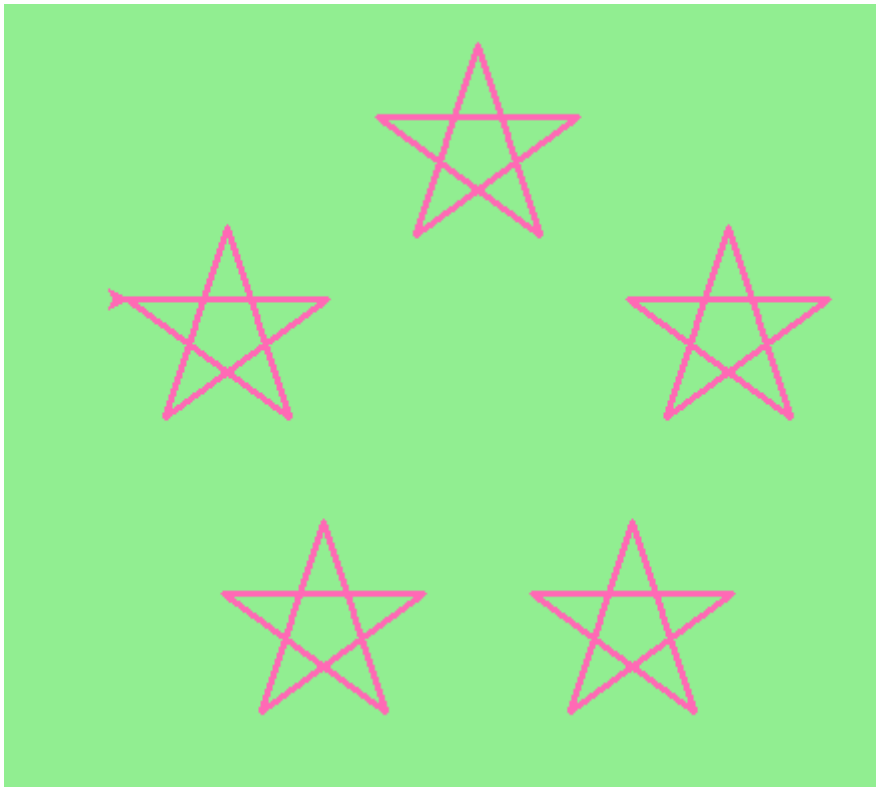


Spirals

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:

```
1  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
```

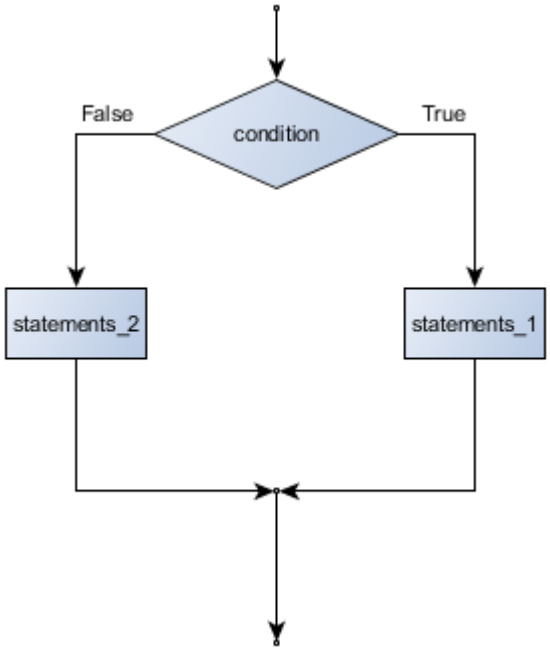
5.5. Conditional execution

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.

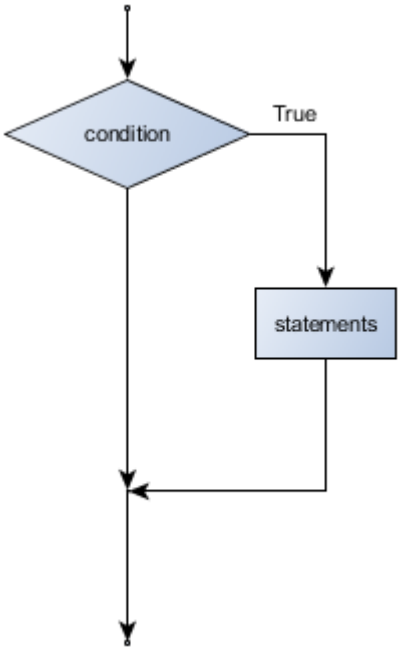
Each of the statements inside the first block of statements are executed in order if the Boolean expression evaluates to `True`. The entire first block of statements is skipped if the Boolean expression evaluates to `False`, and instead all the statements indented under the `else` clause are executed.

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`.

```
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.

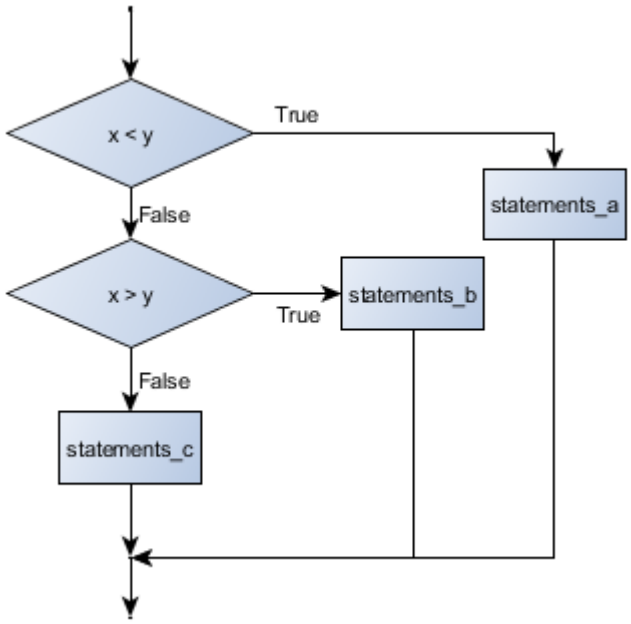
> **Python terminology**
>
> Python documentation sometimes uses the term **suite** of statements to mean what we have called a *block* here. They mean the same thing, and since most other languages and computer scientists use the word block, we'll stick with that.
>
> Notice too that `else` is not a 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**:

```
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:

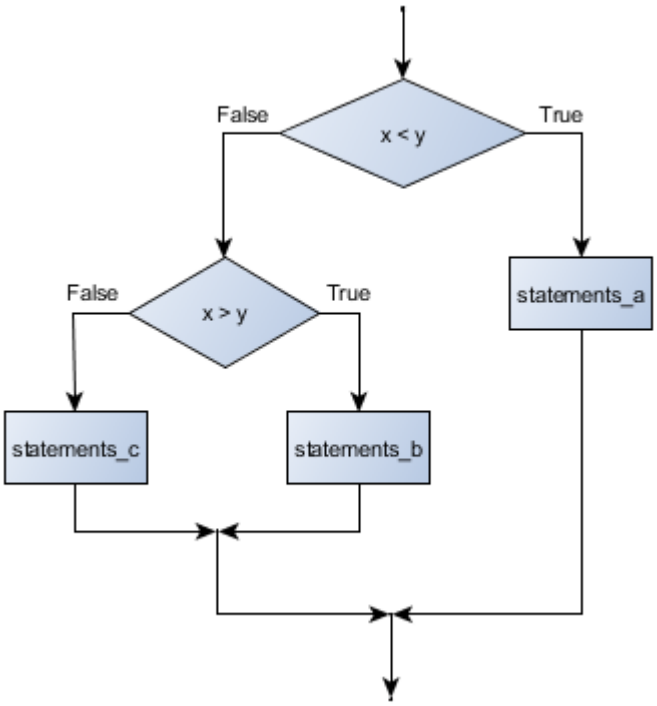
```
if choice == "a":
    function_one()
elif choice == "b":
    function_two()
elif choice == "c":
    function_three()
else:
    print("Invalid choice.")
```

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:

```
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:

```
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:

```
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:

```
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:

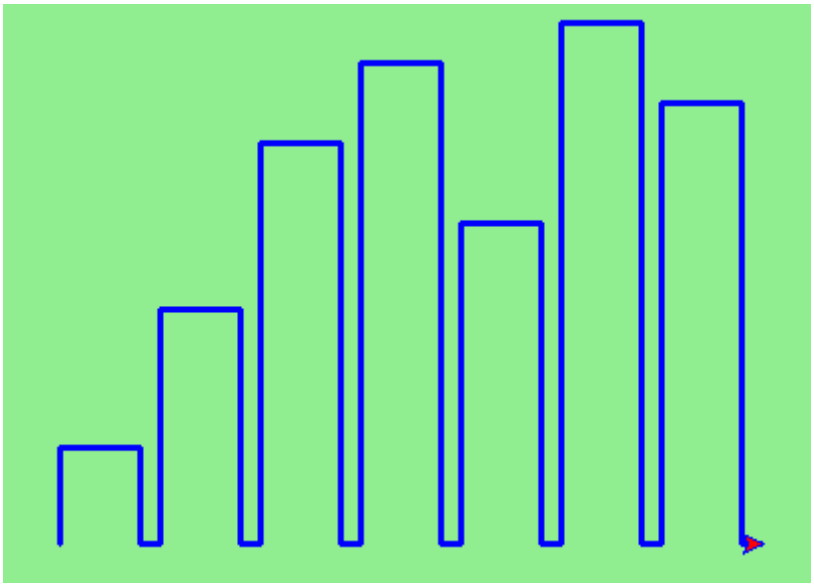
- We can get a turtle to display text on the canvas at the turtle's current position. The method to do that is `alex.write("Hello")`.
- We can fill a shape (circle, semicircle, triangle, etc.) with a color. It is a two-step process. First we call the method `alex.begin_fill()`, then we draw the shape, 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.

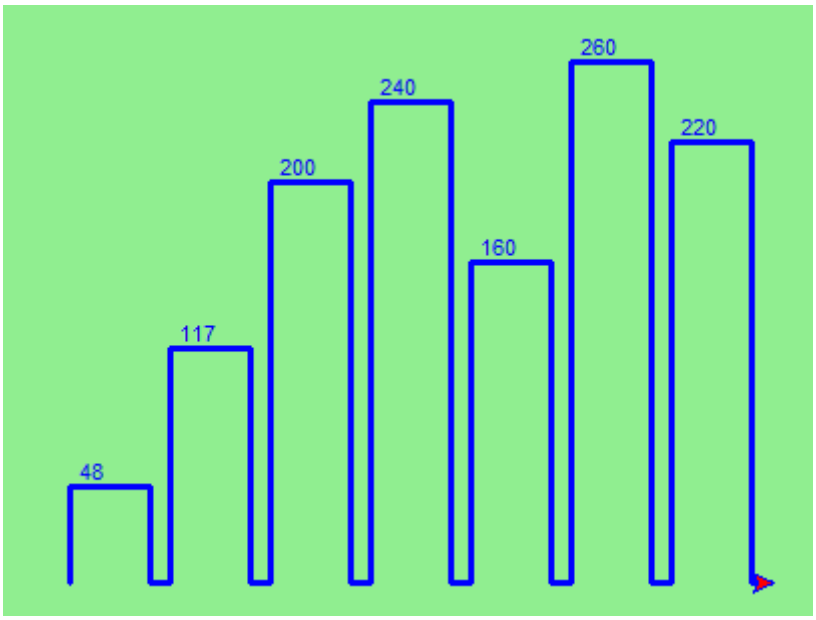
```
def draw_bar(t, height):
    """ Get turtle t to draw one bar, of height. """
    t.left(90)
    t.forward(height)     # Draw up the left side
    t.right(90)
    t.forward(40)         # Width of bar, along the top
    t.right(90)
    t.forward(height)     # And down again!
    t.left(90)            # 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:

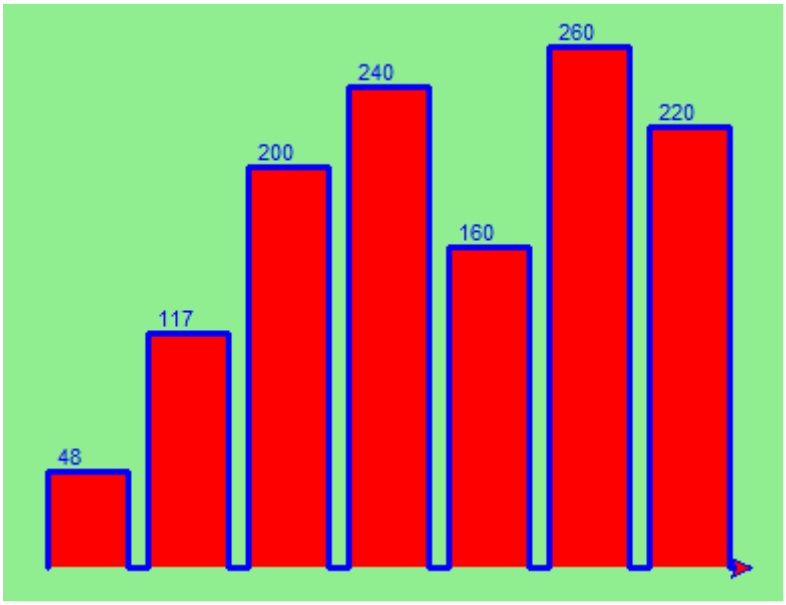


Numbered bar chart

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 Com-

puter 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)
```