

Python for Everybody

Exploring Data Using Python 3

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This is a reduced version for people who want to learn Python for data science purpose.

The full version is available on:
<https://www.py4e.com/>

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Chapter 1

Why should you learn to write programs?

Writing programs (or programming) is a very creative and rewarding activity. You can write programs for many reasons, ranging from making your living to solving a difficult data analysis problem to having fun to helping someone else solve a problem. This book assumes that *everyone* needs to know how to program, and that once you know how to program you will figure out what you want to do with your newfound skills.

We are surrounded in our daily lives with computers ranging from laptops to cell phones. We can think of these computers as our “personal assistants” who can take care of many things on our behalf. The hardware in our current-day computers is essentially built to continuously ask us the question, “What would you like me to do next?”

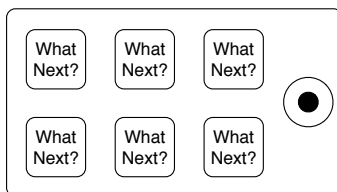


Figure 1.1: Personal Digital Assistant

Programmers add an operating system and a set of applications to the hardware and we end up with a Personal Digital Assistant that is quite helpful and capable of helping us do many different things.

Our computers are fast and have vast amounts of memory and could be very helpful to us if we only knew the language to speak to explain to the computer what we would like it to “do next”. If we knew this language, we could tell the computer to do tasks on our behalf that were repetitive. Interestingly, the kinds of things computers can do best are often the kinds of things that we humans find boring and mind-numbing.

For example, look at the first three paragraphs of this chapter and tell me the most commonly used word and how many times the word is used. While you were able to read and understand the words in a few seconds, counting them is almost painful because it is not the kind of problem that human minds are designed to solve. For a computer the opposite is true, reading and understanding text from a piece of paper is hard for a computer to do but counting the words and telling you how many times the most used word was used is very easy for the computer:

```
python words.py
Enter file:words.txt
to 16
```

Our “personal information analysis assistant” quickly told us that the word “to” was used sixteen times in the first three paragraphs of this chapter.

This very fact that computers are good at things that humans are not is why you need to become skilled at talking “computer language”. Once you learn this new language, you can delegate mundane tasks to your partner (the computer), leaving more time for you to do the things that you are uniquely suited for. You bring creativity, intuition, and inventiveness to this partnership.

1.3 Understanding programming

In the rest of this book, we will try to turn you into a person who is skilled in the art of programming. In the end you will be a *programmer* - perhaps not a professional programmer, but at least you will have the skills to look at a data/information analysis problem and develop a program to solve the problem.

In a sense, you need two skills to be a programmer:

- First, you need to know the programming language (Python) - you need to know the vocabulary and the grammar. You need to be able to spell the words in this new language properly and know how to construct well-formed “sentences” in this new language.
- Second, you need to “tell a story”. In writing a story, you combine words and sentences to convey an idea to the reader. There is a skill and art in constructing the story, and skill in story writing is improved by doing some writing and getting some feedback. In programming, our program is the “story” and the problem you are trying to solve is the “idea”.

Once you learn one programming language such as Python, you will find it much easier to learn a second programming language such as JavaScript or C++. The

new programming language has very different vocabulary and grammar but the problem-solving skills will be the same across all programming languages.

You will learn the “vocabulary” and “sentences” of Python pretty quickly. It will take longer for you to be able to write a coherent program to solve a brand-new problem. We teach programming much like we teach writing. We start reading and explaining programs, then we write simple programs, and then we write increasingly complex programs over time. At some point you “get your muse” and see the patterns on your own and can see more naturally how to take a problem and write a program that solves that problem. **And once you get to that point, programming becomes a very pleasant and creative process.**

We start with the vocabulary and structure of Python programs. Be patient as the simple examples remind you of when you started reading for the first time.

1.4 Words and sentences

Unlike human languages, the Python vocabulary is actually pretty small. We call this “vocabulary” the “reserved words”. These are words that have very special meaning to Python. When Python sees these words in a Python program, they have one and only one meaning to Python. Later as you write programs you will make up your own words that have meaning to you called *variables*. You will have great latitude in choosing your names for your variables, but you cannot use any of Python’s reserved words as a name for a variable.

When we train a dog, we use special words like “sit”, “stay”, and “fetch”. When you talk to a dog and don’t use any of the reserved words, they just look at you with a quizzical look on their face until you say a reserved word. For example, if you say, “I wish more people would walk to improve their overall health”, what most dogs likely hear is, “blah blah blah *walk* blah blah blah blah.” That is because “walk” is a reserved word in dog language. Many might suggest that the language between humans and cats has no reserved words¹.

The reserved words in the language where humans talk to Python include the following:

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

That is it, and unlike a dog, Python is already completely trained. When you say “try”, Python will try every time you say it without fail.

We will learn these reserved words and how they are used in good time, but for now we will focus on the Python equivalent of “speak” (in human-to-dog language). The nice thing about telling Python to speak is that we can even tell it what to say by giving it a message in quotes:

¹<http://xkcd.com/231/>

```
print('Hello world!')
```

And we have even written our first syntactically correct Python sentence. Our sentence starts with the function *print* followed by a string of text of our choosing enclosed in single quotes. The strings in the print statements are enclosed in quotes. Single quotes and double quotes do the same thing; most people use single quotes except in cases like this where a single quote (which is also an apostrophe) appears in the string.

1.7 Writing a program

Typing commands into the Python interpreter is a great way to experiment with Python's features, but it is not recommended for solving more complex problems.

When we want to write a program, we use a text editor to write the Python instructions into a file, which is called a *script*. By convention, Python scripts have names that end with `.py`.

1.8 What is a program?

The definition of a *program* at its most basic is a sequence of Python statements that have been crafted to do something. Even our simple *hello.py* script is a program. It is a one-line program and is not particularly useful, but in the strictest definition, it is a Python program.

It might be easiest to understand what a program is by thinking about a problem that a program might be built to solve, and then looking at a program that would solve that problem.

Lets say you are doing Social Computing research on Facebook posts and you are interested in the most frequently used word in a series of posts. You could print out the stream of Facebook posts and pore over the text looking for the most common word, but that would take a long time and be very mistake prone. You would be smart to write a Python program to handle the task quickly and accurately so you can spend the weekend doing something fun.

For example, look at the following text about a clown and a car. Look at the text and figure out the most common word and how many times it occurs.

the clown ran after the car and the car ran into the tent
and the tent fell down on the clown and the car

Then imagine that you are doing this task looking at millions of lines of text. Frankly it would be quicker for you to learn Python and write a Python program to count the words than it would be to manually scan the words.

The even better news is that I already came up with a simple program to find the most common word in a text file. I wrote it, tested it, and now I am giving it to you to use so you can save some time.

```
name = input('Enter file:')
handle = open(name, 'r')
counts = dict()

for line in handle:
    words = line.split()
    for word in words:
        counts[word] = counts.get(word, 0) + 1

bigcount = None
bigword = None
for word, count in list(counts.items()):
    if bigcount is None or count > bigcount:
        bigword = word
        bigcount = count

print(bigword, bigcount)

# Code: http://www.py4e.com/code3/words.py
```

You don't even need to know Python to use this program. You will need to get through Chapter 10 of this book to fully understand the awesome Python techniques that were used to make the program. You are the end user, you simply use the program and marvel at its cleverness and how it saved you so much manual effort. You simply type the code into a file called *words.py* and run it or you download the source code from <http://www.py4e.com/code3/> and run it.

This is a good example of how Python and the Python language are acting as an intermediary between you (the end user) and me (the programmer). Python is a way for us to exchange useful instruction sequences (i.e., programs) in a common language that can be used by anyone who installs Python on their computer. So neither of us are talking *to Python*, instead we are communicating with each other *through* Python.

1.9 The building blocks of programs

In the next few chapters, we will learn more about the vocabulary, sentence structure, paragraph structure, and story structure of Python. We will learn about the

powerful capabilities of Python and how to compose those capabilities together to create useful programs.

There are some low-level conceptual patterns that we use to construct programs. These constructs are not just for Python programs, they are part of every programming language from machine language up to the high-level languages.

input Get data from the “outside world”. This might be reading data from a file, or even some kind of sensor like a microphone or GPS. In our initial programs, our input will come from the user typing data on the keyboard.

output Display the results of the program on a screen or store them in a file or perhaps write them to a device like a speaker to play music or speak text.

sequential execution Perform statements one after another in the order they are encountered in the script.

conditional execution Check for certain conditions and then execute or skip a sequence of statements.

repeated execution Perform some set of statements repeatedly, usually with some variation.

reuse Write a set of instructions once and give them a name and then reuse those instructions as needed throughout your program.

It sounds almost too simple to be true, and of course it is never so simple. It is like saying that walking is simply “putting one foot in front of the other”. The “art” of writing a program is composing and weaving these basic elements together many times over to produce something that is useful to its users.

The word counting program above directly uses all of these patterns except for one.

1.10 What could possibly go wrong?

As we saw in our earliest conversations with Python, we must communicate very precisely when we write Python code. The smallest deviation or mistake will cause Python to give up looking at your program.

Beginning programmers often take the fact that Python leaves no room for errors as evidence that Python is mean, hateful, and cruel. While Python seems to like everyone else, Python knows them personally and holds a grudge against them. Because of this grudge, Python takes our perfectly written programs and rejects them as “unfit” just to torment us.

```
>>> print 'Hello world!'
File "<stdin>", line 1
    print 'Hello world!'
    ~
SyntaxError: invalid syntax
>>> print ('Hello world')
Traceback (most recent call last):
File "<stdin>", line 1, in <module>
NameError: name 'print' is not defined
```

```
>>> I hate you Python!
File "<stdin>", line 1
    I hate you Python!
    ^
SyntaxError: invalid syntax
>>> if you come out of there, I would teach you a lesson
File "<stdin>", line 1
    if you come out of there, I would teach you a lesson
    ^
SyntaxError: invalid syntax
>>>
```

There is little to be gained by arguing with Python. It is just a tool. It has no emotions and it is happy and ready to serve you whenever you need it. Its error messages sound harsh, but they are just Python's call for help. It has looked at what you typed, and it simply cannot understand what you have entered.

Python is much more like a dog, loving you unconditionally, having a few key words that it understands, looking you with a sweet look on its face (>>>), and waiting for you to say something it understands. When Python says "SyntaxError: invalid syntax", it is simply wagging its tail and saying, "You seemed to say something but I just don't understand what you meant, but please keep talking to me (>>>)."

As your programs become increasingly sophisticated, you will encounter three general types of errors:

Syntax errors These are the first errors you will make and the easiest to fix. A syntax error means that you have violated the "grammar" rules of Python. Python does its best to point right at the line and character where it noticed it was confused. The only tricky bit of syntax errors is that sometimes the mistake that needs fixing is actually earlier in the program than where Python *noticed* it was confused. So the line and character that Python indicates in a syntax error may just be a starting point for your investigation.

Logic errors A logic error is when your program has good syntax but there is a mistake in the order of the statements or perhaps a mistake in how the statements relate to one another. A good example of a logic error might be, "take a drink from your water bottle, put it in your backpack, walk to the library, and then put the top back on the bottle."

Semantic errors A semantic error is when your description of the steps to take is syntactically perfect and in the right order, but there is simply a mistake in the program. The program is perfectly correct but it does not do what you *intended* for it to do. A simple example would be if you were giving a person directions to a restaurant and said, "... when you reach the intersection with the gas station, turn left and go one mile and the restaurant is a red building on your left." Your friend is very late and calls you to tell you that they are on a farm and walking around behind a barn, with no sign of a restaurant. Then you say "did you turn left or right at the gas station?" and they say, "I followed your directions perfectly, I have them written down, it says turn left and go one mile at the gas station." Then you say, "I am very sorry, because while my instructions were syntactically correct, they sadly contained a small but undetected semantic error."

Again in all three types of errors, Python is merely trying its hardest to do exactly what you have asked.

1.11 Debugging

When Python spits out an error or even when it gives you a result that is different from what you had intended, then begins the hunt for the cause of the error. Debugging is the process of finding the cause of the error in your code. When you are debugging a program, and especially if you are working on a hard bug, there are four things to try:

reading Examine your code, read it back to yourself, and check that it says what you meant to say.

running Experiment by making changes and running different versions. Often if you display the right thing at the right place in the program, the problem becomes obvious, but sometimes you have to spend some time to build scaffolding.

ruminating Take some time to think! What kind of error is it: syntax, runtime, semantic? What information can you get from the error messages, or from the output of the program? What kind of error could cause the problem you're seeing? What did you change last, before the problem appeared?

retreating At some point, the best thing to do is back off, undoing recent changes, until you get back to a program that works and that you understand. Then you can start rebuilding.

Beginning programmers sometimes get stuck on one of these activities and forget the others. Finding a hard bug requires reading, running, ruminating, and sometimes retreating. If you get stuck on one of these activities, try the others. Each activity comes with its own failure mode.

For example, reading your code might help if the problem is a typographical error, but not if the problem is a conceptual misunderstanding. If you don't understand what your program does, you can read it 100 times and never see the error, because the error is in your head.

Running experiments can help, especially if you run small, simple tests. But if you run experiments without thinking or reading your code, you might fall into a pattern I call "random walk programming", which is the process of making random changes until the program does the right thing. Needless to say, random walk programming can take a long time.

You have to take time to think. Debugging is like an experimental science. You should have at least one hypothesis about what the problem is. If there are two or more possibilities, try to think of a test that would eliminate one of them.

Taking a break helps with the thinking. So does talking. If you explain the problem to someone else (or even to yourself), you will sometimes find the answer before you finish asking the question.

But even the best debugging techniques will fail if there are too many errors, or if the code you are trying to fix is too big and complicated. Sometimes the best

option is to retreat, simplifying the program until you get to something that works and that you understand.

Beginning programmers are often reluctant to retreat because they can't stand to delete a line of code (even if it's wrong). If it makes you feel better, copy your program into another file before you start stripping it down. Then you can paste the pieces back in a little bit at a time.

1.12 The learning journey

As you progress through the rest of the book, don't be afraid if the concepts don't seem to fit together well the first time. When you were learning to speak, it was not a problem for your first few years that you just made cute gurgling noises. And it was OK if it took six months for you to move from simple vocabulary to simple sentences and took 5-6 more years to move from sentences to paragraphs, and a few more years to be able to write an interesting complete short story on your own.

We want you to learn Python much more rapidly, so we teach it all at the same time over the next few chapters. But it is like learning a new language that takes time to absorb and understand before it feels natural. That leads to some confusion as we visit and revisit topics to try to get you to see the big picture while we are defining the tiny fragments that make up that big picture. While the book is written linearly, and if you are taking a course it will progress in a linear fashion, don't hesitate to be very nonlinear in how you approach the material. Look forwards and backwards and read with a light touch. By skimming more advanced material without fully understanding the details, you can get a better understanding of the "why?" of programming. By reviewing previous material and even redoing earlier exercises, you will realize that you actually learned a lot of material even if the material you are currently staring at seems a bit impenetrable.

Usually when you are learning your first programming language, there are a few wonderful "Ah Hah!" moments where you can look up from pounding away at some rock with a hammer and chisel and step away and see that you are indeed building a beautiful sculpture.

If something seems particularly hard, there is usually no value in staying up all night and staring at it. Take a break, take a nap, have a snack, explain what you are having a problem with to someone (or perhaps your dog), and then come back to it with fresh eyes. I assure you that once you learn the programming concepts in the book you will look back and see that it was all really easy and elegant and it simply took you a bit of time to absorb it.

1.13 Glossary

bug An error in a program.

central processing unit The heart of any computer. It is what runs the software that we write; also called "CPU" or "the processor".

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

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

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

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

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

machine code The lowest-level language for software, which is the language that is directly executed by the central processing unit (CPU).

main memory Stores programs and data. Main memory loses its information when the power is turned off.

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

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

program A set of instructions that specifies a computation.

prompt When a program displays a message and pauses for the user to type some input to the program.

secondary memory Stores programs and data and retains its information even when the power is turned off. Generally slower than main memory. Examples of secondary memory include disk drives and flash memory in USB sticks.

semantics The meaning of a program.

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

source code A program in a high-level language.

1.14 Exercises

Exercise 1: What is the function of the secondary memory in a computer?

- a) Execute all of the computation and logic of the program
- b) Retrieve web pages over the Internet
- c) Store information for the long term, even beyond a power cycle
- d) Take input from the user

Exercise 2: What is a program?

Exercise 3: What is the difference between a compiler and an interpreter?

Exercise 4: Which of the following contains “machine code”?

- a) The Python interpreter
- b) The keyboard
- c) Python source file
- d) A word processing document

Exercise 5: What is wrong with the following code:


```
>>> printt 'Hello world!'
File "<stdin>", line 1
    printt 'Hello world!'
          ^
SyntaxError: invalid syntax
>>>
```

Exercise 6: Where in the computer is a variable such as “x” stored after the following Python line finishes?

```
x = 123
```

- a) Central processing unit
- b) Main Memory
- c) Secondary Memory
- d) Input Devices
- e) Output Devices

Exercise 7: What will the following program print out:

```
x = 43
x = x + 1
print(x)
```

- a) 43
- b) 44
- c) $x + 1$
- d) Error because $x = x + 1$ is not possible mathematically

Exercise 8: Explain each of the following using an example of a human capability: (1) Central processing unit, (2) Main Memory, (3) Secondary Memory, (4) Input Device, and (5) Output Device. For example, “What is the human equivalent to a Central Processing Unit”?

Exercise 9: How do you fix a “Syntax Error”?

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.

The `print` statement also works for integers. We use the `python` command to start the interpreter.

```
python
>>> print(4)
4
```

If you are not sure what type a value has, the interpreter can tell you.

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

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:

```
>>> print(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, which it prints with spaces between.

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 = 3.1415926535897931
```

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

To display the value of a variable, you can use a print statement:

```
>>> print(n)
17
>>> print(pi)
3.1415926535897931
```

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

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

2.3 Variable names and keywords

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

Variable names can be arbitrarily long. They can contain both letters and numbers, but they **cannot start with a number**. 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`. Variable names can start with an underscore character, but we generally avoid doing this unless we are writing library code for others to use.

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 begins with a number. `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 reserves 35 keywords:

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

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 Statements

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

When you type a statement in interactive mode, the interpreter executes it and displays the result, if there is one.

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.

2.5 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)
```

There has been a change in the division operator between Python 2.x and Python 3.x. In Python 3.x, the result of this division is a floating point result:

```
>>> minute = 59
>>> minute/60
0.9833333333333333
```

The division operator in Python 2.0 would divide two integers and truncate the result to an integer:

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

To obtain the same answer in Python 3.0 use floored (`//` integer) division.

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

In Python 3.0 integer division functions much more as you would expect if you entered the expression on a calculator.

2.6 Expressions

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
```

If you type an expression in interactive mode, the interpreter *evaluates* it and displays the result:

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

But in a script, an expression all by itself doesn't do anything! This is a common source of confusion for beginners.

Exercise 1: Type the following statements in the Python interpreter to see what they do:

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

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:

- Parentheses 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.

- Exponentiation has the next highest precedence, so $2**1+1$ is 3, not 4, and $3*1**3$ is 3, not 27.
- Multiplication and Division have the same precedence, which is higher than Addition and Subtraction, 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. So the expression $5-3-1$ is 1, not 3, because the $5-3$ happens first and then 1 is subtracted from 2.

When in doubt, always put parentheses in your expressions to make sure the computations are performed in the order you intend.

2.8 Modulus operator

The *modulus operator* works on integers and yields the remainder when the first operand is divided by the second. In Python, the modulus operator is a percent sign (%). The syntax is the same as for other operators:

```
>>> quotient = 7 // 3
>>> print(quotient)
2
>>> remainder = 7 % 3
>>> print(remainder)
1
```

So 7 divided by 3 is 2 with 1 left over.

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 .

You can also 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.

2.9 String operations

The $+$ operator works with strings, but it is not addition in the mathematical sense. Instead it performs *concatenation*, which means joining the strings by linking them end to end. For example:

```
>>> first = 10
>>> second = 15
>>> print(first+second)
25
>>> first = '100'
```

```
>>> second = '150'
>>> print(first + second)
100150
```

The `*` operator also works with strings by multiplying the content of a string by an integer. For example:

```
>>> first = 'Test '
>>> second = 3
>>> print(first * second)
Test Test Test
```

2.11 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 in Python 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 trade-off.

2.12 Choosing mnemonic variable names

As long as you follow the simple rules of variable naming, and avoid reserved words, you have a lot of choice when you name your variables. In the beginning, this choice can be confusing both when you read a program and when you write your own programs. For example, the following three programs are identical in terms of what they accomplish, but very different when you read them and try to understand them.

```
a = 35.0
b = 12.50
c = a * b
print(c)
```

```
hours = 35.0
rate = 12.50
pay = hours * rate
print(pay)
```

```
x1q3z9ahd = 35.0
x1q3z9afd = 12.50
x1q3p9afd = x1q3z9ahd * x1q3z9afd
print(x1q3p9afd)
```

The Python interpreter sees all three of these programs as *exactly the same* but humans see and understand these programs quite differently. Humans will most quickly understand the *intent* of the second program because the programmer has chosen variable names that reflect their intent regarding what data will be stored in each variable.

We call these wisely chosen variable names “mnemonic variable names”. The word *mnemonic*² means “memory aid”. We choose mnemonic variable names to help us remember why we created the variable in the first place.

While this all sounds great, and it is a very good idea to use mnemonic variable names, mnemonic variable names can get in the way of a beginning programmer’s ability to parse and understand code. This is because beginning programmers have not yet memorized the reserved words (there are only 33 of them) and sometimes variables with names that are too descriptive start to look like part of the language and not just well-chosen variable names.

Take a quick look at the following Python sample code which loops through some data. We will cover loops soon, but for now try to just puzzle through what this means:

```
for word in words:
    print(word)
```

²See <https://en.wikipedia.org/wiki/Mnemonic> for an extended description of the word “mnemonic”.

What is happening here? Which of the tokens (`for`, `word`, `in`, etc.) are reserved words and which are just variable names? Does Python understand at a fundamental level the notion of words? Beginning programmers have trouble separating what parts of the code *must* be the same as this example and what parts of the code are simply choices made by the programmer.

The following code is equivalent to the above code:

```
for slice in pizza:
    print(slice)
```

It is easier for the beginning programmer to look at this code and know which parts are reserved words defined by Python and which parts are simply variable names chosen by the programmer. It is pretty clear that Python has no fundamental understanding of pizza and slices and the fact that a pizza consists of a set of one or more slices.

But if our program is truly about reading data and looking for words in the data, `pizza` and `slice` are very un-mnemonic variable names. Choosing them as variable names distracts from the meaning of the program.

After a pretty short period of time, you will know the most common reserved words and you will start to see the reserved words jumping out at you:

The parts of the code that are defined by Python (**`for`**, **`in`**, **`print`**, and **`:`**) are in bold and the programmer-chosen variables (`word` and `words`) are not in bold. Many text editors are aware of Python syntax and will color reserved words differently to give you clues to keep your variables and reserved words separate. After a while you will begin to read Python and quickly determine what is a variable and what is a reserved word.

2.13 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

>>> month = 09
File "<stdin>", line 1
    month = 09
           ^
SyntaxError: invalid token
```

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 $1/2\pi$, 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.

2.14 Glossary

assignment A statement that assigns a value to a variable.

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.

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.

floating point A type that represents numbers with fractional parts.

integer A type that represents whole numbers.

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.

mnemonic A memory aid. We often give variables mnemonic names to help us remember what is stored in the variable.

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.

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

string A type that represents sequences of characters.

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`).

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

variable A name that refers to a value.

2.15 Exercises

Exercise 2: Write a program that uses input to prompt a user for their name and then welcomes them.

```
Enter your name: Chuck
Hello Chuck
```

Exercise 3: Write a program to prompt the user for hours and rate per hour to compute gross pay.

```
Enter Hours: 35
Enter Rate: 2.75
Pay: 96.25
```

We won't worry about making sure our pay has exactly two digits after the decimal place for now. If you want, you can play with the built-in Python `round` function to properly round the resulting pay to two decimal places.

Exercise 4: Assume that we execute the following assignment statements:

```
width = 17
height = 12.0
```

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`

Use the Python interpreter to check your answers.

Exercise 5: Write a program which prompts the user for a Celsius temperature, convert the temperature to Fahrenheit, and print out the converted temperature.

Chapter 3

Conditional execution

3.1 Boolean expressions

A *boolean expression* is an expression that is either true or false. The following examples use the operator `==`, which compares two operands and produces `True` if they are equal and `False` otherwise:

```
>>> 5 == 5
True
>>> 5 == 6
False
{}
```

`True` and `False` are special values that belong to the class `bool`; they are not strings:

```
>>> type(True)
<class 'bool'>
>>> type(False)
<class 'bool'>
```

The `==` operator is one of the *comparison operators*; the others are:

<code>x != y</code>	<code># x is not equal to y</code>
<code>x > y</code>	<code># x is greater than y</code>
<code>x < y</code>	<code># x is less than y</code>
<code>x >= y</code>	<code># x is greater than or equal to y</code>
<code>x <= y</code>	<code># x is less than or equal to y</code>
<code>x is y</code>	<code># x is the same as y</code>
<code>x is not y</code>	<code># x is not the same as y</code>

Although these operations are probably familiar to you, the Python symbols are different from the mathematical symbols for the same operations. 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. There is no such thing as `=<` or `=>`.

3.2 Logical operators

There are three *logical operators*: **and**, **or**, and **not**. The semantics (meaning) of these operators is similar to their meaning in English. For example,

```
x > 0 and x < 10
```

is true only if x is greater than 0 *and* less than 10.

$n\%2 == 0$ or $n\%3 == 0$ is true if *either* of the conditions is true, that is, if the number is divisible by 2 *or* 3.

Finally, the **not** operator negates a boolean expression, so **not** ($x > y$) is true if $x > y$ is false; that is, if x is less than or equal to y .

Strictly speaking, the operands of the logical operators should be boolean expressions, but Python is not very strict. Any nonzero number is interpreted as “true.”

```
>>> 17 and True
True
```

This flexibility can be useful, but there are some subtleties to it that might be confusing. You might want to avoid it until you are sure you know what you are doing.

3.3 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 > 0 :
    print('x is positive')
```

The boolean expression after the **if** statement is called the *condition*. We end the **if** statement with a colon character (**:**) and the line(s) after the **if** statement are indented.

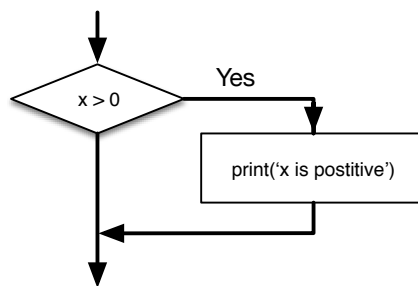


Figure 3.1: If Logic

If the logical condition is true, then the indented statement gets executed. If the logical condition is false, the indented statement is skipped.

`if` statements have the same structure as function definitions or `for` loops¹. The statement consists of a header line that ends with the colon character (`:`) followed by an indented block. Statements like this are called *compound statements* because they stretch across more than one line.

There is no limit on the number of statements that can appear in the body, but there must be at least one. Occasionally, it is useful to have a body with no statements (usually as a place holder for code you haven't written yet). In that case, you can use the `pass` statement, which does nothing.

```
if x < 0 :
    pass          # need to handle negative values!
```

If you enter an `if` statement in the Python interpreter, the prompt will change from three chevrons to three dots to indicate you are in the middle of a block of statements, as shown below:

```
>>> x = 3
>>> if x < 10:
...     print('Small')
...
Small
>>>
```

When using the Python interpreter, you must leave a blank line at the end of a block, otherwise Python will return an error:

```
>>> x = 3
>>> if x < 10:
...     print('Small')
... print('Done')
File "<stdin>", line 3
    print('Done')
    ^
SyntaxError: invalid syntax
```

A blank line at the end of a block of statements is not necessary when writing and executing a script, but it may improve readability of your code.

3.4 Alternative execution

A second form of the `if` statement is *alternative execution*, in which there are two possibilities and the condition determines which one gets executed. The syntax looks like this:

¹We will learn about functions in Chapter 4 and loops in Chapter 5.

```

if x%2 == 0 :
    print('x is even')
else :
    print('x is odd')

```

If the remainder when x is divided by 2 is 0, then we know that x is even, and the program displays a message to that effect. If the condition is false, the second set of statements is executed.

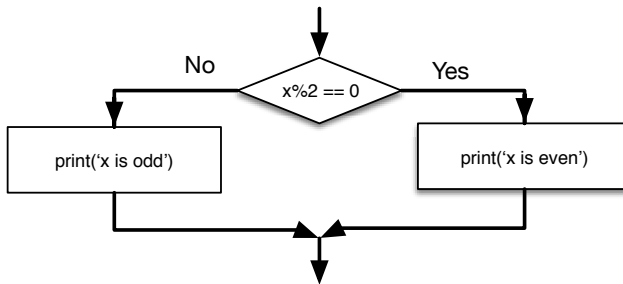


Figure 3.2: If-Then-Else Logic

Since the condition must either be true or false, exactly one of the alternatives will be executed. The alternatives are called *branches*, because they are branches in the flow of execution.

3.5 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:
    print('x is less than y')
elif x > y:
    print('x is greater than y')
else:
    print('x and y are equal')

```

`elif` is an abbreviation of “else if.” Again, exactly one branch will be executed.

There is no limit on the number of `elif` statements. If there is an `else` clause, it has to be at the end, but there doesn't have to be one.

```

if choice == 'a':
    print('Bad guess')
elif choice == 'b':
    print('Good guess')
elif choice == 'c':
    print('Close, but not correct')

```

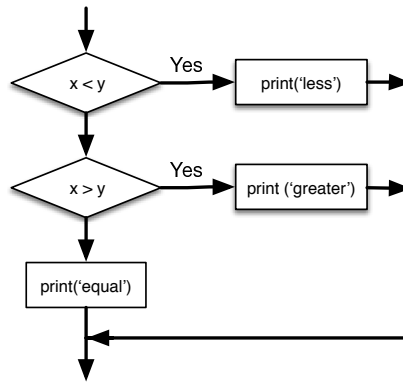



Figure 3.3: If-Then-ElseIf Logic

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.

3.6 Nested conditionals

One conditional can also be nested within another. We could have written the three-branch example like this:

```

if x == y:
    print('x and y are equal')
else:
    if x < y:
        print('x is less than y')
    else:
        print('x is greater than y')
  
```

The outer conditional contains two branches. The first branch contains a simple statement. The second branch contains another `if` statement, which has two branches of its own. Those two branches are both simple statements, although they could have been conditional statements as well.

Although the indentation of the statements makes the structure apparent, *nested conditionals* become difficult to read very quickly. In general, it is a good idea to avoid them when you 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:
    if x < 10:
        print('x is a positive single-digit number.')
  
```

The `print` statement is executed only if we make it past both conditionals, so we can get the same effect with the `and` operator:

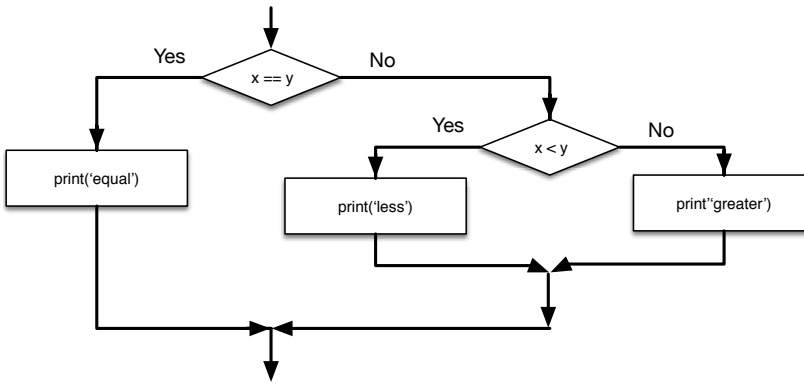


Figure 3.4: Nested If Statements

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

3.7 Catching exceptions using try and except

When we are executing these statements in the Python interpreter, we get a new prompt from the interpreter, think “oops”, and move on to our next statement.

However if an error occurs, your script immediately stops in its tracks with a traceback. It does not execute the following statement.

If the following part is not clear, watch:

https://www.youtube.com/watch?v=NIWwJbo-9_8

There is a conditional execution structure built into Python to handle these types of expected and unexpected errors called “try / except”. The idea of `try` and `except` is that you know that some sequence of instruction(s) *may* have a problem and you want to add some statements to be executed *if an error occurs*. These extra statements (the `except` block) *are ignored if there is no error*.

You can think of the `try` and `except` feature in Python as an “insurance policy” on a sequence of statements.

We can write our temperature converter as follows:

```
inp = input('Enter Fahrenheit Temperature:')
try:
    fahr = float(inp)
    cel = (fahr - 32.0) * 5.0 / 9.0
    print(cel)
except:
    print('Please enter a number')
```

Code: <http://www.py4e.com/code3/fahren2.py>

Python starts by executing the sequence of statements in the `try` block. If all goes well, it skips the `except` block and proceeds. If an exception occurs in the `try` block, Python jumps out of the `try` block and executes the sequence of statements in the `except` block.

```
python fahren2.py
Enter Fahrenheit Temperature:72
22.22222222222222
```

```
python fahren2.py
Enter Fahrenheit Temperature:fred
Please enter a number
```

Handling an exception with a `try` statement is called *catching* an exception. In this example, the `except` clause prints an error message. In general, catching an exception gives you a chance to fix the problem, or try again, or at least end the program gracefully.

3.8 Short-circuit evaluation of logical expressions

When Python is processing a logical expression such as `x >= 2 and (x/y) > 2`, it evaluates the expression from left to right. Because of the definition of `and`, if `x` is less than 2, the expression `x >= 2` is `False` and so the whole expression is `False` regardless of whether `(x/y) > 2` evaluates to `True` or `False`.

When Python detects that there is nothing to be gained by evaluating the rest of a logical expression, it stops its evaluation and does not do the computations in the rest of the logical expression. When the evaluation of a logical expression stops because the overall value is already known, it is called *short-circuiting* the evaluation.

While this may seem like a fine point, the short-circuit behavior leads to a clever technique called the *guardian pattern*. Consider the following code sequence in the Python interpreter:

```
>>> x = 6
>>> y = 2
>>> x >= 2 and (x/y) > 2
True
>>> x = 1
>>> y = 0
>>> x >= 2 and (x/y) > 2
False
>>> x = 6
>>> y = 0
>>> x >= 2 and (x/y) > 2
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
ZeroDivisionError: division by zero
>>>
```

The third calculation failed because Python was evaluating `(x/y)` and `y` was zero, which causes a runtime error. But the second example did *not* fail because the first part of the expression `x >= 2` evaluated to `False` so the `(x/y)` was not ever executed due to the *short-circuit* rule and there was no error.

We can construct the logical expression to strategically place a *guard* evaluation just before the evaluation that might cause an error as follows:

```
>>> x = 1
>>> y = 0
>>> x >= 2 and y != 0 and (x/y) > 2
False
>>> x = 6
>>> y = 0
>>> x >= 2 and y != 0 and (x/y) > 2
False
>>> x >= 2 and (x/y) > 2 and y != 0
Traceback (most recent call last):
```

```
File "<stdin>", line 1, in <module>
ZeroDivisionError: division by zero
>>>
```

In the first logical expression, `x >= 2` is `False` so the evaluation stops at the `and`. In the second logical expression, `x >= 2` is `True` but `y != 0` is `False` so we never reach `(x/y)`.

In the third logical expression, the `y != 0` is *after* the `(x/y)` calculation so the expression fails with an error.

In the second expression, we say that `y != 0` acts as a *guard* to insure that we only execute `(x/y)` if `y` is non-zero.

3.9 Debugging

The traceback Python displays when an error occurs contains a lot of information, but it can be overwhelming. The most useful parts are usually:

- What kind of error it was, and
- Where it occurred.

Syntax errors are usually easy to find, but there are a few gotchas. Whitespace errors can be tricky because spaces and tabs are invisible and we are used to ignoring them.

```
>>> x = 5
>>> y = 6
File "<stdin>", line 1
    y = 6
    ^
IndentationError: unexpected indent
```

In this example, the problem is that the second line is indented by one space. But the error message points to `y`, which is misleading. In general, error messages indicate where the problem was discovered, but the actual error might be earlier in the code, sometimes on a previous line.

In general, error messages tell you where the problem was discovered, but that is often not where it was caused.

3.10 Glossary

body The sequence of statements within a compound statement.

boolean expression An expression whose value is either `True` or `False`.

branch One of the alternative sequences of statements in a conditional statement.

- chained conditional** A conditional statement with a series of alternative branches.
- comparison operator** One of the operators that compares its operands: `==`, `!=`, `>`, `<`, `>=`, and `<=`.
- conditional statement** A statement that controls the flow of execution depending on some condition.
- condition** The boolean expression in a conditional statement that determines which branch is executed.
- compound statement** A statement that consists of a header and a body. The header ends with a colon (`:`). The body is indented relative to the header.
- guardian pattern** Where we construct a logical expression with additional comparisons to take advantage of the short-circuit behavior.
- logical operator** One of the operators that combines boolean expressions: `and`, `or`, and `not`.
- nested conditional** A conditional statement that appears in one of the branches of another conditional statement.
- traceback** A list of the functions that are executing, printed when an exception occurs.
- short circuit** When Python is part-way through evaluating a logical expression and stops the evaluation because Python knows the final value for the expression without needing to evaluate the rest of the expression.

3.11 Exercises

Exercise 1: Rewrite your pay computation to give the employee 1.5 times the hourly rate for hours worked above 40 hours.

```
Enter Hours: 45
Enter Rate: 10
Pay: 475.0
```

Exercise 2: Rewrite your pay program using `try` and `except` so that your program handles non-numeric input gracefully by printing a message and exiting the program. The following shows two executions of the program:

```
Enter Hours: 20
Enter Rate: nine
Error, please enter numeric input
```

```
Enter Hours: forty
Error, please enter numeric input
```

Exercise 3: Write a program to prompt for a score between 0.0 and 1.0. If the score is out of range, print an error message. If the score is between 0.0 and 1.0, print a grade using the following table:

Score	Grade
-------	-------

```
>= 0.9      A
>= 0.8      B
>= 0.7      C
>= 0.6      D
< 0.6       F
```

```
Enter score: 0.95
A
```

```
Enter score: perfect
Bad score
```

```
Enter score: 10.0
Bad score
```

```
Enter score: 0.75
C
```

```
Enter score: 0.5
F
```

Run the program repeatedly as shown above to test the various different values for input.

Chapter 4

Functions

4.1 Function calls

In the context of programming, a *function* is a named sequence of statements that performs a computation. When you define a function, you specify the name and the sequence of statements. Later, you can “call” the function by name. We have already seen one example of a *function call*:

```
>>> type(32)
<class 'int'>
```

The name of the function is `type`. The expression in parentheses is called the *argument* of the function. The argument is a value or variable that we are passing into the function as input to the function. The result, for the `type` function, is the type of the argument.

It is common to say that a function “takes” an argument and “returns” a result. The result is called the *return value*.

4.2 Built-in functions

Python provides a number of important built-in functions that we can use without needing to provide the function definition. The creators of Python wrote a set of functions to solve common problems and included them in Python for us to use.

The `max` and `min` functions give us the largest and smallest values in a list, respectively:

```
>>> max('Hello world')
'w'
>>> min('Hello world')
' '
>>>
```


The `max` function tells us the “largest character” in the string (which turns out to be the letter “w”) and the `min` function shows us the smallest character (which turns out to be a space).

Another very common built-in function is the `len` function which tells us how many items are in its argument. If the argument to `len` is a string, it returns the number of characters in the string.

```
>>> len('Hello world')
11
>>>
```

These functions are not limited to looking at strings. They can operate on any set of values, as we will see in later chapters.

You should treat the names of built-in functions as reserved words (i.e., avoid using “max” as a variable name).

4.3 Type conversion functions

Python also provides built-in functions that convert values from one type to another. The `int` function takes any value and converts it to an integer, if it can, or complains otherwise:

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

`int` can convert floating-point values to integers, but it doesn’t round off; it chops off the fraction part:

```
>>> int(3.99999)
3
>>> int(-2.3)
-2
```

`float` converts integers and strings to floating-point numbers:

```
>>> float(32)
32.0
>>> float('3.14159')
3.14159
```

Finally, `str` converts its argument to a string:

```
>>> str(32)
'32'
>>> str(3.14159)
'3.14159'
```

4.4 Math functions

Python has a `math` module that provides most of the familiar mathematical functions. Before we can use the module, we have to import it:

```
>>> import math
```

This statement creates a *module object* named `math`. If you print the module object, you get some information about it:

```
>>> print(math)
<module 'math' (built-in)>
```

The module object contains the functions and variables defined in the module. To access one of the functions, you have to specify the name of the module and the name of the function, separated by a dot (also known as a period). This format is called *dot notation*.

```
>>> ratio = signal_power / noise_power
>>> decibels = 10 * math.log10(ratio)

>>> radians = 0.7
>>> height = math.sin(radians)
```

The first example computes the logarithm base 10 of the signal-to-noise ratio. The `math` module also provides a function called `log` that computes logarithms base e .

The second example finds the sine of `radians`. The name of the variable is a hint that `sin` and the other trigonometric functions (`cos`, `tan`, etc.) take arguments in radians. To convert from degrees to radians, divide by 360 and multiply by 2π :

```
>>> degrees = 45
>>> radians = degrees / 360.0 * 2 * math.pi
>>> math.sin(radians)
0.7071067811865476
```

The expression `math.pi` gets the variable `pi` from the `math` module. The value of this variable is an approximation of π , accurate to about 15 digits.

If you know your trigonometry, you can check the previous result by comparing it to the square root of two divided by two:

```
>>> math.sqrt(2) / 2.0
0.7071067811865476
```

4.6 Adding new functions

So far, we have only been using the functions that come with Python, but it is also possible to add new functions. A *function definition* specifies the name of a new function and the sequence of statements that execute when the function is called. Once we define a function, we can reuse the function over and over throughout our program.

Here is an example:

```
def print_lyrics():
    print("I'm a lumberjack, and I'm okay.")
    print('I sleep all night and I work all day.')
```

`def` is a keyword that indicates that this is a function definition. The name of the function is `print_lyrics`. The rules for function names are the same as for variable names: letters, numbers and some punctuation marks are legal, but the first character can't be a number. You can't use a keyword as the name of a function, and you should avoid having a variable and a function with the same name.

The empty parentheses after the name indicate that this function doesn't take any arguments. Later we will build functions that take arguments as their inputs.

The first line of the function definition is called the *header*; the rest is called the *body*. The header has to end with a colon and the body has to be indented. By convention, the indentation is always four spaces. The body can contain any number of statements.

If you type a function definition in interactive mode, the interpreter prints ellipses (...) to let you know that the definition isn't complete:

```
>>> def print_lyrics():
...     print("I'm a lumberjack, and I'm okay.")
...     print('I sleep all night and I work all day.')
... 
```

Defining a function creates a variable with the same name.

```
>>> print(print_lyrics)
<function print_lyrics at 0xb7e99e9c>
>>> print(type(print_lyrics))
<class 'function'>
```

The value of `print_lyrics` is a *function object*, which has type “function”.

The syntax for calling the new function is the same as for built-in functions:

```
>>> print_lyrics()
I'm a lumberjack, and I'm okay.
I sleep all night and I work all day.
```

Once you have defined a function, you can use it inside another function. For example, to repeat the previous refrain, we could write a function called `repeat_lyrics`:

```
def repeat_lyrics():
    print_lyrics()
    print_lyrics()
```

And then call `repeat_lyrics`:

```
>>> repeat_lyrics()
I'm a lumberjack, and I'm okay.
I sleep all night and I work all day.
I'm a lumberjack, and I'm okay.
I sleep all night and I work all day.
```

But that’s not really how the song goes.

4.7 Definitions and uses

Pulling together the code fragments from the previous section, the whole program looks like this:

```
def print_lyrics():
    print("I'm a lumberjack, and I'm okay.")
    print('I sleep all night and I work all day.')

def repeat_lyrics():
    print_lyrics()
    print_lyrics()

repeat_lyrics()
```

Code: <http://www.py4e.com/code3/lyrics.py>

This program contains two function definitions: `print_lyrics` and `repeat_lyrics`. Function definitions get executed just like other statements, but the effect is to create function objects. The statements inside the function do not get executed until the function is called, and the function definition generates no output.

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

Exercise 2: Move the last line of this program to the top, so the function call appears before the definitions. Run the program and see what error message you get.

Exercise 3: Move the function call back to the bottom and move the definition of `print_lyrics` after the definition of `repeat_lyrics`. What happens when you run this program?

4.8 Flow of execution

In order to ensure that a function is defined before its first use, you have to know the order in which statements are executed, which is called the *flow of execution*.

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**.

A function call is like a detour in the flow of execution. Instead of going to the next statement, the flow jumps to the body of the function, executes all the statements there, and then comes back to pick up where it left off.

That sounds simple enough, until you 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 good 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 you read a program, you don't always want to read from top to bottom. Sometimes it makes more sense if you follow the flow of execution.

4.9 Parameters and arguments

Some of the built-in functions we have seen require arguments. For example, when you call `math.sin` you pass a number as an argument. Some functions take more than one argument: `math.pow` takes two, the base and the exponent.

Inside the function, the arguments are assigned to variables called *parameters*. Here is an example of a user-defined function that takes an argument:

```
def print_twice(bruce):
    print(bruce)
    print(bruce)
```

This function assigns the argument to a parameter named **bruce**. When the function is called, it prints the value of the parameter (whatever it is) twice.

This function works with any value that can be printed.

```
>>> print_twice('Spam')
Spam
Spam
>>> print_twice(17)
17
17
>>> import math
>>> print_twice(math.pi)
3.141592653589793
3.141592653589793
```

The same rules of composition that apply to built-in functions also apply to user-defined functions, so we can use any kind of expression as an argument for `print_twice`:

```
>>> print_twice('Spam '*4)
Spam Spam Spam Spam
Spam Spam Spam Spam
>>> print_twice(math.cos(math.pi))
-1.0
-1.0
```

The argument is evaluated before the function is called, so in the examples the expressions `'Spam '*4` and `math.cos(math.pi)` are only evaluated once.

You can also use a variable as an argument:

```
>>> michael = 'Eric, the half a bee.'
>>> print_twice(michael)
Eric, the half a bee.
Eric, the half a bee.
```

The name of the variable we pass as an argument (**michael**) has nothing to do with the name of the parameter (**bruce**). It doesn't matter what the value was called back home (in the caller); here in `print_twice`, we call everybody **bruce**.

4.10 Fruitful functions and void functions

Some of the functions we are using, such as the math functions, yield results; for lack of a better name, I call them *fruitful functions*. Other functions, like `print_twice`, perform an action but don't return a value. They are called *void functions*.

When you call a fruitful function, you almost always want to do something with the result; for example, you might assign it to a variable or use it as part of an expression:

```
x = math.cos(radians)
golden = (math.sqrt(5) + 1) / 2
```

When you call a function in interactive mode, Python displays the result:

```
>>> math.sqrt(5)
2.23606797749979
```

But in a script, if you call a fruitful function and do not store the result of the function in a variable, the return value vanishes into the mist!

```
math.sqrt(5)
```

This script computes the square root of 5, but since it doesn't store the result in a variable or display the result, it is not very useful.

Void functions might display something on the screen or have some other effect, but they don't have a return value. If you try to assign the result to a variable, you get a special value called `None`.

```
>>> result = print_twice('Bing')
Bing
Bing
>>> print(result)
None
```

The value `None` is not the same as the string "None". It is a special value that has its own type:

```
>>> print(type(None))
<class 'NoneType'>
```

To return a result from a function, we use the `return` statement in our function. For example, we could make a very simple function called `addtwo` that adds two numbers together and returns a result.

```
def addtwo(a, b):  
    added = a + b  
    return added  
  
x = addtwo(3, 5)  
print(x)  
  
# Code: http://www.py4e.com/code3/addtwo.py
```

When this script executes, the `print` statement will print out “8” because the `addtwo` function was called with 3 and 5 as arguments. Within the function, the parameters `a` and `b` were 3 and 5 respectively. The function computed the sum of the two numbers and placed it in the local function variable named `added`. Then it used the `return` statement to send the computed value back to the calling code as the function result, which was assigned to the variable `x` and printed out.

4.11 Why functions?

It may not be clear why it is worth the trouble to divide a program into functions. There are several reasons:

- Creating a new function gives you an opportunity to name a group of statements, which makes your program easier to read, understand, and debug.
- Functions can make a program smaller by eliminating repetitive code. Later, if you make a change, you only have to make it in one place.
- Dividing a long program into functions allows you to debug the parts one at a time and then assemble them into a working whole.
- Well-designed functions are often useful for many programs. Once you write and debug one, you can reuse it.

Throughout the rest of the book, often we will use a function definition to explain a concept. Part of the skill of creating and using functions is to have a function properly capture an idea such as “find the smallest value in a list of values”. Later we will show you code that finds the smallest in a list of values and we will present it to you as a function named `min` which takes a list of values as its argument and returns the smallest value in the list.

4.12 Debugging

If you are using a text editor to write your scripts, you might run into problems with spaces and tabs. The best way to avoid these problems is to use spaces exclusively (no tabs). Most text editors that know about Python do this by default, but some don’t.

Tabs and spaces are usually invisible, which makes them hard to debug, so try to find an editor that manages indentation for you.

Also, don't forget to save your program before you run it. Some development environments do this automatically, but some don't. In that case, the program you are looking at in the text editor is not the same as the program you are running.

Debugging can take a long time if you keep running the same incorrect program over and over!

Make sure that the code you are looking at is the code you are running. If you're not sure, put something like `print("hello")` at the beginning of the program and run it again. If you don't see `hello`, you're not running the right program!

4.13 Glossary

algorithm A general process for solving a category of problems.

argument A value provided to a function when the function is called. This value is assigned to the corresponding parameter in the function.

body The sequence of statements inside a function definition.

composition Using an expression as part of a larger expression, or a statement as part of a larger statement.

deterministic Pertaining to a program that does the same thing each time it runs, given the same inputs.

dot notation The syntax for calling a function in another module by specifying the module name followed by a dot (period) and the function name.

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

fruitful function A function that returns a value.

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

function call A statement that executes a function. It consists of the function name followed by an argument list.

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

function object A value created by a function definition. The name of the function is a variable that refers to a function object.

header The first line of a function definition.

import statement A statement that reads a module file and creates a module object.

module object A value created by an `import` statement that provides access to the data and code defined in a module.

parameter A name used inside a function to refer to the value passed as an argument.

pseudorandom Pertaining to a sequence of numbers that appear to be random, but are generated by a deterministic program.

return value The result of a function. If a function call is used as an expression, the return value is the value of the expression.

void function A function that does not return a value.

4.14 Exercises

Exercise 4: What is the purpose of the “def” keyword in Python?

- a) It is slang that means “the following code is really cool”
- b) It indicates the start of a function
- c) It indicates that the following indented section of code is to be stored for later
- d) b and c are both true
- e) None of the above

Exercise 5: What will the following Python program print out?

```
def fred():
    print("Zap")
```

```
def jane():
    print("ABC")
```

```
jane()
fred()
jane()
```

- a) Zap ABC jane fred jane
- b) Zap ABC Zap
- c) ABC Zap jane
- d) ABC Zap ABC
- e) Zap Zap Zap

Exercise 6: Rewrite your pay computation with time-and-a-half for over-time and create a function called `compute_pay` which takes two parameters (hours and rate).

```
Enter Hours: 45
Enter Rate: 10
Pay: 475.0
```

Exercise 7: Rewrite the grade program from the previous chapter using a function called `compute_grade` that takes a score as its parameter and returns a grade as a string.

Score	Grade
>= 0.9	A
>= 0.8	B
>= 0.7	C
>= 0.6	D
< 0.6	F

```
Enter score: 0.95
A
```

```
Enter score: perfect
Bad score
```

```
Enter score: 10.0
Bad score
```

```
Enter score: 0.75
C
```

```
Enter score: 0.5
F
```

Run the program repeatedly to test the various different values for input.

Chapter 5

Iteration

5.1 Updating variables

A common pattern in assignment statements is an assignment statement that updates a variable, where the new value of the variable depends on the old.

```
x = x + 1
```

This means “get the current value of `x`, add 1, and then update `x` with the new value.”

If you try to update a variable that doesn’t exist, you get an error, because Python evaluates the right side before it assigns a value to `x`:

```
>>> x = x + 1
NameError: name 'x' is not defined
```

Before you can update a variable, you have to *initialize* it, usually with a simple assignment:

```
>>> x = 0
>>> x = x + 1
```

Updating a variable by adding 1 is called an *increment*; subtracting 1 is called a *decrement*.

5.2 The while statement

Computers are often used to automate repetitive tasks. Repeating identical or similar tasks without making errors is something that computers do well and people do poorly. Because iteration is so common, Python provides several language features to make it easier.

One form of iteration in Python is the `while` statement. Here is a simple program that counts down from five and then says “Blastoff!”.

```

n = 5
while n > 0:
    print(n)
    n = n - 1
print('Blastoff!')

```

You can almost read the **while** statement as if it were English. It means, “While **n** is greater than 0, display the value of **n** and then reduce the value of **n** by 1. When you get to 0, exit the **while** statement and display the word **Blastoff!**”

More formally, here is the flow of execution for a **while** statement:

1. Evaluate the condition, yielding **True** or **False**.
2. If the condition is false, exit the **while** statement and continue execution at the next statement.
3. If the condition is true, execute the body and then go back to step 1.

This type of flow is called a *loop* because the third step loops back around to the top. We call each time we execute the body of the loop an *iteration*. For the above loop, we would say, “It had five iterations”, which means that the body of the loop was executed five times.

The body of the loop should change the value of one or more variables so that eventually the condition becomes false and the loop terminates. We call the variable that changes each time the loop executes and controls when the loop finishes the *iteration variable*. If there is no iteration variable, the loop will repeat forever, resulting in an *infinite loop*.

5.3 Infinite loops

An endless source of amusement for programmers is the observation that the directions on shampoo, “Lather, rinse, repeat,” are an infinite loop because there is no *iteration variable* telling you how many times to execute the loop.

In the case of **countdown**, we can prove that the loop terminates because we know that the value of **n** is finite, and we can see that the value of **n** gets smaller each time through the loop, so eventually we have to get to 0. Other times a loop is obviously infinite because it has no iteration variable at all.

Sometimes you don’t know it’s time to end a loop until you get half way through the body. In that case you can write an infinite loop on purpose and then use the **break** statement to jump out of the loop.

This loop is obviously an *infinite loop* because the logical expression on the **while** statement is simply the logical constant **True**:

```

n = 10
while True:
    print(n, end=' ')
    n = n - 1
print('Done!')

```

If you make the mistake and run this code, you will learn quickly how to stop a runaway Python process on your system or find where the power-off button is on your computer. This program will run forever or until your battery runs out because the logical expression at the top of the loop is always true by virtue of the fact that the expression is the constant value `True`.

While this is a dysfunctional infinite loop, we can still use this pattern to build useful loops as long as we carefully add code to the body of the loop to explicitly exit the loop using `break` when we have reached the exit condition.

For example, suppose you want to take input from the user until they type `done`. You could write:

```
while True:
    line = input('> ')
    if line == 'done':
        break
    print(line)
print('Done!')
```

Code: <http://www.py4e.com/code3/copytildone1.py>

The loop condition is `True`, which is always true, so the loop runs repeatedly until it hits the `break` statement.

Each time through, it prompts the user with an angle bracket. If the user types `done`, the `break` statement exits the loop. Otherwise the program echoes whatever the user types and goes back to the top of the loop. Here's a sample run:

```
> hello there
hello there
> finished
finished
> done
Done!
```

This way of writing `while` loops is common because you can check the condition anywhere in the loop (not just at the top) and you can express the stop condition affirmatively (“stop when this happens”) rather than negatively (“keep going until that happens.”).

5.4 Finishing iterations with `continue`

Sometimes you are in an iteration of a loop and want to finish the current iteration and immediately jump to the next iteration. In that case you can use the `continue` statement to skip to the next iteration without finishing the body of the loop for the current iteration.

Here is an example of a loop that copies its input until the user types “done”, but treats lines that start with the hash character as lines not to be printed (kind of like Python comments).

```

while True:
    line = input('> ')
    if line[0] == '#':
        continue
    if line == 'done':
        break
    print(line)
print('Done!')

# Code: http://www.py4e.com/code3/copytildone2.py

```

Here is a sample run of this new program with `continue` added.

```

> hello there
hello there
> # don't print this
> print this!
print this!
> done
Done!

```

All the lines are printed except the one that starts with the hash sign because when the `continue` is executed, it ends the current iteration and jumps back to the `while` statement to start the next iteration, thus skipping the `print` statement.

5.5 Definite loops using `for`

Sometimes we want to loop through a *set* of things such as a list of words, the lines in a file, or a list of numbers. When we have a list of things to loop through, we can construct a *definite* loop using a `for` statement. We call the `while` statement an *indefinite* loop because it simply loops until some condition becomes `False`, whereas the `for` loop is looping through a known set of items so it runs through as many iterations as there are items in the set.

The syntax of a `for` loop is similar to the `while` loop in that there is a `for` statement and a loop body:

```

friends = ['Joseph', 'Glenn', 'Sally']
for friend in friends:
    print('Happy New Year:', friend)
print('Done!')

```

In Python terms, the variable `friends` is a list¹ of three strings and the `for` loop goes through the list and executes the body once for each of the three strings in the list resulting in this output:

¹We will examine lists in more detail in a later chapter.

```
Happy New Year: Joseph
Happy New Year: Glenn
Happy New Year: Sally
Done!
```

Translating this `for` loop to English is not as direct as the `while`, but if you think of friends as a *set*, it goes like this: “Run the statements in the body of the `for` loop once for each friend *in* the set named `friends`.”

Looking at the `for` loop, *for* and *in* are reserved Python keywords, and `friend` and `friends` are variables.

```
for friend in friends:
    print('Happy New Year:', friend)
```

In particular, `friend` is *the iteration variable for the `for` loop*. The variable `friend` changes for each iteration of the loop and controls when the `for` loop completes. The *iteration variable* steps successively through the three strings stored in the `friends` variable.

5.6 Loop patterns

Often we use a `for` or `while` loop to go through a list of items or the contents of a file and we are looking for something such as the largest or smallest value of the data we scan through.

These loops are generally constructed by:

- Initializing one or more variables before the loop starts
- Performing some computation on each item in the loop body, possibly changing the variables in the body of the loop
- Looking at the resulting variables when the loop completes

We will use a list of numbers to demonstrate the concepts and construction of these loop patterns.

5.6.1 Counting and summing loops

For example, to count the number of items in a list, we would write the following `for` loop:

```
count = 0
for intervar in [3, 41, 12, 9, 74, 15]:
    count = count + 1
print('Count: ', count)
```


We set the variable `count` to zero before the loop starts, then we write a `for` loop to run through the list of numbers. Our *iteration* variable is named `itervar` and while we do not use `itervar` in the loop, it does control the loop and cause the loop body to be executed once for each of the values in the list.

In the body of the loop, we add 1 to the current value of `count` for each of the values in the list. While the loop is executing, the value of `count` is the number of values we have seen “so far”.

Once the loop completes, the value of `count` is the total number of items. The total number “falls in our lap” at the end of the loop. We construct the loop so that we have what we want when the loop finishes.

Another similar loop that computes the total of a set of numbers is as follows:

```
total = 0
for itervar in [3, 41, 12, 9, 74, 15]:
    total = total + itervar
print('Total: ', total)
```

In this loop we *do* use the *iteration variable*. Instead of simply adding one to the `count` as in the previous loop, we add the actual number (3, 41, 12, etc.) to the running total during each loop iteration. If you think about the variable `total`, it contains the “running total of the values so far”. So before the loop starts `total` is zero because we have not yet seen any values, during the loop `total` is the running total, and at the end of the loop `total` is the overall total of all the values in the list.

As the loop executes, `total` accumulates the sum of the elements; a variable used this way is sometimes called an *accumulator*.

Neither the counting loop nor the summing loop are particularly useful in practice because there are built-in functions `len()` and `sum()` that compute the number of items in a list and the total of the items in the list respectively.

5.7 Debugging

As you start writing bigger programs, you might find yourself spending more time debugging. More code means more chances to make an error and more places for bugs to hide.

One way to cut your debugging time is “debugging by bisection.” For example, if there are 100 lines in your program and you check them one at a time, it would take 100 steps.

Instead, try to break the problem in half. Look at the middle of the program, or near it, for an intermediate value you can check. Add a `print` statement (or something else that has a verifiable effect) and run the program.

If the mid-point check is incorrect, the problem must be in the first half of the program. If it is correct, the problem is in the second half.

Every time you perform a check like this, you halve the number of lines you have to search. After six steps (which is much less than 100), you would be down to one or two lines of code, at least in theory.

In practice it is not always clear what the “middle of the program” is and not always possible to check it. It doesn’t make sense to count lines and find the exact midpoint. Instead, think about places in the program where there might be errors and places where it is easy to put a check. Then choose a spot where you think the chances are about the same that the bug is before or after the check.

5.8 Glossary

accumulator A variable used in a loop to add up or accumulate a result.

counter A variable used in a loop to count the number of times something happened. We initialize a counter to zero and then increment the counter each time we want to “count” something.

decrement An update that decreases the value of a variable.

initialize An assignment that gives an initial value to a variable that will be updated.

increment An update that increases the value of a variable (often by one).

infinite loop A loop in which the terminating condition is never satisfied or for which there is no terminating condition.

iteration Repeated execution of a set of statements using either a function that calls itself or a loop.

5.9 Exercises

Exercise 1: Write a program which repeatedly reads numbers until the user enters “done”. Once “done” is entered, print out the total, count, and average of the numbers. If the user enters anything other than a number, detect their mistake using `try` and `except` and print an error message and skip to the next number.

```
Enter a number: 4
Enter a number: 5
Enter a number: bad data
Invalid input
Enter a number: 7
Enter a number: done
16 3 5.333333333333333
```

Exercise 2: Write another program that prompts for a list of numbers as above and at the end prints out both the maximum and minimum of the numbers instead of the average.

Chapter 6

Strings

6.1 A string is a sequence

A string is a *sequence* of characters. You can access the characters one at a time with the bracket operator:

```
>>> fruit = 'banana'
>>> letter = fruit[1]
```

The second statement extracts the character at index position 1 from the `fruit` variable and assigns it to the `letter` variable.

The expression in brackets is called an *index*. The index indicates which character in the sequence you want (hence the name).

But you might not get what you expect:

```
>>> print(letter)
a
```

For most people, the first letter of “banana” is “b”, not “a”. But in Python, the index is an offset from the beginning of the string, and the offset of *the first letter is zero*.

```
>>> letter = fruit[0]
>>> print(letter)
b
```

So “b” is the 0th letter (“zero-th”) of “banana”, “a” is the 1th letter (“one-th”), and “n” is the 2th (“two-th”) letter.

You can use any expression, including variables and operators, as an index, but the value of the index has to be an integer. Otherwise you get:

```
>>> letter = fruit[1.5]
TypeError: string indices must be integers
```

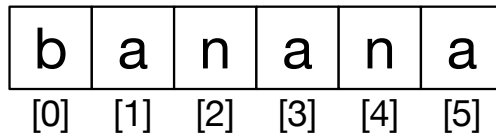


Figure 6.1: String Indexes

6.2 Getting the length of a string using `len`

`len` is a built-in function that returns the number of characters in a string:

```
>>> fruit = 'banana'
>>> len(fruit)
6
```

To get the last letter of a string, you might be tempted to try something like this:

```
>>> length = len(fruit)
>>> last = fruit[length]
IndexError: string index out of range
```

The reason for the `IndexError` is that there is no letter in “banana” with the index 6. Since we started counting at zero, the six letters are numbered 0 to 5. To get the last character, you have to subtract 1 from `length`:

```
>>> last = fruit[length-1]
>>> print(last)
a
```

Alternatively, you can use negative indices, which count backward from the end of the string. The expression `fruit[-1]` yields the last letter, `fruit[-2]` yields the second to last, and so on.

6.3 Traversal through a string with a loop

A lot of computations involve processing a string one character at a time. Often they start at the beginning, select each character in turn, do something to it, and continue until the end. This pattern of processing is called a *traversal*. One way to write a traversal is with a `while` loop:

```
index = 0
while index < len(fruit):
    letter = fruit[index]
    print(letter)
    index = index + 1
```

This loop traverses the string and displays each letter on a line by itself. The loop condition is `index < len(fruit)`, so when `index` is equal to the length of the string, the condition is false, and the body of the loop is not executed. The last character accessed is the one with the index `len(fruit)-1`, which is the last character in the string.

Exercise 1: Write a `while` loop that starts at the last character in the string and works its way backwards to the first character in the string, printing each letter on a separate line, except backwards.

Another way to write a traversal is with a `for` loop:

```
for char in fruit:
    print(char)
```

Each time through the loop, the next character in the string is assigned to the variable `char`. The loop continues until no characters are left.

6.4 String slices

A segment of a string is called a *slice*. Selecting a slice is similar to selecting a character:

```
>>> s = 'Monty Python'
>>> print(s[0:5])
Monty
>>> print(s[6:12])
Python
```

The operator returns the part of the string from the “n-th” character to the “m-th” character, including the first but excluding the last.

If you omit the first index (before the colon), the slice starts at the beginning of the string. If you omit the second index, the slice goes to the end of the string:

```
>>> fruit = 'banana'
>>> fruit[:3]
'ban'
>>> fruit[3:]
'ana'
```

If the first index is greater than or equal to the second the result is an *empty string*, represented by two quotation marks:

```
>>> fruit = 'banana'
>>> fruit[3:3]
''
```

An empty string contains no characters and has length 0, but other than that, it is the same as any other string.

Exercise 2: Given that `fruit` is a string, what does `fruit[:]` mean?

6.5 Strings are immutable

It is tempting to use the operator on the left side of an assignment, with the intention of changing a character in a string. For example:

```
>>> greeting = 'Hello, world!'
>>> greeting[0] = 'J'
TypeError: 'str' object does not support item assignment
```

The “object” in this case is the string and the “item” is the character you tried to assign. For now, an *object* is the same thing as a value, but we will refine that definition later. An *item* is one of the values in a sequence.

The reason for the error is that strings are *immutable*, which means you can’t change an existing string. The best you can do is create a new string that is a variation on the original:

```
>>> greeting = 'Hello, world!'
>>> new_greeting = 'J' + greeting[1:]
>>> print(new_greeting)
Jello, world!
```

This example concatenates a new first letter onto a slice of `greeting`. It has no effect on the original string.

6.6 Looping and counting

The following program counts the number of times the letter “a” appears in a string:

```
word = 'banana'
count = 0
for letter in word:
    if letter == 'a':
        count = count + 1
print(count)
```

This program demonstrates another pattern of computation called a *counter*. The variable `count` is initialized to 0 and then incremented each time an “a” is found. When the loop exits, `count` contains the result: the total number of a’s.

Exercise 3: Encapsulate this code in a function named `count`, and generalize it so that it accepts the string and the letter as arguments.

6.7 The in operator

The word `in` is a boolean operator that takes two strings and returns `True` if the first appears as a substring in the second:

```
>>> 'a' in 'banana'
True
>>> 'seed' in 'banana'
False
```

6.8 String comparison

The comparison operators work on strings. To see if two strings are equal:

```
if word == 'banana':
    print('All right, bananas.')
```

Other comparison operations are useful for putting words in alphabetical order:

```
if word < 'banana':
    print('Your word,' + word + ', comes before banana.')
elif word > 'banana':
    print('Your word,' + word + ', comes after banana.')
else:
    print('All right, bananas.')
```

Python does not handle uppercase and lowercase letters the same way that people do. All the uppercase letters come before all the lowercase letters, so:

```
Your word, Pineapple, comes before banana.
```

A common way to address this problem is to convert strings to a standard format, such as all lowercase, before performing the comparison. Keep that in mind in case you have to defend yourself against a man armed with a Pineapple.

6.9 String methods

Strings are an example of Python *objects*. An object contains both data (the actual string itself) and *methods*, which are effectively functions that are built into the object and are available to any *instance* of the object.

Python has a function called `dir` which lists the methods available for an object. The `type` function shows the type of an object and the `dir` function shows the available methods.


```

>>> stuff = 'Hello world'
>>> type(stuff)
<class 'str'>
>>> dir(stuff)
['capitalize', 'casefold', 'center', 'count', 'encode',
 'endswith', 'expandtabs', 'find', 'format', 'format_map',
 'index', 'isalnum', 'isalpha', 'isdecimal', 'isdigit',
 'isidentifier', 'islower', 'isnumeric', 'isprintable',
 'isspace', 'istitle', 'isupper', 'join', 'ljust', 'lower',
 'lstrip', 'maketrans', 'partition', 'replace', 'rfind',
 'rindex', 'rjust', 'rpartition', 'rsplit', 'rstrip',
 'split', 'splitlines', 'startswith', 'strip', 'swapcase',
 'title', 'translate', 'upper', 'zfill']
>>> help(str.capitalize)
Help on method_descriptor:

capitalize(...)
    S.capitalize() -> str

    Return a capitalized version of S, i.e. make the first character
    have upper case and the rest lower case.
>>>

```

While the `dir` function lists the methods, and you can use `help` to get some simple documentation on a method, a better source of documentation for string methods would be <https://docs.python.org/library/stdtypes.html#string-methods>.

Calling a *method* is similar to calling a function (it takes arguments and returns a value) but the syntax is different. We call a method by appending the method name to the variable name using the period as a delimiter.

For example, the method `upper` takes a string and returns a new string with all uppercase letters:

Instead of the function syntax `upper(word)`, it uses the method syntax `word.upper()`.

```

>>> word = 'banana'
>>> new_word = word.upper()
>>> print(new_word)
BANANA

```

This form of *dot notation* specifies the name of the method, `upper`, and the name of the string to apply the method to, `word`. The empty parentheses indicate that this method takes no argument.

A method call is called an *invocation*; in this case, we would say that we are invoking `upper` on the `word`.

For example, there is a string method named `find` that searches for the position of one string within another:

```
>>> word = 'banana'
>>> index = word.find('a')
>>> print(index)
1
```

In this example, we invoke `find` on `word` and pass the letter we are looking for as a parameter.

The `find` method can find substrings as well as characters:

```
>>> word.find('na')
2
```

It can take as a second argument the index where it should start:

```
>>> word.find('na', 3)
4
```

One common task is to remove white space (spaces, tabs, or newlines) from the beginning and end of a string using the `strip` method:

```
>>> line = ' Here we go '
>>> line.strip()
'Here we go'
```

Some methods such as *startswith* return boolean values.

```
>>> line = 'Have a nice day'
>>> line.startswith('Have')
True
>>> line.startswith('h')
False
```

You will note that `startswith` requires case to match, so sometimes we take a line and map it all to lowercase before we do any checking using the `lower` method.

```
>>> line = 'Have a nice day'
>>> line.startswith('h')
False
>>> line.lower()
'have a nice day'
>>> line.lower().startswith('h')
True
```

In the last example, the method `lower` is called and then we use `startswith` to see if the resulting lowercase string starts with the letter “h”. As long as we are careful with the order, we can make multiple method calls in a single expression.

****Exercise 4:** There is a string method called `count` that is similar to the function in the previous exercise. Read the documentation of this method at:

<https://docs.python.org/library/stdtypes.html#string-methods>

Write an invocation that counts the number of times the letter a occurs in “banana”.

6.10 Parsing strings

Often, we want to look into a string and find a substring. For example if we were presented a series of lines formatted as follows:

```
From stephen.marquard@uct.ac.za Sat Jan 5 09:14:16 2008
```

and we wanted to pull out only the second half of the address (i.e., `uct.ac.za`) from each line, we can do this by using the `find` method and string slicing.

First, we will find the position of the at-sign in the string. Then we will find the position of the first space *after* the at-sign. And then we will use string slicing to extract the portion of the string which we are looking for.

```
>>> data = 'From stephen.marquard@uct.ac.za Sat Jan 5 09:14:16 2008'
>>> atpos = data.find('@')
>>> print(atpos)
21
>>> spos = data.find(' ',atpos)
>>> print(spos)
31
>>> host = data[atpos+1:spos]
>>> print(host)
uct.ac.za
>>>
```

We use a version of the `find` method which allows us to specify a position in the string where we want `find` to start looking. When we slice, we extract the characters from “one beyond the at-sign through up to *but not including* the space character”.

The documentation for the `find` method is available at

<https://docs.python.org/library/stdtypes.html#string-methods>.

6.11 read String Formatting Syntax:

<https://realpython.com/python-formatted-output/#the-python-formatted-string-literal-f-string>

6.12 Debugging

A skill that you should cultivate as you program is always asking yourself, “What could go wrong here?” or alternatively, “What crazy thing might our user do to crash our (seemingly) perfect program?”

For example, look at the program which we used to demonstrate the `while` loop in the chapter on iteration:

```
while True:
    line = input('> ')
    if line[0] == '#':
```

¹A tuple is a sequence of comma-separated values inside a pair of parenthesis. We will cover tuples in Chapter 10

```

        continue
    if line == 'done':
        break
    print(line)
print('Done!')

# Code: http://www.py4e.com/code3/copytildone2.py

```

Look what happens when the user enters an empty line of input:

```

> hello there
hello there
> # don't print this
> print this!
print this!
>
Traceback (most recent call last):
  File "copytildone.py", line 3, in <module>
    if line[0] == '#':
IndexError: string index out of range

```

The code works fine until it is presented an empty line. Then there is no zero-th character, so we get a traceback. There are two solutions to this to make line three “safe” even if the line is empty.

One possibility is to simply use the `startswith` method which returns `False` if the string is empty.

```
if line.startswith('#):
```

Another way is to safely write the `if` statement using the *guardian* pattern and make sure the second logical expression is evaluated only where there is at least one character in the string.:

```
if len(line) > 0 and line[0] == '#):
```

6.13 Glossary

counter A variable used to count something, usually initialized to zero and then incremented.

empty string A string with no characters and length 0, represented by two quotation marks.

format operator An operator, `%`, that takes a format string and a tuple and generates a string that includes the elements of the tuple formatted as specified by the format string.

format sequence A sequence of characters in a format string, like `%d`, that specifies how a value should be formatted.

format string A string, used with the format operator, that contains format sequences.

flag A boolean variable used to indicate whether a condition is true or false.

invocation A statement that calls a method.

immutable The property of a sequence whose items cannot be assigned.

index An integer value used to select an item in a sequence, such as a character in a string.

item One of the values in a sequence.

method A function that is associated with an object and called using dot notation.

object Something a variable can refer to. For now, you can use “object” and “value” interchangeably.

search A pattern of traversal that stops when it finds what it is looking for.

sequence An ordered set; that is, a set of values where each value is identified by an integer index.

slice A part of a string specified by a range of indices.

traverse To iterate through the items in a sequence, performing a similar operation on each.

6.14 Exercises

Exercise 5: Take the following Python code that stores a string:

```
str = 'X-DSPAM-Confidence:0.8475'
```

Use `find` and string slicing to extract the portion of the string after the colon character and then use the `float` function to convert the extracted string into a floating point number.

Exercise 6: Read the documentation of the string methods at <https://docs.python.org/library/stdtypes.html#string-methods>. You might want to experiment with some of them to make sure you understand how they work. `strip` and `replace` are particularly useful.

The documentation uses a syntax that might be confusing. For example, in `find(sub[, start[, end]])`, the brackets indicate optional arguments. So `sub` is required, but `start` is optional, and if you include `start`, then `end` is optional.

Chapter 8

Lists

8.1 A list is a sequence

Like a string, a *list* is a sequence of values. In a string, the values are characters; in a list, they can be any type. The values in list are called *elements* or sometimes *items*.

There are several ways to create a new list; the simplest is to enclose the elements in square brackets (“[” and “]”):

```
[10, 20, 30, 40]
['crunchy frog', 'ram bladder', 'lark vomit']
```

The first example is a list of four integers. The second is a list of three strings. The elements of a list don't have to be the same type. The following list contains a string, a float, an integer, and (lo!) another list:

```
['spam', 2.0, 5, [10, 20]]
```

A list within another list is *nested*.

A list that contains no elements is called an empty list; you can create one with empty brackets, [].

As you might expect, you can assign list values to variables:

```
>>> cheeses = ['Cheddar', 'Edam', 'Gouda']
>>> numbers = [17, 123]
>>> empty = []
>>> print(cheeses, numbers, empty)
['Cheddar', 'Edam', 'Gouda'] [17, 123] []
```

8.2 Lists are mutable

The syntax for accessing the elements of a list is the same as for accessing the characters of a string: the bracket operator. The expression inside the brackets specifies the index. Remember that the indices start at 0:

```
>>> print(cheeses[0])
Cheddar
```

Unlike strings, lists are mutable because you can change the order of items in a list or reassign an item in a list. When the bracket operator appears on the left side of an assignment, it identifies the element of the list that will be assigned.

```
>>> numbers = [17, 123]
>>> numbers[1] = 5
>>> print(numbers)
[17, 5]
```

The one-th element of `numbers`, which used to be 123, is now 5.

You can think of a list as a relationship between indices and elements. This relationship is called a *mapping*; each index “maps to” one of the elements.

List indices work the same way as string indices:

- Any integer expression can be used as an index.
- If you try to read or write an element that does not exist, you get an `IndexError`.
- If an index has a negative value, it counts backward from the end of the list.

The `in` operator also works on lists.

```
>>> cheeses = ['Cheddar', 'Edam', 'Gouda']
>>> 'Edam' in cheeses
True
>>> 'Brie' in cheeses
False
```

8.3 Traversing a list

The most common way to traverse the elements of a list is with a `for` loop. The syntax is the same as for strings:

```
for cheese in cheeses:
    print(cheese)
```


This works well if you only need to read the elements of the list. But if you want to write or update the elements, you need the indices. A common way to do that is to combine the functions `range` and `len`:

```
for i in range(len(numbers)):
    numbers[i] = numbers[i] * 2
```

This loop traverses the list and updates each element. `len` returns the number of elements in the list. `range` returns a list of indices from 0 to $n - 1$, where n is the length of the list. Each time through the loop, `i` gets the index of the next element. The assignment statement in the body uses `i` to read the old value of the element and to assign the new value.

A `for` loop over an empty list never executes the body:

```
for x in empty:
    print('This never happens.')
```

Although a list can contain another list, the nested list still counts as a single element. The length of this list is four:

```
['spam', 1, ['Brie', 'Roquefort', 'Pol le Veq'], [1, 2, 3]]
```

8.4 List operations

The `+` operator concatenates lists:

```
>>> a = [1, 2, 3]
>>> b = [4, 5, 6]
>>> c = a + b
>>> print(c)
[1, 2, 3, 4, 5, 6]
```

Similarly, the `*` operator repeats a list a given number of times:

```
>>> [0] * 4
[0, 0, 0, 0]
>>> [1, 2, 3] * 3
[1, 2, 3, 1, 2, 3, 1, 2, 3]
```

The first example repeats four times. The second example repeats the list three times.

8.5 List slices

The slice operator also works on lists:

```
>>> t = ['a', 'b', 'c', 'd', 'e', 'f']
>>> t[1:3]
['b', 'c']
>>> t[:4]
['a', 'b', 'c', 'd']
>>> t[3:]
['d', 'e', 'f']
```

If you omit the first index, the slice starts at the beginning. If you omit the second, the slice goes to the end. So if you omit both, the slice is a copy of the whole list.

```
>>> t[:]
['a', 'b', 'c', 'd', 'e', 'f']
```

Since lists are mutable, it is often useful to make a copy before performing operations that fold, spindle, or mutilate lists.

A slice operator on the left side of an assignment can update multiple elements:

```
>>> t = ['a', 'b', 'c', 'd', 'e', 'f']
>>> t[1:3] = ['x', 'y']
>>> print(t)
['a', 'x', 'y', 'd', 'e', 'f']
```

8.6 List methods

Python provides methods that operate on lists. For example, `append` adds a new element to the end of a list:

```
>>> t = ['a', 'b', 'c']
>>> t.append('d')
>>> print(t)
['a', 'b', 'c', 'd']
```

`extend` takes a list as an argument and appends all of the elements:

```
>>> t1 = ['a', 'b', 'c']
>>> t2 = ['d', 'e']
>>> t1.extend(t2)
>>> print(t1)
['a', 'b', 'c', 'd', 'e']
```

This example leaves `t2` unmodified.

`sort` arranges the elements of the list from low to high:

```
>>> t = ['d', 'c', 'e', 'b', 'a']
>>> t.sort()
>>> print(t)
['a', 'b', 'c', 'd', 'e']
```

Most list methods are void; they modify the list and return `None`. If you accidentally write `t = t.sort()`, you will be disappointed with the result.

8.7 Deleting elements

There are several ways to delete elements from a list. If you know the index of the element you want, you can use `pop`:

```
>>> t = ['a', 'b', 'c']
>>> x = t.pop(1)
>>> print(t)
['a', 'c']
>>> print(x)
b
```

`pop` modifies the list and returns the element that was removed. If you don't provide an index, it deletes and returns the last element.

If you don't need the removed value, you can use the `del` operator:

```
>>> t = ['a', 'b', 'c']
>>> del t[1]
>>> print(t)
['a', 'c']
```

If you know the element you want to remove (but not the index), you can use `remove`:

```
>>> t = ['a', 'b', 'c']
>>> t.remove('b')
>>> print(t)
['a', 'c']
```

The return value from `remove` is `None`.

To remove more than one element, you can use `del` with a slice index:

```
>>> t = ['a', 'b', 'c', 'd', 'e', 'f']
>>> del t[1:5]
>>> print(t)
['a', 'f']
```

As usual, the slice selects all the elements up to, but not including, the second index.

8.8 Lists and functions

There are a number of built-in functions that can be used on lists that allow you to quickly look through a list without writing your own loops:

```
>>> nums = [3, 41, 12, 9, 74, 15]
>>> print(len(nums))
6
>>> print(max(nums))
74
>>> print(min(nums))
3
>>> print(sum(nums))
154
>>> print(sum(nums)/len(nums))
25
```

The `sum()` function only works when the list elements are numbers. The other functions (`max()`, `len()`, etc.) work with lists of strings and other types that can be comparable.

We could rewrite an earlier program that computed the average of a list of numbers entered by the user using a list.

First, the program to compute an average without a list:

```
total = 0
count = 0
while (True):
    inp = input('Enter a number: ')
    if inp == 'done': break
    value = float(inp)
    total = total + value
    count = count + 1

average = total / count
print('Average:', average)
```

Code: <http://www.py4e.com/code3/avenum.py>

In this program, we have `count` and `total` variables to keep the number and running total of the user's numbers as we repeatedly prompt the user for a number.

We could simply remember each number as the user entered it and use built-in functions to compute the sum and count at the end.

```
numlist = list()
while (True):
    inp = input('Enter a number: ')
    if inp == 'done': break
    value = float(inp)
```

```
numlist.append(value)

average = sum(numlist) / len(numlist)
print('Average:', average)

# Code: http://www.py4e.com/code3/avelist.py
```

We make an empty list before the loop starts, and then each time we have a number, we append it to the list. At the end of the program, we simply compute the sum of the numbers in the list and divide it by the count of the numbers in the list to come up with the average.

8.9 Lists and strings

A string is a sequence of characters and a list is a sequence of values, but a list of characters is not the same as a string. To convert from a string to a list of characters, you can use `list`:

```
>>> s = 'spam'
>>> t = list(s)
>>> print(t)
['s', 'p', 'a', 'm']
```

Because `list` is the name of a built-in function, you should avoid using it as a variable name. I also avoid the letter “l” because it looks too much like the number “1”. So that’s why I use “t”.

The `list` function breaks a string into individual letters. If you want to break a string into words, you can use the `split` method:

```
>>> s = 'pining for the fjords'
>>> t = s.split()
>>> print(t)
['pining', 'for', 'the', 'fjords']
>>> print(t[2])
the
```

Once you have used `split` to break the string into a list of words, you can use the index operator (square bracket) to look at a particular word in the list.

You can call `split` with an optional argument called a *delimiter* that specifies which characters to use as word boundaries. The following example uses a hyphen as a delimiter:

```
>>> s = 'spam-spam-spam'
>>> delimiter = '-'
>>> s.split(delimiter)
['spam', 'spam', 'spam']
```

`join` is the inverse of `split`. It takes a list of strings and concatenates the elements. `join` is a string method, so you have to invoke it on the delimiter and pass the list as a parameter:

```
>>> t = ['pinning', 'for', 'the', 'fjords']
>>> delimiter = ' '
>>> delimiter.join(t)
'pinning for the fjords'
```

In this case the delimiter is a space character, so `join` puts a space between words. To concatenate strings without spaces, you can use the empty string, `""`, as a delimiter.

8.10 Parsing lines

Usually when we are reading a file we want to do something to the lines other than just printing the whole line. Often we want to find the “interesting lines” and then *parse* the line to find some interesting *part* of the line. What if we wanted to print out the day of the week from those lines that start with “From”?

```
From stephen.marquard@uct.ac.za Sat Jan 5 09:14:16 2008
```

The `split` method is very effective when faced with this kind of problem. We can write a small program that looks for lines where the line starts with “From”, `split` those lines, and then print out the third word in the line:

```
fhand = open('mbox-short.txt')
for line in fhand:
    line = line.rstrip()
    if not line.startswith('From '): continue
    words = line.split()
    print(words[2])
```

Code: <http://www.py4e.com/code3/search5.py>

The program produces the following output:

```
Sat
Fri
Fri
Fri
...
```

Later, we will learn increasingly sophisticated techniques for picking the lines to work on and how we pull those lines apart to find the exact bit of information we are looking for.

8.11 Objects and values

If we execute these assignment statements:

```
a = 'banana'
b = 'banana'
```

we know that `a` and `b` both refer to a string, but we don't know whether they refer to the *same* string. There are two possible states:



Figure 8.1: Variables and Objects

In one case, `a` and `b` refer to two different objects that have the same value. In the second case, they refer to the same object.

To check whether two variables refer to the same object, you can use the `is` operator.

```
>>> a = 'banana'
>>> b = 'banana'
>>> a is b
True
```

In this example, Python only created one string object, and both `a` and `b` refer to it.

But when you create two lists, you get two objects:

```
>>> a = [1, 2, 3]
>>> b = [1, 2, 3]
>>> a is b
False
```

In this case we would say that the two lists are *equivalent*, because they have the same elements, but not *identical*, because they are not the same object. If two objects are identical, they are also equivalent, but if they are equivalent, they are not necessarily identical.

Until now, we have been using “object” and “value” interchangeably, but it is more precise to say that an object has a value. If you execute `a = [1, 2, 3]`, `a` refers to a list object whose value is a particular sequence of elements. If another list has the same elements, we would say it has the same value.

8.12 Aliasing

If `a` refers to an object and you assign `b = a`, then both variables refer to the same object:

```
>>> a = [1, 2, 3]
>>> b = a
>>> b is a
True
```

The association of a variable with an object is called a *reference*. In this example, there are two references to the same object.

An object with more than one reference has more than one name, so we say that the object is *aliased*.

If the aliased object is mutable, changes made with one alias affect the other:

```
>>> b[0] = 17
>>> print(a)
[17, 2, 3]
```

Although this behavior can be useful, it is error-prone. In general, it is safer to avoid aliasing when you are working with mutable objects.

For immutable objects like strings, aliasing is not as much of a problem. In this example:

```
a = 'banana'
b = 'banana'
```

it almost never makes a difference whether `a` and `b` refer to the same string or not.

8.13 List arguments

When you pass a list to a function, the function gets a reference to the list. If the function modifies a list parameter, the caller sees the change. For example, `delete_head` removes the first element from a list:

```
def delete_head(t):
    del t[0]
```

Here's how it is used:

```
>>> letters = ['a', 'b', 'c']
>>> delete_head(letters)
>>> print(letters)
['b', 'c']
```


The parameter `t` and the variable `letters` are aliases for the same object.

It is important to distinguish between operations that modify lists and operations that create new lists. For example, the `append` method modifies a list, but the `+` operator creates a new list:

```
>>> t1 = [1, 2]
>>> t2 = t1.append(3)
>>> print(t1)
[1, 2, 3]
>>> print(t2)
None

>>> t3 = t1 + [3]
>>> print(t3)
[1, 2, 3]
>>> t2 is t3
False
```

This difference is important when you write functions that are supposed to modify lists. For example, this function *does not* delete the head of a list:

```
def bad_delete_head(t):
    t = t[1:]                # WRONG!
```

The slice operator creates a new list and the assignment makes `t` refer to it, but none of that has any effect on the list that was passed as an argument.

An alternative is to write a function that creates and returns a new list. For example, `tail` returns all but the first element of a list:

```
def tail(t):
    return t[1:]
```

This function leaves the original list unmodified. Here's how it is used:

```
>>> letters = ['a', 'b', 'c']
>>> rest = tail(letters)
>>> print(rest)
['b', 'c']
```

Exercise 1: Write a function called `chop` that takes a list and modifies it, removing the first and last elements, and returns `None`. Then write a function called `middle` that takes a list and returns a new list that contains all but the first and last elements.

8.14 Debugging

Careless use of lists (and other mutable objects) can lead to long hours of debugging. Here are some common pitfalls and ways to avoid them:

1. Don't forget that most list methods modify the argument and return `None`. This is the opposite of the string methods, which return a new string and leave the original alone.

If you are used to writing string code like this:

```
word = word.strip()
```

It is tempting to write list code like this:

```
t = t.sort()           # WRONG!
```

Because `sort` returns `None`, the next operation you perform with `t` is likely to fail.

Before using list methods and operators, you should read the documentation carefully and then test them in interactive mode. The methods and operators that lists share with other sequences (like strings) are documented at:

docs.python.org/library/stdtypes.html#common-sequence-operations

The methods and operators that only apply to mutable sequences are documented at:

docs.python.org/library/stdtypes.html#mutable-sequence-types

2. Pick an idiom and stick with it.

Part of the problem with lists is that there are too many ways to do things. For example, to remove an element from a list, you can use `pop`, `remove`, `del`, or even a slice assignment.

To add an element, you can use the `append` method or the `+` operator. But don't forget that these are right:

```
t.append(x)
t = t + [x]
```

And these are wrong:

```
t.append([x])          # WRONG!
t = t.append(x)         # WRONG!
t + [x]                # WRONG!
t = t + x               # WRONG!
```

Try out each of these examples in interactive mode to make sure you understand what they do. Notice that only the last one causes a runtime error; the other three are legal, but they do the wrong thing.

3. Make copies to avoid aliasing.

If you want to use a method like `sort` that modifies the argument, but you need to keep the original list as well, you can make a copy.

```
orig = t[:]
t.sort()
```

In this example you could also use the built-in function `sorted`, which returns a new, sorted list and leaves the original alone. But in that case you should avoid using `sorted` as a variable name!

4. Lists, `split`, and files

When we read and parse files, there are many opportunities to encounter input that can crash our program so it is a good idea to revisit the *guardian* pattern when it comes writing programs that read through a file and look for a “needle in the haystack”.

Let’s revisit our program that is looking for the day of the week on the from lines of our file:

```
From stephen.marquard@uct.ac.za Sat Jan 5 09:14:16 2008
```

Since we are breaking this line into words, we could dispense with the use of `startswith` and simply look at the first word of the line to determine if we are interested in the line at all. We can use `continue` to skip lines that don’t have “From” as the first word as follows:

```
fhand = open('mbox-short.txt')
for line in fhand:
    words = line.split()
    if words[0] != 'From' : continue
    print(words[2])
```

This looks much simpler and we don’t even need to do the `rstrip` to remove the newline at the end of the file. But is it better?

```
python search8.py
Sat
Traceback (most recent call last):
  File "search8.py", line 5, in <module>
    if words[0] != 'From' : continue
IndexError: list index out of range
```

It kind of works and we see the day from the first line (Sat), but then the program fails with a traceback error. What went wrong? What messed-up data caused our elegant, clever, and very Pythonic program to fail?

You could stare at it for a long time and puzzle through it or ask someone for help, but the quicker and smarter approach is to add a `print` statement. The best place to add the print statement is right before the line where the program failed and print out the data that seems to be causing the failure.

Now this approach may generate a lot of lines of output, but at least you will immediately have some clue as to the problem at hand. So we add a print of the variable `words` right before line five. We even add a prefix “Debug:” to the line so we can keep our regular output separate from our debug output.

```

for line in fhand:
    words = line.split()
    print('Debug:', words)
    if words[0] != 'From' : continue
    print(words[2])

```

When we run the program, a lot of output scrolls off the screen but at the end, we see our debug output and the traceback so we know what happened just before the traceback.

```

Debug: ['X-DSPAM-Confidence:', '0.8475']
Debug: ['X-DSPAM-Probability:', '0.0000']
Debug: []
Traceback (most recent call last):
  File "search9.py", line 6, in <module>
    if words[0] != 'From' : continue
IndexError: list index out of range

```

Each debug line is printing the list of words which we get when we `split` the line into words. When the program fails, the list of words is empty `[]`. If we open the file in a text editor and look at the file, at that point it looks as follows:

```

X-DSPAM-Result: Innocent
X-DSPAM-Processed: Sat Jan 5 09:14:16 2008
X-DSPAM-Confidence: 0.8475
X-DSPAM-Probability: 0.0000

```

Details: <http://source.sakaiproject.org/viewsvn/?view=rev&rev=39772>

The error occurs when our program encounters a blank line! Of course there are “zero words” on a blank line. Why didn’t we think of that when we were writing the code? When the code looks for the first word (`word[0]`) to check to see if it matches “From”, we get an “index out of range” error.

This of course is the perfect place to add some *guardian* code to avoid checking the first word if the first word is not there. There are many ways to protect this code; we will choose to check the number of words we have before we look at the first word:

```

fhand = open('mbox-short.txt')
count = 0
for line in fhand:
    words = line.split()
    # print('Debug:', words)
    if len(words) == 0 : continue
    if words[0] != 'From' : continue
    print(words[2])

```

First we commented out the debug print statement instead of removing it, in case our modification fails and we need to debug again. Then we added a guardian statement that checks to see if we have zero words, and if so, we use `continue` to skip to the next line in the file.

We can think of the two `continue` statements as helping us refine the set of lines which are “interesting” to us and which we want to process some more. A line which has no words is “uninteresting” to us so we skip to the next line. A line which does not have “From” as its first word is uninteresting to us so we skip it.

The program as modified runs successfully, so perhaps it is correct. Our guardian statement does make sure that the `words[0]` will never fail, but perhaps it is not enough. When we are programming, we must always be thinking, “What might go wrong?”

Exercise 2: Figure out which line of the above program is still not properly guarded. See if you can construct a text file which causes the program to fail and then modify the program so that the line is properly guarded and test it to make sure it handles your new text file.

Exercise 3: Rewrite the guardian code in the above example without two `if` statements. Instead, use a compound logical expression using the `or` logical operator with a single `if` statement.

8.15 Glossary

aliasing A circumstance where two or more variables refer to the same object.

delimiter A character or string used to indicate where a string should be split.

element One of the values in a list (or other sequence); also called items.

equivalent Having the same value.

index An integer value that indicates an element in a list.

identical Being the same object (which implies equivalence).

list A sequence of values.

list traversal The sequential accessing of each element in a list.

nested list A list that is an element of another list.

object Something a variable can refer to. An object has a type and a value.

reference The association between a variable and its value.

8.16 Exercises

Exercise 4: Download a copy of the file www.py4e.com/code3/romeo.txt. Write a program to open the file *romeo.txt* and read it line by line. For each line, split the line into a list of words using the `split` function. For each word, check to see if the word is already in a list. If the word is not in the list, add it to the list. When the program completes, sort and print the resulting words in alphabetical order.

```
Enter file: romeo.txt
['Arise', 'But', 'It', 'Juliet', 'Who', 'already',
'and', 'breaks', 'east', 'envious', 'fair', 'grief',
'is', 'kill', 'light', 'moon', 'pale', 'sick', 'soft',
'sun', 'the', 'through', 'what', 'window',
'with', 'yonder']
```

Exercise 5: Write a program to read through the mail box data and when you find line that starts with “From”, you will split the line into words using the `split` function. We are interested in who sent the message, which is the second word on the From line.

```
From stephen.marquard@uct.ac.za Sat Jan 5 09:14:16 2008
```

You will parse the From line and print out the second word for each From line, then you will also count the number of From (not From:) lines and print out a count at the end. This is a good sample output with a few lines removed:

```
python fromcount.py
Enter a file name: mbox-short.txt
stephen.marquard@uct.ac.za
louis@media.berkeley.edu
zqian@umich.edu

[...some output removed...]

ray@media.berkeley.edu
cwen@iupui.edu
cwen@iupui.edu
cwen@iupui.edu
There were 27 lines in the file with From as the first word
```

Exercise 6: Rewrite the program that prompts the user for a list of numbers and prints out the maximum and minimum of the numbers at the end when the user enters “done”. Write the program to store the numbers the user enters in a list and use the `max()` and `min()` functions to compute the maximum and minimum numbers after the loop completes.

```
Enter a number: 6
Enter a number: 2
Enter a number: 9
Enter a number: 3
Enter a number: 5
Enter a number: done
Maximum: 9.0
Minimum: 2.0
```

Chapter 9

Dictionaries

A *dictionary* is like a list, but more general. In a list, the index positions have to be integers; in a dictionary, the indices can be (almost) any type.

You can think of a dictionary as a mapping between a set of indices (which are called *keys*) and a set of values. Each key maps to a value. The association of a key and a value is called a *key-value pair* or sometimes an *item*.

As an example, we'll build a dictionary that maps from English to Spanish words, so the keys and the values are all strings.

The function `dict` creates a new dictionary with no items. Because `dict` is the name of a built-in function, you should avoid using it as a variable name.

```
>>> eng2sp = dict()
>>> print(eng2sp)
{}
```

The curly brackets, `{}`, represent an empty dictionary. To add items to the dictionary, you can use square brackets:

```
>>> eng2sp['one'] = 'uno'
```

This line creates an item that maps from the key `'one'` to the value `"uno"`. If we print the dictionary again, we see a key-value pair with a colon between the key and value:

```
>>> print(eng2sp)
{'one': 'uno'}
```

This output format is also an input format. For example, you can create a new dictionary with three items. But if you print `eng2sp`, you might be surprised:

```
>>> eng2sp = {'one': 'uno', 'two': 'dos', 'three': 'tres'}
>>> print(eng2sp)
{'one': 'uno', 'three': 'tres', 'two': 'dos'}
```

The order of the key-value pairs is not the same. In fact, if you type the same example on your computer, you might get a different result. ~~In general, the order of items in a dictionary is unpredictable.~~ **As of Python 3.7, Dict order is guaranteed to be insertion order.**

But that’s not a problem because the elements of a dictionary are never indexed with integer indices. Instead, you use the keys to look up the corresponding values:

```
>>> print(eng2sp['two'])
'dos'
```

The key 'two' always maps to the value “dos” so the order of the items doesn’t matter.

If the key isn’t in the dictionary, you get an exception:

```
>>> print(eng2sp['four'])
KeyError: 'four'
```

The `len` function works on dictionaries; it returns the number of key-value pairs:

```
>>> len(eng2sp)
3
```

The `in` operator works on dictionaries; it tells you whether something appears as a *key* in the dictionary (appearing as a value is not good enough).

```
>>> 'one' in eng2sp
True
>>> 'uno' in eng2sp
False
```

To see whether something appears as a value in a dictionary, you can use the method `values`, which returns the values as a type that can be converted to a list, and then use the `in` operator:

```
>>> vals = list(eng2sp.values())
>>> 'uno' in vals
True
```

The `in` operator uses different algorithms for lists and dictionaries. For lists, it uses a linear search algorithm. As the list gets longer, the search time gets longer in direct proportion to the length of the list. For dictionaries, Python uses an algorithm called a *hash table* that has a remarkable property: the `in` operator takes about the same amount of time no matter how many items there are in a dictionary. I won’t explain why hash functions are so magical, but you can read more about it at wikipedia.org/wiki/Hash_table.

Exercise 1: Download a copy of the file www.py4e.com/code3/words.txt

Write a program that reads the words in *words.txt* and stores them as keys in a dictionary. It doesn’t matter what the values are. Then you can use the `in` operator as a fast way to check whether a string is in the dictionary.

9.1 Dictionary as a set of counters

Suppose you are given a string and you want to count how many times each letter appears. There are several ways you could do it:

1. You could create 26 variables, one for each letter of the alphabet. Then you could traverse the string and, for each character, increment the corresponding counter, probably using a chained conditional.
2. You could create a list with 26 elements. Then you could convert each character to a number (using the built-in function `ord`), use the number as an index into the list, and increment the appropriate counter.
3. You could create a dictionary with characters as keys and counters as the corresponding values. The first time you see a character, you would add an item to the dictionary. After that you would increment the value of an existing item.

Each of these options performs the same computation, but each of them implements that computation in a different way.

An *implementation* is a way of performing a computation; some implementations are better than others. For example, an advantage of the dictionary implementation is that we don't have to know ahead of time which letters appear in the string and we only have to make room for the letters that do appear.

Here is what the code might look like:

```
word = 'brontosaurus'
d = dict()
for c in word:
    if c not in d:
        d[c] = 1
    else:
        d[c] = d[c] + 1
print(d)
```

We are effectively computing a *histogram*, which is a statistical term for a set of counters (or frequencies).

The `for` loop traverses the string. Each time through the loop, if the character `c` is not in the dictionary, we create a new item with key `c` and the initial value 1 (since we have seen this letter once). If `c` is already in the dictionary we increment `d[c]`.

Here's the output of the program:

```
{'a': 1, 'b': 1, 'o': 2, 'n': 1, 's': 2, 'r': 2, 'u': 2, 't': 1}
```

The histogram indicates that the letters “a” and “b” appear once; “o” appears twice, and so on.

Dictionaries have a method called `get` that takes a key and a default value. If the key appears in the dictionary, `get` returns the corresponding value; otherwise it returns the default value. For example:

```
>>> counts = { 'chuck' : 1 , 'annie' : 42, 'jan': 100}
>>> print(counts.get('jan', 0))
100
>>> print(counts.get('tim', 0))
0
```

We can use `get` to write our histogram loop more concisely. Because the `get` method automatically handles the case where a key is not in a dictionary, we can reduce four lines down to one and eliminate the `if` statement.

```
word = 'brontosaurus'
d = dict()
for c in word:
    d[c] = d.get(c,0) + 1
print(d)
```

The use of the `get` method to simplify this counting loop ends up being a very commonly used “idiom” in Python and we will use it many times in the rest of the book. So you should take a moment and compare the loop using the `if` statement and `in` operator with the loop using the `get` method. They do exactly the same thing, but one is more succinct.

9.2 Dictionaries and files

One of the common uses of a dictionary is to count the occurrence of words in a file with some written text. Let’s start with a very simple file of words taken from the text of *Romeo and Juliet*.

For the first set of examples, we will use a shortened and simplified version of the text with no punctuation. Later we will work with the text of the scene with punctuation included.

```
But soft what light through yonder window breaks
It is the east and Juliet is the sun
Arise fair sun and kill the envious moon
Who is already sick and pale with grief
```

We will write a Python program to read through the lines of the file, break each line into a list of words, and then loop through each of the words in the line and count each word using a dictionary.

You will see that we have two `for` loops. The outer loop is reading the lines of the file and the inner loop is iterating through each of the words on that particular line. This is an example of a pattern called *nested loops* because one of the loops is the *outer* loop and the other loop is the *inner* loop.

Because the inner loop executes all of its iterations each time the outer loop makes a single iteration, we think of the inner loop as iterating “more quickly” and the outer loop as iterating more slowly.

The combination of the two nested loops ensures that we will count every word on every line of the input file.

```

fname = input('Enter the file name: ')
try:
    fhand = open(fname)
except:
    print('File cannot be opened:', fname)
    exit()

counts = dict()
for line in fhand:
    words = line.split()
    for word in words:
        if word not in counts:
            counts[word] = 1
        else:
            counts[word] += 1

print(counts)

# Code: http://www.py4e.com/code3/count1.py

```

In our `else` statement, we use the more compact alternative for incrementing a variable. `counts[word] += 1` is equivalent to `counts[word] = counts[word] + 1`. Either method can be used to change the value of a variable by any desired amount. Similar alternatives exist for `-=`, `*=`, and `/=`.

When we run the program, we see a raw dump of all of the counts in unsorted hash order. (the *romeo.txt* file is available at www.py4e.com/code3/romeo.txt)

```

python count1.py
Enter the file name: romeo.txt
{'and': 3, 'envious': 1, 'already': 1, 'fair': 1,
'is': 3, 'through': 1, 'pale': 1, 'yonder': 1,
'what': 1, 'sun': 2, 'Who': 1, 'But': 1, 'moon': 1,
>window': 1, 'sick': 1, 'east': 1, 'breaks': 1,
'grief': 1, 'with': 1, 'light': 1, 'It': 1, 'Arise': 1,
'kill': 1, 'the': 3, 'soft': 1, 'Juliet': 1}

```

It is a bit inconvenient to look through the dictionary to find the most common words and their counts, so we need to add some more Python code to get us the output that will be more helpful.

9.3 Looping and dictionaries

If you use a dictionary as the sequence in a `for` statement, it traverses the keys of the dictionary. This loop prints each key and the corresponding value:

```

counts = { 'chuck' : 1 , 'annie' : 42, 'jan': 100}
for key in counts:
    print(key, counts[key])

```

Here's what the output looks like:

```
jan 100
chuck 1
annie 42
```

Again, the keys are in no particular order.

We can use this pattern to implement the various loop idioms that we have described earlier. For example if we wanted to find all the entries in a dictionary with a value above ten, we could write the following code:

```
counts = { 'chuck' : 1 , 'annie' : 42, 'jan': 100}
for key in counts:
    if counts[key] > 10 :
        print(key, counts[key])
```

The `for` loop iterates through the *keys* of the dictionary, so we must use the index operator to retrieve the corresponding *value* for each key. Here's what the output looks like:

```
jan 100
annie 42
```

We see only the entries with a value above 10.

If you want to print the keys in alphabetical order, you first make a list of the keys in the dictionary using the `keys` method available in dictionary objects, and then sort that list and loop through the sorted list, looking up each key and printing out key-value pairs in sorted order as follows:

```
counts = { 'chuck' : 1 , 'annie' : 42, 'jan': 100}
lst = list(counts.keys())
print(lst)
lst.sort()
for key in lst:
    print(key, counts[key])
```

Here's what the output looks like:

```
['jan', 'chuck', 'annie']
annie 42
chuck 1
jan 100
```

First you see the list of keys in unsorted order that we get from the `keys` method. Then we see the key-value pairs in order from the `for` loop.

9.4 Advanced text parsing

In the above example using the file *romeo.txt*, we made the file as simple as possible by removing all punctuation by hand. The actual text has lots of punctuation, as shown below.

```
But, soft! what light through yonder window breaks?
It is the east, and Juliet is the sun.
Arise, fair sun, and kill the envious moon,
Who is already sick and pale with grief,
```

Since the Python `split` function looks for spaces and treats words as tokens separated by spaces, we would treat the words “soft!” and “soft” as *different* words and create a separate dictionary entry for each word.

Also since the file has capitalization, we would treat “who” and “Who” as different words with different counts.

We can solve both these problems by using the string methods `lower`, `punctuation`, and `translate`. The `translate` is the most subtle of the methods. Here is the documentation for `translate`:

```
line.translate(str.maketrans(fromstr, tostr, deletestr))
```

Replace the characters in `fromstr` with the character in the same position in `tostr` and delete all characters that are in `deletestr`. The `fromstr` and `tostr` can be empty strings and the `deletestr` parameter can be omitted.

We will not specify the `tostr` but we will use the `deletestr` parameter to delete all of the punctuation. We will even let Python tell us the list of characters that it considers “punctuation”:

```
>>> import string
>>> string.punctuation
'!"#$%&'()*+,-./:;<=>?@[\\]^_`{|}~'
```

The parameters used by `translate` were different in Python 2.0.

We make the following modifications to our program:

```
import string

fname = input('Enter the file name: ')
try:
    fhand = open(fname)
except:
    print('File cannot be opened:', fname)
    exit()

counts = dict()
for line in fhand:
    line = line.rstrip()
```

```

line = line.translate(line.maketrans('', '', string.punctuation))
line = line.lower()
words = line.split()
for word in words:
    if word not in counts:
        counts[word] = 1
    else:
        counts[word] += 1

print(counts)

# Code: http://www.py4e.com/code3/count2.py

```

Part of learning the “Art of Python” or “Thinking Pythonically” is realizing that Python often has built-in capabilities for many common data analysis problems. Over time, you will see enough example code and read enough of the documentation to know where to look to see if someone has already written something that makes your job much easier.

The following is an abbreviated version of the output:

```

Enter the file name: romeo-full.txt
{'swearst': 1, 'all': 6, 'afeard': 1, 'leave': 2, 'these': 2,
'kinsmen': 2, 'what': 11, 'thinkst': 1, 'love': 24, 'cloak': 1,
a': 24, 'orchard': 2, 'light': 5, 'lovers': 2, 'romeo': 40,
'maiden': 1, 'whiteupturned': 1, 'juliet': 32, 'gentleman': 1,
'it': 22, 'leans': 1, 'canst': 1, 'having': 1, ...}

```

Looking through this output is still unwieldy and we can use Python to give us exactly what we are looking for, but to do so, we need to learn about Python *tuples*. We will pick up this example once we learn about tuples.

9.5 Debugging

As you work with bigger datasets it can become unwieldy to debug by printing and checking data by hand. Here are some suggestions for debugging large datasets:

Scale down the input If possible, reduce the size of the dataset. For example if the program reads a text file, start with just the first 10 lines, or with the smallest example you can find. You can either edit the files themselves, or (better) modify the program so it reads only the first *n* lines.

If there is an error, you can reduce *n* to the smallest value that manifests the error, and then increase it gradually as you find and correct errors.

Check summaries and types Instead of printing and checking the entire dataset, consider printing summaries of the data: for example, the number of items in a dictionary or the total of a list of numbers.

A common cause of runtime errors is a value that is not the right type. For debugging this kind of error, it is often enough to print the type of a value.

Write self-checks Sometimes you can write code to check for errors automatically. For example, if you are computing the average of a list of numbers, you could check that the result is not greater than the largest element in the list or less than the smallest. This is called a “sanity check” because it detects results that are “completely illogical”.

Another kind of check compares the results of two different computations to see if they are consistent. This is called a “consistency check”.

Pretty print the output Formatting debugging output can make it easier to spot an error.

Again, time you spend building scaffolding can reduce the time you spend debugging.

9.6 Glossary

dictionary A mapping from a set of keys to their corresponding values.

hashtable The algorithm used to implement Python dictionaries.

hash function A function used by a hashtable to compute the location for a key.

histogram A set of counters.

implementation A way of performing a computation.

item Another name for a key-value pair.

key An object that appears in a dictionary as the first part of a key-value pair.

key-value pair The representation of the mapping from a key to a value.

lookup A dictionary operation that takes a key and finds the corresponding value.

nested loops When there are one or more loops “inside” of another loop. The inner loop runs to completion each time the outer loop runs once.

value An object that appears in a dictionary as the second part of a key-value pair. This is more specific than our previous use of the word “value”.

9.7 Exercises

Exercise 2: Write a program that categorizes each mail message by which day of the week the commit was done. To do this look for lines that start with “From”, then look for the third word and keep a running count of each of the days of the week. At the end of the program print out the contents of your dictionary (order does not matter).

Sample Line:

```
From stephen.marquard@uct.ac.za Sat Jan 5 09:14:16 2008
```

Sample Execution:

```
python dow.py
Enter a file name: mbox-short.txt
{'Fri': 20, 'Thu': 6, 'Sat': 1}
```

Exercise 3: Write a program to read through a mail log, build a histogram using a dictionary to count how many messages have come from each email address, and print the dictionary.

```
Enter file name: mbox-short.txt
{'gopal.ramasammycook@gmail.com': 1, 'louis@media.berkeley.edu': 3,
'cwen@iupui.edu': 5, 'antranig@caret.cam.ac.uk': 1,
'rjlowe@iupui.edu': 2, 'gsilver@umich.edu': 3,
'david.horwitz@uct.ac.za': 4, 'wagnermr@iupui.edu': 1,
'zqian@umich.edu': 4, 'stephen.marquard@uct.ac.za': 2,
'ray@media.berkeley.edu': 1}
```

Exercise 4: Add code to the above program to figure out who has the most messages in the file. After all the data has been read and the dictionary has been created, look through the dictionary using a maximum loop (see Chapter 5: Maximum and minimum loops) to find who has the most messages and print how many messages the person has.

```
Enter a file name: mbox-short.txt
cwen@iupui.edu 5
```

```
Enter a file name: mbox.txt
zqian@umich.edu 195
```

Exercise 5: This program records the domain name (instead of the address) where the message was sent from instead of who the mail came from (i.e., the whole email address). At the end of the program, print out the contents of your dictionary.

```
python schoolcount.py
Enter a file name: mbox-short.txt
{'media.berkeley.edu': 4, 'uct.ac.za': 6, 'umich.edu': 7,
'gmail.com': 1, 'caret.cam.ac.uk': 1, 'iupui.edu': 8}
```


Chapter 10

Tuples

10.1 Tuples are immutable

A tuple¹ is a sequence of values much like a list. The values stored in a tuple can be any type, and they are indexed by integers. The important difference is that tuples are *immutable*. Tuples are also *comparable* and *hashable* so we can sort lists of them and use tuples as key values in Python dictionaries.

Syntactically, a tuple is a comma-separated list of values:

```
>>> t = 'a', 'b', 'c', 'd', 'e'
```

Although it is not necessary, it is common to enclose tuples in parentheses to help us quickly identify tuples when we look at Python code:

```
>>> t = ('a', 'b', 'c', 'd', 'e')
```

To create a tuple with a single element, you have to include the final comma:

```
>>> t1 = ('a',)
>>> type(t1)
<type 'tuple'>
```

Without the comma Python treats ('a') as an expression with a string in parentheses that evaluates to a string:

```
>>> t2 = ('a')
>>> type(t2)
<type 'str'>
```

Another way to construct a tuple is the built-in function `tuple`. With no argument, it creates an empty tuple:

¹Fun fact: The word “tuple” comes from the names given to sequences of numbers of varying lengths: single, double, triple, quadruple, quintuple, sextuple, septuple, etc.

```
>>> t = tuple()
>>> print(t)
()
```

If the argument is a sequence (string, list, or tuple), the result of the call to `tuple` is a tuple with the elements of the sequence:

```
>>> t = tuple('lupins')
>>> print(t)
('l', 'u', 'p', 'i', 'n', 's')
```

Because `tuple` is the name of a constructor, you should avoid using it as a variable name.

Most list operators also work on tuples. The bracket operator indexes an element:

```
>>> t = ('a', 'b', 'c', 'd', 'e')
>>> print(t[0])
'a'
```

And the slice operator selects a range of elements.

```
>>> print(t[1:3])
('b', 'c')
```

But if you try to modify one of the elements of the tuple, you get an error:

```
>>> t[0] = 'A'
TypeError: object doesn't support item assignment
```

You can't modify the elements of a tuple, but you can replace one tuple with another:

```
>>> t = ('A',) + t[1:]
>>> print(t)
('A', 'b', 'c', 'd', 'e')
```

10.2 Comparing tuples

The comparison operators work with tuples and other sequences. Python starts by comparing the first element from each sequence. If they are equal, it goes on to the next element, and so on, until it finds elements that differ. Subsequent elements are not considered (even if they are really big).

```
>>> (0, 1, 2) < (0, 3, 4)
True
>>> (0, 1, 2000000) < (0, 3, 4)
True
```

The `sort` function works the same way. It sorts primarily by first element, but in the case of a tie, it sorts by second element, and so on.

This feature lends itself to a pattern called *DSU* for

Decorate a sequence by building a list of tuples with one or more sort keys preceding the elements from the sequence,
Sort the list of tuples using the Python built-in `sort`, and
Undecorate by extracting the sorted elements of the sequence.

For example, suppose you have a list of words and you want to sort them from longest to shortest:

```
txt = 'but soft what light in yonder window breaks'
words = txt.split()
t = list()
for word in words:
    t.append((len(word), word))

t.sort(reverse=True)

res = list()
for length, word in t:
    res.append(word)

print(res)

# Code: http://www.py4e.com/code3/soft.py
```

The first loop builds a list of tuples, where each tuple is a word preceded by its length.

`sort` compares the first element, length, first, and only considers the second element to break ties. The keyword argument `reverse=True` tells `sort` to go in decreasing order.

The second loop traverses the list of tuples and builds a list of words in descending order of length. The four-character words are sorted in *reverse* alphabetical order, so “what” appears before “soft” in the following list.

The output of the program is as follows:

```
['yonder', 'window', 'breaks', 'light', 'what',
'soft', 'but', 'in']
```

Of course the line loses much of its poetic impact when turned into a Python list and sorted in descending word length order.

10.3 Tuple assignment

One of the unique syntactic features of the Python language is the ability to have a tuple on the left side of an assignment statement. This allows you to assign more than one variable at a time when the left side is a sequence.

In this example we have a two-element list (which is a sequence) and assign the first and second elements of the sequence to the variables `x` and `y` in a single statement.

```
>>> m = [ 'have', 'fun' ]
>>> x, y = m
>>> x
'have'
>>> y
'fun'
>>>
```

It is not magic, Python *roughly* translates the tuple assignment syntax to be the following:²

```
>>> m = [ 'have', 'fun' ]
>>> x = m[0]
>>> y = m[1]
>>> x
'have'
>>> y
'fun'
>>>
```

Stylistically when we use a tuple on the left side of the assignment statement, we omit the parentheses, but the following is an equally valid syntax:

```
>>> m = [ 'have', 'fun' ]
>>> (x, y) = m
>>> x
'have'
>>> y
'fun'
>>>
```

A particularly clever application of tuple assignment allows us to *swap* the values of two variables in a single statement:

```
>>> a, b = b, a
```

²Python does not translate the syntax literally. For example, if you try this with a dictionary, it will not work as might expect.

Both sides of this statement are tuples, but the left side is a tuple of variables; the right side is a tuple of expressions. Each value on the right side is assigned to its respective variable on the left side. All the expressions on the right side are evaluated before any of the assignments.

The number of variables on the left and the number of values on the right must be the same:

```
>>> a, b = 1, 2, 3
ValueError: too many values to unpack
```

More generally, the right side can be any kind of sequence (string, list, or tuple). For example, to split an email address into a user name and a domain, you could write:

```
>>> addr = 'monty@python.org'
>>> uname, domain = addr.split('@')
```

The return value from `split` is a list with two elements; the first element is assigned to `uname`, the second to `domain`.

```
>>> print(uname)
monty
>>> print(domain)
python.org
```

10.4 Dictionaries and tuples

Dictionaries have a method called `items` that returns a list of tuples, where each tuple is a key-value pair:

```
>>> d = {'a':10, 'b':1, 'c':22}
>>> t = list(d.items())
>>> print(t)
[('b', 1), ('a', 10), ('c', 22)]
```

As you should expect from a dictionary, the items are in no particular order.

However, since the list of tuples is a list, and tuples are comparable, we can now sort the list of tuples. Converting a dictionary to a list of tuples is a way for us to output the contents of a dictionary sorted by key:

```
>>> d = {'a':10, 'b':1, 'c':22}
>>> t = list(d.items())
>>> t
[('b', 1), ('a', 10), ('c', 22)]
>>> t.sort()
>>> t
[('a', 10), ('b', 1), ('c', 22)]
```

The new list is sorted in ascending alphabetical order by the key value.

10.5 Multiple assignment with dictionaries

Combining `items`, tuple assignment, and `for`, you can see a nice code pattern for traversing the keys and values of a dictionary in a single loop:

```
for key, val in list(d.items()):  
    print(val, key)
```

This loop has two *iteration variables* because `items` returns a list of tuples and `key`, `val` is a tuple assignment that successively iterates through each of the key-value pairs in the dictionary.

For each iteration through the loop, both `key` and `value` are advanced to the next key-value pair in the dictionary (still in hash order).

The output of this loop is:

```
10 a  
22 c  
1 b
```

Again, it is in hash key order (i.e., no particular order).

If we combine these two techniques, we can print out the contents of a dictionary sorted by the *value* stored in each key-value pair.

To do this, we first make a list of tuples where each tuple is (`value`, `key`). The `items` method would give us a list of (`key`, `value`) tuples, but this time we want to sort by value, not key. Once we have constructed the list with the value-key tuples, it is a simple matter to sort the list in reverse order and print out the new, sorted list.

```
>>> d = {'a':10, 'b':1, 'c':22}  
>>> l = list()  
>>> for key, val in d.items():  
...     l.append( (val, key) )  
...  
>>> l  
[(10, 'a'), (22, 'c'), (1, 'b')]  
>>> l.sort(reverse=True)  
>>> l  
[(22, 'c'), (10, 'a'), (1, 'b')]  
>>>
```

By carefully constructing the list of tuples to have the value as the first element of each tuple, we can sort the list of tuples and get our dictionary contents sorted by value.

10.6 The most common words

Coming back to our running example of the text from *Romeo and Juliet* Act 2, Scene 2, we can augment our program to use this technique to print the ten most common words in the text as follows:

```
import string
fhand = open('romeo-full.txt')
counts = dict()
for line in fhand:
    line = line.translate(str.maketrans('', '', string.punctuation))
    line = line.lower()
    words = line.split()
    for word in words:
        if word not in counts:
            counts[word] = 1
        else:
            counts[word] += 1

# Sort the dictionary by value
lst = list()
for key, val in list(counts.items()):
    lst.append((val, key))

lst.sort(reverse=True)

for key, val in lst[:10]:
    print(key, val)

# Code: http://www.py4e.com/code3/count3.py
```

The first part of the program which reads the file and computes the dictionary that maps each word to the count of words in the document is unchanged. But instead of simply printing out `counts` and ending the program, we construct a list of `(val, key)` tuples and then sort the list in reverse order.

Since the value is first, it will be used for the comparisons. If there is more than one tuple with the same value, it will look at the second element (the key), so tuples where the value is the same will be further sorted by the alphabetical order of the key.

At the end we write a nice `for` loop which does a multiple assignment iteration and prints out the ten most common words by iterating through a slice of the list (`lst[:10]`).

So now the output finally looks like what we want for our word frequency analysis.

```
61 i
42 and
40 romeo
34 to
34 the
```

```
32 thou
32 juliet
30 that
29 my
24 thee
```

The fact that this complex data parsing and analysis can be done with an easy-to-understand 19-line Python program is one reason why Python is a good choice as a language for exploring information.

10.7 Using tuples as keys in dictionaries

Because tuples are *hashable* and lists are not, if we want to create a *composite* key to use in a dictionary we must use a tuple as the key.

We would encounter a composite key if we wanted to create a telephone directory that maps from last-name, first-name pairs to telephone numbers. Assuming that we have defined the variables `last`, `first`, and `number`, we could write a dictionary assignment statement as follows:

```
directory[last,first] = number
```

The expression in brackets is a tuple. We could use tuple assignment in a `for` loop to traverse this dictionary.

```
for last, first in directory:
    print(first, last, directory[last,first])
```

This loop traverses the keys in `directory`, which are tuples. It assigns the elements of each tuple to `last` and `first`, then prints the name and corresponding telephone number.

10.8 Sequences: strings, lists, and tuples - Oh My!

I have focused on lists of tuples, but almost all of the examples in this chapter also work with lists of lists, tuples of tuples, and tuples of lists. To avoid enumerating the possible combinations, it is sometimes easier to talk about sequences of sequences.

In many contexts, the different kinds of sequences (strings, lists, and tuples) can be used interchangeably. So how and why do you choose one over the others?

To start with the obvious, strings are more limited than other sequences because the elements have to be characters. They are also immutable. If you need the ability to change the characters in a string (as opposed to creating a new string), you might want to use a list of characters instead.

Lists are more common than tuples, mostly because they are mutable. But there are a few cases where you might prefer tuples:

1. In some contexts, like a **return** statement, it is syntactically simpler to create a tuple than a list. In other contexts, you might prefer a list.
2. If you want to use a sequence as a dictionary key, you have to use an immutable type like a tuple or string.
3. If you are passing a sequence as an argument to a function, using tuples reduces the potential for unexpected behavior due to aliasing.

Because tuples are immutable, they don't provide methods like **sort** and **reverse**, which modify existing lists. However Python provides the built-in functions **sorted** and **reversed**, which take any sequence as a parameter and return a new sequence with the same elements in a different order.

10.9 Debugging

Lists, dictionaries and tuples are known generically as *data structures*; in this chapter we are starting to see compound data structures, like lists of tuples, and dictionaries that contain tuples as keys and lists as values. Compound data structures are useful, but they are prone to what I call *shape errors*; that is, errors caused when a data structure has the wrong type, size, or composition, or perhaps you write some code and forget the shape of your data and introduce an error. For example, if you are expecting a list with one integer and I give you a plain old integer (not in a list), it won't work.

10.10 Glossary

comparable A type where one value can be checked to see if it is greater than, less than, or equal to another value of the same type. Types which are comparable can be put in a list and sorted.

data structure A collection of related values, often organized in lists, dictionaries, tuples, etc.

DSU Abbreviation of “decorate-sort-undecorate”, a pattern that involves building a list of tuples, sorting, and extracting part of the result.

gather The operation of assembling a variable-length argument tuple.

hashable A type that has a hash function. Immutable types like integers, floats, and strings are hashable; mutable types like lists and dictionaries are not.

scatter The operation of treating a sequence as a list of arguments.

shape (of a data structure) A summary of the type, size, and composition of a data structure.

singleton A list (or other sequence) with a single element.

tuple An immutable sequence of elements.

tuple assignment An assignment with a sequence on the right side and a tuple of variables on the left. The right side is evaluated and then its elements are assigned to the variables on the left.

10.11 Exercises

Exercise 1: Revise a previous program as follows: Read and parse the “From” lines and pull out the addresses from the line. Count the number of messages from each person using a dictionary.

After all the data has been read, print the person with the most commits by creating a list of (count, email) tuples from the dictionary. Then sort the list in reverse order and print out the person who has the most commits.

Sample Line:

From stephen.marquard@uct.ac.za Sat Jan 5 09:14:16 2008

Enter a file name: mbox-short.txt
cwen@iupui.edu 5

Enter a file name: mbox.txt
zqian@umich.edu 195

Exercise 2: This program counts the distribution of the hour of the day for each of the messages. You can pull the hour from the “From” line by finding the time string and then splitting that string into parts using the colon character. Once you have accumulated the counts for each hour, print out the counts, one per line, sorted by hour as shown below.

```
python timeofday.py
Enter a file name: mbox-short.txt
04 3
06 1
07 1
09 2
10 3
11 6
14 1
15 2
16 4
17 2
18 1
19 1
```

Exercise 3: Write a program that reads a file and prints the *letters* in decreasing order of frequency. Your program should convert all the input to lower case and only count the letters a-z. Your program should not count spaces, digits, punctuation, or anything other than the letters a-z. Find text samples from several different languages and see how letter frequency varies between languages. Compare your results with the tables at https://wikipedia.org/wiki/Letter_frequencies.

Chapter 14

Object-oriented programming

14.1 Managing larger programs

At the beginning of this book, we came up with four basic programming patterns which we use to construct programs:

- Sequential code
- Conditional code (if statements)
- Repetitive code (loops)
- Store and reuse (functions)

In later chapters, we explored simple variables as well as collection data structures like lists, tuples, and dictionaries.

As we build programs, we design data structures and write code to manipulate those data structures. There are many ways to write programs and by now, you probably have written some programs that are “not so elegant” and other programs that are “more elegant”. Even though your programs may be small, you are starting to see how there is a bit of art and aesthetic to writing code.

As programs get to be millions of lines long, it becomes increasingly important to write code that is easy to understand. If you are working on a million-line program, you can never keep the entire program in your mind at the same time. We need ways to break large programs into multiple smaller pieces so that we have less to look at when solving a problem, fix a bug, or add a new feature.

In a way, object oriented programming is a way to arrange your code so that you can zoom into 50 lines of the code and understand it while ignoring the other 999,950 lines of code for the moment.

14.2 Getting started

Like many aspects of programming, it is necessary to learn the concepts of object oriented programming before you can use them effectively. You should approach this chapter as a way to learn some terms and concepts and work through a few simple examples to lay a foundation for future learning.

The key outcome of this chapter is to have a basic understanding of how objects are constructed and how they function and most importantly how we make use of the capabilities of objects that are provided to us by Python and Python libraries.

14.3 Using objects

As it turns out, we have been using objects all along in this book. Python provides us with many built-in objects. Here is some simple code where the first few lines should feel very simple and natural to you.

```
stuff = list()
stuff.append('python')
stuff.append('chuck')
stuff.sort()
print (stuff[0])
print (stuff.__getitem__(0))
print (list.__getitem__(stuff,0))

# Code: http://www.py4e.com/code3/party1.py
```

Instead of focusing on what these lines accomplish, let's look at what is really happening from the point of view of object-oriented programming. Don't worry if the following paragraphs don't make any sense the first time you read them because we have not yet defined all of these terms.

The first line *constructs* an object of type `list`, the second and third lines *call* the `append()` *method*, the fourth line calls the `sort()` method, and the fifth line *retrieves* the item at position 0.

The sixth line calls the `__getitem__()` method in the `stuff` list with a parameter of zero.

```
print (stuff.__getitem__(0))
```

The seventh line is an even more verbose way of retrieving the 0th item in the list.

```
print (list.__getitem__(stuff,0))
```

In this code, we call the `__getitem__` method in the `list` class and *pass* the list and the item we want retrieved from the list as parameters.

The last three lines of the program are equivalent, but it is more convenient to simply use the square bracket syntax to look up an item at a particular position in a list.

We can take a look at the capabilities of an object by looking at the output of the `dir()` function:

```
>>> stuff = list()
>>> dir(stuff)
['__add__', '__class__', '__contains__', '__delattr__',
 '__delitem__', '__dir__', '__doc__', '__eq__',
 '__format__', '__ge__', '__getattribute__', '__getitem__',
 '__gt__', '__hash__', '__iadd__', '__imul__', '__init__',
 '__iter__', '__le__', '__len__', '__lt__', '__mul__',
 '__ne__', '__new__', '__reduce__', '__reduce_ex__',
 '__repr__', '__reversed__', '__rmul__', '__setattr__',
 '__setitem__', '__sizeof__', '__str__', '__subclasshook__',
 'append', 'clear', 'copy', 'count', 'extend', 'index',
 'insert', 'pop', 'remove', 'reverse', 'sort']
>>>
```

The rest of this chapter will define all of the above terms so make sure to come back after you finish the chapter and re-read the above paragraphs to check your understanding.

14.4 Starting with programs

A program in its most basic form takes some input, does some processing, and produces some output. Our elevator conversion program demonstrates a very short but complete program showing all three of these steps.

```
usf = input('Enter the US Floor Number: ')
wf = int(usf) - 1
print('Non-US Floor Number is',wf)
```

Code: <http://www.py4e.com/code3/elev.py>

If we think a bit more about this program, there is the “outside world” and the program. The input and output aspects are where the program interacts with the outside world. Within the program we have code and data to accomplish the task the program is designed to solve.

One way to think about object-oriented programming is that it separates our program into multiple “zones.” Each zone contains some code and data (like a program) and has well defined interactions with the outside world and the other zones within the program.

If we look back at the link extraction application where we used the BeautifulSoup library, we can see a program that is constructed by connecting different objects together to accomplish a task:



Figure 14.1: A Program

```

# To run this, download the BeautifulSoup zip file
# http://www.py4e.com/code3/bs4.zip
# and unzip it in the same directory as this file

import urllib.request, urllib.parse, urllib.error
from bs4 import BeautifulSoup
import ssl

# Ignore SSL certificate errors
ctx = ssl.create_default_context()
ctx.check_hostname = False
ctx.verify_mode = ssl.CERT_NONE

url = input('Enter - ')
html = urllib.request.urlopen(url, context=ctx).read()
soup = BeautifulSoup(html, 'html.parser')

# Retrieve all of the anchor tags
tags = soup('a')
for tag in tags:
    print(tag.get('href', None))

# Code: http://www.py4e.com/code3/urllinks.py

```

We read the URL into a string and then pass that into `urllib` to retrieve the data from the web. The `urllib` library uses the `socket` library to make the actual network connection to retrieve the data. We take the string that `urllib` returns and hand it to `BeautifulSoup` for parsing. `BeautifulSoup` makes use of the object `html.parser`¹ and returns an object. We call the `tags()` method on the returned object that returns a dictionary of tag objects. We loop through the tags and call the `get()` method for each tag to print out the `href` attribute.

We can draw a picture of this program and how the objects work together.

The key here is not to understand perfectly how this program works but to see how we build a network of interacting objects and orchestrate the movement of information between the objects to create a program. It is also important to note that when you looked at that program several chapters back, you could fully understand what was going on in the program without even realizing that the

¹<https://docs.python.org/3/library/html.parser.html>

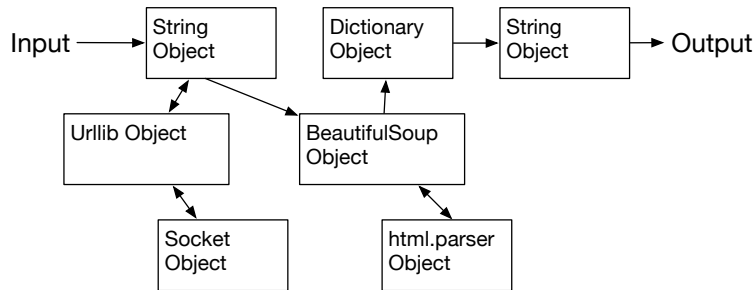


Figure 14.2: A Program as Network of Objects

program was “orchestrating the movement of data between objects.” It was just lines of code that got the job done.

14.12 Glossary

attribute A variable that is part of a class.

class A template that can be used to construct an object. Defines the attributes and methods that will make up the object.

child class A new class created when a parent class is extended. The child class inherits all of the attributes and methods of the parent class.

constructor An optional specially named method (`__init__`) that is called at the moment when a class is being used to construct an object. Usually this is used to set up initial values for the object.

destructor An optional specially named method (`__del__`) that is called at the moment just before an object is destroyed. Destructors are rarely used.

inheritance When we create a new class (child) by extending an existing class (parent). The child class has all the attributes and methods of the parent class plus additional attributes and methods defined by the child class.

method A function that is contained within a class and the objects that are constructed from the class. Some object-oriented patterns use ‘message’ instead of ‘method’ to describe this concept.

object A constructed instance of a class. An object contains all of the attributes and methods that were defined by the class. Some object-oriented documentation uses the term ‘instance’ interchangeably with ‘object’.

parent class The class which is being extended to create a new child class. The parent class contributes all of its methods and attributes to the new child class.