Think Python

How to Think Like a Computer Scientist

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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 learn is Python. Python is an example of a **high-level language**; other high-level languages you might have heard of are C, C++, Perl, and Java.

There are also **low-level languages**, sometimes referred to as "machine languages" or "assembly languages." Loosely speaking, computers can only run programs written in low-level languages. So programs written in a high-level language have to be processed before they can run. This extra processing takes some time, which is a small disadvantage of high-level languages.

The advantages are enormous. First, it is much easier to program in a high-level language. Programs written in a high-level language 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. Low-level programs can run on only one kind of computer and have to be rewritten to run on another.

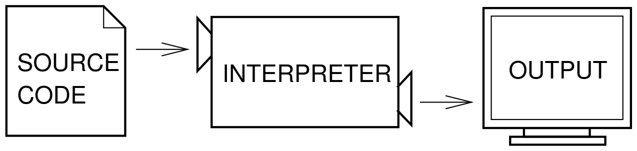

Figure 1.1: An interpreter processes the program a little at a time, alternately reading lines and performing computations.

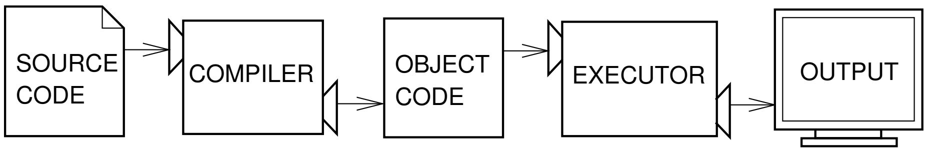

Figure 1.2: A compiler translates source code into object code, which is run by a hardware executor.

Due to these advantages, almost all programs are written in high-level languages. Low-level languages are used only for a few specialized applications.

Two kinds of programs process high-level languages into low-level languages: **interpreters** and **compilers**. An interpreter reads a high-level program and executes it, meaning that it does what the program says. It processes the program a little at a time, alternately reading lines and performing computations. Figure 1.1 shows the structure of an interpreter.

A compiler reads the program and translates it completely before the program starts running. In this context, the high-level program is called the **source code**, and the translated program is called the **object code** or the **executable**. Once a program is compiled, you can execute it repeatedly without further translation. Figure 1.2 shows the structure of a compiler.

Python is considered an interpreted language because Python programs are executed by an interpreter. There are two ways to use the interpreter: **interactive mode** and **script mode**. In interactive mode, you type Python programs and the interpreter displays the result:

```
>>> 1 + 1
2
```

The chevron, >>>, is the **prompt** the interpreter uses to indicate that it is ready. If you type `1 + 1`, the interpreter replies `2`.

Alternatively, you can store code in a file and use the interpreter to execute the contents of the file, which is called a **script**. By convention, Python scripts have names that end with `.py`.

To execute the script, you have to tell the interpreter the name of the file. If you have a script named `dinsdale.py` and you are working in a UNIX command window, you type `python dinsdale.py`. In other development environments, the details of executing scripts are different. You can find instructions for your environment at the Python website `http://python.org`.

Working in interactive mode is convenient for testing small pieces of code because you can type and execute them immediately. But for anything more than a few lines, you should save your code as a script so you can modify and execute it in the future.

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 code.

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 pretty much like these. So you can think of 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 one of these basic instructions.

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

1.3 What is debugging?

Programming is error-prone. For whimsical reasons, programming errors are called **bugs** and the process of tracking them down is called **debugging**.

Three kinds of errors can occur in a program: syntax errors, runtime errors, and semantic errors. It is useful to distinguish between them in order to track them down more quickly.

1.3.1 Syntax errors

Python can only execute a program if the syntax is correct; otherwise, the interpreter displays an error message. **Syntax** refers to the structure of a program and the rules about that structure. For example, parentheses have to come in matching pairs, so `(1 + 2)` is legal, but `8)` is a **syntax error**.

In English, readers can tolerate most syntax errors, which is why we can read the poetry of e. e. cummings without spewing error messages. 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, you will make fewer errors and find them faster.

1.3.2 Runtime errors

The second type of error is a runtime error, so called because the error does not appear until after the program has started running. 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.

1.3.3 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.

1.3.4 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 about 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 that contains thousands 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 printing 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.

1.4 Formal and natural languages

Natural languages are the languages 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 $3+ = 3\$6$ is not. H_2O is a syntactically correct chemical formula, 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, and chemical elements. One of the problems with $3+ = 3\$6$ is that \$ is not a legal token in mathematics (at least as far as I know). Similarly, ${}_2Zz$ is not legal 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 $3+ = 3$ is illegal because even though $+$ and $=$ are legal tokens, you can't have one right after the other. Similarly, in a chemical formula the subscript comes after the element name, not before.
Exercise 1.1. *Write a well-structured English sentence with invalid tokens in it. Then write another sentence with all valid tokens but with invalid structure.*

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 penny dropped," you understand that "the penny" is the subject and "dropped" is the predicate. 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 penny is and what it means to drop, 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 some 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: Natural languages are full of idiom and metaphor. If I say, "The penny dropped," there is probably no penny and nothing dropping (this idiom means that someone realized something after a period of confusion). Formal languages mean exactly what they say.

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.

Programs: 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. Small errors in spelling and punctuation, which you can get away with in natural languages, can make a big difference in a formal language.

1.5 The first program

Traditionally, the first program you write in a new language is called "Hello, World!" because all it does is display the words "Hello, World!". In Python, it looks like this:

```
print 'Hello, World!'
```

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

```
Hello, World!
```

The quotation marks in the program mark the beginning and end of the text to be displayed; they don't appear in the result.

In Python 3, the syntax for printing is slightly different:

```
print('Hello, World!')
```

The parentheses indicate that `print` is a function. We'll get to functions in Chapter 3.

For the rest of this book, I'll use the print statement. If you are using Python 3, you will have to translate. But other than that, there are very few differences we have to worry about.

1.6 Debugging

It is a good idea to read this book in front of a computer so you can try out the examples as you go. You can run most of the examples in interactive mode, but if you put the code in a script, it is easier to try out variations.

Whenever you are experimenting with a new feature, you should try to make mistakes. For example, in the "Hello, world!" program, what happens if you leave out one of the quotation marks? What if you leave out both? What if you spell `print` wrong?

This kind of experiment helps you remember what you read; it also helps with debugging, because you get to know what the error messages mean. It is better to make mistakes now and on purpose than later and accidentally.

Programming, and especially debugging, sometimes brings out strong emotions. If you are struggling with a difficult bug, you might feel angry, despondent or embarrassed.

There is evidence that people naturally respond to computers as if they were people. When they work well, we think of them as teammates, and when they are obstinate or rude, we respond to them the same way we respond to rude, obstinate people (Reeves and Nass, *The Media Equation: How People Treat Computers, Television, and New Media Like Real People and Places*).

Preparing for these reactions might help you deal with them. One approach is to think of the computer as an employee with certain strengths, like speed and precision, and particular weaknesses, like lack of empathy and inability to grasp the big picture.

Your job is to be a good manager: find ways to take advantage of the strengths and mitigate the weaknesses. And find ways to use your emotions to engage with the problem, without letting your reactions interfere with your ability to work effectively.

Learning to debug can be frustrating, but it is a valuable skill that is useful for many activities beyond programming. At the end of each chapter there is a debugging section, like this one, with my thoughts about debugging. I hope they help!

1.7 Glossary

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

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

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

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

interpret: To execute a program in a high-level language by translating it one line at a time.

compile: To translate a program written in a high-level language into a low-level language all at once, in preparation for later execution.

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

object code: The output of the compiler after it translates the program.

executable: Another name for object code that is ready to be executed.

prompt: Characters displayed by the interpreter to indicate that it is ready to take input from the user.

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

interactive mode: A way of using the Python interpreter by typing commands and expressions at the prompt.

script mode: A way of using the Python interpreter to read and execute statements in a script.

program: A set of instructions that specifies a computation.

algorithm: A general process for solving a category of problems.

bug: An error in a program.

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

syntax: The structure of a program.

syntax error: An error in a program that makes it impossible to parse (and therefore impossible to interpret).

exception: An error that is detected while the program is running.

semantics: The meaning of a program.

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

natural language: Any one of the languages that people speak that evolved naturally.

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.

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

parse: To examine a program and analyze the syntactic structure.

print statement: An instruction that causes the Python interpreter to display a value on the screen.

1.8 Exercises

Exercise 1.2. *Use a web browser to go to the Python website* `http://python.org`*. This page contains information about Python and links to Python-related pages, and it gives you the ability to search the Python documentation.*

For example, if you enter `print` *in the search window, the first link that appears is the documentation of the* `print` *statement. At this point, not all of it will make sense to you, but it is good to know where it is.*

Exercise 1.3. *Start the Python interpreter and type* `help()` *to start the online help utility. Or you can type* `help('print')` *to get information about the* `print` *statement.*

If this example doesn't work, you may need to install additional Python documentation or set an environment variable; the details depend on your operating system and version of Python.

Exercise 1.4. *Start the Python interpreter and use it as a calculator. Python's syntax for math operations is almost the same as standard mathematical notation. For example, the symbols* `+`, `-` *and* `/` *denote addition, subtraction and division, as you would expect. The symbol for multiplication is* `*`.

If you run a 10 kilometer race in 43 minutes 30 seconds, what is your average time per mile? What is your average speed in miles per hour? (Hint: there are 1.61 kilometers in a mile).

Chapter 2

Variables, expressions and statements

2.1 Values and types

A **value** is one of the basic things a program works with, like a letter or a number. The values we have seen so far are `1`, `2`, and `'Hello, World!'`.

These values belong to different **types**: `2` 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 type a value has, the interpreter can tell you.

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

Not surprisingly, strings belong to the type `str` and integers belong to the type `int`. Less obviously, numbers with a decimal point belong to a type called `float`, because these numbers are represented in a format called **floating-point**.

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

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

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

They're strings.

When you type a large integer, you might be tempted to use commas between groups of three digits, as in `1,000,000`. This is not a legal integer in Python, but it is legal:

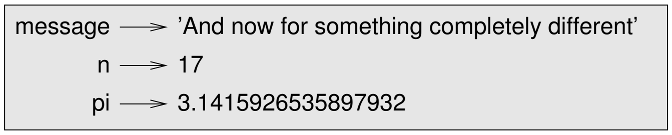

Figure 2.1: State diagram.

```
>>> 1,000,000
(1, 0, 0)
```

Well, that's not what we expected at all! Python interprets `1,000,000` as a comma-separated sequence of integers. This is the first example we have seen of a semantic error: the code runs without producing an error message, but it doesn't do the "right" thing.

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.

An **assignment statement** creates new variables and gives them values:

```
>>> message = 'And now for something completely different'
>>> n = 17
>>> pi = 3.1415926535897932
```

This example makes three assignments. The first assigns a string to a new variable named `message`; the second gives the integer `17` to `n`; the third assigns the (approximate) value of π to `pi`.

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 diagram** because it shows what state each of the variables is in (think of it as the variable's state of mind). Figure 2.1 shows the result of the previous example.

The type of a variable is the type of the value it refers to.

```
>>> type(message)
<type 'str'>
>>> type(n)
<type 'int'>
>>> type(pi)
<type 'float'>
```

2.3 Variable names and keywords

Programmers generally choose names for their variables that are meaningful—they document what the variable is used for.

Variable names can be arbitrarily long. They can contain both letters and numbers, but they have to begin with a letter. It is legal to use uppercase letters, but it is a good idea to begin variable names with a lowercase letter (you'll see why later).

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

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 = 'Advanced Theoretical Zymurgy'
SyntaxError: invalid syntax
```

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

It turns out that `class` is one of Python's **keywords**. The interpreter uses keywords to recognize the structure of the program, and they cannot be used as variable names.

Python 2 has 31 keywords:

```
and       del       from      not       while
as        elif      global    or        with
assert    else      if        pass      yield
break     except    import    print
class     exec      in        raise
continue  finally   is        return
def       for       lambda    try
```

In Python 3, `exec` is no longer a keyword, but `nonlocal` is.

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.

2.4 Operators and operands

Operators are special symbols that represent computations like addition and multiplication. The values the operator is applied to are called **operands**.

The operators `+`, `-`, `*`, `/` and `**` perform addition, subtraction, multiplication, division and exponentiation, as in the following examples:

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

In some other languages, `^` is used for exponentiation, but in Python it is a bitwise operator called XOR. I won't cover bitwise operators in this book, but you can read about them at `http://wiki.python.org/moin/BitwiseOperators`.

In Python 2, the division operator might not do what you expect:

```
>>> minute = 59
>>> minute/60
0
```

The value of `minute` is 59, and in conventional arithmetic 59 divided by 60 is 0.98333, not 0. The reason for the discrepancy is that Python is performing **floor division**. When both of the operands are integers, the result is also an integer; floor division chops off the fraction part, so in this example it rounds down to zero.

In Python 3, the result of this division is a `float`. The new operator // performs floor division.

If either of the operands is a floating-point number, Python performs floating-point division, and the result is a `float`:

```
>>> minute/60.0
0.98333333333333328
```

2.5 Expressions and statements

An **expression** is a combination of values, variables, and operators. A value all by itself is considered an expression, and so is a variable, so the following are all legal expressions (assuming that the variable `x` has been assigned a value):

```
17
x
x + 17
```

A **statement** is a unit of code that the Python interpreter can execute. We have seen two kinds of statement: print and assignment.

Technically an expression is also a statement, but it is probably simpler to think of them as different things. The important difference is that an expression has a value; a statement does not.

2.6 Interactive mode and script mode

One of the benefits of working with an interpreted language is that you can test bits of code in interactive mode before you put them in a script. But there are differences between interactive mode and script mode that can be confusing.

For example, if you are using Python as a calculator, you might type

```
>>> miles = 26.2
>>> miles * 1.61
42.182
```

The first line assigns a value to `miles`, but it has no visible effect. The second line is an expression, so the interpreter evaluates it and displays the result. So we learn that a marathon is about 42 kilometers.

But if you type the same code into a script and run it, you get no output at all. In script mode an expression, all by itself, has no visible effect. Python actually evaluates the expression, but it doesn't display the value unless you tell it to:

```
miles = 26.2
print miles * 1.61
```

This behavior can be confusing at first.

A script usually contains a sequence of statements. If there is more than one statement, the results appear one at a time as the statements execute.

For example, the script

```
print 1
x = 2
print x
```

produces the output

```
1
2
```

The assignment statement produces no output.
Exercise 2.1. *Type the following statements in the Python interpreter to see what they do:*

```
5
x = 5
x + 1
```

Now put the same statements into a script and run it. What is the output? Modify the script by transforming each expression into a print statement and then run it again.

2.7 Order of operations

When more than one operator appears in an expression, the order of evaluation depends on the **rules of precedence**. For mathematical operators, Python follows mathematical convention. The acronym **PEMDAS** is a useful way to remember the rules:

- **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 if it doesn't change the result.

- **E**xponentiation has the next highest precedence, so `2**1+1` is 3, not 4, and `3*1**3` is 3, not 27.

- **M**ultiplication and **D**ivision have the same precedence, which is higher than **A**ddition and **S**ubtraction, which also have the same precedence. So `2*3-1` is 5, not 4, and `6+4/2` is 8, not 5.

- Operators with the same precedence are evaluated from left to right (except exponentiation). So in the expression `degrees / 2 * pi`, the division happens first and the result is multiplied by `pi`. To divide by 2π, you can use parentheses or write `degrees / 2 / pi`.

I don't work very hard to remember rules of precedence for other operators. If I can't tell by looking at the expression, I use parentheses to make it obvious.

2.8 String operations

In general, you can't perform mathematical operations on strings, even if the strings look like numbers, so the following are illegal:

```
'2'-'1'    'eggs'/'easy'    'third'*'a charm'
```

The + operator works with strings, but it might not do what you expect: it performs **concatenation**, which means joining the strings by linking them end-to-end. For example:

```
first = 'throat'
second = 'warbler'
print first + second
```

The output of this program is `throatwarbler`.

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

This use of + and `*` makes sense by analogy with addition and multiplication. Just as `4*3` is equivalent to `4+4+4`, we expect `'Spam'*3` to be the same as `'Spam'+'Spam'+'Spam'`, 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 has that string concatenation does not?

2.9 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. These notes are called **comments**, and they start with the # symbol:

```
# compute the percentage of the hour that has elapsed
percentage = (minute * 100) / 60
```

In this case, the comment appears on a line by itself. You can also put comments at the end of a line:

```
percentage = (minute * 100) / 60     # percentage of an hour
```

Everything from the # to the end of the line is ignored—it has no effect on the program.

Comments are most useful when they document non-obvious features of the code. It is reasonable to assume that the reader can figure out *what* the code does; it is much more useful to explain *why*.

This comment is redundant with the code and useless:

```
v = 5     # assign 5 to v
```

This comment contains useful information that is not in the code:

```
v = 5     # velocity in meters/second.
```

Good variable names can reduce the need for comments, but long names can make complex expressions hard to read, so there is a tradeoff.

2.10 Debugging

At this point the syntax error you are most likely to make is an illegal variable name, like `class` and `yield`, which are keywords, or `odd~job` and `US$`, which contain illegal characters.

If you put a space in a variable name, Python thinks it is two operands without an operator:

```
>>> bad name = 5
SyntaxError: invalid syntax
```

For syntax errors, the error messages don't help much. The most common messages are `SyntaxError: invalid syntax` and `SyntaxError: invalid token`, neither of which is very informative.

The runtime error you are most likely to make is a "use before def;" that is, trying to use a variable before you have assigned a value. This can happen if you spell a variable name wrong:

```
>>> principal = 327.68
>>> interest = principle * rate
NameError: name 'principle' is not defined
```

Variables names are case sensitive, so `LaTeX` is not the same as `latex`.

At this point the most likely cause of a semantic error is the order of operations. For example, to evaluate $\frac{1}{2\pi}$, you might be tempted to write

```
>>> 1.0 / 2.0 * pi
```

But the division happens first, so you would get $\pi/2$, which is not the same thing! There is no way for Python to know what you meant to write, so in this case you don't get an error message; you just get the wrong answer.

2.11 Glossary

value: One of the basic units of data, like a number or string, that a program manipulates.

type: A category of values. The types we have seen so far are integers (type `int`), floating-point numbers (type `float`), and strings (type `str`).

integer: A type that represents whole numbers.

floating-point: A type that represents numbers with fractional parts.

string: A type that represents sequences of characters.

variable: A name that refers to a value.

statement: A section of code that represents a command or action. So far, the statements we have seen are assignments and print statements.

assignment: A statement that assigns a value to a variable.

state diagram: A graphical representation of a set of variables and the values they refer to.

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

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

operand: One of the values on which an operator operates.

floor division: The operation that divides two numbers and chops off the fraction part.

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

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

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

concatenate: To join two operands end-to-end.

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.

2.12 Exercises

Exercise 2.2. *Assume that we execute the following assignment statements:*

```
width = 17
height = 12.0
delimiter = '.'
```

For each of the following expressions, write the value of the expression and the type (of the value of the expression).

1. `width/2`
2. `width/2.0`
3. `height/3`
4. `1 + 2 * 5`
5. `delimiter * 5`

Use the Python interpreter to check your answers.

Exercise 2.3. *Practice using the Python interpreter as a calculator:*

1. *The volume of a sphere with radius r is* $\frac{4}{3}\pi r^3$. *What is the volume of a sphere with radius 5? Hint: 392.7 is wrong!*
2. *Suppose the cover price of a book is $24.95, but bookstores get a 40% discount. Shipping costs $3 for the first copy and 75 cents for each additional copy. What is the total wholesale cost for 60 copies?*
3. *If I leave my house at 6:52 am and run 1 mile at an easy pace (8:15 per mile), then 3 miles at tempo (7:12 per mile) and 1 mile at easy pace again, what time do I get home for breakfast?*