VISUAL QUICKSTART GUIDE

Python

Third Edition

TOBY DONALDSON

LEARN THE QUICK AND EASY WAY!

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Python

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Contents at a Glance

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Flow of Control

The programs we've written so far are *straight-line* programs that consist of a sequence of Python statements executed one after the other. The flow of execution is simply a straight sequence of statements, with no branching or looping back to previous statements.

In this chapter, we look at how to change the order in which statements are executed by using if-statements and loops. Both are essential in almost any nontrivial program.

Both if-statements and loops are controlled by logical expressions, and so the first part of this chapter will introduce the idea of Boolean logic.

Read the sample programs in this chapter carefully. Take the time to try them out and make your own modifications.

In This Chapter

Boolean Logic

In Python, as in most programming languages, decisions are made using *Boolean logic*. Boolean logic is all about manipulating so-called truth values, which in Python are written **`True`** and **`False`**. Boolean logic is simpler than numeric arithmetic, and is a formalization of logical rules you already know.

We combine Boolean values using four main *logical operators* (or *logical connectives*): **`not`**, **`and`**, **`or`**, and **`==`**. All decisions that can be made by Python—or any computer language, for that matter—can be made using these logical operators.

Suppose that **`p`** and **`q`** are two Python variables each labeling Boolean values. Since each has two possible values (**`True`** or **`False`**), altogether there are four different sets of values for **`p`** and **`q`** (see the first two columns of **Table 4.1**). We can now define the logical operators by specifying exactly what value they return for the different truth values of **`p`** and **`q`**. These kinds of definitions are known as *truth tables*, and Python uses an internal version of them to evaluate Boolean expressions.

TABLE 4.1 Truth Table for Basic Logical Operators

`p`	`q`	`p == q`	`p != q`	`p and q`	`p or q`	`not p`
False	False	True	False	False	False	True
False	True	False	True	False	True	True
True	False	False	True	False	True	False
True	True	True	False	True	True	False

Logical equivalence

Let's start with **`==`**. The expression **`p == q`** is **`True`** only when **`p`** and **`q`** both have the same truth value—that is, when **`p`** and **`q`** are either both **`True`** or both **`False`**. The expression **`p != q`** tests if **`p`** and **`q`** are not the same, and returns **`True`** only when they have different values.

```
>>> False == False
True
>>> True == False
False
>>> True == True
True
>>> False != False
False
>>> True != False
True
>>> True != True
False
```

Logical "and"

The Boolean expression **`p and q`** is **`True`** only when both **`p`** is **`True`** and **`q`** is **`True`**. In every other case it is **`False`**. The fifth column of Table 4.1 summarizes each case.

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

Logical "or"

The Boolean expression **`p or q`** is **`True`** exactly when **`p`** is **`True`** or **`q`** is **`True`**, or when both are **`True`**. This is summarized in the sixth column of Table 4.1. The only slightly tricky case is when both **`p`** and **`q`** are **`True`**. In this case, the expression **`p or q`** is **`True`**.

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

Logical negation

Finally, the Boolean expression **`not p`** is **`True`** when **`p`** is **`False`**, and **`False`** when **`p`** is **`True`**. It essentially *flips* the value of the variable.

```
>>> not True
False
>>> not False
True
```

Evaluating larger Boolean expressions

Since Boolean expressions are used to control both if-statements and loops, it is important to understand how they are evaluated. Just as with arithmetic expressions, Boolean expressions use both brackets and operator precedence to specify the order in which their sub-parts are evaluated.

To evaluate a Boolean expression with brackets:

Suppose we want to evaluate the expression **`not (True and (False or True))`**. We can do it by following these steps:

- **`not (True and (False or True))`**

  Expressions in brackets are always evaluated first, and so we first evaluate **`False or True`**, which is **`True`**. This makes the original expression equivalent to this simpler one: **`not (True and True)`**.

- **`not (True and True)`**

  To evaluate this expression, we again evaluate the expression in brackets first: **`True and True`** evaluates to **`True`**, which gives us the equivalent expression: **`not True`**.

- **`not True`**

  Finally, to evaluate this expression, we simply look up the answer in the last column of Table 4.1: **`not True`** evaluates to **`False`**. Thus, the entire expression **`not (True and (False or True))`** evaluates to **`False`**. You can easily check that this is the correct answer in Python itself:

  ```
  >>> not (True and (False or
  → True))
  False
  ```

TABLE 4.2 Boolean Operator Priority (Highest to Lowest)

`p == q`
`p != q`
`not p`
`p and q`
`p or q`

To evaluate a Boolean expression without brackets:

Suppose we want to evaluate the expression **`not True and False or True`**. This is the same as the previous one, but this time there are no brackets.

- **`not True and False or True`**

  We first evaluate the operator with the highest precedence, as listed in **Table 4.2**. In this case, **`not`** has the highest precedence, and so **`not True`** is evaluated first (the fact that it happens to be at the start of the expression is a coincidence). This simplifies the expression to **`False and False or True`**.

- **`False and False or True`**

  We again evaluate the operator with the highest precedence. According to Table 4.2, **`and`** has higher precedence than **`or`**, and so **`False and True`** is evaluated first. The expression simplifies to **`False or True`**.

- **`False or True`**

  This final expression evaluates to **`True`**, which is found by looking up the answer in Table 4.1. Thus the original expression, **`False and not False or True`**, evaluates to **`True`**.

TIP Writing complicated Boolean expressions without brackets is usually a bad idea because they are hard to read and evaluate—not all programmers remember the order of precedence of Boolean operators!

TIP One exception is when you use the *same* logical operator many times in a row. Then it is usually easier to read without the brackets. For example:

```
>>> (True or (False or (True or
→ False)))
True
>>> True or False or True or False
True
```

Short-circuit evaluation

The definition of the logical operators given in Table 4.1 is the standard definition you would find in any logic textbook. However, like most modern programming languages, Python uses a simple trick called *short-circuit evaluation* to speed up the evaluation of some Boolean expressions.

Consider the Boolean expression **`False and X`**, where **`X`** is *any* Boolean expression. It turns out that no matter whether **`X`** is **`True`** or **`X`** is **`False`**, the entire expression is **`False`**. The reason is that the initial **`False`** makes the whole **`and`**-expression **`False`**. The value of **`False and X`** does not depend on **`X`**—it is *always* **`False`**. In such cases, Python does not evaluate **`X`** at all—it simply stops and returns the value **`False`**. This can speed up the evaluation of Boolean expressions.

Similarly, Boolean expressions of the form **`True or X`** are *always* **`True`**, no matter the value of **`X`**. The precise rules for how Python does short-circuiting are given in Table 4.3.

Most of the time you can ignore short-circuiting and just reap its performance benefits. However, it is useful to remember that Python does this, since every once in a while it could be the source of a subtle bug.

TIP It's possible to use the definitions of and and `or` from Table 4.3 to write short and tricky code that simulates if-statements (which we will see in the next section). However, such expressions are usually quite difficult to read, so if you ever run across such expressions in other people's Python code (*you* should never put anything so ugly in *your* programs!), you may need to refer to Table 4.3 to figure out exactly what they are doing.

TABLE 4.3 Definition of Boolean Operators in Python

Operation	Result
`p or q`	if **`p`** is **`False`**, then **`q`**, else **`p`**
`p and q`	if **`p`** is **`False`**, then **`p`**, else **`q`**

If-Statements

If-statements let you change the flow of control in a Python program. Essentially, they let you write programs that can decide, while the programming is running, whether or not to run one block of code or another. Almost all nontrivial programs use one or more if-statements, so they are important to understand.

If/else-statements

Suppose you are writing a password-checking program. The user enters their password, and if it is correct, you log them in to their account. If it is not correct, then you tell them they've entered the wrong password:

```
# password1.py

pwd = input('What is the password? ')

if pwd == 'apple': # note use of == #
→ instead of =

  print('Logging on ...')

else:

  print('Incorrect password.')

print('All done!')
```

It's pretty easy to read this program: If the string that **`pwd`** labels is **`'apple'`**, then a login message is printed. But if **`pwd`** is anything other than **`'apple'`**, the message *incorrect password* is printed.

An if-statement always begins with the keyword **`if`**. It is then (always) followed by a Boolean expression called the *if*-condition, or just *condition* for short. After the if-condition comes a colon (**`:`**). As we will see, Python uses the **`:`** token to mark the end of conditions in if-statements, loops, and functions.

Everything from the **if** to the **:** is referred to as the *if-statement* header. If the condition in the header evaluates to **True**, then the statement **print('Logging on ...')** is immediately executed, and **print('Incorrect password.')** is skipped and never executed.

If the condition in the header evaluates to **False**, then **print('Logging on ...')** is skipped, and only the statement **print('Incorrect password.')** is executed.

In all cases, the final **print('All done!')** statement is executed.

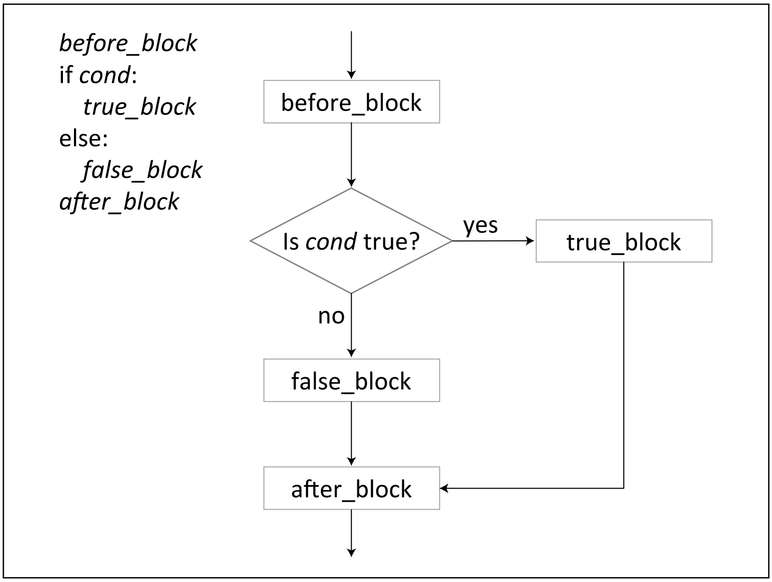
The general structure of an if/else-statement is shown in A.

TIP We will often refer to the entire multiline if structure as a single if-statement.

TIP You must put at least one space after the if keyword.

TIP The if keyword, the condition, and the terminating : must appear all on one line without breaks.

TIP The else-block of an if-statement is optional. Depending on the problem you are solving, you may or may not need one.



A This flow chart shows the general format and behavior of an if/else-statement. The code blocks can consist of any number of Python statements (even other if-statements!).

Code Blocks and Indentation

One of the most distinctive features of Python is its use of indentation to mark blocks of code. Consider the if-statement from our password-checking program:

```
if pwd == 'apple':
  print('Logging on ...')
else:
  print('Incorrect password.')
print('All done!')
```

The lines **`print('Logging on ...')`** and **`print('Incorrect password.')`** are two separate *code blocks*. These ones happen to be only a single line long, but Python lets you write code blocks consisting of any number of statements.

To indicate a block of code in Python, you must indent each line of the block by the same amount. The two blocks of code in our example if-statement are both indented four spaces, which is a typical amount of indentation for Python.

In most other programming languages, indentation is used only to help make the code look pretty. But in Python, it is required for indicating what block of code a statement belongs to. For instance, the final **`print('All done!')`** is *not* indented, and so is *not* part of the else-block.

Programmers familiar with other languages often bristle at the thought that indentation matters: Many programmers like the freedom to format their code how they please. However, Python's indentation rules follow a style that many programmers already use to make their code readable. Python simply takes this idea one step further and gives meaning to the indentation.

TIP IDLE is designed to automatically indent code for you. For instance, pressing Return after typing the `:` in an if-header automatically indents the cursor on the next line.

TIP The amount of indentation matters: A missing or extra space in a Python block could cause an error or unexpected behavior. Statements within the same block of code need to be indented at the same level.

If/elif-statements

An if/elif-statement is a generalized if-statement with more than one condition. It is used for making complex decisions. For example, suppose an airline has the following "child" ticket rates: Kids 2 years old or younger fly for free, kids older than 2 but younger than 13 pay a discounted child fare, and anyone 13 years or older pays a regular adult fare. This program determines how much a passenger should pay:

```
# airfare.py
age = int(input('How old are you? '))
if age <= 2:
  print(' free')
elif 2 < age < 13:
  print(' child fare)
else:
  print('adult fare')
```

After Python gets **age** from the user, it enters the if/elif-statement and checks each condition one after the other in the order they are given. So first it checks if **age** is less than 2, and if so, it indicates that the flying is free and jumps out of the elif-condition. If **age** is not less than 2, then it checks the next elif-condition to see if **age** is between 2 and 13. If so, it prints the appropriate message and jumps out of the if/elif-statement. If neither the if-condition nor the elif-condition is **True**, then it executes the code in the else-block.

TIP **elif is short for *else if*, and you can use as many elif-blocks as needed.**

TIP **Each of the code blocks in an if/elif-statement must be consistently indented the same amount.**

TIP **As with a regular if-statement, the else-block is optional. In an if/elif-statement *with* an else-block, *exactly one* of the if/elif-blocks will be executed. If there is no else-block, then it is possible that none of the conditions are True, in which case none of the if/elif-blocks are executed.**

Conditional expressions

Python has one more logical operator that some programmers like (and some don't!). It's essentially a shorthand notation for if-statements that can be used directly within expressions. Consider this code:

```
food = input("What's your favorite
→ food? ")
reply = 'yuck' if food == 'lamb'
→ else 'yum'
```

The expression on the right-hand side of `=` in the second line is called a *conditional expression*, and it evaluates to either `'yuck'` or `'yum'`. It's equivalent to the following:

```
food = input("What's your favorite
→ food? ")
if food == 'lamb':
  reply = 'yuck'
else:
  reply = 'yum'
```

Conditional expressions are usually shorter than the corresponding if/else-statements, although not always as flexible or easy to read. In general, you should use them when they make your code simpler.

Loops

Now we turn to loops, which are used to repeatedly execute blocks of code. Python has two main kinds of loops: *for-loops* and *while-loops*. For-loops are generally easier to use and less error prone than while-loops, although not quite as flexible.

For-loops

The basic for-loop repeats a given block of code some specified number of times. For example, this snippet of code prints the numbers 0 to 9 on the screen:

```
# count10.py
for i in range(10):
  print(i)
```

The first line of a for-loop is called the *for-loop header*. A for-loop always begins with the keyword **for**. After that comes the *loop variable*, in this case **i**. Next is the keyword **in**, typically (but not always) followed by **range(n)** and a terminating **:** token. A for-loop repeats its *body*, the code block underneath it, exactly **n** times.

Each time the loop executes, the loop variable **i** is set to be the next value. By default, the initial value of **i** is 0, and it goes up to **n - 1** (not **n**!) by ones. Starting numbering at 0 instead of 1 might seem unusual, but it is common in programming.

If you want to change the starting value of the loop, add a starting value to **range**:

```
for i in range(5, 10):
  print(i)
```

This prints the numbers from 5 to 9.

Lingo Alert

Programmers often use the variable **i** because it is short for *index*, and is also commonly used in mathematics. When we start using loops within loops, it is common to use **j** and **k** as other loop variable names.

TIP If you want to print the numbers from 1 to 10 (instead of 0 to 9), there are two common ways of doing so. One is to change the start and end of the range:

```
for i in range(1, 11):
  print(i)
```

Or, you can add 1 to `i` inside the loop body:

```
for i in range(10):
  print(i + 1)
```

TIP If you would like to print numbers in *reverse* order, there are again two standard ways of doing so. The first is to set the `range` parameters like this:

```
for i in range(10, 0, -1):
  print(i)
```

Notice that the first value of `range` is 10, the second value is 0, and the third value, called the *step*, is −1. Alternatively, you can use a simpler range and modify `i` in the loop body:

```
for i in range(10):
  print(10 - i)
```

TIP For-loops are actually more general than described in this section: They can be used with any kind of *iterator*, which is a special kind of programming object that returns values. For instance, we will see later that for-loops are the easiest way to read the lines of a text file.

While-loops

The second kind of Python loop is a *while-loop*. Consider this program:

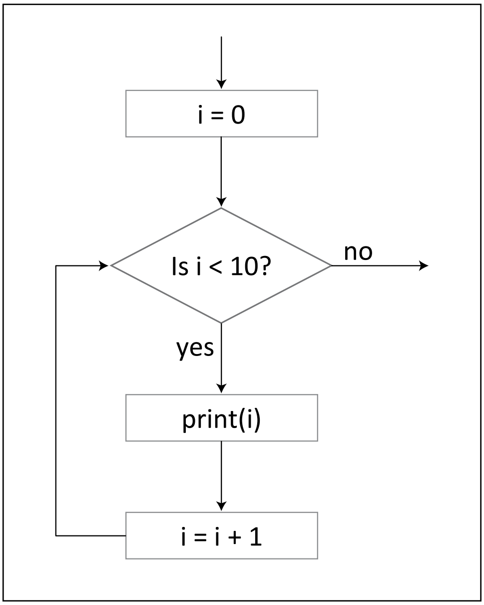
```
# while10.py
i = 0
while i < 10:
    print(i)
    i = i + 1 # add 1 to i
```

This prints out the numbers from 0 to 9 on the screen. It is noticeably more complicated than a for-loop, but it is also more flexible.

The while-loop itself begins on the line beginning with the keyword **`while`**; this line is called the *while-loop header*, and the indented code underneath it is called the *while-loop body*. The header always starts with **`while`** and is followed by the *while-loop condition*. The condition is a Boolean expression that returns **`True`** or **`False`**.

The flow of control through a while-loop goes like this: First, Python checks if the loop condition is **`True`** or **`False`**. If it's **`True`**, it executes the body; if it's **`False`**, it skips over the body (that is, it jumps out of the loop) and runs whatever statements appear afterward. When the condition is **`True`**, the body is executed, and then Python checks the condition again. As long as the loop condition is **`True`**, Python keeps executing the loop. B shows a flow chart for this program.

The very first line of the sample program is **`i = 0`**, and in the context of a loop it is known as an *initialization statement*, or an *initializer*. Unlike with for-loops, which automatically initialize their loop variable, it is the programmer's responsibility to give initial values to any variables used by a while-loop.

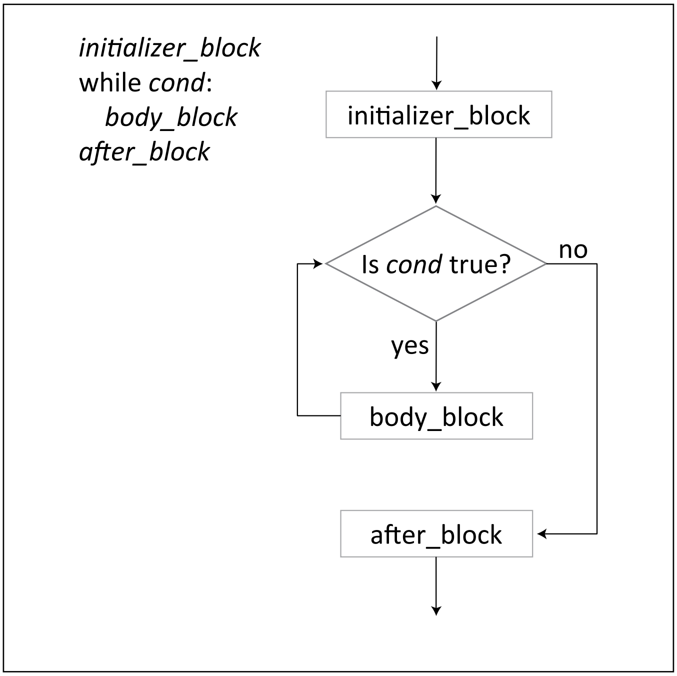


B This is a flow chart for code that counts from 0 to 9. Notice that when the loop condition is **`False`** (that is, the *no* branch is taken in the decision box), the arrow does not go into a box. That's because in our sample code there is nothing after the while-loop.

The last line of the loop body is **`i = i + 1`**. As it says in the source code comment, this line causes **`i`** to be incremented by 1. Thus, **`i`** increases as the loop executes, which guarantees that the loop will eventually stop. In the context of a while-loop, this line is called an *increment,* or *incrementer*, since its job is to increment the loop variable.

The general form of a while-loop is shown in the flow chart of C.

Even though almost all while-loops need an initializer and an incrementer, Python does not require that you include them. It is entirely up to you, the programmer, to remember these lines. Even experienced programmers find that while-loop initializers and incrementers are a common source of errors.



C A flow chart for the general form of a while-loop. Note that the incrementer is not shown explicitly: It is embedded somewhere in **`body_block`**, often (but not always) at the end of that block.

TIP While-loops are *extremely* flexible. You can put any code whatsoever before a while-loop to do whatever kind of initialization is necessary. The loop condition can be *any* Boolean expression, and the incrementer can be put *anywhere* within the while-loop body, and it can do whatever you like.

TIP A loop that never ends is called an *infinite loop*. For instance, this runs forever:

```
while True:
  print('spam')
```

TIP Some programmers like to use infinite loops as a quick way to write a loop. However, this is generally considered to be poor style because such loops often become complex and hard to understand.

TIP Many Python programmers try to use for-loops whenever possible and use while-loops only when absolutely necessary.

TIP While-loops can be written with an else-block. However, this unusual feature is rarely used in practice, so we haven't discussed it. If you are curious, you can read about it in the online Python documentation—for example, http://docs.python.org/3/reference/compound_stmts.html.

Comparing For-Loops and While-Loops

Let's take a look at a few examples of how for-loops and while-loops can be used to solve the same problems. Plus we'll see a simple program that can't be written using a for-loop.

Calculating factorials

Factorials are numbers of the form *1 × 2 × 3 × ... × n*, and they tell you how many ways *n* objects can be arranged in a line. For example, the letters ABCD can be arranged in 1 × 2 × 3 × 4 = 24 different ways. Here's one way to calculate factorials using a for-loop:

```
# forfact.py
n = int(input('Enter an integer
→>= 0: '))
fact = 1
for i in range(2, n + 1):
  fact = fact * i
print(str(n) + ' factorial is ' +
→str(fact))
```

Here's another way to do it using a while-loop:

```
# whilefact.py
n = int(input('Enter an integer
→>= 0: '))
fact = 1
i = 2
while i <= n:
  fact = fact * i
  i = i + 1
print(str(n) + ' factorial is ' +
→str(fact))
```

continues on next page

Both of these programs behave the same from the user's perspective, but the internals are quite different. As is usually the case, the while-loop version is a little more complicated than the for-loop version.

TIP In mathematics, the notation *n!* is used to indicate factorials. For example, 4! = 1 × 2 × 3 × 4 = 24. By definition, 0! = 1. Interestingly, there is *no* simple formula for calculating factorials.

TIP Python has no maximum integer, so you can use these programs to calculate very large factorials. For example, a deck of cards can be arranged in exactly 52! ways:

```
Enter an integer >= 0: 52
52 factorial is 80658175170943878571
→ 66063685640376697528950544088327782
→ 4000000000000
```

Summing numbers from the user

The following programs ask the user to enter some numbers, and then prints their sum. Here is a version using a for-loop:

```
# forsum.py
n = int(input('How many numbers to
→ sum? '))
total = 0
for i in range(n):
    s = input('Enter number ' +
    → str(i + 1) + ': ')
    total = total + int(s)
print('The sum is ' + str(total))
```

Here's a program that does that same thing using a while-loop:

```
# whilesum.py
n = int(input('How many numbers to
→ sum? '))
total = 0
i = 1
while i <= n:
    s = input('Enter number ' +
    → str(i) + ': ')
    total = total + int(s)
    i = i + 1
print('The sum is ' + str(total))
```

Again, the while-loop version is a little more complex than the for-loop version.

TIP These programs assume that the user is entering integers. Floating point numbers will be truncated when `int(s)` is called. Of course, you can easily change this to `float(s)` if you want to allow floating point numbers.

Summing an unknown number of numbers

Now here's something that can't be done with the for-loops we've seen so far. Suppose we want to let users enter a list of numbers to be summed without asking them ahead of time how many numbers they have. Instead, they just type **'done'** when they have no more numbers to add. Here's how to do it using a while-loop:

```
# donesum.py

total = 0

s = input('Enter a number (or
→ "done"): ')

while s != 'done':

  num = int(s)

  total = total + num

  s = input('Enter a number (or
→ "done"): ')

print('The sum is ' + str(total))
```

The idea here is to keep asking users to enter a number, quitting only when they enter **'done'**. The program doesn't know ahead of time how many times the loop body will be executed.

Notice a few more details:

- We must call **`input`** in two different places: before the loop and inside the loop body. This is necessary because the loop condition decides whether or not the input is a number or **`'done'`**.
- The ordering of the statements in the loop body is very important. If the loop condition is **`True`**, then we know **`s`** is not **`'done'`**, and so we assume it is an integer. Thus we can convert it to an integer, add it to the running total, and then ask the user for more input.
- We convert the input string **`s`** to an integer only *after* we know **`s`** is not the string **`'done'`**. If we had written

  ```
  s = int(input('Enter a number
  → (or "done"): '))
  ```

  as we had previously, the program would crash when the user typed **`'done'`**.
- There is no need for the **`i`** counter variable anymore. In the previous summing programs, **`i`** tracked how many numbers had been entered so far. As a general rule, a program with fewer variables is easier to read, debug, and extend.

Breaking Out of Loops and Blocks

The **break** statement is a handy way for exiting a loop from anywhere within the loop's body. For example, here is an alternative way to sum an unknown number of numbers:

```
# donesum_break.py
total = 0
while True:
  s = input('Enter a number (or
  → "done"): ')
  if s == 'done':
    break # jump out of the loop
  num = int(s)
  total = total + num
print('The sum is ' + str(total))
```

The while-loop condition is simply **True**, which means it will loop forever unless **break** is executed. The only way for **break** to be executed is if **s** equals **'done'**.

An advantage of this program over **donesum.py** is that the **input** statement is not repeated. But a disadvantage is that the reason for why the loop ends is buried in the loop body. It's not so hard to see it in this small example, but in larger programs **break** statements can be tricky to see. Furthermore, you can have as many **break**s as you want, which adds to the complexity of understanding the loop.

Generally, it is wise to avoid the **`break`** statement, and to use it only when it makes your code simpler or clearer.

A relative of **`break`** is the **`continue`** statement: When **`continue`** is called inside a loop body, it immediately jumps up to the loop condition—thus continuing with the next iteration of the loop. It is a little less common than **`break`**, and generally it should be avoided altogether.

TIP Both `break` and `continue` also work with for-loops.

Loops Within Loops

Loops within loops, also known as *nested loops,* occur frequently in programming. For instance, here's a program that prints the times tables up to 10:

```
# timestable.py
for row in range(1, 10):
  for col in range(1, 10):
    prod = row * col
    if prod < 10:
      print(' ', end = '')
    print(row * col, ' ', end = '')
  print()
```

Look carefully at the indentation of the code in this program: It's how you tell what statements belong to what blocks. The final **`print()`** statement lines up with the second **`for`**, meaning it is part of the outer for-loop (but not the inner).

Note that the statement **`if prod < 10`** is used to make the output look neatly formatted. Without it, the numbers won't line up nicely.

TIP When using nested loops, be careful with loop index variables: Do not accidentally reuse the same variable for a different loop. Most of the time, every individual loop needs its own control variables.

TIP You can nest as many loops within loops as you need, although the complexity increases greatly as you do so.

TIP As mentioned previously, if you use `break` or `continue` with nested loops, `break` only breaks out of the innermost loop, and `continue` only "continues" the innermost loop.

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