12. Dictionaries

All of the compound data types we have studied in detail so far---strings, lists, and tuples---are sequence types, which use integers as indices to access the values they contain within them.

Dictionaries are a different kind of compound type. They are Python's built-in **mapping type**. They map **keys**, which can be any immutable type, to values, which can be any type, just like the values of a list or tuple.

As an example, we will create a dictionary to translate English words into Spanish. For this dictionary, the keys are strings.

One way to create a dictionary is to start with the empty dictionary and add **key-value pairs**. The empty dictionary is denoted `{}`:

```
>>> eng2sp = {}
>>> eng2sp['one'] = 'uno'
>>> eng2sp['two'] = 'dos'
```

The first assignment creates a dictionary named `eng2sp`; the other assignments add new key-value pairs to the dictionary. We can print the current value of the dictionary in the usual way:

```
>>> print eng2sp
{'two': 'dos', 'one': 'uno'}
```

The key-value pairs of the dictionary are seperated by commas. Each pair contains a key and a value separated by a colon.

The order of the pairs may not be what you expected. Python uses complex algorithms to determine where the key-value pairs are stored in a dictionary. For our purposes we can think of this ordering as unpredicatable.

Another way to create a dictionary is to provide a list of key-value pairs using the same syntax as the previous output:

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

It doesn't matter what order we write the pairs. The values in a dictionary are accessed with keys, not with indices, so there is no need to care about ordering.

Here is how we use a key to look up the corresponding value:

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

The key `'two'` yields the value `'dos'`.

12.1 Dictionary operations

The `del` statement removes a key-value pair from a dictionary. For example, the following dictionary contains the names of various fruits and the number of each fruit in stock:

```
>>> inventory = {'apples': 430, 'bananas': 312, 'oranges': 525, 'pears': 217}
>>> print inventory
{'oranges': 525, 'apples': 430, 'pears': 217, 'bananas': 312}
```

If someone buys all of the pears, we can remove the entry from the dictionary:

```
>>> del inventory['pears']
>>> print inventory
{'oranges': 525, 'apples': 430, 'bananas': 312}
```

Or if we're expecting more pears soon, we might just change the value associated with pears:

```
>>> inventory['pears'] = 0
>>> print inventory
{'oranges': 525, 'apples': 430, 'pears': 0, 'bananas': 312}
```

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

```
>>> len(inventory)
4
```

12.2 Dictionary methods

Dictionaries have a number of useful built-in methods

The `keys` method takes a dictionary and returns a list of its keys.

```
>>> eng2sp.keys()
['three', 'two', 'one']
```

As we saw earlier with strings and lists, dictionary methods use dot notation, which specifies the name of the method to the right of the dot and the name of the object on which to apply the method immediately to the left of the dot. The parentheses indicate that this method takes no parameters.

A method call is called an **invocation**; in this case, we would say that we are invoking the `keys` method on the object `eng2sp`. As we will see in a few chapters when we talk about object oriented programming, the object on which a method is invoked is actually the first argument to the method.

The `values` method is similar; it returns a list of the values in the dictionary:

```
>>> eng2sp.values()
['tres', 'dos', 'uno']
```

The `items` method returns both, in the form of a list of tuples---one for each key-value pair:

```
>>> eng2sp.items()
[('three', 'tres'), ('two', 'dos'), ('one', 'uno')]
```

The `has_key` method takes a key as an argument and returns `True` if the key appears in the dictionary and `False` otherwise:

```
>>> eng2sp.has_key('one')
True
>>> eng2sp.has_key('deux')
False
```

This method can be very useful, since looking up a non-existant key in a dictionary causes a runtime error:

```
>>> eng2esp['dog']
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
KeyError: 'dog'
>>>
```

12.3 Aliasing and copying

Because dictionaries are mutable, you need to be aware of aliasing. Whenever two variables refer to the same object, changes to one affect the other.

If you want to modify a dictionary and keep a copy of the original, use the `copy` method. For example, `opposites` is a dictionary that contains pairs of opposites:

```
>>> opposites = {'up': 'down', 'right': 'wrong', 'true': 'false'}
>>> alias = opposites
>>> copy = opposites.copy()
```

`alias` and `opposites` refer to the same object; `copy` refers to a fresh copy of the same dictionary. If we modify `alias`, `opposites` is also changed:

```
>>> alias['right'] = 'left'
>>> opposites['right']
'left'
```

If we modify `copy`, `opposites` is unchanged:

```
>>> copy['right'] = 'privilege'
>>> opposites['right']
'left'
```

12.4 Sparse matrices

We previously used a list of lists to represent a matrix. That is a good choice for a matrix with mostly nonzero values, but consider a sparse matrix like this one:

$$\begin{bmatrix} 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 \end{bmatrix}$$

The list representation contains a lot of zeroes:

```
matrix = [[0, 0, 0, 1, 0],
          [0, 0, 0, 0, 0],
          [0, 2, 0, 0, 0],
          [0, 0, 0, 0, 0],
          [0, 0, 0, 3, 0]]
```

An alternative is to use a dictionary. For the keys, we can use tuples that contain the row and column numbers. Here is the dictionary representation of the same matrix:

```
matrix = {(0, 3): 1, (2, 1): 2, (4, 3): 3}
```

We only need three key-value pairs, one for each nonzero element of the matrix. Each key is a tuple, and each value is an integer.

To access an element of the matrix, we could use the `[]` operator:

```
matrix[(0, 3)]
1
```

Notice that the syntax for the dictionary representation is not the same as the syntax for the nested list representation. Instead of two integer indices, we use one index, which is a tuple of integers.

There is one problem. If we specify an element that is zero, we get an error, because there is no entry in the dictionary with that key:

```
>>> matrix[(1, 3)]
KeyError: (1, 3)
```

The `get` method solves this problem:

```
>>> matrix.get((0, 3), 0)
1
```

The first argument is the key; the second argument is the value `get` should return if the key is not in the dictionary:

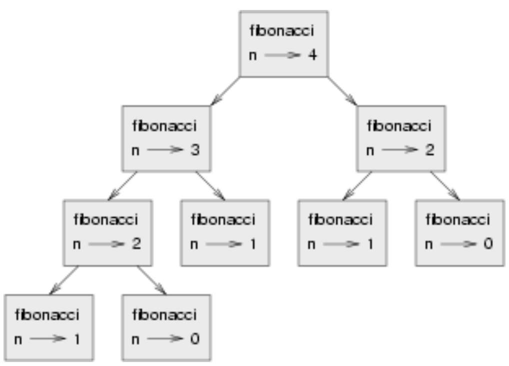
```
>>> matrix.get((1, 3), 0)
0
```

`get` definitely improves the semantics of accessing a sparse matrix. Shame about the syntax.

12.5 Hints

If you played around with the `fibonacci` function from the last chapter, 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. On one of our machines, `fibonacci(20)` finishes instantly, `fibonacci(30)` takes about a second, and `fibonacci(40)` takes roughly forever.

To understand why, consider this **call graph** for `fibonacci` with `n = 4`:



A call graph shows a set 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 far worse as the argument gets bigger.

A good 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 **hint**. Here is an implementation of `fibonacci` using hints:

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

def fibonacci(n):
    if previous.has_key(n):
        return previous[n]
    else:
        new_value = fibonacci(n-1) + fibonacci(n-2)
        previous[n] = new_value
        return new_value
```

The dictionary named `previous` keeps track of the Fibonacci numbers we already know. We start with only two pairs: 0 maps to 1; and 1 maps to 1.

Whenever `fibonacci` is called, it checks the dictionary to determine if it contains the result. If it's there, the function can return immediately without making any more recursive calls. If not, it has to compute the new value. The new value is added to the dictionary before the function returns.

Using this version of `fibonacci`, our machines can compute `fibonacci(100)` in an eyeblink.

```
>>> fibonacci(100)
354224848179261915075L
```

The `L` at the end of the number indicates that it is a `long` integer.

12.6 Long integers

Python provides a type called `long` that can handle any size integer (limited only by the amount of memory you have on your computer).

There are three ways to create a `long` value. The first one is to compute an arithmetic expression too large to fit inside an `int`. We already saw this in the `fibonacci(100)` example above. Another way is to write an integer with a capital `L` at the end of your number:

```
>>> type(1L)
<type 'long'>
```

The third is to call `long` with the value to be converted as an argument. `long`, just like `int` and `float`, can convert `ints`, `floats`, and even strings of digits to long integers:

```
>>> long(7)
7L
>>> long(3.9)
3L
>>> long('59')
59L
```

12.7 Counting letters

In Chapter 7, we wrote a function that counted the number of occurrences of a letter in a string. A more general version of this problem is to form a histogram of the letters in the string, that is, how many times each letter appears.

Such a histogram might be useful for compressing a text file. Because different letters appear with different frequencies, we can compress a file by using shorter codes for common letters and longer codes for letters that appear less frequently.

Dictionaries provide an elegant way to generate a histogram:

```
>>> letter_counts = {}
>>> for letter in "Mississippi":
...   letter_counts[letter] = letter_counts.get (letter, 0) + 1
...
>>> letter_counts
{'M': 1, 's': 4, 'p': 2, 'i': 4}
```

We start with an empty dictionary. For each letter in the string, we find the current count (possibly zero) and increment it. At the end, the dictionary contains pairs of letters and their frequencies.

It might be more appealing to display the histogram in alphabetical order. We can do that with the `items` and `sort` methods:

```
>>> letter_items = letter_counts.items()
>>> letter_items.sort()
>>> print letter_items
[('M', 1), ('i', 4), ('p', 2), ('s', 4)]
```

12.8 Case Study: Robots

The game

In this case study we will write a version of the classic console based game, robots.

Robots is a turn-based game in which the protagonist, you, are trying to stay alive while being chased by stupid, but relentless robots. Each robot moves one square toward you each time you move. If they catch you, you are dead, but if they collide they die, leaving a pile of dead robot junk in their wake. If other robots collide with the piles of junk, they die.

The basic strategy is to position yourself so that the robots collide with each other and with piles of junk as they move toward you. To make the game playable, you also are given the ability to teleport to another location on the screen -- 3 times safely and randomly thereafter, so that you don't just get forced into a corner and loose every time.

Setting up the world, the player, and the main loop

Let's start with a program that places the player on the screen and has a function to move her around in response to keys pressed:

```
#
# robots.py
#
from gasp import *

SCREEN_WIDTH = 640
SCREEN_HEIGHT = 480
GRID_WIDTH = SCREEN_WIDTH/10 - 1
GRID_HEIGHT = SCREEN_HEIGHT/10 - 1


def place_player():
    x = random.randint(0, GRID_WIDTH)
    y = random.randint(0, GRID_HEIGHT)
    return {'shape': Circle((10*x+5, 10*y+5), 5, filled=True), 'x': x, 'y': y}


def move_player(player):
    update_when('key_pressed')
    if key_pressed('escape'):
        return True
    elif key_pressed('4'):
        if player['x'] > 0: player['x'] -= 1
    elif key_pressed('7'):
        if player['x'] > 0: player['x'] -= 1
        if player['y'] < GRID_HEIGHT: player['y'] += 1
    elif key_pressed('8'):
        if player['y'] < GRID_HEIGHT: player['y'] += 1
```

```
    elif key_pressed('9'):
        if player['x'] < GRID_WIDTH: player['x'] += 1
        if player['y'] < GRID_HEIGHT: player['y'] += 1
    elif key_pressed('6'):
        if player['x'] < GRID_WIDTH: player['x'] += 1
    elif key_pressed('3'):
        if player['x'] < GRID_WIDTH: player['x'] += 1
        if player['y'] > 0: player['y'] -= 1
    elif key_pressed('2'):
        if player['y'] > 0: player['y'] -= 1
    elif key_pressed('1'):
        if player['x'] > 0: player['x'] -= 1
        if player['y'] > 0: player['y'] -= 1
    else:
        return False

    move_to(player['shape'], (10*player['x']+5, 10*player['y']+5))

    return False


def play_game():
    begin_graphics(SCREEN_WIDTH, SCREEN_HEIGHT)
    player = place_player()
    finished = False
    while not finished:
        finished = move_player(player)
    end_graphics()


if __name__ == '__main__':
    play_game()
```

Programs like this one that involve interacting with the user through **events** such as key presses and mouse clicks are called **event-driven programs**.

The main **event loop** at this stage is simply:

```
while not finished:
        finished = move_player(player)
```

The event handling is done inside the `move_player` function. `update_when('key_pressed')` waits until a key has been pressed before moving to the next statement. The multi-way branching statement then handles the all keys relevent to game play.

Pressing the escape key causes `move_player` to return `True`, making `not finished` false, thus exiting the main loop and ending the game. The 4, 7, 8, 9, 6, 3, 2, and 1 keys all cause the player to move in the appropriate direction, if she isn't blocked by the edge of a window.

Adding a robot

Now let's add a single robot that heads toward the player each time the player moves.

Add the following `place_robot` function between `place_player` and `move_player`:

```
def place_robot():
    x = random.randint(0, GRID_WIDTH)
    y = random.randint(0, GRID_HEIGHT)
    return {'shape': Box((10*x, 10*y), 10, 10), 'x': x, 'y': y}
```

Add `move_robot` immediately after `move_player`:

```
def move_robot(robot, player):
    if robot['x'] < player['x']: robot['x'] += 1
    elif robot['x'] > player['x']: robot['x'] -= 1

    if robot['y'] < player['y']: robot['y'] += 1
    elif robot['y'] > player['y']: robot['y'] -= 1

    move_to(robot['shape'], (10*robot['x'], 10*robot['y']))
```

We need to pass both the robot and the player to this function so that it can compare their locations and move the robot toward the player.

Now add the line `robot = place_robot()` in the main body of the program immediately after the line `player = place_player()`, and add the `move_robot(robot, player)` call inside the main loop immediately after `finished = move_player(player)`.

We now have a robot that moves relentlessly toward our player, but once it catches her it just follows her around wherever she goes. What we want to happen is for the game to end as soon as the player is caught. The following function will determine if that has happened:

```
def collided(robot, player):
    return player['x'] == robot['x'] and player['y'] == robot['y']
```

Place this new function immediately below the `move_player` function. Now let's modify `play_game` to check for collisions:

```
def play_game():
    begin_graphics(SCREEN_WIDTH, SCREEN_HEIGHT)
    player = place_player()
    robot = place_robot()
    defeated = False

    while not defeated:
        quit =  move_player(player)
        if quit:
            break
        move_robot(robot, player)
        defeated = collided(robot, player)

    if defeated:
        remove_from_screen(player['shape'])
        remove_from_screen(robot['shape'])
        Text("They got you!", (240, 240), size=32)
        sleep(3)

    end_graphics()
```

We introduce a new variable, `defeated` which is set to the result of `collided`. The main loop now runs as long as `defeated` is false. Pressing the <Escape> key still ends the program as well, since we check for `quit` and break out of the main loop if it is true. Finally, we check for `defeated` immediately after the main loop and display an appropriate message if it is true.

Adding more robots

There are several things we could do next:

- provide "safe" placement of the player so that it never starts on top of a robot.
- give the player the ability to *teleport* to another location to escape pursuit.
- add more robots.

While anyone of these tasks could be taken on first, we will start with the last one: adding more robots.

To add a second robot, we could just create another variable named something like `robot2` with another call to `place_robot`. The problem with this approach is that we will soon want lots of robots, and giving them all their own names will be cumbersome. A more elegant solution will is to place all the robots in a list:

```
def place_robots(numbots):
    robots = []
    for i in range(numbots):
        robots.append(place_robot())
    return robots
```

Now instead of calling `place_robot` in `play_game`, call `place_robots`, which returns a single list containing all the robots:

```
robots = place_robots(2)
```

With more than one robot placed, we have to handle moving each one of them. We already have solved the problem of moving a single robot, however, so simply traversing the list and moving each one in turn does the trick:

```
def move_robots(robots, player):
    for robot in robots:
        move_robot(robot, player)
```

Add `move_robots` immediately after `move_robot`, and change `play_game` to call `move_robots` instead of `move_robot`.

We now need to check each robot to see if it has collided with the player:

```
def check_collisions(robots, player):
    for robot in robots:
        if collided(robot, player):
            return True
    return False
```

We change the line in `play_game` that sets `defeated` to call `check_collisions` instead of `collided`.

12.9 Glossary

dictionary:
A collection of key-value pairs that maps from keys to values. The keys can be any immutable type, and the values can be any type.

mapping type:

A mapping type is a data type comprised of a collection of keys and associated values. Python's only built-in mapping type is the dictionary. Dictionaries implement the associative array abstract data type.

key:
A data item that is *mapped to* a value in a dictionary. Keys are used to look up values in a dictionary.

key-value pair:
One of the pairs of items in a dictionary. Values are looked up in a dictionary by key.

hint:
Temporary storage of a precomputed value to avoid redundant computation.

event:
A signal such as a keyboard press, mouse click, or message from another program.

event-driven program:

event loop:
A programming construct that waits for events and processes them.

overflow:
A numerical result that is too large to be represented in a numerical format.

12.10 Exercises

1. Write a program that reads in a string on the command line and returns a table of the letters of the alphabet in alphabetical order which occur in the string together with the number of times each letter occurs. Case should be ignored. A sample run of the program would look this this:

```
$ python letter_counts.py "ThiS is String with Upper and lower case Letters."
a  2
c  1
d  1
e  5
g  1
h  2
i  4
l  2
n  2
o  1
p  2
r  4
s  5
t  5
u  1
w  2
$
```

2. Give the Python interpreter's response to each of the following from a continuous interpreter session:

a.
```
>>> d = {'apples': 15, 'bananas': 35, 'grapes': 12}
>>> d['banana']
```

b.

```
>>> d['oranges'] = 20
>>> len(d)
```

c.

```
>>> d.has_key('grapes')
```

d.

```
>>> d['pears']
```

e.

```
>>> d.get('pears', 0)
```

f.

```
>>> fruits = d.keys()
>>> fruits.sort()
>>> print fruits
```

g.

```
>>> del d['apples']
>>> d.has_key('apples')
```

Be sure you understand why you get each result. Then apply what you have learned to fill in the body of the function below:

```
def add_fruit(inventory, fruit, quantity=0):
    """
    Adds quantity of fruit to inventory.

      >>> new_inventory = {}
      >>> add_fruit(new_inventory, 'strawberries', 10)
      >>> new_inventory.has_key('strawberries')
      True
      >>> new_inventory['strawberries']
      10
      >>> add_fruit(new_inventory, 'strawberries', 25)
      >>> new_inventory['strawberries']
```

```
    """
```

Your solution should pass the doctests.

3. Write a program called `alice_words.py` that creates a text file named `alice_words.txt` containing an alphabetical listing of all the words found in alice_in_wonderland.txt together with the number of times each word occurs. The first 10 lines of your output file should look something like this:

```
Word              Count
=======================
a                 631
a-piece           1
abide             1
able              1
about             94
above             3
absence           1
absurd            2
```

   How many times does the word, `alice`, occur in the book?

4. What is the longest word in "Alice in Wonderland"? How many charactes does it have?
5. Copy the code from the *Setting up the world, the player, and the main loop* section into a file named `robots.py` and run it. You should be able to move the player around the screen using the numeric keypad and to quit the program by pressing the escape key.
6. Laptops usually have smaller keyboards than desktop computers that do not include a seperate numeric keypad. Modify the robots program so that it uses 'a', 'q', 'w', 'e', 'd', 'c', 'x', and 'z' instead of '4', '7', '8', '9', '6', '3', '2', and '1' so that it will work on a typical laptop keyboard.
7. Add all the necessary code from the *Adding a robot* section in the places indicated. Make sure the program works and that you now have a robot following around your player.
8. Add all the necessary code from the *Adding more robots* section in the places indicated. Make sure the program works and that you now have two robots following around your player. Change the argument from 2 to 4 in `robots = place_robots(2)` and confirm that you have 4 robots all working as expected.

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