

Lists

10.1 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 a 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] []
```

10.2 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. 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-eth 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. Figure 10.1 shows the state diagram for `cheeses`, `numbers` and `empty`:

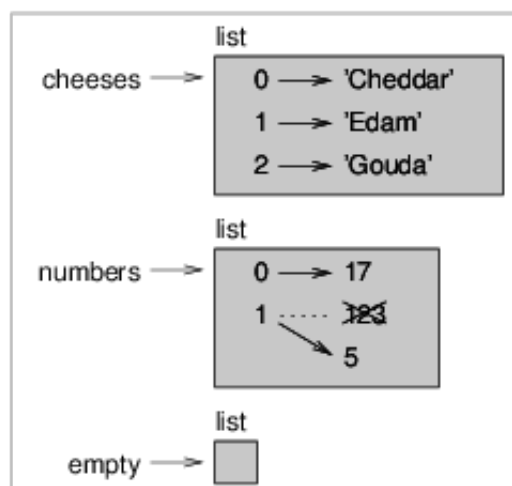


Figure 10.1: State diagram.

Lists are represented by boxes with the word “list” outside and the elements of the list inside. `cheeses` refers to a list with three elements indexed 0, 1 and 2. `numbers` contains two elements; the diagram shows that the value of the second element has been reassigned from 123 to 5. `empty` refers to a list with no 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
```

10.3 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 []:
    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]]
```

10.4 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 `[0]` four times. The second example repeats the list `[1, 2, 3]` three times.

10.5 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']
```

10.6 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']
```

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

10.7 Map, filter and reduce

To add up all the numbers in a list, you can use a loop like this:

```
def add_all(t):
    total = 0
```

```
for x in t:
    total += x
return total
```

`total` is initialized to 0. Each time through the loop, `x` gets one element from the list. The `+=` operator provides a short way to update a variable. This **augmented assignment statement**:

```
total += x
```

is equivalent to:

```
total = total + x
```

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

Adding up the elements of a list is such a common operation that Python provides it as a built-in function, `sum`:

```
>>> t = [1, 2, 3]
>>> sum(t)
6
```

An operation like this that combines a sequence of elements into a single value is sometimes called **reduce**.

Exercise 1

Write a function called `nested_sum` that takes a nested list of integers and add up the elements from all of the nested lists.

Sometimes you want to traverse one list while building another. For example, the following function takes a list of strings and returns a new

list that contains capitalized strings:

```
def capitalize_all(t):
    res = []
    for s in t:
        res.append(s.capitalize())
    return res
```

`res` is initialized with an empty list; each time through the loop, we append the next element. So `res` is another kind of accumulator.

An operation like `capitalize_all` is sometimes called a **map** because it “maps” a function (in this case the method `capitalize`) onto each of the elements in a sequence.

Exercise 2

Use `capitalize_all` to write a function named `capitalize_nested` that takes a nested list of strings and returns a new nested list with all strings capitalized.

Another common operation is to select some of the elements from a list and return a sublist. For example, the following function takes a list of strings and returns a list that contains only the uppercase strings:

```
def only_upper(t):
    res = []
    for s in t:
        if s.isupper():
            res.append(s)
    return res
```

`isupper` is a string method that returns `True` if the string contains only upper case letters.

An operation like `only_upper` is called a **filter** because it selects some of

the elements and filters out the others.

Most common list operations can be expressed as a combination of map, filter and reduce. Because these operations are so common, Python provides language features to support them, including the built-in function `map` and an operator called a “list comprehension.”

Exercise 3

Write a function that takes a list of numbers and returns the cumulative sum; that is, a new list where the i th element is the sum of the first $i+1$ elements from the original list. For example, the cumulative sum of `[1, 2, 3]` is `[1, 3, 6]`.

10.8 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.

Exercise 4

Write a function called *middle* that takes a list and returns a new list that contains all but the first and last elements. So *middle*(`[1, 2, 3, 4]`) should return `[2, 3]`.

Exercise 5

Write a function called *chop* that takes a list, modifies it by removing the first and last elements, and returns `None`.

10.9 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 `l` because it looks too much like `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']
```

An optional argument called a **delimiter** 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 = ['pining', '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.

10.10 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, shown in Figure 10.2.

Figure 10.2: State diagram.

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
```

So the state diagram looks like Figure 10.3.

Figure 10.3: State diagram.

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 `[1, 2, 3]`, you get a list object whose value is a sequence of integers. If another list has the same elements, we say it has the same value, but it is not the same object.

10.11 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 state diagram looks like Figure 10.4.

Figure 10.4: State diagram.

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.

10.12 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. The stack diagram looks like Figure 10.5.

Figure 10.5: Stack diagram.

Since the list is shared by two frames, I drew it between them.

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 + [4]
>>> print t3
[1, 2, 3, 4]
```

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']
```

10.13 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

<http://docs.python.org/2/library/stdtypes.html#typeseq>. The

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

<http://docs.python.org/2/library/stdtypes.html#typeseq-mutable>.

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. Assuming that `t` is a list and `x` is a list element, 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!

10.14 Glossary

list:

A sequence of values.

element:

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

index:

An integer value that indicates an element in a list.

nested list:

A list that is an element of another list.

list traversal:

The sequential accessing of each element in a list.

mapping:

A relationship in which each element of one set corresponds to an element of another set. For example, a list is a mapping from indices to elements.

accumulator:

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

augmented assignment:

A statement that updates the value of a variable using an operator like `+=`.

reduce:

A processing pattern that traverses a sequence and accumulates the elements into a single result.

map:

A processing pattern that traverses a sequence and performs an operation on each element.

filter:

A processing pattern that traverses a list and selects the elements that satisfy some criterion.

object:

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

equivalent:

Having the same value.

identical:

Being the same object (which implies equivalence).

reference:

The association between a variable and its value.

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.

10.15 Exercises

Exercise 6 Write a function called *is_sorted* that takes a list as a parameter and returns *True* if the list is sorted in ascending order and *False* otherwise. You can assume (as a precondition) that the elements of

the list can be compared with the relational operators `<`, `>`, etc.

For example, `is_sorted([1,2,2])` should return `True` and `is_sorted(['b','a'])` should return `False`.

Exercise 7

Two words are anagrams if you can rearrange the letters from one to spell the other. Write a function called `is_anagram` that takes two strings and returns `True` if they are anagrams.

Exercise 8

The (so-called) Birthday Paradox:

- 1. Write a function called `has_duplicates` that takes a list and returns `True` if there is any element that appears more than once. It should not modify the original list.*
- 2. If there are 23 students in your class, what are the chances that two of you have the same birthday? You can estimate this probability by generating random samples of 23 birthdays and checking for matches. Hint: you can generate random birthdays with the `randint` function in the `random` module.*

You can read about this problem at

http://en.wikipedia.org/wiki/Birthday_paradox, and you can download my solution from <http://thinkpython.com/code/birthday.py>.

Exercise 9

Write a function called `remove_duplicates` that takes a list and returns a new list with only the unique elements from the original. Hint: they don't have to be in the same order.

Exercise 10

Write a function that reads the file `words.txt` and builds a list with one element per word. Write two versions of this function, one using the `append` method and the other using the idiom `t = t + [x]`. Which one takes longer to run? Why?

Hint: use the `time` module to measure elapsed time. Solution:

<http://thinkpython.com/code/wordlist.py>.

Exercise 11

To check whether a word is in the word list, you could use the `in` operator, but it would be slow because it searches through the words in order.

Because the words are in alphabetical order, we can speed things up with a bisection search (also known as binary search), which is similar to what you do when you look a word up in the dictionary. You start in the middle and check to see whether the word you are looking for comes before the word in the middle of the list. If so, then you search the first half of the list the same way. Otherwise you search the second half.

Either way, you cut the remaining search space in half. If the word list has 113,809 words, it will take about 17 steps to find the word or conclude that it's not there.

Write a function called `bisect` that takes a sorted list and a target value and returns the index of the value in the list, if it's there, or `None` if it's not.

Or you could read the documentation of the `bisect` module and use that!
Solution: <http://thinkpython.com/code/inlist.py>.

Exercise 13

Two words “interlock” if taking alternating letters from each forms a new word. For example, “shoe” and “cold” interlock to form “schooled.”

Solution: <http://thinkpython.com/code/interlock.py>. Credit: This exercise is inspired by an example at <http://puzzlers.org>.

1. Write a program that finds all pairs of words that interlock. Hint: don't enumerate all pairs!
2. Can you find any words that are three-way interlocked; that is, every third letter forms a word, starting from the first, second or third?

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A **dictionary** is like a list, but more general. In a list, the indices have to be integers; in a dictionary they 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 squiggly-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:

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

But if you print `eng2sp`, you might be surprised:

```
>>> 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.

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 list, and then use the `in` operator:

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

The `in` operator uses different algorithms for lists and dictionaries. For lists, it uses a search algorithm, as in Section [8.6](#). As the list gets longer, the search time gets longer in direct proportion. For dictionaries, Python uses an algorithm called a **hashtable** 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 how that's possible, but

you can read more about it at

http://en.wikipedia.org/wiki/Hash_table.

Exercise 1

Write a function 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.

If you did Exercise [11](#), you can compare the speed of this implementation with the list `in` operator and the bisection search.

11.1 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:

```
def histogram(s):
    d = dict()
    for c in s:
        if c not in d:
            d[c] = 1
        else:
            d[c] += 1
    return d
```

The name of the function is **histogram**, which is a statistical term for a set of counters (or frequencies).

The first line of the function creates an empty dictionary. 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 how it works:

```
>>> h = histogram('brontosaurus')
>>> print h
{'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.

Exercise 2

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:

```
>>> h = histogram('a')
>>> print h
{'a': 1}
>>> h.get('a', 0)
1
>>> h.get('b', 0)
0
```

Use `get` to write `histogram` more concisely. You should be able to eliminate the `if` statement.

11.2 Looping and dictionaries

If you use a dictionary in a `for` statement, it traverses the keys of the dictionary. For example, `print_hist` prints each key and the corresponding value:

```
def print_hist(h):
    for c in h:
        print c, h[c]
```

Here's what the output looks like:

```
>>> h = histogram('parrot')
>>> print_hist(h)
a 1
p 1
r 2
t 1
o 1
```

Again, the keys are in no particular order.

Exercise 3

Dictionaries have a method called `keys` that returns the keys of the dictionary, in no particular order, as a list.

Modify `print_hist` to print the keys and their values in alphabetical order.

11.3 Reverse lookup

Given a dictionary `d` and a key `k`, it is easy to find the corresponding value `v = d[k]`. This operation is called a **lookup**.

But what if you have `v` and you want to find `k`? You have two problems: first, there might be more than one key that maps to the value `v`.

Depending on the application, you might be able to pick one, or you might have to make a list that contains all of them. Second, there is no simple syntax to do a **reverse lookup**; you have to search.

Here is a function that takes a value and returns the first key that maps to that value:

```
def reverse_lookup(d, v):
    for k in d:
        if d[k] == v:
            return k
    raise ValueError
```

This function is yet another example of the search pattern, but it uses a feature we haven't seen before, `raise`. The `raise` statement causes an exception; in this case it causes a `ValueError`, which generally indicates that there is something wrong with the value of a parameter.

If we get to the end of the loop, that means `v` doesn't appear in the dictionary as a value, so we raise an exception.

Here is an example of a successful reverse lookup:

```
>>> h = histogram('parrot')
>>> k = reverse_lookup(h, 2)
>>> print k
r
```

And an unsuccessful one:

```
>>> k = reverse_lookup(h, 3)
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
  File "<stdin>", line 5, in reverse_lookup
ValueError
```

The result when you raise an exception is the same as when Python raises one: it prints a traceback and an error message.

The `raise` statement takes a detailed error message as an optional argument. For example:

```
>>> raise ValueError('value does not appear in the dictionary')
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
ValueError: value does not appear in the dictionary
```

A reverse lookup is much slower than a forward lookup; if you have to do it often, or if the dictionary gets big, the performance of your program will suffer.

Exercise 4

Modify `reverse_lookup` so that it builds and returns a list of all keys that map to `v`, or an empty list if there are none.

11.4 Dictionaries and lists

Lists can appear as values in a dictionary. For example, if you were given a dictionary that maps from letters to frequencies, you might want to invert it; that is, create a dictionary that maps from frequencies to letters. Since there might be several letters with the same frequency, each value in the inverted dictionary should be a list of letters.

Here is a function that inverts a dictionary:

```
def invert_dict(d):
    inverse = dict()
    for key in d:
        val = d[key]
        if val not in inverse:
            inverse[val] = [key]
        else:
            inverse[val].append(key)
    return inverse
```

Each time through the loop, `key` gets a key from `d` and `val` gets the corresponding value. If `val` is not in `inverse`, that means we haven't seen it before, so we create a new item and initialize it with a **singleton** (a list that contains a single element). Otherwise we have seen this value before, so we append the corresponding key to the list.

Here is an example:

```
>>> hist = histogram('parrot')
>>> print hist
{'a': 1, 'p': 1, 'r': 2, 't': 1, 'o': 1}
>>> inverse = invert_dict(hist)
>>> print inverse
{1: ['a', 'p', 't', 'o'], 2: ['r']}
```

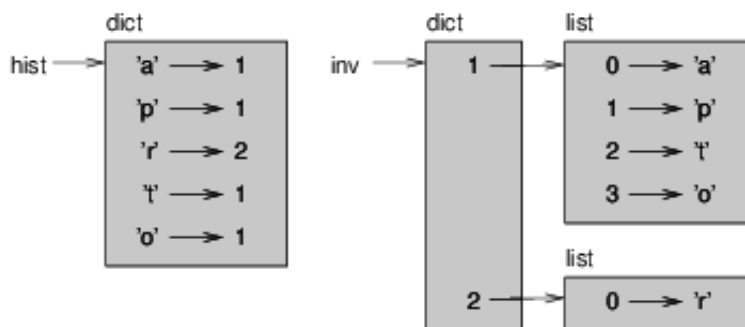


Figure 11.1: State diagram.

Figure 11.1 is a state diagram showing `hist` and `inverse`. A dictionary is represented as a box with the type `dict` above it and the key-value pairs inside. If the values are integers, floats or strings, I usually draw them inside the box, but I usually draw lists outside the box, just to keep the diagram simple.

Lists can be values in a dictionary, as this example shows, but they cannot be keys. Here's what happens if you try:

```
>>> t = [1, 2, 3]
>>> d = dict()
>>> d[t] = 'oops'
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
TypeError: list objects are unhashable
```

I mentioned earlier that a dictionary is implemented using a hashtable and that means that the keys have to be **hashable**.

A **hash** is a function that takes a value (of any kind) and returns an integer. Dictionaries use these integers, called hash values, to store and look up key-value pairs.

This system works fine if the keys are immutable. But if the keys are mutable, like lists, bad things happen. For example, when you create a key-value pair, Python hashes the key and stores it in the corresponding

location. If you modify the key and then hash it again, it would go to a different location. In that case you might have two entries for the same key, or you might not be able to find a key. Either way, the dictionary wouldn't work correctly.

That's why the keys have to be hashable, and why mutable types like lists aren't. The simplest way to get around this limitation is to use tuples, which we will see in the next chapter.

Since lists and dictionaries are mutable, they can't be used as keys, but they *can* be used as values.

11.5 Memos

If you played with the `fibonacci` function from Section [6.7](#), you might have noticed that the bigger the argument you provide, the longer the function takes to run. Furthermore, the run time increases very quickly.

To understand why, consider Figure 11.2, which shows the **call graph** for `fibonacci` with `n=4`:

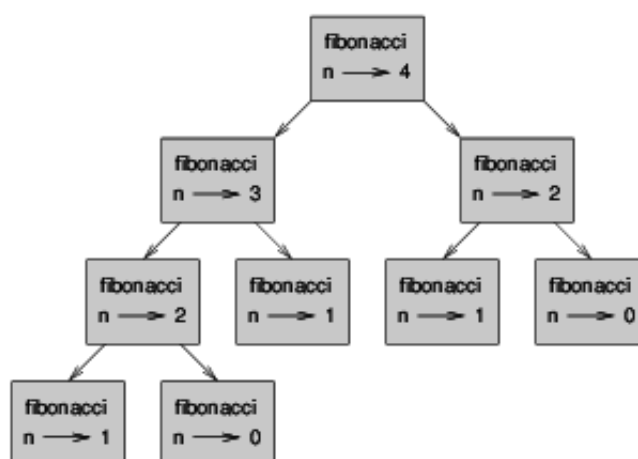


Figure 11.2: Call graph.

A call graph shows a set of function frames, with lines connecting each

frame to the frames of the functions it calls. At the top of the graph, `fibonacci` with `n=4` calls `fibonacci` with `n=3` and `n=2`. In turn, `fibonacci` with `n=3` calls `fibonacci` with `n=2` and `n=1`. And so on.

Count how many times `fibonacci(0)` and `fibonacci(1)` are called. This is an inefficient solution to the problem, and it gets worse as the argument gets bigger.

One solution is to keep track of values that have already been computed by storing them in a dictionary. A previously computed value that is stored for later use is called a **memo**. Here is a “memoized” version of `fibonacci`:

```
known = {0:0, 1:1}

def fibonacci(n):
    if n in known:
        return known[n]

    res = fibonacci(n-1) + fibonacci(n-2)
    known[n] = res
    return res
```

`known` is a dictionary that keeps track of the Fibonacci numbers we already know. It starts with two items: 0 maps to 0 and 1 maps to 1.

Whenever `fibonacci` is called, it checks `known`. If the result is already there, it can return immediately. Otherwise it has to compute the new value, add it to the dictionary, and return it.

Exercise 6

Run this version of `fibonacci` and the original with a range of parameters and compare their run times.

11.6 Global variables

In the previous example, `known` is created outside the function, so it belongs to the special frame called `__main__`. Variables in `__main__` are sometimes called **global** because they can be accessed from any function. Unlike local variables, which disappear when their function ends, global variables persist from one function call to the next.

It is common to use global variables for **flags**; that is, boolean variables that indicate (“flag”) whether a condition is true. For example, some programs use a flag named `verbose` to control the level of detail in the output:

```
verbose = True

def example1():
    if verbose:
        print 'Running example1'
```

If you try to reassign a global variable, you might be surprised. The following example is supposed to keep track of whether the function has been called:

```
been_called = False

def example2():
    been_called = True          # WRONG
```

But if you run it you will see that the value of `been_called` doesn't change. The problem is that `example2` creates a new local variable named `been_called`. The local variable goes away when the function ends, and has no effect on the global variable.

To reassign a global variable inside a function you have to **declare** the global variable before you use it:

```
been_called = False

def example2():
    global been_called
    been_called = True
```

The `global` statement tells the interpreter something like, “In this function, when I say `been_called`, I mean the global variable; don’t create a local one.”

Here’s an example that tries to update a global variable:

```
count = 0

def example3():
    count = count + 1          # WRONG
```

If you run it you get:

```
UnboundLocalError: local variable 'count' referenced before assignment
```

Python assumes that `count` is local, which means that you are reading it before writing it. The solution, again, is to declare `count` global.

```
def example3():
    global count
    count += 1
```

If the global value is mutable, you can modify it without declaring it:

```
known = {0:0, 1:1}

def example4():
    known[2] = 1
```

So you can add, remove and replace elements of a global list or dictionary, but if you want to reassign the variable, you have to declare it:

```
def example5():  
    global known  
    known = dict()
```

11.7 Long integers

If you compute `fibonacci(50)`, you get:

```
>>> fibonacci(50)  
12586269025L
```

The `L` at the end indicates that the result is a long integer, or type `long`. In Python 3, `long` is gone; all integers, even really big ones, are type `int`.

Values with type `int` have a limited range; long integers can be arbitrarily big, but as they get bigger they consume more space and time.

The mathematical operators work on long integers, and the functions in the `math` module, too, so in general any code that works with `int` will also work with `long`.

Any time the result of a computation is too big to be represented with an integer, Python converts the result as a long integer:

```
>>> 1000 * 1000  
1000000  
>>> 100000 * 100000  
10000000000L
```

In the first case the result has type `int`; in the second case it is `long`.

11.8 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 “insane.”

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. We saw an example in Section [6.9](#). The `pprint` module provides a `pprint` function that displays built-in types in a more human-readable format.

Again, time you spend building scaffolding can reduce the time you spend debugging.

11.9 Glossary

dictionary:

A mapping from a set of keys to their corresponding values.

key-value pair:

The representation of the mapping from a key to a value.

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.

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.”

implementation:

A way of performing a computation.

hashtable:

The algorithm used to implement Python dictionaries.

hash function:

A function used by a hashtable to compute the location for a key.

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.

lookup:

A dictionary operation that takes a key and finds the corresponding value.

reverse lookup:

A dictionary operation that takes a value and finds one or more keys that map to it.

singleton:

A list (or other sequence) with a single element.

call graph:

A diagram that shows every frame created during the execution of a program, with an arrow from each caller to each callee.

histogram:

A set of counters.

memo:

A computed value stored to avoid unnecessary future computation.

global variable:

A variable defined outside a function. Global variables can be accessed from any function.

flag:

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

declaration:

A statement like `global` that tells the interpreter something about a variable.

11.10 Exercises

Exercise 9

If you did Exercise [8](#), you already have a function named `has_duplicates`

that takes a list as a parameter and returns `True` if there is any object that appears more than once in the list.

Use a dictionary to write a faster, simpler version of `has_duplicates`.

Solution: http://thinkpython.com/code/has_duplicates.py.

Exercise 11

Here's another Puzzler from Car Talk

(<http://www.cartalk.com/content/puzzlers>):

This was sent in by a fellow named Dan O'Leary. He came upon a common one-syllable, five-letter word recently that has the following unique property. When you remove the first letter, the remaining letters form a homophone of the original word, that is a word that sounds exactly the same. Replace the first letter, that is, put it back and remove the second letter and the result is yet another homophone of the original word. And the question is, what's the word?

Now I'm going to give you an example that doesn't work. Let's look at the five-letter word, 'wrack.' W-R-A-C-K, you know like to 'wrack with pain.' If I remove the first letter, I am left with a four-letter word, 'R-A-C-K.' As in, 'Holy cow, did you see the rack on that buck! It must have been a nine-pointer!' It's a perfect homophone. If you put the 'w' back, and remove the 'r,' instead, you're left with the word, 'wack,' which is a real word, it's just not a homophone of the other two words.

But there is, however, at least one word that Dan and we know of, which will yield two homophones if you remove either of the first two letters to make two, new four-letter words. The question is, what's the word?

You can use the dictionary from Exercise 1 to check whether a string is in

the word list.

To check whether two words are homophones, you can use the CMU Pronouncing Dictionary. You can download it from

<http://www.speech.cs.cmu.edu/cgi-bin/cmudict> or from

<http://thinkpython.com/code/c06d> and you can also download

<http://thinkpython.com/code/pronounce.py>, which provides a function named `read_dictionary` that reads the pronouncing dictionary and returns a Python dictionary that maps from each word to a string that describes its primary pronunciation.

Write a program that lists all the words that solve the Puzzler. Solution:

<http://thinkpython.com/code/homophone.py>.

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