9. Lists

A **list** is an ordered set of values, where each value is identified by an index. The values that make up a list are called its **elements**. Lists are similar to strings, which are ordered sets of characters, except that the elements of a list can have any type. Lists and strings---and other things that behave like ordered sets---are called **sequences**.

9.1 List values

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

```
[10, 20, 30, 40]
["spam", "bungee", "swallow"]
```

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 (mirabile dictu) another list:

```
["hello", 2.0, 5, [10, 20]]
```

A list within another list is said to be **nested**.

Finally, there is a special list that contains no elements. It is called the empty list, and is denoted `[]`.

Like numeric 0 values and the empty string, the empty list is false in a boolean expression:

```
>>> if []:
...     print 'This is true."
... else:
...     print 'This is false."
...
This is false.
>>>
```

With all these ways to create lists, it would be disappointing if we couldn't assign list values to variables or pass lists as parameters to functions. We can:

```
>>> vocabulary = ["ameliorate", "castigate", "defenestrate"]
>>> numbers = [17, 123]
>>> empty = []
>>> print vocabulary, numbers, empty
['ameliorate', 'castigate', 'defenestrate'] [17, 123] []
```

9.2 Accessing elements

The syntax for accessing the elements of a list is the same as the syntax for accessing the characters of a string---the bracket operator (`[ ]` -- not to be confused with an empty list). The expression inside the brackets specifies the index. Remember that the indices start at 0:

```
>>> print numbers[0]
17
```

Any integer expression can be used as an index:

```
>>> numbers[9-8]
5
>>> numbers[1.0]
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: list indices must be integers
```

If you try to read or write an element that does not exist, you get a runtime error:

```
>>> numbers[2]
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
IndexError: list index out of range
```

If an index has a negative value, it counts backward from the end of the list:

```
>>> numbers[-1]
5
>>> numbers[-2]
```

```
17
>>> numbers[-3]
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
IndexError: list index out of range
```

`numbers[-1]` is the last element of the list, `numbers[-2]` is the second to last, and `numbers[-3]` doesn't exist.

It is common to use a loop variable as a list index.

```
horsemen = ["war", "famine", "pestilence", "death"]

i = 0
while i < 4:
    print horsemen[i]
    i += 1
```

This `while` loop counts from 0 to 4. When the loop variable `i` is 4, the condition fails and the loop terminates. So the body of the loop is only executed when `i` is 0, 1, 2, and 3.

Each time through the loop, the variable `i` is used as an index into the list, printing the `i`-eth element. This pattern of computation is called a **list traversal**.

9.3 List length

The function `len` returns the length of a list, which is equal to the number of its elements. It is a good idea to use this value as the upper bound of a loop instead of a constant. That way, if the size of the list changes, you won't have to go through the program changing all the loops; they will work correctly for any size list:

```
horsemen = ["war", "famine", "pestilence", "death"]

i = 0
num = len(horsemen)
while i < num:
    print horsemen[i]
    i += 1
```

The last time the body of the loop is executed, `i` is `len(horsemen) - 1`, which is the index of the last element. When `i` is equal to `len(horsemen)`, the condition fails and the body is not executed, which is a good thing, because `len(horsemen)` is not a legal index.

Although a list can contain another list, the nested list still counts as a single element. The length of this list is 4:

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

9.4 List membership

`in` is a boolean operator that tests membership in a sequence. We used it previously with strings, but it also works with lists and other sequences:

```
>>> horsemen = ['war', 'famine', 'pestilence', 'death']
>>> 'pestilence' in horsemen
```

```
True
>>> 'debauchery' in horsemen
False
```

Since "pestilence" is a member of the `horsemen` list, the `in` operator returns `True`. Since "debauchery" is not in the list, `in` returns `False`.

We can use the `not` in combination with `in` to test whether an element is not a member of a list:

```
>>> 'debauchery' not in horsemen
True
```

9.5 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.

9.6 List slices

The slice operations we saw with strings also work on lists:

```
>>> a_list = ['a', 'b', 'c', 'd', 'e', 'f']
>>> a_list[1:3]
['b', 'c']
>>> a_list[:4]
['a', 'b', 'c', 'd']
>>> a_list[3:]
['d', 'e', 'f']
>>> a_list[:]
['a', 'b', 'c', 'd', 'e', 'f']
```

9.7 The `range` function

Lists that contain consecutive integers are common, so Python provides a simple way to create them:

```
>>> range(1, 5)
```

```
[1, 2, 3, 4]
```

The `range` function takes two arguments and returns a list that contains all the integers from the first to the second, including the first but *not the second*.

There are two other forms of `range`. With a single argument, it creates a list that starts at 0:

```
>>> range(10)
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
```

If there is a third argument, it specifies the space between successive values, which is called the **step size**. This example counts from 1 to 10 by steps of 2:

```
>>> range(1, 10, 2)
[1, 3, 5, 7, 9]
```

If the step size is negative, then `start` must be greater than `stop`

```
>>> range(20, 4, -5)
[20, 15, 10, 5]
```

or the result will be an empty list.

```
>>> range(10, 20, -5)
[]
```

9.8 Lists are mutable

Unlike strings, lists are **mutable**, which means we can change their elements. Using the bracket operator on the left side of an assignment, we can update one of the elements:

```
>>> fruit = ["banana", "apple", "quince"]
>>> fruit[0] = "pear"
>>> fruit[-1] = "orange"
>>> print fruit
['pear', 'apple', 'orange']
```

The bracket operator applied to a list can appear anywhere in an expression. When it appears on the left side of an assignment, it changes one of the elements in the list, so the first element of `fruit` has been changed from `'banana'` to `'pear'`, and the last from `'quince'` to `'orange'`. An assignment to an element of a list is called **item assignment**. Item assignment does not work for strings:

```
>>> my_string = 'TEST'
>>> my_string[2] = 'X'
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: 'str' object does not support item assignment
```

but it does for lists:

```
>>> my_list = ['T', 'E', 'S', 'T']
>>> my_list[2] = 'X'
>>> my_list
['T', 'E', 'X', 'T']
```

With the slice operator we can update several elements at once:

```
>>> a_list = ['a', 'b', 'c', 'd', 'e', 'f']
>>> a_list[1:3] = ['x', 'y']
>>> print a_list
['a', 'x', 'y', 'd', 'e', 'f']
```

We can also remove elements from a list by assigning the empty list to them:

```
>>> a_list = ['a', 'b', 'c', 'd', 'e', 'f']
>>> a_list[1:3] = []
>>> print a_list
['a', 'd', 'e', 'f']
```

And we can add elements to a list by squeezing them into an empty slice at the desired location:

```
>>> a_list = ['a', 'd', 'f']
>>> a_list[1:1] = ['b', 'c']
>>> print a_list
['a', 'b', 'c', 'd', 'f']
>>> a_list[4:4] = ['e']
>>> print a_list
['a', 'b', 'c', 'd', 'e', 'f']
```

9.9 List deletion

Using slices to delete list elements can be awkward, and therefore error-prone. Python provides an alternative that is more readable.

`del` removes an element from a list:

```
>>> a = ['one', 'two', 'three']
>>> del a[1]
>>> a
['one', 'three']
```

As you might expect, `del` handles negative indices and causes a runtime error if the index is out of range.

You can use a slice as an index for `del`:

```
>>> a_list = ['a', 'b', 'c', 'd', 'e', 'f']
>>> del a_list[1:5]
>>> print a_list
['a', 'f']
```

As usual, slices select all the elements up to, but not including, the second index.

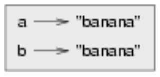
9.10 Objects and values

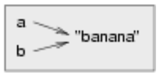
If we execute these assignment statements,

```
a = "banana"
b = "banana"
```

we know that `a` and `b` will refer to a string with the letters `"banana"`. But we can't tell whether they point to the *same* string.

There are two possible states:





In one case, `a` and `b` refer to two different things that have the same value. In the second case, they refer to the same thing. These "things" have names---they are called **objects**. An object is something a variable can refer to.

Every object has a unique **identifier**, which we can obtain with the `id` function. By printing the identifier of `a` and `b`, we can tell whether they refer to the same object.

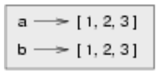
```
>>> id(a)
135044008
>>> id(b)
135044008
```

In fact, we get the same identifier twice, which means that Python only created one string, and both `a` and `b` refer to it. Your actual id value will be probably be different.

Interestingly, lists behave differently. When we create two lists, we get two objects:

```
>>> a = [1, 2, 3]
>>> b = [1, 2, 3]
>>> id(a)
135045528
>>> id(b)
135041704
```

So the state diagram looks like this:



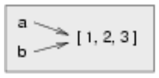
`a` and `b` have the same value but do not refer to the same object.

9.11 Aliasing

Since variables refer to objects, if we assign one variable to another, both variables refer to the same object:

```
>>> a = [1, 2, 3]
>>> b = a
>>> id(a) == id(b)
True
```

In this case, the state diagram looks like this:



Because the same list has two different names, `a` and `b`, we say that it is **aliased**. Changes made with one alias affect the other:

```
>>> b[0] = 5
>>> print a
[5, 2, 3]
```

Although this behavior can be useful, it is sometimes unexpected or undesirable. In general, it is safer to avoid aliasing when you are working with mutable objects. Of course, for immutable objects, there's no problem. That's why Python is free to alias strings when it sees an opportunity to economize.

9.12 Cloning lists

If we want to modify a list and also keep a copy of the original, we need to be able to make a copy of the list itself, not just the reference. This process is sometimes called **cloning**, to avoid the ambiguity of the word "copy."

The easiest way to clone a list is to use the slice operator:

```
>>> a = [1, 2, 3]
>>> b = a[:]
>>> print b
[1, 2, 3]
```

Taking any slice of `a` creates a new list. In this case the slice happens to consist of the whole list.

Now we are free to make changes to `b` without worrying about `a`:

```
>>> b[0] = 5
>>> print a
[1, 2, 3]
```

9.13 Lists and `for` loops

The `for` loop also works with lists. The generalized syntax of a `for` loop is:

```
for VARIABLE in LIST:
    BODY
```

This statement is equivalent to:

```
i = 0
while i < len(LIST):
    VARIABLE = LIST[i]
    BODY
    i += 1
```

The `for` loop is more concise because we can eliminate the loop variable, `i`. Here is the previous loop written with a `for` loop.

```
for horseman in horsemen:
    print horseman
```

It almost reads like English: "For (every) horseman in (the list of) horsemen, print (the name of the) horseman."

Any list expression can be used in a `for` loop:

```
for number in range(20):
    if number % 3 == 0:
        print  number

for fruit in ["banana", "apple", "quince"]:
    print "I like to eat " + fruit + "s!"
```

The first example prints all the multiples of 3 between 0 and 19. The second example expresses enthusiasm for various fruits.

Since lists are mutable, it is often desirable to traverse a list, modifying each of its elements. The following squares all the numbers from `1` to `5`:

```
numbers = [1, 2, 3, 4, 5]

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

Take a moment to think about `range(len(numbers))` until you understand how it works. We are interested here in both the *value* and its *index* within the list, so that we can assign a new value to it.

This pattern is common enough that Python provides a nicer way to impliment it:

```
numbers = [1, 2, 3, 4, 5]

for index, value in enumerate(numbers):
    numbers[index] = value**2
```

`enumerate` generates both the index and the value associated with it during the list traversal. Try this next example to see more clearly how `enumerate` works:

```
>>> for index, value in enumerate(['banana', 'apple', 'pear', 'quince']):
...     print index, value
...
0 banana
```

```
1 apple
2 pear
3 quince
>>>
```

9.14 List parameters

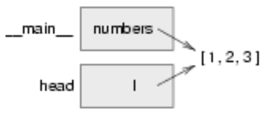
Passing a list as an argument actually passes a reference to the list, not a copy of the list. Since lists are mutable changes made to the parameter change the argument as well. For example, the function below takes a list as an argument and multiplies each element in the list by 2:

```
def double_stuff(a_list):
    for index, value in enumerate(a_list):
        a_list[index] = 2 * value
```

If we put `double_stuff` in a file named `ch09.py`, we can test it out like this:

```
>>> from ch09 import double_stuff
>>> things = [2, 5, 'Spam', 9.5]
>>> double_stuff(things)
>>> things
[4, 10, 'SpamSpam', 19.0]
>>>
```

The parameter `a_list` and the variable `things` are aliases for the same object. The state diagram looks like this:



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

If a function modifies a list parameter, the caller sees the change.

9.15 Pure functions and modifiers

Functions which take lists as arguments and change them during execution are called **modifiers** and the changes they make are called **side effects**.

A **pure function** does not produce side effects. It communicates with the calling program only through parameters, which it does not modify, and a return value. Here is `double_stuff` written as a pure function:

```
def double_stuff(a_list):
    new_list = []
    for value in a_list:
        new_list += [2 * value]
    return new_list
```

This version of `double_stuff` does not change its arguments:

```
>>> from ch09 import double_stuff
>>> things = [2, 5, 'Spam', 9.5]
>>> double_stuff(things)
[4, 10, 'SpamSpam', 19.0]
>>> things
[2, 5, 'Spam', 9.5]
>>>
```

To use the pure function version of `double_stuff` to modify `things`, you would assign the return value back to `things`:

```
>>> things = double_stuff(things)
>>> things
[4, 10, 'SpamSpam', 19.0]
>>>
```

9.16 Which is better?

Anything that can be done with modifiers can also be done with pure functions. In fact, some programming languages only allow pure functions. There is some evidence that programs that use pure functions are faster to develop and less error-prone than programs that use modifiers. Nevertheless, modifiers are convenient at times, and in some cases, functional programs are less efficient.

In general, we recommend that you write pure functions whenever it is reasonable to do so and resort to modifiers only if there is a compelling advantage. This approach might be called a *functional programming style*.

9.17 Nested lists

A nested list is a list that appears as an element in another list. In this list, the element with index 3 is a nested list:

```
>>> nested = ["hello", 2.0, 5, [10, 20]]
```

If we print `nested[3]`, we get `[10, 20]`. To extract an element from the nested list, we can proceed in two steps:

```
>>> elem = nested[3]
>>> elem[0]
10
```

Or we can combine them:

```
>>> nested[3][1]
20
```

Bracket operators evaluate from left to right, so this expression gets the three-eth element of `nested` and extracts the one-eth element from it.

9.18 Matrices

Nested lists are often used to represent matrices. For example, the matrix:

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}$$

might be represented as:

```
>>> matrix = [[1, 2, 3], [4, 5, 6], [7, 8, 9]]
```

`matrix` is a list with three elements, where each element is a row of the matrix. We can select an entire row from the matrix in the usual way:

```
>>> matrix[1]
[4, 5, 6]
```

Or we can extract a single element from the matrix using the double-index form:

```
>>> matrix[1][1]
5
```

The first index selects the row, and the second index selects the column. Although this way of representing matrices is common, it is not the only possibility. A small variation is to use a list of columns instead of a list of rows. Later we will see a more radical alternative using a dictionary.

9.19 Test-driven development (TDD)

Test-driven development (TDD) is a software development practice which arrives at a desired feature through a series of small, iterative steps motivated by automated tests which are *written first* that express increasing refinements of the desired feature.

Doctest enables us to easily demonstrate TDD. Let's say we want a function which creates a `rows` by `columns` matrix given arguments for `rows` and `columns`.

We first setup a test for this function in a file named `matrices.py`:

```
def make_matrix(rows, columns):
    """
      >>> make_matrix(3, 5)
      [[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0]]
    """


if __name__ == '__main__':
    import doctest
    doctest.testmod()
```

Running this returns in a failing test:

```
**********************************************************************
File "matrices.py", line 3, in __main__.make_matrix
Failed example:
    make_matrix(3, 5)
Expected:
    [[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0]]
Got nothing
**********************************************************************
1 items had failures:
   1 of   1 in __main__.make_matrix
```

```
***Test Failed*** 1 failures.
```

The test fails because the body of the function contains only a single triple quoted string and no return statement, so it returns `None`. Our test indicates that we wanted it to return a matrix with 3 rows of 5 columns of zeros.

The rule in using TDD is to use the *simplest thing that works* in writing a solution to pass the test, so in this case we can simply return the desired result:

```
def make_matrix(rows, columns):
    """
      >>> make_matrix(3, 5)
      [[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0]]
    """
    return [[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0]]
```

Running this now the test passes, but our current implimentation of `make_matrix` always returns the same result, which is clearly not what we intended. To fix this, we first motivate our improvement by adding a test:

```
def make_matrix(rows, columns):
    """
      >>> make_matrix(3, 5)
      [[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0]]
      >>> make_matrix(4, 2)
      [[0, 0], [0, 0], [0, 0], [0, 0]]
    """
    return [[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0]]
```

which as we expect fails:

```
**********************************************************************
File "matrices.py", line 5, in __main__.make_matrix
Failed example:
    make_matrix(4, 2)
Expected:
    [[0, 0], [0, 0], [0, 0], [0, 0]]
Got:
    [[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0]]
**********************************************************************
1 items had failures:
   1 of   2 in __main__.make_matrix
***Test Failed*** 1 failures.
```

This technique is called *test-driven* because code should only be written when there is a failing test to make pass. Motivated by the failing test, we can now produce a more general solution:

```
def make_matrix(rows, columns):
    """
      >>> make_matrix(3, 5)
      [[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0]]
      >>> make_matrix(4, 2)
      [[0, 0], [0, 0], [0, 0], [0, 0]]
    """
    return [[0] * columns] * rows
```

This solution appears to work, and we may think we are finished, but when we use the new function later we discover a bug:

```
>>> from matrices import *
>>> m = make_matrix(4, 3)
>>> m
[[0, 0, 0], [0, 0, 0], [0, 0, 0], [0, 0, 0]]
>>> m[1][2] = 7
>>> m
[[0, 0, 7], [0, 0, 7], [0, 0, 7], [0, 0, 7]]
>>>
```

We wanted to assign the element in the second row and the third column the value 7, instead, *all* elements in the third column are 7!

Upon reflection, we realize that in our current solution, each row is an *alias* of the other rows. This is definitely not what we intended, so we set about fixing the problem, *first by writing a failing test*:

```
def make_matrix(rows, columns):
    """
      >>> make_matrix(3, 5)
      [[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0]]
      >>> make_matrix(4, 2)
      [[0, 0], [0, 0], [0, 0], [0, 0]]
      >>> m = make_matrix(4, 2)
      >>> m[1][1] = 7
      >>> m
      [[0, 0], [0, 7], [0, 0], [0, 0]]
    """
    return [[0] * columns] * rows
```

With a failing test to fix, we are now driven to a better solution:

```
def make_matrix(rows, columns):
    """
      >>> make_matrix(3, 5)
      [[0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0]]
      >>> make_matrix(4, 2)
      [[0, 0], [0, 0], [0, 0], [0, 0]]
      >>> m = make_matrix(4, 2)
      >>> m[1][1] = 7
      >>> m
      [[0, 0], [0, 7], [0, 0], [0, 0]]
    """
    matrix = []
    for row in range(rows):
        matrix += [[0] * columns]
    return matrix
```

Using TDD has several benefits to our software development process. It:

- helps us think concretely about the problem we are trying solve *before* we attempt to solve it.
- encourages breaking down complex problems into smaller, simpler problems and working our way toward a solution of the larger problem step-by-step.

- assures that we have a well developed automated test suite for our software, facilitating later additions and improvements.

9.20 Strings and lists

Python has a command called `list` that takes a sequence type as an argument and creates a list out of its elements.

```
>>> list("Crunchy Frog")
['C', 'r', 'u', 'n', 'c', 'h', 'y', ' ', 'F', 'r', 'o', 'g']
```

There is also a `str` command that takes any Python value as an argument and returns a string representation of it.

```
>>> str(5)
'5'
>>> str(None)
'None'
>>> str(list("nope"))
"['n', 'o', 'p', 'e']"
```

As we can see from the last example, `str` can't be used to join a list of characters together. To do this we could use the `join` function in the `string` module:

```
>>> import string
>>> char_list = list("Frog")
>>> char_list
['F', 'r', 'o', 'g']
>>> string.join(char_list, '')
'Frog'
```

Two of the most useful functions in the `string` module involve lists of strings. The `split` function breaks a string into a list of words. By default, any number of whitespace characters is considered a word boundary:

```
>>> import string
>>> song = "The rain in Spain..."
>>> string.split(song)
['The', 'rain', 'in', 'Spain...']
```

An optional argument called a **delimiter** can be used to specify which characters to use as word boundaries. The following example uses the string `ai` as the delimiter:

```
>>> string.split(song, 'ai')
['The r', 'n in Sp', 'n...']
```

Notice that the delimiter doesn't appear in the list.

`string.join` is the inverse of `string.split`. It takes two arguments: a list of strings and a *separator* which will be placed between each element in the list in the resultant string.

```
>>> import string
>>> words = ['crunchy', 'raw', 'unboned', 'real', 'dead', 'frog']
>>> string.join(words, ' ')
'crunchy raw unboned real dead frog'
>>> string.join(words, '**')
'crunchy**raw**unboned**real**dead**frog'
```

9.21 Glossary

list:
A named collection of objects, where each object is identified by an index.

index:
An integer variable or value that indicates an element of a list.

element:
One of the values in a list (or other sequence). The bracket operator selects elements of a list.

sequence:
Any of the data types that consist of an ordered set of elements, with each element identified by an index.

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

step size:
The interval between successive elements of a linear sequence. The third (and optional argument) to the `range` function is called the step size. If not specified, it defaults to 1.

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

mutable type:
A data type in which the elements can be modified. All mutable types are compound types. Lists are mutable data types; strings are not.

object:
A thing to which a variable can refer.

aliases:
Multiple variables that contain references to the same object.

clone:
To create a new object that has the same value as an existing object. Copying a reference to an object creates an alias but doesn't clone the object.

modifier:
A function which changes its arguments inside the function body. Only mutable types can be changed by modifiers.

side effect:
A change in the state of a program made by calling a function that is not a result of reading the return value from the function. Side effects can only be produced by modifiers.

pure function:
A function which has no side effects. Pure functions only make changes to the calling program through their return values.

test-driven development (TDD):
A software development practice which arrives at a desired feature through a series of small, iterative steps motivated by automated tests which are *written first* that express increasing refinements of the desired feature. (see the Wikipedia article on Test-driven development for more information.)

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

9.22 Exercises

1. Write a loop that traverses:

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

   and prints the length of each element. What happens if you send an integer to `len`? Change `1` to `'one'` and run your solution again.

2. Open a file named `ch09e02.py` and with the following content:

   ```
   #  Add your doctests here:
   """
   """

   # Write your Python code here:


   if __name__ == '__main__':
       import doctest
       doctest.testmod()
   ```

   Add each of the following sets of doctests to the docstring at the top of the file and write Python code to make the doctests pass.

   a.
   ```
   """
     >>> a_list[3]
     42
     >>> a_list[6]
     'Ni!'
     >>> len(a_list)
     8
   """
   ```

   b.
   ```
   """
     >>> b_list[1:]
     ['Stills', 'Nash']
     >>> group = b_list + c_list
     >>> group[-1]
     'Young'
   """
   ```

   c.
   ```
   """
     >>> 'war' in mystery_list
     False
     >>> 'peace' in mystery_list
     True
     >>> 'justice' in mystery_list
     True
     >>> 'oppression' in mystery_list
     False
   ```

```
  >>> 'equality' in mystery_list
  True
"""
```

d.

```
"""
  >>> range(a, b, c)
  [5, 9, 13, 17]
"""
```

Only add one set of doctests at a time. The next set of doctests should not be added until the previous set pass.

3. What is the Python interpreter's response to the following?

```
>>> range(10, 0, -2)
```

The three arguments to the *range* function are *start*, *stop*, and *step*, respectively. In this example, `start` is greater than `stop`. What happens if `start < stop` and `step < 0`? Write a rule for the relationships among `start`, `stop`, and `step`.

4.

```
a = [1, 2, 3]
b = a[:]
b[0] = 5
```

Draw a state diagram for `a` and `b` before and after the third line is executed.

5. What will be the output of the following program?

```
this = ['I', 'am', 'not', 'a', 'crook']
that = ['I', 'am', 'not', 'a', 'crook']
print "Test 1: %s" % (id(this) == id(that))
that = this
print "Test 2: %s" % (id(this) == id(that))
```

Provide a *detailed* explaination of the results.

6. Open a file named `ch09e06.py` and use the same procedure as in exercise 2 to make the following doctests pass:

a.

```
"""
  >>> 13 in junk
  True
  >>> del junk[4]
  >>> junk
  [3, 7, 9, 10, 17, 21, 24, 27]
  >>> del junk[a:b]
  >>> junk
  [3, 7, 27]
"""
```

b.
```
"""
  >>> nlist[2][1]
  0
  >>> nlist[0][2]
  17
  >>> nlist[1][1]
  5
"""
```

c.
```
"""
  >>> import string
  >>> string.split(message, '??')
  ['this', 'and', 'that']
"""
```

7. Write a function `add_lists(a, b)` that takes two lists of numbers of the same length, and returns a new list containing the sums of the corresponding elements of each.

```
def add_lists(a, b):
    """
      >>> add_lists([1, 1], [1, 1])
      [2, 2]
      >>> add_lists([1, 2], [1, 4])
      [2, 6]
      >>> add_lists([1, 2, 1], [1, 4, 3])
      [2, 6, 4]
    """
```

   `add_lists` should pass the doctests above.

8. Write a function `mult_lists(a, b)` that takes two lists of numbers of the same length, and returns the sum of the products of the corresponding elements of each.

```
def mult_lists(a, b):
    """
      >>> mult_lists([1, 1], [1, 1])
      2
      >>> mult_lists([1, 2], [1, 4])
      9
      >>> mult_lists([1, 2, 1], [1, 4, 3])
      12
    """
```

   Verify that `mult_lists` passes the doctests above.

9. Add the following two functions to `matrices.py` introduced in section on test-driven development:

```
def add_row(matrix):
    """
      >>> m = [[0, 0], [0, 0]]
      >>> add_row(m)
      [[0, 0], [0, 0], [0, 0]]
      >>> n = [[3, 2, 5], [1, 4, 7]]
      >>> add_row(n)
      [[3, 2, 5], [1, 4, 7], [0, 0, 0]]
      >>> n
      [[3, 2, 5], [1, 4, 7]]
    """

def add_column(matrix):
    """
      >>> m = [[0, 0], [0, 0]]
      >>> add_column(m)
      [[0, 0, 0], [0, 0, 0]]
      >>> n = [[3, 2], [5, 1], [4, 7]]
      >>> add_column(n)
      [[3, 2, 0], [5, 1, 0], [4, 7, 0]]
      >>> n
      [[3, 2], [5, 1], [4, 7]]
    """
```

Your new functions should pass the doctests. Note that the last doctest in each function assures that `add_row` and `add_column` are pure functions.

10. Write a function `add_matrices(m1, m2)` that adds `m1` and `m2` and returns a new matrix containing their sum. You can assume that `m1` and `m2` are the same size. You add two matrices by adding their corresponding values.

```
def add_matrices(m1, m2):
    """
      >>> a = [[1, 2], [3, 4]]
      >>> b = [[2, 2], [2, 2]]
      >>> add_matrices(a, b)
      [[3, 4], [5, 6]]
      >>> c = [[8, 2], [3, 4], [5, 7]]
      >>> d = [[3, 2], [9, 2], [10, 12]]
      >>> add_matrices(c, d)
      [[11, 4], [12, 6], [15, 19]]
      >>> c
      [[8, 2], [3, 4], [5, 7]]
      >>> d
      [[3, 2], [9, 2], [10, 12]]
    """
```

Add your new function to `matrices.py` and be sure it passes the doctests above. The last two doctests confirm that `add_matrices` is a pure function.

11. Write a function `scalar_mult(n, m)` that multiplies a matrix, `m`, by a scalar, `n`.

```
def scalar_mult(n, m):
    """
      >>> a = [[1, 2], [3, 4]]
      >>> scalar_mult(3, a)
      [[3, 6], [9, 12]]
      >>> b = [[3, 5, 7], [1, 1, 1], [0, 2, 0], [2, 2, 3]]
      >>> scalar_mult(10, b)
      [[30, 50, 70], [10, 10, 10], [0, 20, 0], [20, 20, 30]]
      >>> b
      [[3, 5, 7], [1, 1, 1], [0, 2, 0], [2, 2, 3]]
    """
```

Add your new function to `matrices.py` and be sure it passes the doctests above.

12.
```
def row_times_column(m1, row, m2, column):
    """
      >>> row_times_column([[1, 2], [3, 4]], 0, [[5, 6], [7, 8]], 0)
      19
      >>> row_times_column([[1, 2], [3, 4]], 0, [[5, 6], [7, 8]], 1)
      22
      >>> row_times_column([[1, 2], [3, 4]], 1, [[5, 6], [7, 8]], 0)
      43
      >>> row_times_column([[1, 2], [3, 4]], 1, [[5, 6], [7, 8]], 1)
      50
    """

def matrix_mult(m1, m2):
    """
      >>> matrix_mult([[1, 2], [3,  4]], [[5, 6], [7, 8]])
      [[19, 22], [43, 50]]
      >>> matrix_mult([[1, 2, 3], [4,  5, 6]], [[7, 8], [9, 1], [2, 3]])
      [[31, 19], [85, 55]]
      >>> matrix_mult([[7, 8], [9, 1], [2, 3]], [[1, 2, 3], [4, 5, 6]])
      [[39, 54, 69], [13, 23, 33], [14, 19, 24]]
    """
```

Add your new functions to `matrices.py` and be sure it passes the doctests above.

13.
```
import string

song = "The rain in Spain..."
```

Describe the relationship between `string.join(string.split(song))` and `song`. Are they the same for all strings? When would they be different?

14. Write a function `replace(s, old, new)` that replaces all occurences of `old` with `new` in a string `s`.

```
def replace(s, old, new):
    """
      >>> replace('Mississippi', 'i', 'I')
      'MIssIssIppI'
      >>> s = 'I love spom!  Spom is my favorite food.  Spom, spom, spom, yum!'
      >>> replace(s, 'om', 'am')
      'I love spam!  Spam is my favorite food.  Spam, spam, spam, yum!'
      >>> replace(s, 'o', 'a')
      'I lave spam!  Spam is my favarite faad.  Spam, spam, spam, yum!'
    """
```

Your solution should pass the doctests above. *Hint: use `string.split` and `string.join`.*